How Smart Is 'Smart Factory'?: Causes and Consequences of Factory Smartization*

Sunghoon Chung†
Korea Development Institute

Minho Kim‡
Korea Development Institute

May 2019

Abstract

This study investigates a new manufacturing paradigm called "smart factory" from an economics perspective. We first define two core characteristics of smart factory and quantitatively measure the degree to which a factory is smart. We then examine the effect of factory smartization on three types of performance indicators (i.e., productivity, cost efficiency, and new variety). Finally, the drivers of change in the smartization are identified. Using a detailed survey data that we designed and a first-difference model estimation, we find that the smartization induces better factory performances but at different magnitudes depending on the type of production process. This performance-enhancing smartization is attainable when factories invest in relevant technologies, but the investment should be coupled with good management practices.

JEL Classification: F1, F4, F6
Keywords: Smart Factory, Organizational Capital, Technology Adoption.

*We thank seminar participants at Korea Development Institute for helpful comments and discussions. All errors are ours.

†Corresponding author, Email: sunghoon.chung@kdi.re.kr
‡Email: minhokim@kdi.re.kr

1 Introduction

A new manufacturing paradigm called the "smart factory" has been gaining hot attention from industries all around the world. Competitive global firms have already adopted relevant technologies by investing a massive amount of time and money, but those investments are still only at an early stage. Some manufacturing based countries, like Germany and Korea, set the smart factory as the top priority among their industrial policies. Despite this significant change in the manufacturing environment, the smart factory as a research topic has been only studied in the engineering literature from a technology perspective.

This paper investigates the smart factory from an economics perspective. We provide a conceptual framework based on which the degree of smartness of a factory or what we call "smartization" (just as we call automation or robotization) is quantitatively measured. Our economic interpretation of the smartization is not just an adoption of enabling technologies, but rather a process of accumulating certain types of intangible, organizational capitals. In particular, we argue that two types of organizational capitals constitute the smartization of a factory. One is the horizontal as well as vertical integration of factory manufacturing system (system integration or SI in short) and the other is data sharing and decision making based on the data (data share and use or DSU).

The quantitative measure of smartization requires detailed data at the plant level. We surveyed about 1,000 manufacturing establishments (hereafter, factories or plants) in South Korea to obtain relevant information. Our survey questionnaire is designed to construct indices representing the degree of SI and DSU in year 2015 and 2017, respectively, so that a panel data can be constructed. We also ask in the survey other important questions related to the smartization. They include new technologies adopted by type, the degree of production automation, and basic management practices for which questions are drawn from the Management and Organizational Practices Survey (MOPS) (Buffington et al., 2016; Bloom et al., 2019).

Once the factory smartization is measured by averaging the level of SI and DSU, we use the measure to answer two questions that follows naturally: (1) what are the consequences of the factory smartization? and (2) what are the causes of it? Regarding the first question, we evaluate the effect of the smartization on three aspects of factory performances, i.e, productivity, cost efficiency, and new variety. Using a first-difference estimation model, we find that the factory smartization induces improvements of productivity and cost efficiency. Also, the smartization turns out to be conducive to develop a new product variety and attract a new customer. These effects are, however, heterogeneous depending on the type of production processes. For example, factories with small batch process experienced a more increase in product varieties, while factories with complex assembly lines benefitted from a greater reduction in the defect rate of their products.

Turning to the second question, we not only investigate which factors drive the change in the factory smartization, but also whether those factors have complimentarities with each other in smatizing a factory. We find that the adoption of relevant technologies, a good management practice, and CEO's willingness to upgrade manufacturing system are all important drivers for a smarter factory. Moreover, some of these factors are shown complementary to one another: only the factories that practice a good incentive managment tend to succeed in upgrading the level of smartization.

This paper contributes to the academic literature at least in two ways. First, we are the first to conceptualize factory smartization as a set of organizational capitals, quantitatively measure the degree, and evaluate its effect on the factory perfermance. Second, we also provide a part of the answer to the question of what determines the difference in accumulating the smartization. Our study contributes to policy and public dialogues related to so called the fourth industrial revolution or industry 4.0 as well.

[More literature to come...]

The rest of the paper is proceeded as follows. The next section provides a conceptual framework for defining, interpreting, and measuring the smartization. Section 3 introduces the survey questionnaire and its outcome data along with the way we construct the smartization. Section 4 explains our empirical strategies to deal with the questions of this paper. Our findings are documented and discussed in section 5. Section 6 concludes.

2 Conceptual Framework

2.1 Technical Concept of Smart Factory

Smart factory can be defined in a simplest form as a factory that digitizes and networks all processes, products, and resources (Kagermann et al., 2013; Bitkom e.V. et al., 2016).[1] The rapidly evolving information and communication technologies (ICTs) and operating technologies (OTs) makes it much easier to digitize and network all of the information about inputs and outputs as well as their production processes. Networking of digitized information not only enables integrated management but also helps to create new values such as productivity improvement, cost reduction, and the development of new products or business models.

An exemplary case can be found in Nobilia, a German kitchen furniture maker. Nobilia applies cutting-edge technologies to its factories to automatically order and assemble all pieces to build customized kitchen furniture. During this process, it digitizes all information that is generated and reflects it in the decision-making for value creation. As an illustration, the location of holes required to assemble each piece is recorded and managed by a Data Warehouse and information generated during drilling (motor power, vibration, etc.) is transferred to a Manufacturing Execution System (MES) to optimize the process. In addition, Radio-Frequency

[1] In fact, extension of this definition to all industries gave birth to Industrie 4.0, the national strategy initiative in Germany. The specific wording used in the definition follows the presentation of Detlef Zühlke at a conference in 2018 Hannover Messe. Dr. Zühlke is known as the one who first came up with the idea of smart factory. See also Radziwon et al. (2014) and Burke et al. (2017), among others, for more technical definitions.

Identifications (RFIDs) or bar codes are attached to all the pieces to identify any defect realized even after product delivery. The number of data transfers from a Nobilia plant is more than one million per day, but the data is handled at 100 milli-seconds per case (PC Control, 2014).

Two key characteristics are notable in the example above. First, the factory of Nobilia has constructed an integrated manufacturing system in which all parts, equipments, and outputs can be monitored and controlled in all processes at any time. Second, real-time digital data generated from each process flow through the whole system as the lifeblood to deliver information to all production entities so that they can implement their tasks properly or even improve efficiency. Although some additional features can be mentioned when describing a smart factory, these two are arguably the core, necessary conditions that any factory should possess if it wants to claim itself as smart.[2] Indeed, the two features are just enough to describe the definition we introduced above.

More generally, smart factory maximizes the scope of the network through vertical integration of different hierarchical levels within the production phase, as well as horizontal integration among all the entities involved in the value chain of the product (Kagermann et al., 2013).[3] To aid understanding, Figure 1 visually shows the comprehensive manufacturing system. Within the production phase, the system can be integrated vertically from devices and raw materials in the shopfloor (level 1) to the enterprise-wide management (level 4).[4] The scope of integration need not be limited to the production phase alone. All the entities within the factory (e.g., each department) and outside (e.g., sellers and buyers) on the value chain can also be integrated horizontally. Smart factory also maximizes the volume of the network through sharing and utilizing data in the integrated manufacturing system. Note that even if a factory constructed a physical system where data are generated in real time from all processes, it is another story whether and how the factory actually shares and uses the data.

2.2 Economic Interpretation

To be added...

[2]One feature of smart factory often emphasized is the flexible and adaptive manufacturing system through modularizing production units. A reference architecture of such factories has been developing at SmartFactory-KL, a technology initiative founded by Dr. Zühlke (See Kolberg et al., 2018, for more explanation). This plug-and-produce approach is clearly new, but to our knowledge, it has never been implemented in the real business world yet. Moreover, it is not very clear that all factories should have such a production system. Hence, we do not consider the modularization as a key characteristic of a smart factory.

[3]In addition to vertical and horizontal integration, the literature also emphasizes the integration of end-to-end engineering into which all phases of the Product Life-Cycle (such as planning and launching, maintenance, recycling and disposal) can be consistently connected and managed (Bitkom e.V. et al., 2016; Stock and Seliger, 2016).

[4]Many argue that the current pyramid-type manufacturing structure will gradually be transformed into a non-hierarchical networked architecture in smart factory (Monostori, 2014).

3 Data and Measuring Method for Smartization

3.1 Survey Design and Sample

The population for the sample survey is confined to all manufacturing establishments (hereafter, factories or plants) that meet the following three conditions. First, factory employed at least 10 or more employees in 2017. Second, its business must have started in or before 2015. Third, the main activity must be one of six 3-digit or two 5-digit industries based on the 10th revision of Korea Standard Industrial Classification (KSIC): dyeing and finishing of textiles and wearing apparel (C134), manufacture of plastics products (C222), manufacture of other fabricated metal products (C259), manufacture of electronic components (C262), manufacture of general purpose machinery (C291), manufacture of parts and accessories for motor vehicles (C303), manufacture of perfumes and cosmetics (C20423) and manufacture of mould and metallic patterns (C29294).

The size criterion of more than 10 employees considers that small factories are less likely to promote smartization yet, and the age criterion comes as the survey needs factory information for both 2015 and 2017. The selection of the eight specific industries reflects not only their importance in Korean manufacturing, but also their accelerated adoption of enabling technologies with assistance of government subsidies.[5] The eight industries account for about 35% of the aggregate manufacturing employment and 27% of the total value-added as of 2016. In addition, more than half of the 3,200 factories that benefited from the government subsidies between 2014 and 2017 are included in those eight industries.[6] Such targeting to a few narrowly defined industries clearly helps reducing heterogeneous, unobserved characteristics across factories and providing a better identification setup (Ichniowski and Shaw, 2013). One should note, however, that the benefit comes only at the expense of sacrificing external validity.

There are more than 22,000 population factories that meet the three criteria based on the FactoryOn, the database of all registered manufacturing factories in Korea provided by the Industrial Complex Corporation (KICOX). We surveyed 1,000 of these factories. The sampling method is as follows. The distribution of eight industries in the sample is designed to conform to the population distribution. Within each industry, the size of the factory (based on employment in 2017) was divided into four groups: (i) 10 to 19, (ii) 20 to 49, (iii) 50 to 99 and (iv) 100 or more persons. Moreover, the recipient factories of government subsidy are set to constitute about 30% of observations in each industry-size cell. Factories were extracted in random order within the groups by industry, size and subsidy status. Table 1 shows the distribution of 952 factories obtained from this process.

[5]The government subsidy typically covers half of the total cost of installing a certain type of technology for smartization. The overall program started from 2014 and is run by the Korea Smart Factory Foundation (KOSF), a public-private partnership agency.

[6]The list of factories that received the government subsidies is generously provided by the Ministry of SMEs and Startups.

3.2 Measure of Smartization and Other Variables

A main goal in this paper is to quantitatively measure the level of factory smartization reflecting its engineering concept described in Section 2.1. To do so, our measure of smartization has two dimensions, (i) the integration of plant operating systems (hereafter, system integration or SI) and (ii) the data share and utilization (hereafter, DSU). The level of SI is calculated by adjusting the selected choices in C5 and C6 into a 0–1 scale and averaging them.[7] The level of DSU is calculated by adjusting all 12 (=2+6+4) detailed questions evenly from 0 to 1, including C9-2 and C9-3 and C10 and 4 detailed questions from C11.[8] Finally, the overall level of smartization is calculated as the average of the measured SI and DSU level.

Figure 2 shows the distribution of smartization of 952 sample factories calculated by the above method for 2015 and 2017, respectively. The distribution has moved to the right for two years and the overall level of smartization has improved. The average level increased by 0.68 from 0.305 in 2015 to 0.373 in 2017. However, changes in the level of smartization are not the same for all factories. To confirm this, Figure 3 shows the changes in the level of smartization by each factory. The circles above the 45-degree line mean a factory with an improved level in the figure. Also, the farther away from the 45 degree line, the greater the level change. It is well observed that the level of smartization has been improved at 580 sample factories, but their level changes are very different. In addition, about one-third of the factories have never changed in level, and 34 of the factories have been less smart. We will analyze the effects of factory smartization on various performance indicators by utilizing these different level changes for different factories.

In addition to the level of smartization, the key variables to be used in our analysis are the degree of smartizing technology adoption, the level of automation, and the level of management practices. The measurement of each variable is as follows. First, the degree of smartizing technology adoption is measured at the cumulative sum of the number of related technologies adopted each year (regardless of its type). Refer to [Figure 4-4] for the introduction of individual technologies. For example, if a factory adopts only two and three types of technologies in 2015 and 2017, respectively, the degree of technology adoption is 0 in 2014, 2 in 2015 and 2016, and 5 in 2017 . The level of automation was the same as the B1 in the survey. Therefore, the level is determined between 1 and 5. Finally, the level of management practices was measured in the same way as Bloom et al. (2019).

[7] That is, we rescale 1 to 0, 2 to 0.25 to 3, 4 to 0.75 and 5 to 1.

[8] The first, fourth, and fifth subquestions in C9 are excluded, since they overlaps the details of C10. However, including them did not affect the results of the analysis.

4 Empirical Strategy

4.1 Consequences of Factory Smartization

To assess the effect of factory smartization, we employ the following econometric model.

$$ln(KPI_{ijt}) = \alpha + \beta Smart_{ijt} + X_{ijt}\gamma + (G_g \times t)\delta + \lambda_{ij} + \mu_t + \epsilon_{ijt} \tag{1}$$

where KPI_{ijt} is a key performance index (KPI) in factory i in industry j at year t. We use six different measures of KPI to identify various effects of factory smartization. They include (i) daily production: quantity of the main output produced per day, (ii) lead time: the total time spent from the initial ordering to the shipment of the main product, (iii) defect rate: the percentage of outputs that fail to satisfy a quality target, (iv) operating rate: the percentage of capacity being utilized, (v) product variety: number of customized or differentiated products, and (vi) number of customers.

The right hand side of Eq. (1) includes the measure of smartization, $Smart_{ijt}$, and other plant- and industry-level observables in X_{ijt}. This model also allows that the effect of smartization on KPIs may vary over time from one group to another: the group dummies (G_g) interacted with the linear time trend capture the effects (Heckman and Hotz, 1989). The specific groups include each industry group based on 5-digit KSIC, start-ups group with less than five years old, and the subsidized group with government support to adopt smart factory solutions. λ_{ij} and μ_t absorb time-invariant unobserved heterogeneity across industries and factories and year-specific effect, respectively.

We then consider the first-difference model of Eq. (1) as following:

$$\Delta ln(KPI_{ijt}) = \beta \Delta Smart_{ijt} + \Delta X_{ijt}\gamma + G_g\delta + \eta_t + u_{ijt} \tag{2}$$

where $\Delta = t - (t-2)$ as we have data for 2015 and 2017. $\eta_t = \Delta\mu_t$ and $u_{ijt} = \Delta\epsilon_{ijt}$. Note that $\Delta Smart_{ijt}$ is a level change, but the difference in dependent variable implies the percentage change. Thus, the coefficient β in Eq. (2) exhibits the semi-elasticity.

Eq. (2) can estimate the average effect of smartization, regardless of the type of production processes. However, as noted above, the effect on KPIs is likely to be different depending on the process type of factory. In Bartel et al. (2007), for example, the performance improvement of the CNC machine in the batch process was linked to a reduction in setup time and an increase in product variety. Although not directly analyzed in the study, more production of customized valves could imply more number of customers which can be important for a long-run growth of the business. We can expect a similar effect for the job shop process, since it is a form of batch process with a batch size of 1. On the other hand, it is difficult to expect the product variety to increase in the case of a continuous process. The smartization of the continuous process, instead, may reduce the lead time and daily production. Also, in the line process that assembles a large number of parts to produce a complex product, the defect rate due to the mis-assembly can be minimized if those parts are more systematically managed and monitored.

We account for the role of different production processes in our estimation by adding interaction terms as follows:

$$\Delta ln(KPI_{ijt}) = \beta_0 \Delta Smart_{ijt} + \sum_{k=1}^{2} \beta_k \Delta Smart_{ijt} Process_k + \Delta X_{ijt}\gamma + G_g\delta + \eta_t + u_{ijt} \tag{3}$$

where $process_{k\in\{1,2\}}$indicates assembly line and continuous processes. Hence, β_0 is the effect on KPIs for job shop or small batch process, while $\beta_0 + \beta_1$ and $\beta_0 + \beta_2$ are the effects for line and continuous processes, respectively.

4.2 Causes of Factory Smartization

The next question is what drives the difference in the level of factory smartization. One obvious source of smartization is the adoption of relevant technologies. Hence, we first estimate a model similar to Eq. (2):

$$\Delta Smart_{ijt} = \beta_0 \Delta Tech_{ijt} + \Delta X_{ijt}\gamma + G_g\delta + \eta_t + u_{ijt} \tag{4}$$

where $Tech_{ijt}$ measures the cumulative number of adopted technologies up to year t. As argued earlier, however, the technololgy adoption itself does not guarantee a smarter factory and other complementary factors may have to be accompanied. Potential candidates for the complements suggested in the literature include the structured management practices and existence of ICT division in factory. Hence, we will also test whether $Tech_{ijt}$ has some complementary effects with these characteristics.

5 Estimation Results

5.1 Main Findings

Turning to the estimation results, Table 2 shows the effect of smartization on daily production and lead time of the main product. The two KPIs are often regarded as the best measures of the plant-level productivity. In fact, they tend to be negatively correlated with one another because the reduction in lead time means an increase in production over a given period of time. However, rapid production does not always induce more production, unless there is sufficient demand. All specifications in the table include industry-specific linear time trend and year dummy. Robust standard errors for coefficients are clustered at KSIC 5-digit industry level in parentheses.

The first column only includes the change in smartization and estimate its effect on daily production. The increase in smartization has a significantly positive effect on the growth of daily production. In the second column, we include the number of adopted technologies for smartization between 2015 and 2017 ($\Delta Tech$) as the only explanatory variable. According to Brynjolfsson and Hitt (2003), the estimated coefficient in the second column should not be interpreted as the pure effect of technology adoption, but rather as the mixed effect of the technology adoption and its complementary investment in intangible organizational and human capital. However, since they were not able to observe the investment, their argument remains as a conjecture. In this study, we do observe at least a part of such intangible organization capital, the level of factory smartization. The third column shows a result supporting the argument of Brynjolfsson and Hitt (2003). The estimation result indicates that the significant growth of daily production did not automatically come from the technology adoption but it came with the upgrading of smartization. The technology adoption indirectly influences the daily production by improving the level of smartization. We will show how the adoption of relevant technologies enhances the level of factory smartization in a more detail.

Columns (4) through (6) in Table 2 reports the estimation results in the same manner as in columns (1) through (3), but the KPI of our interest is lead time. The findings are broadly consistent with the results for daily production: upgrading the level of smartization tends to reduce the lead time of the main product, but the adoption of technologies in itself do not have a significant impact.

Table 3 estimates Eq. (3). All specifications now include two interaction terms multiplied by the dummies for the line process and continuous process. However, the coefficients for the interaction terms in column (1) through (3) are not shown statistically significant. This means that the effect of smartization in all types of production processes is similar, at least, for daily production. In addition to the change in smartization, the second column controls for additional factory-level characteristics (ΔX_{ijt}), such as the level change in automation, the percentage changes in employment and raw material costs, as well as two group dummies for start-ups and government-subsidized factories (G_g), respectively. However, the inclusion of these controls does not qualitatively change the effect of smartization on daily production.

The third column shows the result of estimating the same specification as the second column, but it changes the sample used for estimation. This study relies entirely on the survey data and its reliability is a central, unavoidable concern. In particular, one may raise doubts as to whether the survey respondents knew the true values of daily production in both 2015 and 2017 if they did not keep record on them. Our survey indeed asks in question D2 about how many KPIs are monitored, but about 6% of sample factories said that they have no KPI, and about one-third answered that they have one or two KPIs to be monitored. The survey answers on various KPIs in these factories may be particularly less reliable. Therefore, we present the estimation result using only subsample of factories with at least three or more KPIs that are actually monitored in column (3). Nonetheless, the result does not differ significantly from that in column (2).

The same estimation results for lead time are reported in column (4) to (6) in Table 3. In column (4) and (5), the coefficients for smartization and its interaction terms are not individually significant. In the second row from the bottom of the table, however, indicates that the three coefficients are jointly significant at the 5% and 10%, respectively. Moreover, we find a disproportionately large, negative effect on the lead time for the continuous production process in column (6). This result is consistent with our expectation that the benefit of smartization in factories with the continuous process would mostly come from the reduction of lead time.

[More results to come...]

5.2 Robustness Checks

To be added.

6 Concluding Remarks

To be added.

References

BARTEL, A., C. ICHNIOWSKI, AND K. SHAW (2007): "How Does Information Technology Affect Productivity? Plant-Level Comparisons of Product Innovation, Process Improvement, and Worker Skills," *The Quarterly Journal of Economics*, 122, 1721–1758.

BITKOM E.V., VDMA E.V., AND ZVEI E.V. (2016): "Implementation Strategy Industrie 4.0: Report on the results of the Industrie 4.0 Platform," .

BLOOM, N., E. BRYNJOLFSSON, L. FOSTER, R. JARMIN, M. PATNAIK, I. SAPORTA-EKSTEN, AND J. VAN REENEN (2019): "What Drives Differences in Management Practices?" *American Economic Review*, 109, 1648–1683.

BRYNJOLFSSON, E. AND L. M. HITT (2003): "Computing Productivity: Firm-Level Evidence," *The Review of Economics and Statistics*, 85, 793–808.

BUFFINGTON, C., L. FOSTER, R. JARMIN, AND S. OHLMACHER (2016): "The Management and Organizational Practices Survey (MOPS): An Overview," CES Research Papers 16-28, Center for Economic Studies, U.S. Census Bureau.

BURKE, R., A. MUSSOMELI, S. LAAPER, M. HARTIGAN, AND B. SNIDERMAN (2017): "The smart factory: Responsive, adaptive, connected manufacturing," *Deloitte University Press*.

HECKMAN, J. J. AND V. J. HOTZ (1989): "Choosing among Alternative Nonexperimental Methods for Estimating the Impact of Social Programs: The Case of Manpower Training," *Journal of the American Statistical Association*, 84, 862–874.

ICHNIOWSKI, C. AND K. SHAW (2013): "Insider Econometrics," in *The Handbook of Organizational Economics*, ed. by R. Gibbons and J. Roberts, Princeton University Press, 263–311.

KAGERMANN, H., W. WAHLSTER, AND J. HELBIG (2013): "Recommendations for implementing the strategic initiative INDUSTRIE 4.0: Final report of the Industrie 4.0 Working Group," Tech. rep., Forschungsunions and acatech.

KOLBERG, D., J. HERMANN, AND F. MOHR (2018): "SmartFactoryKL System Architecture for Industrie 4.0 Production Plants," Whitepaper SF-1.2: 04/2018, Technology Initiative SmartFactory KL e.V., Kaiserslautern.

MONOSTORI, L. (2014): "Cyber-physical Production Systems: Roots, Expectations and R&D Challenges," *Procedia CIRP*, 17, 9–13.

PC CONTROL (2014): "Nobilia, Germany: Series production with lot-size-1 flexibility demonstrates the true potential of Industry 4.0," *No. 4*, 28–33.

RADZIWON, A., A. BILBERG, M. BOGERS, AND E. S. MADSEN (2014): "The Smart Factory: Exploring Adaptive and Flexible Manufacturing Solutions," *Procedia Engineering*, 69, 1184–1190.

STOCK, T. AND G. SELIGER (2016): "Opportunities of Sustainable Manufacturing in Industry 4.0," *Procedia CIRP*, 40, 536–541.

Figure 1: Horizontal & Vertical Integration of Manufacturing ecosystem

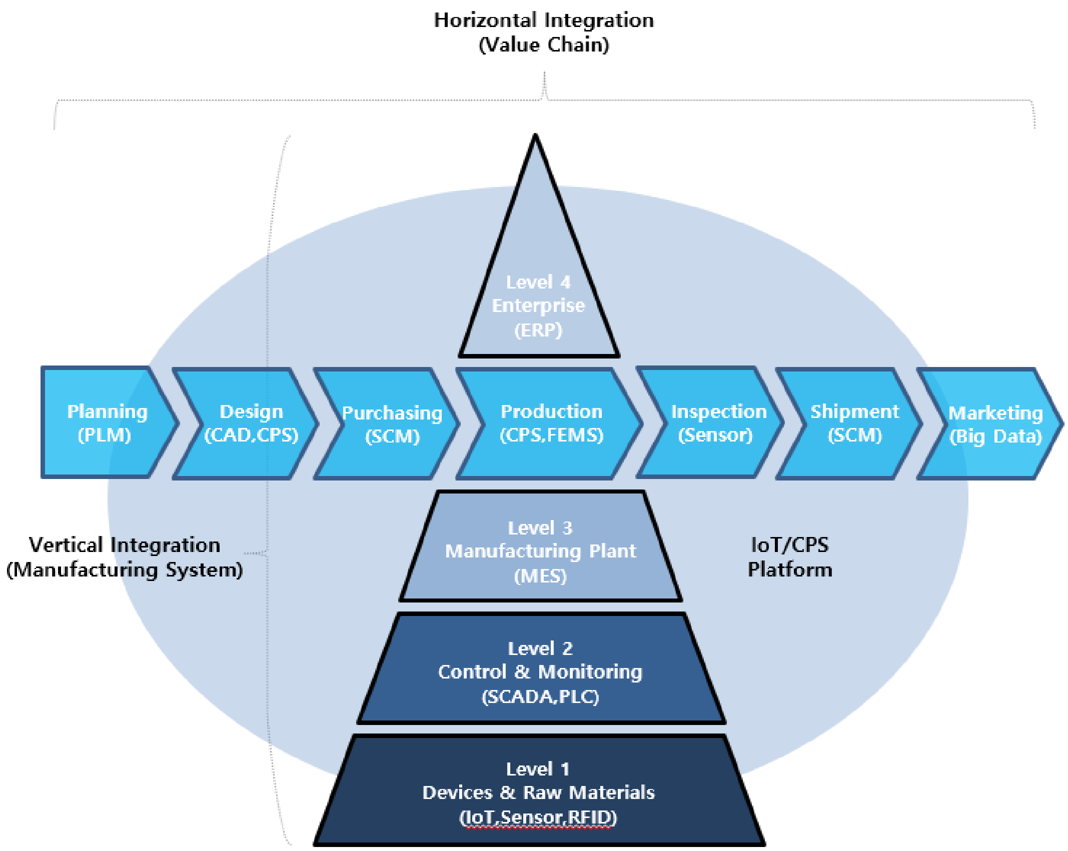


Figure 2: Distribution of Factory Smartization: 2015 vs. 2017

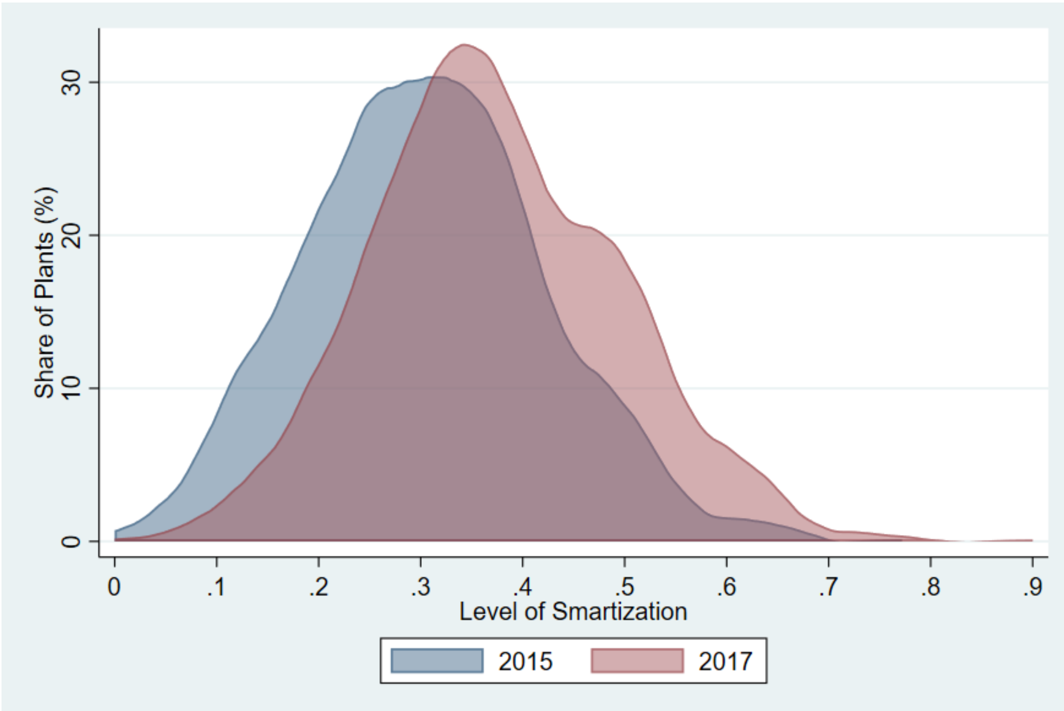


Figure 3: Change in Smartization

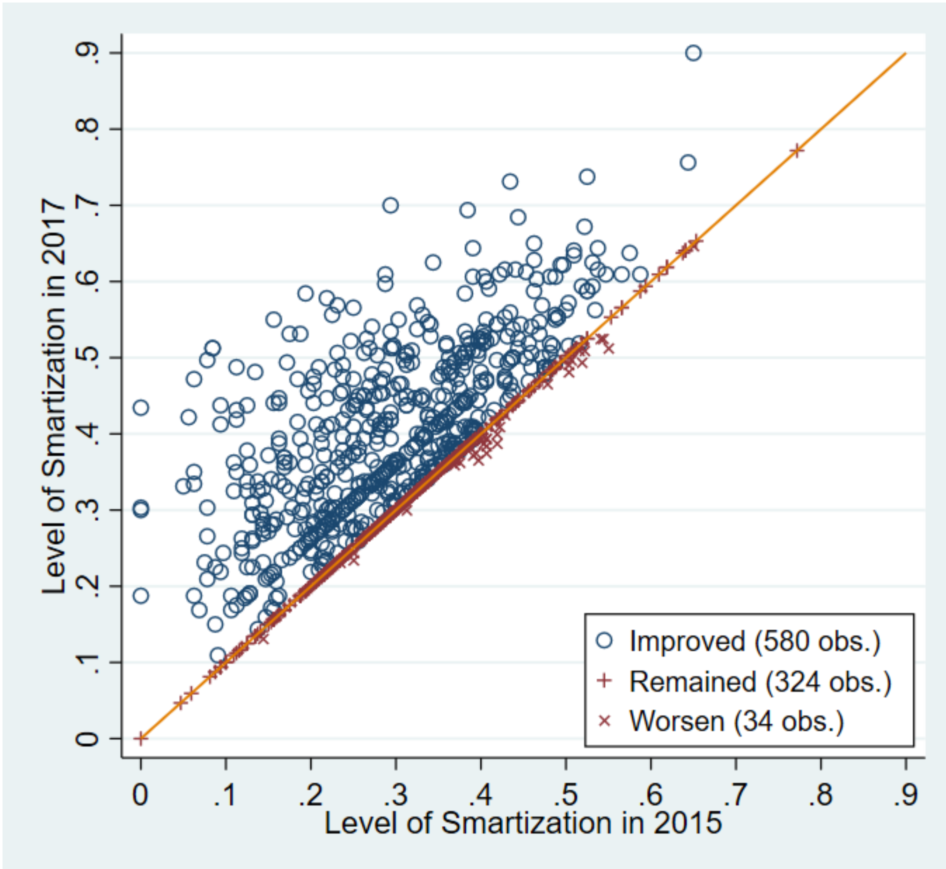


Figure 4: Relationship between Smartization and Other Variables

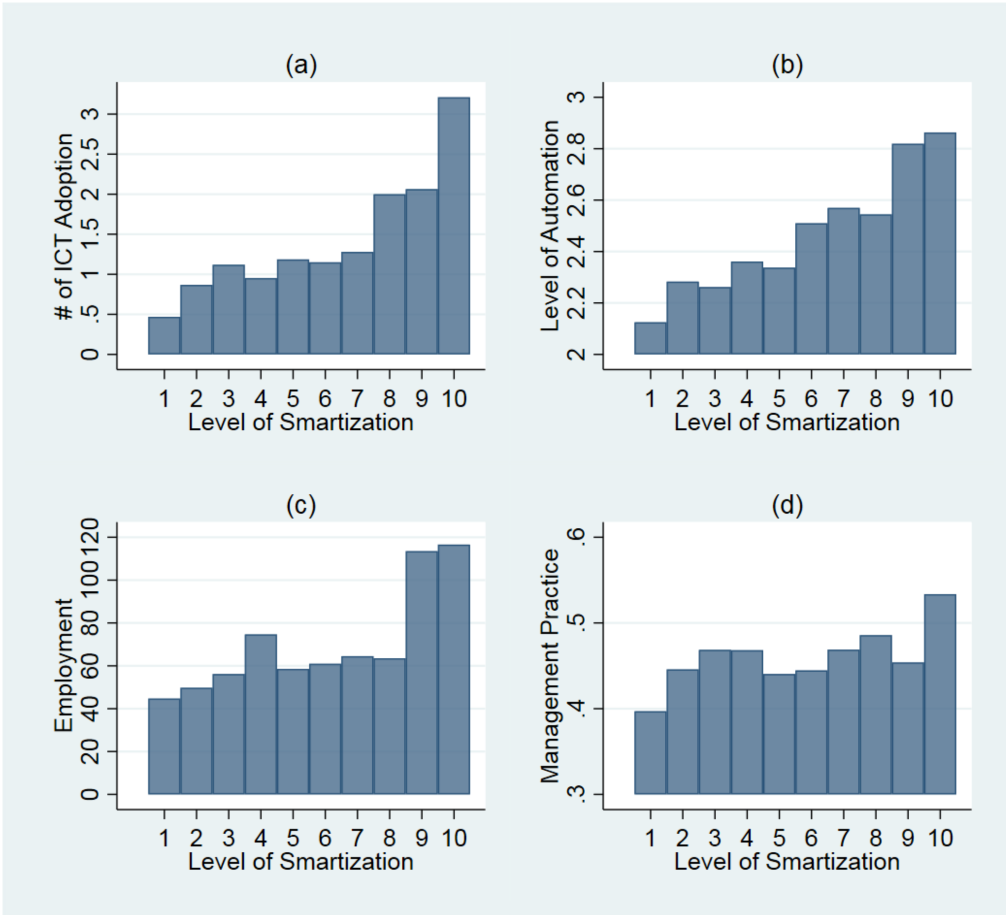


Figure 5: Trends in Enabling Technology Adoption

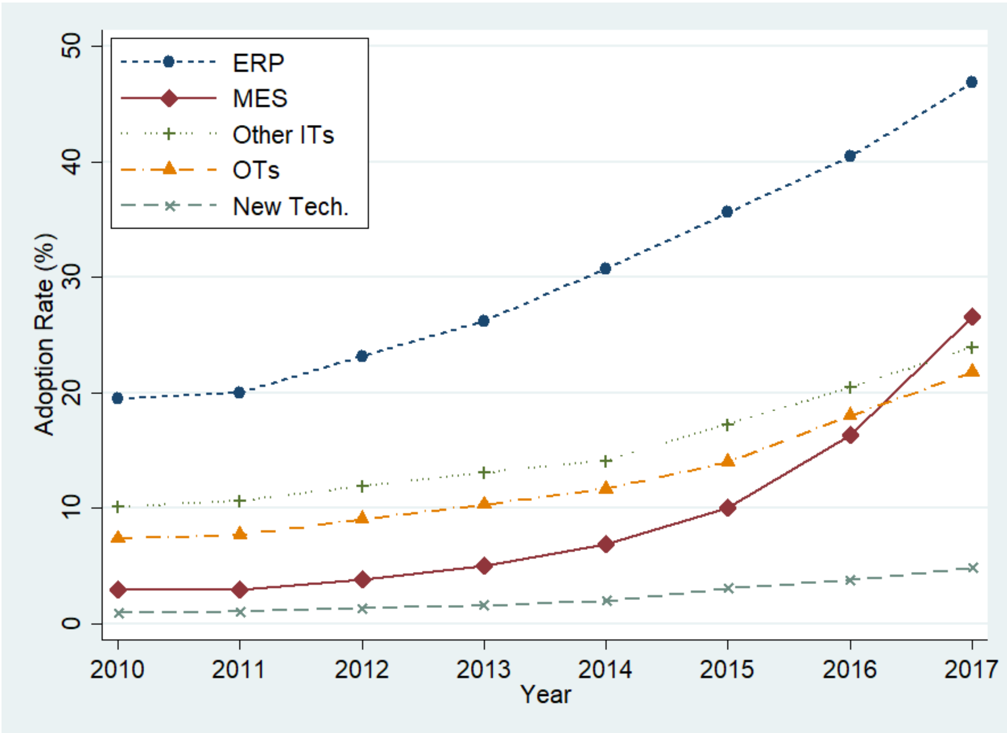


Table 1: Sample Distribution by Industry and Size

Industry (3 or 5-digit)	Size (Employment in 2017)				Total
	10~19	20~49	50~99	100 or more	
C134	12	40	18	9	79
C222	25	48	25	25	123
C259	24	64	30	24	142
C262	24	45	30	27	126
C291	32	55	26	29	142
C303	30	77	50	46	203
C20423	12	12	11	5	40
C29294	20	43	28	6	97
Total	179	384	218	171	952

Notes: C134=dyeing and finishing of textiles and wearing apparel, C222=manufacture of plastics products, C259=manufacture of other fabricated metal products, C262=manufacture of electronic components, C291=manufacture of general purpose machinery, C303=manufacture of parts and accessories for motor vehicles, C20423=manufacture of perfumes and cosmetics, C29294=manufacture of mould and metallic patterns.

Table 2: Overall Effects of Smartization on Daily Production and Lead Time

	Daily Production			Lead Time		
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta Smart$	0.660***		0.516**	-0.225*		-0.298**
	(0.231)		(0.233)	(0.121)		(0.149)
$\Delta Tech$		0.575**	0.376		0.075	-0.193
		(0.252)	(0.256)		(0.082)	(0.117)
Observations	807	807	807	890	890	890
R^2	0.124	0.119	0.129	0.104	0.097	0.110
N_Clusters	81	81	81	82	82	82

Notes: All specifications include industry-specific linear time trend and year dummy. Robust standard errors for coefficients are clustered at KSIC 5-digit industry level in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 3: Differential Effects of Smartization on Daily Production and Lead Time

	Daily Production			Lead Time		
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta Smart$	0.660***	0.588***	0.650***	-0.141	-0.135	-0.100
	(0.223)	(0.193)	(0.215)	(0.088)	(0.096)	(0.095)
$\Delta Smart \times Line$	-0.022	-0.042	-0.112	-0.057	-0.050	0.021
	(0.253)	(0.237)	(0.251)	(0.190)	(0.207)	(0.262)
$\Delta Smart \times Cont.$	0.214	0.389	1.001	-0.316	-0.339	-0.458**
	(0.463)	(0.467)	(0.887)	(0.239)	(0.259)	(0.222)
$\Delta Automation$		-0.232**	-0.313**		-0.038	-0.118
		(0.114)	(0.130)		(0.082)	(0.110)
$\Delta ln(Employment)$		-0.204*	0.184*		0.025	0.006
		(0.107)	(0.103)		(0.034)	(0.044)
$\Delta ln(Material\ Cost)$		0.189***	0.184***		0.010	-0.000
		(0.052)	(0.052)		(0.019)	(0.017)
Start-ups		0.091	0.105		0.003	-0.003
		(0.057)	(0.079)		(0.023)	(0.023)
Gov't Subsidy		0.051	0.049		0.016	-0.016
		(0.037)	(0.065)		(0.029)	(0.029)
Observations	807	763	458	890	831	498
F-stat	3.10**	3.36**	3.44**	2.87**	2.27*	2.86**
R^2	0.124	0.228	0.256	0.108	0.115	0.199
N_Clusters	81	81	71	82	82	73

Notes: All specifications include industry-specific linear time trend and year dummy. Robust standard errors for coefficients are clustered at KSIC 5-digit industry level in parentheses. F-stat is the test statistics for the joint significance of the three coefficients for $\Delta Smart$, $\Delta Smart \times line$ and $\Delta Smart \times cont.$ ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 4: Effects of Smartization on Defect Rate and Operating Rate

	Defect Rate			Operating Rate		
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta Smart$	-0.147	-0.163	-0.505	0.065	0.042	0.036
	(0.224)	(0.273)	(0.357)	(0.055)	(0.051)	(0.077)
$\Delta Smart \times Line$	-0.833*	-0.844*	-0.976**	0.019	0.002	-0.031
	(0.469)	(0.449)	(0.488)	(0.085)	(0.087)	(0.122)
$\Delta Smart \times Cont.$	0.087	0.114	0.046	-0.064	-0.047	-0.049
	(0.305)	(0.335)	(0.509)	(0.058)	(0.064)	(0.121)
$\Delta Automation$		-0.074	-0.015		0.013	-0.008
		(0.194)	(0.323)		(0.034)	(0.045)
$\Delta ln(Employment)$		-0.096	-0.039		0.067***	0.102**
		(0.096)	(0.136)		(0.025)	(0.044)
$\Delta ln(Material\ Cost)$		-0.000	-0.003		0.062***	0.099***
		(0.036)	(0.047)		(0.017)	(0.022)
Start-ups		0.036	-0.038		-0.003	-0.007
		(0.038)	(0.052)		(0.010)	(0.016)
Gov't Subsidy		0.011	-0.008		-0.013	-0.004
		(0.040)	(0.057)		(0.011)	(0.021)
Observations	840	790	479	887	832	500
R^2	0.104	0.114	0.157	0.067	0.155	0.259
N_Clusters	82	82	72	82	82	73

Notes: All specifications include industry-specific linear time trend and year dummy. Robust standard errors for coefficients are clustered at KSIC 5-digit industry level in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 5: Effects of Smartization on Product Variety and Number of Customers

	Product Variety			Number of Customers		
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta Smart$	0.258*	0.257*	0.399**	0.526***	0.555***	0.572**
	(0.153)	(0.154)	(0.193)	(0.141)	(0.184)	(0.221)
$\Delta Smart \times Line$	0.147	0.057	-0.002	-0.244	-0.326*	-0.446***
	(0.131)	(0.131)	(0.160)	(0.164)	(0.182)	(0.166)
$\Delta Smart \times Cont.$	-0.300**	-0.321**	-0.356**	-0.326*	-0.344	-0.209
	(0.131)	(0.132)	(0.167)	(0.179)	(0.217)	(0.263)
$\Delta Automation$		0.022	0.034		0.048	0.171*
		(0.047)	(0.070)		(0.070)	(0.091)
$\Delta ln(Employment)$		0.055	0.084		0.179***	0.207*
		(0.048)	(0.075)		(0.057)	(0.106)
$\Delta ln(Material\ Cost)$		0.032**	0.036		0.078***	0.107**
		(0.015)	(0.026)		(0.028)	(0.053)
Start-ups		0.039*	0.047		0.015	0.014
		(0.021)	(0.041)		(0.022)	(0.034)
Gov't Subsidy		-0.003	-0.005		-0.023	-0.030
		(0.019)	(0.032)		(0.029)	(0.042)
Observations	899	834	502	889	828	501
R^2	0.091	0.117	0.207	0.081	0.131	0.171
N_Clusters	82	82	72	81	81	73

Notes: All specifications include industry-specific linear time trend and year dummy. Robust standard errors for coefficients are clustered at KSIC 5-digit industry level in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 6: Additional Results

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	Daily Production	Lead Time	Defect Rate	Operating Rate	Product Variety	Number of Customers
$\Delta Smart$	0.522***	-0.179	-0.390*	0.031	0.234**	0.334***
	(0.191)	(0.181)	(0.216)	(0.065)	(0.111)	(0.126)
$\Delta Smart \times Top20\%$	0.106	-0.194	-0.571	-0.021	0.024	0.092
	(0.274)	(0.157)	(0.408)	(0.055)	(0.101)	(0.135)
$\Delta Tech$	0.205	0.189*	0.456*	0.050	-0.057	-0.110
	(0.287)	(0.100)	(0.245)	(0.045)	(0.059)	(0.089)
$\Delta Automation$	-0.221*	-0.051	-0.126	0.012	0.018	0.035
	(0.112)	(0.080)	(0.210)	(0.034)	(0.044)	(0.068)
$\Delta ln(Employment)$	0.200*	0.019	-0.125	0.066***	0.058	0.182***
	(0.104)	(0.032)	(0.102)	(0.025)	(0.048)	(0.059)
$\Delta ln(Material\ Cost)$	0.186***	0.010	-0.009	0.062***	0.034**	0.078***
	(0.052)	(0.019)	(0.036)	(0.017)	(0.015)	(0.029)
Start-ups	0.090	0.003	0.047	-0.005	0.037*	0.011
	(0.058)	(0.024)	(0.039)	(0.011)	(0.020)	(0.021)
Gov't Subsidy	0.035	0.004	-0.015	-0.016	0.001	-0.014
	(0.045)	(0.027)	(0.039)	(0.011)	(0.020)	(0.033)
Observations	762	830	789	831	833	827
R^2	0.228	0.117	0.114	0.157	0.111	0.128
N_Clusters	81	82	82	82	82	81

Notes: All specifications include industry-specific linear time trend and year dummy. Robust standard errors for coefficients are clustered at KSIC 5-digit industry level in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Appendix. Survey Structure

The survey consists largely of six sections. Since the full survey is attached to the appendix, we breifly explain questions introduced in each section.

A. Production Environment

This section asks about the main products of the plant(No. A1), their location in the supply chain(No. A2), and the production process type(No. A3). The production process types are categorized into four processes: one-off or job shop process, batch process, flow process, and continuous process. Process type can play an important role in this study because the effects of smartization of plant can vary depending on the process type. For example, one-off and batch processes are known to be the most suitable processes for producing a large variety of products in small quantities, whereas flow and continuous processes are suitable for mass production of products with low variety. Therefore, while smartization of plant can increase the number of products produced in one-off and batch processes, it may not be the case for flow and continuous processes.

B. Automation Level

This section measures plant automation levels as of 2015 and 2017. The question B1 asks plant's automation levels ranging from 1(mainly manual work) to 5 (entire process automation). This section also asks about the number of industrial robots (B2) and plant's demand for robots.

C. Smartization Level

This section consists of questions about the plant's smartization level and its introduction status of related technologies, and the reasons of its introduction and plans to introduce in two years. First, the questions about the plant's smartization level were largely intended to identify the following two dimensions, according to our definition of smart factory. The first dimension is the degree in which all the production activities of the plant are integrated systemically. It measures how close the plant is to the state that all processes, products, and components are networking with each other. The integration of production activities is important goal of a smart factory (see Figure 2-1). The second dimension captures the degree in which data is collected, shared and utilized in each production activity. It measures the plant's performance of data utilization. Even if each production activities are integrated into the system, plants can show different performance in sharing, analyzing and utilizing data. In particular, sharing information with other departments and factories or analyzing data and reflecting it in decision-making are possible when the ability of individual workers and business management practices are ready. For each of the two dimensions, this survey asks the level of vertical integration (No. C5) in the production process as of 2015 and 2017 and the level of horizontal integration (No. C6) from sales forecasting to production, inventory management and logistics. Both vertical and horizontal integration levels are measured with five stages. In addition, we asked how frequently various types of data collected from production activities are used in decision making (No. C9), how often the data analysis results are utilized (No. C10) and how much the data is shared among the participants in the value-generating process of the product (No. C11). They were asked to be answered in five or six separate steps. Some of the questions in No. C9 are from Buffinfton et al. (2016). We discuss the literature in more detail in Section D.

Another important information surveyed in this section is the plant's current introduction state of a dozen types of technology related to smart factory (No. C7). Specifically, No. C7 asks about the introduction year and future plans for introducing five types of ICT(Information and Communication Technology), three types of OT(Operational Technology), and four recently developed technologies related to smart factory. The five types of ICT correspond to Product Lifecycle Management system (PLM), Manufacturing Execution System (MES), Enterprise Resource Planning system (ERP), Supply Chain Management system (SCM), and Factory Energy Management system (FEMS), while the three types of OT correspond to digital control unit (Programmable Logit Controller, PLC), smart sensor (RFID), and central control system (Supervisory Control and Data Acquisition, SCADA). The four types of technologies related to smart factories include factory big data analytics, cloud computing services, artificial intelligence and machine learning, and Cyber Physical System(CPS). Survey No. C7 contains berief explanations on each individual technologies. As depicted in [Figure 2-1], these technologies can be introduced at various stages of production, directly and indirectly affecting the level of vertical integration of the plant operating system and the level of horizontal integration in sharing and utilization of data.

In addition, this section asks the degree of prior knowledge on smart factories (No. C1), the number of nearby factories that introduced smart factory technologies (No. C2), whether the plant conducted preliminary investigation for introducing smart factory-related technologies (No. C3), whether the plant offered training for the adoption of smart factory-related technologies (No. C4), plant's satisfaction and expected effects after technology introduction (No. C7-3 and C7-4), major reasons for the (non)introduction smart factories (No. C7-6 and C8), and whether the plant has recieved government support (No. C12).

D. Management Status

This section surveys on plant's management practices. This study utilize the quantitative measurement of management practices by **?**. The authors collaborated with the U.S. Census Bureau to devise a method for measuring a business's level of management practices with 16 multiple choice questions. They showed that the measured level of management practices is positively related to the productivity of the business. The survey, called MOPS (The Management and Organizational Practice Survey), is detailed in Buffington et al. (2016). The MOPS has been conducted in several countries including Britain, Australia and Japan.Chung (2018) has performed the MOPS in Korea. He found the level of management practices for manufacturing plants in Korea has a significant positive correlation not only with the plant's productivity but also with the level of introduction of new technologies. This section D of our survey includes all questions related to management practices covered in MOPS (No. D1~D8). The management practices include practices on monitoring the production process and setting goals, as well as personnel management and incentive management for employees. We sorted the questions into two categories: Production Management (No. D1~D6) and People Management (No. D6-1~D8).

This section also includes questions such as the degree of participation of production workers in decision-making and problem-solving in production process (No. D9 and D10), the degree of the CEO's interest in process innovation (No. D11), the presence of personnel or departments dedicated to integrating and optimizing production process (No. D12), and the CEO's risk preference (No. D14).

E. Employment and Work Characteristics

This section aims to understand the impact of smartization on employment and demand for workers' job competency (No. E2). Worker types are categorized into 3 types which are office workers, process control engineers and production workers. The question No. E3 asks expected change in demand for each type of workers.

F. Establishment Characteristics

This section asks about basic characteristics of the plant (total number of establishments, number of overseas subsidiaries, labor union status, foreign investment, etc. in No. F1) and the various performance indicators of the plant (No. F2). Key performance indicators include (i) the daily production of the main product; (ii) the lead time of the main product (from order to factory delivery); (ii) the defect rate of the main product; (iv) the number of products produced; and (vi) the number of customers. The question No. F2 also includes accounting information such as sales and costs of raw materials which enables us to calculate value-added.

<Survey> ID

A Survey on the Adoption and Effect of Smart Factories

EIEC | Economic Information and Education Center

How are you?

The Korea Development Institute (KDI) is conducting a survey on the adoption and effect of smart factories. The purpose of this survey is to identify the management practices and problems of smart factories comprehensively and systematically.

I'm sure you're busy, but I'd appreciate it if you could understand the importance of this survey and answer the questions. **The results of the survey are strictly confidential by the Statistics Act.**

Please give us a sincere answer so that your opinion can be reflected in the policy making.

Thank you.

Aug. 2018.
Responsible for survey: KDI Public Opinion Analysis Unit
(Economic Information and Education Center)
Phone: 044-550-4655, 4639, 4626 Fax: 044-550-4941

▶ Matters to be attended to when responding. ◀

1. This survey is for factory managers who have a good understanding of the overall situation of the factory, so please do not respond if you are not applicable.

2. Answer every questionnaire in order from the first page.

3. Please check (V) one box on the list when there is no other specific request.

4. Even if the information is related to management, please write down the details as much as possible.

Name of establishment	
Industrial classification (5 digit)	☐☐☐☐☐ (Direct entry: ______)
Year of establishment	( )Year
Location of head office	① Seoul ② Busan ③ Daegu ④Incheon ⑤ Gwangju ⑥ Daejeon ⑦ Ulsan ⑧ Sejong ⑨ Gyeonggi ⑩ Gangwon ⑪ Chungbuk ⑫ Chungnam ⑬ Jeonbuk ⑭ Jeonnam ⑮ Gyeongbuk ⑯ Gyeongnam ⑰ Jeju
Location of this establishment	① Seoul ② Busan ③ Daegu ④Incheon ⑤ Gwangju ⑥ Daejeon ⑦ Ulsan ⑧ Sejong ⑨ Gyeonggi ⑩ Gangwon ⑪ Chungbuk ⑫ Chungnam ⑬ Jeonbuk ⑭ Jeonnam ⑮ Gyeongbuk ⑯ Gyeongnam ⑰ Jeju

e.g.) Manufacture of new electric devices for automobiles: | 3 | 0 | 3 | 3 | 2 |

A. Manufacturing Environment

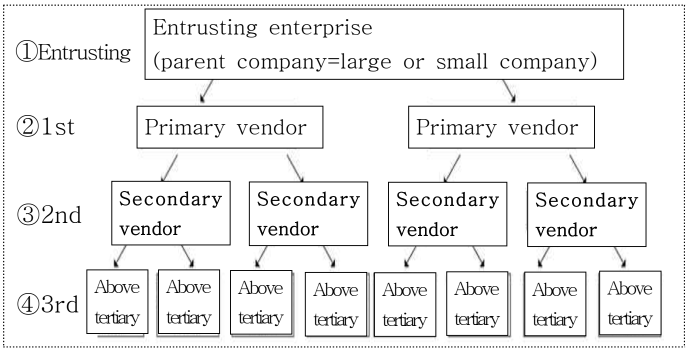
A1. Please respond to the following information regarding your establishment's products:

1) Major products (names)	
2) Type of major products (optional1)	① Intermediate goods (including parts, components and semi-finished products) ② Capital goods (tools, machinery, equipment used for production) ③ Final consumer goods ④ Outsourced goods

A2. Which type of company does this establishment belong, based on, the major products?

① Entrusting enterprise
② Primary vendor enterprise
③ Secondary vendor enterprise
④ Above tertiary vendor enterprise

※ Note: Corporate types according to production type



A3. Which of the following is the production method at this establishment?

① One-off, Job Process: Individual product production (e.g. Prototype, machine tool manufacturing, shipbuilding, etc)
② Batch Process: Similar items are grouped together and rotated to produce with the same equipment.(e.g. shoals, ceramics, etc.)
③ Line Process : Step-by-step production along the production line (e.g. refrigerator, car, etc.)
④ Continuous Process: Processes with automated facilities running non-stop (e.g. steel, beer, paper, etc.)

B. Automation Level

B1. During the entire production process, what best describes the automation level at this establishment? Also, what is the goal for the next year? Check one box for each year.

	① Mainly manual work	② Parts of process	③ Major process	④ Most processes	⑤ Entire process
1) 2015	①	②	③	④	⑤
2) 2017	①	②	③	④	⑤
3) 2019	①	②	③	④	⑤

※ The following questions survey the degree of adoption and utilization of robots* in the production process.

Robots: An automatically controlled, reprogrammable1), multipurpose manipulator programmable in three or more axes2), which is used in industrial applications from product production to shipment.

**NOTE 1) Reprogrammable: Designed to allow programmed motion or auxiliary functions to be changed without physical alteration*

2) Axis: Direction used to specify robot motion in linear or rotary mode

B2. As of the end of 2017, does this establishment have industrial robots? If so, how many?

① Have (__________ robots) ☞ B2-1
② Don't have one. ☞ B3

B2-1. What was the amount paid for the maintenance of industrial robots throughout the year 2017?

million won

B2-2. What was the total number of new robots purchased and their costs between 2016 and 2017?

Number of robots purchased	robots
Cost of purchasing	million won

B3. Did this company buy or plan to buy robots this year and next year (2019)? If it did, how many?

① Have (_____________ robots) ☞ B3-1
② Don't have one ☞ B 4

B3-1. How much will this company spend on robots this year and next year (2019)?

million won

B4. What choice would your company make under the following circumstances?

The volume of orders has increased, giving us at least five years of orders for the following years. To meet these orders, we need to hire at least 10 more production workers with this year's productivity level. One robot can replace five production workers. The total costs of purchasing and maintaining one robot add up to 200 million won at its present value, and its lifespan is 10 years.

① Don't buy robots, don't hire more workers.
② Buy robots, don't hire more workers
③ Don't buy robots, hire more workers.
④ Buy robots, hire more workers.

B5. In the context of question B4, if a robot could replace 10 people instead of five production workers, what would your company choose?

① Don't buy robots, don't hire more workers.
② Buy robots, don't hire more workers
③ Don't buy robots, hire more workers.
④ Buy robots, hire more workers.

C. Smartization Level

※ The following questions survey the level of smartization or smart factory* at this establishment.

<Smart Factory>
Factories that **integrate and optimize the entire process** from **Planning and design → Production → Distribution → to Sales**, etc., by using ICT (Information and Communication Technologies that include Internet of Things, Software, etc.) to **digitize** the data produced in the process and utilize the data.

C1. In 2015 and 2017, did your establishment have some prior knowledge of the smart factory concepts and related technologies presented above?

2015	2017

① Had no idea.
② Knew the basic concept and purpose.
③ Was aware of the concept and the related technology and applications in general.
④ Had expertise in concepts and related technologies and applications.

C2. Were there any establishments around your site that introduced or promoted the introduction of technology for smart factories over the past two years (2016-2017)? Mark all that apply.

① There wasn't.
② There were one or two businesses seeking to introduce the technology.
③ There were three or more businesses seeking to introduce technology.
④ There were already one or two businesses that introduced the technology.
⑤ There were already three or more businesses that introduced the technology.
⑥ I was not aware of the situation in other establishments near this site.

C3. Has this establishment conducted preliminary investigation for the introduction of smart factory-related technologies?

① No
② Conducted an in-house investigation
③ Conducted outside consultation
④ Others(   )

C4. Has this establishment offered training for the adoption of smart factory-related technologies? Mark all that apply.

① No
② Managers participate in relevant seminars or training programs
③ Provide training (within establishment or commissioned) for production line workers
④ Provide training (within establishment or commissioned) to all employees
⑤ Others(   )

C5. What best describes the **production process level** at this establishment? Also, what level is this establishment aiming for the year 2019? Enter a number for each year.

2015	2017	2019

① (Check) Managing production logs or checklistsmanually or making a simple plan using EXCEL
② (Monitoring) Production capacity is systematically managed so that production information can be checked and tracked at any point in time.
③ (Control) Data automatically enables real-time identification of abnormalities, and resolves problems by remote control.
④ (Optimization) Optimize the entire process, control the overall process, and anticipate problems in advance by leveraging factory big data and optimization solutions.
⑤ (Autonomous operation) Optimized factory can control and solve problems in case of abnormalities with little human intervention

C6. From sales forecasting to production, inventory management and logistics, what best describes the utilization level of **ICT(Information Communication Technology)**? Mark for each year.

List / Year	① Information generated at each step is not linked to ICT	② Linked to management system on specific operation (design, operation, inventory, accounting, etc.)	③ Some real-time links between management systems on each operation (order information=> production plan)	④ Real-time link between management systems on each operation (sales⇔ design⇔ production ⇔ resource management)	⑤ Information enerated at all levels is linked by ICT*
2015	①	②	③	④	⑤
2017	①	②	③	④	⑤
2019	①	②	③	④	⑤

* Sales forecasts are automatically reflected in production and logistics in real time

C7. **When** did this establishment **introduce** the ICT solutions and systems below? If it did not introduced them yet, do this establishment have plans for **introduction until 2019**?

※ Marked as 2010 if year of introduction is before 2010

Technology		Introduction status
1)	Digital Control Unit (PLC,CNC,HMI,etc)a device that monitors and controls mechanical information	① Yes(Year of introduction : ___) ② No (Introduction plan: ① Yes ②No)
2)	Central Control System (DCS, SCADA) A system that monitors and controls data collected by visualizing it with uptime, operating rate, etc.	① Yes(Year of introduction : ___) ② No (Introduction plan: ① Yes ②No)
3)	Product Design/Development System(PLM) (e.g. PDM, CAD, CAM, CAE, etc.) A system that consistently manages the whole process from design to production to increase value-added and reduce costs	① Yes(Year of introduction : ___) ② No (Introduction plan: ① Yes ②No)

	(Continuously)	Introduction status
4)	Manufacturing Execution System(MES) Collects/analyzes real-time information from product orders to shipments and optimizes production activities	① Yes(Year of introduction : __) ② No (Introduction plan: ① Yes ②No)
5)	Enterprise Resource Management System(ERP) Integrated, real-time management of key information from corporate activities	① Yes(Year of introduction : __) ② No (Introduction plan: ① Yes ②No)
6)	Supply Chain Management System(SCM) Optimize the Level of Supply Chain through information sharing among companies involved in transactions such as parts supply and distribution	① Yes(Year of introduction : __) ② No (Introduction plan: ① Yes ②No)
7)	Energy Saving System(FEMS) Optimize energy use in real time through monitoring, analysis, and remote control	① Yes(Year of introduction : __) ② No (Introduction plan: ① Yes ②No)
8)	Collection and utilization of device or product data using smart sensors, radio recognition tags (RFIDs, NFCs, Bluetooth)	① Yes(Year of introduction : __) ② No (Introduction plan: ① Yes ②No)
9)	Factory big data analysis, actual time, device information, production information, etc. processed and used for production process	① Yes(Year of introduction : __) ② No (Introduction plan: ① Yes ②No)
10)	Cloud Computing Services Store and utilize data on Internet servers rather than on individual PCs	① Yes(Year of introduction : __) ② No (Introduction plan: ① Yes ②No)
11)	AI (Artificial Intelligence) and Machine Learning Computer recognizes facility information, product images, etc., learns them on its own and utilizes them for decision making.	① Yes(Year of introduction : __) ② No (Introduction plan: ① Yes ②No)
12)	Virtual Factory System (CPS) A virtual process system identical to the actual process is established and utilized for various simulations	① Yes(Year of introduction : __) ② No (Introduction plan: ① Yes ②No)

※ Regarding the ICT solutions listed in the table above,:
- If any of these are introduced, ☞ C7-1
- If not one is introduced ☞ C 8

C7-1. Approximately what was the amount paid for the maintenance of ICT solutions and systems throughout the year 2017?

million won

C7-2. Approximately what was the total costs of purchasing new ICT solutions and systems introduced between 2016 and 2017?

million won

C7-3. How satisfied are you with the ICT solutions and systems introduced in this establishment?

① Very dissatisfied respect to what I expected.
② Somewhat dissatisfied respect to what I expected.
③ Satisfied as much as I expected.
④ A little more satisfied than I expected.
⑤ Much more satisfied than I expected.

C7-4. How much do you expect to see the effects of the ICT solutions and systems introduced in this establishment in the next two years?

① It will be much lower than it is now.
② It will be a little lower than it is now.
③ It will be similar to the present.
④ It will be slightly higher than it is now.
⑤ It will be much higher than it is now.

C7-5. How did your business choose suppliers for ICT solutions and systems?

① Promotion and advice from suppliers or consulting companies
② Use the list of suppliers provided by Korea Smart Factory Foundation
③ Use cases from other establishments
④ Self investigation
⑤ Selected or designated by a participating consortium
⑥ Others( )

C7-6. Why did your business adopt ICT solutions and systems? Please tell two priorities.

1st		2nd	

① Improve productivity (production per hour)
② Reduce lead time (from order to factory delivery)
③ Reduce defect rate of products
④ Efficient Inventory Management
⑤ Improve operating rate
⑥ Improve efficiency in energy and raw material usage
⑦ Improve of working environment at production site for workers
⑧ Forcasting demand and establishing marketing strategies
⑨ Developing new products or business models
⑩ Strengthening the connection with buyers and suppliers
⑪ Others(   )

☞ C 9

C8. Why are ICT solutions and systems not introduced at this establishment? Please tell two priorities.

1st		2nd	

① Lack of information on smart factories
② Too high investment costs
③ Hard to keep maintenance/repair and upgrade after introduction
④ Difficulty in securing professionals
⑤ Concerns about information or technology leaks
⑥ Lack of confidence in the effects
⑦ A sense of disapproval from employee
⑧ Concerns about becoming more dependent for the buyer (contracting) company
⑨ Not recommended from a consultant (technical commissioner or coordinator) or a supplier
⑩ Others(   )

C9. How frequently were the following data used to make decisions at this establishment? Mark for each year.

Types of data		① Real-time	② Every day	③ Every week	④ Every month	⑤ Every year	⑥ Not used
1) Indicators from machines or instruments	2015	①	②	③	④	⑤	⑥
	2017	①	②	③	④	⑤	⑥
2) Manager's formal or informal feedback	2015	①	②	③	④	⑤	⑥
	2017	①	②	③	④	⑤	⑥
3) Production workers' formal or informal feedback	2015	①	②	③	④	⑤	⑥
	2017	①	②	③	④	⑤	⑥
4) Data collected from outside the establishment (suppliers, buyers, external data providers, etc.)	2015	①	②	③	④	⑤	⑥
	2017	①	②	③	④	⑤	⑥

C10. How often did your business apply data analysis results into the following activities at this establishment? Mark for each year.

Establishment activities		① Real-time	② Every day	③ Every week	④ Every month	⑤ Every year	⑥ Not used
1) Optimization of production process lines	2015	①	②	③	④	⑤	⑥
	2017	①	②	③	④	⑤	⑥
2) Product quality improvement and reduction of defect rate	2015	①	②	③	④	⑤	⑥
	2017	①	②	③	④	⑤	⑥
3) Anticipating failures of Production Facilities in advance	2015	①	②	③	④	⑤	⑥
	2017	①	②	③	④	⑤	⑥
4) Development of new products or services	2015	①	②	③	④	⑤	⑥
	2017	①	②	③	④	⑤	⑥
5) Supply chain (supplier or customer related information) management	2015	①	②	③	④	⑤	⑥
	2017	①	②	③	④	⑤	⑥
6) Forecasting product demand and establishing marketing strategies	2015	①	②	③	④	⑤	⑥
	2017	①	②	③	④	⑤	⑥

C11. At what level and scope were the data that are collected and analysed from activities such as production, logistics, and sales at this establishment shared? Mark for each year.

Level and scope of sharing data		① Not sharing at all	② Partially share as needed	③ Always share within pre-agreed scope and use	④ In addition to pre-agreed scope, share as often as needed	⑤ Always share all information
1) Between staffs in the business division	2015	①	②	③	④	⑤
	2017	①	②	③	④	⑤
2) Between business divisions in the establishment	2015	①	②	③	④	⑤
	2017	①	②	③	④	⑤
3) Between the establishments within the affiliated company	2015	①	②	③	④	⑤
	2017	①	②	③	④	⑤
4) Between suppliers or buyers within supply chain	2015	①	②	③	④	⑤
	2017	①	②	③	④	⑤

C12. Has your establishment received the following government support for smart factories over the past 4 years (2014-2017)? If so, how much did each program help to build smart factory at this establishment?

Government support program	Received		Degree of contribution(Answer when you replied 1'Yes' to receiving government support)				
	① Yes	② No	① Not helpful at all	② Not very helpful	③ Normal	④ A little help	⑤ Very helpful
1) Implementation Support: Industrial Innovation Movement (supporting 2nd and 3rd partner companies, etc. from a mutual growth fund contributed by large enterprises)	①	②	①	②	③	④	⑤
2) Implementation Support: ICT convergence smart factory support and spread program (Korea Smart Factory Foundation: support 50% total costs up to 50 million won)	①	②	①	②	③	④	⑤
3) Implementation Support: Support for Regional Specialized Industry Process Innovation and Spread of Smart Factories (Techno Park)	①	②	①	②	③	④	⑤
4) Implementation Support: Cloud type Smart factory support program	①	②	①	②	③	④	⑤
5) Financial support (Warranty and loans for businesses that have confirmation from Korea Smart Factory Foundation)	①	②	①	②	③	④	⑤
6) R&D Support (Smart Factory Technology Development, etc.)	①	②	①	②	③	④	⑤
7) Education support (Smart Factory Academy, Implementation Practices, etc.)	①	②	①	②	③	④	⑤
8) Training support (training personnel specialized in process design of smart factories, etc.)	①	②	①	②	③	④	⑤

C13. In addition to smart factory support programs in the past 4 years (2014-2017), has your establishment received government or public support programs in the following areas? Mark all that apply.

① Financial support
② Human resource, personnel management, education and training support
③ R&D support
④ Marketing and export Support
⑤ Others(   )

D. Management Practices

※ The following questions survey management practices at this establishment such as performance management, personnel management, and organizational practices. For each question, please select that best describes the general situation at this establishment in 2017.

D1. What happened at this establishment when a problem in the production process arose (e.g. finding a quality defect in a product or a piece of machinery breaking down, etc.)?

① No action was taken
② We fixed the problem but did not take further action.
③ We fixed the problem and took measures to prevent it from happening again.
④ We fixed the problem and took measures to prevent it from happening again, and had a continuous improvement process to anticipate problems like these in advance

D2. How many Key Performance Indicators (KPI)* were monitored at this establishment?

① None.
② 1 to 2 indicators
③ 3 to 5 indicators
④ 6 to 9 indicators
⑤ More than ten

* *Key Performance Indicators: Quantitative indicators of factors that should be managed in production activities (e.g. production per hour, defect rate, inventory cost, lead time, etc.).*

D3. Where were the production display boards (bulletins presenting information) showing key performance indicators(KPI) at this establishment?

① Display boards are not installed
② The display boards were located in multiple places. (e.g. at multiple stages of the production line)
③ All display boards were located in one place (e.g. the end of the production line)

D4. How frequently did the managers and non-managers at this establishment typically review the Key Performance Indicators (KPI)?

	① Every hour or more often	② Once a day	③ Once a week	④ Once a month	⑤ Once a quarter	⑥ Once a year	⑦ Do not confirm
1) Managers	①	②	③	④	⑤	⑥	⑦
2) Non-managers	①	②	③	④	⑤	⑥	⑦

※ Note: Manager and Non-manager

Manager: A person who has an employee who reports directly, meets employees regularly and is involved in their wages and promotions. Generally applicable to mid-level management positions above the chief level and senior management positions at the executive level
Non-manager : All employees who are not manager

D5. Who was aware of the production targets at this establishment?

① Only senior managers
② Most managers and some production workers
③ Most managers and most production workers
④ All Managers and most production workers

D6. What best describes the time frame of production targets* at this establishment?

* *Examples of production targets: increased production, improved quality, cost reduction, on-time delivery, etc.*

① Main focus was on short-term (less than 1 year) production targets ☞D6-1
② Main focus was on long-term (more than one year) production targets ☞D6-1
③ Combination of short term and long term production targets ☞D6-1
④ No production targets ☞D7

D6-1. How much effort did it take to achieve production targets at this establishment?

① Failed to achieve
② Achieved without much effort.
③ Achieved with some effort.
④ Achieved with normal amount of effort.
⑤ Achieved with more than normal effort
⑥ Achieved with extraordinary effort.

D6-2. What were managers and non-managers' performance bonuses based on at this establishment?

	① Each worker's performance against the targets	② Their team or shift performance against the targets	③ Their establish-ment's performance against the targets	④ Their comapny's peformance against the targets	⑤ No performance bonuses.
1) Managers	①	②	③	④	⑤
2) Non-managers	①	②	③	④	⑤

D6-3. When production target were met at this establishment, what percent of managers and non-managers received performance bonuses?

	① 0%	② 1~33%	③ 34~66%	④ 67~99%	⑤ 100%	⑥ Produc-tion targets not met
1) Managers	①	②	③	④	⑤	⑥
2) Non-managers	①	②	③	④	⑤	⑥

D7. What was the primary way managers and non-managers were promoted at this establishment?

	① Only performance and ability	② Performance, ability and other factors*	③ Mainly on factors other than performance and ability.	④ Normally no promotions
1) Managers	①	②	③	④
2) Non-managers	①	②	③	④

* Examples of other factors: tenure, connections, etc.

D8. When was an under-performing manager or non-manager reassigned or dismissed at this establishment once manager or non-manager under-performance was identified?

	① Within six months	② After six months	③ No reassignment or dismissal
1) Manager	①	②	③
2) Non-manager	①	②	③

D9. Did the workers at production site participate in decision-making on reorganizing process and work organization?

① Participated
② Not participated

D10. To what extent did the workers at production site participate in problem solving if there was a problem with the production process?

① No participation at all
② Assisted a separate troubleshooting team
③ Participated considerable part of the matter
④ Took full responsibility

D11. How interested was <u>this company's CEO</u> in process innovation such as introducing robots for automation or ICT solutions for smart factory?

① Was not interested
② Had little interest
③ Had some interest
④ Was very interested

D12. Does this establishment have staffs or department exclusively in charge of optimizing the ICT solution-based production process?

① No staffs
② There are staffs, but not a separate department
③ There is a sesparate department

D12-1. How did this establishment employ key people in charge of optimizing production process? Mark all that apply.

① Continued to leverage existing staff
② Recruited experienced personnel in related industries
③ Hired new employees and trained them
④ Others(   )

D13. What are <u>the most important challenges that this establishment needs to improve</u> over the next two years(2018-2019)? Please tell two priorities.

1st		2nd	

① Improve productivity (production per hour)
② Reduce lead time (from order to factory delivery)
③ Reduction of defect rate of products
④ Efficient Inventory Management
⑤ Improve operating rate
⑥ Improve efficiency in energy and raw material usage
⑦ Improve of working environment at production site for workers
⑧ Forcasting demand and establishing marketing strategies
⑨ Developing new products or business models
⑩ Strengthening the connection with buyers and suppliers
⑪ Others(   )

D14. What best describes the management philosophy of you and this company's CEO? Choose the nearest score.

(You: ________score/ CEO:_______score)

Avoid risk as much as possible and seek the most stable direction					↔					Take the risk and take the adventure
0	1	2	3	4	5	6	7	8	9	10

E. Employment and work characteristics

※ The following questions survey on the employment and job characteristics at this establishment.

E1. Please choose the nearest number that best describes overall personnel management objectives and key principles at this establishment.

1) Objectives of Personnel Management

Primary goal is to <u>reduce fixed labor costs</u> as much as possible.		↔		Primary goal is <u>to increase the loyalty and attachment</u> of workers to this company.
①	②	③	④	⑤

2) Major Principles of Personnel Management

It is operated on the basis of <u>individual performance/outputs</u>		↔		It is operated based on <u>teamwork.</u>
①	②	③	④	⑤

E2. <u>How important</u> was your employees' <u>job</u>

competency for each skill at the end of 2017 compared to 2015? Also, how much more important do you expect to be in the next two years (2018-2019)?

Skills Classification		① Significantly reduced in importance	② ↔	③ Similar importance	④ ↔	⑤ Significantly increasing in importance
1) Perform tasks without making mistakes	‘17 compared to ’15	①	②	③	④	⑤
	The next two years (‘18~’19)	①	②	③	④	⑤
2) Ability to solve problems in response to unexpected situations	‘17 compared to ’15	①	②	③	④	⑤
	The next two years (‘18~’19)	①	②	③	④	⑤
3) Ability to quickly learn and skillfully handle the latest technology	‘17 compared to ’15	①	②	③	④	⑤
	The next two years (‘18~’19)	①	②	③	④	⑤
4) Versatile ability to perform various tasks as needed	‘17 compared to ’15	①	②	③	④	⑤
	The next two years (‘18~’19)	①	②	③	④	⑤
5) Communication skills within team	‘17 compared to ’15	①	②	③	④	⑤
	The next two years (‘18~’19)	①	②	③	④	⑤
6) Ability to analyze and utilize data	‘17 compared to ’15	①	②	③	④	⑤
	The next two years (‘18~’19)	①	②	③	④	⑤

※ We will categorize the workers into three types at this establishment: 1) Office worker, 2) Process control engineer, and 3) Production worker.

Office worker: Workers who carry out general office and management tasks

Process control engineer: Workers who operate and manage facilities and production processes using technical knowledge

Production worker: Workers performing simple tasks on the production line

E3. Given this establishment’s plan to introduce ICT solutions and systems, how much change do you expect in demand of workforce over the next two years? Please respond for each type of workers.

E3-1. Demand in office workers for the next two years

① Decrease by more than 10% ☞ E3-1-1
② Decrease below 10% ☞ E3-1-1
③ No big change ☞ E3-2
④ An increase of less than 10% ☞ E3-2
⑤ An increase of more than 10% ☞ E3-2

E3-1-1. To whom do you expect to see a major decline in demand of office workers?

① Less than 5 years of experience
② 5-9 years of experience
③ More than 10 years of experience

E3-2. Demand in process control engineers for the next two years

① Decrease by more than 10% ☞ E3-2-1
② Decrease below 10% ☞ E3-2-1
③ No big change ☞ E3-3
④ An increase of less than 10% ☞ E3-3
⑤ An increase of more than 10% ☞ E3-3

E3-2-1. To whom do you expect to see a major decline in demand of process control engineers?

① Less than 5 years of experience
② 5-9 years of experience
③ More than 10 years of experience

E3-3. Demand in <u>production workers</u> for the next 2 years

① Decrease by more than 10% ☞ E3-3-1
② Decrease below 10% ☞ E3-3-1
③ No big change ☞ E 4
④ An increase of less than 10% ☞ E 4
⑤ An increase of more than 10% ☞ E 4

E3-3-1. To whom do you expect to see a major decline in demand of production workers?

① Less than 5 years of experience
② 5-9 years of experience
③ More than 10 years of experience

E3-3-2. If the demand for production workers decreases, do you have plans to reassign? If you have plans to reassign, where are these workers reassigned?

① Reassign to process control engineer
② Reassign to office worker
③ No plan for reassignment

E4. Over the next two years, to whom do you expect to see to learn and lead the technology needed to improve production process among process control engineers?

① Less than 5 years of experience
② 5-9 years of experience
③ More than 10 years of experience

E5. What is the plan to conduct training and training on process innovation, including smart factories?

① In-house education program
② Education program of partner large companies
③ Training program by specialized provider
④ Educational programs by government agencies
⑤ Others( )

F. Establishment Characteristics

F1. The following are the business activities of <u>this establishment</u> and <u>the firm that this establishment belongs to</u>. Please fill in the blanks.

	Classification	Current status
1)	Total number of establishments of the firm (Including this site)	unit
2)	Percentage share of this establishment's shipments to total firm sales	%
	2)-1. <u>If the answer 2) is not known,</u> percentage share of the production capacity of this establishment to the total capacity of the firm.	%
3)	Foreigners or foreign companies' share in investment (percentage of shares)	%
4)	Number of overseas subsidiaries	unit
5)	Labor union status	① Yes ② No
6)	Founder(s) or member(s) of a founder's family is a representative of the firm	① Yes ② No
7)	Affiliate status	① Affiliate ② An independent company

F2. Please fill in the following production information at this establishment:

Classification	2015	2017
1) Sales	million won	million won
2) Export amount	million won	million won
3) Operating profit	million won	million won
4) Number of products produced		
5) Number of export products		
6) Number of customers (Including foreign companies)		
7) Daily output of main product	(unit:)	(unit:)
8) Lead time of main product (time taken from order to factory delivery)	days	days
9) Defect rate of main product	%	%
10) Operating rate	%	%
11) Raw materials cost (including subsidiary, auxiliary, and packaging material cost)	million won	million won
12) Percentage share of import out of raw materials cost	%	%
13) Outsourcing cost (consignment manufacturing cost)	million won	million won
14) Percentage share of costs paid to foreign companies out of outsourcing cost	%	%

F3. The following questions survey the employment status and employment information for production workers and technical worker at this establishment. Please fill in the blanks.

F3-1. Number of workers

Year		Number of workers
1) Total number of employees at the end of 2015*		person
2) At the end of 2017,	Total number of workers	person
	Office workers	person
	Process Control Engineers	person
	Production workers	person

* Exclude workers from service company and dispatched workers that your business does not pay wages directly.

F3-2. Occupation characteristics (as of the end of 2017)

Category	Current status
1) Women's ratio	%
2) Ratio of foreign workers	%
3) Ratio of workers under 35 years of age	%
4) Ratio of workers over 55 years of age	%
5) Ratio of workers with less than 5 years of experience at this establishment	%
6) Ratio of workers with more than 20 years of experience at this establishment	%
7) Ratio of full-time employees	%
8) Ratio of production workers who can manage the machines and systems that control the production process	%
9) Number years of experience that a production worker can take a technical position*	years

* If a production worker cannot become a technical worker, respond with 9999.

F3-3. Production and technical workers' wages and working hours (as of the end of 2017)

Cateory		Production workers	Process control engineers
1) Wage system		① A seniority system ② Performance-based pay system ③ An hourly wage system	① A seniority system ② Performance-based pay system ③ An hourly wage system
2) Monthly average wage	First-time employment	ten thousand won	ten thousand won
	Fifth year	ten thousand won	ten thousand won
	10th year	ten thousand won	ten thousand won
3) Average working hours per week		hours	hours
4) A change In working hours per week	'17 compared to '15	① Reduction ② Increase ③ Same	① Reduction ② Increase ③ Same
	'19 compared to '17 in expectation	① Reduction ② Increase ③ Same	① Reduction ② Increase ③ Same
5) Shift system			
6) Shift system change plan		① Yes ② No	① Yes ② No

Thank you for taking the survey.

Record after an interview

Respondent's name	
Respondent position	① Executive ② Manager's level ③ Deputy director/section head level ④ Asst. Manager/employee level ⑤ Others( )
Respondent telephone number	
Respondent E-mail	
Establishment address	city gu/si/gun eup/myeon/dong
Date of survey	year month day
Degree of cooperation	① High ② Medium ③ Low
Response reliability	① High ② Medium ③ Low
Investigator's name	