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Industrial automation findings: Smart Manufacturing Kaizen Level (SMKL) based maturity evaluation access to digital transformation and decarbonization

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ABSTRACT

Digital transformation is fostering the evolution within the manufacturing industry, entering a new era of smart manufacturing. Manufacturers are facing the challenge in organizing various of disruptive events, while supporting their business sustainability in a coordinated manner across manufacturing. Especially, in response to Paris Agreement, decarbonization has arisen as one of the essential keys to smart manufacturing for manufacturers to achieve their business sustainability.

In this paper, we present a maturity model called Smart Manufacturing Kaizen Level (SMKL), which evaluate smart manufacturing implementation maturity by applying manufacturing data and supporting on implementation with reasonable investment. With SMKL, manufacturers can have a better understanding of their efforts in the smart manufacturing journey and how to commit to their decarbonization targets in scaling up implementation continuously. We also provide real life case studies utilizing SMKL to lower the barriers in understanding and assure the effectiveness of smart manufacturing assessment in practice.

1. INTRODUCTION

With the rapid revolution of digitalization technologies, the advantage of having digital transformation has been quickly recognized in manufacturing industry. Evolution through digital transformation is fostering manufacturing entering a new era of smart manufacturing. Enabling technologies such as the Industrial Internet of Things (IIoT) and Artificial Intelligence (AI) are attracting attention for their importance to smart manufacturing to become connected and adaptive to meet market demands.

More recently the effort towards decarbonization in manufacturing has become increasingly important in manufacturing industry. Manufacturing companies raises an urgent need for a transition to green manufacturing. This decarbonization needs has once again powered smart manufacturing to a higher level of smartness across the manufacturing value chain in enabling dynamic response to changing conditions in manufacturing and environmental demands.

The purpose of SMKL is to accommodate disruptive demands such as productivity and CO_2 emission reduction in smart manufacturing, while supporting the guidance of implementation and methods of evaluating system performance to achieve a coordination of implementation processes links to Kaizen [1]. SMKL is applicable as an evaluation tool across smart manufacturing system implementation journey found within manufacturing companies.

Section 2 reviews the related work to figure out the issues in existing practice with a better understanding of having SMKL. Section 3 presents SMKL concept associated with its evaluation framework. Section 4 provides examples to use the SMKL in action to apply to digital transformation and decarbonization scenarios. Section 5 concludes with a guidance principle for addressing the contribution of SMKL in smart manufacturing. Future work is specified in the end.

2. STATE OF ART

2.1. Digital transformation in smart manufacturing

IIoT fuses the digital realm with the real-world of the things with data systems and human activities. Then building upon IIoT with AI, smart manufacturing is emergent characteristic of manufacturing enables the application to machine and interconnected manufacturing process to gain insights into the operations, optimize them intelligently to boost flexibility and deliver values to customers. Many strategic initiatives such as e-F@ctory Alliance [2], have widely discussed the concept of smart manufacturing, underlying enabling technologies, and impacts on different views of industrial use.

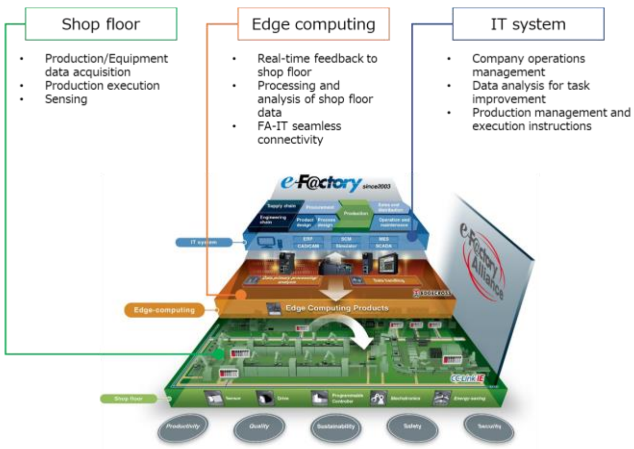

Figure 1 Smart manufacturing in practice with e-F@ctory.

Digital transformation is a new topic in smart manufacturing which is a catch-all characteristic refers to digital technologies to power up the change throughout the overall business with organizational changes. These changes optimize and transform the way business operate and deliver values to both customer side and related manufacturing side more efficiently and competitively on different time scales. Digital transformation is a journey that is addressed in three steps: digitization, digitalization, and digital transformation. Digitization is the step to convert analog data into digital data to facilitate the visualization of manufacturing process to improve their operations. Digitalization is the step to ingest and analyze the digitized data into manufacturing processes for optimization by integrating and potentially re-engineering them. Finally, digital transformation is the step to ultimate the things to maximizing profitability and create new business opportunities in a coordinated manner across the variety of customers, suppliers at various stages in the value chain.

To benefit from the full potential of digital transformation in smart manufacturing, many manufacturing companies are capitalizing on their essential investment and functions as well as innovation to stay ahead of competitors and embrace the change in manufacturing. It is very important to have a clear and applicable roadmap for every individual manufacturing company not only to maintain but also to increase their competitive edge of digital transformation in smart manufacturing, that can cover multiple views and abstraction levels of their systems implementation to aid the firm in making continuously improvements. There is a need to measure how well the current system has employed or its capability and predict the capability and the process that can be deployed from a different perspective of views. Satisfying the need with a holistic methodology that useful to analyze, integrate and improve every individual situation is the principle of the smart manufacturing implementation.

2.2. Decarbonization

Decarbonization is an environmental-specific aspect of smart manufacturing with the structural and behavioral properties intended to promote business sustainability. As a means of promoting energy conservation by improvements in operations, achieving energy efficiency and efficiency in the optimization cycle through energy management as well as the use of integrated digital and control technologies to express smart manufacturing to be green has been attracting attention. However, most of current smart manufacturing practice provides implementation with better opportunities for achieving functions of systems that take full advantage of technologies. Environment issues occur during specifying performance tradeoff with environmental management level in smart manufacturing.

Manufacturing companies want to measure capability of systems and proliferate with specified environmental indicators to their smart manufacturing. There is a need to measure how well the existing systems have employed in architecture and functions along with environmental management, to predict the target capability to achieve performance improvement both manufacturing and environment to underlie the implementation easiness with the process.

3. SMKL METHODOLOGY FOR MATURITY EVALUATION

3.1. SMKL definition

SMKL (Figure 2) is a maturity model of smart manufacturing evaluating maturity based on a matrix of five levels of maturity and four levels of management. The maturity levels are “collect, visualize, analyze, optimize, and predict” as defined in Table 1, classifies digital transformation steps into maturity levels. Management level are “installation and workers, workshop, factory, and supply chain” as shown in Figure 3, specifies the scope of smart manufacturing regarding to the enterprise hierarchy [3]. The maturity level in manufacturing operation with the interests of continuous improvement, is used as the reification of capability measurement of understanding and improving manufacturing operation by drawing the characteristics in terms of process capabilities at a corresponding level of data utilization residing at management level. Management levels capture the complexity and pace from current situation to target point leading to different points of implementation efforts.

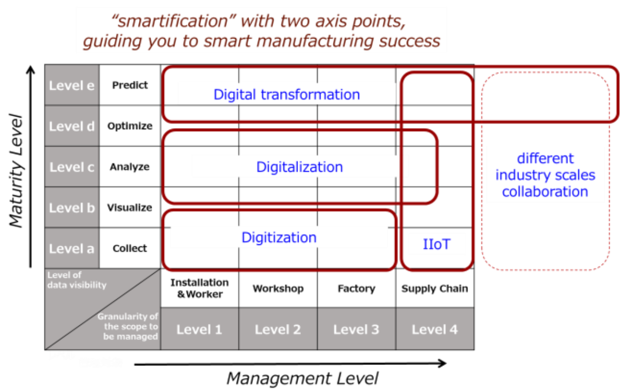

Figure 2. SMKL definition.

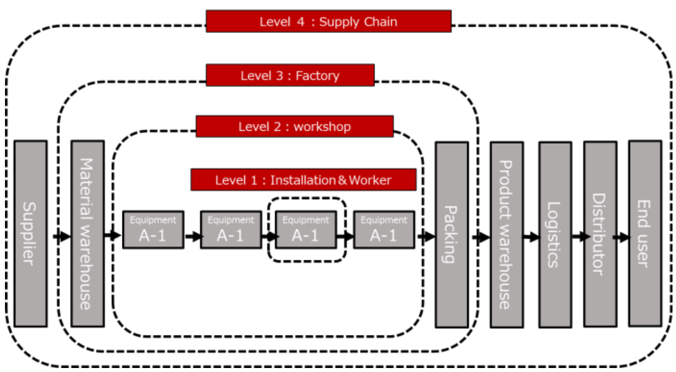

Figure 3. Management level granularity based on IEC62264:2013.

3.2. SMKL assessment framework in action

SMKL comes in for helping manufacturing companies to use maturity models as an essential tool to sustainable improve their smart manufacturing system implementation with a structured evaluation of technologies, physical architecture, manufacturing process and use cases, weapon key performance indicator (KPI). SMKL conforms to the assessment of capability level retaining implementation scales or cost quantified in KPI to help manufacturing companies to make the right investment decisions. It is a framework driven by data that understanding what digital transformation is happening in smart manufacturing and identifies issues, helps to improve them[4].

Given in Figure 4, as for a maturity model SMKL can define the target point of smart manufacturing implementation along with individual business practice needs, and in the meantime, it can describe the intermediate steps in process. SMKL evaluates smart manufacturing current situation through its matrix. Starting with the collection of various manufacturing data, SMKL ask if it can be visualized or analyzed, then how far it can be optimized and predicted can be calculated to point out the target point. SMKL also considers the level of

Table 1. Maturity level definition.

Maturity Level		Description	Example
a	Collect	Manufacturing data, installation or work status are collected and stored in an electrical way automatically or manually with simple input action	-Database -CSV file
b	Visualize	Charts or tables are automatically generated based on collected and/or stored manufacturing data along with management objective	-List description -Graph description (Histogram, trend etc.)
c	Analyze	Charts and tables describing the comparison of a target performance with as-is status with variance are automatically generated according to the maturity level. For example, manually analytics at worker can be exempted.	-Manufacturing operation management -Trouble handling
d	Optimize	Kaizen instrument is automatically feedback to management objectives to solve the performance difference that specified in maturity level.	-AI powered Kaizen
e	Predict	Manufacturing data is automatically categorized with analytics that make predictions about future outcomes. Based on the prediction, management objective can be integrated and rationalized overall.	-Equipment predictive maintenance -Manufacturing operation simulation based on equipment allocation ratio

data granularity which is expressed by the management level. The overall scales of enterprise hierarchy are covered. SMKL recommend the right solution to raise levels for both maturity and management scope, one step at a time, many small steps head to big growth. A detailed assessment flow is shown in Figure 5.

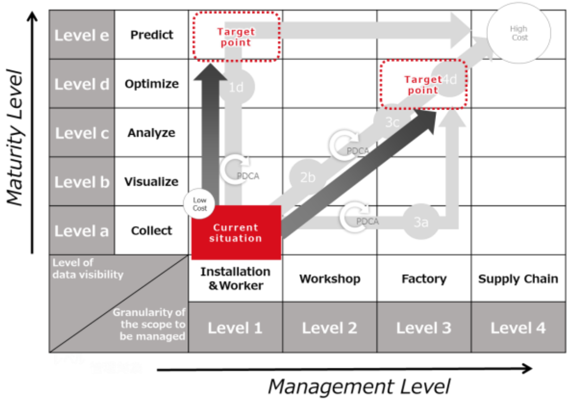

Figure 4. Conceptual framework of SMKL.

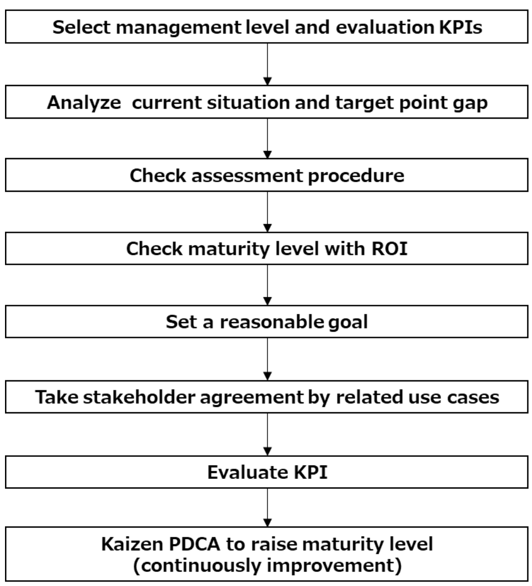

Figure 5 SMKL assessment flow.

4. MAKING DIGITAL TRANSFORMATION AND DECARBONIZATION REAL: USING OF SMKL

To validate the usage of SMKL in smart manufacturing, we examine the effectiveness of having digital transformation in smart manufacturing residing within CO_2 emission reduction by objectifying maturity level.

In this case as given in Table 2, CO_2 emission reduction goal and KPIs are set first. Since both digital transformation and decarbonization performance are to evaluate, KPIs specify in both operational KPI which (represents digital transformation) and environmental KPI (represents decarbonization). In both operational KPI and environmental KPI calculation, manufacturing data is used in common. Then SMKL current situation and target point is evaluated. For most of the manufacturing companies, the starting point to get CO_2 emission reduction is at factory level by manually measuring the energy consumption. Current situation is default set to "SMKL=3a". For manufacturing companies who have advanced solution in measuring energy consumption, SMKL current situation can be set accordingly., To achieve the CO_2 emission reduction goal, digital transformation is the way, where "SMKL=4d" is tentatively set as target point. Step up path may vary upon individual implementation restrictions. In this case, machine efficiency is used as the operational KPI for example. To have a higher machine efficiency [5], the path goes to the management level of machine first and raise the maturity level afterwards, given as "3a->1a->1c->3c->4d". For each step, operational KPI, environmental KPI, digital transformation status and decarbonization status can be specified then. With these build on steps, necessary machine installation and investment to achieve the goal can be calculated.

Figure 6 shows the case that described in Table 2. Maturity evaluation example for digital transformation in smart manufacturing, the step-up path is plotted in SMKL matrix and system image examples that implemented in each step is given as well.

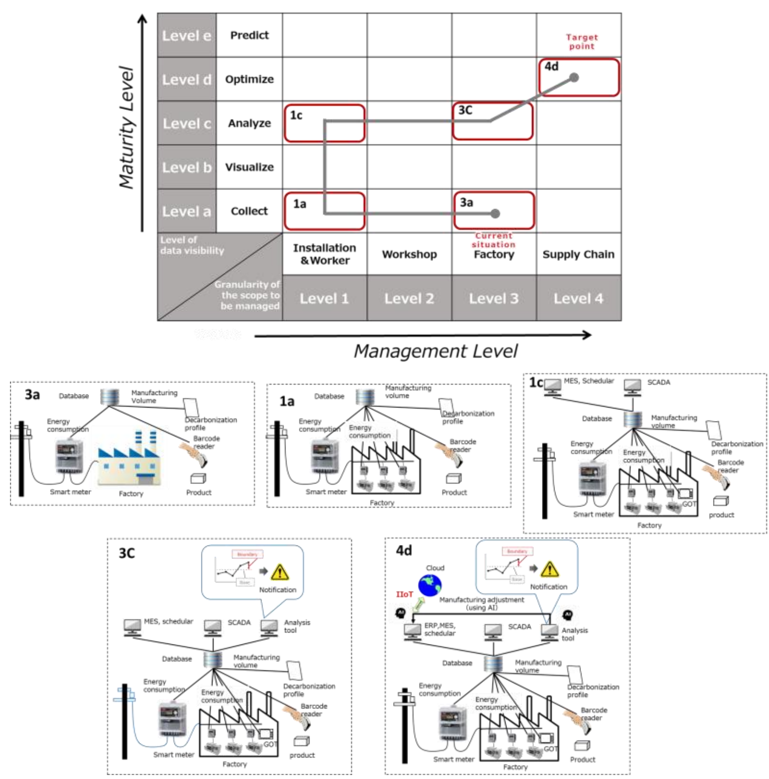

Figure 6. SMKL application example

Table 2. Maturity evaluation example for digital transformation in smart manufacturing residing within CO_2 emission reduction.

CO2 emission reduction goal	20%				
SMKL current situation	3a				
SMKL target point	4d				
Machine installation	Machine_1（¥〇〇〇）×8 S/W_1（¥〇〇〇〇）×5 Machine_2（¥〇〇〇〇〇）×1 S/W_2（¥〇〇〇）×2 …				
Investment	¥〇〇〇〇〇〇〇 & payback period				
Kaizen step	3a	1a	1c	3c	4d
Operational KPI	Machine efficiency 70%	Machine efficiency 80%	Machine efficiency 85%	Machine efficiency 90%	Machine efficiency 95%
Environmental KPI	CO_2 emission reduction 5%	CO_2 emission reduction 8%	CO_2 emission reduction 15%	CO_2 emission reduction 17%	CO_2 emission reduction 20%
Digital transformation status	manual	digitization	digitalization	digitalization	Digital transformation
Decarbonization status (Factor for countable energy loss)	0.5	0.6	0.8	0.9	1.0
Reference use case	xxx (System image)	xxx	xxx xxx	xxx xxx	xxx xxx

5. CONCLUSION

Digital technologies such as IIoT initiative that are appropriately tailored to the business of individual manufacturing company are essential to achieving digital transformation in smart manufacturing. Data driven digital transformation reside within decarbonization requires collection of various types of data throughout enterprise hierarchy with a high investment and time before optimization is achieved. Nevertheless, SMKL introduced in this paper is an assessment model emphasis exclusively to maturity within Kaizen which despite the hype behind the smart manufacturing and examine its performance.

Future work should focus on performing a parametric study on different industry scales, to develop SMKL semantically that could be used in various digital transformation in smart manufacturing. Furthermore, the effort of promoting SMKL as a de facto assessment model formed Kaizen in smart manufacturing. Therefore, this can trigger further use case storage to explore the digital transformation in smart manufacturing and power up the marketing implementation.

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