A Continuous Improvement (Kaizen) Driven Approach for Realistic Digital Transformation

in Smart Manufacturing

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Authors:

Nicole Shonan Otoki, Ph.D.
Senior Research Scientist, Mitsubishi Electric Corp.
Otoki.Shonannicole@bc.MitsubishiElectric.co.jp

Hajime Sugiyama
Digital Manufacturing Architect, Mitsubishi Electric Corp.
Sugiyama.Hajime@ak.MitsubishiElectric.co.jp

Mitsushiro Fujishima
Senior Manager**,** Mitsubishi Electric Corp.
Fujishima.Mitsushiro@da.MitsubishiElectric.co.jp

CONTENTS

FIGURES

1 Overview

Digital transformation is fostering an evolution of the manufacturing industry, entering a new era of smart manufacturing. This new era, including the shift to mass customization, refers to a significant change in manufacturing, and higher levels of intelligence and optimization across the manufacturing value chain.[1] Digital transformation-enabling technologies such as the Internet of Things (IoT) have once again powered manufacturing to become connected and adaptive to meet customer needs. Manufacturers are facing challenges in organizing the unprecedented integration of systems across manufacturing hierarchy, domain boundaries and life cycle phases.

Many strategic initiatives such as the Industry IoT Consortium (IIC) and e-F@ctory[2] Alliance, have widely discussed the concept of smart manufacturing, underlying enabling technologies, and impacts on different views of industrial use. To benefit from the full potential of smart manufacturing, many manufacturers are capitalizing on their essential functions as well as innovation to stay ahead of competitors and embrace the change in manufacturing.

However, the broader views of smart manufacturing that manufacturers try to cover, the more difficult it is to abstract the implementation. As a result, the journey to have smart manufacturing fails to achieve its intended results. Therefore, it is vital to take a realistic approach, as manufacturing implementations and improvements happen in steps, not jumps. In business practice, it is equally important to monitor the Return on Investment (ROI), where a good ROI can elevate the value capture of a company's sustainability. There is a need in every step of smart manufacturing practice to measure how well the current manufacturing has been employed and predict the achievable capability with reasonable ROI.

In this article, we present a concept for a maturity model to assist manufacturers with a better understanding of the status of their efforts in smart manufacturing and visualize ROI to aid the firm in making continuous improvements for sustainability. We also would like to provide real life case studies utilizing maturity assessment to lower the barriers in understanding.

[1] IEC MSB FOF white paper
[2] e-F@ctory available at *https://www.mitsubishielectric.com/fa/sols/digital-manufacturing/en/index.html*

2 Leveraging the Opportunities Provided by Smart Manufacturing

Globalization has intensified worldwide competition with frequent product introduction and rapid changes in product demand. The evolution of the value chain brought by globalization impels the manufacturing revolution, in which digitalization becomes essential.

Digital transformation is at the heart of the manufacturing revolution, creating a new, unprecedented landscape for the manufacturing industry with the use of data. New technology trends combined with innovative business processes, offer manufacturers unprecedented opportunities to enhance their value proposition. The manufacturing industry is changing its way many strategic initiatives such as IIC and e-F@ctory Alliance, touch the challenges by developing reference models with pilot studies to establish smart manufacturing and tap its potential. Technologies such as IoT, data analytics, additive manufacturing, 5G, etc., are highlighted to enable the implementation of smart manufacturing.

The manufacturing industry is then endeavoring to answer the call of smart manufacturing by setting out action plans for implementation. A process (Figure 2-1) proven in e-F@ctory shows that the successful implementation needs a strong combination of enabling technologies, concerns in practice, and reasonable ROI (Return on Investment) to achieve a successful implementation output. It firmly believes, if delivered as a combined package of measures, will achieve the manufacturer ambition of becoming a global competitive leader in smart manufacturing.

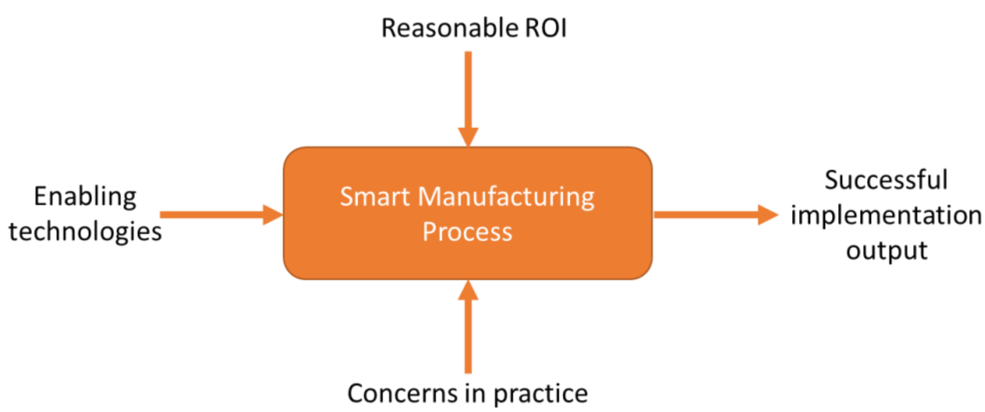

Figure 2-1 Realistic approach in smart manufacturing practice

3 USE MATURITY LEVELS TO STRENGTHEN SUSTAINABLE SMART MANUFACTURING

The impact of smart manufacturing is evident. To leverage the opportunities it provides, many manufacturers are shifting their focus on smart manufacturing implementation. However, according to a recent survey, 85% of businesses say they understand the potential of smart manufacturing, but only 10-15% of them have detailed strategies in place[3]. Many of them are struggling to understand what smart manufacturing implementation really means to them. There are few references showing how to utilize and implement them on-site. Furthermore, looking into ROI, the implementation remains much uncharted, making future decisions and investment difficult for manufacturers to begin their first step of implementation.

As a result, many manufacturers are far behind their goals in the smart manufacturing practice. Manufacturers need guidance on common knowledge for measuring the impact of smart manufacturing implementation and benchmarking to monitor their process continuously and with a reasonable ROI.

A concept used in evaluating software capability maturity[4] has been introduced to measure and communicate the readiness of the smart manufacturing implementation. With the objective of providing maturity level guidance, manufacturers can visualize their capabilities in terms of a result they have achieved in the implementation process (Figure 3-1). This maturity-based approach can also be a vehicle to encourage manufacturers to achieve higher levels of performance for stepping toward sustainable smart manufacturing.

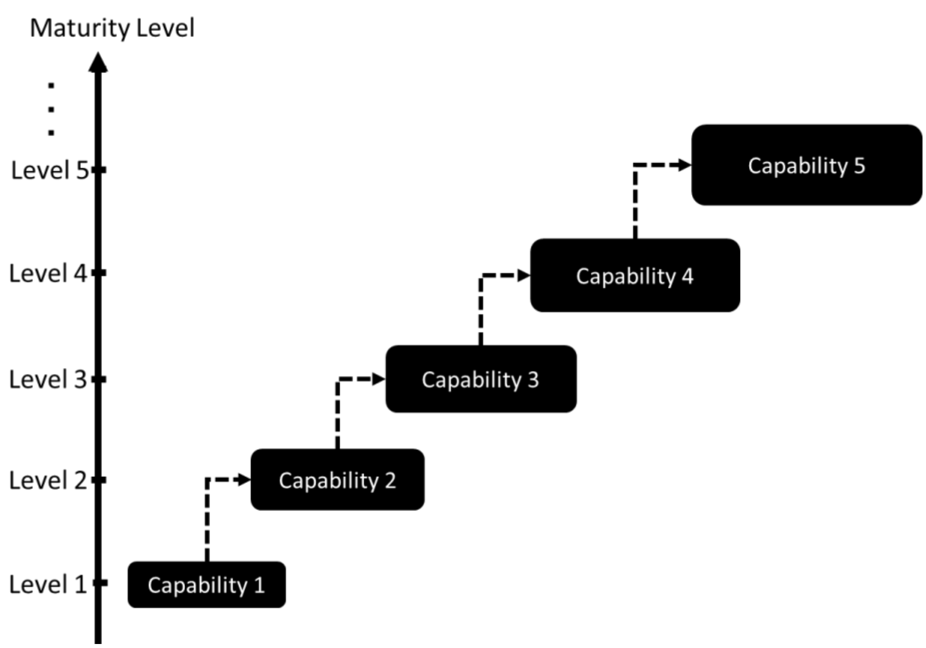

Figure 3-1 General concept of maturity assessment

[3] Results of global industry 4.0 survey/info graphic Infosys
[4] Mark C. Paulk, Bill Curtis, et al, "Capability Maturity Model for Software, Version 1.1," CMU/SEI-93-TR-24

4 Smart Manufacturing Kaizen Level Capabilities for Businesses Practice

To scale the support on smart manufacturing implementation and help manufacturers to make the right investment, a maturity-based framework named Smart Manufacturing Kaizen (continuous improvement) Level or SMKL[5] (continuous improvement) driven by data is picking up speed. SMKL utilizes KPI[6] (Key Performance Indicators) measures to provide insight about what's happening in practice. SMKL identifies gaps between the current situation and the goals of implementation and helps organizations to understand the issues and address them.

As shown in Figure 4-1, SMKL evaluated the implementation situation through two axis points. The vertical axis is the maturity level, the level of data visibility. The horizontal axis is the management level, the level of data granularity that defined in IEC 62264[7].

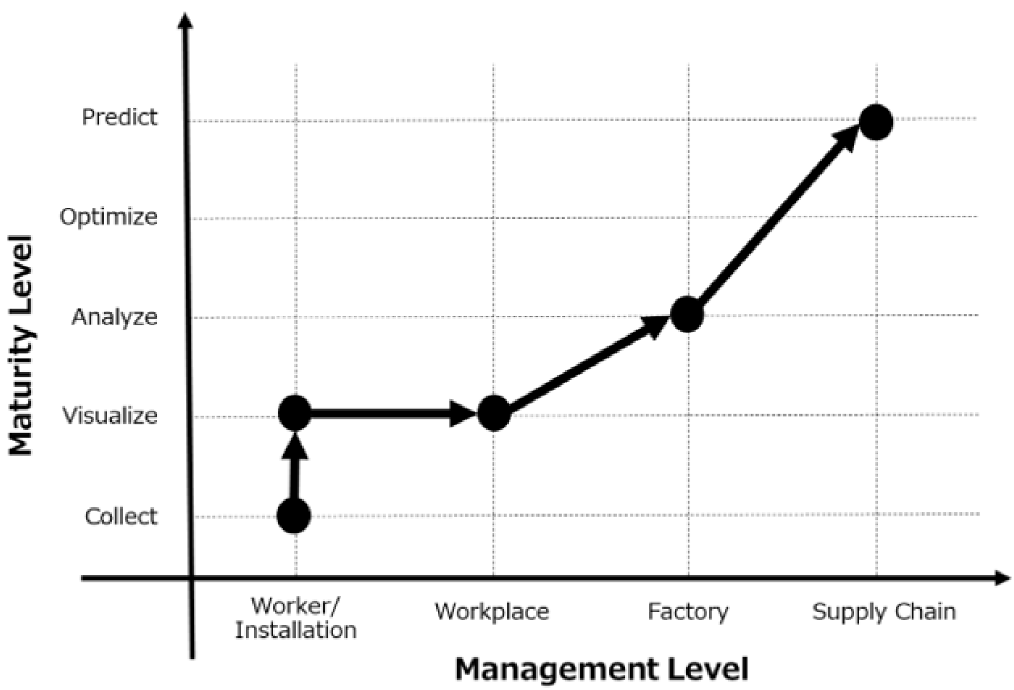

Figure 4-1 Characteristics of SMKL

[5] SMKL available at *https://www.mitsubishielectric.com/fa/sols/digital-manufacturing/en/smkl/*

[6] ISO 22400-2:2014 Automation systems and integration – Key performance indicators (KPIs) for manufacturing operations management – Part 2: Definitions and descriptions

[7] IEC 62264-1:2013 Enterprise-control system integration part 1 models and terminology

Using the process flow below (Figure 4-2), SMKL helps identify the right implementation solution to raise the maturity level, one step at a time[8]. Many small steps lead to big growth, which can maximize ROI.

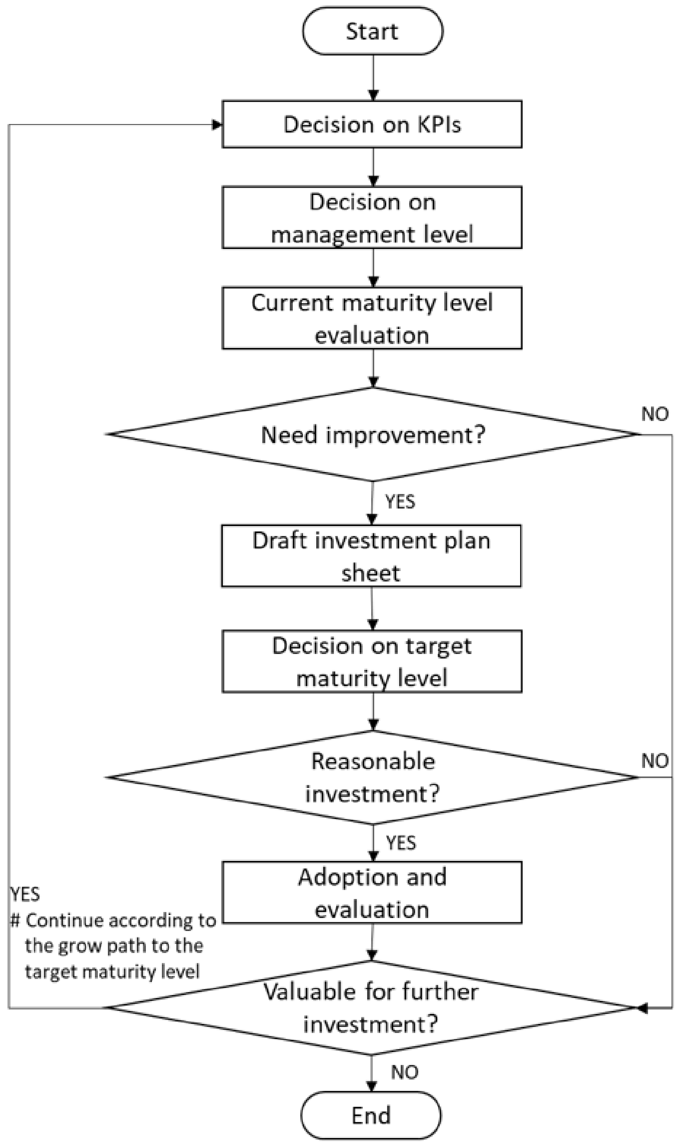

Figure 4-2 SMKL process flow

[8] Shi, X./Baba, N./Osagawa, D./Fujishima, M./Ito, T.: "Maturity Assessment: A Case Study Toward Sustainable Smart Manufacturing Implementation." In: 2019 IEEE International Conference on Smart Manufacturing, Industrial & Logistics Engineering, April 19–21, 2019

5 SMKL CASE STUDIES

There are remarkable track records in a wide range of industries around the world by using SMKL. We would like to introduce 3 case studies to capture the value of improving smart manufacturing implementation in practice. As for manufacturer, ROI is defined as shown in Equation 5-1. When user demands keep on increasing at a steady pace, the income will flatten out. Then, how to control the cost is the key point to ensure success for manufacturer's business. We also look into ROI in each use case to check the cost efficiency that meets the needs of business performance improvement.

$$\mathrm{ROI} = \frac{\boldsymbol{I} - \boldsymbol{C}}{\boldsymbol{C}} \times 100$$

I: income
I= $P_U \times P_N$
P_U: product price per unit
P_N: amount of product
C: operation cost

Equation 5-1 ROI formula

Case Study 1: Poka Yoke Empowered Worker

Despite smart manufacturing, manual work is still vital in manufacturing, especially for workstations with small batch quantities or complex processes. The Japanese Poka Yoke principle is a solution that aims at the systematic elimination of human errors, coupled with guided worker. Poka Yoke in this case study provides consistent worker guidance to eliminate mistakes by integrating on-site technology, visualization, and wide range of components for individualization. Poka Yoke has empowered workers eliminate human errors, and ensured high assembly quality[9].

- Issue specified:
  Low worker production efficiency and uncontrollable cost management
  - Work speed and errors vary depending on workers
  - Difficult to distinguish the worker mistake and the frequency it happens
- Implementation:

In this use case, we introduce a Guided Operator Solution for the worker assembly process and integrate it to the workstation to have an error-free workstation (

Figure 5-1). In the Guided Operator Solution, a controller is installed on-site in a small control cabinet, which is the intelligent, individually configurable and expandable heart of the solution that controls the picking and assembly sequences. Apart from the controller,

[9] Poka Yoke available at *https://www.mitsubishielectric.com/fa/cssty/09_martinshof/index.html*

sensors, actuators and HMI are used to handle the digital torque wrench and a system for industrial image processing. The connection of a barcode printer is also implemented.

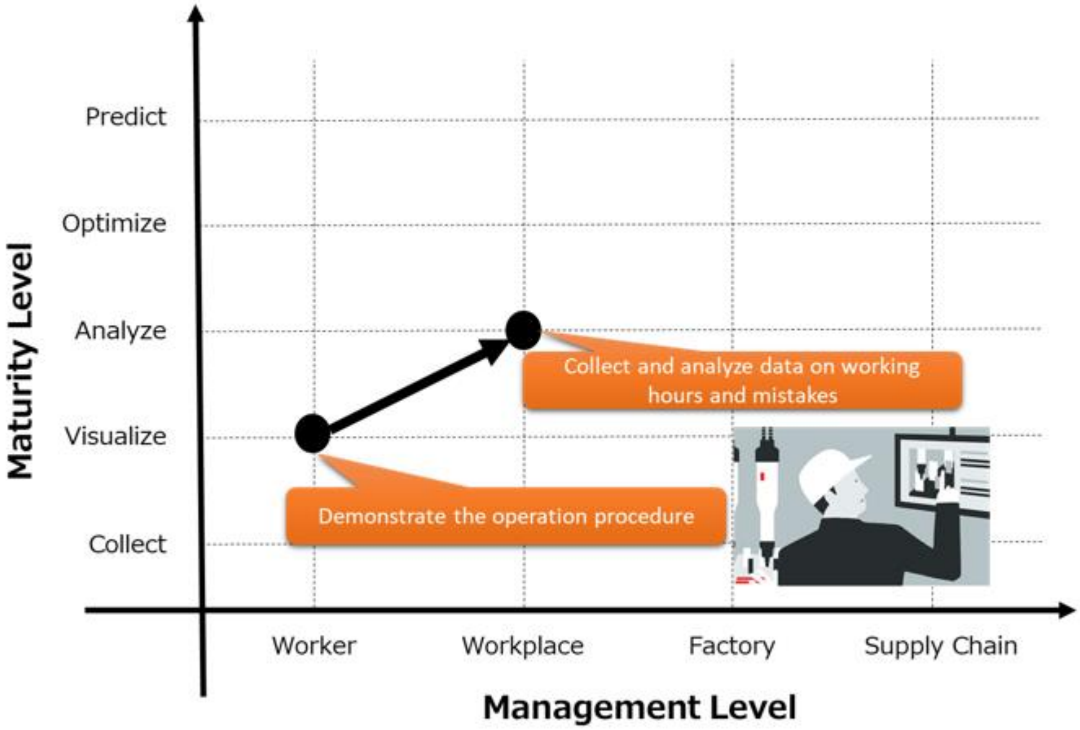

Figure 5-1 Poka Yoke empowered worker

- Improvement:
  Using the Guided Operator Solution at workstation, a quick and flexible adaptation can be obtained to meet the needs of the persons working there, and to the requirements of the process. As a result, a new error-free workstation is achieved by improving worker production efficiency by minimizing operational mistakes.

  In this use case, the worker efficiency is essentially used as a rudimentary gauge of operation cost. Comparing with the traditional assembly cells or manual workstation which have no additional information input, the Guided Operator Solution provides an intelligent one-step workstation by actively guiding the workers through the production process. It is viable that the worker efficiency is increased, and the overall operation cost is reduced. ROI calculating upon the operation cost is then increased, where the manufacturer can evaluate their investment profitability approximately.

Case Study 2: Cost-Effective (Energy-Saving) Factory

Energy saving is another objective for smart manufacturing. How energy management can be transformed is vital to manufacturers. With the ability to measure and track energy usage in every hierarchy level of a factory comes the capability to report the energy efficiency in cost efficiency performance[10].

- Issue specified:
  High power consumption and manufacturing costs
  - Difficult to grasp the power consumption of every production line and/or facility
  - Difficult to identify the place that occurred waste

- Implementation:
  In this use case, we introduce an EcoServer solution for visualizing and managing the use of energy on each production line and piece of equipment and visualize on a dashboard (Figure 5-2). An energy calculation unit is installed at the equipment and facility side, and an EcoServer is installed at the management side to collect energy data and calculate the energy consumption. Any client computer can visualize the energy consumption graphically. When a specified task is required, such as peak shift, the EcoServer then analyze the related energy data to identify the energy consumption peak to help the manufacturer to understand not only when the peak comes, but also helps determine if your improvement measures were effective.

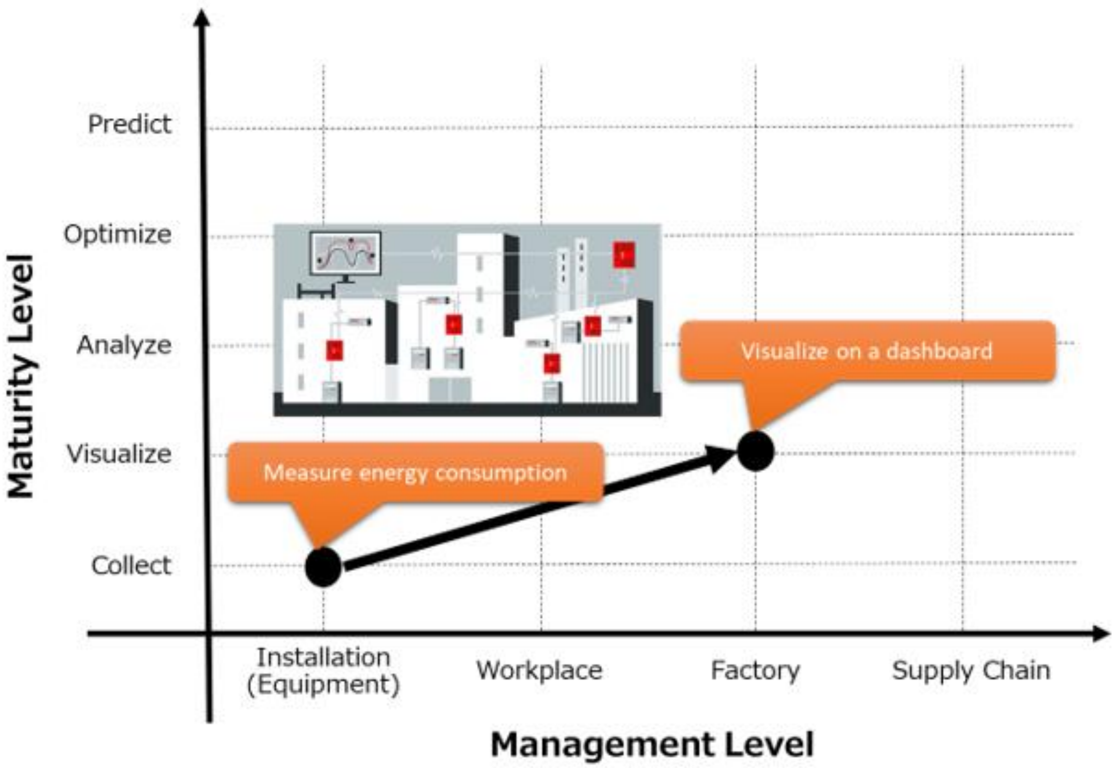

Figure 5-2 Cost reduced (energy saving) factory

[10] Energy saving available at *https://www.mitsubishielectric.com/fa/cssty/14_aida/index.html*

- Improvement:
  Using the EcoServer, a successful control of energy consumption can be achieved for the entire factory. This benefit occurs during:
  - Identify and analyze equipment and its location with higher than expected energy consumption
  - Allow additional general control measures to be implemented from equipment to workstation, line levels and even if facilities, with added flexibility to take quick pre-emptive action during fault conditions until the situation is corrected.

  As we know, energy consumption is another object for operation cost. In this use case, by visualizing and shifting the peak of energy consumption to the time of day when the energy price is low, the manufacturer is able to reduce their electricity bills by 15%. The effect in operation cost is immense as well. Manufacturer can collect the energy data what they need, and what's more, the pay-back in ROI is significant.

Case Study 3: Edge Computing-Based Model Line

Smart manufacturing requires the involvement of many diverse stakeholders. Linking all instances between OT (Operation Technology) and IT (Information Technology) through edge computing helps manufacturers build systems easily, utilize data in real-time, and create new added value in the supply chain[11].

- Issue specified:
  In reality, it is not easy to identify the bottleneck/issues and make an actively optimization along production networks. Because many of the manufacturers are stand-alone, and the horizontal integration on the business level such as required in the supply chain has its difficulties in utilizing information technology as well as sharing the information securely. Furthermore, to increase the level of detail and quality in distributed manufacturing optimization, a close-to real-time and product or process specific information is required to be exchanged. Thus, the demand is rising across the manufacturers for solutions offering greater openness and effective supply chain in real-time.
- Implementation:

[11] Edge computing-based model line available at *https://kr.mitsubishielectric.com/fa/ko/fa/ko/showroom/img/efactory/e-f@ctory_leaflet(en).pdf*

In this use case, we introduce an edge computing approach that connect OT side and IT side. In doing so, boundaries of using data are extended. Edge computing is addressed as a platform to do data collection, analysis, diagnosis, and feedback in real time and secured. Accordingly, horizontal integration towards supply chain is then possible by utilizing application specific establishment of information access and workflows through edge computing platform. For instance, when a balance is needed in every manufacturers' OEE (Overall Equipment Effectiveness) of supply chain to guarantee a quick response to user's demand, edge computing enables real-time and seamless intra and inter factory integration and facilitate dynamic scaling of supply chain related integration and data analysis according to the changing needs of the manufacturer. A wide range of application that given in

Figure 5-3 would accelerate the optimization by providing more speed and insight into the supply chain.

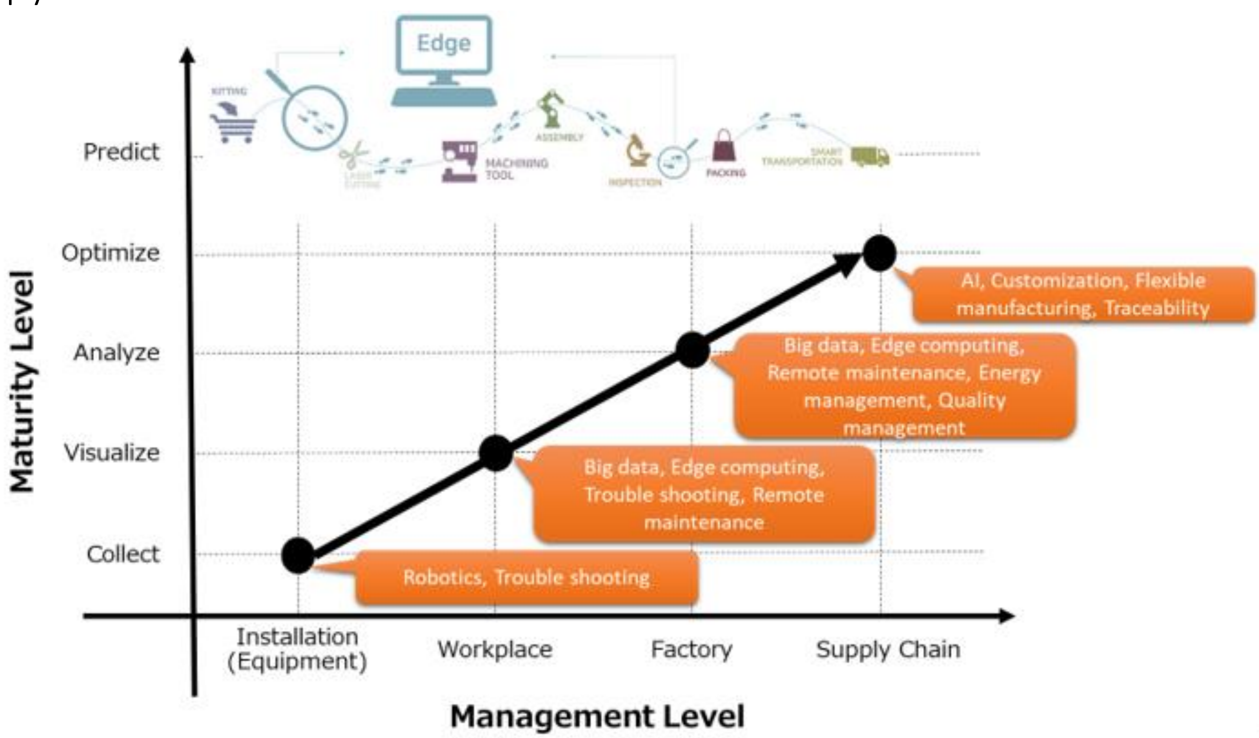

Figure 5-3 Supply chain optimized manufacturing model line

- Improvement:
  Using of edge computing platform, manufacturers are allowed to reduce the required core computing infrastructure in real-time and will enable them to respond flexibly to change infrastructure needs that in turn are caused by changing requirements in the manufacturing OEE. In addition, by absorbing the difference from equipment to the entire supply chain, using of edge computing platform can also provide insights of knowing what subset of right data needs to be accessed to facilitate manufacturing process improvement and optimization. At this point, OEE measured by every manufacturer on the supply chain can then be investigated deeply and broadly. As a result, the operation cost is reduced, the ROI is increased.

6 CONCLUSION

This article first discussed the opportunities and practice issues of smart manufacturing. Afterward, a maturity-derived SMKL approach for implementing smart manufacturing captures the complexity and pace of system development leading to different implementation efforts by raising maturity levels. Together, covering a wide range of management levels with the step-by-step approach holds opportunities for manufacturers to gain actionable insights and benefit from various growth path in maturity to pursue an adaptable system implementation with a reasonable investment. We call this approach "think big, start small." In this context, manufacturers can capitalize their essentials of organizing an unprecedented performance of smart manufacturing.

7 ACKNOWLEDGEMENTS

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