Rev 1.0

White Paper

“SMKL（Smart Manufacturing Kaizen Level）

～Approach to Smart Manufacturing～

（first published edition）

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IAF (Industrial Automation Forum)

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Table of Contents

1. Foreword 4

1 .1 Background and Challenges 4

1 .2 Proposals 5

2. SMKL Overview 7

2.1 Key Features of SMKL 7

2.2 SMKL Deployment Environment 8

2.3 Other Indicators 9

3. SMKL Indicator 10

3.1 Maturity Levels 10

3.2 Management Levels 12

3.3 About SMKL's Maturity Data 14

3.4 About SMKL levels name 14

3.5. SMKL Implementation Procedures 15

4. How to evaluate the current state of SMKL 17

5. Determination of SMKL improvement targets 21

5.1 Use case to make the first target "management level" 21

5.2 Use case to make the first target "KPI" 22

6. Smart Manufacturing Investment Decision 23

7. About SMKL Operating 24

7.1 PDCA Sequence Diagram with SMKL 24

7.2 Sequence diagram of KPI management work 25

８. SMKL Technology Map for Smart Manufacturing 26

９. Conclusion 27

１０. References 28

＜Appendix A＞ 「KPI（ISO 22400-2）」 29

＜Appendix B＞ "SMKL KPI management sheet" 30

＜Appendix C＞ 「Smart Manufacturing Investment Plan Application」 33

＜Appendix D＞ "SMKL KPIs Maturity Level Radar Chart " 35

＜Appendix E＞ "SMKL integrated management sheet" 37

＜Appendix F＞ "Comparison with other indicators" 38

1. Foreword

1.1 Background and Challenges

We often see or hear a word “Industry 4.0 (I 4.0)” which is a near-future digitalized manufacturing concept introduced by Germany in 2011. Not only this but also people popularly use the terms “Industrial IoT (IIoT: Industrial Internet of Things)” and “smart manufacturing (SM: Smart Manufacturing)” in manufacturing area. On the other hand, although the introduction of Smart Manufacturing is gradually progressing at the manufacturing sites of plants and a lot of laboratories and manufacturing companies conduct many test operations such as test beds, we can find only a few actual efforts, and a few investment decisions are made by locally assessing the cost-effectiveness of Smart Manufacturing.

Factory owners and company directives have high expectations that applying Smart Manufacturing into their factory will improve their productivity, quality, inventory control, product traceability, efficient maintenance, and environmental conditions. However, It need huge investment when they apply full-system that converts all the information in a factory into Smart Manufacturing at once and analyse it, and link the information to the supply chain at once, and it is difficult for decision makers to judge in feasibility study how much they should promote Smart Manufacturing at first, and when they should continue, enlarge or terminate the trial Smart Manufacturing project because they are hard to forecast and evaluate the project cost-effectiveness well. Especially SMEs (Small and Middle size Enterprises) manufacturing company has little chance to have consulting about Smart Manufacturing because they tend to have no internal Smart Manufacturing specialists and they have no connection to consultants and system integrators (SIers) who are familiar with Smart Manufacturing.

It is tremendously difficult to achieve suitable Smart Manufacturing for size of their manufacturing factory and for their area of business. For example, there are a lot of things they take into considerations to achieve product traceability in the management of inventory and product life cycle. How do they introduce equipment to attach IC tags to their products? Do they need additional equipment or systems to collect data from IC tags? How do they analyse the information collected throughout system and products? Is it possible to recover investment utilizing these analysed data against the cost of IC tags? In order to achieve this goal, they will spend a lot of time and resources to consult a various kinds of stakeholders including equipment manufacturers machine builders and IT integrators by themselves, and Although, even if they achieved product traceability on this way, it does not mean achieve Smart Manufacturing.

Regarding Smart Manufacturing, several Smart Manufacturing authorities and consortium in Europe, U.S., China, Japan, Singapore, and others propound and advocate maturity levels. They are mostly based on the Capability Maturity Model Integration (CMMI: Capability Maturity Model Integration, ISO/IEC 15504) for S/W. However, it is very difficult to understand and use them because these Smart Manufacturing maturity model contains organizational management scheme and evaluation for employee education, Therefore, unfortunately, as of April 2020, there are no international standards for Smart Manufacturing maturity model.

1.2 Proposals

To solve these issues, this White Paper proposes the Smart Manufacturing Kaizen Level (SMKL) as a simple maturity level for Smart Manufacturing based on Key Performance Indicators (KPIs: Key Performance Indicator) for productivity, quality, inventory, maintenance, and environment. This indicator scoops from worker or installation to supply chain.

SMKL makes it relatively easy for factory owners and manufacturing engineer to conduct feasibility study for Smart Manufacturing projects. In addition, it is a very simple indicator enough to make people who do not have expert knowledge in Smart Manufacturing, like plant managers, facility staff consultants, SIers, and even sales staff to discuss about Smart Manufacturing application for the factory.

A purpose of SMKL project is making international recognition and common understanding for this everyone's simple Smart Manufacturing maturity level not only in Japan but also all over the world. This SMKL is proposed to ISO/TC 184 as a technical report (TR) of international standards. Regarding on word SMKL, we applied a term KAIZEN that symbolizes the Japanese method of continuous improvement, because all member relating to the facility, includes workers and operators, can use this level for improving them like Kaizen activities.

This White Paper defines Smart Manufacturing as "Achieving optimized manufacturing factory based on clarifying KPIs utilization level calculated through digitalized information in the factory, such as "data collection", "visualization", "analysis" and "optimizing" SMKL is defined on 2 dimensional 4x4 matrix which has 2 axis. The vertical axle is 4-level "maturity level" from "data collecting" to "optimizing" and horizontal axle is 4-level "management level" from" worker or installation" to "supply chain". Through any Smart Manufacturing project, target facility has current level and goal which are plotted on this index. (See Figure 1).

Level d	Optimizing				
Level c	Analyzing				
Level b	Visualizing				
Level a	Collecting				
Maturity Level / Management Level		Worker or Installation	Workstation	Factory	Supply Chain
		Level 1	Level 2	Level 3	Level 4

Figure 1 SMKL (Smart Manufacturing Kaizen Level)

This SMKL White Paper consists of following two parts.

Part1 White Paper on Smart Manufacturing Kaizen Level - clarifying Smart Manufacturing level using KPIs (First Edition) -Implementation into factory -

This paper target people concerning manufacturing directly. It provides for self-diagnosis and improvement for Smart Manufacturing levels utilizing SMKL.

Part2 White Paper on Smart Manufacturing Kaizen Level for Sales and Consulting (tentative): (under consideration)

This paper targets suppliers providing for Smart Manufacturing equipment, machine, installation, software, solutions and consulting services such as equipment manufacturers, machine builders and consultants. This paper helps to explain how their products and services realize Smart Manufacturing concepts using SMKL.

2. SMKL Overview

SMKL is a simple maturity level indicator defined on 2 dimensional 4x4 matrix which has 2 axes. The vertical axle is 4-level “maturity level” and horizontal axle is 4-level “management level. This shows how well the factory has achieved smart manufacturing (Figure 1).

2.1 Key Features of SMKL

1) This maturity level provides for a simple index which shows "What is the purpose of Smart Manufacturing project (KPI)", "On which area the project targets", and "How much level it does and will achieve "

2) SMKL shows “evaluation for each path to reach target Smart Manufacturing maturity level” according to “Installation and worker”, “workshop”, “factory” and “supply chain” units.

3) SMKL helps continuous improvement (Kaizen) activities in Smart Manufacturing, with “understanding Smart Manufacturing maturity level”, such as “data collecting”, “visualizing”, “Analysing” and “Optimizing”.

4) SMKL has a common understanding of "systematic investment decisions for the introduction of smart manufacturing in factories" among factory owners, manufacturing engineers, managers, workers, and other stakeholders in the factory.

5) SMKL can be a tool for Smart Manufacturing consultants and Smart Manufacturing SIers to make their customer easily understanding future vision and target on their facility with evaluation their factory with SMKL indicator.

2.2 SMKL Deployment Environment

To achieve Smart Manufacturing with SMKL, both managements' will and direction and employees' eagerness that they want to realize ideal working condition are needed.

1) The managements direct to promote Smart Manufacturing project in factory.
2) The management gives practical improvement targets such as productivities and quality.
3) The management have common Smart Manufacturing benchmark or criteria throughout several different factory.
4) The workers want to give up manual input and handwriting logging. They request to digitalize and automate logging factory management data,
5) Maintenance staff need to determine why production factory stop. Digitalized data collected by sensors will help the process.
6) Using predictive maintenance with these digitalized data, they optimize production and maintenance plan.

SMKL is suitable for conversation tools that express the direction of visualization and improvement among the managements who makes investment decisions for Smart Manufacturing and practitioner who install equipment in the field such as the workers, consultants, SIers, and vendors.

Therefore, it can be a suitable Smart Manufacturing evaluation method for continuously improving by means of a bottom-up approach taking up executioners' ideas and suggestion for betterment their working fields, rather than top-down approach that only managements determine them all.

SMKL aims to improve factory efficiency and to create a comfortable working environment through Smart Manufacturing. SMKL is not intended to strictly manage and operate factories. When SMKL is used for strictly management and operation, just raising the level of SMKL becomes its purpose. In this case, if the level of SMKL is not raised, the investment for the project will not be made even though it is cost-effective. Or some managements do not want to use this indicator because it looks "level down" due to changing its viewpoint.

SMKL is just a rough indicator for Smart Manufacturing feasibility study. Therefore, it is used as a conversation tool between the plant manager and the person in charge of the site, and when they make actual decision for investments, they should prepare for a facility investment plan to measure the cost-effectiveness. (Refer to <Appendix C> " Smart Manufacturing Investment Plan").

2.3 Other Indicators

Several governments and initiatives advocate corporate diagnostic indices for Smart Manufacturing. such as The "DX (Digital Transformation) Promotion Indicators" recommended by the Ministry of Economy, Trade and Industry of Japan, the "SIRI (Smart Industry Readiness Index) index" prepared by the Government of Singapore with reference to I 4.0 Please refer to the <Appendix F> "Comparison with other indicators" and which summarizes the differences between SMKL.

Standing on analogy of health check, the DX and SIRI indicators are "Annually questionnaire and blood test " diagnostics conducted by doctors and other medical specialists. On the other hand, the SMKL indicator is a “daily weight check” by yourself. Managements and executioners use SMKL not only for short-term PDCA cycle managements of improving factory considering cost-effectiveness but also for middle and long term (such as 5 years) Smart Manufacturing application project.

Each indicator has its own characteristics suits for each application. However, it is recommended for SMEs to apply the SMKL indicator because it is hard to find Smart Manufacturing specialists in their area and SMKL can provide for an easy-to-understand indicator for all managements and executioner. It is also suitable for small start.

3. SMKL Indicator

3.1 Maturity Levels

Maturity level consists of 4 levels; level a is electrized “data collection”. level b is “visualizing” using HMI devices, level c is “analysing” collected data and level d is “optimizing” by Ais and automation systems. (see Table 1).

At any level, each process shall be digitized automatically or simplified manually.

For example, if manufacturing data is stored in electrical database and it is indicated by printed paper, it should be level a, not at level b.

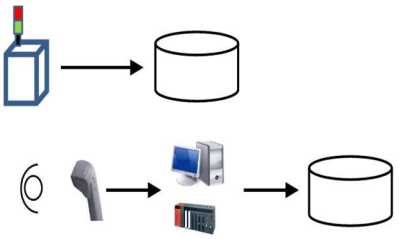
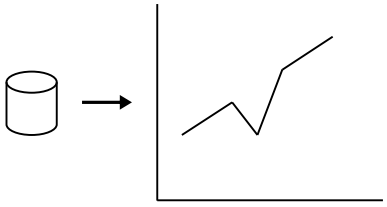
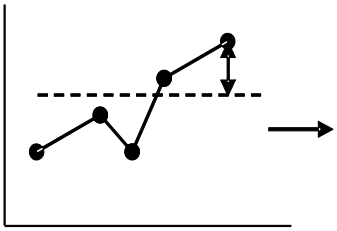
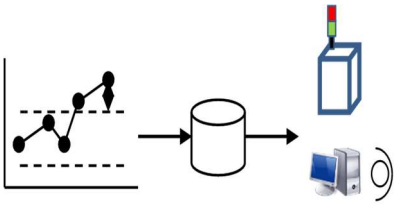
In another case, data used for managing manufacturing facility is indicated by HMI device such as monitor or PC display however it does not analyse them or does not alert practitioners, it should be level b. it does not reach to level c.

Furthermore, when the system can analyse data, however its countermeasure is manually installed to the facility, it should be level c, not level d.

In order to achieve level d, it is necessary to utilize automatic processing and algorithms utilizing AI, etc. to recognize and execute improvement from the results.

If the facility does not reach to level a, it should be level 0 (zero).

Table 1 Maturity Level

Maturity Level	Evaluation criteria	Image diagram	Example
Level a Collecting	▪ Production data and machine status is collected and stored in electrical method, automatically or manually with simple action (example: scanner, code reader) Exemption: electrical copy of handwriting daily report*This does not apply to entries in Excel, such as handwritten daily reports.		▪ Automatically stored in the data server
Level b Visualizing	▪ Charts and lists are automatically generated in real time based on collected data of the level a. Exemption: Manually generating charts and lists using table calculation tools.		▪ Automatic display line graph of data ▪ histogram
Level c Analyzing	▪ Charts and lists include real-time analysis data that shows the difference between Level b and target values. ·It warns automatically to operators when it is necessary for a variance to be adjusted. In addition, for any difference which requires action against the difference, a notice urging action to the parties concerned shall be automatically given.		▪ process skip control ▪ Process failure management ·Action Warning
Level d Optimizing	·Automatically perform feedback control on people, devices, and other objects based on Level c analysis results.		▪ AI ▪ Automatic adjustment

This basic idea of maturity level can be applied to indicate Smart Manufacturing capability of each hardware, software, and solution products. For example, sensors which collect data from the facility is “level a” capability, HMI device which indicate data has “level b” capability, CPU and programs analyzing these data is “level c” capability and AI system for optimization has “level d” capability.(8.Refer to "Technology to realize Smart Manufacturing ").

3.2 Management Levels

For factory automation plants (FA), Management levels are set to 4 levels, workers or installations is defined as Level 1, workstations as Level 2, the factory as Level 3, and the supply chain as Level 4 (Figure 2, Table 2).

Whether the management level of SMKL is managed accurately or easily depends on how it is used. When you start using SMKL, we recommend that you manage it more easily than accuracy. For example, all workstations in the factory are required to reach level 3, but it is okay if one workstation reaches level 3. It will increase the motivation of smart manufacturing stakeholders.

In addition, it is necessary to change the definition of the management level if the domain changes. For example, in the field of building automation (BA), level 1 is a room, level 2 is a floor, level 3 is a building, and level 4 is outside of the building.

This document introduces an example in a certain Factory Automation plants.

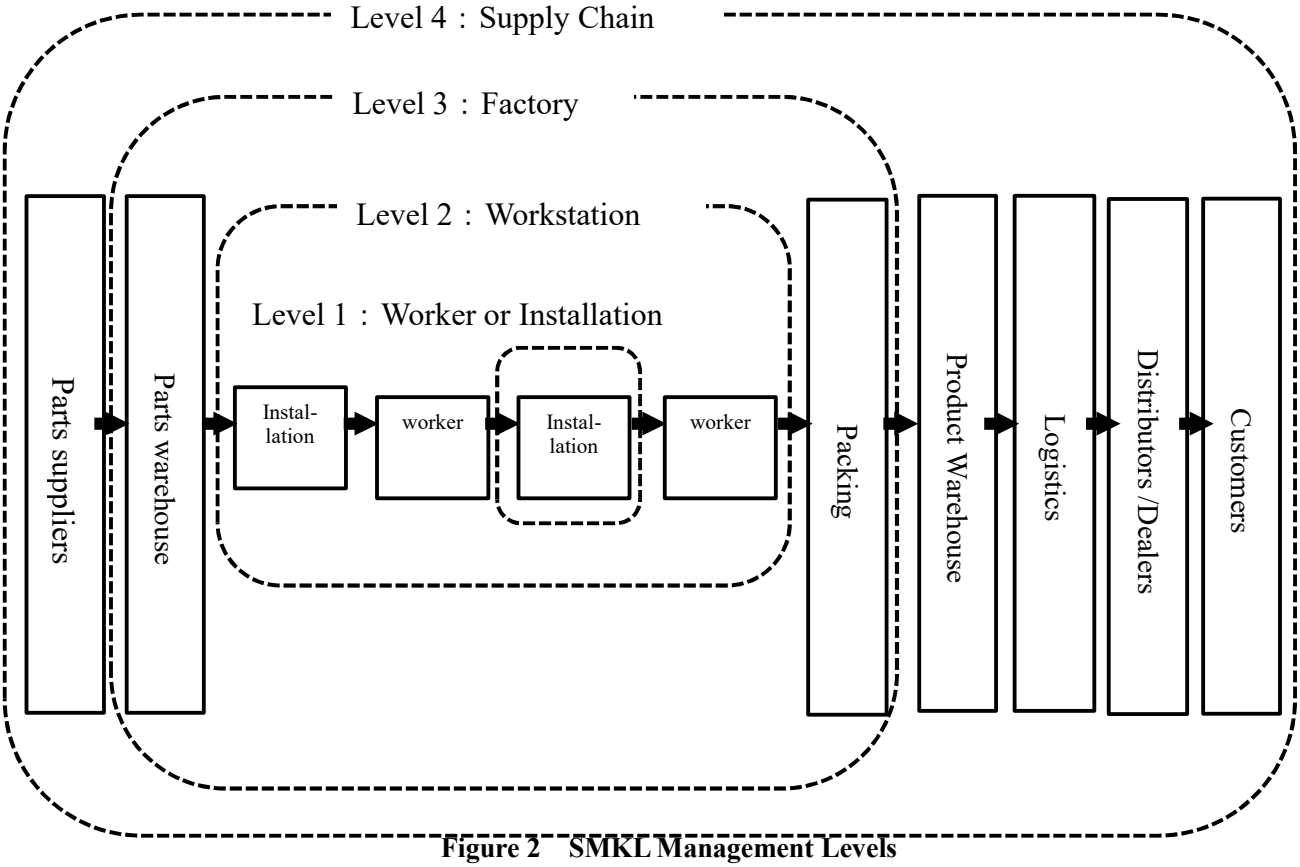


Figure 2 SMKL Management Levels

Table 2 SMKL Management levels

Management Level	Evaluation criteria	Example
Level 1 Worker or Installation	Management objective describes the smallest unit of the manufacturing process. (IEC 62264:2013, Levels2,1,0, Work Units)	·human cell ·equipment ·machine tools ·inspection equipment
Level 2 Workstation	Management objective consists of one or more workers or Installation and has the basic functions of the manufacturing process. (IEC 62264:2013, Levels 3, Work Centers, Area)	・Product processes (Processing, assembly, painting, etc.) ·product line
Level 3 Factory	Management objective consists of one or more workstations in a location. Series of these workstations perform a manufacturing process. (IEC 62264:2013, Levels 4, Enterprise, Site)	・factory of a product
Level 4 Supply Chain	The supply chain includes the outside of the factory. (Enhancement Industrial 4.0, Connected World)	・entire distribution of the product: parts makers, logistics, and customers.

*Supplement:
Level 1: "Worker or Installation" can be called "Unit of Work" or "Worker or Equipment".
Level 2: "workstation" can be called "workplace" or "production line" or "manufacturing process"

3.3 About SMKL's Maturity Data

It is desirable to create maturity data by referring to ISO 22400 (<Appendix A> "KPI (ISO 22400-2)") as KPI in the factory.

There are generally a variety of products, and the required KPIs differ depending on the factory. You need to select a KPI suitable for your factory from ISO 22400 or create a new KPI. If you want to create a new KPI, please refer to <Appendix B> "SMKL KPI Management Sheet".

Data collection methods, visualize methods, analysis methods, and optimize methods differ depending on the type of KPI. Which KPI you choose is also an important decision to invest in smart manufacturing.

This white paper provides examples of key production, inventory, cost, quality, maintenance, and environmental KPIs in electronic component assembly plants.

3.4 About SMKL levels name

The maturity levels described in Section 3.1 and the Management levels described in Section 3.2 are collectively referred to as follows.

"Management level" + "Maturity level"

For example, if the Management level is “2” and the maturity level is “b”, then the name is level "2b".

If the management level is "2" and the maturity level is "0", it is called "2 zero".

3.5. SMKL Implementation Procedures

SMKL is a simple maturity level of smart manufacturing based on KPIs for productivity, quality, inventory, maintenance, and environment. This indicator scoops from worker or installation to supply chain. The implementation steps are shown in the below (Refer to the operation flow diagram in Fig. 3).

Step 1: First, evaluate the current situation. Manufacturing engineers will consider the KPIs needed for improvement of Smart Manufacturing. Then use SMKL to assess the management level and maturity level of the current factory.

Step 2: Based on the evaluation results, manufacturing engineers and managers consider the need for improvement. If there is a need for improvement, they will make a smart manufacturing investment plan that describes all the equipment and factory, data collection methods, cost-effectiveness, etc. to realize it. (Reference: <Appendix C> " Smart Manufacturing Investment Plan")

Step 3: Submit the investment plan for smart manufacturing to the management when implementing improvement activities. This investment plan can be submitted to management at various times. For example, 1) factory equipment renewal, 2) factory equipment expansion, 3) company annual planning, 4) worker improvement activity planning, etc. The owner makes a judgment based on the SMKL value and cost-effectiveness described in the investment plan, referring to the opinions of other SMKL-related actors as to whether the investment direction is suitable for the company.

Step 4: If the investment is approved at the owner's discretion, the manufacturing engineer will install equipment such as smart manufacturing and assess whether improvements have been achieved as targeted. In addition, decide whether to continuously improve the equipment. If the improvement does not reach the target, it is sometimes important to decide to stop investing in smart manufacturing.

If you want to comprehensively judge various KPIs that are important to your factory, use <Appendix D> "SMKL radar chart by management item" or <Appendix E> "SMKL comprehensive management sheet".

SMKL's ideal is to have the highest 4d level for all KPIs, but that shouldn't be the goal. We will use SMKL to discuss what we want to do with smart manufacturing between owner and other related actors. It is most important to achieve step-by-step optimal smart manufacturing that is cost effective for your factory.

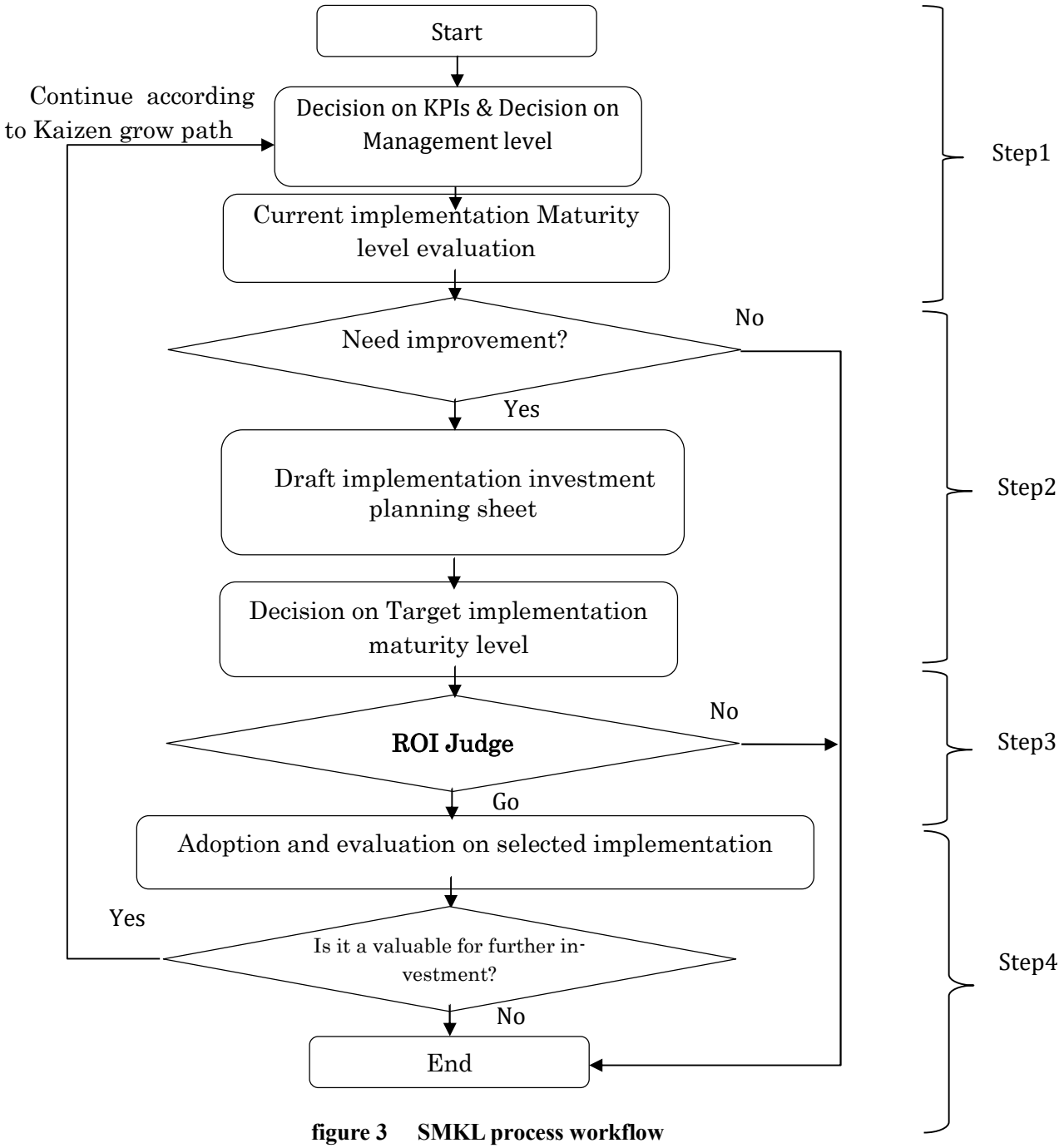


figure 3 SMKL process workflow

4. How to evaluate the current state of SMKL

There are two approaches to the evaluation method of SMKL, one is to decide the management target and the other is to decide KPIs.

1) Evaluation method of first determine the "management level"

You can roughly evaluate the status of smart manufacturing by people, installations, workstations, factories, and so on. The feature of this method is that it does not take much time to evaluate, so even a manufacturing engineer can easily evaluate it.

This method gives rough idea of smart manufacturing. It is also an effective way to choose a location for smart manufacturing, or to first use SMKL to get a rough idea of the maturity level of a factory.

2) Evaluation method of first determine the "KPIs"

This method is a general SMKL usage and follows the SMKL workflow in Figure 3. It is used when the KPI that you want to manage is decided in advance, such as the equipment operation status and power consumption. It has the advantage that the purpose of improvement is easy to set.

However, for evaluation, not only manufacturing engineers but also members who have experience in installation and factory management should be included.

4.1 Evaluation method use case to select "Management level" first

First, select some candidates for management targets that you want to make smart manufacturing.

Next, the manufacturing engineers and managers related to the target will judge how far smart manufacturing is currently done, along with the reasons, referring to SMKL in Table 1.

As a point at this time, please select the KPI that seems to have the highest SMKL level (operation information, power consumption, temperature control, etc.) (see Table 3).

Table 3 Use case of evaluation method that first determines "management level"

No.	Manage-ment Level	Maturity level	Reason
1	Factory A	a	The operation record information of the entire factory is collected and accumulated as electronic data, but the graph of the operation record is printed and posted on the bulletin board.
2	Factory B	b	The power consumption of the entire factory is visualized, and the actual data is also displayed as a graph on the monitor. However, there is no function to set a threshold value and issue an alarm, and a person analyzes and judges by looking at a graph.
3	Factory C	d	Air conditioning is automatically managed throughout the factory. A temperature sensor and humidity sensor are attached to the required positions in the factory, and the correction control is automatically performed at 25 ° C ± 1 ° C.
4	Factory D	zero	The entire factory is mostly manual, and there is no digitized KPI data.

You can use the SMKL index to compare and evaluate the smart manufacturing status of each factory, as in the use cases in Table 3.

The maturity level of each KPI is basically considered with reference to the maturity level in Table 1.

4.2 Evaluation method use case to select "KPI" first

First, select the KPIs you need for your factory.

It is desirable to create maturity data by referring to ISO 22400 (<Appendix A> "KPI (ISO 22400-2)") as KPI in the factory.

There are generally a variety of products, and the required KPIs differ depending on the factory. You need to select a KPI suitable for your factory from ISO 22400 or create a new KPI. If you want to create a new KPI, please refer to <Appendix B> "SMKL KPI Management Sheet".

This white paper provides examples of key production, inventory, cost, quality, maintenance, and environmental KPIs in electronic component assembly plants (see Table 8).

Data collection methods, visualize methods, analysis methods, and optimize methods differ depending on the type of KPI. Which KPI you choose is also an important decision to invest in smart manufacturing (See the selection reason column in Table 8).

Next, select the management targets (level) to which you want to apply the KPI.

As a guideline for management targets (level), it is a good idea to choose a place where products with a large improvement effect are manufactured. For example, products for important customers and mass production.

Then evaluate the SMKL for each KPI.

Table 4 Examples of Electrical Parts Assembly Plants

Classification of KPI		KPIs	motivation for selection
pro-duction	Function to manage the condition of equipment required for production	(1) Installation operation management	I would like to analyse which lines and processes are often stopped due to occasional stoppages, etc.
Inven-tory	Function to manage the state of work in process required for production	(2) Product management	I want to analyse product management and improve the status of work in process.
Deliv-ery	A function to create a production plan, considering delivery dates, product features, equipment restrictions, etc.	(3) Daily production control	We would like to obtain on-site production control information in order to provide accurate delivery date answers to customers. I also want to plan resources.
		(4) Hourly production control	I want to change manufacturing instructions in real time so that it can be linked with resource reallocation and delivery time according to the difference between the plan and the actual result.
Cost	A function to manage worker ID information (work qualification, hourly wage, authorization history, etc.) and work status (workload, work time, work history, etc.). This information is also used for resource allocation and optimal work allocation.	(5) Worker performance management	I want to improve the work cost by looking at the actual results of which product took how much man-hours.
		(6) Worker state management	I want to improve and analyse work efficiency to see if each worker is doing a job that suits their skills.
Quality	A function that analyzes measurement data collected from the manufacturing site and manages and tracks the quality of appropriate products and processes. (This information links causes, symptoms, countermeasures and consequences.)	(7) Product quality management	I want to know whether the product quality is stable from the characteristics of product inspection.
		(8) Process quality control	I want to catch changes in manufacturing conditions (temperature, etc.) and prevent product defects.
		(9) Product trace management	I want to give an ID to a semi-finished product in production or a final product to find out from which lot the defect occurred.
Mainte nance	A function to manage master information (ID, name, etc.) of jigs and tools required for production. And a function to manage the schedule and results of regular maintenance and preventive maintenance of equipment.	(10) Tool management	I want to see when to replace jigs and tools.
		(11) Regular maintenance management	I want to visualize the maintenance time of equipment.
		(12) Preventive maintenance management	I want to perform preventive maintenance before the equipment stops.
Envi-ron-ment	A function to manage the target and performance of equipment, air conditioning, temperature and humidity of buildings and electric energy.	(13) Temperature management	I want to eliminate defective products due to environmental changes.
		(14) Humidity management	I want to eliminate defective products due to environmental changes.
		(15) Power consumption management	I want to reduce the power cost by suppressing the peak power by linking with the production plan.

5. Determination of SMKL improvement targets

Next, we determine the improvement target based on the current value of SMKL. This white paper presents two cases.

5.1 Use case to make the first target "management level"

This method gives rough idea of smart manufacturing. It is also an effective way to choose a location for smart manufacturing, or to first use SMKL to get a rough idea of the maturity level of a factory.

For example, consider the following based on the current evaluation results by SMKL.

1) Factory A: Is it necessary to stop printing out KPI data and display it on the monitor in real time? (from SMKL level a to level b)

2) Factory B: Is it necessary to analyse the power consumption of the factory and issue an alarm? (SMKL level b to level c). Or is it not necessary to visualize the operating status like Factory A?

3) Factory C: Air conditioning is level d, but is it necessary to visualize the power consumption like Factory B?

4) Factory D: Is it necessary to promote smart manufacturing?

Manufacturing engineers and owners who make investment decisions will be able to discuss improvement goals from the same perspective of SMKL.

However, as the maturity level is raised and the management level is expanded, investment costs will also increase, so it is necessary to consider cost effectiveness and implement possible improvement items within the budget.

5.2 Use case to make the first target "KPI"

This method is a general SMKL usage and follows the SMKL workflow in Figure 3.

It is used when the KPI that you want to manage is decided in advance, such as the equipment operation status and power consumption. It has the advantage that the purpose of improvement is easy to set.

However, if you choose a lot of KPIs, the investment cost will increase accordingly. You need to consider cost-effectiveness and implement the best improvements you can make within your budget. If your budget is exceeded, it is also important to plan a step-by-step long-term level-up in separate years.

It is also important to judge that KPIs that are ineffective for your company will not be improved.

6. Smart Manufacturing Investment Decision

In many cases, choose KPIs, maturity levels, and management levels that can have a significant return on investment in improving your factory. At first, it's a good idea to choose something that is easy to get started and effective, including education for smart manufacturing (see Table 24).

And, it is best for many people, such as manufacturing engineers, managers, and owners, to understand the SMKL index before starting smart manufacturing.

Based on the evaluation results, manufacturing engineers and managers consider the need for improvement. If there is a need for improvement, they will make a smart manufacturing investment plan that describes all the equipment and factory, data collection methods, cost-effectiveness, etc. to realize it. (Reference: <Appendix C> " Smart Manufacturing Investment Plan").

Manufacturing engineers create smart manufacturing investment plans with the following (Reference: <Appendix C> " Smart Manufacturing Investment Plan"):

a) Management location
b) SMKL levels before and after achievement
c) Selected KPI
d) Easy-to-understand explanation of the contents before and after improvement
e) Investment cost
f) Investment effect (reduction time, improvement cost, side effects, other precautions)

Even if SMKL has not leveled up within the 4x4 square, you should invest if the direction of improvement and the effect of sufficient improvement are expected. Also, even if you do not expect a significant cost effect, you should invest if there are other secondary or long-term effects. For example, training new employees regarding smart manufacturing and increasing worker motivation.

Table 5 Examples of SMKL Status and Improvement Targets

KPIs		Current Level (Before)	Target Level (After)
(P)production	(1) facility operation management	3b	3b
(I)stock	**(2) physical control**	1b	**2b**
(D)delivery date	(3) daily production control	2a	2a
	(4) production control by time	0	**1 a**
(C)Cost	(5) Worker Performance Manage-	0	0
	(6) operator status control	0	0
(Q)Quality	(7) product quality control	0	0
	(8) process quality control	0	0
	(9) product tracking management	0	0
(M)maintenance	**(10) tool management**	0	**2a**
	(11) routine maintenance manage-	0	0
	(12) preventive maintenance man-	0	0
(E)Environment	(13) temperature control	1 a	1 a
	(14) humidity control	0	0
	(15) power management	0	**1b**

7. About SMKL Operating

For improvement activities by SMKL, it is necessary to clarify the roles of managers and other persons in charge of each role in the factory.

7.1 PDCA Sequence Diagram with SMKL

Extract the actors required to use SMKL and create a UML (ISO / IEC 19501: 2005) sequence diagram with PDCA (see Figure 4).
PDCA: Plan: Planning, Do: Execution, Check: Confirmation, Act: Next Action.

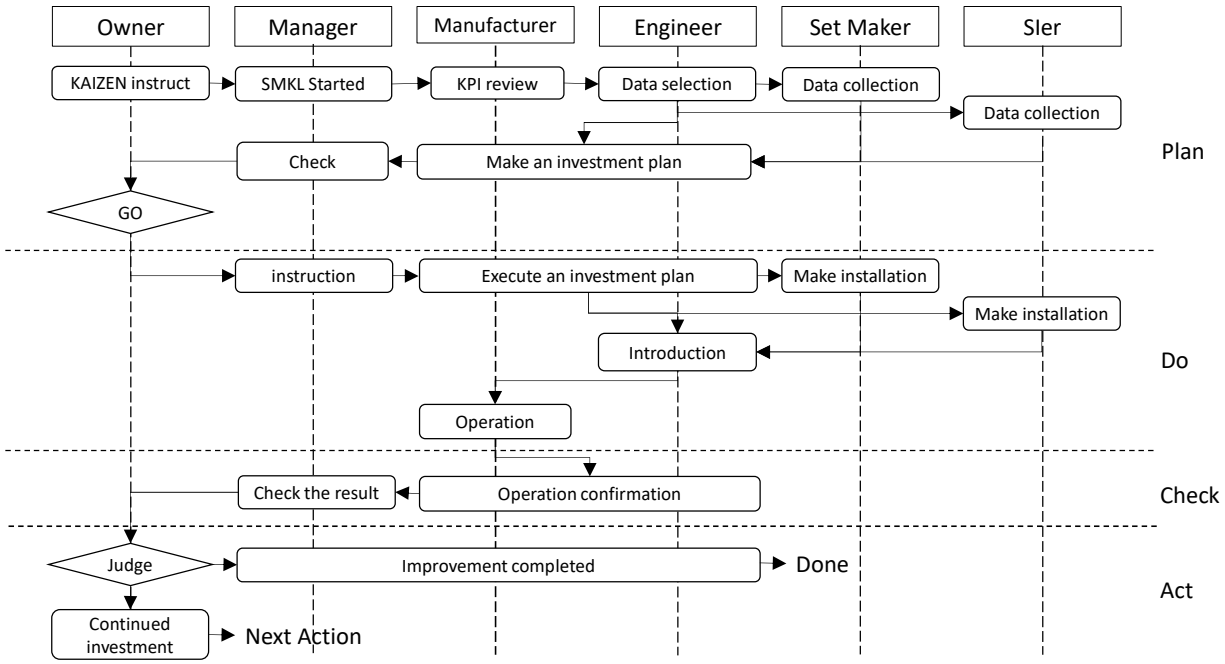


Figure 4 PCDA Sequence Diagram with SMKL (Example)

7.2 Sequence diagram of KPI management work

Create daily, weekly, and monthly actor workflows for the KPI items in Table 8 (see Figure 5).

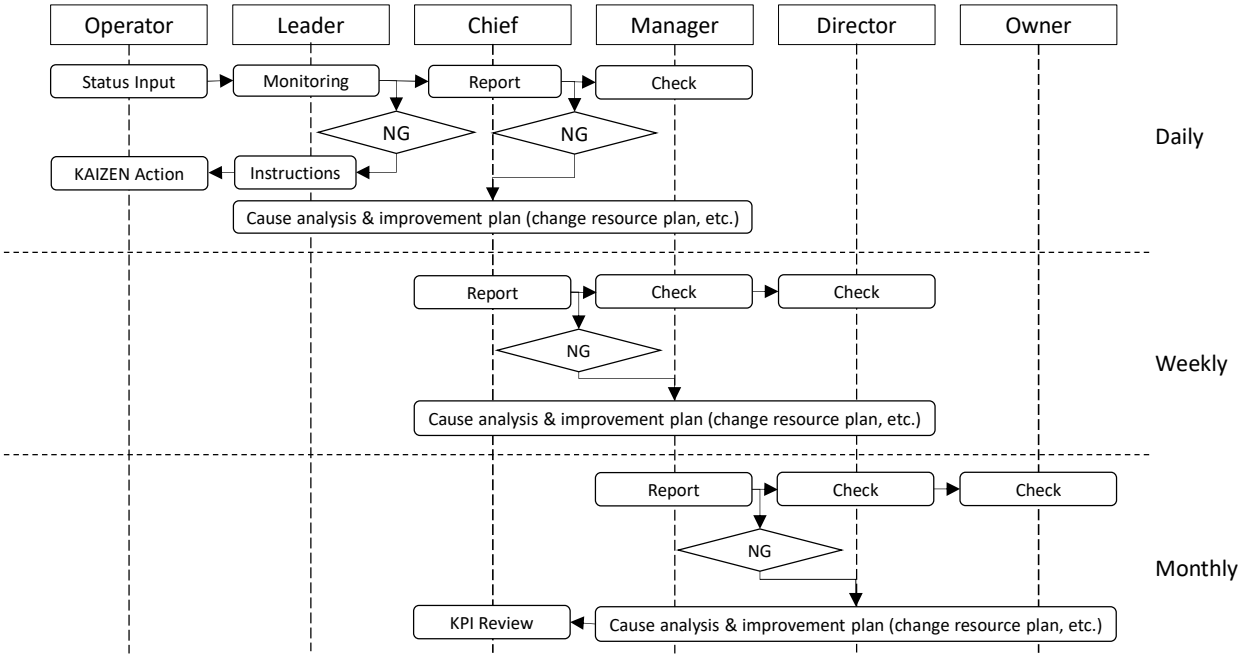


Figure 5 Business flow for production (P) and facility operation management (1) in Table 24 (example)

8. SMKL Technology Map for Smart Manufacturing

When a vender provides customers with products and solutions related to smart manufacturing, the SMKL indicator can be used to clearly explain what level of product is useful (see Figure 6). In addition, customers can quickly realize the optimum level of smart manufacturing in factories by using the products and solutions.

·At the data collection level, various sensors, networks, and 5G products suitable for KPI
·At the visualization level, visualization products or applications such as HMI displays or SCADA
·At the analyzing level, edge computing
·At the Optimizing level, system solutions that utilize various AI, etc.
·it is necessary to consider security and utilize the cloud in order to upgrade the coverage from the factory to the supply chain.

Vender will be able to effectively sell their equipment, facility, software, solutions, etc. by using SMKL to introduce the best products related to smart manufacturing in the customer's factory.

Consultants and SIers can use SMKL to explain to customers the services and solutions they offer regarding smart manufacturing.

Details of this matter are planned in the "SMKL White Paper for Vender (tentative name)".

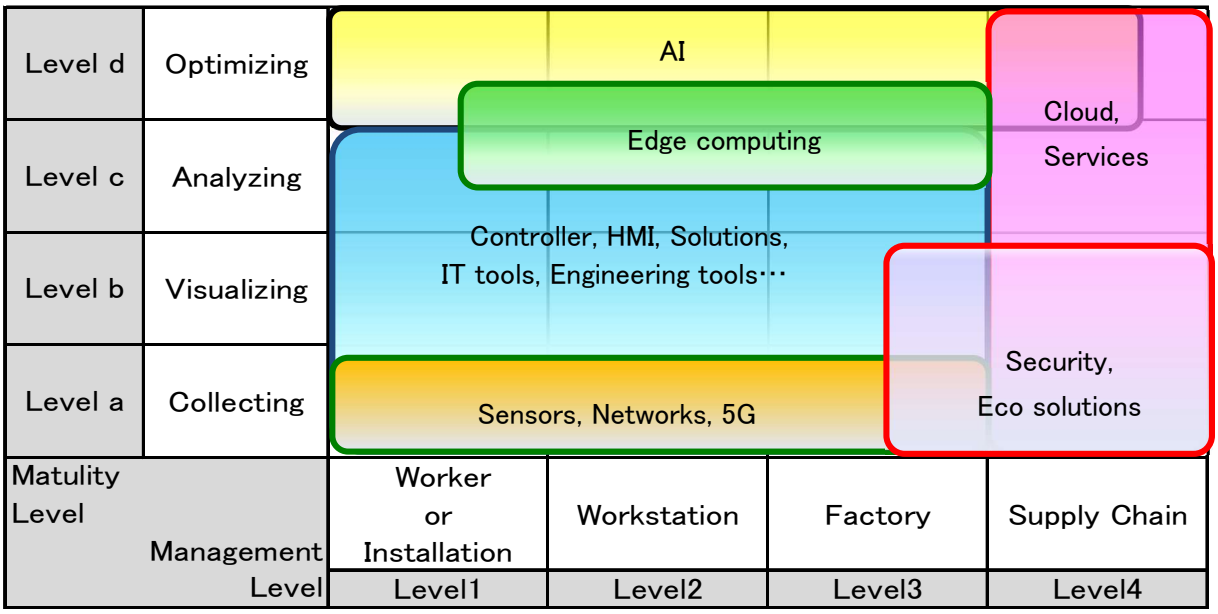


Figure 6 SMKL Technical Map (Example)

9. Conclusion

In this document, we explained SMKL, which is a simple indicator for Smart Manufacturing.

SMKL allows factory owners and manufacturing engineers to have the same level of conversation about Smart Manufacturing's cost-effectiveness and direction of improvement. SMKL is a suitable tool for PDCA improvement activities step by step to realize smart manufacturing.

Since this SMKL indicator is simple and easy to understand, it can be used by anyone who understands the basic concepts of Maturity-Level and Management-level without special expertise or education regarding Smart Manufacturing.

And, many people regarding smart manufacturing, such as product developers, consultants, SIers, sales, finance and insurance, may be able to use SMKL's technical maps in their businesses.

The IAF / CLiC / KPI Subcommittee will continue to consider these possibilities in the future.

If you are interested in this project, please join the IAF.

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＜Appendix A＞　「KPI（ISO 22400-2）」

It is recommended to convert each KPI of ISO22400 to the language of each country.

Classification	Item (English)	Item (Japanese)
productivity index (Efficiency indicators)	Worker efficiency	労働生産性
	Allocation degree	負荷度
	Throughput	生産量
	Allocation efficiency	負荷効率
	Utilization Efficiency	利用効率
	OEE Index	設備総合効率
	NEE Index	正味設備効率
	Availability	設備有効性
	Effectiveness	工程効率
quality indicator (Quality indicators)	Quality ratio	品質率；良品率
	Preparation degree	段取率
	Technical usage level	設備保全利用率
	First pass yield	直行率
	Scrap degree	廃棄度合
	Scrap ratio	廃棄率
	Production process ratio	工程利用率
	Rework ratio	手直率
	Fall-off ratio	減衰率
Ability index (Capacity index)	Machine capability index	機械能力指数： **Cm**
	Critical machine capability index	クリティカル機械能力指数： **Cmk**
	Process Capability Index	工程能力指数： **Cp**
	Critical process capability index	クリティカル工程能力指数： **Cpk**
Environmental indicators (Environmental indicators)	Ratio of used material	材料使用率
	Harmful substances	有害物質
	Hazardous waste ratio	危険物質廃棄率
	Comprehensive energy consumption	総合エネルギー消費量
Inventory management indicators	Inventory turns	在庫回転率
	Finished goods ratio	良品率
	Integrated goods ratio	総合良品率
	Production lost ratio	製品廃棄率
	Storage and transportation lost ratio	在庫輸送廃棄率
	Another lost ratio	その他廃棄率
Conservation index (Maintenance indicators)	Equipment load rate	設備負荷率
	Mean time between failures	平均故障間隔
	Corrective maintenance ratio	改良保全率

＜Appendix B＞　"SMKL KPI management sheet"

"SMKL KPI management sheet"

Management level:[B Factory] □level 1, □level 2, ■level 3, □Level4

KPI	Ma-turity Levels	Concept (criterion)	judgment column
electric (al) power con-sumption	a		
	b		
	c		
	d		

Reason for determining the maturity level

Smart Manufacturing Kaizen Level				
Level d: Optimizing				
Level c: Analyzing				
Level b: Visualizing				
Level a: Collecting				
	Installation or Worker	Workstation	Factory	Supply Chain

*SMKL = Level 0 is all “-”, current level is ”●”, improvement target level is "◎"

"SMKL KPI management sheet" (Example 1)

Management level:[B Factory] □level 1, □level 2, ■level 3, □Level4

KPI	Maturity Levels	Concept (criterion)	judgment column
electric (al) power consumption	a	Are electric power generated electronically?	●
	b	Are actual values of electric power consumption and unit energy consumption visualized? (Or is the target value of the electric energy and the basic unit digitized, and is the difference between the electric energy and the actual value of the basic unit visualized?)	●
	c	Is there a function to notify relevant parties (Workers, manufacturing staff, production engineering staff, etc.) when there is a difference between the target value and the actual value of electric energy consumption and basic unit?(Or is there a function that can analyse the cause of the difference between the target value of electric energy consumption and the basic unit and the actual result?)	◎
	d	Is there a function of action (Control of facilities and lighting) according to the difference between the target value and the actual result of the electric energy consumption and the basic unit?	—

Reason for determining the maturity level
The power consumption of the entire B factory is visualized, and the actual data is displayed graphically on the monitor. Tan Therefore, there is no function of setting a threshold value and issuing an alarm, and a person analyses the graph and makes a judgment. In addition, power consumption is not visualized for each facility, line, process, or unit.

Smart Manufacturing Kaizen Level				
Level d: Optimizing	—	—	—	—
Level c: Analyzing	—	—	◎	—
Level b: Visualizing	—	—	●	—
Level a: Collecting	—	—	●	—
	Installation or Worker	Workstation	Factory	Supply Chain

*SMKL = Level 0 is all “-”, current level is ”●”, improvement target level is "◎"

"SMKL management sheet" (Example 2)

Management level:[B Factory] □level 1, □level 2, ■level 3, □Level4

KPI	Maturity Levels	Concept (criterion)	judgment column
electric (al) power consumption	a	Are operating results (Operation time, stop time, number of good products, error code, cycle time, setup time, etc.) digitized?	●
	b	Are operating results visualized? (Or is the difference between the target value and the actual value visualized? Or are various control charts of operating results generated/trended?)	●
	c	Is there a function that can analyse the factors that cause the difference between the target and actual utilization values? (Or is there a function to determine silent abnormalities in the operation results? Example: It detects not only equipment stoppage but also productivity degradation due to efficiency degradation.)	◎
	d	Is there a function to automatically instruct the improvement action based on the factor of the difference between the operation result target value and the actual value? (Or is there a function to detect an abnormality in the operation results, stop the equipment, change the manufacturing conditions of the equipment, or support the decision making to correct or improve the work of the operator?)	—

Reason for determining the maturity level
The operation status of the C line is digitized and displayed on the display. When there is a difference between the target value and the actual value, an alarm is notified to the smart phone of the line reader based on the set threshold. However, there is no instruction to improve the utilization rate by automatically relocating resources using AI, etc.

Smart Manufacturing Kaizen Level				
Level d: Optimizing	—	◎	—	—
Level c: Analyzing	—	●	—	—
Level b: Visualizing	—	●	—	—
Level a: Collecting	—	●	—	—
	Installation or Worker	Workstation	Factory	Supply Chain

*SMKL = Level 0 is all “-”, current level is ”●”, improvement target level is "◎"

＜Appendix C＞ 「Smart Manufacturing Investment Plan Application」

"Smart Manufacturing (SM) Investment Plan"

SMKL※

d	—	—	—	—
c	—	—	—	—
b	—	◎	—	—
a	—	●	—	—
／	1	2	3	4

Depart-ment		Date	/ /	Managed	
Subject		KPI	Production, Quality, Preventive maintenance, Environment, etc.		
Before (As-Is)		After (To-Be)			
<<Issues>>		<<improvement point>>			
im-prove-ment ef-fect	<<investment cost>>				
	<<investment effect>>				

*SMKL = Level 0 is all “-”, current level is ”●”, improvement target level is "◎"

Authorizer	Check	Applicant

"Smart Manufacturing (SM) Investment Plan" (example)

SMKL※

d	—	—	—	—
c	—	—	—	—
b	—	◎	—	—
a	—	●	—	—
／	1	2	3	4

Department	Manufacturing Department A	Date	2019/10/01	Managed	Workstation B
Subject	C Streamline drawing checks by introducing a tablet for workers during product production	KPI	Production, Quality, Preventive maintenance, Environment, etc.		

Before (As-Is)	After (To-Be)
The worker carried out the product check by the paper drawing in the production of product C in the workstation B.	When producing product C on workstation B, workers can perform product check on electronic drawings without paper by using a tablet for workers.
<<Issues>> ·The data from the old drawings are only available on paper. ·The new drawings have CAD data and are digitized, but they cannot be read by a tablet sold directly.	<<improvement point>> ·All previous drawings underwent high-resolution scanning. ·The data conversion S/W was introduced so that the new drawing can be displayed directly on the commercial tablet from CAD.

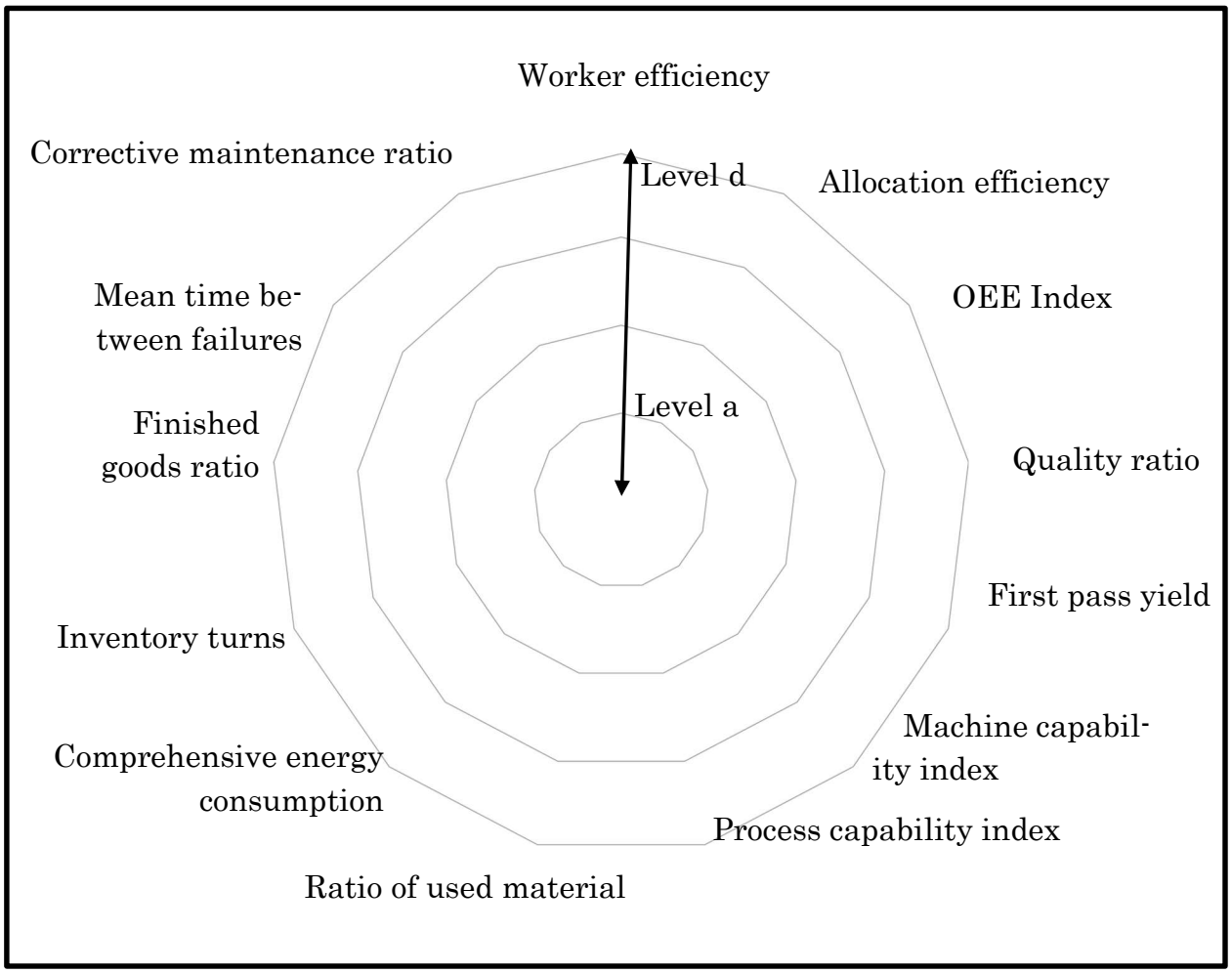
improvement effect	<<investment cost>> 10 tablets (10 thousand yen), 1000 scans (200 yen), 10 CAD data conversion S/W (30,000 yen) SI outsourcing cost 1 man/month x ¥100 million Total: ¥250 million
	<<investment effect>> Time saved: Search time 10 people x 4 products/day x ▲ 0.25 h/case = ▲ 10 h/day = ▲ 2500 h/year (250 days) Improvement cost: - 2500 h x 4 1000 yen (hourly rate) = -10 million yen/year -> Side benefits of investment that can be recovered in 3 months: Workers can magnify drawings on tablets, making them easier to see than paper drawings and reducing errors.

*SMKL = Level 0 is all "-", current level is "●", improvement target level is "◎"

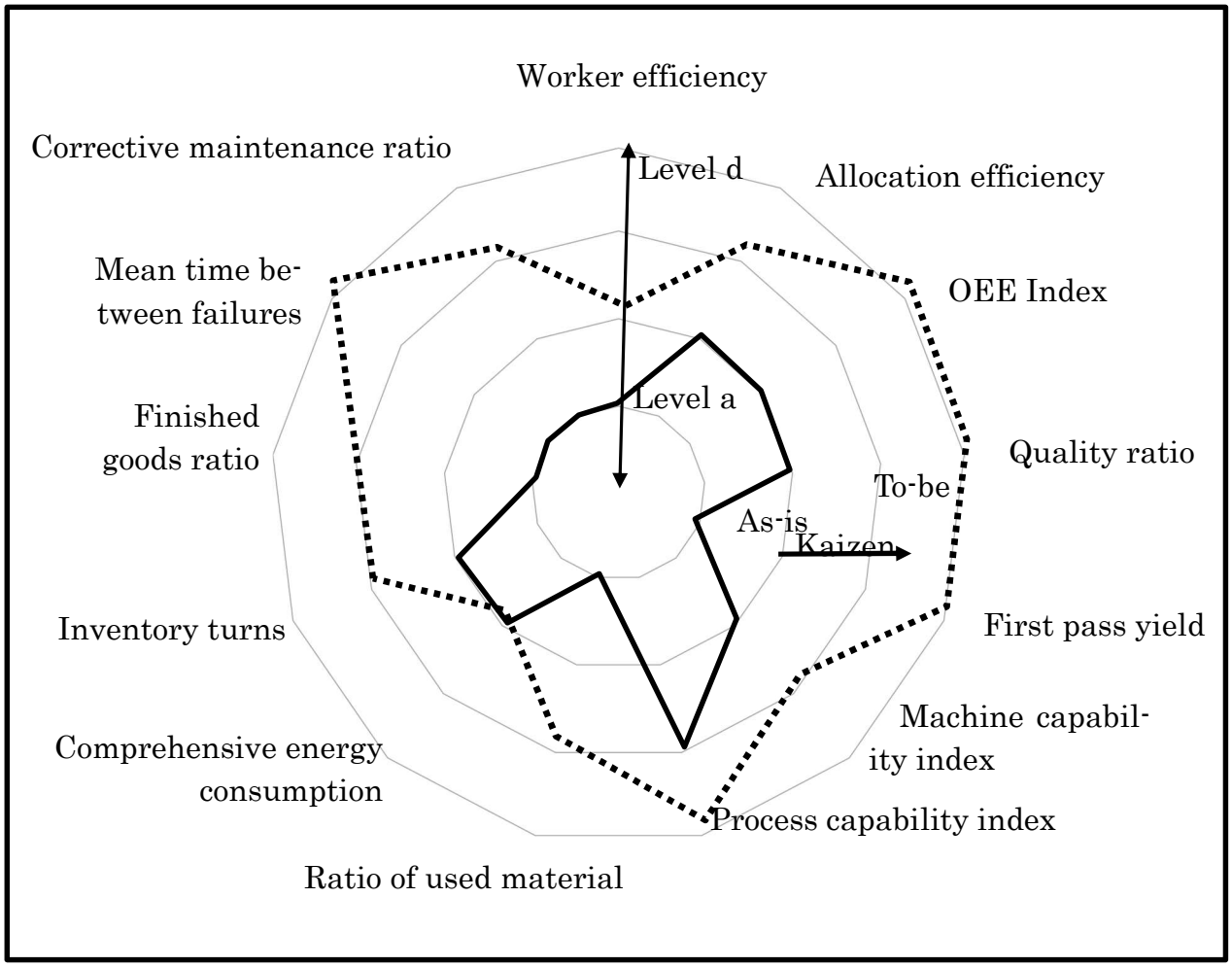
Authorizer	Check	Applicant
2018/10/4 Owner C	2018/10/2 Manager B	2018/10/1 Engineer A

＜Appendix D＞　”SMKL KPIs Maturity Level Radar Chart ”

”SMKL KPIs Maturity Level Radar Chart ”



”SMKL KPIs Maturity Level Radar Chart ”（example）



＜Appendix E＞　"SMKL integrated management sheet"

"SMKL integrated management sheet" (example of use case)

*Enter the name of the object to be managed: "-" is left blank.
List maturity levels: Level 0 is all “- ”, current level is“ ● ”, improvement target level is "(◎)"

Classification	KPI	No	Maturity Level	Man-age-ment Level	Management name							
				4	–	–	–	–	–	–	–	Supply Chine H
				3	–	–	–	–	–	Factory F	Factory G	–
				2	–	–	–	Work-station D	Work-station E	–	–	–
				1	Instal-lation A	Instal-lation B	Worker C	–	–	–	–	–
P: Production	(1) OEE	1	a		●	◎	–	●	●	●	●	–
		2	b		●	–	–	●	◎	●	◎	–
		3	c		◎	–	–	◎	–	◎	–	–
		4	d		–	–	–	–	–	–	–	–
I: Inventory	(2) Inventory turns	5	a		●	◎	–	●	●	●	●	◎
		6	b		●	–	–	●	◎	●	◎	–
		7	c		◎	–	–	◎	–	◎	–	–
		8	d		–	–	–	–	–	–	–	–
…												

＜Appendix F＞ "Comparison with other indicators"

There are several indicators of maturity for smart manufacturing like SMKL, and there are differences in how they are used. SMKL is very simple and easy to use and can be used by various actors. It is suitable for activities that improve smart manufacturing step by step using the PDCA cycle.

The following is a comparison table of "DX promotion index" recommended by METI, "SIRI index" recommended by Singapore, and "SMKL index".

Items	DX Promotion Index (Ministry of Economy, Trade and Industry of Japan)	SIRI index (Singapore)	SMKL index
Diagnostic purpose (Target)	Visualization of the state of DX in enterprises (Corporate units such as personnel, systems, and IT systems)	Helping companies strengthen their organizational knowledge of I 4.0 (3 Components = Process, Technology, Organization)	Visualization of plant information (computerization) (Production, quality, cost, maintenance, environment, etc.)
Audience	Executive, Business, DX, IT (Other: Consulting)	Management, IT, internal employees, and external partners and customers	Executives, Facilities, (Other: IT, Product Development, Product Sales, Consulting), Customers
Target company	For all companies (However, it is mainly medium and large enterprises that have the ability to promote DX, such as the establishment of a real DX division.)	From SMEs to multinational enterprises, including discrete and process manufacturing facilities	For all companies (Large enterprises to small and medium enterprises)
frequency of use (continuity)	Assuming annual diagnosis (Increase or decrease of the number of times depending on the load) Yes)	Continuous use, not one-time evaluation	Used for improvement and proposal activities every time (It can also be used for new installations and mid-term plans.)
Person who performed the diagnosis	Management and employees (IT should not be left alone.) Currently, web diagnosis is available from the Ministry of Economy, Trade and Industry website.	No provisions. (Supported by TUV-SUD) include cross-functional teams that include key stakeholders such as the general manager of the plant and senior leaders of the operating, digital, and facilities teams	Same as the intended audience
usage scene	Board of Directors and other management meetings	The company needs to define the scope of the evaluation and choose whether to evaluate the entire manufacturing facility or individual product groups	(Other: Product development, product sales, consulting) during improvement activities or the introduction of new equipment
original author	University professors, business executives, and group executives	Business owners, technology providers, trade associations, higher education institutions, research institutions, government agencies, etc.	Manufacturing Engineer and manager
Achievements applied	Over 100 companies since 2019 Perform PoC ->Data collected is not disclosed.	More than 200 companies have participated since 2018. (33% of SMEs, 12 manufacturers, 14 countries)	Implemented from 2015 at multiple plants of one company ->Open, Several Companies Planning PoC
Summary	The DX index is like the "Questionnaire and blood test levels" and is assessed once a year. It is used as an index when management consults with advisors and others to make management decisions.	SIRI indicator provides a snapshot of the current state of the enterprise, not future possibilities (That is, the same as the DX index) (Eight Pillars: Operations, Supply Chain, Product Lifecycle, Automation, Connectivity, Intelligence, Readiness Assessment, Structure and Management)	The SMKL index is like a “Body Weight Meter” and is used as an index for continuous improvement activities by PDCA under self-management, and managers and facility staff examine the evaluation and cost-effectiveness step by step.

White Paper

SMKL (Smart Manufacturing Kaizen Level)
～Approach to Smart Manufacturing～

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