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Industrial Value Chain Reference Architecture revision 1

Strategic implementation for connected industries – IVRA Next

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Contents

Chapter 1: Overview 1
Three Layers of the Architecture 1
Fundamental Axes of Manufacturing 2
Four Cycles of Manufacturing Management 3
Smart Manufacturing Unit : SMU 5
Chapter 2: Modeling of SMU 9
AS-IS Model and TO-BE Model 9
Four Stages for Autonomous Evolution 10
Method of Activity Scenario Modeling 11
Connection of the Cyber World and the Physical World 14
Chapter 3: Platform Reference Model 16
Overview of Platform Architecture 16
Categories of Components 18
Object Models for Scenario Modeling 18
Hierarchy of System Connection 20
Profiles Specifications 21
Chapter 4: Framework for Connected Industries 23
PLU for SMU Connection 23
Basic Structure of Open Connection 24
Structure of Hyper Connection Server 25
Data Dictionary Management by Loosely Defined Standard 26

Chapter 1: Overview

Three Layers of the Architecture

The Industrial Value Chain Reference Architecture has three layers.

1) Management Layer

In the management layer, from a perspective of enterprise management the focus of discussions is put on fundamental structure of manufacturing, organization forms for manufacturing, presence of essential views and axes as well as philosophy and concept of values to overview the whole picture. The management layer includes views such as a view related to products or services that manufacturers provide to customers, a view of positioning for business strategies, a view of money in transactions among businesses and a view of intellectual property and values of commodities and services.

2) Activity Layer

The activity layer has a view point of activities actually conducted in the factory floor. Human and machines executing activities, activity of human, processing by machines, and things or information as an object of such activities or processing are brought up for discussion. In every production site of every manufacturer, concrete activities of manufacturing are conducted in a different way. In consideration of such diversity, systems that take advantage of the circumstances are defined in the activity layer.

3) Operation Layer

In the operation layer, detailed operations of human activities and machine processing are discussed together with items and attribute as those operations' objects. Since the operation layer contains know-hows and trade secrets of individual production sites in many cases, its contents are not mentioned here but their description form and a modeling framework are defined. The targets of operations in this layer are things in case of the physical world, and data in case of the cyber world.

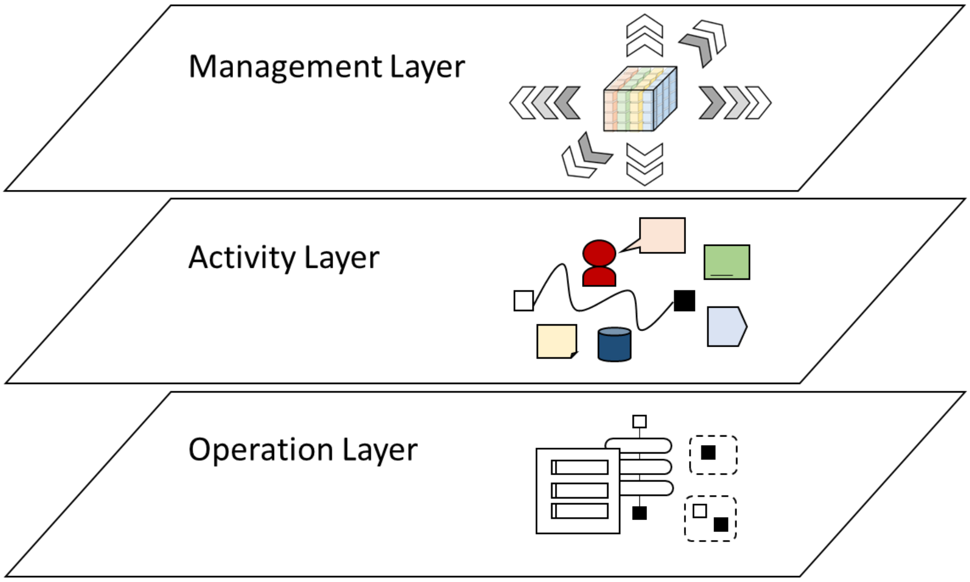

Fig. 1 Three layers of manufacturing

Fundamental Axes of Manufacturing

As an organization to run a business, a manufacturer creates added value by a process starting from purchasing materials through manufacturing products to selling them to customers. On the other hand, new types of manufacturers, such as fabless enterprises having no factory and ones which earn income mainly from added value of after-sales services, represent progress of digitalization and shift to service and software industries.

The following are three axes to look at such transformation.

1) Product Axis

The product axis includes flows of things along supply chains which start as product materials and end as final products, as well as flows in demand chains that consist of needs and demands corresponding to the former. Technical information and engineering information on final products, constituent parts and (raw) materials are also included.

2) Service Axis

Production activities conducted in factories are defined as service activities. Therefore, human, equipment and production methods are dealt in the service axis. Activities providing actions or systems for production are also regarded as services.

3) Knowledge Axis

Things actually existing in a physical site are dealt as instances, whereas their category information or drawings information to create them are included in types which can utilized by abstraction or transformation into knowledge. Things and occurrences conventionally categorized as instances are being digitalized with IoT. Conversion to data is becoming possible.

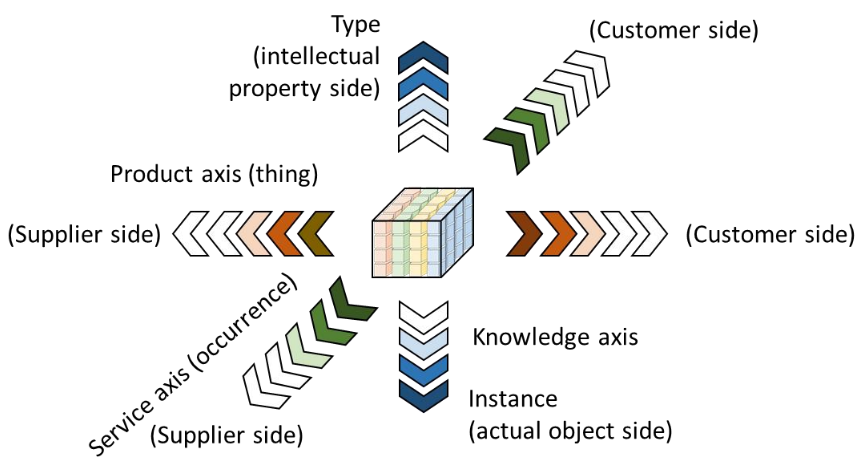

Fig. 2 Axes to look at manufacturing

Four Cycles of Manufacturing Management

In the real world, each manufacturer deploys various activities along the product axis and service (equipment) axis. All of those activities form cycles. Such cycles are categorized based on the length of their targeted contents as follows.

1) Product/Material Supply Chain

In a supply chain, a set of processes, in which materials received is processed into products and they are shipped, composes a cycle in each manufacturer. Such a cycle is repeated in daily production. The length of a cycle in a supply chain corresponds to a product lead time. It differs depending on whether the focus is on a single enterprise or on a whole supply chain.

2) Production/Equipment Engineering Chain

Equipment and devices that constitute production lines are allocated in factories as needed.

Maintenance processes, such as replacing consumables, resetting parameters, repairing failures and renewing if necessary, are conducted periodically or irregularly during a period when targeted products are produced.

3) Product development Life Cycle

A product life cycle corresponds to a case of development of a new product or a design change of an existing product. This cycle which responds to introduction of a new product model includes processes such as planning, development, product designing and production engineering (prototyping and (mass) production) and eventually a point when the product model is discontinued.

4) Production Engineering Life Cycle

When a product model is partially changed, its production line does not need to be modified largely. But in case a product of a totally new category is introduced, processes have to be also newly developed and implemented. In some cases, it can be a cycle to significantly change manufacturing systems in units of factories, for example through joint development with a new business partner.

A life cycle of a business (enterprise) has a longer period than cycles described above. In other words, the outermost is a cycle of disruptive innovation such as a scrap-and-build of a business itself and a business model innovation.

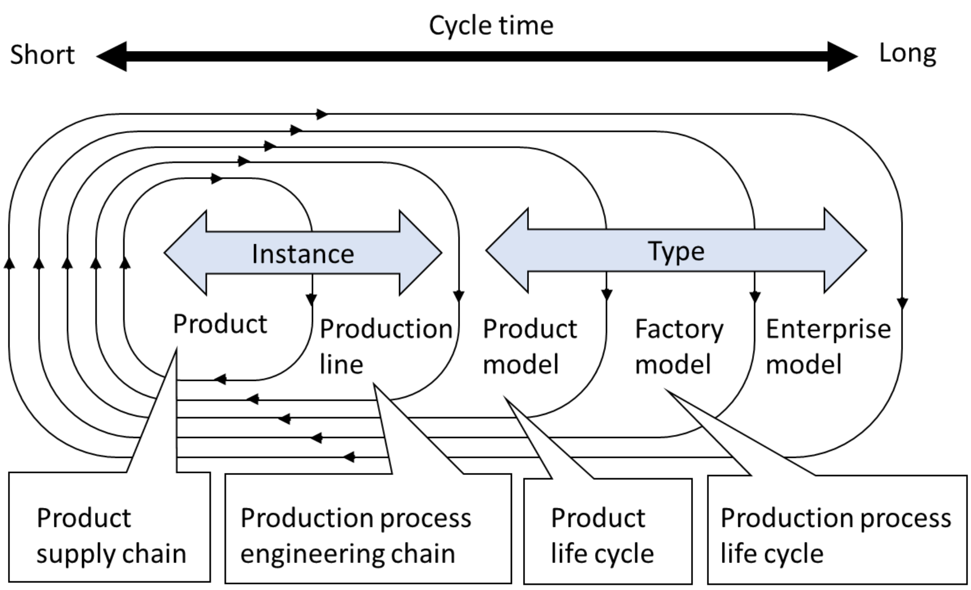

Fig. 3 Four cycles of manufacturing

Smart Manufacturing Unit : SMU

An autonomous body conducting connected manufacturing is called an SMU. An SMU is an organization unit constituting a basic structure of a new type of manufacturing which is characterized by maximizing added value through getting connected. Here, new manufacturing means an industry seamlessly connected to other industries such as mining, agriculture, fishery, farming and service industry which is closer to end consumers. New manufacturing does not require its border to be defined. Moreover, by having such a system capable of connecting beyond sections, enterprises, industries, business types or different enterprise sizes, an SMU makes it possible to dynamically reconstruct a supply chain and an engineering chain responding to needs or seeds in society.

An SMU generally corresponds to an enterprise or a smaller unit. However, among units for production processes, there are cases that cannot be SMUs such as a work centers and a device that cannot be SMUs. To be recognized as an SMU, a unit needs to have human(s) who manage its internal structure and be able to modify itself when needed. In other words, an SMU can autonomously make decisions.

SMU consists of three views.

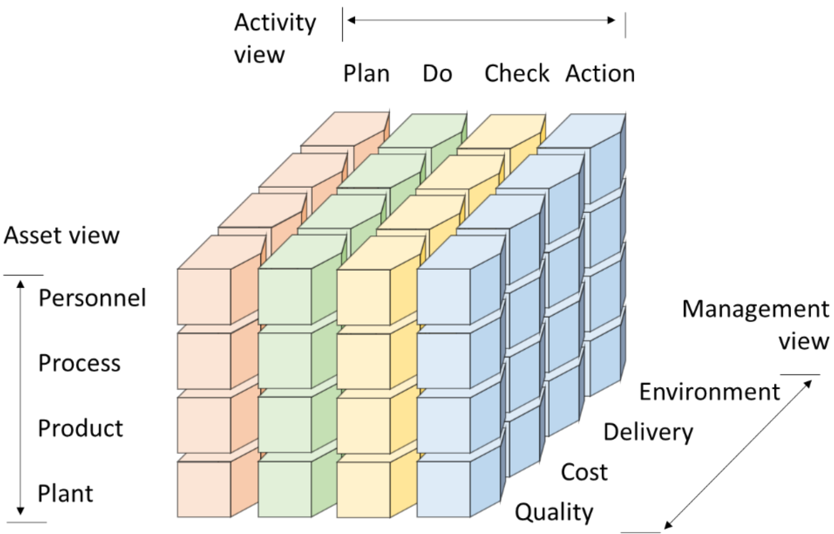

Fig. 4 Smart manufacturing unit (SMU)

1) Asset View

The asset view of an SMU shows assets valuable to the manufacturing organization. Assets identified in this view are properties of the SMU, and some of them can be transferred between different SMUs as needed.

An asset would be an object of any activities. It can also be a proactive subject executing such activities. For example, personnel in some cases conducts an activity upon receiving instructions, and in other cases it acts based on own decision regarding the situation. In this view, there are four classes of assets as follows.

■ **Personnel assets**

Personnel working at production sites are valuable assets. Plant workers conducts operations such as producing a product in the physical world. Personnel also makes decisions and gives instruction to other persons, regardless of whether being a manager or not.

■ **Process assets**

Manufacturing sites have valuable knowledge of the operation such as production processes, methods and know-hows. These knowledge on processes are also assets for manufacturing.

■ **Product assets**

Products created as an outcome of manufacturing and materials to be consumed during production are both assets. In addition, things that eventually become a part of product such as components and assemblies are also counted as product assets.

■ **Plant assets**

Equipment, machines and devices used for manufacturing products are regarded as assets of the plant. Things necessary for operation of equipment such as jigs, tools and subsidiary materials that are also constituent of a plant belong to this kind of assets.

2) Management View

The management view shows purposes and indices relevant for management. Assets and activities of SMUs should be appropriately steered in terms of quality, cost, delivery and environment, which represent the management view. An SMU is subject to be questioned whether it is eventually totally optimized.

Each item of the view can be managed independently. The management classes such as quality management, cost management, delivery management and environment management exist across different asset views or activity views within the targeted SMU.

■ **Quality**

Quality is an index to measure how the characteristic of a product or service provided by

SMU serves the needs of customers or the external world. It is possible to discuss improvement of various kinds of qualities e.g. quality of products which are directly connected to value of customers, quality of plants or equipment to make the products or services, and all the quality related to humans and methods.

- **Cost**

Cost is understood as the sum of financial resources and goods spent directly and indirectly in order for an SMU to provide a certain product or service. The concept of cost includes materials consumed to be converted into products, service invested for operating equipment, consumption of energy, as well as financial resources and goods spent indirectly to maintain and manage plants. Here, value of pre-existing assets is not included.

- **Delivery accuracy**

Delivery accuracy is an index showing how date and time to deliver to the customer meet the needs of the customers of SMU. Location and method to provide products or services to the customers are also considered. It is required not only to ensure meeting the requested deadline but also to fulfill demands to deliver at the exact time and place indicated, and to deliver in a way optimized for each of customers.

- **Environment**

Environment is an index measuring the extent SMU is harmonious with the environment without giving excessive load when conducting its activities. It becomes possible to be environmentally friendly by maintaining a favorable relationship with the environment and neighboring regions. It includes managing emission of toxic substances and flow of CO2 and materials, and optimizing energy consumption.

3) Activity View

Smart manufacturing creates value as outcome of various activities conducted by human and equipment. The activity view covers such activities performed in SMUs. The activities are done at each manufacturing site in the physical world. They can be seen as a dynamic cycle continuously improving targeted issues proactively.

Regardless of the purpose or the object of an activity, the activity view is composed of the cycle of four elemental classes of activities: “Plan”, “Do”, “Check” and “Action”.

- **Plan**

“Plan” is an activity to make a list of action items to be executed either in a certain period or by a deadline. It may also decide the goal of behaviors in order to complete a given mission or to accomplish objectives of an SMU.

■ **Do**

"Do" means to make effort for achieving a certain goal by executing concrete activities at the actual site in the physical world. It can create new assets or change the state of existing asset based on the given goal.

■ **Check**

"Check" is an elementary class of activities to examine whether the goal set by the planning activities has been achieved. It is analytically measuring or sensing how the physical world has changed as a result of execution, as well as to investigate causes when the goal has not been achieved.

■ **Action**

Based on the result of the check, "Action" is a KAIZEN element improving the function of an SMU by defining the ideal situation and tasks for fixing any problems of the target. The action tries to change the structure or the system of the SMU itself in order to fill the gap of the current condition. Although machines and devices do not modify their own structures by themselves, an SMU in which human is immanent changes its mechanism autonomously.

Chapter 2: Modeling of SMU

AS-IS Model and TO-BE Model

In the activity layer of the IVRA, contents of an SMU are described in the level of activities conducted by individual actors. Two types of models – AS-IS model and TO-BE model – are used for describing concrete activities in SMUs.

AS-IS Model

For each of the cyber world and the physical world, existing “things” and real “occurrences” in the activity layer can be picked up and described according to a particular problem recognition. A model described in such a way is referred to as an AS-IS model. An activity scenario described as an AS-IS model is referred to as an AS-IS scenario. An AS-IS scenario is what expresses the current way of working. The real situation is expressed as it is by intention in order to enable discussions on its good/bad points and where problems lie.

The purpose of an AS-IS model is to clarify the problem to be concerned. A problem to be concerned means a state the situation in reality is different from a desired state. For the purpose, the real situation should be visualized and shared among stakeholders. In general, a problem is described in the form of “XX is YY”.

TO-BE Model

Likewise, things that should exist and occurrences that should happen in reality are described as a desired state of the future. This model is called a TO-BE model. An activity scenario described as a TO-BE model is referred to as a TO- BE scenario. TO-BE is what expresses how a situation should be. It does not mean an ideal state. A TO-BE scenario describes a status which is expected to be realized by utilizing digital technologies such as IT and IoT.

The target of a TO-BE model is to clarify the problem to be solved. A problem to be solved means actions that should be taken to bring the reality to a desired state. For that, how the situation should be is described and means to achieve there is clarified. Generally it is written in the form of “XX will be made YY”.

Four Stages for Autonomous Evolution

An SMU is a unit for smart manufacturing that thinks by itself and autonomously changes. It defines its own current condition, problems and tasks as well as how it should become. Based on that, it evolves by modifying its structure or composition elements.

A PDCA cycle in the activity view of SMU is a KAIZEN cycle that is originated in a production site. This cycle is suitable for solving relatively small problems. In case of a larger change such as a change in organization structure or a workflow, an EROR cycle is executed.

An EROR cycle to realize smart manufacturing starts from the current system at all times and are evolutionary. In other words, a system existing at a point of time is referred as the origin when a new system for connected manufacturing is designed and embodied. This cycle is executed repeatedly.

An EROR cycle is composed of four steps: Exploration, Recognition, Orchestration and Realization. A cycle completes usually in one to three months and at most one year.

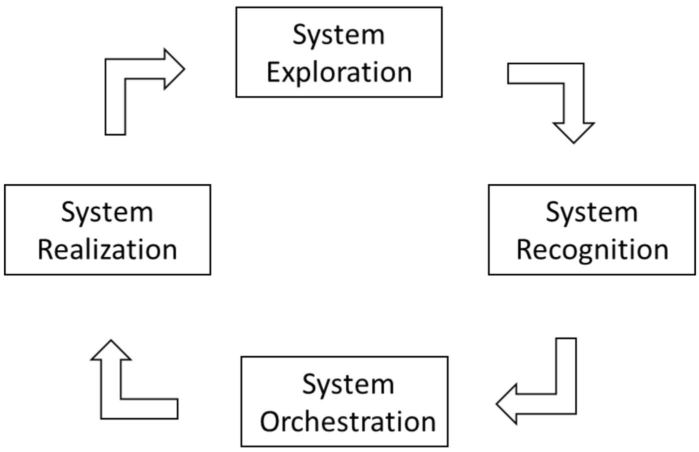

Fig. 5 EROR cycle for evolution

Stage 1: System Exploration

In the stage of system exploration, fundamental issues such as where a problem lies and what the problem is are discussed. Firstly the range or scope of a targeted problem is set. Then through conducting as many hearings as possible from actual persons in charge and persons concerned, the real situation such as who has a problem where is grasped concretely, and the contents are arranged. After that, a problem structure revealed as well as and the nature of a problem which can be detected from the structure are discussed. For example, brain storming and the KJ method (affinity diagram) are effective means.

Stage 2: System Recognition

In the stage of system recognition, persons concerned need to mutually understand the real situation correctly. Given that a concern is an interpretation of a situation, it becomes possible to share an understanding of the matter by expressing situation in which the issue concerned arises as an activity scenario. An activity scenario shows a picture in which multiple actors conducting operations in a manufacturing site perform various activities through exchanges of things and information.

Stage 3: System Orchestration

In system orchestration, a problem to be solved is clarified by expressing a desired state of a manufacturing organization or system as an activity scenario based on the problem in the current situation. In comparison to an activity scenario for the current situation (AS-IS scenario), useless parts are eliminated from information flows in a scenario for a desired state (TO-BE scenario) and added value is increased by automation and adoption of cyber technology. Means to achieve such targets or goals are also discussed in the stage.

Stage 4: System Realization

Current flows of operations or ways of working have to be changed in order to realize an activity scenario of a desired state (TO-BE scenario). At the same time, uselessness is eliminated and efficiency is enhanced by digitalization of traditional activities and taking advantage of platforms that effectively utilize the cyber world. By gradually expanding world connected with digital technology, new operation flows which used to be impossible to realize will be created as well as added value will be drastically enhanced.

Method of Activity Scenario Modeling

Here, activity scenarios are cut out from operation flows as meaningful bundles and used as contents to write models. A scenario has the same meaning as that for a play or a novel. A scenario always has a writer who describes it based on his/her intension, but the contents are composed of elements existing (or likely to exist) in reality.

Activity scenarios are easy to understand and memorable for listeners and readers as stories unfold from a perspective of an actor who appears there. Expressing manufacturing activity models in the activity layer as scenarios is effective for building consensus and communicating accurately, since it helps stakeholders understand the contents.

This section introduces elements composing activity scenarios. First, there are four elements in the physical world which corresponds to production sites.

Actor

An actor conducts activities related to production by independently making decisions. Not only workers in charge but also automated machines can be regarded as actors. An actor in charge of a work in each scene is defined by his/her role. Actors are named in a manner the role (function) is obvious instead of using proper names.

Activity

An activity is a unit of work conducted by an actor. It is defined as a unit of work whose output can be taken over by another actor. In other words, if an activity is stopped in the middle and the remained part can be continued by a substitute actor, it is regarded as a single set of activity.

Thing

A thing is a visible object existing physically. It exists at a point in the physical space at a certain point of time. All products, parts, equipment and jigs in a manufacturing site can be “things” but here the term indicates targets of concrete operations in activities.

Information

Information is what expresses contents needed by actors to make some decision. In reality, physical things such as paper, boards and display devices become media. Here information means contents shown on them.

On the other hand, the four elements in the cyber world are defined as below.

Service

When an activity, which used to be conducted by an actor, is done in the cyber world a part of it is executed by an alternative existence. This is a service. It is embodied by a software using digital technologies to work in a platform.

Process

A process is a unit of function constituting a service which corresponds to an activity in the physical world. Inputs and outputs of processes are data. A function of a process is defined by the states before and after the process.

Data

Data is a unit existing in the cyber world which has contents describing things and information in the physical world. In practice, a unit of data is composed of multiple attributes which have values. It becomes an input or an output of a process, and in some cases data can be correspondent to things or information.

Condition

In the cyber world, a category of a condition is decided depending on values that data attributes have. Thus, and it changes from time to time. Categories of conditions are utilized in several ways such as logics inside various processes, execution of processes and triggers for sending alerts to the physical world.

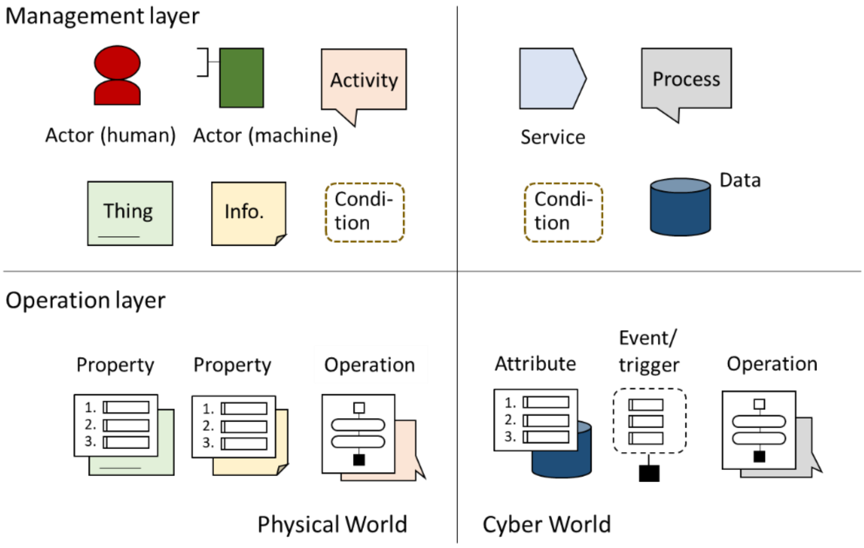

Fig. 9 Icons of scenario defining elements

Most of elements constituting activity scenarios belong to the activity layer of the IVRA, but a part of them also cover the operation layer. The following are elements in the operation layer.

Operation

An operation is a unit expressing contents of an activity of an actor in the physical world or a process in a service defined in the cyber world. It is possible to differentiate the term by referring to as an activity operation in case of the physical world and as process operation in the cyber world.

Property

A property is a unit that expresses a concrete content of a thing or information in the physical world. In some cases it is specified as a thing property or an information property. Contents of properties are modified by activity operations. For example, when a thing is lifted a value of the property of location (altitude) is changed.

Attribute

An attribute is a constituent element to express contents of data in the cyber world. It is also called data attribute. For a unit of data one or more attributes are defined. The data is concretized by values of attributes. A value of an attribute is set or changed by a process operation. A condition category is changed by a combination of attribute values

Event/Trigger

An event is an occurrence defined beforehand. It is specified in a condition or a process. For example, it includes a phenomenon that temperature exceeded a certain threshold defined in the cyber world. Among events, ones which start certain processes are referred to as triggers.

Connection of the Cyber World and the Physical World

A cyber-physical system is a system in which the physical world such as production sites and the digitalized cyber world are harmoniously combined. In fact, digital technologies and network technologies have been used for years on factory floors. Here the point is that, in addition to digitalization by data input conventionally done by workers, IoT has made it possible to create data directly from things as well as send data directly from network to things. The diagram shows a cross section of an activity scenario in which the physical world consisting of actors, activities, things and information and the cyber world with data and service are interconnected.

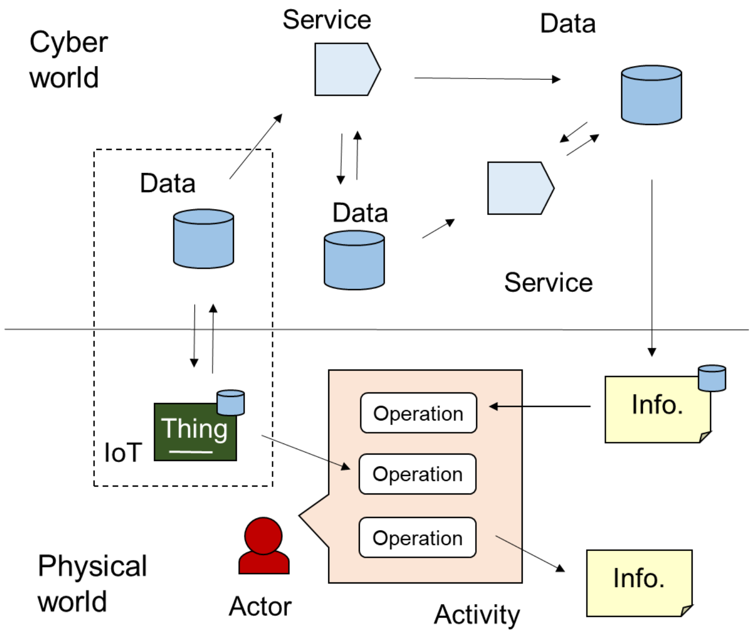

Fig. 10 Cyber and physical connection

Things and information in the physical world which are connected to data in the cyber world are distinguished by attaching digital marks (small icons indicating data). Information with a digital mark is equal to a device such as a display device. On the other hand, a thing with a digital mark is a so-called IoT device characterized by sending data directly from the thing on the factory floor to the cyber world.

Chapter 3: Platform Reference Model

Overview of Platform Architecture

Platforms cover the activity layer and the operation layer in the IVRA as shown in the Fig. 7. Various actual activities on the factory floor of manufacturers can be transferred to the cyber world and processed by using digital technologies.

From a viewpoint of an activity scenario, a platform can be defined as a system to effectively utilize the cyber world. Therefore, a use case of a platform indicates a form of usage such as how data or digital technology in the cyber world can be utilized by an activity scenario.

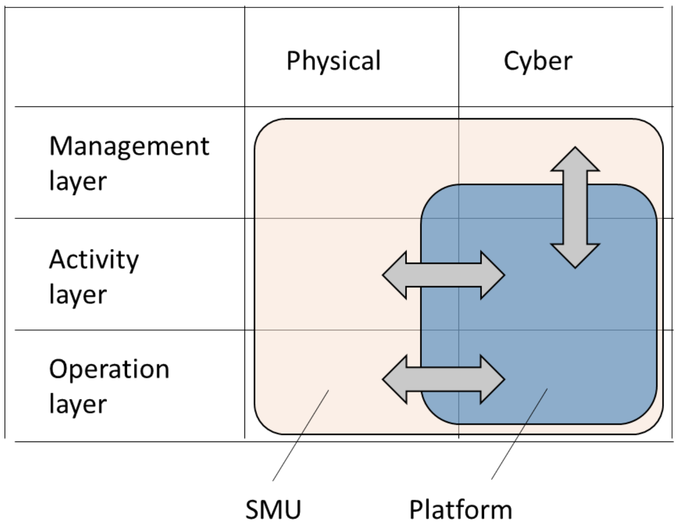

Fig. 7 Positioning of platform

To look from the perspective of the system granularity or hierarchy, platforms, which are positioned in the cyber side of the IVRA, have the following hierarchies.

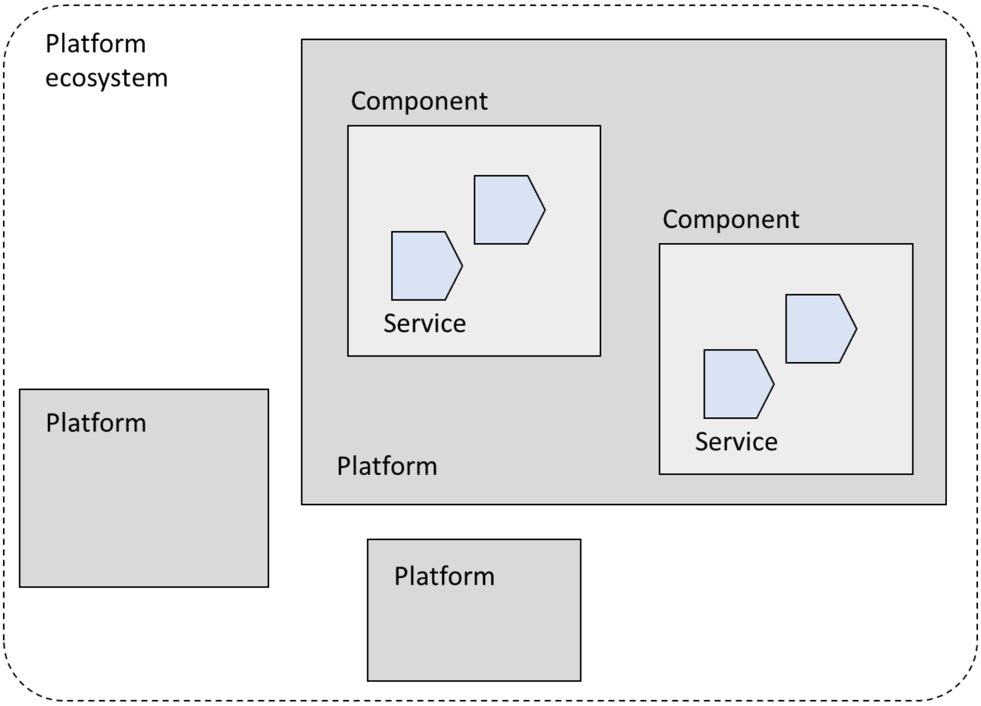

Fig. 11 Hierarchical structure of platforms

Platform ecosystem

The uppermost of the hierarchy is platform ecosystems. A platform ecosystem is a state in which different constituent platforms are loosely connected by some relations. Each platform in an ecosystem is its constituting element but it is not in position being able to control the ecosystem. Thus, a platform ecosystem as a whole is made up based on autonomous decision makings of individual platform. Here connection among ecosystems is not considered.

Platform

A platform is a unit which beforehand ensures or supports interoperability of its components by some rule or terms. A manager of a platform (platformer) has two aspects: It collects components constituting the platform; and at the same time it provides a service gathering users who actually utilize the platform for manufacturing.

Component

Components include softwares that are designed in advance and meet a quality level to be provided as products as well as necessary hardwares. A component has some function independently which can be provided to users. But in many cases it is needed to connect to other components in order to execute its function.

Connection among components is precisely what platforms exist for, so it is discussed in the level of platforms. The topic is explained later in this chapter.

Service

A service is a unit of software that constitutes a component. It provides customers with values directly or indirectly. If a connection of services is within a component, it is provided in a form defined by the component in advance.

Categories of Components

A platform is a system that realized connected manufacturing in the cyber side. It is composed of the following four kinds of components. In a precise sense, they are types of services constituting components, or in other words, types of functions which provide those services.

IoT device

A device is located on the border of the physical world and the cyber world and conducts conversion between things or information needed in operations and data used in the cyber side. Such conversions consist of ones from the physical world to the cyber world and ones in the opposite direction.

Application

An application serves a function in the cyber world which used to be performed in an operation. It consists of one or more services. An application can be also defined as a conversion function that transforms input data to output data.

Service tool

A tool has a secondary function to facilitate efficient and proper functioning of devices and applications. Secondary functions of tools include ones specific for devices (but not specific for applications) and ones which are shared among different devices and applications. For example, there are tools such as construction tools, diagnostic tools, conversion tools and optimization tools.

Data infrastructure

Infrastructures have functions to accumulate and save data, to take it out if necessary and to transfer data between different sites in the cyber world. They also have secondary functions to facilitate such functions.

Object Models for Scenario Modeling

In an SMU, the physical world and the cyber world are integrated to practice connected manufacturing. Processes constituting services as well as data and data attribute as their targets are correlated with actors, things and information in the physical side. Fig. 12 illustrates the relationship of objects in the cyber world and ones in the physical world.

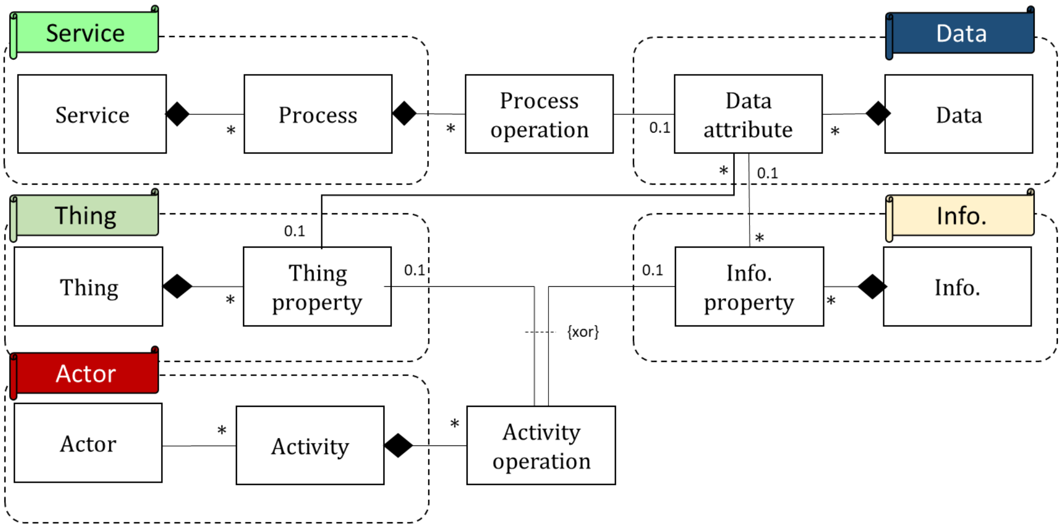

Fig. 12 Object diagram of scenario elements

Elements in the cyber world and the physical world indicate relationship between data attribute and thing property, or between data attribute and information property. In addition, they are also connected with triggers based on events as shown in Fig. 13.

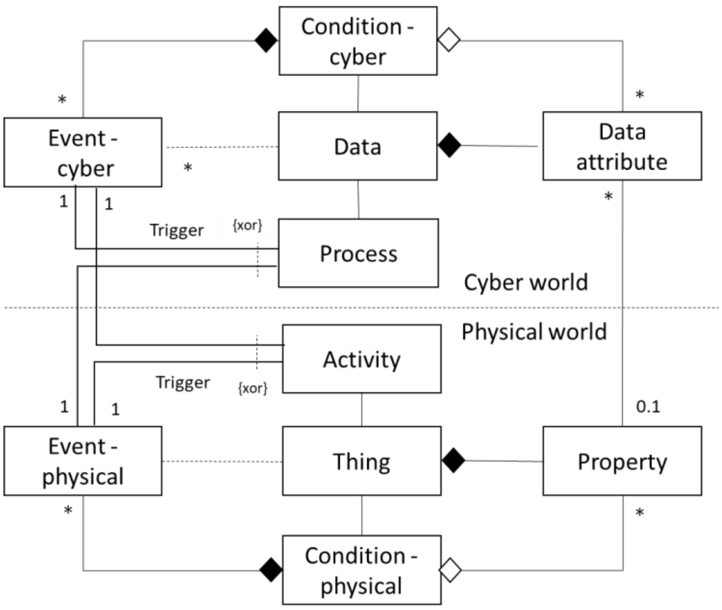

Fig. 13 Relationship between the cyber world and the physical world

Hierarchy of System Connection

In a cyber-physical system, production site in the physical world and the cyber world having platforms as its core realize connected manufacturing by mutually complementing functions. A cyber-physical system is a system of systems in which systems in different levels are interconnected. That makes possible to deal with problems in high levels that cannot be solved by a single system.

Connections of systems are classified as follow by granularity (hierarchy) of objects to be connected.

Connection among Services
A service is a unit its result can be evaluated by physical users or upper level users in the management layer. Connections in this level are managed by individual components.

Connection among Components
A component is a unit of multiple services which are tightly coupled. Mutual connections of components are ensured in the range assumed by the suppliers. Thus, connections among components are conducted by the users or platforms.

Connection among Platforms
In most cases, connections among platforms are autonomous decentralized systems without core management functions. Thus, it is not basically ensured connections are correctly made. However, it is possible to connect multiple platforms as an ecosystem when the platforms agree with a unified rule, terms or connection procedures.

There are two forms for interconnections of components: tight coupling inter-operation and loose coupling inter-operation.

1) Tight coupling inter-operation
The tight coupling inter-operation is a form of connection that components mutually boot a service of the other component and utilize it by using API (Application Interface) and SDK (Software developer's Kit). This type enables speedy and high quality connections, but has a task in serviceability for example when a function of one of the components is extended.

2) Loose coupling inter-operation
The loose coupling inter-operation is a form which minimizes effects of future function extension of the other component as well as enables components' own function extension by loosing the degree of a coupling between components. API protocols in the lower implementation level are limited to versatile ones which are already widely diffused, and

those semantic usages are described in profiles.

Profiles Specifications

Given that a platform is a system to improve interoperability among components, component profiles are necessary to connect constituent components by the form of loose coupling inter-operation. When components are connected across platforms, profiles for messages exchanged there are also needed. Fig. 14 illustrates positionings of profiles for connection.

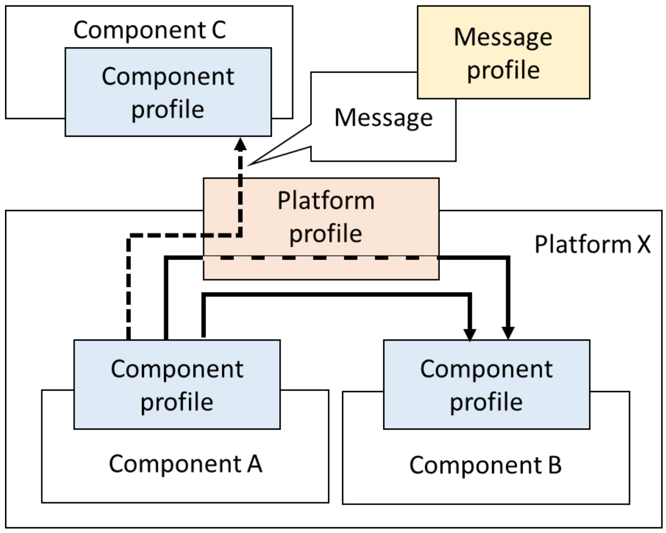

Fig. 14　Connection by profiles

The following are types of profiles related to component connection.

1) Platform Profile

A platform profile specifies contents of a platform. It includes an internal profile concerning components composing the platform and an external profile describing external features of the platform.

2) Component Profile

A component profile describes contents of the component service and necessary data. Component profiles are written in a manner understandable for developers of systems to connect systems in accordance with individual model dictionaries or a common model dictionary.

3) Message Profile

A message profile shows contents of a message and the condition in which the message is sent, so that a message delivered from a sender to a receiver can be managed when it is separated from the environment.

Platform profiles, component profiles and message profiles have contents explained below.

Service Profile

A service profile describes contents of a service that a component has. It contains information such as service contents, use cases, restrictions and authority in usage of the service.

Data Profile

A data profile describes the structure and properties of data which is input/output by a component or included in a message. Contents of an individual data dictionary or a common data dictionary are used in a data profile depending on the level.

Communication Profile

A communication profile documents contents corresponding to a notification protocol in a broad sense such as timing or procedures of data exchanges and responses to authentication or errors when a component uses a service of another component.

Security Profile

A security profile describes contents concerning security such as authorization related to contents or usages, ownership and encryption.

Chapter 4: Framework for Connected Industries

PLU for SMU Connection

An SMU which is a unit executing manufacturing cannot create the final form of value by itself. Value created in an SMU at a point is conveyed along the product axis and the service axis to an end user, where a value chain completes. SMU connections enable efficient and effective value chains among businesses having different philosophies or values.

As SMUs have physical and spatial sites in the physical world, transfers of things and information are particularly needed in connections among SMUs. It is also necessary to manage such transfers of physical things and information together with transfers of data and money in the cyber world. A unit managing transfers of a set of thing, information, data and money between SMUs is referred to as a portable loading unit (PLU).

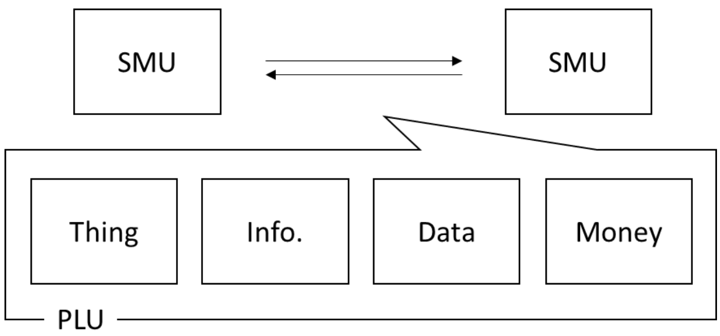

Fig. 16 Management of connection by PLU

In the management layer a PLU corresponds to an economic transaction in which a product or service is exchanged between SMUs. Not only exchanges among businesses but also those within an enterprise can be managed by PLUs if the units such as sections, factories and groups are profit centers.

Usage of PLUs enables secure transfers and at the same time objective management value of transfer by improvement of traceability since transfer histories are neutrally grasped.

Basic Structure of Open Connection

Transfers in the cyber world and the physical world between SMUs which are managed in correspondence by PLUs have different routes. Transfers in the physical world are mostly done in daily works of logistics service providers, and are managed by physical containers. On the other hand, transfers in the cyber world are managed by cyber containers which are correlated as PLUs by setting unified IDs called U-CODEs.

Since a PLU include a movement of value, when correspondence of a cyber container and a physical container is confirmed value transfer is also decided. At that point virtual currency is exchanged by tokens.

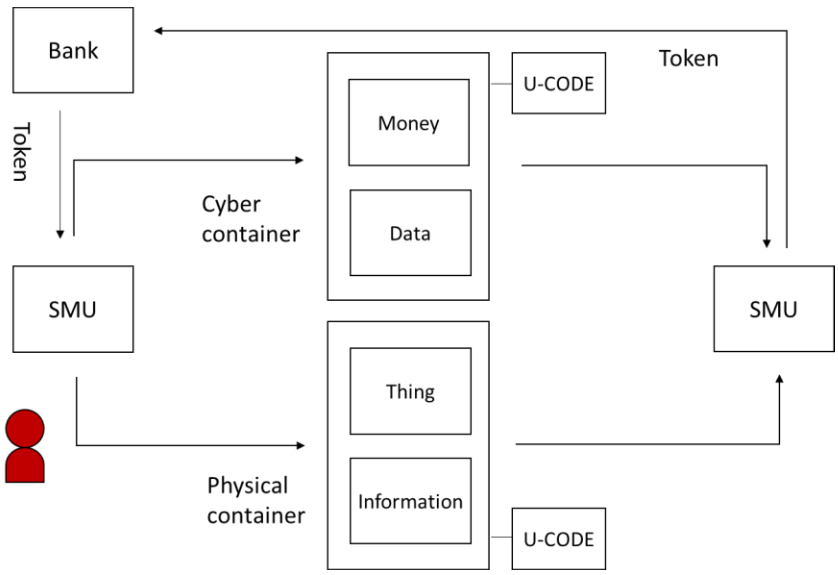

Fig. 17 Mechanism of PLU transfer

In transfers of PLUs in the physical world, it is common that there are some stopping points between a lading site and a receiving site due to physical restrictions, institutions of countries and regions and business restrictions of enterprises. Here, such stopping points are also defined as SMUs. Their basic elements such as actors, things, information and activities as well as relationship among them can be defined in the activity layer.

All SMUs including stopping points which are related to transfers of PLUs manage receipts and shipments by local connection servers (LCSs) in each of the sites and send the contents to traceability servers each time. LCSs at lading sites and receiving sites handle both cyber containers (PLU-Cs) and physical containers (PLU-Ps) correspondently and send sets of those contents to traceability servers. PLU-Cs and PLU-Ps are treated separately in other

SMUs between the two points since they take different routes.

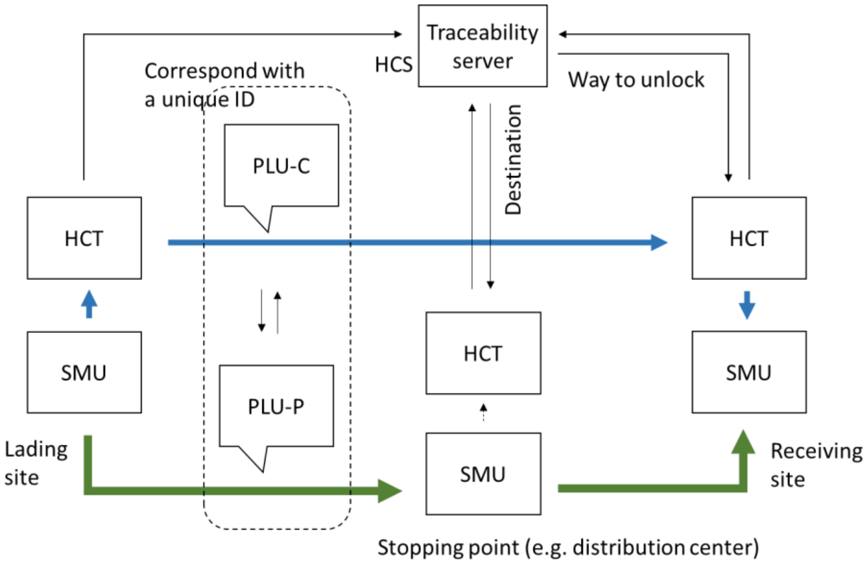

Fig. 18 Traceability management

From a business viewpoint, it is not ensured all stopping points and the receiving site that receive a PLU convey a fact of receipt to a traceability server via LCSs. Although costs for digitalization at production sites are decreased because of progress in IoT technologies, it will not realize if benefits do not meet the costs. Hence, a mechanism of SMU connection with PLUs should coordinate with payment systems of banks in order to make commercial transactions close only after facts of receiving PLUs are reported.

Structure of Hyper Connection Server

Hyper connection terminals (HCTs) are base points for connection among SMUs in the cyber world. They directly manage activities of SMUs as starting points, stopping points and last stops of PLUs.

On the other hand, a hyper connection server (HCS) has functions enabling HCTs to mutually send and receive PLU-Cs. They are composed of traceability servers, authentication servers, U-CODE servers and common dictionary servers.

Authentication server

An authentication server registers authentication of each HCT, an SMU under that, and services of the SMU and manages service IDs of starting points and final stops in PLU connections. It also manages public keys for data encryption.

Traceability server

A traceability server contains all records of transfers of PLUs in the cyber space and the physical space. Records are set in a manner that senders, receivers and data contents to be sent can be specified.

U-CODE server

All PLUs receive unique IDs from U-CODE servers before they are shipped for traceability during and after they are transferred from senders to receivers. U-CODE servers collaborate with each other in order to avoid overlapping of IDs and ensure that they are globally unique.

Common dictionary server

Terms used on factory floors are heterogeneous. Therefore, systems in accordance with such terminology in the levels of components and platforms also have heterogeneous terms. A common dictionary server manages such dictionaries and a communalized dictionary.

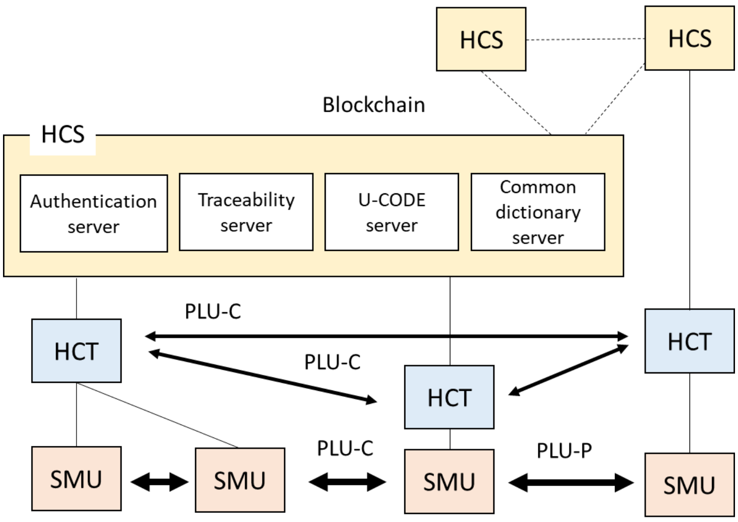

Fig. 19 Structure of HCS

Management by HCSs is not conducted by a sole server but done by multiple servers in a decentralized manner. HCT list and SMU lists of authentication servers, transaction records of traceability servers, information on codes issued by U-CODE servers, and dictionary information of common dictionary servers are managed decentrally by blockchains.

Data Dictionary Management by Loosely Defined Standard

A common data dictionary is created to assure component connections in platforms and to facilitate adding new components to platforms. However, such common data is constantly renewed depending on updates in each component or addition of new components.

A loosely defined standard in this case means that definitions in a data dictionary are not fixed in advance but decided temporarily by commonalizing from actual situations of components in a bottom-up approach. When usage of the systems advances and an operation itself evolves, the temporal data dictionary is reviewed and updated.

A cycle of updating a data dictionary is usually from a half year to one year. A cycle consists of four steps.

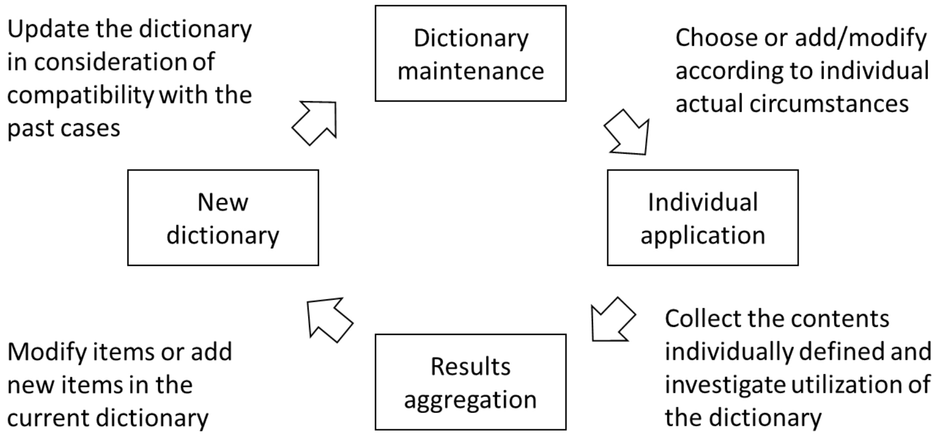

Fig. 15 Cycle of updating a data dictionary

When a data dictionary registered at a point in time is utilized for an individual model, suitable terms are selected from it but if there is a lack or an irrelevance, a term is added as needed. Through gradually accumulating such differences, a new dictionary is created by remaining terms frequently used, adding important items which lacked and removing ones not used.

Practically, a problem may happen in terms of compatibility with an old system when a data dictionary is updated. Systems should be able to evolve by adaption in order to avoid such problems. Such a mechanism for dictionary maintenance is of particular importance in management of an integrated data dictionary for connections among platforms.