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IFAC-PapersOnLine 49-31 (2016) 103–108

Manufacturing Information Bus from the Perspective of Cyber Physical Manufacturing System (CPMS)

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Abstract: Smart Factory of Industry 4.0 is a complex system containing various aspects and capabilitis of the factory of the future based on Internet of Things (IoT), Internet of Men (IoM), and Internet of Service (IoS). There have been numerous concepts and scenarios how it looks like, how it should be, and commercial vendors advocate their products can provide solutions to some parts of the Smart Factory. This often confuses stakeholders who want to adopt Smart Factory. To show and guide the multi-aspects and technology for Smart Factory in a comprehensive fashion, our research team developed a conceptual framework, called Cyber Physical Manufacturing System (CPMS^{PS}). In this paper, we focus on the manufacturing information bus from the perspective of CPMS. Specifically, we developed a reference architecture for the manufacturing information bus for the Smart Factory that can be used for information acquisition, analysis, and application for the various stakeholders at the levels of Machine, Factory, and Enterprise Resource Planning. Also in this paper, an implementation process of the reference architecture is presented and demonstrated via case study.

Keywords: Smart Factory, Manufacturing Information Service, Manufacturing Information Pipeline, Cyber Physical Manufacturing System

1. INTRODUCTION

Industry 4.0 has been highlighted as one of the key issues of global industry, and a concept of smart factory is emerging as a means of achieving Industry4.0 by incorporating recent Information and Communication Technology (ICT) in manufacturing system, especially Internet-of-Things(IoT). Factory-of-things using wireless technology and Service Oriented Architecture(SOA)based automation is suggested as one of smart factory model(Zuehlke 2010), and Cyber-Physical System is being highlighted as means of achieving industry 4.0 (Lee et al. 2015). There are many definitions and description of the smart factory, but most have the following aspects in common: 1) Components in smart factories are networked and it is possible to collect useful data from them; 2) The current status of manufacturing components can be determined and visualized in real time; 3) Autonomous and automatic processes can be executed based on optimized manufacturing plans; and 4) Advanced manufacturing services can be provided on shopfloor and to external systems.

Cyber Physical Manufacturing System (CPMS^{PS}), developed by POSTECH Center for Ubiquitous Manufacturing, provides well-organized architecture to realize smart factory for Industry 4.0 into in an optimized and systematic fashion (Fig. 1). CPMS is composed of four components: 1) smart shop floor, 2) smart manufacturing execution system (MES), 3) smart factory service, and adoption engineering. Smart shop floor is a key driver for making the manufacturing system smart based on IoT and factory things. Smart MES is capable of carrying out legacy functions as well as smart functions. Smart factory service provides advanced factory applications as service item through enterprise network. Smart factory adoption engineering provides methodology about how to adapt and develop the smart factory in a systematic way.

In terms of information, the essence of a smart factory is how data are acquired, analyzed, and applied for the various internal and external stakeholders. To access the full potential of the IoT for efficient data and information flow, a specialized information service bus is needed for manufacturing in a smart factory, as described in Fig. 1 as Enterprise network for office floor, and Real-time Network for shop floor. This paper is concerned with such a bus, namely the "Manufacturing Information Bus for CPMS" (MIB). The purpose of MIB is to transfer manufacturing information and services efficiently so that the total manufacturing performance can be improved.

Nowadays, Manufacturing Service Bus(MSB) which incorporating Enterprise Service Bus(ESB) in manufacturing domain is widely used(Boyd el al. 2008). The core of MSB is to provide standard manufacturing data format and to integrate legacy information systems based on Service Oriented Architecture (SOA) paradigm. There are commercial solutions containing MSB concept such as

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.12.169

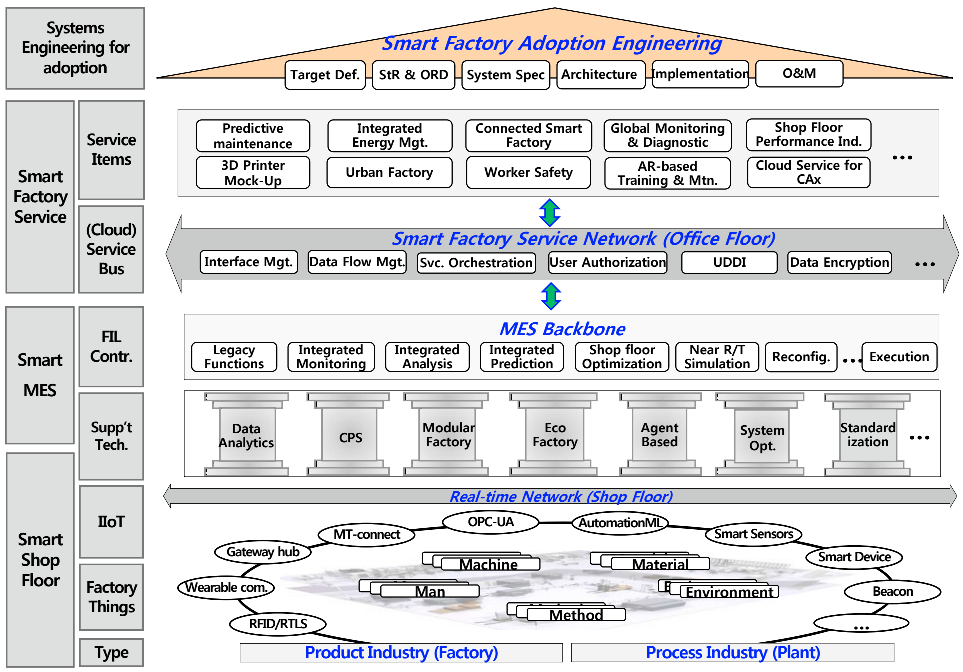

Fig. 1. Architecture of Cyber Physical Manufacturing System (CPMS^{PS})

SIMENS WinCC OA, or Rockwell Automation FactoryTalk PhamaSuite, but more shopfloor oriented middleware is required for CPMS^{PS} and industry 4.0.

Previous research on data and information technology has been concerned with information content such as the design and exchange of product, process, resource (Lee and Jeong 2006; Suh et al. 2008; Wang and Xu 2012), manufacturing (Lee et al. 2012; Yoon et al. 2012), monitoring (Bogdanski et al. 2012), and maintenance (Espindola et al. 2013). As far as information services are concerned, the ubiquitous product lifecycle support (UPLS) system has been proposed (Lee and Suh 2009). UPLS is an information middleware that supports product related activities in the product lifecycle with product data models. However, since UPLS deals with product-oriented data, it is not suitable to be adapted as a smart factory information middleware. Smart factories aim to improve the overall manufacturing performance, so the data target should cover machine, factory and enterprise levels.

As far as information content is concerned, previous research has mostly used productivity as the key performance indicator (KPI). However, the manufacturing information and architecture should be designed to cover various KPIs comprehensively. In this research, productivity, environment, and social impact are used as the components of the total performance index (TPI) of a generic smart factory, rather than focusing on specific KPIs.

Based on the state-of-the-art outlined, this paper proposes a reference architecture for an information bus or middleware as a means of network system for CPMS. The middleware can be used for information acquisition, analysis, and application by the various stakeholders at machine, factory, and ERP levels. This paper suggests characteristics and architecture of the information service bus, and implementation procedure.

2. ARCHITECTURE OF INFORMATION BUS

In this section, a conceptual model of MIB will be developed that reflects its role and significance in delivering smart-factory services.

2.1 Vision of Information Bus

A smart factory is expected to provide various services for improved manufacturing performance based on manufacturing information. However, it is not easy to find the desired service among numerous sources because the services are scattered all over the manufacturing system.

MIB acts as an intelligent information middleware that helps users to find the desired information and deliver the corresponding service by collecting, linking and summarizing distributed services as shown in Fig. 2. MIB provides services in a well-structured form, and users can request services and get results easily and quickly.

2.2 Characteristics of Information Bus

In order to realize the vision of MIB, four major functions are required: 1) Connect to the manufacturing services; 2) Itemize the services in a well-defined structure; 3) Describe the detail of each service; and 4) Manage service requests and their subsequent provision. In this section, the characteristics of MIB for implementing each function will be introduced.

First characteristic is conceptual aspects. If user-specific smart-factory services are provided by the middleware, rather than by separate and specific service providers, then the user feels as though the middleware is providing all the services. This is a simple description of the conceptual aspects of MIB.

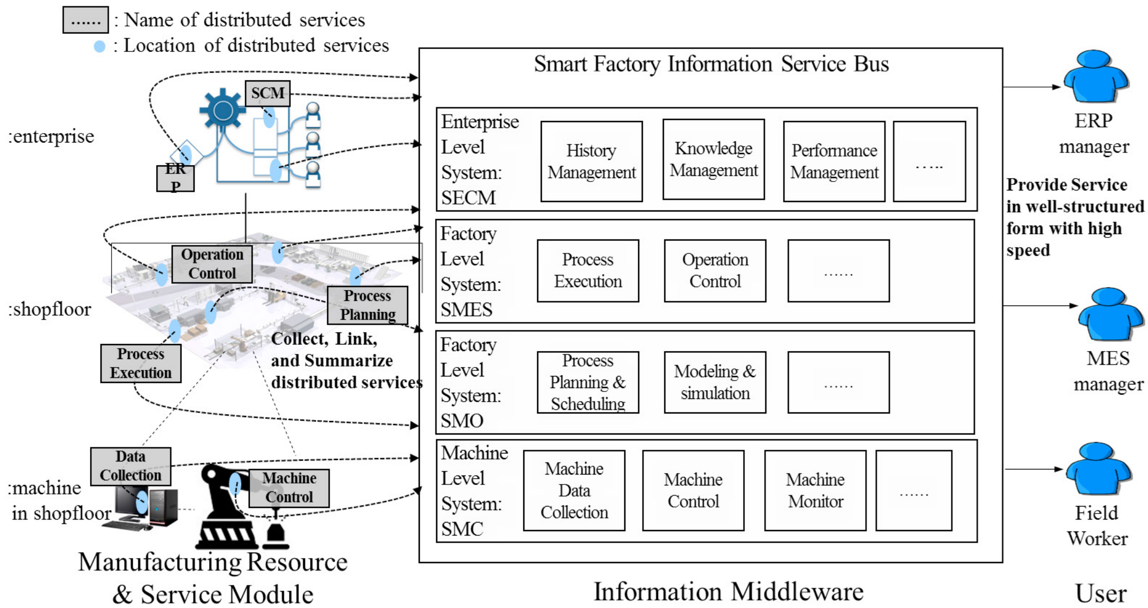

Fig. 2. Conceptual model of MIB

MIB is linked to each manufacturing system and delivers the results of services to users. MIB plays the role of a trigger for performing actual smart factory services, and it visualizes services in a well-defined structure.

MIB service description language is the second characteristic. Before requesting manufacturing services, a user needs to know exactly which services can be provided. To deliver such details, the middleware should have a standard for describing services. For this, a service description language is defined for MIB. Using the language, the service can represent which functions will be executed, what information will be delivered, what input and output will be.

The last one is service request process application. Various systems and users are connected through MIB. There are many issues in service provision, such as convenience, reusability, security, and different data models between systems. For this, the MIB process application modules for service requests are developed. There are six main modules of the unified product lifecycle data model: (i) unified product lifecycle data model (ii) process execution management, (iii) user authentication and data accessibility, (iv) user-defined process support, (v) service search support, and (vi) service history management.

2.3 *Reference Architecture of Information Bus*

The characteristics of MIB relate its functionalities as information middleware. However, the middleware aspect is not enough to satisfy the requirements of a smart factory. As stated earlier, a smart factory aims to enhance TPI through manufacturing services, so the middleware should reflect TPI perspectives. In this section, a reference architecture of MIB is proposed, with lists of services according to the service level.

The services and reference architecture for MIB are developed (Fig. 3). Each service is categorized as Smart Machine Controller (SMC), Smart Manufacturing Optimizer (SMO), Smart Manufacturing Execution System (SMES), or Smart Enterprise Contents Management (SECM) according to its characteristics. Process application modules are applied for the sound use of each service.

SMC is composed of services for controlling and managing manufacturing machines. Intelligent resource control and monitoring services are defined, and it is possible to evaluate manufacturing processes at the machine level.

SMO is composed of services for optimizing manufacturing processes. It provides machine-level process planning and services for sustainable TPI improvement.

SMES is composed of services for manufacturing execution. It provides services for manufacturing-process planning and execution, monitoring, measuring, and maintenance. In order to provide SMES services, three smart agents are designed as a sub-module of SMES.

The product agent provides services for supporting the manufacturing progress of a product. Through the product agent, the location and information of product are managed in real time. The resource agent provides services for monitoring the condition of a resource. Through the resource agent, it is possible to provide sensor data, to identify the machine, and to react quickly to unforeseen events. People are sources of data for some services and consumers of other services. Thus, the human agent contains two types of services: customer and provider. As a customer, the human agent provides support for smart-device usage, augmented reality support, knowledge for manufacturing and maintenance operations, and other context-based information. As a data provider, it mainly reports the person's current state.

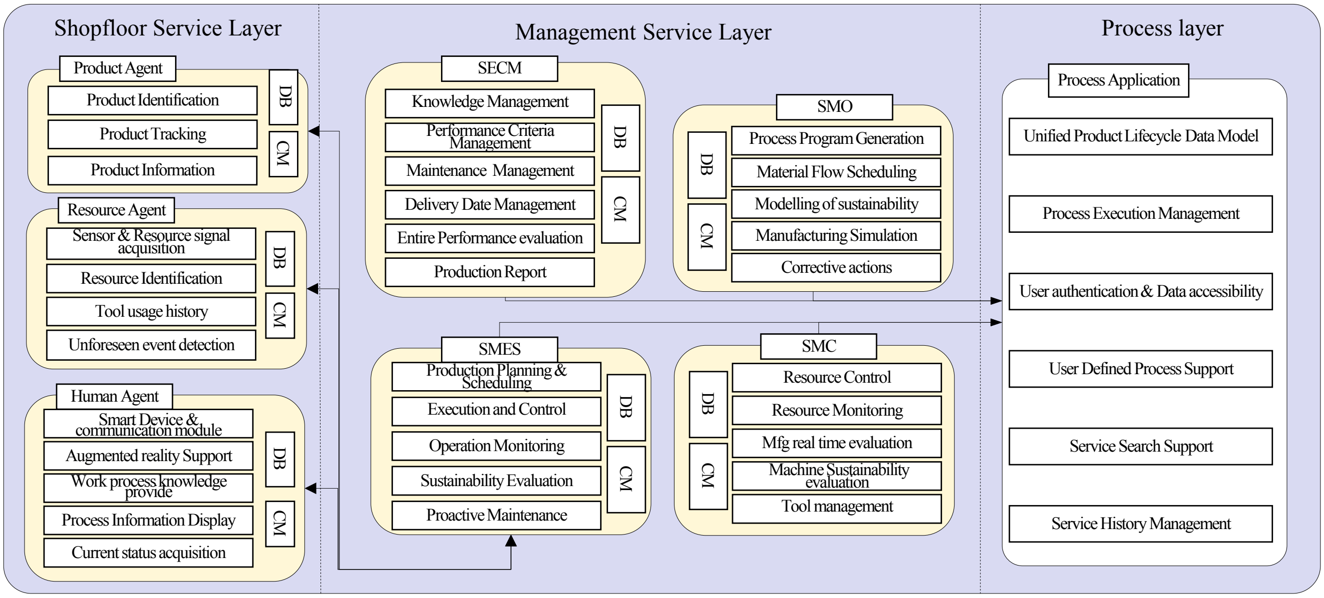

Fig. 3. Reference architecture for MIB

SECM provides services for managing the information of a manufacturing system. Through SECM services, it is possible to manage manufacturing process history, knowledge for operation and control, real-time manufacturing information, criteria for process evaluation, and maintenance information and knowledge. The delivery date can be controlled in conjunction with a process plan and performance can be evaluated on the entire manufacturing-system level. SECM generates reports for the operational results.

3. IMPLEMENTATION PROCEDURE

The MIB reference architecture presents the smart-factory services needed to improve productivity, environment, and social impact. However, not every manufacturing company needs to introduce all services at once when implementing a smart factory. Rather, they need services for each specific performance that requires improvement. In this section, an implementation procedure for extracting such services is proposed based on the MIB reference architecture.

The methodology supports the identification of services to be implemented in the shopfloor and management service layers in the MIB architecture. Implementation Procedure consists of eight steps, as shown in Fig. 4, and some of which can be operated repeatedly according to the implementing procedure. The following are detailed descriptions of each step.

- Goal and scope definition: Define the goal of the smart factory to be implemented and the scope of the system. The goal represents performances to be improved in the manufacturing system, and scope refers to the range of information the system has to include.
- Build factory model: Build an As-Is model representing current features of the manufacturing system and a To-Be one representing the system after smart-factory implementation. In the latter model, the effect of the smart factory should be described. Each model has to show the factory elements, the level of each manufacturing process, and the manufacturing activity flow.
- Identify information flow of As-Is factory model: Identify and describe the information flow between elements and activities in the current manufacturing system.
- Identify information flow required for To-Be model: Identify and describe the information flow to achieve a goal from the perspective of the data acquisition, data analysis and application provided.

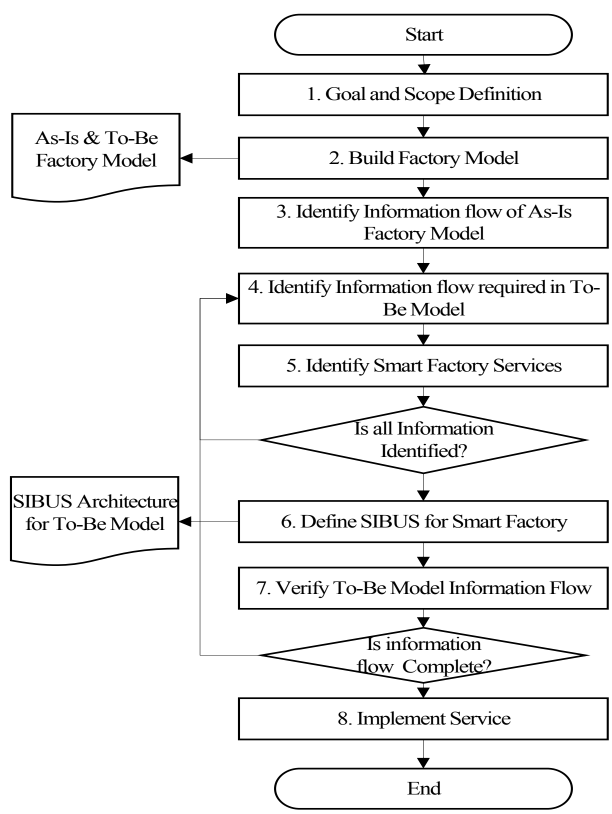

Fig. 4. Implementation Procedure

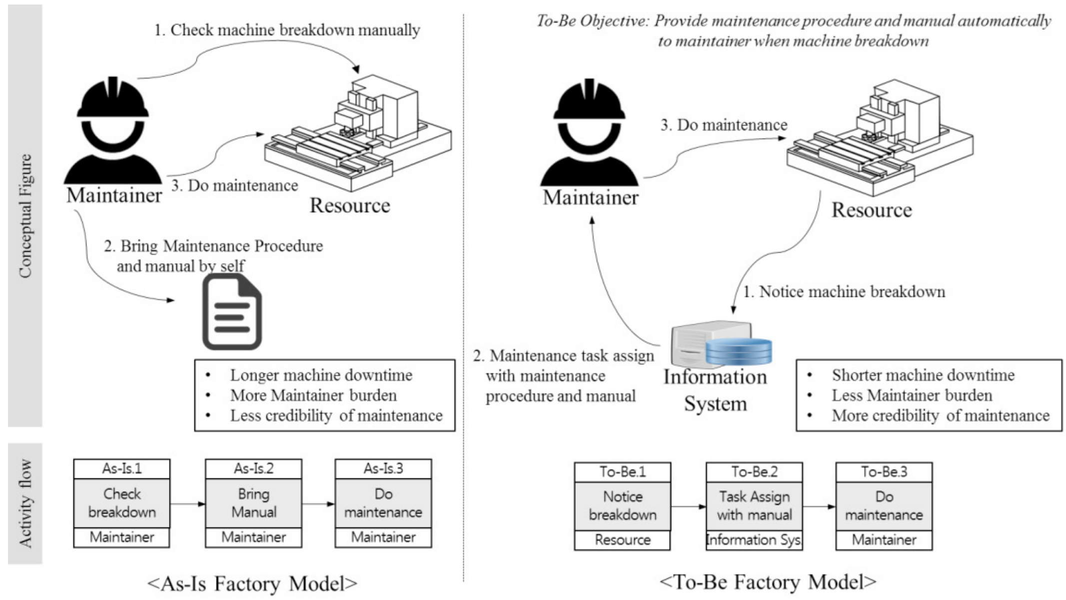

Fig. 5. As-Is and To-Be Factory Model for case study

- Identify smart factory services: Define the services that provide the information identified in step 4. Generally, two types of services are defined: generating information and transport. If all the information is identified, go to step 6; otherwise, go back to step 4.

- Define MIB for smart factory: Define MIB architecture by organizing the identified systems and services. Define detailed information of each service and assign a system that will actually work.

- Verify To-Be model information flow: Verify the information flow of the TO-BE model and whether all information and services have been defined sufficiently to achieve the goal. If not, go back to step 4.

- Implement service: Implement MIB and the service systems.

4. CASE STUDY

To show the effect of MIB architecture and implementation methodology, a case study has been conducted for general maintenance activity. Currently a maintainer does operations without any help of IT, and brings himself procedure and manual for the operations. Now the company is trying to build smart maintenance system which automatically notice the breakdown and inform the maintainer what to do. A smart factory system and MIB architecture will be developed by following implementation procedure described in section 3.

In goal and scope definition, the goal is defined as to provide maintenance procedure and manual automatically to maintainer when machine breakdown. The system includes maintainer, resource and information system as scope. In build factory model, As-Is and To-Be factory model are defined (Fig. 5). Currently, maintainer checks the machine breakdown and does maintenance using paper manual. When smart factory has been adapted, the machine checks the breakdown by itself, and inform to information system. The information system generates maintenance procedure and manual, and assigns to maintainer. The maintainer does operations according to procedure and manual received.

In identify information flow of As-Is factory model, only factory elements can be found since there is no information flow in As-Is model (Fig. 6 left). In identify information flow in To-Be model, and in identify smart factory services, 3 of information flow and 3 of service are identified (Fig. 6 right). As a first, the maintainer needs maintenance procedure and manual, and they are defined as d1, and d2. Maintenance Management of SECM is needed to generate d1 and d2, and it is defined as one of service. To operate Maintenance Management, Machine breakdown notice is required, and defined as d3. Similarly, Resource Monitoring of SMC, d4. Unforeseen event notice, d5. Sensor data, d6. Resource Signal data, Sensor & Resource Signal Acquisition, and Unforeseen event detection of resource agent is figured out sequentially.

In define MIB for smart factory, tailored architecture is defined using data and services (Fig. 6 bottom). In verify To-Be model information flow, all data flow from resource to maintainer is verified. Implementation of service is supposed to be operated in this study.

In this case study, KPI can be defined as Mean time to repair (MTTR) based on ISO 22400 for general manufacturing purpose. In As-Is model, there are times to repair including t1: recognizing breakdown, t2: finding tools and manual, t3: approaching to machine and t4: repairing machine. Total time to repair is sum of t1 to t4. In To-Be model, the system itself recognize breakdown and provide manual automatically, so t1 and t2 are decreased dramatically. As a result, MTTR is decreased through MIB and services, which means that TPI is increased.

5. CONCLUSION

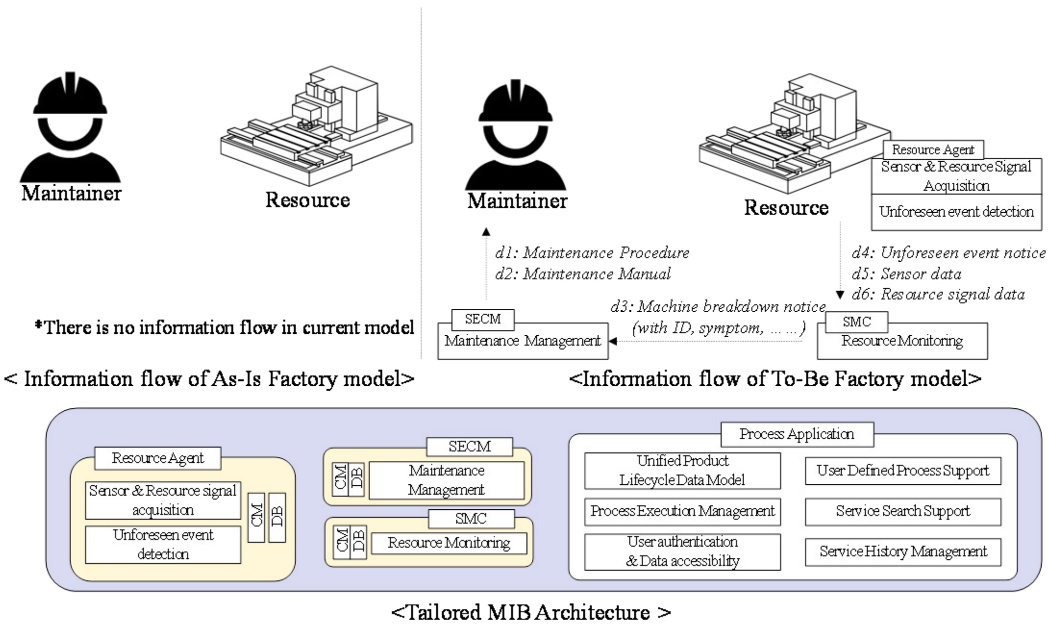

Fig. 6. Information flow and Tailored MIB Architecture for case study

This paper developed the MIB architecture as an information middleware for smart factory. The architecture and its implementation procedure are useful in designing smart-factory systems and identifying required services according to the purposes of stakeholders. MIB supports service exchanges as a middleware and provides lists of services, reflecting general requirements to improve the TPI in terms of productivity, environment, and social impact.

The most novel aspect of MIB is that MIB aims to improve TPI according to the purpose of the stakeholder. Based on this property, it can support activities that improve productivity, environment, and sociality at the machine, factory, and enterprise levels, respectively.

To realize MIB and smart factories it is necessary to develop technologies for factory elements. In particular, smart agent technology is needed to enable each element to provide a service. In addition, many platform technologies are needed to handle massive calls for services; basically platforms for machine learning, factory simulation, complex event processing, and distributed databases are needed, all of which are commonly required by current factories.

Acknowledgment

This research was supported by the Ministry of Trade, Industry and Energy of Korea (Development of Integrated Operational Technologies for Smart Factory Application with Manufacturing Big Data), and by the Institute for Information and Communications Technology Promotion of Korea (Establishment of the Testbed for a convergence of IoTs and manufacturing technology).

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