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An architecture design for smart manufacturing execution system

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ABSTRACT
MES (Manufacturing Execution System) puts plans given by enterprise system such as ERP(Enterprise Resource Planning) into practice in the shop floor. As contemporary companies are faced with challenge represented by customer-centric market environment and intense competitions, it becomes increasingly important for companies to cope with dynamic customers' demand and shop floor situation rapidly. Even though current MESs gets some improvement on collecting raw data, they fall short of expectation on analyzing data and takes action by cooperating various manufacturing management functions. Furthermore, even though many researches treat data collection, data analysis based on shop floor situation, little number of previous researches deals with collaboration among various functionalities provided by MES. In this paper, we introduce the design of advanced MES (namely Smart MES) for helping MES collect, analyze, take measure by collaborating various functions. This paper consists of two parts. In the first part, current MES problem analysis and corresponding design consideration are presented. In the second part, architecture design of Smart MES is proposed based on design consideration and an operation scenario of TO-BE model is provided for comparison with AS-IS model.

KEYWORDS
Manufacturing execution system (MES); data integration; system architecture; collaboration

1. Introduction

Contemporary manufacturing companies have been confronting with various demands such as fast response to shop floor fault, balancing inventory while aiming at customized production, flexibly changing operation schedule according to products and shop floor status, which is hard to be satisfied concurrently [33]. Even though ERP (Enterprise Resource Planning) system supports information flow between enterprise and outside stakeholder, using ERP alone isn't enough since ERP mainly concentrates on managerial level issues and it doesn't meticulously treat shop floor situation [34]. To deal with above challenges, not only information from enterprise systems such as ERP but also shop floor data should be utilized so that appropriate judgement can be brought with various demands from shop floor and enterprise being in harmony. The MES was introduced for managing shop floor activities based on production schedule and shop floor situation. MES is the system which performs manufacturing execution from work order to finished product with optimization of overall manufacturing operation management [26]. Besides means for information exchange between shop floor and enterprise information system, MES is in charge of managing various shop floor activities like operation scheduling, production execution and control, equipment status management linking shop-floor supervisor, material delivery and consumption management [2].

It's important to deal with shop floor event such as quality problem and facility failure in real-time. However, many of current manufacturing companies have a difficulty in handling manufacturing management activities using MES mainly due to lack of infrastructure for data collection, analysis, integration of manufacturing data [16] and collaboration and cooperation on each functionality of MES system. Cooperation work is mainly done via call conversation or email etc., which means that worker should know in detail how to deal with or get around manufacturing management issues. Lots of companies still have a hard time collecting shop floor data mainly due to inhibition on approaching detail protocol of control devices without paying money [19][27][28]. It means that there's no way to get useful shop floor data except adopting sensor technology or other integration means such as MTConnect or OPC-UA. MTConnect and OPC-UA can integrate different data protocols by

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specifying the data types, attributes, protocol for unifying data model. Servers and Clients attached in facilities should have the ability to convert different types of protocols and data to the unified model and vice versa. In this sense, we will develop MES architecture which not only can it collects and analyzes various manufacturing data but also respond to shop floor situation through collaboration among various functionalities.

Before solving this, literature survey on improving MES system is conducted. Data collection research is mainly done with AUTO-ID and sensor network technology. Hua, et al. [12] presented RFID based data collection. It tries to integrate with current MES by referencing a cotton spinning company. Hori, et al.[11] suggest scalable MES based on distributed object computing because of vendor independent, scalability. It used CORBA as a means for object computing and data integration. It mainly focuses on production control as illustration. Huang, et al.[13] suggest management of job shop by using RFID tag. It's mainly focusing on gathering WIP inventory information. It points out the current job shop management problem as paper-work based data collection. RFID technology is also used in repair work in car production industries [15]. Kadri, et al.[17] used WSN(wireless sensor network) to monitor air-quality by integrating sensor network with web environment. Many of research treated are mainly focusing on utilizing one-or two sensor types to get data. Since typical manufacturing ground has many types of sensors, some means to integrate them are needed. To get around, web-based open sensor web architecture is suggested to overcome the obstacle of connecting heterogeneous sensor resources [6]. Fumagalli, et al. [9] use ontology as a means for integrating various shop floor data. Picking system is used as a use case for ontology-based modeling of manufacturing system.

Even though there are many use case for data analysis, MES data analysis is mainly related to scheduling, production control. Zhong, et al. [34] used RFID data and production order to derive appropriate operation schedule. The schedule is modified according to RFID data which denote whether worker is operating machine or not which could change an original schedule. Rolon, et al. [25] suggest using agent-based modeling and simulation for efficient scheduling by using order agent and resource agent and their communication. Each agent does monitor-analyze-plan-execute cycle. Order agent monitors overall schedule/order monitoring, specifies process route, books appropriate resource, executes production control. Resource agent monitors whether corresponding resource can be operated or not and its operation schedule, registers task schedule by communicating with order agent, executes task. Chen, et al. [3] proposes intelligent MES which integrates MES with data warehouse, OLAP (On-Line Analytic Processing), Data-mining to extract useful information from collected data. It describes only delivering extracted information to enterprise information system such as ERP. Chen, et al. [4] apply context-aware computing to MES so that event can be interpreted through shop floor data and then appropriate services which can handle corresponding event can be called. Likewise, it doesn't clearly show top-down information flow. NEXUS platform [8] combines top-down application execution which shop floor data are used and bottom-up event-delivering. Literatures on collaboration among functionalities in MES system were hard to find.

Above mentioned research leaves three major implications. We need (1) infrastructure which can collect shop floor data overcoming various protocol, analyze data and extract some useful information, (2) various functions other than just operation scheduling, production control, part tracking, some function needs to be included such as quality management, maintenance management[20]. (3) Collaboration among various functions to optimize manufacturing management activity in shop floor. (4) Data synchronization among various functions to optimize the effect of cooperation.

We will solve these issues by making architecture for MES dealing with shop floor situation or enterprise demand in real-time by cooperating among various MES functions. Collaboration among functions is important because each function is correlated to other functions. However, there are little researches that treat interconnection or association among MES functions. Smart MES is the MES that can recognize and deal with shop floor situation in real-time manner with having 4 things mentioned above. Collaboration among various functions based on shop floor event and enterprise system information is the main point. By implementing this system, it can contribute to: (1) shorten response time when dealing with shop floor situation or stakeholder requirement, (2) provide user convenience with consistent response to shop floor situation because user doesn't need to know all of details on collaboration of functionalities, (3) cope with varying operation schedule flexibly. Furthermore, it can be one of approaches on contemporary industrial innovation campaign other than American initiative "Industrial Internet" and German initiative "Industry 4.0".

This paper is organized as follows. Section 2 gives requirement the Smart MES will satisfy. Section 3 derives design consideration from requirement. Section 4 suggests architecture for Smart MES by reflecting on design consideration. Section 5 suggests an operation scenario applied to car door assembly company.

2. Problem on current manufacturing execution system

To design Smart MES, problem derived from current MES solution and previous research should be identified and should be reflected. We used this approach for recognizing field problems in the perspective of implications and reflecting into the design of architecture. We organize problem based on literature review, some interview with shop floor workers, engineers in car door making company and refractory-brick making company. These are substantial companies that most of automation on facility is completed but have something to be desired on information management and handling. The major requirements are summarized as follows.

- [Problem (PR) #1] Workers should record data by hand which coming from machine controller and type into MES or DB (Database). This means that utilization of the data will be less helpful due to time gap.
- [PR #2] Sensor technology is often used as a means for getting data from shop floor. However, since there're many existing communication standard on sensors [23] and the PLC (Programmable Logic Controller) supports different types of sensor depending on vendors, integrating these data is hard. It causes loss of opportunity for maximizing of current data utilization.
- [PR #3] Even though some companies invest money to extract data from facilities by utilizing controller protocol, it's hard to integrate data because of different protocol controller supports. It also causes loss of opportunity for maximizing of current data utilization.
- [PR #4] It's hard to modify operation schedule based on stakeholder requirement or shop floor situation once manufacturing schedule is initially determined. So, if some situation happens it brings about lots of communication between MES operator and shop floor workers, which cause lots of time consumption in rescheduling.
- [PR #5] It's difficult for MES operator to track the WIP (work-in-piece) in real-time. When some parts go to wrong route, manual search is usually done but it causes time delay.
- [PR #6] Allocating right preventive maintenance schedule is challenging one since it should consider resource status and production operation schedule. It causes delay on making both operation schedule and preventive maintenance schedule and requires lots of communication load.
- [PR #7] Generally, it's hard to recognize what kind of failure happened in machine. It mostly depends on workers' tacit knowledge to get around. If user doesn't have experience and insight, then it'll take lots of time to figure out problem. That is, there exists deviation among workers.
- [PR #8] Most of information processing in many manufacturing companies was conducted in simple way such as facility on/off check or x-R chart. Since there are some cases that the problem is compositively caused by a number of factors other than one variable, it's hard to figure out that problem if we use the simple data processing. It mostly depends on insight of workers.
- [PR #9] It's hard to figure out what kind of quality problem on product happened, what brought about that problem and when that problem started to happen. Even though manual inspection is conducted, it also depends on insight or expertise of workers so it can cause deviation among workers.
- [PR #10] Estimating material consumption for production is barely linked with SCM(supply chain management), which means that demand prediction relies on experience of manager and feedback work is mainly done call conversation, which causes lots of communication load and reduction of work efficiency.
- [PR #11] In manufacturing company, production performance analysis mainly manages the amount of production. Since there are lots of perspectives on the performance evaluation of manufacturing management, mainly evaluating the amount of production loses the other opportunity for feedback in various perspectives.
- [PR #12] Data integration /synchronization between MES and Enterprise information system isn't fully established. It can pose lots of communication loads and manual work since one system can't utilize the data from other systems, which causes reduction of work efficiency.
- [PR #13] There is a lack of collaboration between MES functions. In general, every function of MES isn't independent. Each of them in some sense is closely related. However, due to lack of it, lots of communication and waiting for call conversation or email is required, which causes reduction of work efficiency. Furthermore, user should have all knowledge on communicating with different workers when cooperation is needed, which means that deviation happen among workers.

3. Design consideration for smart manufacturing execution system

To design a field-centric Smart MES with considering previous research, requirements presented in section 2 should be reflected into design consideration in the perspective of data collection, integration, analysis, and collaboration among various MES functions. We adopted this approach to reflect requirements derived in previous section into the design of Smart MES architecture. Detailed consideration is given as follows.

- [Design Consideration(DC) #1] Real-time data acquisition via sensor technology: To realize real-time data analysis and response, it's essential to gather shop floor data to recognize shop floor situation. It can contribute to reduce time gap on data value between shop floor and Smart MES. Furthermore it can help to extract data from some facilities which are prohibited to access data in controller for some reasons. Adopting OPC-UA technology will help to collect sensor data to the upper system with platform independence (To solve PR #1)
- [DC #2] Reliability of data generated from shop floor: Since analysis and judgement are based on shop floor data, it's crucial to ensure the reliability of data. In general, accuracy and reliability is two important factors for measurement. Reliability has precedence over accuracy because error can be adjusted using several software filter such as Kalman filter [29]. (To solve PR #1)
- [DC #3] Communication means for various sensors and controllers: Even though PLC can retrieve sensor data from sensor, controller and then send to MES, not all types of sensors are supported. For example, RFID data isn't easy to input to PLC. OPC-UA will help to get around as mentioned in [DC #1]. Furthermore, since each PLC vendors support different types of sensors, it needs various communication means to receive data. Controller data can be gathered through various means such as RS-232, RS-485, Ethernet/IP. (To solve PR #1, #2, #3)
- [DC #4] Close connection with enterprise information system: Communication between enterprise information system and MES should be established so that information can be exchanged effectively between them. (To solve PR #12)
- [DC #5] Data storage in distributed database: Not all data collected from shop floor can't be handled immediately due to processing capability of system. To get around, temporary storage space is needed. Using relational database such as MySQL is not good option because manufacturing data is complex that relational database can't deal with it efficiently. Distributed database is an appropriate option because of high performance, efficiency, scalability. (To solve PR #1, #5, #7, #8, #9, #10, #11)
- [DC #6] Data analysis methodology: Gathering shop floor data only isn't enough. Some methodology like data mining is needed to extract some useful information. Supporting functions of data mining include prediction, classification, clustering etc [21]. (To solve PR #7, #8, #9, #10, #11)
- [DC #7] Visualization / Report for analysis result: Big data analysis result is needed to be organized so that Smart MES operator or other users can understand the behavior of shop floor. (To solve PR #7, #8, #9, #10, #11)
- [DC #8] Collaboration among production management functions: It's desired to be linked among MES functions to share data generated or stored in each function. Especially, various information is needed to compose operation schedule.(To solve PR#4, #5, #6, #10, #11, #13)
- [DC #9] Pervasive access to analysis result and execution result of MES functions from shop floor and user devices: Pervasive access to analysis result is a basis for accomplishing pervasive use for the result. (To solve PR #4, #5, #6, #7, #9, #10, #13)
- [DC #10] Unified data model: Each facility, even though it supports same function, has different attributes set. That means that it requires unified data model to integrate data from shop floor. Moreover, since MES plays a role as a broker between enterprise information system and shop floor, there must exists unified data model that accommodate enterprise information system and shop floor data. (To solve PR #2, #3, #12)
- [DC #11] Data transformation between shop floor and Smart MES: For transforming data between Smart MES and shop floor using unified data model, there must exists some means to deal with.(To solve PR #2, #3)
- [DC #12] Data transformation between Smart MES and Enterprise information system: For transforming data between Smart MES and enterprise information system using unified data model, there must exists some means to deal with. (To solve PR #12)

4. Smart MES architecture

In this section, architecture of Smart MES is provided based on system concept which is derived from design consideration.

4.1. Smart MES architecture and description of main components

Before proposing architecture, system concept which applies to design of reference architecture are defined. This comes from the design consideration presented and these are big block of architecture. System concept is formed by reflecting design consideration. Details are presented below.

- [System Concept(SC) #1] Adoption of real-time communication environment: It's an infrastructure that connects Smart MES, shop floor, enterprise information system, ERP, user. It is necessary to have this infrastructure so that shop floor data and enterprise system information can be flowed lively. (Reflected DC #1, #2, #3, #4, #9)
- [SC #2] Data integration & transformation: Data integration and transformation should be mounted for gathering information efficiently from different type of systems and efficient analysis. (Reflected DC #2, #3, #5, #10, #11, #12)
- [SC #3] Adoption of Big data module: As platform for storing, analysis, visualization of large amount of data, it plays a critical role for Smart MES since several MES functions utilize output of big data module for conducting each own duty. In this module, there exists some tools to change existing analysis model so that whenever shop floor data behavior changed, relevant model can be changed to cope with. And if there are some changes in certain applications such as input data coming from analysis result, then corresponding analysis model can be modified. (Reflected DC #5, #6, #7)
- [SC #4] Smart MES functionality as application: Smart MES functionality modules utilize analysis data to judge what they should do and conduct accordingly. Furthermore, each function can collaborate each other to optimize shop floor production activity. We adopt form of Smart MES functions as applications because application can be modified and added flexibly so that whenever new functionalities are required to MES, then it'll be configured and reflected with flexibility. Moreover, data synchronization and module for supporting application collaboration are needed to optimize overall manufacturing operation management. (Reflected #8)

Overall traceability among PR, DC, SC is shown in Fig. 1 and based on above system concept and design consideration, we provide the reference architecture for

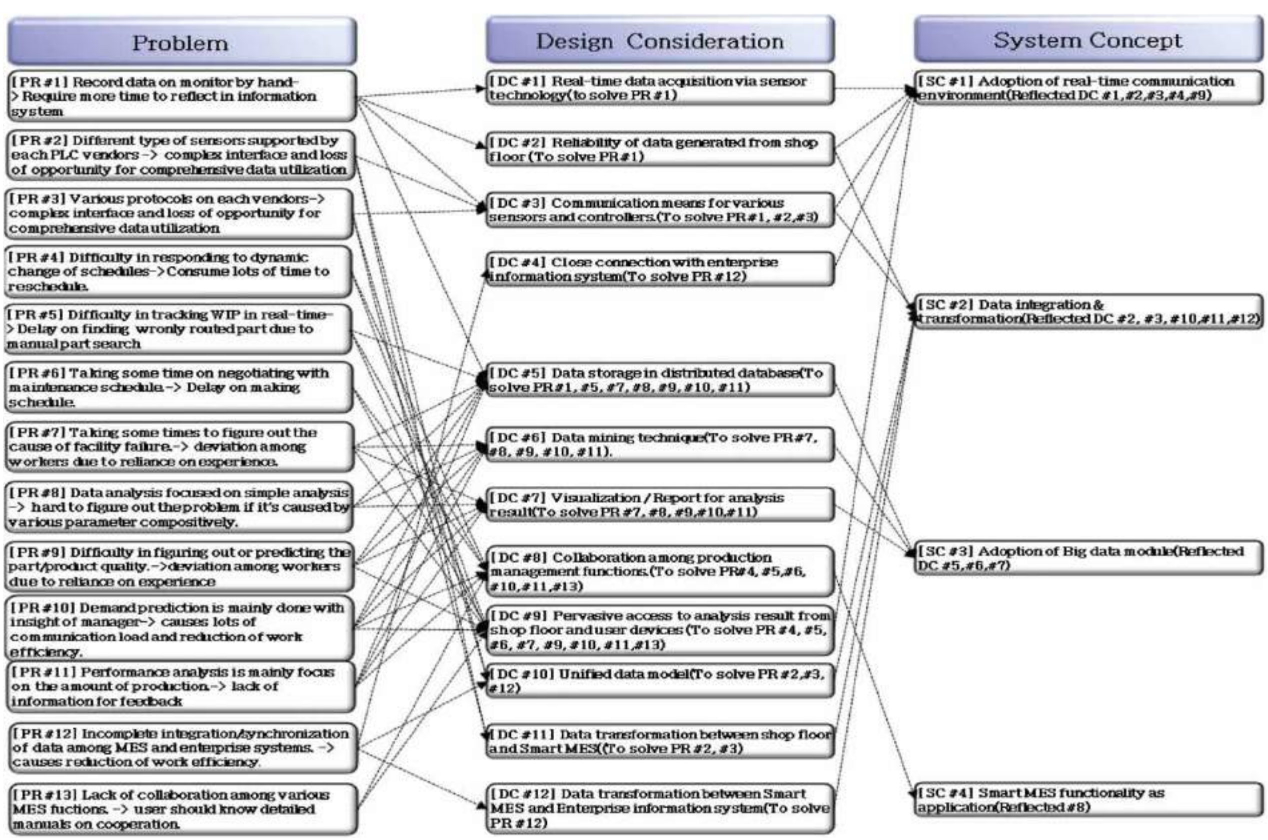

Figure 1. PR-DC-SC traceability diagram.

Smart MES as shown in Fig. 2.We give description on overall architecture including main components in the smart MES. Detailed description is given as follows.

- Device middleware: Device middleware integrates different communication protocol existing in the shop floor. As shown in figure, there are several communication means in the shop floor. To gather data from different communication protocols, there must exists a mean to integrate different protocols.
- Enterprise information DB: Information coming from enterprise information system and information created from Smart MES application are stored and transformed. It functions two ways: (1): it can play a role as a temporal storage area if either of them can't receive the message due to processing capability limit. (3) it can transform data so that the data can be
- utilized in both systems. Nowadays, many of database support data transformation function [14].
- Enterprise Service Bus: In general, each of enterprise system is constructed independently, which means that it needs additional work for each of enterprise system to be able to communicate with each other [10][22][24].
- Data storage & integration: Data coming from shop floor needs to be integrated in unified format to be able to analyze efficiently. Traditionally, transformation is normally done in specific module other than storage module. However, due to processing speed, Some approaches have been developed so that data processing can be done in data storage area [31].
- Data analysis Engine: After storage & integration, data is moved to data analysis engine to extract useful information for application. Overall process of analysis is shown in Fig. 3. The set of data that are transferred are determined by model builder. Model builder builds analysis model and specifies output by connecting appropriate pre-processing and data mining method with parameters for specific analysis problem. Pre-processing methods and data mining methods are extracted from pre-processing module and data mining module, respectively. Data behavior from shop floor can be changed because different criteria for quality, manufacturing process, WIP (work-in-piece) tracking on new product are proposed. Furthermore, they can be changed when new sensors or facilities are introduced. Model builder can deal with by creating or updating model. After analysis, visualization & report

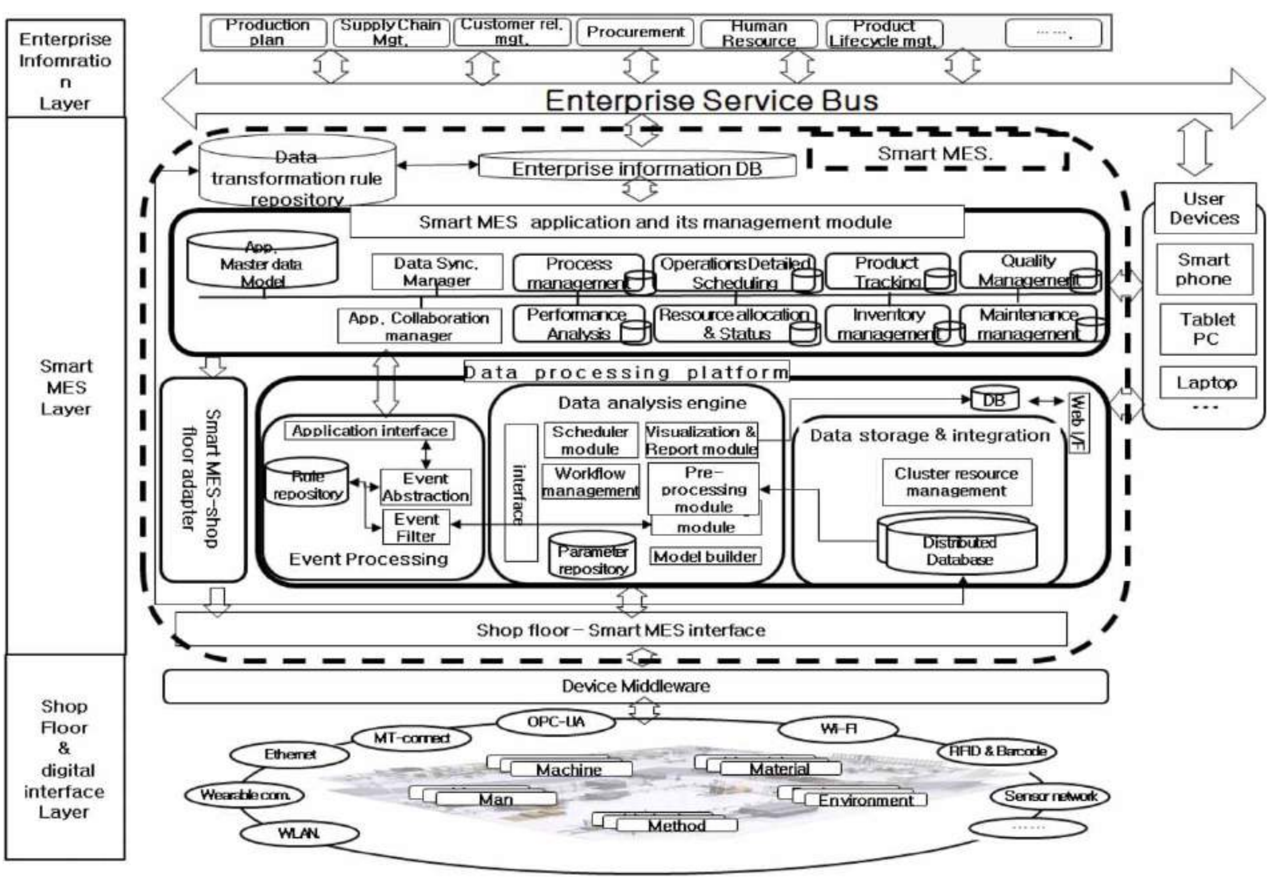

Figure 2. Smart MES architecture

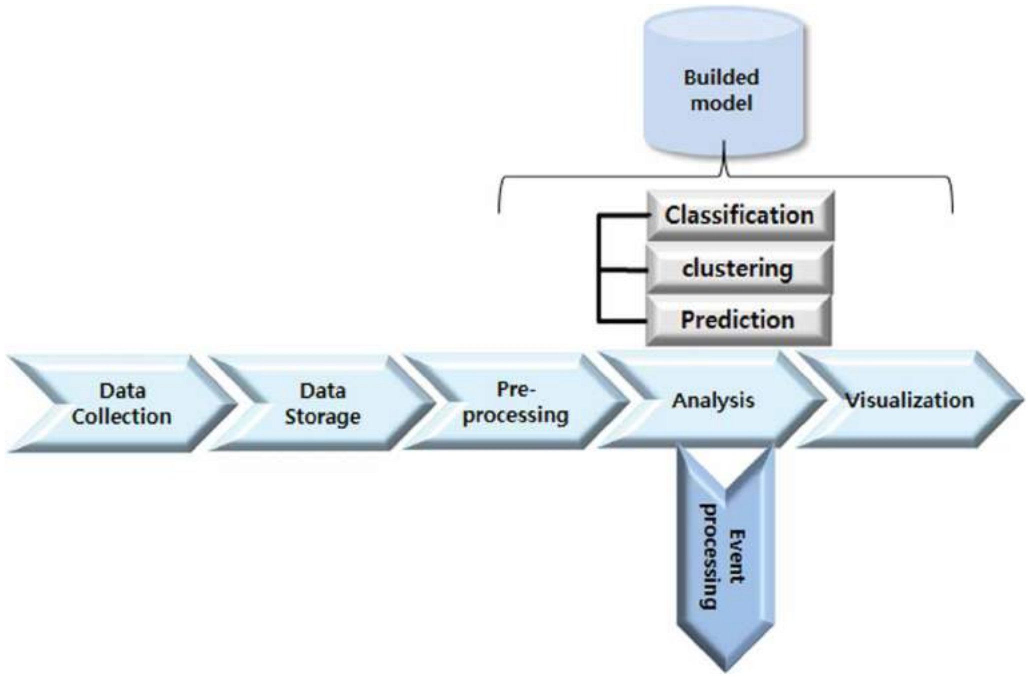

Figure 3. Data analysis procedure.

module processes result of data analysis so that user can understand what the result stands for. Visualized material or report can be transferred via web interface so that every user is available to access.

- Event Processing: Analysis result coming out from data analysis comes to this module. Each result of data analysis is regarded as an event. Event filter sees each of events and records whether this denote abnormal or normal situation. It hands over to event abstraction. Then event abstraction transforms the filtered event so that application of smart MES can understand. Abstracted event goes to application collaboration manager via application interface. Rule repository defines filtering rule and abstraction rule. Event data format is given in Fig. 4.
- Smart MES application and its management module: Each function in this module utilizes result of data analysis to determine which action should be taken to shop floor and what kind of information should be delivered to enterprise information system. Function like operation detailed scheduling can also use information from enterprise information system. Application can be handled and monitored by user via user device such as smart phone. Authorized personnel are only allowed to use. Data synchronization is handled by Data sync. Manager. Along with data synchronization, collaboration between applications and initial event reception is handled by Application Collaboration Manager. Both of them will be elaborated on following section. When new application is installed or modified, then there are 3 things should be done. : (1) If new application uses data attributes that doesn't exist in previous master data set or have different names, then it will be reflected and enrolled

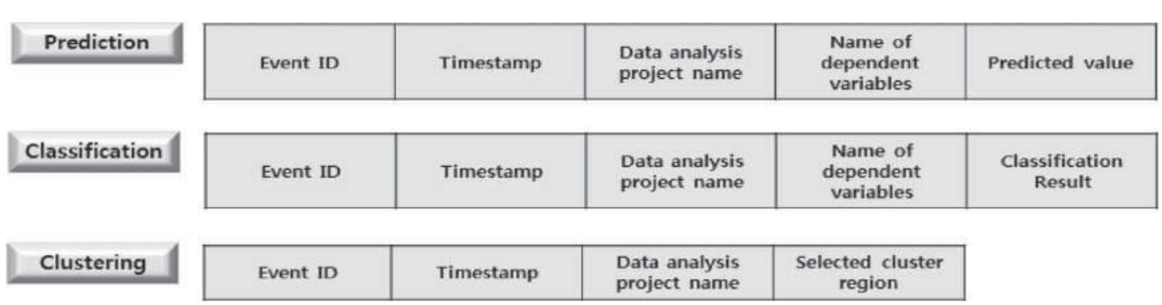

Figure 4. Event data format.

in master data model. Even though it's easy to configure application so that application should abide by pre-defined master data model through unified data model, we emphasize flexibility rather than speed and design simplicity. (2) Collaboration information of various applications for newly installed application should be enrolled in Application Collaboration manager. (3) Data synchronization should be modified to embrace new or modified data attributes.

- Data transformation rule repository: This repository specifies rules that transform different data formats. The rule defines the transformation relationship among enterprise information system format from enterprise service bus, Smart MES application, Shop floor data in distributed database in data analysis engine, shop floor data format.

4.2. Data synchronization manager and application collaboration manager

For right decision based on shop floor situation and enterprise system, data synchronization among applications and application collaboration can play important role. Data synchronization should exist because it's meaningless when different applications use different data value to judge and take action. Each application uses its own database to avoid access collision which can happen when central DB is used. Furthermore, using central DB causes concentration of the number of communication related to central DB access, which cause low speed. To get around, it's desired to place database in each application and for manager to manage data synchronization [7].

Collaboration among applications should be treated because each application presented in the architecture can't act independently. Each function needs to collaborate with each other to optimize overall shop floor manufacturing management activities. Even though overall structure can be configured such that each application has its own logic to determine where to send, we choose to make centralized collaboration manager. If we adopt the structure that each application handles its own forwarding logic, then the number of change of interface will be huge if some of applications interface need to be updated due to some reason. In this subsection, we develop top-level architecture and sequence diagram for Data Sync. Manager, App. Collaboration Manager. Sequence diagram is frequently used tool to clarify workflow among various systems. Fig. 5 shows top-level architecture for Data Sync. Manager and App. Collaboration Manager.

Data Sync. Manager consists of data interface, data grouping module, data routing module, data collection DB, conflict resolver, and data attribute repository. Data interface is a passage that updated data comes in and then corrected data which go through data grouping module and conflict resolver goes out. Data collection DB temporally stores data which comes to Data Sync. Manager. Data grouping module groups data which denotes same attributes but may have different value or number of updates. More than two elements in a group means two or more applications update same data concurrently. Data attribute repository stores attributes defined in App. master data model. Groups in which there are more than two data elements are sent to conflict resolver to handle. Data whose number of update is recorded to the highest is selected to send data. That is, each data attribute in

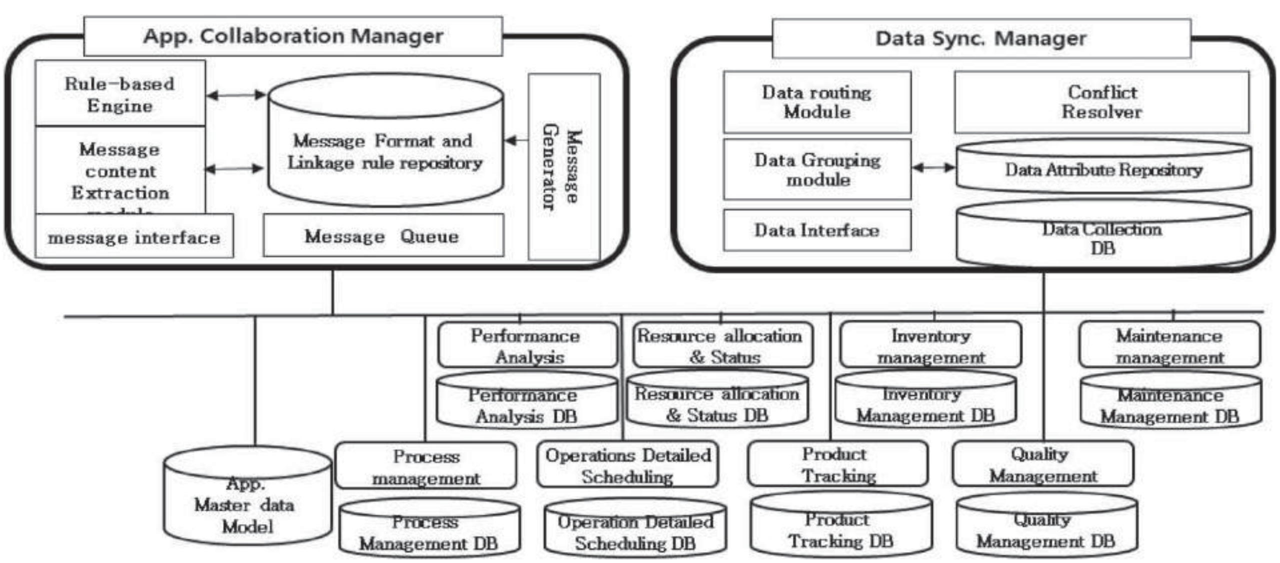

Figure 5. Data sync. manager and application collaboration manager architecture.

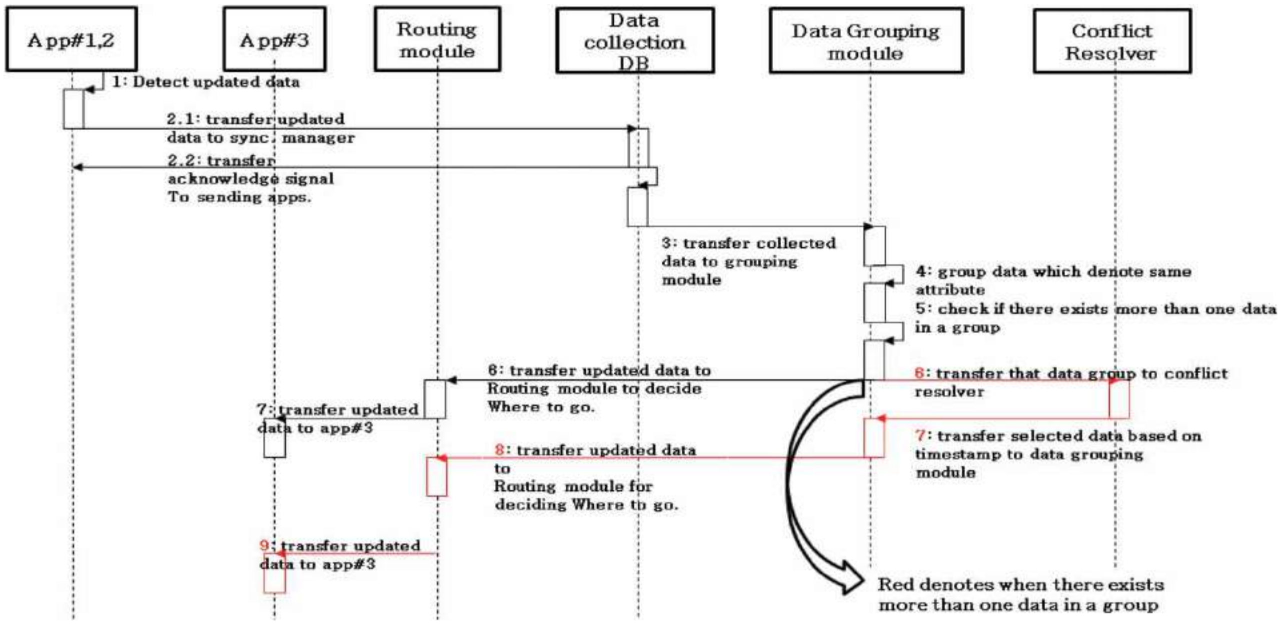

Figure 6. Data sync. manager sequence diagram.

each MES application DB accompanies its own number of update so that latest information can be reflected in the application and increased number of update is recorded in application. After conflict resolver, data routing module determines where they should be transferred based on rule specified in it. Sequence diagram representing data flow is provided in Fig. 6. It shows data flow from sending updated data in application #1, #2 to sending updated data to application #3 after some update conflict checking. It includes two cases: (1) when there's no conflict. (2): exists conflict.

Application Collaboration Manager consists of message interface, message queue, message content extraction module, message generator, rule-based engine for collaboration rule. Whenever an application recognizes that it needs to send some request or information to other applications, it makes and sends message to application collaboration manager to decide where to send that message.

Message interface is a passage that message sent from an application comes in and goes out after decision on where to send. Message queue is a temporary storage

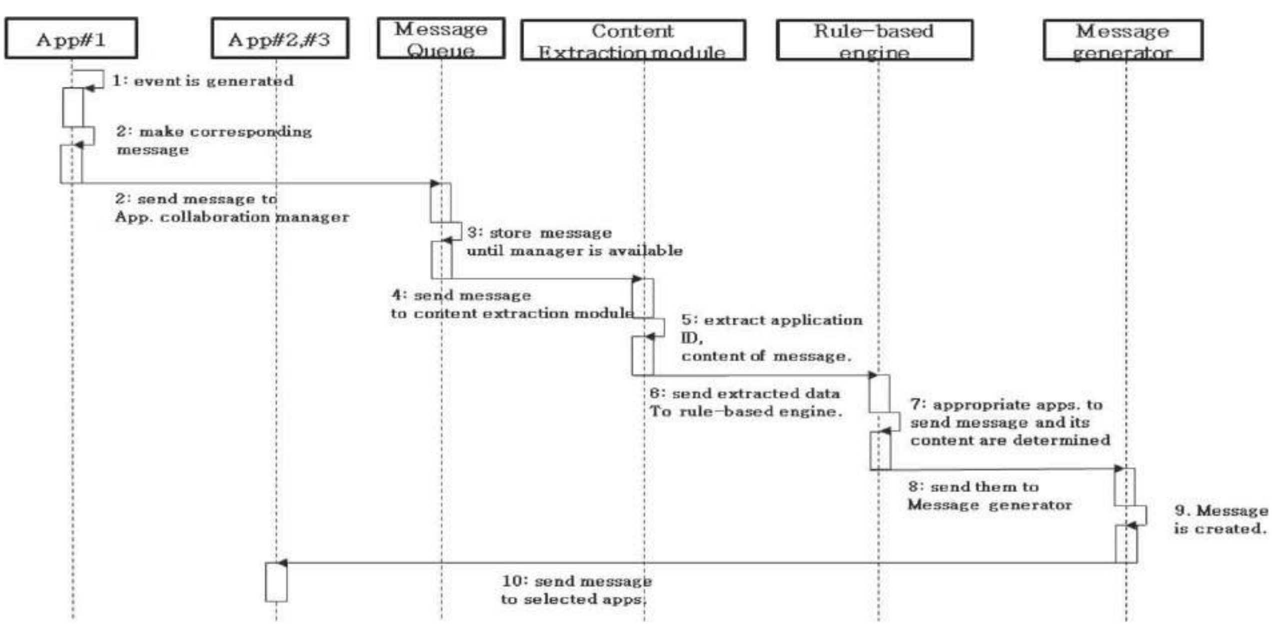

Figure 7. Application collaboration manager sequence diagram.

area that stores incoming data when computing resources in App. Collaboration Manager aren't available. When computing resources are available for deciding message destination, then that message is transferred to message content extraction module. It extracts content in message so that App. Collaboration Manager can know what the message stands for. It is usually done by mapping given message to pre-specified message structure. From this procedure, we can find some useful information such as where this message comes from, which request the message includes etc.

Based on this content, rule-based engine clarifies where this message should be transferred by using rules which is stored in collaboration rule repository. After deciding where to send, then it goes through message generator that generates messages that delivered to related applications. Sequence diagram representing data flow is provided in Fig. 7. It shows data flow from sending a message generated from app #1 to send messages to some applications specified by rule-based engine. Here, the event includes the message from enterprise system and application interface in the event processing.

5. Operation scenario and prototype based on architecture

Even though the best way to prove the validity of the architecture that suggested above section is implementation, we don't adopt that approach since MES itself consists of so many components that one can't handle all of them. Thus, operation scenario and corresponding prototype based on that architecture is presented. Among various scenarios that can be proposed and derived, we choose a scenario on WIP quality diagnosing and repairing facilities in a car door assembly company A. In making car door, tens of welding should be gone through. It's often conducted by spot welding robots. However, a WIP (work-in-piece) sometimes isn't welded in right position due to several reasons. It's sometimes caused by wrong position of jig or spot robot. However, consider that problem is caused by facility failure such as worn bearing or servo driver malfunction in this operation scenario.

According to the interview with IT engineer, most of all components of shop floor are connected to MES with

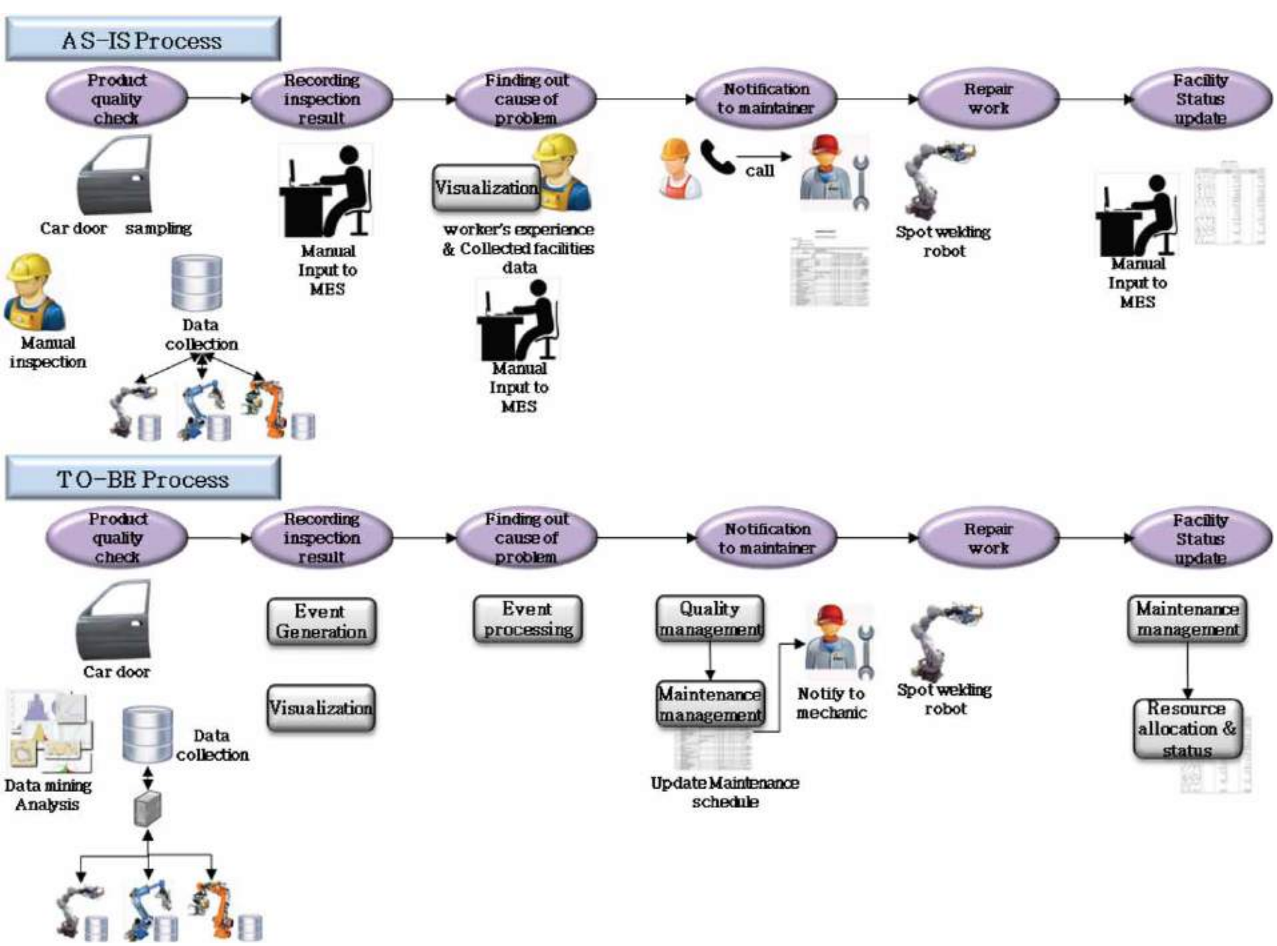

Figure 8. Comparison between As-Is and To-Be process.

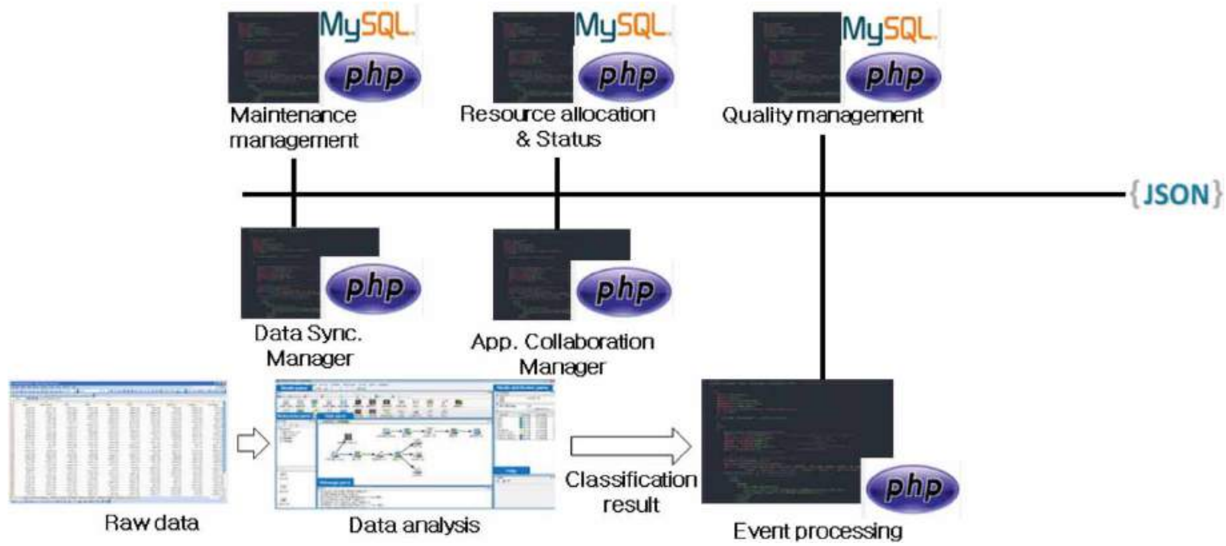

Figure 9. Prototype implementation architecture for the operation scenario.

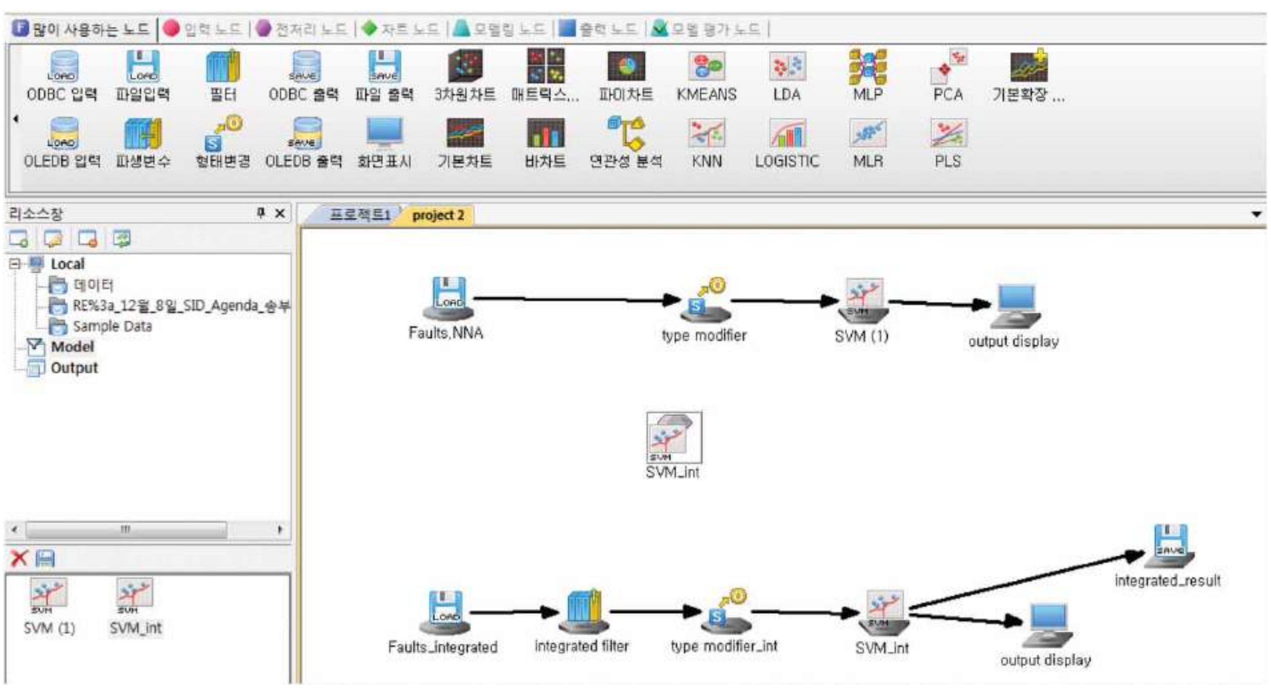

Figure 10. ECMiner interface.

1:n structure. Enterprise systems such as ERP are also connected to MES with 1: n structure. This originates from different types of protocols and interfaces, data format. The process to deal with is shown as AS-IS process in Fig. 8. Quality inspection and recording on MES system is done by manual work and accuracy of them depends on the expertise. Even though workers get some clue from collected shop floor data such as current value etc., it takes some time for judgement because there are lots of things to be concerned. If it needs to be repaired urgently due to some reason such as servo driver malfunction, then call to mechanic to deal with the spot welding robot first.

Now, we describe improved scenario and advantages of this system which is also shown in Fig. 8. Fig. 9 shows the prototype implementation architecture for the operation scenario. When data is collected, then it goes through data mining for classification of quality fault. We used the data mining software named ECMiner[1]. Here, we adopted the SVM (support vector machine) technique

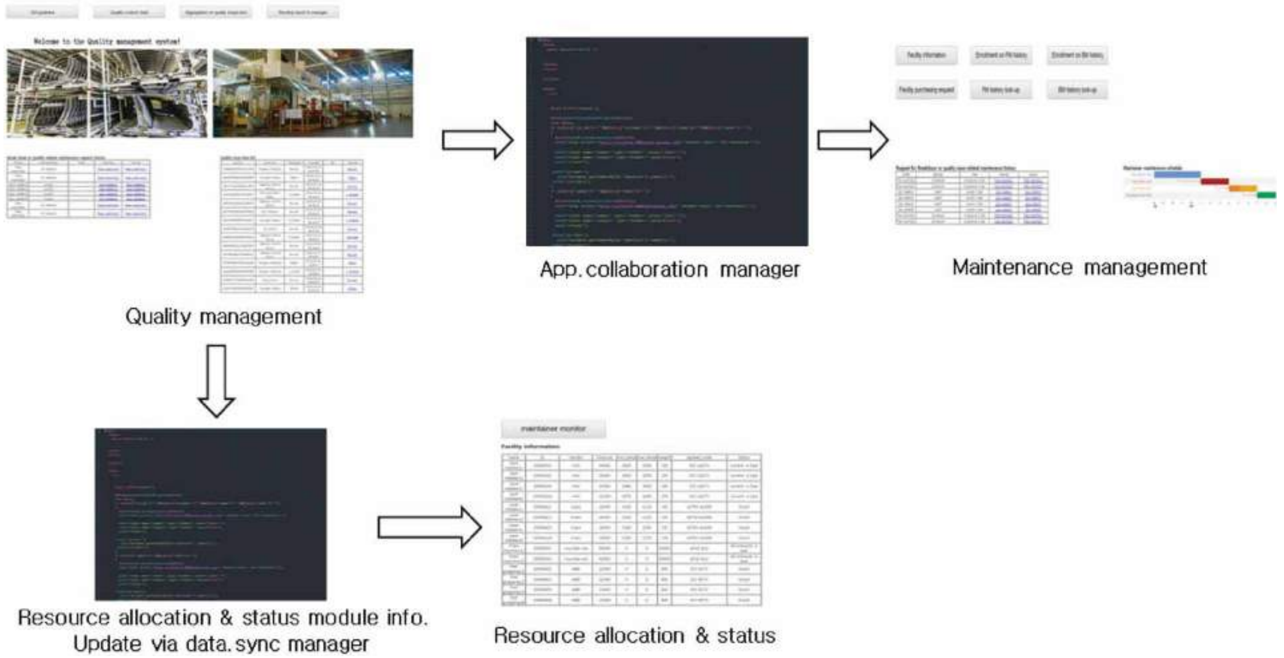

Figure 11. Data flow from quality management to other modules.

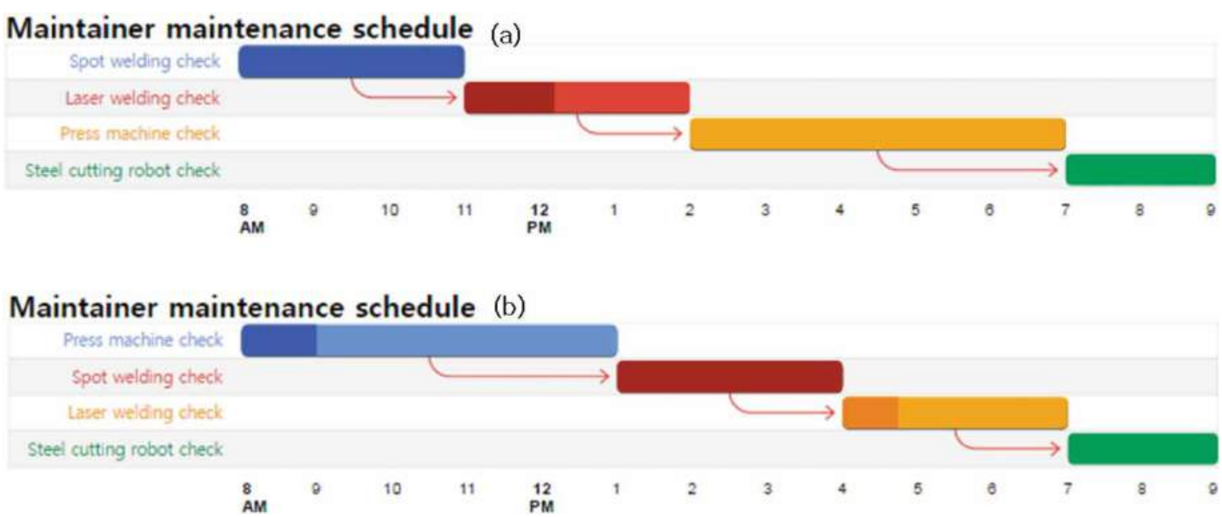

Figure 12. Change of maintenance schedule.

for classification. SVM can classify by drawing hyperplanes in the n-dimensional vector space if the number of x variables is n. Fig. 10 shows the ECMiner interface. After analysis, event processing is conducted for judging whether there exists quality issue or not. If there exists product quality issue, then it sends the message to application collaboration manager to deal with. Application collaboration manager gets the message, interpret it and then send new message to quality management. If that quality fault is related to facility issue, then it generates the new message and then sends to application collaboration manager for sending it to the maintenance management. Meanwhile, when resource status is updated in quality management, then it is reflected in the resource allocation & status management via data sync manager. Fig. 11 shows the flow mentioned above. After the message is sent to maintenance management, then change of schedule is done. Fig. 12 shows the change of schedule due to the problem of part grapping robot deployed after press machine. Fig. 12(a) denotes the normal case and Fig. 12(b) denotes the case when press machine caused the quality issue. So, the maintenance schedule is updated so that press machines are inspected first.

Based on operation scenario, we find out the advantages of the proposed Smart MES compared with current MES operation scenario are summarized into Tab. 1. It

Table 1. Advantage of the Smart MES compared with current MES.

Task	Current-MES(As-Is)	Smart MES(To-Be)	Advantages
Recording inspection result	Inspector records result by manually writing to database in MES.	Inspector doesn't have to manually write that result. If event happens, then that event is recorded by quality management service.	Recording work is automatically done by service in smart MES module. It means that MES can recognize the quality result faster.
Find out the cause of problem	Inspector relies on his/her expertise knowledge on product and collected data expressed by graph to find out problem on WIP.	Inspector doesn't have to rely only on his/her expertise knowledge. Data analysis can deal with it and give lots of help.	Even non-skilled inspector can handle a variety of WIP defect in real-time manner. It means the detection time is reduced.
Notify to Maintenance department	MES operator should give a call to maintenance worker to repair that machine. Usually, maintenance worker doesn't willing to change original schedule flexibly if it's not urgent such as facility failure.	Quality management service can deliver message to maintenance management service via application collaboration manager.	Notification to Maintenance management service is done automatic manner.
Deciding what kind of action should be taken	Inspector should remember manuals to respond to each different quality issue.	Application collaboration manager can deal with it.	Worker can handle various issues without memorizing all details of manual.
Notify to mechanic on change of maintenance schedule.	Since the contact for maintenance is usually done by call, so mechanic doesn't know unless it receives call.	Mechanics receive change of schedule generated from maintenance management service automatically.	Mechanics can receive necessary information in real-time. It implies that response time is reduced.
Facility status update	After repair work is done, resource status update is done by manual input.	After repair work is done, then it's not necessary to manually input because status update is done by data synchronization manager when repair work is done.	Status update is done automatic manner. So, corresponding facility can be reflected in next operation schedule faster than as-is model.

turns out that overall response time is reduced while quality inspection is systematically approached. Furthermore, since facility update can be automatically updated and reflected in next scheduling or process management, Smart MES can contribute to flexibly adjust operation schedule according to shop floor situation. Furthermore, from the user perspective, they don't need to know all of details of cooperation work on each shop floor issues, which gives user sort of convenience. These points are written as contribution in the end of introduction section.

6. Conclusion

In this paper, we described the problem for current MES system by pointing out lack of environment for analysing and interpreting, collecting shop floor data in real-time manner. Even though many researches try to solve these problems, they didn't deal with collaboration among various MES functions. To solve above issues, System of interest named Smart MES is defined and requirement and design consideration is defined for architecture design. Operation scenario making use of Smart MES is introduced to show the validity and usefulness of smart MES against current MES. Through the operation scenario, we showed that Smart MES can comprehensively and effectively deal with shop floor situation in real-time manner. The scenario introduced is only one example and many cases can be derived.

The developed works in this paper can be utilized as base framework for development. Further research is needed to establish and apply data model to the Smart MES architecture to ensure that data flow among various components can be shown. Detailed functions of smart MES can be elaborated by developing data model in Smart MES since data model itself represents physical entity, logical relationship among data, concept. Furthermore, since the Smart MES system is a huge system, full implementation of it will take time to realize. So, full functional system of smart MES is under development.

Note

1. ECMiner is the big data analysis solution developed by ECMiner.

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