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MES FRAMEWORK FOR SYSTEMATIC MANUFACTURING OPERATIONS MANAGEMENT

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Abstract. *Smart manufacturing has attracted worldwide attention in order to reinforce manufacturing innovation and competitiveness. Manufacturing Execution System (MES) is widely used as a key driving force in smart manufacturing, but it has various functions depending on the characteristics and requirements of the company. Previous studies have focused on the functions of MES needed to operate the plant. Although the functions required for manufacturing operations management concepts are standardized, the integration framework is lacking. In this study, MES integration framework was proposed by analyzing the functions of previous studies and MES standards. The framework of this study, which analyzed an integrated viewpoint of MES, could be used as a reference model when realizing smart manufacturing.*

Keywords: Manufacturing execution system, Smart manufacturing, Information framework, Manufacturing operations management

1. **Introduction.** In order to be competitive in manufacturing, it is necessary to systematize industrial activities and to apply digital innovation technologies. In addition, when process anomalies occur, rapid and flexible processing and optimization of real-time process steps are important for the economic efficiency of manufacturing. MES is one of the ways to gain competitive advantages in the manufacturing by increasing the production efficiency through monitoring the shop floor. Also, it can increase productivity by analyzing accumulated production data. Since MES is an essential element of smart manufacturing, not only small and medium-sized enterprises but also large companies are interested in introducing it. However, when introducing MES, the requirements of the company are different according to the characteristics of the industry and require various functions depending on the type of equipment and the characteristics of the manufacturing process. Many organizations such as the International Society of Automation (ISA) and the Manufacturing Enterprise Solutions Association International (MESA) have announced MES-related standards. In addition, related studies have been presented. However, MES functions have not been defined and standardized from an integrated viewpoint of manufacturing systems. Existing standards are for each field so there is a limit to managing the overall MES flow. In order to apply MES in any manufacturing industry, it is necessary to have a whole framework before dealing with functions according to each field.

In this study, we defined an MES framework by subdividing manufacturing operational functions and reclassifying them from an integrated viewpoint of manufacturing system. In Sections 2 and 3, we reviewed trends in which previous studies have been conducted for MES, and the characteristics of MES defined in each organization. We reclassified the functions of MES from an integrated system perspective and compose an integrated MES

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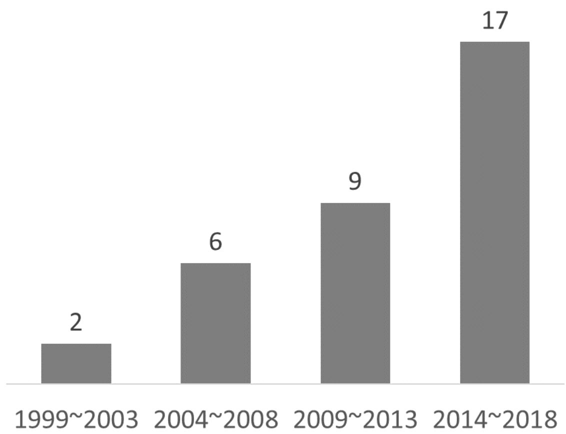
framework in Section 4. We re-categorized the studies that were analyzed in Section 2 according to the framework in Section 5. Finally, Section 6 concludes the paper.

2. **Analysis of Existing Research.** In this study, to analyze how MES is being researched, we analyzed the research based on 11 functions of MES which were announced by the MESA. We searched for papers with keywords 'MES' and 'manufacturing execution system' in Google scholar and Elsevier and collected 34 papers from 2002 to 2018. Coronado et al. introduced Android-based MES to collect data from the machine and conducted a case study to track production based on it [1]. Iarovyi et al. have acquired a higher level of knowledge through data using cyber-physical system to apply open knowledge-based manufacturing execution systems [2]. Yang et al. used RFID tag records to identify the location information of the employees, the status of the workplace, the location of the Work-in-Process (WIP) [3]. Based on this information, work on the labor management, equipment and inventory management and production management were conducted. Xu et al. designed new MES architectures utilizing intelligent monitoring based on wireless sensor network in error-prone assembly systems [4]. Naedele et al. said that the integration of all interconnected data in all areas is critical to successful MES [5].

Previous studies have focused on the functions of MES necessary to operate the factory, and the contents of data collection and resource allocation have frequently been studied. The number of MES-related papers is steadily increasing, and the number of papers published in five years since 2014 is about half of the total number of thirty-four papers (Figure 1(a)). In addition, when categorizing the papers based on the MES functions announced by the MESA, MES functions of resource allocation and status, operation detail scheduling and dispatching production units, account for 19%, 15% and 13%, respectively, accounting for 47% of the total MES functions mentioned in the papers (Figure 1(b)). MES is introduced mainly at the phase of establishing. It can be seen the use of MES in the actual production process seems insufficient. This shows that the application of MES in the actual process is required.



(a) The number of MES-related papers by year

1. Resource Allocation and Status	28
2. Operations Detail Scheduling	21
3. Dispatching Production Units	19
4. Document Control	15
5. Data Collections/Acquisition	14
6. Labor Management	10
7. Quality Management	9
8. Process Management	9
9. Maintenance Management	9
10. Product Tracking and Genealogy	7
11. Performance Analysis	4

(b) The functions of MES-related papers

FIGURE 1. Existing research analysis

3. **Review of Standards.** The organizations that announced MES-related standards are ISA, MESA, Verein Deutsche Ingenieure (VDI), User Association of Automation Technology in Process Industries (NAMUR).

ISA developed an enterprise-control system standard ISA-95 in 1995 based on the Purdue Enterprise Reference Architecture (PERA) model released in 1992. The model focused on information architecture and helped address questions like which tasks can be executed by which functions and what information must be exchanged between applications. The model divided production systems into five levels and defined boundaries between the enterprise systems and the control systems. Intelligent devices such as sensors belong to Level 1. Control systems such as Programmable Logic Controller (PLC), Distributed Control System (DCS) belong to Level 2. MES belongs to Level 3. Enterprise Resource Planning (ERP) belongs to Level 4. The ISA defines 10 functions related to production operations. The functions of defined in ISA-95 are order processing, production scheduling, production control, product shipping administration, product cost accounting, material and energy control, procurement, product inventory control, quality assurance, and maintenance management. ISA defines the system boundary between the business system and the MES domain in the 10 functions. The business system consists of four functions of order processing, product shipping administration, product cost accounting, and procurement.

MESA formally defined MESA-11 that included eleven core functions in 1997. The model focused on business process. The functions of MESA-11 are operations/detailed scheduling, dispatching production units, product tracking and genealogy, labor management, quality management, maintenance management, resource allocation and status, document control, performance analysis, process management, data collection and acquisition. In 2004, MESA expanded the model with a focus on how core operations interact with business operations. The model, called collaborative MES, included that supply focused systems such as procurement sustainable consumption and production, customer focused systems such as Customer Relationship Management (CRM), financial and performance focused systems such as ERP and business intelligence, product focused systems such as Computer Aided Design/Manufacturing (CAD/CAM) and Product Lifecycle Management (PLM), logistics focused systems such as transportation management system and warehouse management system, control PLC, DCS and compliance focused systems such as document management, environment health and safety. In 2008, MESA defined another model that expanded not only to production but also to quality and compliance, to the life cycle of the product.

In 2004, VDI defined MES standards in the area of discrete manufacturing such as process-oriented manufacturing management system and comprehensive and execution of the production process. This standard seeks to distinguish MES requirements and functions by various manufacturing types. Its structure defined the work that MES should perform in the manufacturing enterprise. The MES functions in this standard are detailed planning and detailed scheduling control, operating resource management, material management, personnel management, data acquisition and processing, interface management, performance analysis, quality management, information management [6]. And NAMUR, focusing on the pharmaceutical and chemical industry, defined MES standard related to interface between work floor and business systems based on ISA-95. NAMUR has many work areas, among which the MES standard is studied in automation system for processes and plants.

4. **Framework Presentation.** Since the manufacturing companies have various characteristics, the MES functions must be classified in detail. Therefore, in this study, we define an integrated MES framework by redefining and classifying all functions based on two standards of ISA and MESA. We integrated four common MES functions into one and added a function about system management. We excluded four functions of order processing, product shipping administration, product cost accounting, and procurement because they are included in the upper-level system. All functions are divided into 21 function-categories based on the contents and are divided into 36 function-items. We coded the MES functions of the MESA as M, the MES functions of the ISA are I, the common functions are A, and the newly added functions are N.

In this study, we present a new framework that 36 function-items are classified into four modules of INPUT, PROCESS, OUTPUT, and INTEGRATION. The overall structure and meanings of four modules are as follows. The INPUT module plans and establishes a production control system to be implemented in the manufacturing process. It identifies the resource requirements needed in the manufacturing process, establishes work schedules, and defines the data to be collected in each production unit. The PROCESS module represents the entire process from beginning to end. It checks that the process is proceeding according to the plan and control. If anomalies occur, this module systematically intercepts the process and solves it immediately. These lead to process control and quality control. It also records the production history of all finished products, enabling traceability after production runs. The OUTPUT module provides status information of all resources to the operators and managers. It manages production records including productivity and yield, the Key Performance Indicator (KPI) to improve defective elements. The INTEGRATION module integrates management of operators, facilities, and systems for all processes such as input, process, output and eliminates work loss by integrating between system layers.

The details of four modules and classified functions are as follows. Tables 1 to 4 show the function-items and named codes corresponding to each module.

4.1. **INPUT.** This module includes the functions for establishment of production management system and management of necessary plans and resources before manufacturing goods. The included functions are as follows: Arranging resources and equipment appropriately in the process flow, and organizing and distributing work plans; Being responsible

Table 1. Function-items of INPUT module

Function-items	**Code**
Set-up the detailed history of the resource and the equipment in real time according to the process flow	M-1.1.1
Scheduling and distribution to meet resource management work schedule goals	M-1.1.2
Providing real-time status of equipment to identify equipment failure	M-1.2.1
Ensuring that equipment is properly installed and operating	M-1.2.2
Production scheduling to minimize equipment set-up time based on movement patterns	A-1.3.1
Managing work order by considering alternative and redundant processes	M-1.3.2
Identifying long term requirements of raw material	I-1.3.3
Establishing schedule that identifies alternatives for calculating the equipment loading and transportation types at precise times	A-1.4.1
Production flow management in the form of work content, work units and work instructions	M-1.5.1
Creating list of production personnel for each unit of work	M-1.6.1
Offering ability to edit information such as work orders, prescriptions, drawings, and standard work procedures	M-1.7.1
Providing organized data to the operator or providing a prescription for device control	M-1.7.2
Providing interface such as barcode and RFID to collect data	M-1.8.1
Collecting field data from equipment automatically or manually	M-1.8.2
Authorizing operators to operate products and resources	M-1.10.1
Providing a manual of action to solve problems in case of anomalies	M-1.12.1
Purchase requisition according to energy material quantity, inventory level and movement	I-1.18.1

for the production scheduling for the whole process and for the purpose of optimized work order management; Providing equipment and interfaces for data collection and editing; Allowing flexible decision-making on priorities within a given planning period for each process.

4.2. **PROCESS.** This module includes the functions for manager's process control and quality control, worker's work management, and data management through material and product tracking in the process. The included functions are as follows: Process flow control and real-time monitoring of recorded data. In the event of anomalous signs, the signs should be communicated to the preceding process and immediately resolved. Engineering data such as machining specifications, inspection specifications, packaging and printing specifications of products are sent to operators or facilities to control the complicated manufacturing processes. In addition, recording the history of all finished goods and WIP according to the defined data types, tracing the raw materials used in production, process route, work condition, inspection condition, shipment history, etc. And responding to the quality problem quickly by analyzing the defect factors.

Table 2. Function-items of PROCESS module

Function-items	**Code**
Redistribution of production units according to the tasks that need to be performed in the event of a problem at the manufacturing site	M-2.5.1
Worker attendance reporting	M-2.9.1
Tracing indirect actions such as material and tool preparation	M-2.9.2
Statistical process control and quality control using software such as SPC and NCMS	A-2.11.1
Immediate resolution when abnormal symptoms occur and control quality	M-2.12.1
Monitoring the entire manufacturing process to avoid confusion in the process	M-2.12.2
Improving decision-making to improve operator performance or eliminate unnecessary waste	A-2.13.1
Process planning to the requirements with tracking and monitoring	A-2.13.2
Recording the history of all finished goods and WIP according to defined data types	M-2.14.1
Tracking preventive activities to maintain equipment and tools	A-2.15.1
Optimizing preventive maintenance work to reduce manufacturing impact	A-2.15.2
Keeping track of past events and issues to help diagnose new problems	A-2.15.3
Checking that the actual inventory of the product matches the inventory of the computer	I-2.19.1

4.3. **OUTPUT.** This module includes two functions of production performance management and management of productivity and yield. The included functions are as follows: State information management that provides information to managers or workers by linking all resources, facilities, operator deployment status, and operational status information. And improve production yield and productivity by controlling the process of manufacturing. Also based on production results and facility operation status, productivity and yield for each process/facility/worker are calculated and statistically, and KPI management improves bottleneck process and fault occurrence to improve productivity and yield.

4.4. **INTEGRATION.** This module includes the functions for integrative management of workers, facilities and information systems, Integration between system tiers. The included functions are as follows: Integrate workers, facilities, and information systems

TABLE 3. Function-items of OUTPUT module

Function-items	Code
Reporting actual operational results through comparison of historical records with expected results	M-3.17.1
Consolidating data to calculate key performance indicators such as rework, process capability, and facility efficiency	M-3.17.2

TABLE 4. Function-items of INTEGRATION module

Function-items	Code
Providing a history of the location of the job, the worker, the quantity of material required, or the current production conditions	M-4.16.1
Managing associated history of all manufacturing data from raw materials to part assemblies	M-4.16.2
Providing information to administrators or operators by linking all resources, facilities, operator deployment status, and operational status information	N-4.20.1
Establishing standard information and plan/instruction/performance information interface for system operation and ERP, SCM, APS	N-4.21.1

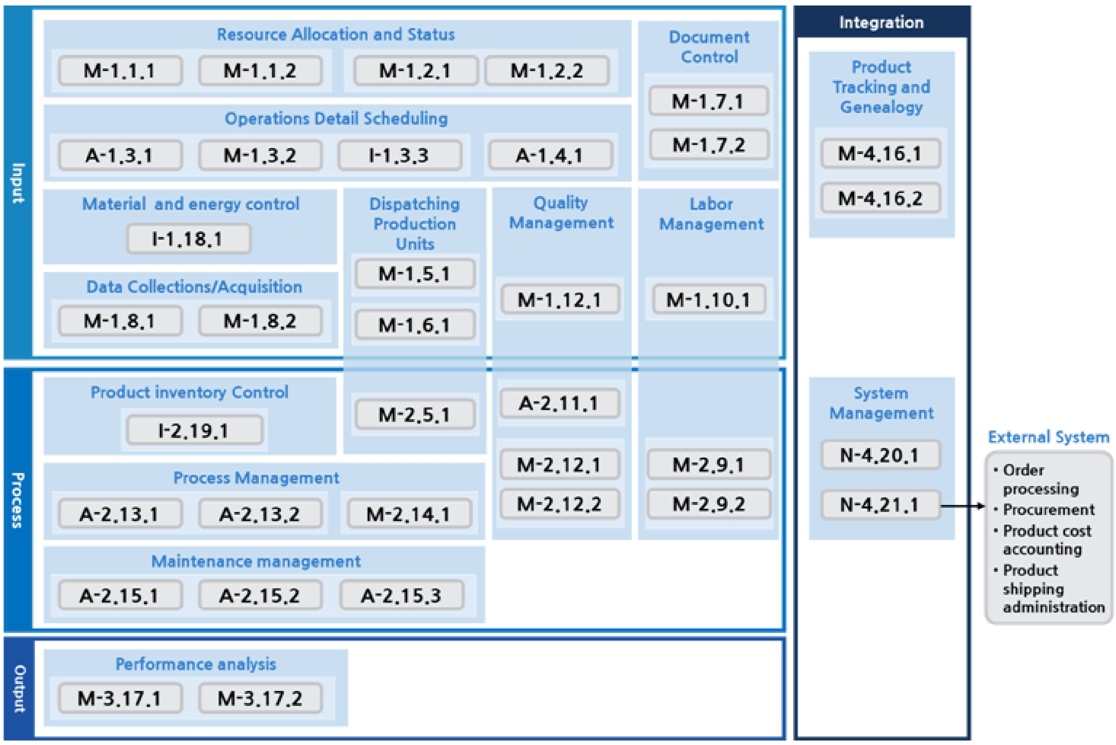


FIGURE 2. Functional framework of MES

for automation and standardization as much as possible and provide an interface to collect data in order to minimize operations by porting it to the system. Also provide some interface with master data and transaction data of upper system such as ERP, Supply Chain Management (SCM) and Advanced Planning and Scheduling (APS). N-4.21.1 provides interfaces with external systems, such as the four functions (order processing, procurement, product cost accounting, and product shipping administration) of the ISA's upper system. Figure 2 shows 21 MES functions and 36 functional-items mapped to the framework.

5. **Reanalysis of Existing Research.** Based on the MES framework redefined in this study, we reanalyzed the existing studies. The studies, which deal with the functions of INPUT module and INTEGRATION module, showed increasing trends as shown in Figure 3. The studies on INPUT module accounted for 48% of the total. It can be seen that the MES is concentrated on establishing the production management system rather than introducing it into the actual manufacturing process. Most of the data collection and acquisition functions of the INPUT module have been studied. It can be seen that automatic collection of data must be prioritized in establishing the production management system. In the case of INTEGRATION module, system management research emphasizing integration between system layers has increased.

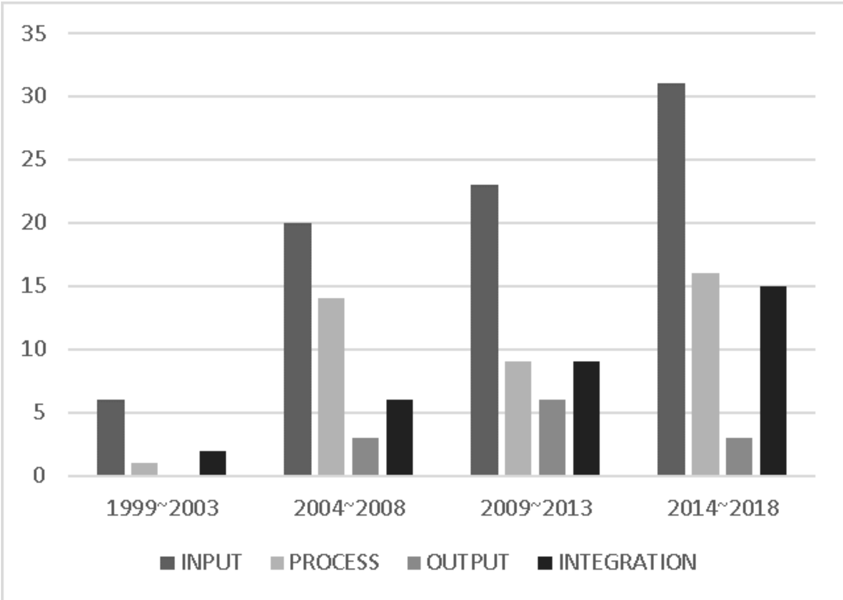


Figure 3. Research trends from the MES framework perspective

6. **Conclusion.** MES is a key software system for smart manufacturing. It continues to be studied in related academic papers and industry standards, and manufacturing companies are promoting its introduction to increase competitiveness and to achieve manufacturing innovation. However, in order to ensure that many companies apply MES in a consistent and unified way, it needs an integrated framework reflecting actual manufacturing system for companies that have various characteristics and requirements. In addition, for effective manufacturing management, it is important to establish an integrated information system by linking MES with other systems. Therefore, in this study, we analyzed research trends through the review of MES-related literature. In addition, we analyzed MES standards of several organizations and classified the functions of MES mainly based on two standards defined by MESA and ISA. We presented a framework to satisfy the requirements of manufacturing companies, the categorized functions of which were remapped into four modules from an integrated perspective of manufacturing system. The redefined framework could provide guidelines, when introducing MES, to identify the functions required for the modules corresponding to the requirement of each company. It is expected that more standardized framework will be presented if the services and functions related to the currently implemented MES are further analyzed and applied to this framework.

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REFERENCES

[1] P. D. U. Coronado, R. Lynn, W. Louhichi, M. Parto, E. Wescoat and T. Kurfess, Part data integration in the shop floor digital twin: Mobile and cloud technologies to enable a manufacturing execution system, *Journal of Manufacturing Systems*, vol.48, pp.25-33, 2018.

[2] S. Iarovyi, W. M. Mohammed, A. Lobov, B. R. Ferrer and J. L. M. Lastra, Cyber-physical systems for open-knowledge-driven manufacturing execution systems, *Proc. of the IEEE*, vol.104, no.5, pp.1142-1154, 2016.

[3] Z. Yang, P. Zhang and L. Chen, RFID-enabled indoor positioning method for a real-time manufacturing execution system using OS-ELM, *Neurocomputing*, vol.174, pp.121-133, 2016.

[4] W. Xu, Z. Yang and X. Wang, A technical and business perspective on wireless sensor network for manufacturing execution system, *Mathematical Problems in Engineering*, vol.2015, Article ID 267195, 2015.

[5] M. Naedele, R. Kazman and Y. Cai, Making the case for a manufacturing execution system for software development, *Communications of the ACM*, vol.57, no.12, pp.33-36, 2014.

[6] VDI-Richtlinien, *Fertigungsmanagementsysteme (Manufacturing Execution Systems – MES)*, VDI 5600, 2013.