Building a reference model for a Manufacturing Execution System (MES) platform in an Industry 4.0 context

Lei Yue *, Linkun Wang, Pengfei Niu, Nan Zheng
Instrumentation Technology and Economy Institute, Beijing 100055, China

Abstract. To fill the reference model gaps in the Manufacturing Execution System (MES) platform software field, the definitions for platform software and reference model are put forward, and a reference model for MES platform conforming to Industrie 4.0 specification is proposed. The MES platform was characterized by the reference model from three dimensions of problem space, lifetime and infrastructure, in which, each dimension was represented by a view that consists of a number of viewpoints. In building the reference model, the viewpoints selection processes were discussed based on the current standards in each area corresponding to each dimension, and then a concept of reference model building block was defined. Furthermore, in order to explain how the reference model can be applied in use, some examples were performed for a representative application scenario in Industrie 4.0 and illustrating the reference model in combination with the application of specific technologies. A conclusion and expectation for the reference model research were summarized in the end of the paper.

1. Introduction
The Industry 4.0 reference architecture model (RAMI 4.0), published by the German Electrotechnics and Information Technology Standardization Committee (DKE) in 2015, regards the ISA-95 and ISA-88 standards as an important foundation for the construction of RAMI 4.0, both of which were very early. The standards proposed by ISA have also been mentioned to an unprecedented level of importance. The German Electrical Engineering and Electronics Industry Association (ZVEI) issued Position Paper "Industrie 4.0: MES - Prerequisite for Digital Operation and Production Management" [1] on April 12, 2017, clarifying a series of issues related to the Industry 4.0 In the question of the direction of MES development in the era, the conclusion given in [1] is that the business objectives of Industry 4.0 require the emergence of more flexible and dynamic MES, and that the future MES will be integrated, modularized and digitized. The Manufacturing Operations Management (MOM) system evolves and conforms to the various information models passed in the MOM defined in the ISA-95 standard.

The current popular MES concept was first proposed by the Advanced Manufacturing Research (AMR) in 1990. By 1997, the International Federation of Manufacturing Execution Systems (MESA) published the MES white paper, giving a description of the MES. Sexuality was defined and a MES function model containing 11 module functions was proposed. MES has experienced a series of problems during its development and application for nearly 30 years. Due to the differences between industries applied by MES, the design concepts of different MES products are not the same, and there is a lack of a common and clear object scope. Therefore, in addition to its own concept as the main body of the software system, it also includes the concept and description of the problem domain that it faces, and the differences between MES products that face specific issues, which leads to the MES boundary is difficult to clearly define, the concept is also very vague [2].
2. Research foundation

2.1. Platform concept
Combining the research results currently available in academic circles both at home and abroad ([3][4]), the definition of the term “platform” used in the paper is first given: Platform refers to the collection of subsystems and interfaces that make up the public infrastructure. The public infrastructure can be used to develop a group of related products and to shield itself and the underlying technical details.

The MES platform discussed here is located in the software platform hierarchy between the business infrastructure platform and the Application Software System and belongs to the business infrastructure platform. However, compared to the general business infrastructure platform, the MES platform has a richer Manufacturing and management services related public infrastructure, as shown in Figure 1.

![Figure 1 Position of the MES Platform in the Software Platform Hierarchy](image)

2.2. Reference model and reference architecture
The Reference Model expresses a class in a domain and the relationship between these classes, so it is a conceptual framework and can be used to build a blueprint for an information system [5]. In addition, the use of reference models for communication and exchange is conducive to different people or groups, achieving common understanding and understanding at the macro level.

A reference model can be mapped to a set of software components and the data flow between these components, so that the so-called Reference Architecture can be obtained. Based on the reference architecture, the details can be further refined. The system architecture [6]. The reference architecture first appeared in the domain of software architecture and enterprise architecture. It provided template-based solutions for specific architectures in specific domains, and also provided a common vocabulary for discussing implementation details, often emphasizing the versatility of the solution.

3. Selection of mens platform reference model perspective
Since the MES platform contains a large number of reusable software infrastructures, the subsystems or components that make up these infrastructures have a very complex relationship. Therefore, it is necessary to clearly and accurately describe the tasks that the MES platform needs to accomplish. First, the dimensions of the reference model of the MES platform are divided. For this purpose, according to the recommendations provided by the ISO/IEC 42010-2011 System and Software Engineering – Architecture Description [7], the reference model for the MES platform is selected from three views:

- Problem space dimension: the business field corresponding to the MES platform;
Time dimension: the implementation phase of the MES platform (as an enabling system for MES applications);
IT infrastructure hierarchy: The hierarchical structure of the software infrastructure included in the MES platform.

Each dimension is described by a view. Each view consists of several views.

3.1. Field view
There are many international standards relating to MES, some are international, such as ISA’s S95 and S88 standards, MESA’s MES function model, etc.; some are regional, such as the German Institute of Engineers’ VDI 5600 standard, German machinery and equipment manufacturing The VDMA 66412-10 standard of the Confederation of Industries, among other relevant standards, ISA’s S95 is a widely recognized and accepted standard worldwide, and the scope of its defined manufacturing operations management activities is that which MES can cover. The maximum limit of the field.

The third part of the ISA-95 standard defines the business activities in manufacturing operations management [8]. According to the importance of business activities, it is divided into core activities and support activities, and then divided according to the nature of its business. The core activities are production respectively. Operations, quality operations, inventory operations and maintenance operations; support activities are information management, security management, document management, configuration management, compliance management and abnormal deviation management. Although the third part of ISA-95 makes detailed provisions on the four core activity areas, there is no supportive support activity, but the support activities have been integrated into major business activities in various ways.

After defining various activities (including detailed sub-activities) in the field of business activities of manufacturing operations management, the following perspectives can be extracted to describe the MES platform domain view. The focus of each perspective is its corresponding activities and the sub-activities are shown in Table 1. The collection of all these activities constitutes the upper limit of the business domain of the MES platform. The specific MES application boundary is not within the scope of the reference model and needs to be determined according to the specific company’s situation and needs.

Table 1 Perspectives of MES Platform Field Views

| Perspective | maintain | produce | quality | in stock |
|-------------|----------|---------|---------|---------|
| activity    | Maintenance and operation management | Production operation management | Quality Operation Management | Inventory operation management |
| Child activities | |

| 3.2. Stage view |
Reuse activities in the MES platform take place at various stages of the evolution of the life cycle. Therefore, the life cycle model of the system is established first. The “system” referred to here is the meaning of “system” defined in the first part of the ISO/IEC TS 24748-1-2016 standard “System and Software Engineering – Lifecycle Management”. The MES platform and MES application discussed in the paper All belong to this “system” category.

The ISO/IEC TS 24748-1-2016 standard establishes a representative system life cycle model. Since each system has its own life cycle phase and there are intricate and complex relationships among the various systems, it is at the life cycle stage of the system, it will inevitably involve the correlation with the life cycle of other systems. To this end, the standards distinguish between the roles played by the
various systems: system-of-interests that are selected as research objects and consider the life cycle of the system and support the focus during the life cycle of the focus system. The system that does not directly constitute the runtime system runtime function is defined as the enabling system [9].

The MES platform is ultimately for the rapid development and deployment of MES applications. The MES application system life cycle should be supported by the MES platform. Therefore, in the context of the discussion, after selecting the MES application system as the focus system, the MES platform will as the role of the enabling system, the interaction between the two phases of the life cycle is shown in Figure 2.

![Figure 2 Life cycle interaction between MES platform and MES application](image)

In the life cycle of the MES application system, the phases directly supported by the MES platform are the development phase and the operation and maintenance phase. In the standard ANSI/IEEE1517-2010 on the software reuse process, the application system is based on the reusable software infrastructure. Development, operation and maintenance are also the focus of attention, and application system development also refers to application engineering [10].

In order to illustrate how the MES platform supports the MES application implementation in the time dimension, the MES application development, operation, and maintenance phases are selected as two perspectives of the phase view to indicate the application design time and operation based on the MES platform. Two technical processes were used to examine the multiplexing activities that occurred in the MES platform.

3.3. It infrastructure hierarchy view

With the release of the RAMI 4.0 specification, Industry 4.0 components (referred to as I4.0 components) have gradually established their core position. The goal is to establish a service-oriented, interoperable and consistent communications industry with I4.0 components as a unit. 4.0 system (I4.0 system). This requires that any asset object that accesses the Industry 4.0 system must comply with the specifications of the I4.0 component. Therefore, the MES platform as a company’s software assets must also be in the form of I4.0 components in the context of Industry 4.0. exist. RAMI4.0 provides IT infrastructure for the I4.0 components.

The core of the I4.0 component is the asset management shell, which not only bridges the tangible assets and the information world, but also enables the physical asset object to have semantic interoperability and consistent communication capabilities and can exist as a service in the Industry 4.0 system. in. MES platform and MES applications, in addition to the hardware resources in their operating environment, the ontology belongs to the information world, so in the IT infrastructure shown in Figure 4, the MES platform is mainly in the "business", "function" and "Data" provides external technical means at three levels to support the implementation of the corresponding Industry 4.0 application
scenario. Here, these three perspectives are chosen to establish the IT infrastructure level of the MES platform.

4. Mes platform reference model
The above three views examine the characteristics that an MES platform should have under the Industry 4.0 environment from different perspectives. These three aspects interact and interact with each other to form a trinity MES platform reference model, as shown in Figure 3.

Figure 3 MES platform reference model

For example, in an Industry 4.0 system, any two I4.0 components must be able to interoperate with each other in a consistent I4.0 communication manner, such as the interaction between MES and ERP systems. Therefore, the information that first requires the MES to be exposed to the outside must be structured data with standard semantics. The organization framework for defining and expressing information is called an information model.

Under the environment of Industry 4.0, a typical scenario of MES platform participation is: In the MES application development stage, information modeling tools are used to establish an information model for production operation management. The information model will be used as the ERP and MES, MES and the basis for data exchange and interoperability among devices, between MES and products, and within MES, and to ensure that the semantics of the data conforms to the specifications of the I4.0 component and asset management shell.

To accomplish this task on the MES platform, the MES platform infrastructure must provide at least one information modeling tool and provide a data dictionary that conforms to the I4.0 component and asset management shell specifications. Application developers can use the standard data dictionary. Select the properties that need to be used for modeling. Among the alternative technologies for information modeling, the OPC UA specification with strong semantic expression capability can be selected to describe the information flow in the specific production operation management [11].

In addition, for the MES platform, the main purpose of the MES platform is to reuse existing functions and services during the development phase of the MES application to reduce the development workload. Therefore, the MES platform can provide a repository and related design. Tools, repositories are made up of reusable infrastructure units. If the infrastructure units in the repository do not yet meet new application requirements, application developers can be allowed to use the design and development tools provided by the platform to meet new applications demand.

5. Conclusion
As the MES platform, the study of its reference model has just begun. There are still many topics in this topic that need to be further studied and discussed, such as:

Further enrich the details based on the existing reference model

In order to ensure its universality in various industries, the ANSI/ISA-95 standard only stipulates the business activities of MES at the macro level. Therefore, when it is adopted, it still needs to be supplemented with specific business activities or used in combination with other business activities. The
model or standard, such as the supply chain reference model SCOR, the German Engineers Association's MES standard VDI 5600, etc., to enrich the specific details.

Using Reference Model to Conduct MES Platform Product Evaluation

The reference model provides the basic conceptual framework and observation perspective for the MES platform. Based on these basic concepts and perspectives, combined with the requirements of the standard, an evaluation index system can be established. Based on this, the MES platform and MES application for different suppliers on the market can be applied. The product is evaluated. The evaluation of MES platform products will help manufacturers to compare MES products from a unified point of view before implementing MES construction projects and help them to make reasonable product selection based on their own needs.

Guide the development of the MES platform architecture

Combining the concepts in the MES platform reference model with specific software technologies and mapping the concepts and functions into specific software components can guide future MES platform architecture development.

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About the Author:
+ Yue Lei (1984-), male, Beibei, Liaoning, engineer, master, research direction: manufacturing operation management, intelligent manufacturing reference model, etc., E-mail: yuelei@tc124.com;

Linlin Wang (1974-), male, Jiamusi, Heilongjiang Province, professor-level senior engineer, Ph.D., research direction: intelligent manufacturing total solution, industrial communication and integration, etc., E-mail: wlk@tc124.com;

Niu Pengfei (1985-), male, Baoding, Hebei, engineer, master's degree, research direction: design and implementation of manufacturing execution system, information model, etc., E-mail: npf@tc124.com;

Zheng Nan (1987-), male, Lianyungang, Jiangsu, engineer, master, research direction: manufacturing execution system design and implementation, factory and process simulation technology, E-mail: zhengnan@tc124.com.

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