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Study on interoperation and its' implementation of MES to support virtual factory

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Abstract. The data interoperation between VF (virtual factory) platform and MES (Manufacturing Execution System) plays an important role in intelligent factory construction. The study focuses on the integration strategy between the VF and the MES by incorporating VF manufacturing assets in two ways, i.e., vertical integration (used for production line performance evaluation) and the horizontal integration (cloud manufacturing based on manufacturing assets services discovery and their composition). The VF platform which integrates the manufacturing assets in two manners is designed as the bottom layer in the entire integration framework. It has been applied to build a four tiers integration model in an intelligent production system construction of a domestic ship manufacturer and verified its feasibility and availability.

1. Introduction

The virtual factory technology can effectively be used to control product manufacturing quality, business collaboration efficiency, demand response speed, and reduce manufacturing costs on a large-scale customized collaborative business chain. The collaborative manufacturing industry chain links based on the VF framework are composed of manufacturers or service providers with the best comprehensive competitiveness. Therefore, the establishment of a VF system is the key to achieving manufacturing business innovation. The VF is an upgrade of the digital factory and it has more connotations and functions. Because, from one hand, it's based on the automation of workshop equipment and applies technologies such as the Industrial Internet of Things to realize automatic data collection and information integration of the physical resources of the manufacturing system; on the other hand, it can use the CPS (Cyber Physics System) to construct a digital twin model to realize the control of the virtual and real two ways of the manufacturing system. In short, the VF platform/system is focused on the manufacturing assets management. As a result, the production workshops of a VF should need a full-featured, well-interactive MES to solve the tasks such as manufacturing parts/materials dispatch, production resource management etc. Otherwise, it is difficult to map the manufacturing assets of the virtual factory to the actual production tasks and realize data integration. From this perspective, the MES interoperability of the workshop is the key to the operation of the entire VF system.

The MES interoperability framework supporting VF operation plays a bridge role in many links such as product design, manufacturing process planning, production process management, and quality inspection. It organizes the manufacturing assets, schedules production cycles, and optimizes the entire production systems by integrating the useful data sources from different information systems. Therefore, the interoperability of MES in the VF environment is the key link of whether the VF system can operate smoothly and effectively. However, the existing MES integration framework lacks a mechanism to integrate the VF platform. Consequently, the MES is necessary to adopt an improvement development manner for this purpose. Through a literature review, it is found that there are rarely applicable researches in this field. Therefore, it becomes the motivation of the research on MES interoperability to support manufacturing business innovation.

The research objective of the project is that aims to explore a way of how to improve the existing MES systems functions and their application ranges via integration strategies. It can effectively integrate distributed manufacturing resources (machine tools, equipment, robots, stackers, operators, etc.) and provide corresponding MES that meets the requirements of the industrial software layer in an intelligent software system. Among them, the following two specific questions need to be addressed.

(1) The MES uses what method to collect and process of the real-time operating data of the distributed workshop manufacturing assets of VF reliably. By acquiring these data, the MES system can provide the shop floor production management staff with reliable data required for manufacturing resource planning and scheduling.

(2) According to the integrated distributed manufacturing assets and their operating data, how the MES uses the information to evaluate the feasibility of the initially formed production plan and manufacturing resource scheduling plan of VF? That is, the production plan established by MES according to the product production process, and the corresponding machine tools, equipment, robots, operators, etc., whether the combination of these resources is optimal which can be evaluated by using some software tools, e.g., ProModel, Flexsim, etc. As a result, there is a problem with how to integrate the MES and the simulation software tools combined the distributed manufacturing assets. Then, MES can use the results of the assessment to decide whether to adjust these production plans and manufacturing resource scheduling plans.

2. Literature review

2.1. Virtual factory

A series of research projects related to virtual factories, such as ComVantage, MSEE, IMAGINE, LinkedDesign, EPES, ExtremeFactories, PREMANUS, and ADVENTURE, were funded by the EU Innovation Research Program Framework FP7 (2007-2013) [1]. These research projects mainly focus on issues such as complex supply chain collaborative management, manufacturing knowledge management, and support for multidisciplinary collaborative simulation software platforms. At the same time, the enterprise information system security management and sensitive information sharing strategies are also involved. According to the funded VF project, more attention is paid to the IT platform, which can be regarded as a general term for the hardware, system architecture, and software systems necessary to undertake a series of related tasks.

Besides, many scholars have carried out corresponding research on virtual factory technology. Ghielmini [2] and Mourtzis [3] believe that existing ICT solutions have low levels of interoperability in supporting the integration of distributed manufacturing resources for the small and medium-sized enterprises; then they proposed the method to develop a virtual factory framework (VFF) to solve these problems, including the semantic shared data model, virtual factory manager (VFM), etc. Mourtzis proposes an integrated quality monitoring method in supporting cloud manufacturing of virtual factories [4].

The FIRST project, which is co-funded by EU Horizon H2020 (2014-2020) and China Key Research and Development Program, believes that the VF is an extension of the concept of a virtual enterprise, that is, the creation of a VF requires integration of collaborative business processes, as well as integration of product design, manufacturing processes, inspection processes, to form a cross-enterprise collaborative activity process. One of the key evaluation indicators of the integration is whether the integration platform can ensure the related data global consistency or direct compatibility between machines, products, processes, inspections, related products and services, and any of their descriptions.

According to the literature review, the latest VF study can be roughly summarized into two aspects.

(1) Vertical integration. In order to support large-scale customization, a collaborative manufacturing chain of products needs to be established to ensure that each link in the industrial chain has the best comprehensive performance. Therefore, a VF model needs a module to support the evaluation of the production line performance of the industrial chain, such as Arena, Flexsim, ProModel and other simulation software [5]. The VF vertical integration platform can not only provide an integrated evaluation platform for the design and analysis of manufacturing systems, but also integrate the evaluation results with the entire manufacturing system, thereby optimizing the entire manufacturing system and building the manufacturing chain as a whole [6].

(2) Horizontal integration. In addition to supporting the simulation to optimize the performance of the collaborative manufacturing chain, the VF horizontal integration platform also manages information about various business activities in the VF, supports multiple levels of integration of manufacturing resources throughout the product lifecycle, and establishes the real and the virtual interactions mapped digital twin model [7]. It is also called as cloud manufacturing that supports the integration of the distributed manufacturing assets cross the entire VF. This integration focuses more on data integration between systems other than hardware. In horizontal integration application, the CPS (Cyber-Physical System) is key technology to build the twin model that continuously to collect the real-time production data via various intelligent electronic systems, sensors, robots, and embedded systems [8, 9].

In summary, the VF platform can be integrated with the existing related systems to build the networked collaborative manufacturing chain, improve the manufacturing system's operational efficiency, and ensuring the data consistency and interoperability.

2.2. MES and its interoperation

The MES is a production process management and real-time information management system for the workshop. It mainly solves the problem of execution of workshop production tasks, bridges the gap between the upper-level production plan and the lower-level industrial control. It can help to make the entire enterprise information system and its manufacturing system organically integrated. Because of the important role of MES in the enterprise information system, the research and development of MES has developed rapidly in Europe and the United States since it was formally proposed in the early 1990s. In China, many research institutions and software companies have also devoted a lot of effort to the development of MES systems since 2000.

Currently, the popular MES systems in domestic market include AspenTech Mfg.Suite from AspenTech, Ciplicity Advantage from GE Fanuc, SIMATIC IT Production Suite from Siemens etc. In addition to the MES systems, some domestic MES systems have been developed and applied in industries, such as Baoxin MES (in steel industry) and Sinopec MES (S-MES V1.0, in petrochemical enterprise), KMMES (in discrete manufacturing industry), etc. From the perspective of data and its interactivity (refer to Figure 1), the main objects managed by MES are the static assets data, the dynamic assets data, and the dynamic production data of a workshop.

(1) The static manufacturing assets management

The static manufacturing assets of a workshop include machine tools, mechanical equipment, tools, process equipment, and even employees. The system establishes data correlation models by predefining the data objects, which can support the subsequent dynamic data management in MES. During the operation of MES, the status of the static data will change. For example, the processing conditions on the machine tool are dynamic, and the use of tools and process tools is also dynamic. Also, the static data includes product technical documents, such as product design schemes (e.g., CAD models) and production process plans/specifications. MES uses the information to establish a static data model of the manufacturing assets and the related document, and then associates it with a dynamic data model. It will be utilized later for the dynamic data management on the production floor.

(2) The dynamic manufacturing assets management

With the follow-up production activities, the operating status of workshop assets (machine tools, equipment, robotics, etc.), the number of raw materials for production parts, the status of materials, the working status of employees and other information will change along with the execution of parts processes. Therefore, MES needs to solve the real-time management of equipment operation status, material tracking management, parts processing status management, workshop event management; also multi-dimensional monitoring of personnel, materials, equipment and other factors. Furthermore, it needs to provide statistical analysis tools for the dynamic assets status supervising and to improve the manufacturing assets operation performance of workshop.

(3) Production information management

The information of the workshop production system includes production planning, job planning, task scheduling, quality management, etc., most of which are dynamically and continuously with the execution of parts manufacturing processes. According to the main production plan from ERP and the component/part processing plan generated by CAPP (Computer Aided Process Planning), the workshop needs to prepare specific production operation plans for the manufacturing units, processing stations, and machine tools and personnel of the workshop. In this process, an APS (Advanced Planning and Scheduling) system will be used to perform a detail tasks scheduling according to multiple constraints of the workshop, such as machine tools numbers and their capability, and tools/personnel availability. The published production plans will be used in the manufacturing units, stations, and processing machine tools; and then to track the status of the components/parts being processed. Also, the quality assurance module of the MES should be utilized to collect the machining quality data in real-time, to statistically analyze the current situation of product quality and its development trend and to improve the production operation plan and equipment maintenance plan during the production process.

3. MES interoperability framework integrated with VF platform

The VF is the key to achieving large-scale customized services in Industry 4.0. The establishment of a VF can focus on the manufacturers in the advantageous industrial chain to form a dynamic production system with high-level, reliable production and transparent management.

According to the foregoing, combined with the VF production system performance evaluation technology based on VF manufacturing assets vertical integration method, and the cloud manufacturing model based on VF manufacturing assets horizontal integration technology, the existing MES can be extended to support the integration with virtual factories platform (refer to Figure 1).

In terms of vertical integration method, the VF uses the information model to interconnect and interoperate with equipment via the standards/ protocols, e.g., MTConnect, AutomationML, and OPC-UA (Unified Architecture), to read the running data of the equipment layer in the workshop in real-time. The data from the IoT platform provides a reliable input for the evaluation of the operating effectiveness and efficiency of a VF manufacturing system. By integrating MES into the VF platform, on the one hand, the evaluation results can be utilized to provide a basis for the MES production scheduling and task scheduling of the VF, on the other hand, it can also be used as an auxiliary to dynamically build or improve the performance of the VF production system.

Using VF horizontal integration technology, it can integrate the distributed manufacturing assets and then establish a cloud manufacturing model. In addition to evaluating the performance of the collaborative manufacturing production line, the VF integration platform also manages product manufacturing business activities and related information in the VF environment. The IDEF (Integrated Definition Methodology) can be used for platform modeling. The platform supports multiple levels and multi-view integration of the manufacturing assets throughout the product life cycle and establishes a real and virtual digital twin model of mutual mapping. The MES can more reasonably perform production management, scheduling, and task scheduling, and optimize the performance of job tasks than the past, by integrated the digital twin model.

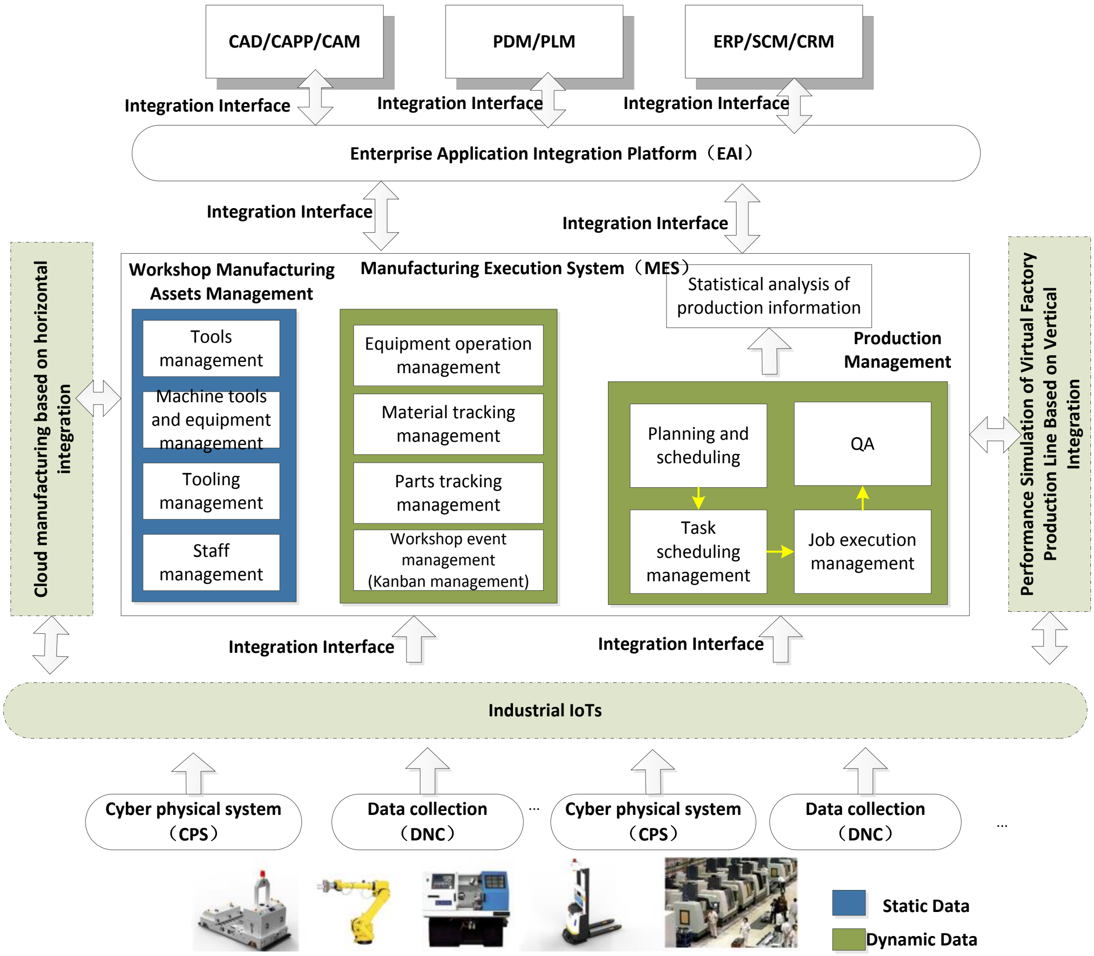

Figure 1. MES interoperability framework supporting VF applications.

4. Case study

A large domestic ship manufacture group that has tens of subordinate manufacturing plants and research institutes has formed an industrial chain that is similar to a VF. It has applied the intelligent manufacturing systems developed by KM-Soft Co since 2006. Recently, the group started the construction of the National Intelligent Manufacturing Demonstration Project, called Digital Workshop of Shipbuilding Engineering Mechanical and Electrical Equipment, which focused on the construction of the KM-MES based on an integration platform of the manufacturing assets from the distributed subordinate manufacturing enterprises (refer to Figure 2). Therefore, this study takes the case as an example to explain the availability of the aforementioned MES interoperability framework model which can be used to support VF operation.

First, the bottom layer is the VF platform. It uses MTConnect [10]/AutomationML [11]/ OPC-OA and other protocols to collect hardware data, such as machine tools, robots, and transportation equipment of the companies on the manufacturing chain. Through CPS/DNC and other methods, the dynamic data of the hardware equipment is transmitted to the IoT database. The vertically integrated subsystem for the distributed manufacturing assets can be established used to the VF production line evaluation purpose by combining with the production order information from the VF; the horizontally integrated subsystem of the distributed manufacturing assets can be established to provide services such as manufacturing assets discovery and optimized combination in the form of cloud manufacturing.

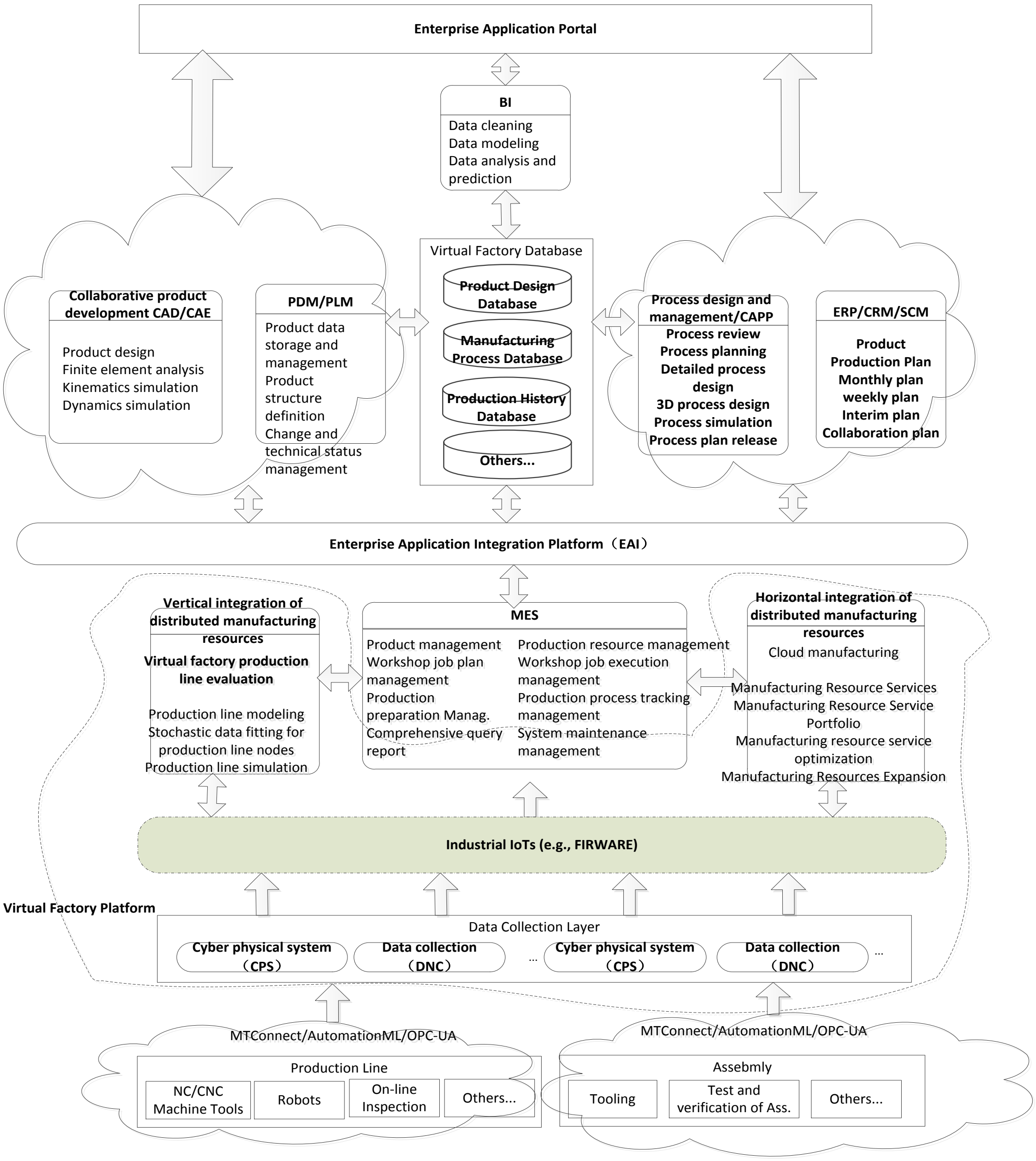

Figure 2. A case of virtual manufacturing platform between MES and VF.

Second, it is the MES system layer. By integrating with the VF platform, it can optimize the establishment of the marine power propeller product manufacturing chain and form an optimized VF production line by utilizing the manufacturing assets discovery and combination services provided by the cloud manufacturing subsystem. Also, it can integrate the subsystem which vertically integrates the manufacturing resources based on the VF platform, and to evaluate the performance of the established VF production line. Furthermore, it can continuously improve the performance of the VF production line.

The third layer is the industrial software layer. This layer is composed of CAD/CAE/CAX, the systems of PDM/PLM, the process design and management system, and the enterprise manufacturing assets management ERP/CRM/SCM. A production database of the VF is required at this layer to support the operation of the entire VF information system. The MES on the second layer can integrate the industrial software system on the layer through the enterprise application integration platform to realize the functions of production planning, organization, and manufacturing resource management in the workshop. The top layer is the enterprise user layer. This layer uses real-time data from the VF database to mine the manufacturing data. It can help to provide users with multi-view and multi-dimensional data mining results by BI technology, which assists corporate decision-making quickly and reliably. The other functions, e.g., browse and query personalized data via a graphical interface, are also provided.

5. Summary

Through the integration of the VF platform, its vertical integration (production line performance evaluation) and horizontal integration technology (cloud manufacturing) are taken as two aspects. (1) MES can effectively manage the distributed manufacturing resources of the VF by integration with the virtual manufacturing assets discovery, combination, and management services. (2) Combining the production plan information of ERP/MES, it can be used to evaluate the performance of the VF production lines, to continuously optimize and improve the performance of VF production lines, and to realize manufacturing business innovation.

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