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DOMAIN MODEL CONSTRUCTION METHOD OF AVIATION EQUIPMENT MANUFACTURING OPERATION MANAGEMENT

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Abstract

Aiming at the characteristics and management and control requirements of aviation equipment manufacturing process, this paper striped, abstracted and modeled the traditional organization-oriented Manufacturing Execution System(MES), constructed the Aviation Equipment Manufacturing Operation Management(MOM) Domain Model, and proposed a Reference Application Architecture of Manufacturing Operation Management Platform for aviation equipment manufacturing. Combined with the actual application requirements, the effectiveness and practicability of the proposed model and application architecture were verified.

Keywords: aviation equipment, MES, MOM, domain model, reference application architecture

1. Introduction

Aviation equipment has extremely high complexity, such as aircraft, with a large number of parts, complex manufacturing process, long development cycle, high cost and high risk[1][2]. Its manufacturing process data sources are wide (such as automatic equipment data acquisition, manual input and information system integration) [3][4][5], various types (such as information flow, logistics and capital flow) [6], complex structure (such as structured, semi-structured and unstructured) [7] and obvious hierarchy (such as design data, process data, manufacturing data, quality data, delivery data, etc.) [8], which need to be recorded, reviewed and archived in a standardized way. It is not only the basis of production management decision-making, but also an important guarantee for product quality and process traceability. Therefore, the main participants of the aviation equipment industry chain (including design units, OEMs, suppliers at all levels, etc.) [9] adopt manual paper records or paperless records in the information system to ensure the integrity and traceability of manufacturing process data.

For a long time, the OEMs of aviation equipment manufacturing had basically built a Manufacturing Execution System (MES) covering professional organizations such as machining, sheet metal, clamp welding, composite material, heat meter, cable, assembly, flight test and inspection[10]-[15], so as to realize the structured, semi-structured and unstructured data recording of manufacturing process and drive the management of manufacturing process. However, under the demand of rapid development and efficient batch production of aviation equipment, the traditional MES management mode led to the following problems:

- The main production plans came from the centralized department, but the internal plan management mode of the factories were very different and lacked the support of the integrated planning system.
- The change process was difficult to trace, and the real-time manufacturing data failed to realize two-way transmission.
- The product status data was not connected in series in all aspects, the quality process control ability was weak, and the efficiency of quality status cleaning (forward) and tracing (reverse) was low.
- There were many production supporting emergency responses, lack of advance planning, low use efficiency of logistics resources, low logistics operation efficiency, and unable to monitor the logistics process.

- On-site production resource management was chaotic and production matching was difficult.
- There were many types and quantities of manufacturing resources, difficult management and control, and high risks. Different roles such as process, production, and were house shared perception of resources, and resource requirements could not be sensed in advance.

Manufacturing Operations Management (MOM) refers to the integration of all production elements based on a unified domain model, through the manufacturing process, synchronizing quality operation, inventory operation, equipment operation and other platforms, and based on this for comprehensive operation optimization. In view of the above problems, this paper focused on the characteristics of aviation equipment manufacturing process management and control elements, large business span, many participants and strict quality control, analyzed its manufacturing process management and control requirements, and stripped, abstracted and modeled the traditional MES for organization division, constructed Aviation Equipment MOM Domain Models, including production planning model, production execution model, quality management model, production assurance model, logistics operation model, resource execution model, and proposed a Reference Application Architecture of MOM Platform for aviation equipment manufacturing. Combined with the actual application requirements of aviation manufacturing enterprise, the application verification of the proposed domain models and application architecture was carried out, in order to provide a useful reference for the construction of the industry MOM Platform.

2. Aviation Equipment MOM Domain Model Construction

Domain modeling is the process of analyzing and summarizing the actual problems solved by a system. On the basis of abstracting the specific business domains of each specialty, a unified business model as shown in Figure 1 was established to form a unified abstract business architecture to support specific business work.

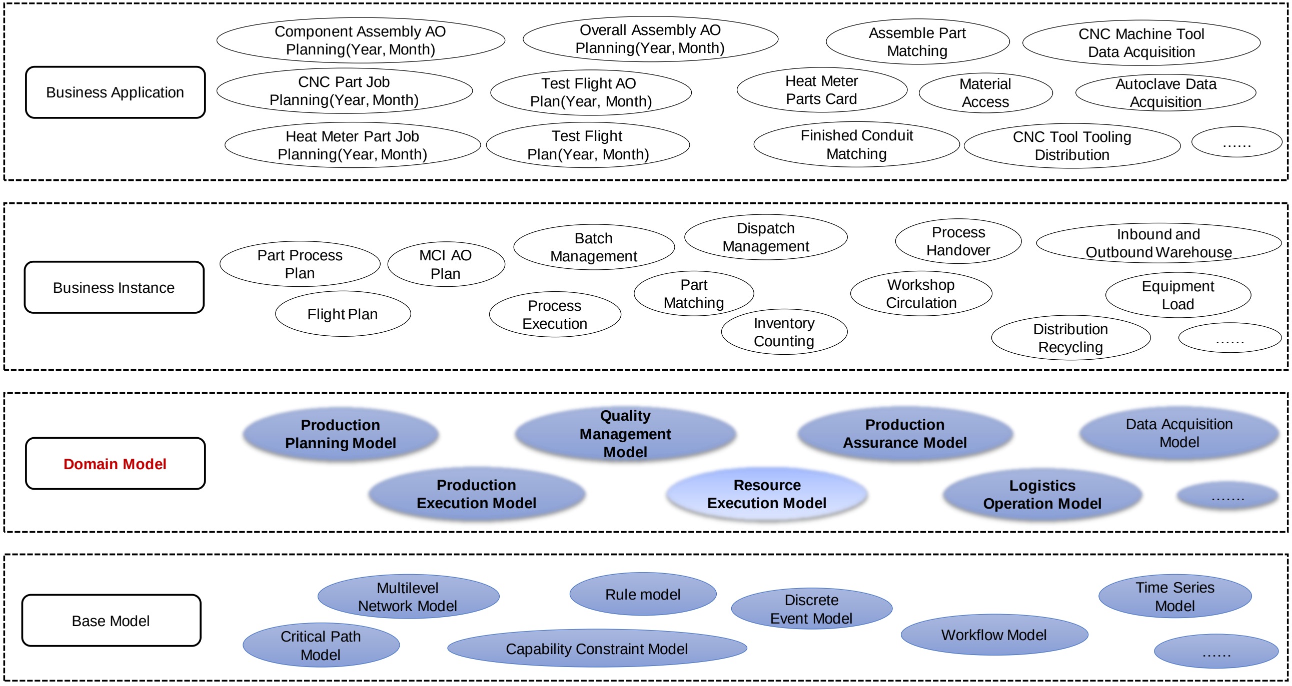

Figure 1 – Domain business model of Aviation Equipment MOM.

As the core link between the basic model and business model of aviation equipment manufacturing, the domain model involves four major business areas: quality operation, production operation, inventory operation, and maintenance operation, and covers six core business areas including quality management, production planning management, production execution management, production assurance management, logistics operation management, and resource execution management. In order to support the professional core business management requirements of parts, assembly, and test flight in the complex aviation equipment manufacturing process, this paper designed the domain model framework of Aviation Equipment MOM, as shown in Figure 2, and illustrated the detailed process of domain model constructed by focusing on the process of production planning domain model construction, entity abstraction and core service design. Due to the generality of the data acquisition model, there were industry-specific solutions for CNC machine tools, autoclaves, mobile equipment and other equipment, which would not be described in this paper.

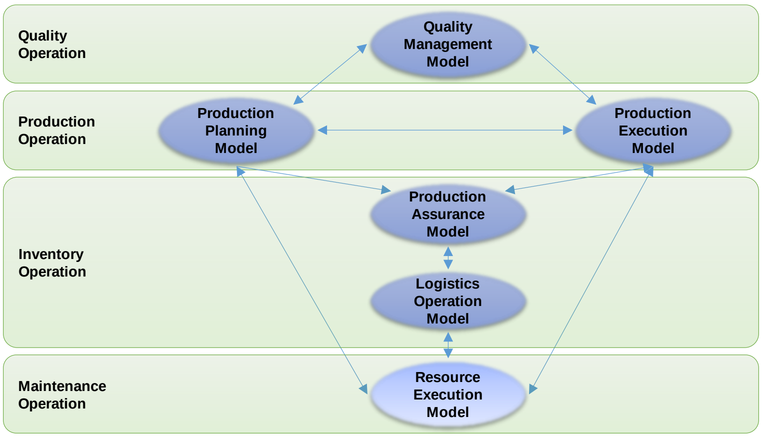

Figure 2 – Domain model framework of Aviation Equipment MOM.

2.1 Production Planning Model

Aviation equipment manufacturing enterprises are typical manufacturing-to-order production enterprises, which have the characteristics of simultaneous development and manufacturing, many product models, small batches, complex assembly and processing processes, and multi-professional collaborative production. The core of modeling in the domain of production planning was to solve problems such as plan breakpoints, overall plan scheduling difficulties, low resource utilization, weak production execution monitoring, delayed delivery, and overdue items in the manufacturing cycle, and established an integrated planning system to realize limited resource capacity scheduling, dynamic planning adjustment and multi-process integration, supporting dynamic scheduling based on multi-factor disturbances, and realized planning diagnosis and early warning in the whole process of parts, assembly, and flight test.

According to the business process and data flow characteristics of production planning, as shown in Figure 3, domain of production planning was divided into the following sub-domains: basic data, rough capacity scheduling (usually implemented in ERP), constraint scheduling, planning coordination, dynamic scheduling, and material requirement. By modeling the main entity data in these sub-domains, the object model was bound to the actual application, as shown in Figure 4. Comparing the relationship between the object model and the instance model, the actual business requirements and the application functions of the current MES system, it was identified that the current application mainly had the following four points to be improved.

(1) Basic data

- The granularity of the basic data was coarse. (Some AO data defined the overall assembly activity time in days)
- The data structure was incomplete. (The tooling and equipment information in the AO data was incomplete and partially missing. There was a lack of corresponding production resource requirements such as sites and personnel. The construction period data also had complete data and missing data);
- The data cannot support iterative update. (The data such as the planned period was not static during the use process, and need to be updated in time according to the actual use situation)

(2) Plan preparation

- The ERP system formulated the station plan (MCI plan), and the AO plan was mainly compiled by the personnel offline and uploaded to the system.
- In the offline compilation process, it mainly relied on human experience to use the method of safe time to make necessary corrections to basic data such as planning period.
- Information such as resource status and planning could not be checked through the system, and planners were relied on to coordinate conflicts between resources by manually considering relevant constraints.
- The system did not support the work package plan required for future development.

(3) Execution feedback

- After the plan was issued, the feedback on the execution of the plan was managed through the daily progress collection.
- There were problems such as lagging plan feedback and coarse management granularity, and the delivery risk assessment work urgently needed for plan management could not be implemented through the system.
- The difference between the plan and the execution was mainly through the form of verbal confirmation and empirical judgment to adjust the follow-up plan.

(4) Change response

- The high frequency of production changes and disturbances in complex manufacturing execution was the main reason for the deviation of plan execution. It was necessary to adjust the plan in time to reduce the impact on subsequent production execution and order delivery.
- At present, the judgment of the follow-up plan, resource occupation, and order delivery caused by production change disturbance was mainly made offline by personnel. On the basis of judgment and manual experience, the current plan and subsequent plans were adjusted and issued.
- In the above process, there were problems such as insufficient risk identification, difficulty in confirming the scope of influence, and inability to quantitatively evaluate the adjustment plan.

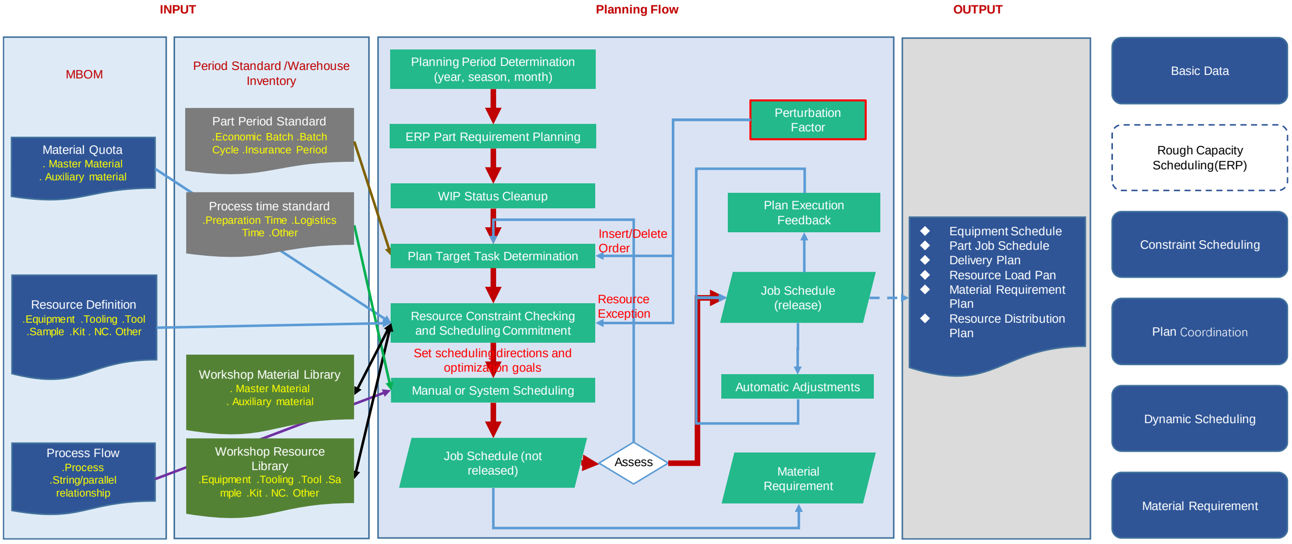

Figure 3 – Division of the production planning domain model.

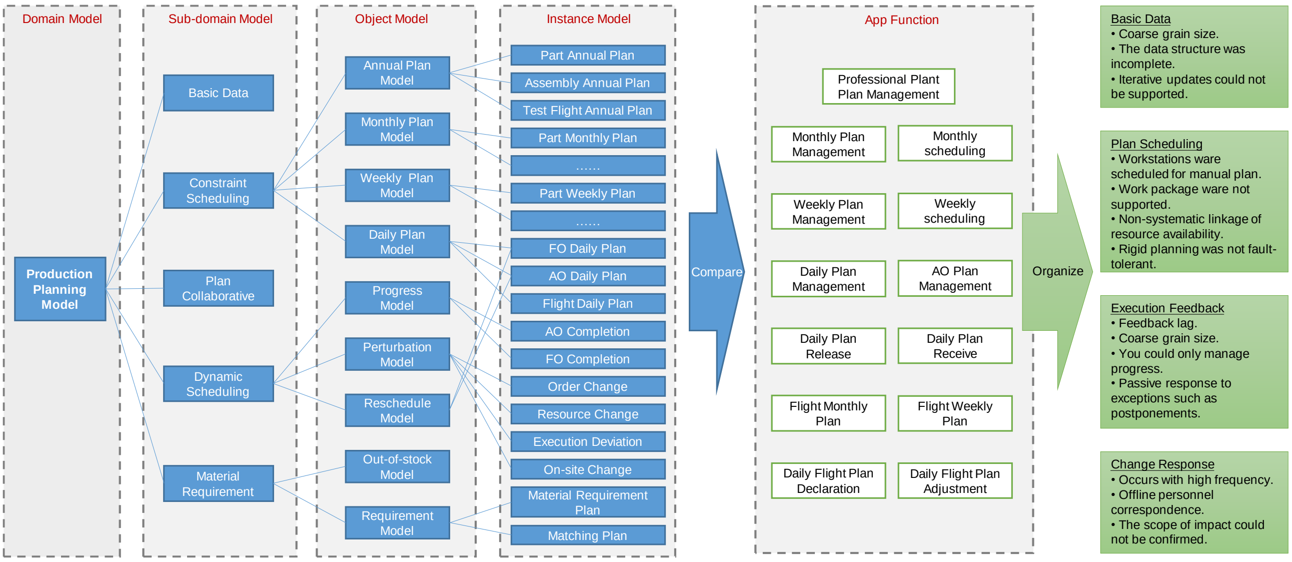

Figure 4 – Refinement of the production planning domain model.

In view of the above problems, entity abstraction and service design were carried out based on the production planning domain model, which was mapped and compared with the current application functions, and the core services corresponding to the planning module, externally dependent services and services provided to the outsides were defined, as shown in Figure 5.

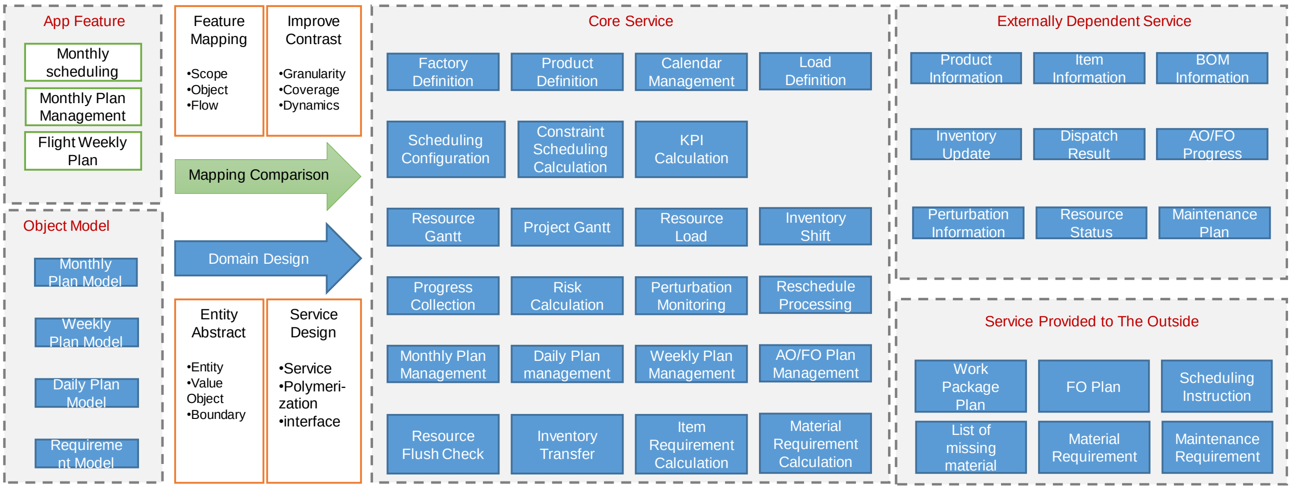

Figure 5 – Core service in production planning domain.

After completing the domain model mapping and core service construction, the relationship between the MOM planning module and the upper ERP and NICE system, the MOM planning module and the manufacturing execution, logistics management, resource management and other modules within the MOM system were analyzed through the panorama shown in Figure 6.

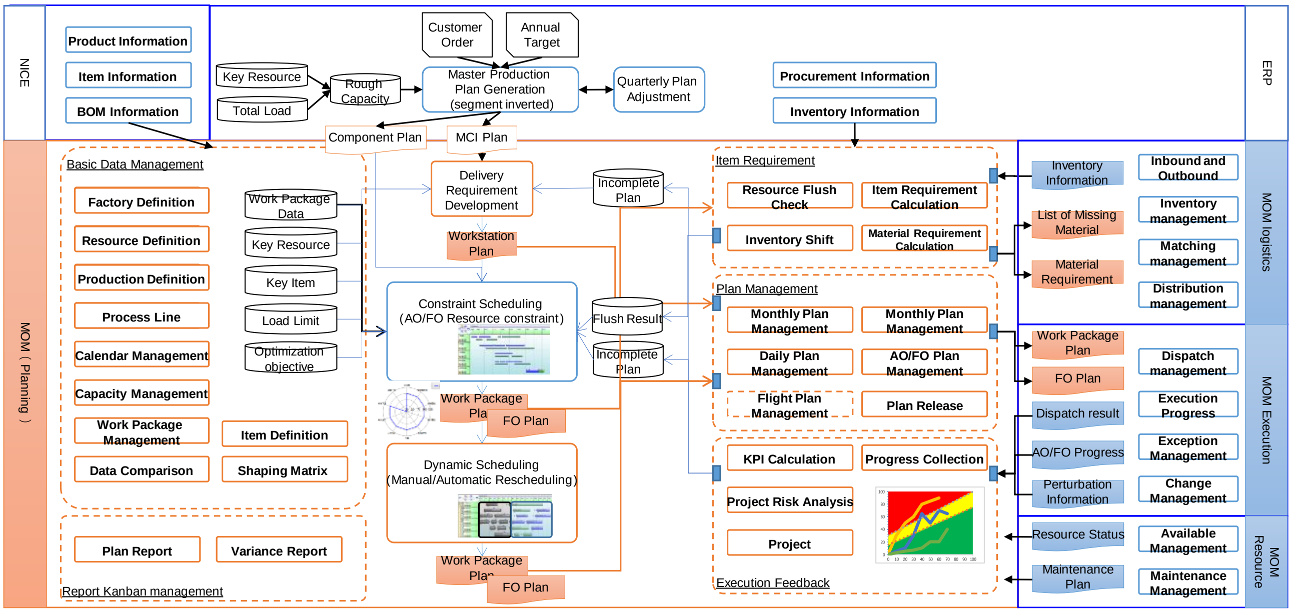

Figure 6 – The panorama of production planning domain.

- Upper NICE system: The NICE system mainly managed product information, BOM information, process route information, and basic process information of material information.
- Upper ERP system: The ERP system formulated the master production plan according to the rough capabilities commonly formed by key resources (such as frames), total load, and standard production line takt.
- MOM planning module: The planning module mainly included basic data management, constraint scheduling and deployment, planning management, execution feedback and dynamic scheduling, material requirement. The related functions of constraint scheduling performed constraint scheduling for assembly work packages and parts FO according to the delivery constraints of the MCI plan and detailed constraints such as material and load restrictions, and formed a work package plan/FO plan. The assembly work package plan was planned to be developed in the form of AO forward row to obtain the AO plan.
- MOM manufacturing execution module: Received AO/FO plans, and given feedback on dispatch results. Fed back the AO/FO production progress and disturbance information in the production process to the planning module.

- MOM logistics management module: Fed back the inventory information to the planning module to support the completeness check. Received the material shortage list and material requirements generated in the planning module, and process them accordingly.
- MOM resource management module: Fed back the resource status, resource maintenance plan, etc. to the planning module to support resource availability check. At the same time, the production plan generated by the planning module was received, and the corresponding material guarantee processing was carried out.

2.2 Production Execution Model

Production execution is a key link in the generation of core data in the production and manufacturing process of complex aviation equipment. The core of modeling was to solve the problems that the change process was difficult to trace and the real-time manufacturing data could not be transmitted in both directions based on the workflow and established a WIP data feedback mechanism, coordinated the change process, optimize and improve the existing configuration change and process change functions, and realized the traceability of the WIP details change process of parts, assembly, and test flight, and two-way transmission of real-time manufacturing data.

The production execution model mainly included three sub-domain models: work batch model, work activity model, and work flow model. The object model and instance model were designed from top to bottom, as shown in Figure 7.

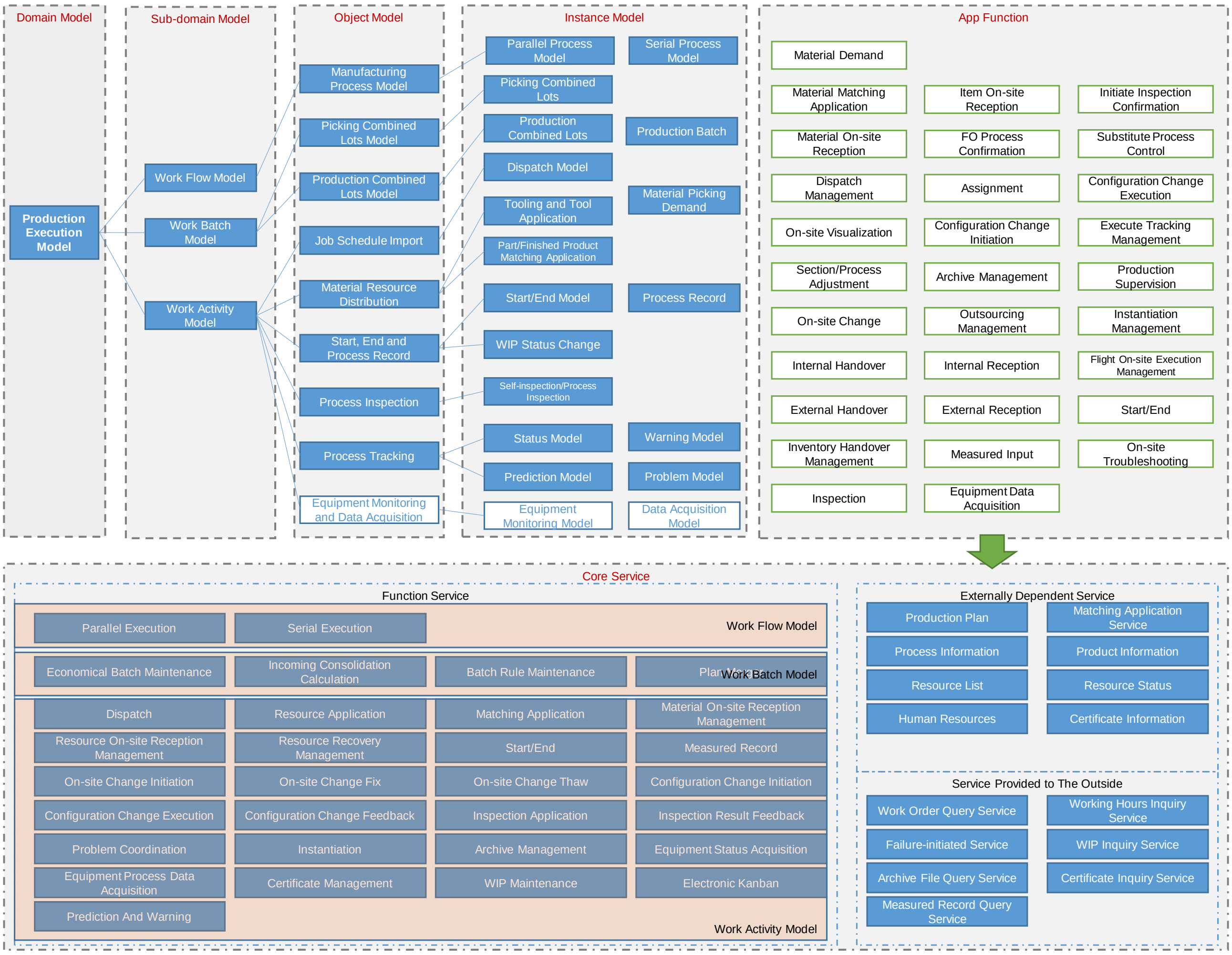

Figure 7 – Production execution domain model.

A certain number of objects are decomposed into one-to-one or one-to-many management units according to the rules, and these management units are called work batches. The work batch model was the cornerstone of the manufacturing process management. By monitoring and recording the status of the batch, it met the requirements of "tracking, controlling, and tracing" the product manufacturing process. The work batch model corresponded specifically to the part batch. The work flow model corresponded to the process flow. The work activity model included seven core links: job schedule import, material resource distribution, process data download, start/finish/process record, process inspection, process tracking, equipment monitoring and data acquisition. The work activity model specifically corresponded to the process execution.

The production execution model realized the traceability of the manufacturing process and the grasp of the WIP status by abstracting the core business and stripping the functions of the original MES system, as shown in Figure 8.

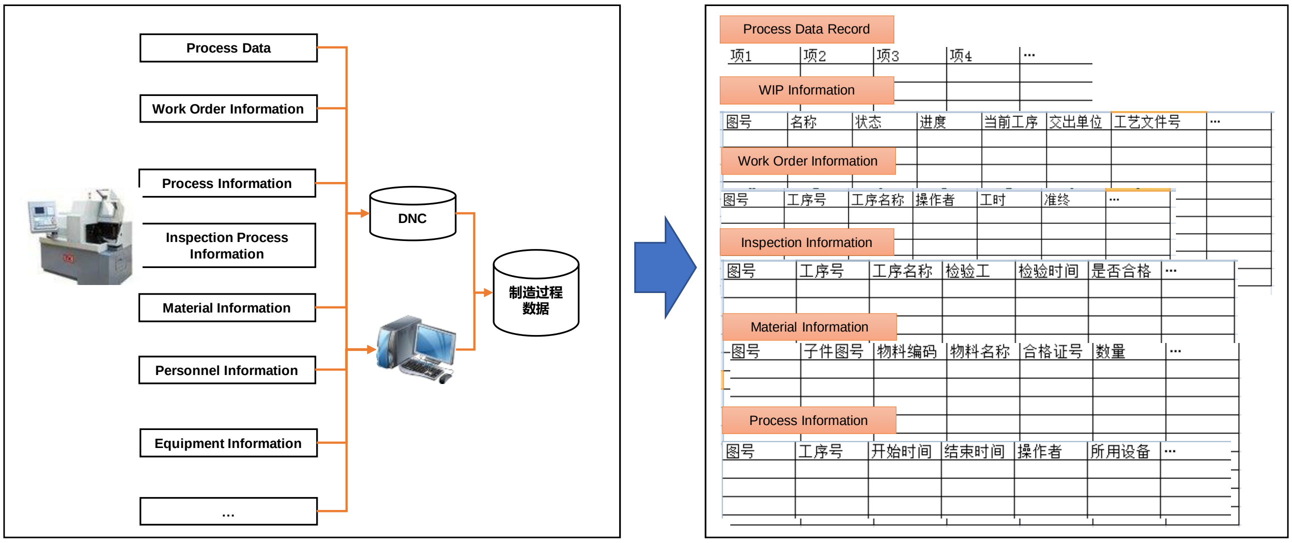

Figure 8 – Manufacturing process traceability and WIP status tracking.

As shown in Figure 9, through the two-way mapping of process activities and work activities, two-way change process traceability and real-time manufacturing data transfer on the professional value chain were realized.

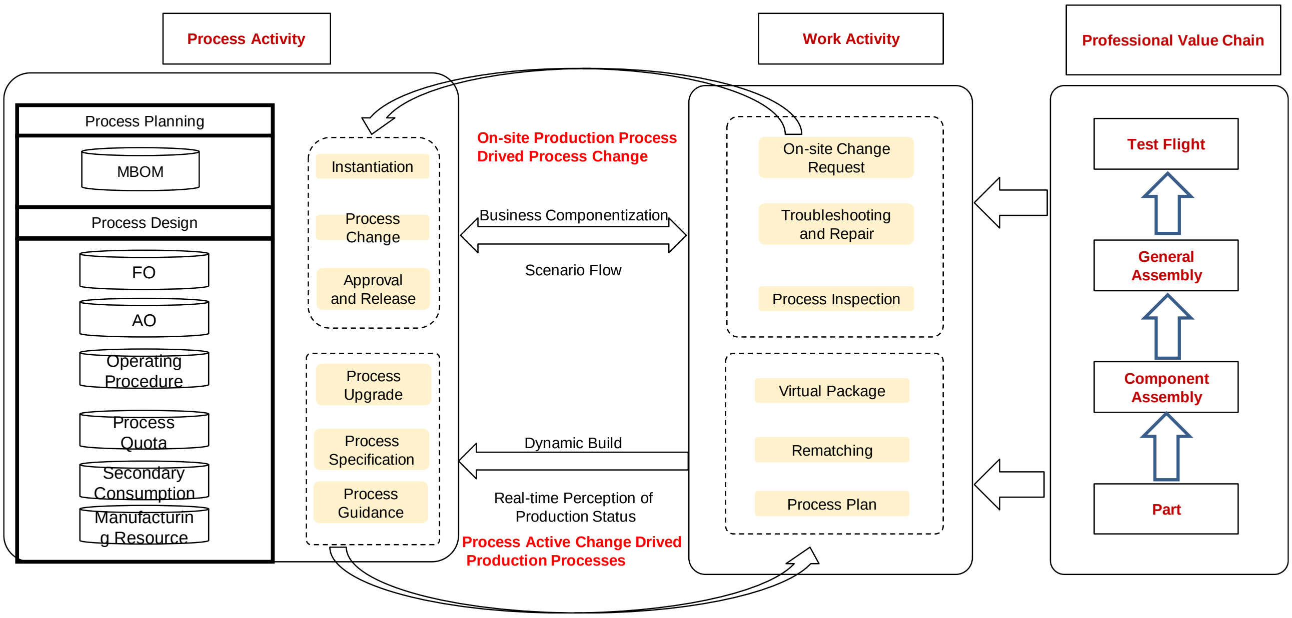

Figure 9 – Collaboration of process changes and work activities.

2.3 Logistics Operation Model and Production Assurance Model

The logistics operation model and production assurance model realized the management of different states of materials and resources and the transition between different states, including five sub-fields of logistics/warehousing planning, logistics execution, matching, inbound and outbound, and in-warehouse operations, as shown in Figure 10.

Aiming at the chaotic management of on-site production resources and the difficulty of supporting production, the model optimized and integrated traditional MES functions. Key optimizations included:

- Increased warehousing/logistics planning.
- Established logistics scheduling and execution driven by production planning and logistics tasks.
- Unified and standardized warehouse inbound and outbound rules and logic to achieve standardized management.

- Deconstructed the identification and binding function of physical objects and information flow and the inventory function, which realized the configurable management of various physical identification methods.

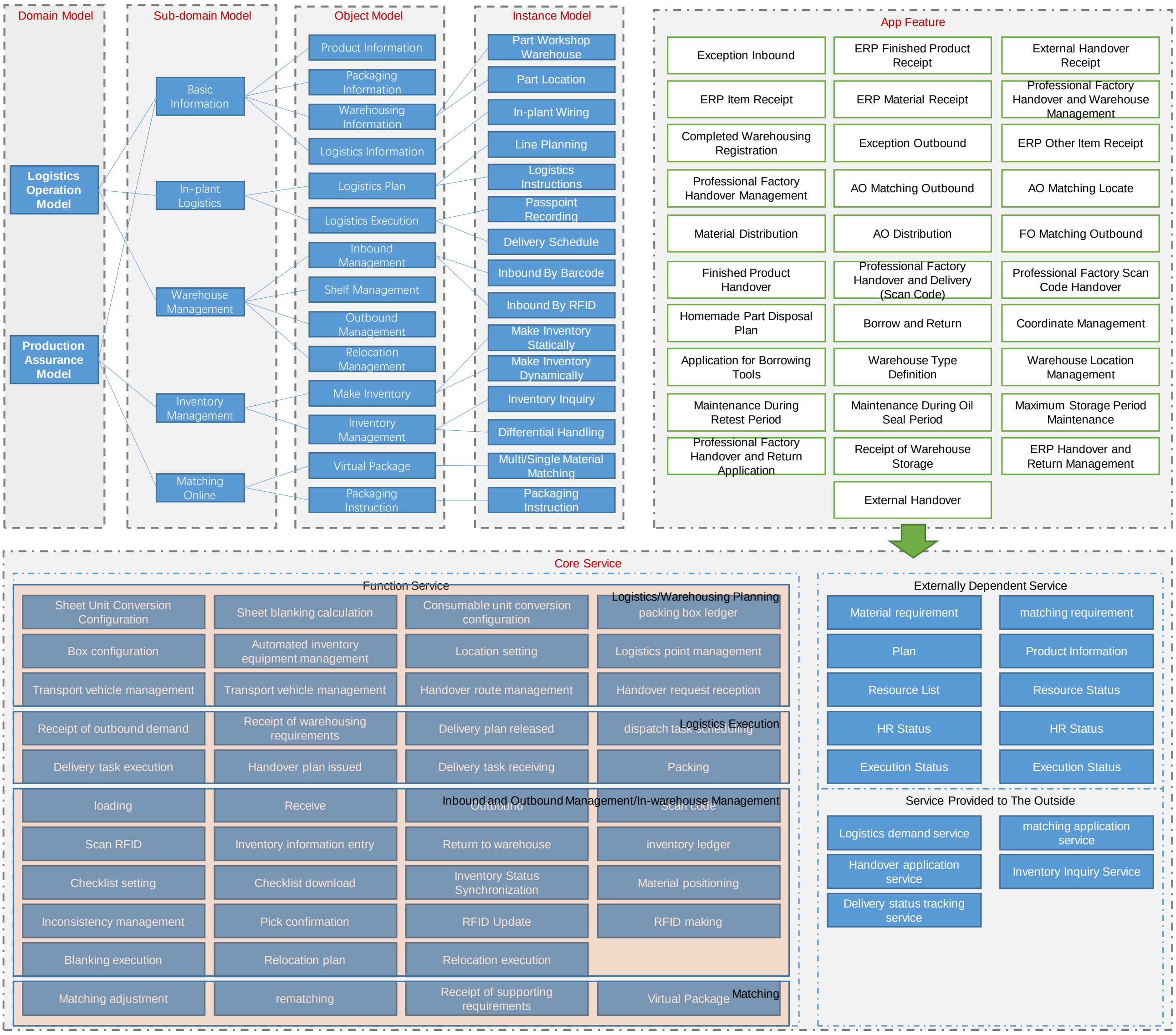

Figure 10 – Logistics operation and production assurance domain model.

2.4 Quality Management Model

The quality management model includes inspection basis model, inspection execution model, quality record model, and quality improvement model, as shown in Figure 11.

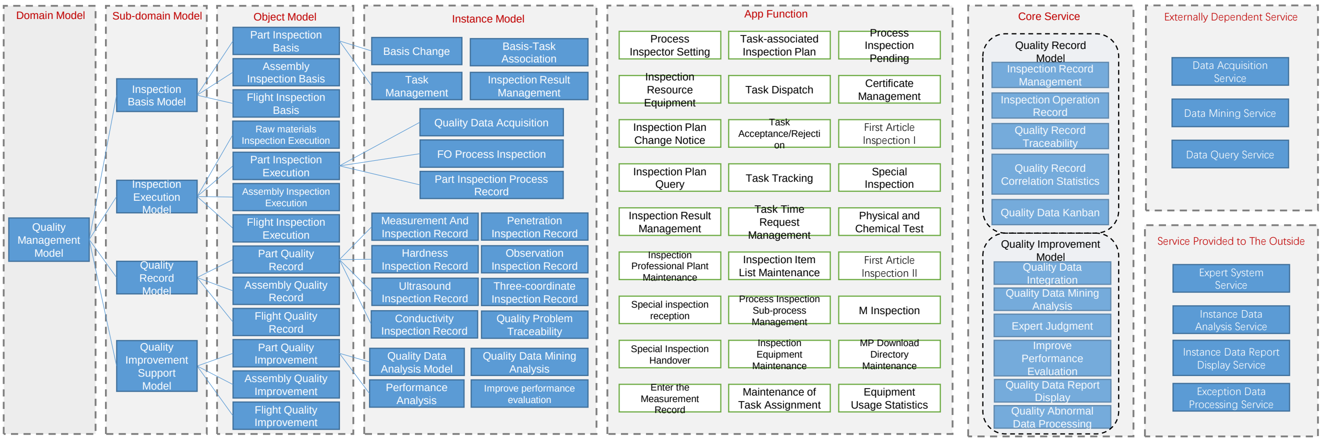

Figure 11 – Quality management domain model.

Aiming at the problems of unreasonable scheduling of inspection tasks, incomplete quality record data, low availability of quality data, and low inheritance of automated inspection equipment, the model guided inspection execution based on inspection basis, and fed quality records back into the inspection process, thereby realizing the overall quality improvement. At the same time, it was integrated with the NICE/ERP system to strengthen the process control of the inspection business, which realized the quality control of the whole production process from parts, assembly to flight test.

2.5 Resource Execution Model

The resource execution model mainly focused on "manufacturing resource management" to create a comprehensive and efficient management system for manufacturing resources such as personnel, equipment, tooling/tools, etc. to support the orderly and efficient production activities. The resource execution model was divided into resource structure model, resource status Model, resource planning model and resource maintenance model, as shown in Figure 12.

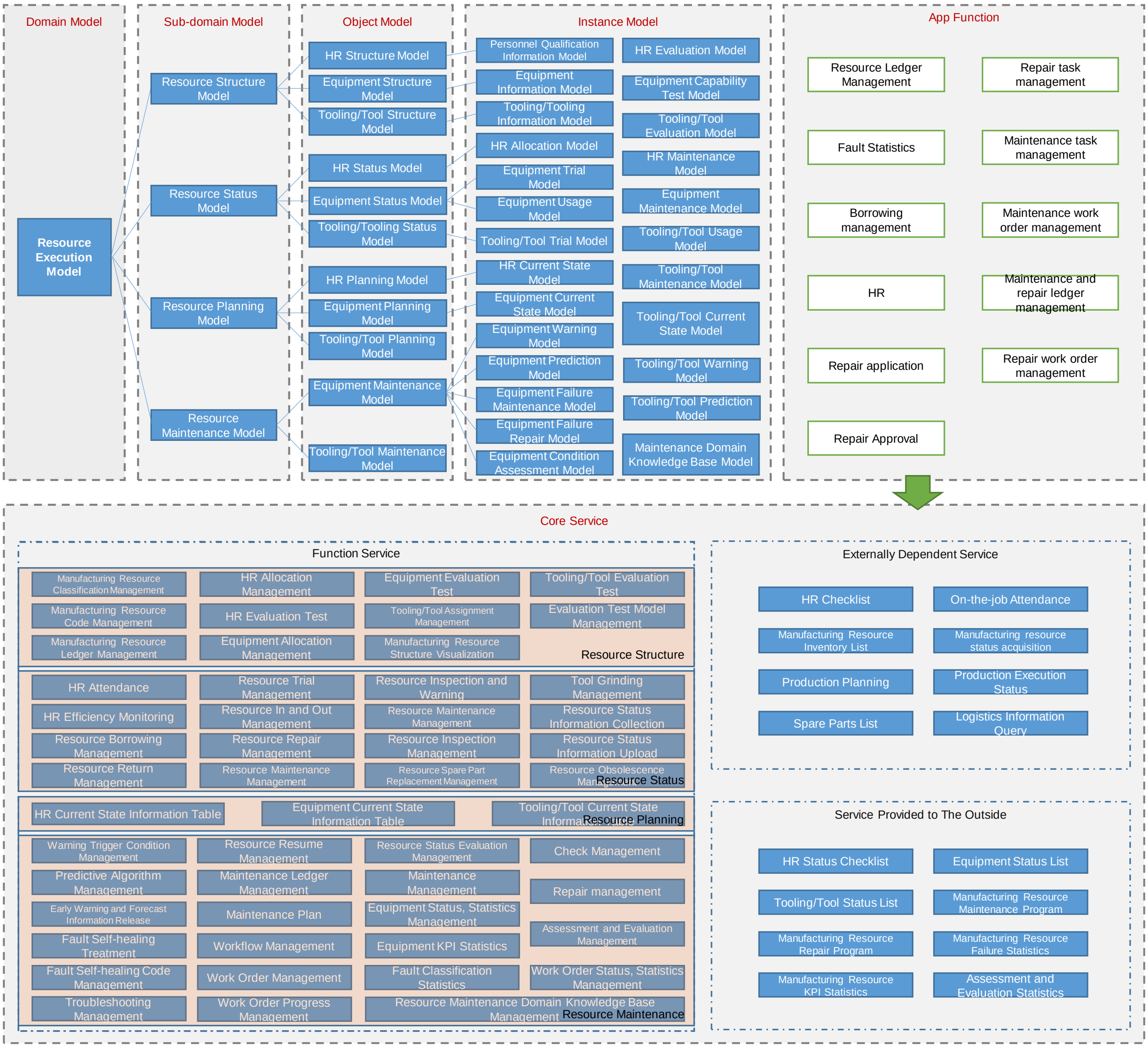

Figure 12 – Resource execution domain model.

3. Reference Application Architecture of Aviation Equipment MOM Platform

Based on domain model construction, entity abstraction and core service design process, the Reference Application Architecture of Aviation Equipment MOM Platform designed and proposed in this paper supporting lean manufacturing operations. As shown in Figure 13, the platform was divided into 7 layers: Industrial internet platform, equipment data acquisition and interconnection, data management, application, specialized unit production APP, on-site kanban and digital twins, manufacturing operation monitoring.

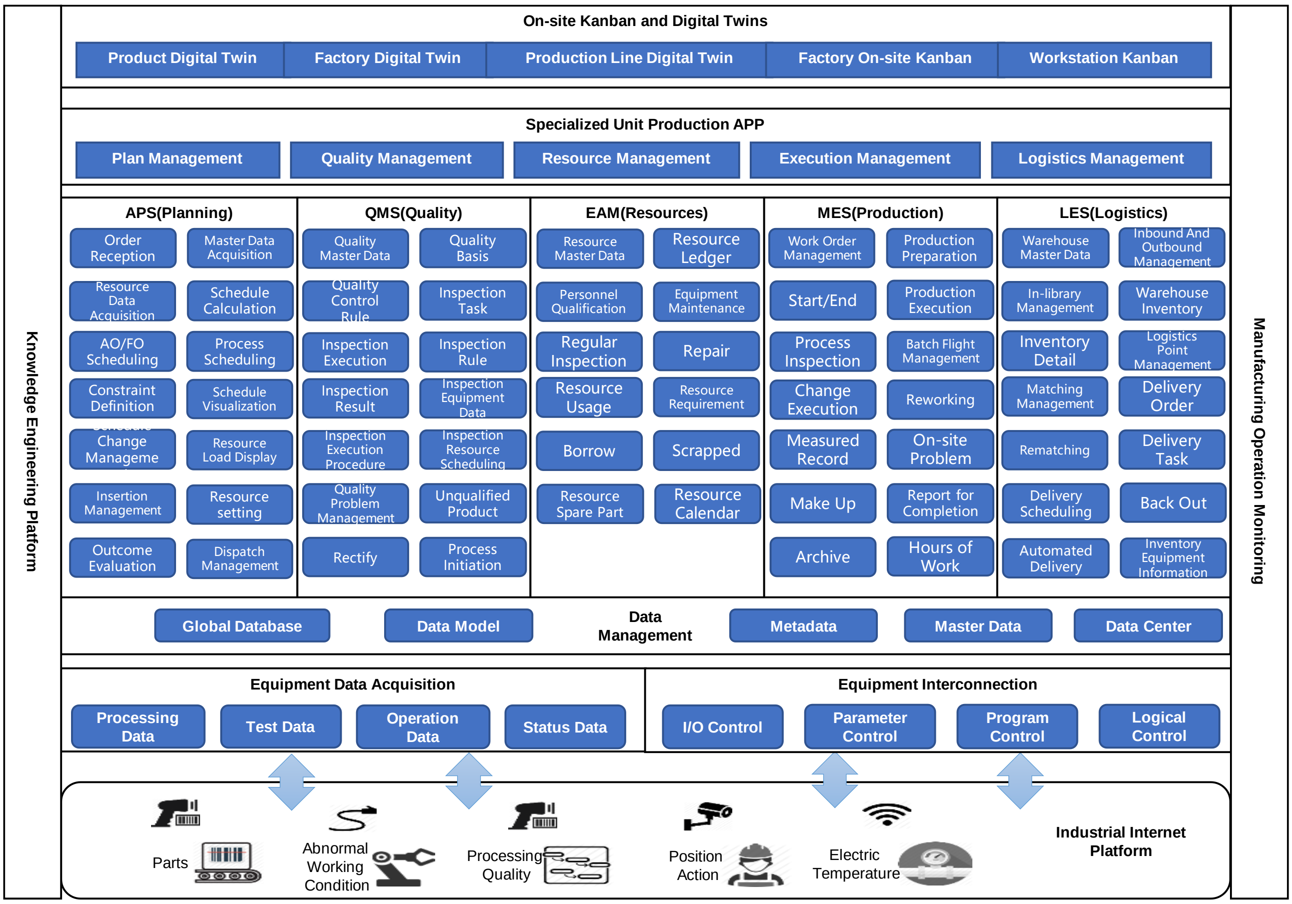

Figure 13 – Reference Application Architecture of Aviation Equipment MOM Platform.

(1) Industrial internet platform

This layer was an integrated environment for industrial interconnection supported by various types of equipment and network environment, including mechanical processing equipment, digital inspection and testing equipment for assembly, automatic storage equipment, etc. In the industrial Internet, network ports or host computers were used to achieve network-wide equipment intercommunication.

(2) Equipment data acquisition and interconnection

This layer was to realize the exchange of equipment and system information, including equipment parameter acquisition, equipment status acquisition, equipment instruction issuance, equipment execution program transmission, etc. Its realization was provided by the industrial equipment data acquisition system.

(3) Data management

This layer was a data logic expression layer based on the unified data architecture of the enterprise. Its core was mainly metadata management, master data management, and data model management. The system data architecture design adopted the enterprise unified standards and tools.

(4) Application

This layer was the core business application layer implemented by the system. According to the business domain, it was divided into five sub-domains (sub-systems), namely planning, quality, production, resources, and logistics, using the object-oriented inheritance and expansion thinking for business organization.

(5) Specialized unit production APP

This layer was a specialized APP application based on the service assembly of the core application layer, which could be classified according to the production organization form of the production unit, such as sheet metal APP, finishing APP, heat treatment APP, butt joint APP, etc. All on-site APPs adopted the service assembly method, and used the built-in application layer functions for free assembly. The assembled APP must contain all the business of the five sub-domains, namely planning, quality, production, resources and logistics.

(6) On-site kanban and digital twins

This layer was to utilize the data of the system operation process. The management of data assets and the operation process were managed by the enterprise statistical data center and the industrial big data platform. The data in this layer came from the unified data services provided by the two platforms. The implementation content included on-site Kanban, model-based digital twin, data mining analysis (SPC analysis), etc.

(7) Manufacturing operation monitoring

This layer was an important supplement to the system operation idea. Its core logic was to monitor and track the operation status, operation logic, and data status of each business sub-domain and functional module to ensure the normal operation of the entire system.

4. Application Case - Complex Equipment Manufacturing Operation Platform

Combined with the actual application scenario of company A, an aviation manufacturing company, based on the domain model construction method and platform reference architecture proposed in this paper, the original MES function of company A for professional organizations was stripped, abstracted, and encapsulated (implemented according to the logic of Figure 14). First, business scenarios for core business domains was abstracted. Then, based on the good encapsulation, reusability and collaboration of the domain model, the page development method based on the visual arrangement of components as shown in Figure 15 was used to form a reusable and configurable core service library to support the manufacturing operations of Company A business operation. Finally, through service organization, orchestration, release and management, Complex Equipment Manufacturing Operation Platform was formed (as shown in Figure 16).

The platform was fully compatible with the functional model and data model of the original MES, and the core services were reduced by 2/3 compared to the original functional menu, which greatly reduced the amount of code development. It greatly improved the fault tolerance, stability and scalability of the platform through service organization and orchestration. New functions or new versions were released in the form of services, and version upgrades could be completed through configuration, avoiding changes at the underlying code level.

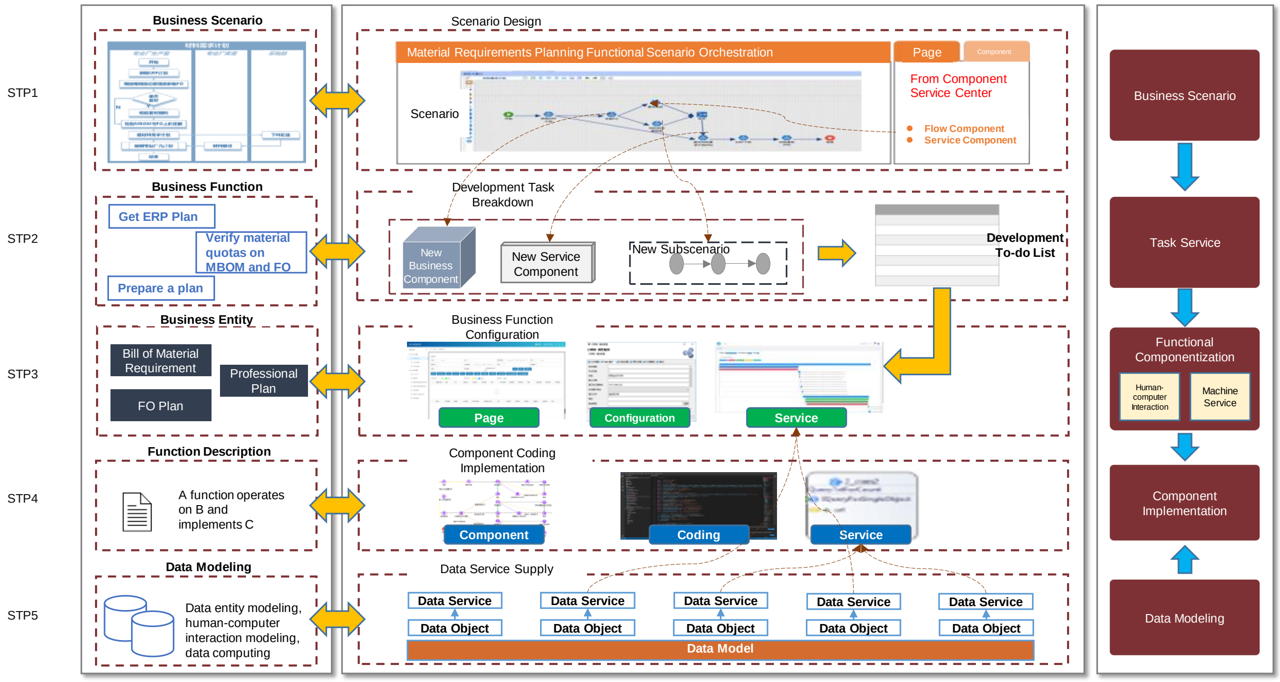

Figure 14 – Domain model implementation logic.

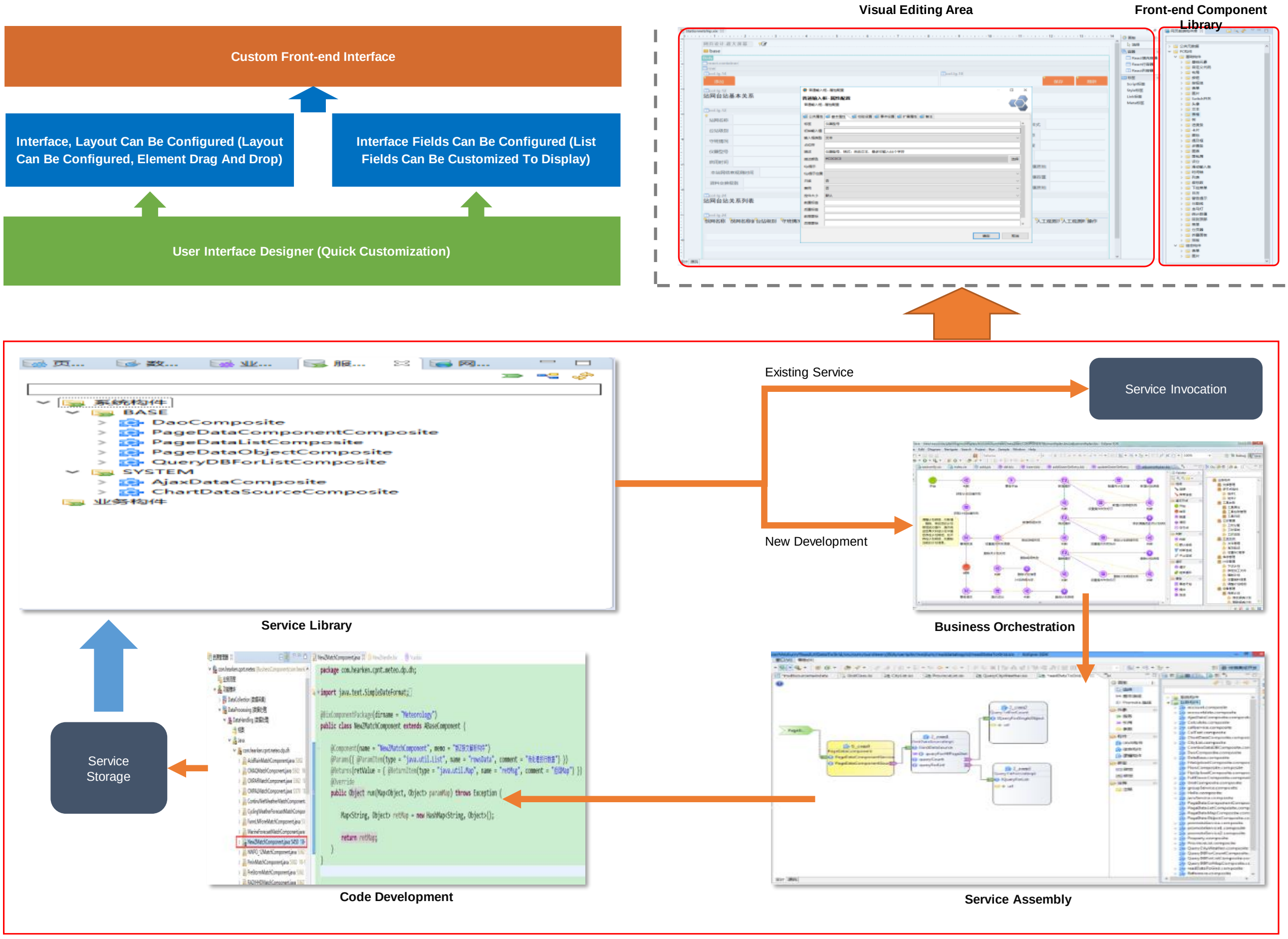

Figure 15 – Page development based on component visual arrangement.

工艺规程。它是一种在确定的生产条件下，说明并具体规定零件加工工艺过程的技术指导性文件。它是保证产品质量，降低成本，提高劳动生产率的基本依据。

工艺规程是用文字、图表和其他载体确定下来，指导产品加工和工人操作的主要工艺文件。它是企业计划、组织和控制生产的基本依据，是企业保证产品质量，提高劳动生产率的重要保证。在机械制造企业中.

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Figure 16 – Platform implementation example.

5. Conclusion

(1) Striped, abstracted, and modeled the traditional MES system oriented to organizational division, and constructed the Aviation Equipment MOM Domain Models, including production planning model, production execution model, quality management model, production assurance model, logistics operation model and resource execution model.

(2) Based on the unified domain model, the Reference Application Architecture of the Aviation Equipment MOM Platform was proposed, including the industrial internet platform, equipment data acquisition and interconnection, data management, application, specialized unit production APP, on-site kanban and digital twins, manufacturing operation monitoring.

(3) Based on the proposed domain model and application architecture, combined with the actual application requirements of aviation manufacturing company A, the Complex Equipment Manufacturing Operation Platform was successfully constructed, the validity and practicability of the domain modeling method were verified, which provided a useful reference for the industry to build a manufacturing operation system.

References

[1] Huang W, Xu A, Li X, et al. Key technologies of intelligent process cloud construction for aviation structural parts manufacturing. *Manufacturing Technology & Machine Tool*, No. 09, pp 101-106, 2021.

[2] Sui S, Mu W, Gong Q, et al. Digital workshop and intelligent manufacturing practices. *Aeronautical Manufacturing Technology*, No. 7, pp 46-50, 2017.

[3] Zhang J, Sheng X, Zhang P, et al. Two-stage unsupervised feature selection method oriented to manufacturing procedural data. *Journal of Mechanical Engineering*, Vol. 55, No. 17, pp 133-144, 2019.

[4] Lv S, Qiao L, Liu W. Formalized and semantic modeling of manufacturing process data. *Journal of Mechanical Engineering*, Vol. 48, No. 10, pp 184-191, 2012.

[5] Wang J, Zheng P, Lv Y, et al. Fog-IBDIS: industrial big data integration and sharing with fog computing for manufacturing systems. *Engineering*, Vol. 5, No. 4, pp 662-670, 2019.

[6] Xiao Y, Li B, Hou B, et al. Planning and scheduling technology review of supply chain management in smart manufacturing cloud. *Computer Integrated Manufacturing Systems*, Vol. 22, No. 07, pp 1619-1635, 2016.

[7] Jiang Z, Su H. Research on knowledge management for engineering design. *Computer Integrated Manufacturing Systems*, No. 10, pp 1225-1232, 2004.

[8] Bai Y, Liang K, Zhou S, et al. Research on the Cooperative Association of Aircraft Design and Manufacturing Based on MBD. *Aeronautical Manufacturing Technology*, No. 18, pp 40-44, 2015.

[9] Sui S, Xu A, Li X, et al. Fusion application of DT and AI for aviation intelligent manufacturing. *Acta Aeronautica et Astronautica Sinica*, Vol. 41, No. 07, pp 7-17, 2020.

[10] Song J, You J, Chen S, et al. Production planning and manufacturing execution system for integration of scientific research and production. *Aeronautical Manufacturing Technology*, No. 18, pp 108, 2014.

[11] Wang J, Zhou X, Guo Y, et al. Design and implementation of software architecture for extensible manufacturing execution system. *Computer Integrated Manufacturing Systems*, Vol. 20, No. 05, pp 1035-1050, 2014.

[12] Zhang L. Manufacture execution system in aviation digitization environment. *Aeronautical Manufacturing Technology*, No. 09, pp 54-57, 2014.

[13] Li Y, He W, Dong R. Functional-evolution method for implementation of manufacturing execution system. *Computer Integrated Manufacturing Systems*, Vol. 19, No. 03, pp 507-515, 2013.

[14] Du H, Ye W, Lou P. Design and implementation of manufacturing execution system for aircraft tools. *China Mechanical Engineering*, Vol. 21, No. 21, pp 2578-2583, 2010.

[15] Wang C. Application of lean manufacturing and MES in aviation manufacturing enterprise. *Aeronautical Manufacturing Technology*, No. 19, pp 42-45, 2008.

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