Exploration and Practice of Digital Factory of Complex Electronic Equipment

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Abstract. For the characteristics of many varieties, small batch, short delivery cycle and high quality requirements of complex electronic equipment manufacturing, combined with a new generation of information and communication technologies and the research of advanced manufacturing technology, This paper puts forward the implementation framework of digital factory of complex electronic equipment, analyzes the connotation of digital factory, explores the application of digital twin in the manufacturing stage, discusses the process of data perception, fusion and analysis of digital factory, and establishes the factory production operation control platform. This paper verifies the feasibility of complex electronic equipment digital factory floor by the example of radar assembly digital factory, and provides theoretical basis and method reference for the comprehensive application of digital factory in complex electronic equipment field in the future.

1. Introduction

Complex electronic equipment is widely used in the fields of machinery, electric power, ships and aircraft, and is an important pillar of the national people's livelihood and national defense security. Complex electronic equipment involves many subjects, ranging from information science and technology such as electronics, communication, computer and control, to advanced manufacturing technologies such as additive manufacturing, micro-assembly and automation. It covers a wide range of knowledge and many fields, which means higher requirements for complex electronic equipment enterprises [3]. Its typical characteristics is strict manufacturing process standards, fast switching of mixed production line, strict production task planning, high product quality requirements. The traditional "equipment + artificial management" model has been difficult to meet the requirements of fine control in factory. Therefore, we must be with the aid of new technology and production mode to adapt to the intense competition of product performance, quality, cost and delivery of complex electronic equipment factory.

Generalized digital factory is geared to the needs of whole life cycle of products, based on the simulation technology and virtual reality technology, and that a physical entity of the whole production process is digital simulated, evaluated and optimized in virtual environment is a new production organization way. Digital information and the data flow as the main characteristics, its purpose is to achieve rapid, low cost and high quality manufacturing [7]. In the narrow sense, digital factory is oriented to the production and manufacturing process of products, and design, management, simulation, optimization and visualization of the production resources and production process of people, machine, material, method, environment and measurement, etc., which is also aimed at reducing cost, improving quality and increasing efficiency[6] [23]. This article discusses the complex digital electronic equipment factory in digital information and the data flow as the main characteristics,

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by means of digital, networked, intelligent, improving the production organization and management to realize workshop sophisticated controls, to satisfy flexible, efficient, high quality, transparent manufacturing needs of complex electronic equipment [5].

The world's most prestigious digital factory is the Siemens Amberg plant in Bavaria, Germany. The factory was founded in 1989. During 30 years of development, it experienced from the introduction of workshop management system, to RFID, to data optimization management, and then to the process line management system, to achieve a high degree of automation of the production process, 75% of the process work by the production equipment and computer processing. In recent years, the product information and physical entities in the virtual environment of Digital Twin system are mapped to each other to optimize and control the manufacturing process in real time. At present, the factory can produce one control device per second on average, and the product qualification rate is as high as 99.9988%[8].

GE aviation engine manufacturing center, located in Ohio, is a typical representative of another model of digital factory: "sensor + big data" industrial Internet model. Predix is GE's first cloud service platform developed specifically for industrial data analysis, enabling engine data acquisition and status monitoring through seamless integration with various applications and services deployed in the cloud [24]. At the same time, for the complex discrete manufacturing process of engines, GE has established a powerful production management and manufacturing execution system, which combines lean concepts with automation and digital methods to achieve comprehensive improvement of manufacturing performance [9, 10]

Qingdao Haier mold co., LTD. (hereinafter referred to as Haier mold) is the largest mold and fixture manufacturer in China, and is one of nine interconnected factory demonstration units. Aiming at the digital factory featuring automation and fewer people, Haier mold has built the leading CPS collaborative production management system in China since 2013, realizing the free flow of data through equipment interconnection. Through system integration, information sharing and collaborative manufacturing can be realized; Through data collection, analysis and display, to achieve scientific management; Through real-time monitoring of equipment status, predictive maintenance is realized. The successful implementation of the CPS system has improved the production efficiency and enterprise competitiveness of Haier mold, and achieves good economic and social benefits.

Ningxia sharing group, located in western China, which belongs to traditional manufacturing industry, is one of the first batch of 46 intelligent manufacturing pilot and demonstration projects of the ministry of industry and information technology. Through the information integration of ERP, PLM, MES, DNC and other systems, it realizes the digitalization and transparency of workshop production process. The free and orderly flow of data in the workshop can be realized through the integration between information systems, production equipment, physical world and virtual world.

Digital factory is the foundation of intelligent manufacturing and the only way for industry 4.0. Many domestic and foreign manufacturers have built or started to build their own digital factories [2]. In the face of rapid emerging technologies and increasingly fierce market competition, digital factories will integrate various new technologies such as artificial intelligence and data mining, so that factories can learn, think and make decisions just like people, and finally realize intelligent factories.

Compared with Siemens, GE and other international leading enterprises, the domestic digital factory started relatively late. At present, that is mainly used in casting, machining and other traditional industries. It is not yet mature for electronics industry whose characteristics are many varieties, small batch. And the construction of standard system, data fusion analysis, digital twin, control operating platform construction of research remains to be strengthened.

This paper, firstly, introduces the concept and implementation method of digital factory for complex electronic equipment, and then analyzes its connotation and frame, and discusses the key technology of digital factory practice. Finally, based on theoretical exploration, the paper combined digital factory with complex electronic equipment production and manufacturing, introduces the application cases of complex electronic equipment in digital factory, and provided a method reference for the implementation of digital factory in many-varieties and small-batch manufacturing enterprises.

2. Connotation of complex electronic equipment digital factory

Complex electronic equipment is the product of the integration of multiple subsystems through complex coupling relation. In addition to meeting the individual functions in their respective fields, it is also required to meet the overall functions of the system after coupling integration. Therefore, the manufacturing process of complex electronic equipment emphasizes more on reliability and integrity [4].

Digital factory of complex electronic equipment is the mutual mapping between physical entity operation and information flow in the assembly process of complex electronic equipment from parts to complete machine, which can truly reflect the integration process and meshing relationship of each part from single to whole. On the basis of operation control platform, it is targeted at refined production factors such as human, machine, material, method and environment, and combined with advanced scheduling, data collection and analysis, digital twining and other application functions to digitize physical entities and visualize plant operation, so as to realize the research and application of complex electronic equipment digital factory.

Digital factory, factors of production, operation process and product as the core, on the basis of whole life cycle of product data, applies simulation technology, virtual reality technology, data fusion and analysis technology, etc., digitize all the physical activities of products in the factory, and analyze these activities, optimization and feedback mode of an integrated organization [8].

Digital factory emphasizes the digitization of production factors, processes and products, which is the digitization record of each step in the real factory (such as process planning, manufacturing, quality inspection, process management, fault maintenance, etc.). Compared with traditional factories, what is more important is that digital factories can optimize and control the production process, through the perception, integration and analysis of data, real-time monitoring and adjustment of product quality, equipment status and worker operation, so as to keep the factory on a stable and reliable running track.

3. Digital factory framework for complex electronic equipment

Digital factory covers the whole process of manufacturing complex electronic equipment. Its framework is shown in figure 1, including execution layer, acquisition layer and equipment layer. In a general sense, digital factory also includes business layer.

The equipment layer of the digital factory includes various production resources necessary for the production and manufacturing of the digital factory, including manufacturing equipment, production personnel, tooling and so on. Among them, manufacturing equipment undertakes the tasks of material distribution, production execution, testing and inspection, and a large number of digital equipment is adopted to automatically collect information or execute instructions. A small part of equipment can be equipped with sensors to achieve information collection and transmission. The production staff undertakes the task of monitoring, guiding and correcting the production process, and digitizes the operation through human-computer interaction interface. Equipment tools assist manufacturing equipment to complete the production activities of the digital factory, but they also do not have the ability of digital communication. They can participate in the digital activities of the factory through bar code, scanning gun, RFID and other technologies.

The acquisition layer of complex electronic equipment includes data acquisition and feedback control on the equipment layer. The data collection is to perceive the production process data through RFID, WIFI, Ethernet and other communication technologies, and effectively utilize the data through multi-source heterogeneous fusion analysis technology to achieve predictive maintenance, visual display and other functions. Feedback control is to transfer the orders of equipment execution and correction issued by the execution layer to the equipment layer, so as to realize accurate control of production equipment.

Execution layer includes process management, schedule management, order management, material management, quality management, equipment management, and other six function module and a basic support module, for all kinds of business, activity in the production process and elements of digital management, realizing the ordering of factory production, lean and transparent.

Four layers framework of digital factory and two basic requirements, "digital" and "manufacturing", is considered from the production implementation, information collection and manufacturing resources three dimensions, covering the technology, production, logistics, quality, resources, connectivity, systems integration and other factors, to complete and accurate description of digital factory [26].

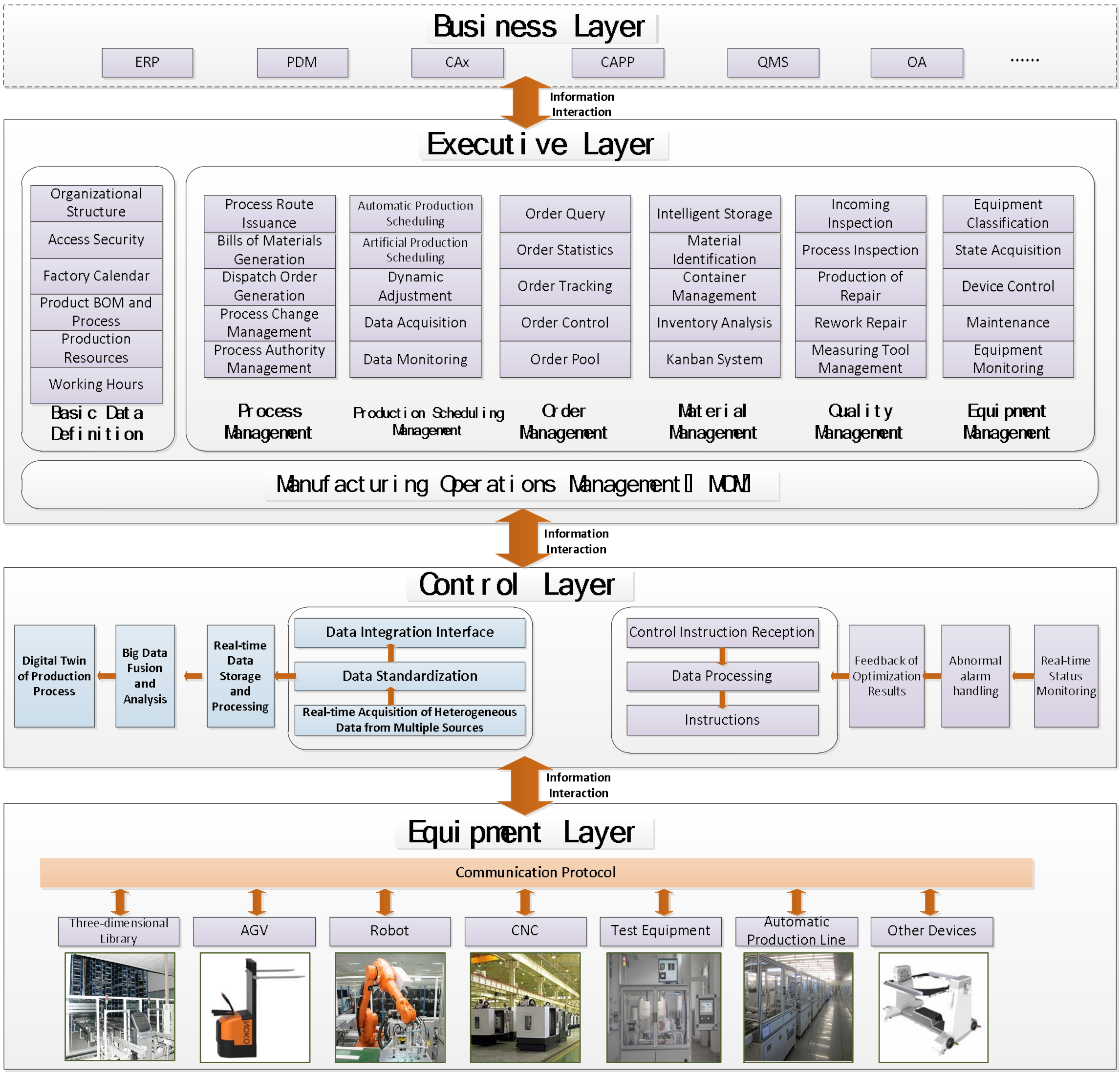

Figure 1. Digital factory structure of complex electronic equipment.

4. Key technology exploration

As the core unit of intelligent manufacturing, digital factory is a complex coupling of multiple fields and disciplines [25]. Digital factory framework and its technology have been widely used in casting, machining and other traditional manufacturing, but in complex electronic equipment manufacturing field, characteristics of many varieties, small batch, the application is still not in-depth enough. Based on the above mentioned digital factory architecture, and need to explore a series of key technologies, including production operation control technology, digital twin dynamic perception and fusion technology, and production data analysis technology.

4.1. Production data dynamic perception and fusion analysis technology

In the manufacturing process of complex electronic equipment, the data collected by various sensor devices are characterized by syntactical, semantic and structural heterogeneity. Analysis technology can achieve dynamic perception and production data fusion of different interface and communication protocol data conversion and packaging, and through the data classification, association and combination operation, integrating multi-source information for data mining, digital twin model needed by the simulation analysis, the computer can recognize the certainty of information, digital twin model for data mining, provide the underlying data support.

4.1.1. Production data dynamic perception and modelling. Complex electronic equipment manufacturing system is a dynamic system with continuous information generation and change. Its assembly site data has the characteristics of multi-source, real-time, massive and heterogeneous [20]. The field data of complex electronic equipment assembly can be roughly divided into product data, production process data and equipment data. Production process data mainly includes task information, quality information, personnel information, material information, environmental information and abnormal production information. Device data mainly refers to device state information, device operation parameters information, etc., classified as shown in figure 2.

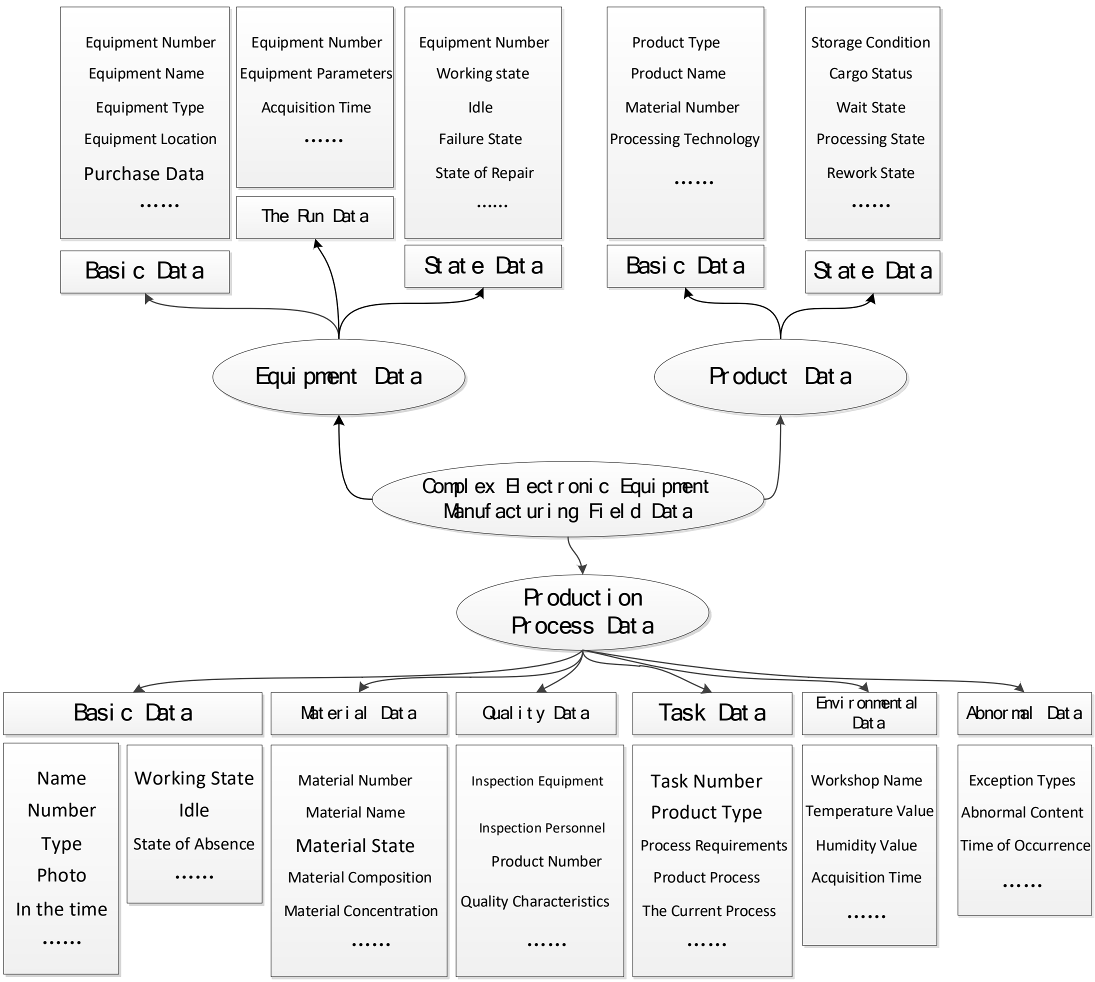

Figure 2. Data classification of complex electronic equipment manufacturing process.

On the basis of the analysis and classification of these data, the data collection objects are established according to various elements of personnel, equipment, materials, testing equipment and other elements involved in equipment manufacturing. For the monitoring of equipment, the objects to be collected are assembly equipment and the collected information is equipment status and other information. As for the production quality control, the production quality is affected by the operation parameters of the equipment, that is, the collection object is the assembly equipment. As the collected objects are different, some of the collected data are real-time, some are discrete, and differ in time dimension, and their data structure, format and collection method are also different. Therefore, it is necessary to establish a multi-source data collection object model with standard and formal methods, so as to realize the unified expression of the collected data. On the basis of the establishment of the acquisition model, the corresponding acquisition methods can be determined, such as sensor, bar code, device networking, human-machine interaction (HMI) and MES/ERP interface.

According to the assembly process data analysis and classification, combined with the data collection model, with modern sensor and the corresponding intelligent terminal as the main acquisition methods, and combining the industry establish a IOT workshop environment of Internet technology, using the unified and efficient data exchange protocol and the data interface, realize the complex electronic equipment manufacturing field of multi-source heterogeneous data real-time, accurate, reliable, acquisition and transmission.

4.1.2. Production data fusion and analysis. With the big data analysis method, combined with artificial intelligence as the main tool and the technology of data fusion, data feature extraction, data mining and visualization as the technical support, the production data of complex electronic equipment was analyzed and processed to provide data support for the intelligent decision of the management of the factory.

According to the business content in the process of equipment manufacturing, based on association rules, such as correlation coefficient data correlation analysis method, based on quantitative indicators, such as coverage, correlation in multi-source heterogeneous data based on the unified description of the process of extracting associated with strong business data, data on the original data cleaning, integration, reduction and transformation operations such as pretreatment, get consistent, accurate, high quality data, to construct a data warehouse of equipment manufacturing in the main body, finally realizes the data in the complex electronic equipment data integration platform, for equipment manufacturing process and dynamic optimization to provide reliable, reusable data resources.

By means of wavelet transform, Fourier transform, principal component analysis, mathematical statistics and other methods, the business characteristic data is extracted, and the business data model is simplified, which is convenient for subsequent data analysis and processing. Then on the basis of subject oriented data warehouse, using real-time stream processing combined with static batch hybrid parallel computing framework, through the behavior of the large data analysis, semantic analysis, statistical analysis, combined with the association rules, linear regression, forecasting, clustering data mining methods, to achieve implementation of the process parameters, equipment status, such as manufacturing data correlation analysis. According to the manufacturing data coupling mechanism of the business which is strong correlation between the data and its relevance as based on big data technologies, such as the depth of the intelligent technology such as neural network, the convolutional neural network input, to implement production scheduling, quality control, failure prediction and other business of pattern recognition, the results of prediction, workshop evolution rule knowledge acquisition etc., provide service for the intelligent decision support in the end.

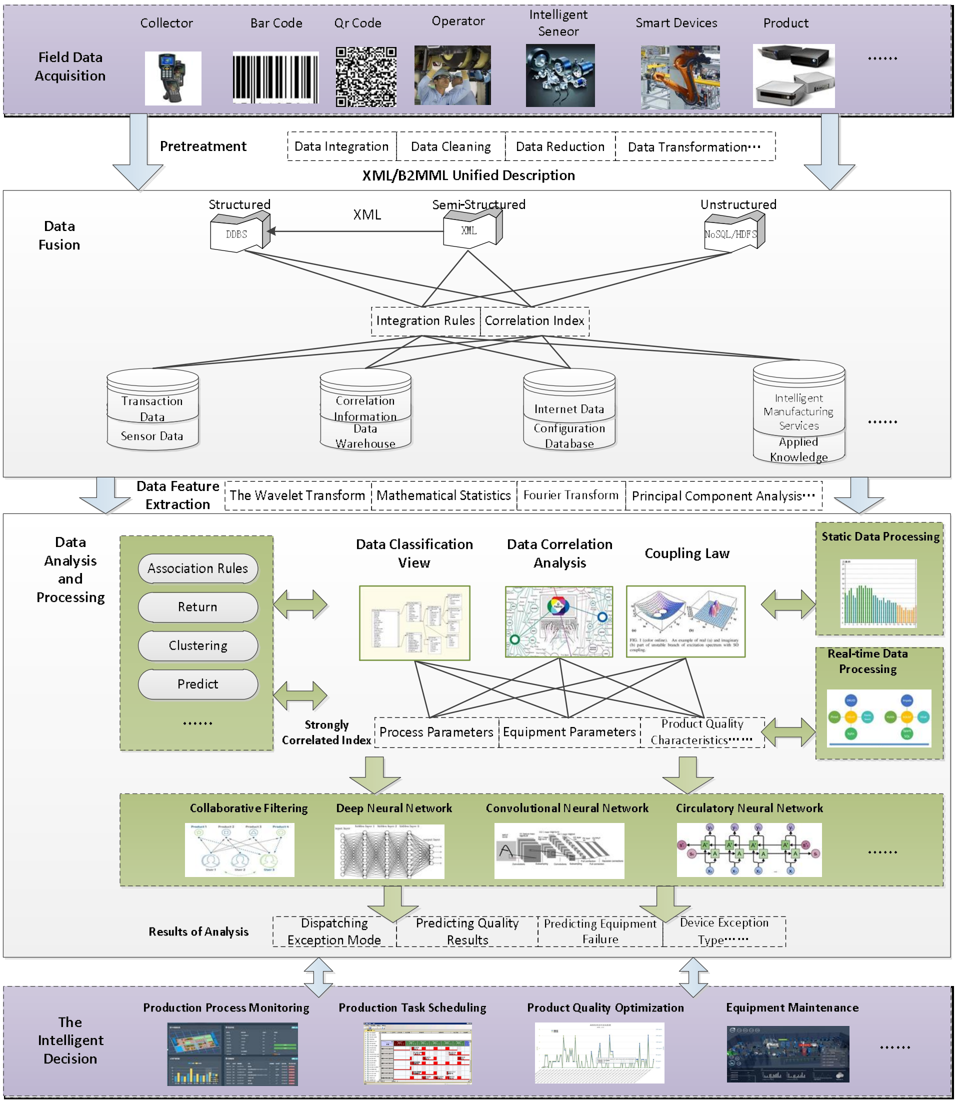

Figure 3. Technical framework of multi-source heterogeneous manufacturing data fusion and analysis.

4.2. Digital twin technology

Based on the digital twin, plant operation monitoring and prediction is on the basis of the connectivity of the whole process of equipment, collects total assembly factor information and mapped to a virtual environment, building digital twin model including assembly environment for assembly entity and equipment elements, by the deep fusion of assembling the physical process and the information world, constructs an extra realistic model of virtual assembly process, using intelligent methods of data analysis, deep learning to run the digital factory monitoring and prediction, realize the whole process of assembly production "model driven, real-time sensing, dynamic feedback, analysis, optimization", promote the transformation of the assembly mode from "open loop" to "closed loop" intelligent control mode, and improve the assembly quality and efficiency of complex electronic equipment [1].

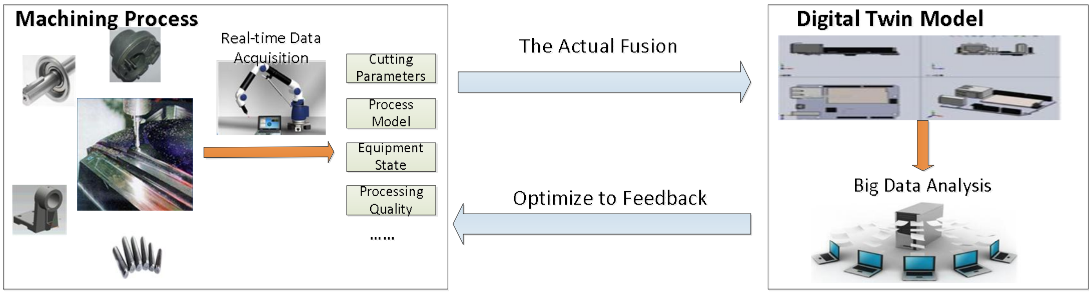

Figure 4. Complex parts processing based on digital twinning.

4.2.1. Workshop operation process modelling. To establish the digital twin model, a uniform structure should be constructed first. Facing different physical entity types and diversified functions, as well as the data generated by the entity, the twin model in the digital space should be constructed. In the whole machine assembly process, key factors involved in production include products/parts/materials, equipment, personnel and production environment, etc. Therefore, the whole process digital twin model is uniformly expressed as follows:

$$DT_{\mathrm{ws}} = DT_{equip} \cup DT_{prod} \cup DT_{pers} \cup DT_{env}$$

DT_{ws} DT_{equip} DT_{prod} DT_{pers} DT_{env} on behalf of digital twin model of workshop production process, equipment, product, personnel and environment respectively [27].

Digital factory equipment includes industrial robot, special process equipment, AGV car, etc. In order to complete the real mapping of the twin model to the physical entity, the 3d size and behavior of the model must be highly consistent with the entity [18]. At the same time, the twin model needs to establish the interface of virtual and real communication control, obtaining the entity data in real time, and defining the related virtual service to complete its behavior.

In the production process, human twin is mainly reflected in human movement and space position. Human body structure is mapped through 3d structure model, physical space location and joint motion data are obtained through location/motion data interface, and activity monitoring service is used to drive the update of movement and position of digital twin model.

For products/parts/materials, in different stages of assembly process, the product corresponding to different geometry, and accompanied by orders, coding and the quality of the whole life cycle information. This information may be retained by data interface in virtual label each product digital space according to its process data driven products/parts/material geometric state of evolution.

For the production environment, its twin model is identified by virtual label, and environmental data is acquired through sensors and displayed in quantitative formation.

4.2.2. Workshop running real-time mapping. The mapping of digital twin to physical space is the basis of virtual and real interaction of digital twin technology. After realizing the real-time mapping, the analysis and optimization of the real-time production situation in the digital twin space will be more real-time, more convenient and more multidimensional than the traditional way, which is also the basis of "virtual control real". The real-time mapping and interaction of digital space are mainly divided into five parts: product, equipment, personnel, system and environment.

1) The product is the core of the production line. The entire life cycle from the removal of parts from the warehouse to the storage of finished products is driven by the actual production data to complete the product evolution. The process data and quality data of the product are stored dynamically in the label of the virtual product and accompanied by the whole life cycle of the product.

2) Carry out real-time mapping of the movement, spatial position and running state of robots, AGVs, processing equipment and other equipment in the production line to complete the processing of each station.

3) Real-time mapping of personnel's identity, location and other information to complete visual management of personnel.

4) Real-time mapping of production schedule, operation schedule, process schedule and other information. Among them, the information such as inventory status, logistics situation, process of processing station and work-in-process data volume can be visualized and managed by digital twin space.

5) Display the current assembly environment parameter information of the factory and the changes of the factory environment parameter in a period of time in real time, and be able to give early warning of the current parameter as well as the assembly process requirements.

In order to realize the synchronous operation of digital space to each element of physical space, a large number of driving signals and data need to be obtained from the field to effectively drive data at all levels in the digital space. Multi-source data acquisition is the basis of realizing digital twin.

4.2.3. Monitor and forecast workshop operation. By constructing the digital twin of complex electronic equipment manufacturing factory, the production site situation can be understood in real time and the global information can be grasped [19]. In view of abnormal production conditions in manufacturing process, the sensitivity technology of collaborative perception is used to improve the sensitivity of important information closely related to production and reduce the sensitivity of interference information that is not important or averse to production. Combined with event processing function, processing workflow can be established for different alarm events. Realize the notice, judgment, processing, tracking, analysis, recovery and closure of the exception, form a closed loop of workshop exception management, improve the timeliness of exception handling.

Through real-time collection of quality data and correlation with production order, batch and other information, potential quality risks and problems can be found in time to realize rework and repair, quality visualization, and quality whole-process traceability management. In addition, analyzing the causes of quality problems in time provides analysis data and statements for the factory and quality department, improves the product qualification rate, and reduces the occurrence of similar problems.

Based on digital twin technology, the professional diagnosis of equipment in the factory is completed, including state analysis and fault diagnosis. Based on the equipment residual life evaluation technology, the evaluation model of equipment state deterioration trend was established, and the prediction model reflecting the correlation rule between variables was established with the quantitative analysis technology. The accumulated historical data are used for statistical analysis and data-driven equipment state modeling. According to different types of equipment objects, nonlinear prediction models, parameter optimization techniques and alarm strategies are established to accurately grasp the deterioration trend of equipment state, prevent abnormal equipment and ensure smooth production.

4.3. Production operation control technology

Through the construction of production operation control platform, the flow of production factors such as personnel, equipment, materials and energy in the factory is recorded and managed. Coordination and optimization are the most distinctive functional characteristics of the platform. The three major technologies for building a production operation control platform include dynamic scheduling and configuration technology, material identification and logistics tracking technology, and product quality control and traceability technology.

4.3.1. Production dynamic scheduling configuration technology. The production of complex electronic equipment is characterized by multi-variety, variable batch and mixed line production[11]. No matter how optimized the job plan generated by the traditional mixed line production scheduling algorithm is, it only ensures the rationality of the planning level, but cannot consider the disturbance factors such as production time/sequence change, equipment failure, production preparation and order change.

Dynamic scheduling configuration technology for mixed flow production, driven by production disturbance, is a planning and scheduling technology, mainly realizing two goals of intelligent scheduling and lean coordination: optimizing production scheduling of core equipment and site station, and lean coordination of main line/auxiliary line/complete set [13]. The overall process of dynamic scheduling configuration technology for mixed flow production is shown in figure 5.

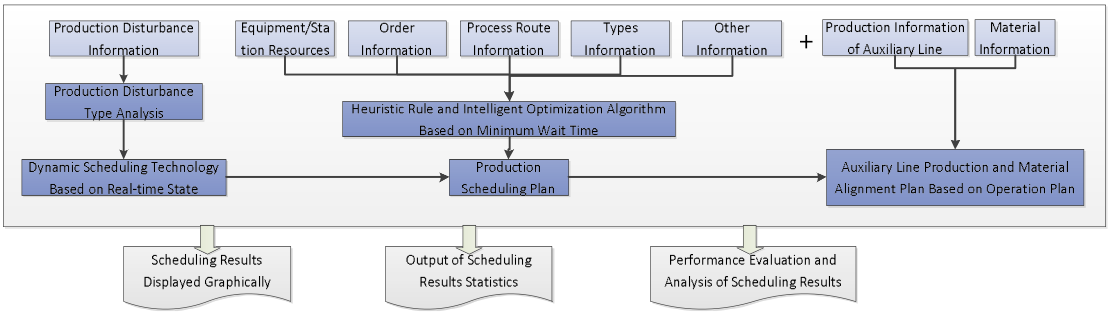

Figure 5. Overall research scheme of dynamic scheduling configuration technology for mixed flow production.

Dynamic scheduling configuration technology for mixed flow production is mainly reflected in the following aspects:

(1) On the basis of the scheduling target and constraint modeling: with complicated electronic equipment manufacturing process, the core equipment/position resource, process execution working time data as the basis, establishing process - resource map matching relationship, according to the difference of task to clear order priority, combining with the complex electronic equipment machine delivery date, resource utilization, form the coupling relation of constraint model [14].

(2) Focus on mainline production planning and scheduling: generate integrated production plans that are refined to specific process links and specific equipment/site resources based on the thought of combining heuristic scheduling rules and intelligent optimization algorithm.

(3) Disturbance driving the dynamic planning and scheduling of production as the core: adopting production disturbance events modeling and its classification modular processing mechanism, realizing timely response of production disturbance events such as the orders from task, resource allocation, equipment failure, field conflict, executive deviation, sub line/kitltems ill-prepared, to ensure the effectiveness of the production plan for the actual execution status.

(4) Lean coordination of the production plan of kitltems/sub line driven by the main line process plan: based on the key process nodes of kitltems/sub line, and guided by the process link plan of production, lean coordination and supply can be realized on time and according to the quantity.

4.3.2. Material identification and logistics tracking technology. The whole machine assembly of complex electronic equipment involves many processes and a long production process. The identification, storage and distribution of materials have a great impact on the production efficiency and quality. With the acceleration of batch production and research and development of complex electronic equipment, the characteristics of co-production and mixed production are more and more prominent, and the demand for fast introduction, fast switch, flexible production and accurate control of production lines is increasingly high. The material identification and logistics tracking technology of digital factory of complex electronic equipment focuses on solving the problems of insufficient material perception coverage, high material distribution error rate, low delivery accuracy and low efficiency.

The overall scheme of material identification and logistics tracking for digital factory of complex electronic equipment is shown in figure 6:

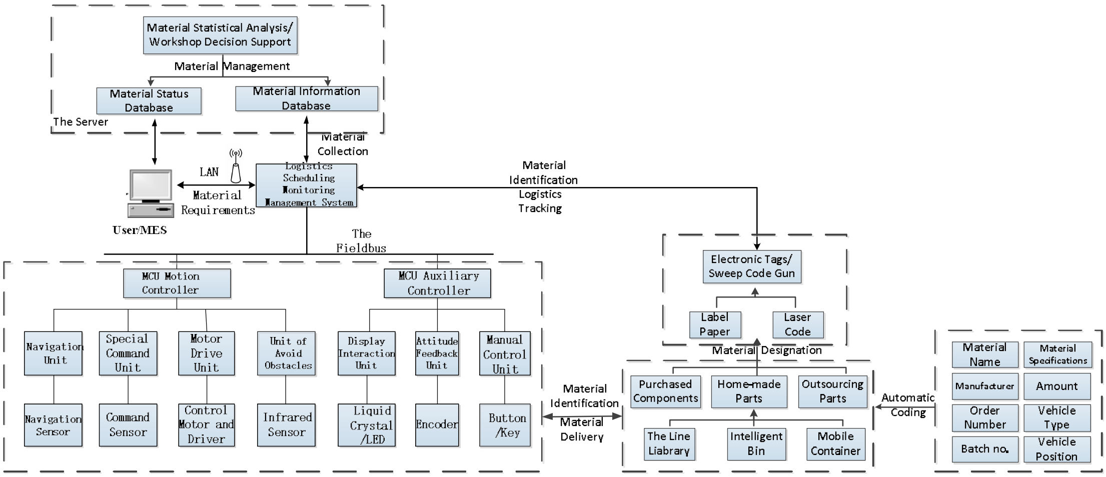

Figure 6. Material identification and logistics tracking technical scheme.

Material identification is the accurate definition and systematic classification of material type, and the unique code is given to each material according to its inherent properties. Through visual sensors, electronic tags, RFID and other technical forms to identify the material, material data real-time collection and tracking to provide technical support.

Logistics tracking is the collection and tracking management of the whole process of materials from storage, storage to delivery, circulation to finished product storage, so as to grasp the storage position, product in process position, process status, assembly queue, work station, operator and other information corresponding to materials in real time.

Material identification and logistics tracking are based on material data collection and management. Based on the management and maintenance of the basic material data and material knowledge base, apply the six sigma concept and SPC control analysis technology to conduct statistical analysis on material data, generate material inventory list, consumption list, quality list, material distribution matching degree, etc.

Material identification and logistics tracking technology through the acquisition of real-time data of the whole process of materials in the digital factory, make material management optimization plan, realize accurate and fast identification of materials, improve the high utilization rate of cargo space, eliminate the phenomenon of material shortage or accumulation; At the same time, the quantity and time of material distribution meet the production rhythm of the assembly line, to ensure continuous production without shortage of materials, accurate material distribution, avoid the occurrence of wrong materials, missing materials.

4.3.3. Product quality control and traceability technology. Users pay more and more attention to product quality, which requires enterprises to strictly control the quality of complex electronic equipment in the production process to prevent the production from unqualified products and avoid economic losses of enterprises and users [12]. In the digital factory, through real-time collection and analysis of the process parameters of manufacturing equipment and testing equipment in the production process, the fluctuation of product quality can be found timely and unqualified products can be reduced. After a period of production and data accumulation, a comprehensive analysis of process flow, process parameters and resource allocation will be conducted to provide scientific and quantitative reference data for managers to improve the factory, and to ensure the consistency and stability of products by controlling these parameters [15].

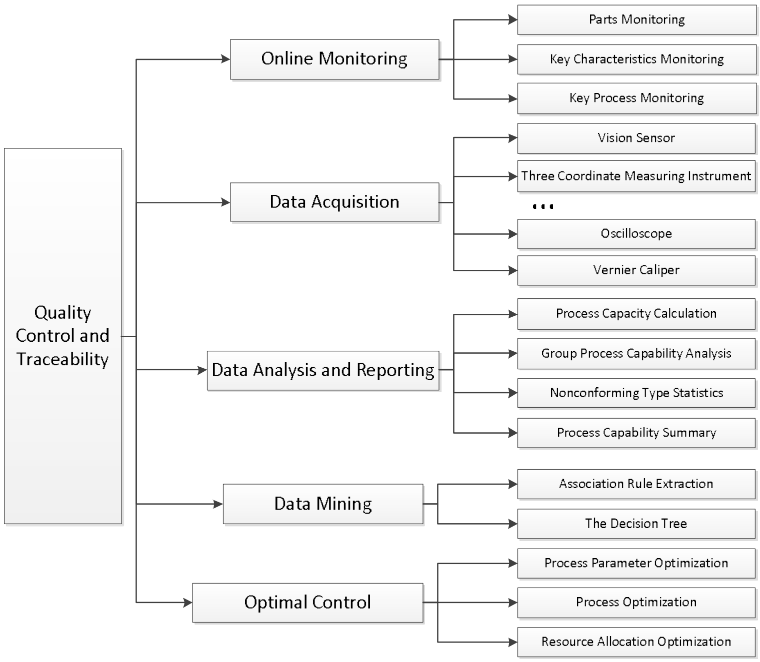

Figure 7. Quality control and traceability system.

The quality control and traceability system of digital factory of complex electronic equipment includes five functional modules: online monitoring, data collection, data analysis and report, data mining and optimization control [17].

Online monitoring module is mainly used to comprehensively monitor parts, key parameters and key processes in the production process through digital means [22].

The data acquisition module mainly faces all the detection equipment in the factory, realizes the collection of data in the inspection and measurement process, and stores the data into the database, providing support for data analysis and statements.

Based on the collected test data, the analysis and report module mainly realizes the functions of process capability calculation, key process capability analysis, unqualified type statistics and process capability summary.

The data mining module is a further study of the analysis and report module. By extracting association rules and establishing decision trees, it can find out the potential and valuable associations of each data item, and provides quantitative basis for optimal control.

Based on data mining, the optimal control module integrates and optimizes the process flow, process parameters and resource allocation [21]. In the digital factory, in order to ensure the stability and continuity of product quality, each process should carry out real-time optimization feedback according to the set value of process parameters and quality characteristics of the pre-process monitored online, so as to realize dynamic quality control and accurate manufacturing of complex electronic equipment.

5. Application example of radar assembly digital factory

Radar is a complex electromechanical coupling system and typical complex electronic equipment. The final assembly process has complex process flow and high requirements for controlling process parameters, and many factors that affect the stability of product quality and the precise execution of the production process in the manufacturing process. It is necessary to improve the overall production level of the radar final assembly workshop through the implementation of digital factory.

Based on the production requirements of many varieties, small batch and the beat of flexible, this example constructed the manufacturing operations management system based on big data and data acquisition and control system, enhanced the level of digital production process and assembly process equipment specialization level, implementation capacity up to that of origin can shorten the production waiting time by 30%or more, assembly a success rate is better than that of 99%, realize intelligent scheduling of production plan and production process of intelligent control.

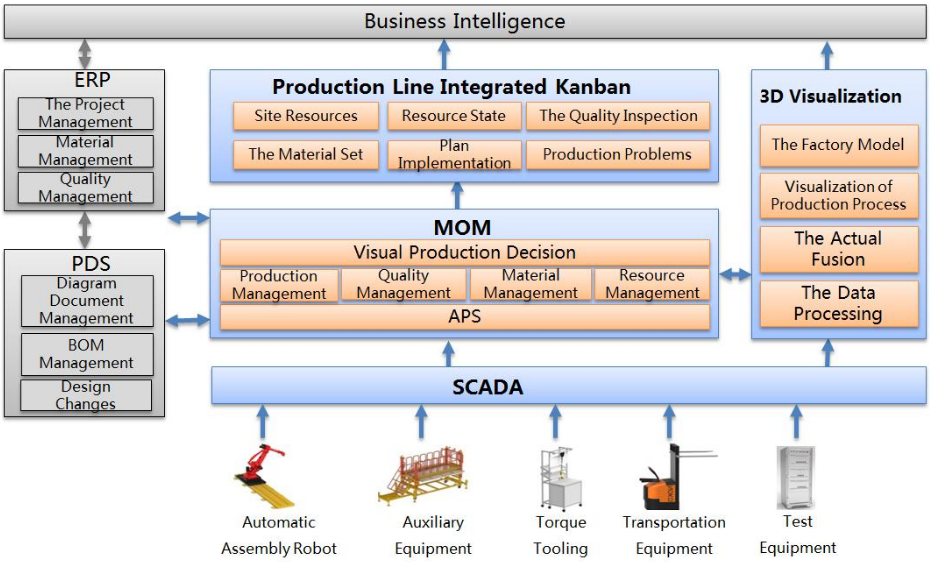

Figure 8. Overall framework of radar assembly digital factory.

The radar final assembly digital factory would build intelligent assembly lines characterized by the organic combination of intelligent units, human-machine hybrid lines and automatic production lines, and form a production mode of “three flows in one” of human flow, logistics and information flow, so as to enhance the production capacity and core competitiveness of the factory. The implementation idea of radar assembly digitization factory is as follows:

- Product Cluster Analysis: Design batch production line and develop production line according to product structure and process characteristics.
- Process Reengineering: Break through the traditional design idea, the whole life cycle analysis of the product assembly and general adjustment process, reconstructing the radar machine assembly and adjustment process.
- Optimize Station Layout: Analyze the product assembly process, integrate and optimize the operation content of each station.
- Production Line Means Upgrade: Configuration automation and professional equipment, planning and construction of production line intelligent logistics system.
- Improve Networking and Informatization: Build the production operation control platform to realize the interconnection of production and test equipment and data acquisition and application.

5.1. Process reengineering and layout optimization

Process reengineering and layout optimization are the premise of digital factory construction, including process reengineering and layout optimization.

Process reengineering mainly improves the overall assembly efficiency by optimizing the process route, balancing the beat of the station and improving the assembly capacity of the station. Firstly, the existing general assembly process was analysed in depth, and part of the mechanical assembly and electronic assembly were changed from serial work to parallel work, and the electrical performance test was changed from the test rack to the product loading, which greatly reduced the assembly and separation time between the array and the test rack. Then, the optimized process flow was divided into different parts to realize the parallel operation of multiple stations and to balance the operation time of each station, so as to achieve the pulsating production. This example set 8 stations in the process of product assembly and adjustment, including 6 mainline stations and 2 branch stations.

Plant layout is simulated and optimized based on process reengineering. Digital process simulation and verification system is used for digital simulation of dynamic assembly, man-machine cooperation, welding assembly, mechanical assembly and assembly accuracy, combining with the system for production line layout and simulation, workshop layout and simulation, logistics planning and simulation to realize the plant layout adjustment and the optimization of process equipment design.

Through the simulation process reengineering and factory layout optimization, shortening the period of the complicated electronic equipment assembly, assembly and tuned efficiency increased 28.7%.

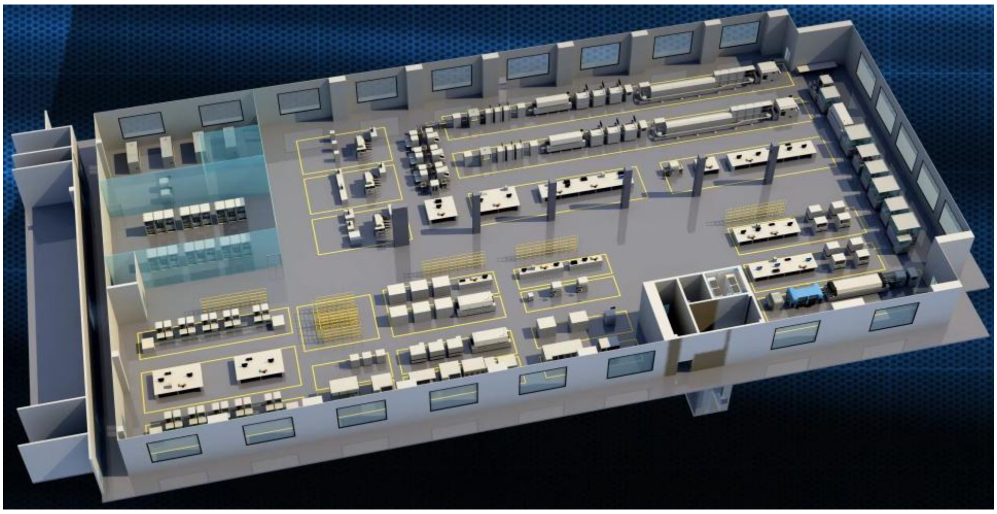

Figure 9. Layout of digital factory.

5.2. Digitalization of plant equipment

Digitalization of plant equipment is the premise and foundation of the construction of digital factory, which provides basic data support for design, research, production and other links.

The digital equipment accomplishes process management, network transmission, data acquisition, data analysis and visualization display with one or more servers to connectivity of factory equipment, through the Ethernet, RS232, RS485, Modus, OPC and other communication protocols. And also the digital factory realizes a more detailed and comprehensive management through the deep integration with the production and operation control platform.

Digital factory of complex electronic equipment includes not only traditional equipment such as CNC machine tools and PLC, but also advanced processing equipment such as robot, AGV and automatic three-dimensional warehouse. Therefore, digital transformation of complex electronic equipment factory includes DNC/MDC and other functions, as well as digital monitoring and intelligent control and other functions.

Taking the radar final assembly factory as an example, equipment digitalization mainly includes digitizing the existing equipment and developing the numerical control intelligent unit [16]. Digital transformation of existing equipment is mainly to embed sensors, integrated circuits, software or other digital components into existing equipment to add data acquisition interface, and realize the function of state monitoring. Intelligent unit mainly based on industrial robots, combined with the actual production demands, equipped with sensors, track, control software, etc., of intelligent equipment of non-standard custom development, assembly parameters can be controlled, process parameters can collect, and other functions, such as T/R component assembly robot, electric assembly robots, etc.

As shown in figure 10, with the support of the data collection system and the visual display function of the production line, the equipment status, production orders, maintenance records and task completion in the factory are displayed comprehensively to realize the connectivity rate of equipment 100%, achieve factory transport management.

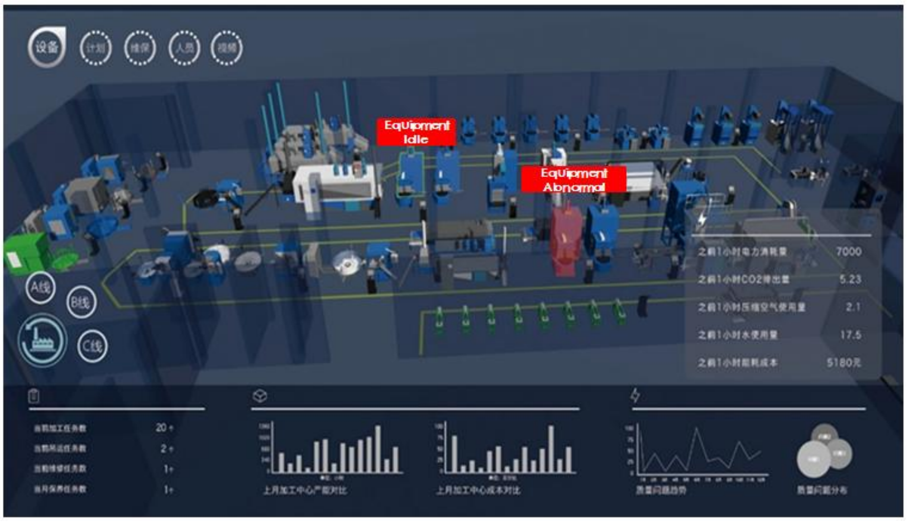

Figure 10. Digital display of factory production line and equipment

5.3. Digitalization of factory logistics

Logistics digitization is mainly to realize intelligent identification and bidirectional traceability of materials, including material identification, material data collection and material statistical analysis.

Firstly, the material identification module establishes coding rules for different types of materials and storage facilities, and endows manufacturing resources with unique identification. Then use the scanning gun, electronic label, RFID and other forms to quickly identify the material code, and bind the material information with processes, products and operators, so as to facilitate follow-up inquiries and traceability.

Material data acquisition module based on distributed collection technology, realizes real-time acquisition of multi-source material data. Automatic sensing of material storage location by means of electronic label; Identify the basic attribute information of the material by the scanning gun; Obtain material processing information from automatic equipment; In addition, MOM, ERP and other information systems are used to collect information such as subordinate orders, processes and quality feedback of materials. All collected material data is classified and stored in the remote database.

Material statistical analysis module adopts six sigma management idea and SPC and other data analysis tools to conduct statistical analysis on material status. Build the material query and traceability model, establish the connection between the operating system on application layer and the background material data, take the order name, material name, process, personnel and so on as the screening conditions, can query the consumption of a certain material; With the order name as the filter, you can query out the inventory list associated with the order. The forward and reverse traceability algorithm of material state is studied. To realize forward traceability, name, package, batch number and other information of the assembly material can be indexed according to number, batch number and other information of the order, while the assembly equipment information of the material can be inquired according to the name, batch number and other information of the material.

As shown in figure 11, the material management and logistics tracking module is constructed with the support of the production operation control platform, and the storage and transportation of materials in the factory are recorded digitally. The logistics operation in the factory is visualized by means of graphical modeling, and the on-time delivery rate of materials is 100%. The matching degree of material distribution and plan is better than 99%.

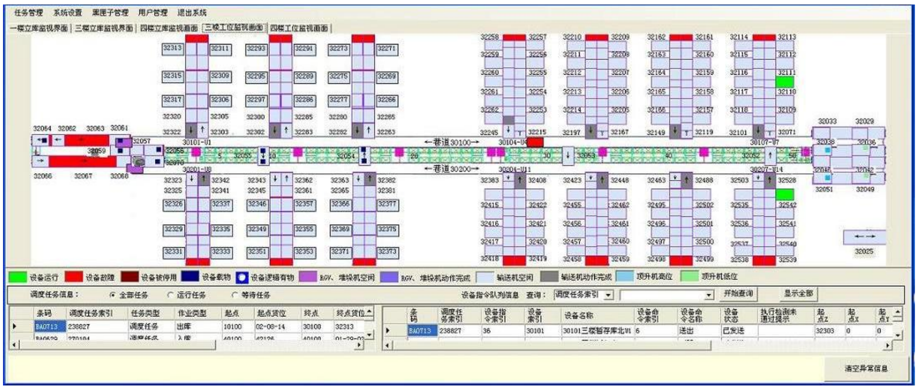

Figure 11. Plant logistics management and tracking.

5.4. Digitalization of production process

Digitalization of production process means that all production activities in the factory are recorded, managed and monitored through the information system, which mainly includes manufacturing execution system, data acquisition system and visual KANBAN.

Manufacturing execution system (MES) includes 6 functional modules including production twin, scheduling, production execution, quality management, material management and equipment management, covering manufacturing resources, planning control, production execution, quality management and other production total factors management. Record the plan, task, quality, material, equipment, personnel and other elements through the information system, form the production process resume, and provide support for follow-up inquiry and traceability.

Based on the Internet of things technology, the data collection system collects data of raw materials, processed components, equipment, personnel and other production factors, so as to realize the dynamic perception of production line equipment information, personnel information, logistics information and quality information. Taking radar as an example, the main data types collected include: data obtained by industrial sensors such as photoelectric sensors, thermal sensors and force sensors; 3 d drawings, processes and procedures of field assembly; Calibration pictures of key processes; Data generated by MES, QMS, WMS and other information systems.

Visual kanban is based on the manufacturing executive management system and data acquisition system to monitor the running status of the radar assembly plant in real time. Through transformation processing of the collected data, the LAYOUT module, rendering module, scene and UI editing module were imported, and the overall running state, assembly process and key process running state of the factory were visually managed from three dimensions of factory level, production line level and unit level.

As shown in figure 12, real-time display of information such as plans, tasks and capacity in the factory is conducted by using the perceived and collected data. The data acquisition coverage is greater than 99% to realize the transformation and upgrading of factory management ability.

Figure 12. Digital display of production process.

The implementation of the digital factory of radar final assembly, through the functions of the intelligent material management system, such as early warning, pulling, etc., to improve the material evenness. Through the management and control of the manufacturing operation management system, reduce the stagnation of the final assembly process, realize the traceability of quality data, and improve the degree of informatization and digitalization of the factory; Through data collection and control system, we can improve the professional level of final assembly process equipment, improve the efficiency of factory management, and form a final assembly digital factory with batch production line and intelligent final assembly unit as the main body.

6. Conclusion

This paper studied the important technology of digital factory of complex electronic equipment including the perception and fusion of dynamic production data, digital twin and manufacturing operation management. Based on the method of the configuration of dynamic scheduling of production, the materials and logistics tracking and product quality control and trace, this paper developed the production operation control platform, realized the monitoring and prediction of digital factory running, and applied in the radar assembly production factory, which improved the efficiency and quality of radar assembly and the plant management efficiency, to form the radar digital factory of mixture of batch and research production lines. And this paper heralded the digital factory is mature, and can be extended to other fields of complex electronic equipment. Further research will be carried out on key technologies and operating mechanisms such as artificial intelligence, additive manufacturing, data mining, etc. that would help digital factory advances to intelligent factory.

References

[1] Tao F, et al. 2018 Digital Twin and Its Potential Application Exploration, *Comput. Integr. Manuf. Syst*. **24(1)** 1-18.
[2] Shoudian L I 2018 Discussion on Construction Plan of Digital Factory, *Manuf. Antom.* **40(4)** 109-14.
[3] Liu S 2010 Research into Complicated Electronic Equipment Design System Based on Knowledge Engineering, *Shipb. Elect. Counterm.* **33(5)** 111-14.
[4] Hu C, et al. 2017 Exploration and Practice Structure Digital Prototype of Complex Electronic Equipment, *Electro-Mechan. Eng* **33(6)** 1-9.
[5] State Administration for Market Regulation China Standardization Administration. GB/T 37393 2019 Digital Factory-General Technology Requirements *China Standard Press.*
[6] Zhu D, Zhao M 2018 Machine Intelligence: From Digital Workshop to Intelligent

Manufacturing, *Beijing: China Machine Press* **10**.
[7] Chen Y 2013 Research on Digital Factory Application Technology for Discrete Manufacturing *Electr. World* 49-50.
[8] Bo J 2016 Framework and Implementation of Digital Factory *China Industrial Review* **5** 28-33.
[9] Zhu Q 2018 Research and Development of Smart Jobshop for Commercial Aero-Engine Based on Industrial Internet, *Microcomp. App.* **34(8)** 108-11.
[10] Li T, Li S 2016 Digital Factory Path Exploration of Aircraft Complex System Assembly, *Avia. Manuf. Technol.* **10** 41-47.
[11] Li Z, Wang A, Long Z 2014 Dynamic Batch and Materials Coordination Technology of Complex Manufacturing Execution, *Compu. Integr. Manuf. Syst.* **20(4)** 836-46.
[12] Yang H, et al. 2016 Discussion on Quality Control and Supervision Mode and Method of Aircraft Manufacturing Based on MBD, *Avia. Manuf. Technol.***5** 105-9.
[13] Li J, et al. 2012 Distributed Coordination Scheduling Technology Based on Dynamic Manufacturing Ability Service, *Compu. Integr. Manuf. Syst.***18(7)** 1563-74.
[14] Lu Z, Wang A, Tang C 2017 Multi-Level Relevance Resources Coordinated Scheduling Based on Improved Genetic Algorithm, *Transac. Beijing Instit Technol.***37(7)** 711-6.
[15] Xu G, et al. 2017 Online Monitoring and Control Method of Product Quality Based on Embedded Cyber-Physical System Models, *J. Mechan. Eng*. **53(12)** 94-100.
[16] Cai M, Wang T, Shang T 2016 Evaluation of Digital Factory for Manufacturing Enterprisem, *Sci. Technol. Manage. Res.* **15** 63-9.
[17] Mu P 2016 Research on Fine Quality Control Under Flexible Manufacturing Mode, *Jiangsu Sci. Technol. Info*. **10** 54-6.
[18] Chen H, et al. 2014 Data-driven Rapid Modeling of Manufacturing System *J. Hebei Uni. Sci. Technol.* **35(6)** 504-11.
[19] Yue J 2017 Discussion on Construction of Digital Factory, *Electr. Proc. Technol.* **38(4)** 193-6.
[20] Zhang G, Huang G 2013 Digital Factory: Its Application Situation and Trend, *Avia. Manuf. Technol.* **8** 34-7.
[21] Sun Y, et al. 2013 Digital Factory Application in Electronic Manufacturing, *J. CAEIT* **6** 551-6.
[22] Wang G 2016 Design and Implementation of Manufacturing Process Quality Control Software System, *Avia Standa. Quali.***5** 20-3.
[23] Chan D S 2002 Digital Factory-A Technology Show Case for Teaching and Research in Digital Manufacturing, *Machi. Develop*. **31(6)** 109-11.
[24] GE, Predix 2018. Available: https://www.ge.com/cn/b2b/difital/predix.
[25] Kossiakoff A, Sweet W N, Seymour S J, Biemer S M 2011 Systems engineering principles and practice, *2nd Ed. John Wiley Sons* **83**.
[26] Pouly M, Berthold S 2010 Digital Factory for Collaborative Supply Chains, *Procee. Int. Conf. Compu. Support. Coope. Work Desg. (CSCWD)* 579-84.
[27] Liu L, et al. 2019 Construction and Application of Digital Twin System for Production Process in Workshop, *Compu. Integr. Manuf. Syst.* **25(6)** 1536-45.