A Data-Driven Framework for Cloud MES Implementation in Smart Manufacturing Environments

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Abstract: ***Modern manufacturing production has increasingly embraced intelligent and automated development, driven by advancements in technologies such as artificial intelligence, robotics, and the Internet of Things. However, many small and medium-sized manufacturing enterprises (SMEs) face significant challenges in achieving full-scale intelligent manufacturing due to constraints in technological capabilities and financial resources. These limitations hinder their ability to compete effectively in the evolving market landscape, where efficiency, flexibility, and innovation are critical for survival. The rapid proliferation of intelligent technologies, including Industry 4.0 and smart factory solutions, underscores the urgency for SMEs to adapt and integrate these tools into their operations. Failure to do so may result in a loss of market share and reduced competitiveness. To address this issue, this paper proposes a cloud-based Manufacturing Execution System (MES) design scheme tailored for intelligent manufacturing workshops. By leveraging cloud computing services, SMEs can overcome their own infrastructure limitations by renting cloud servers from providers, thereby enabling cost-effective access to advanced MES functionalities. This approach facilitates the gradual intelligent transformation of manufacturing workshops, ensuring that SMEs can enhance productivity, reduce operational costs, and improve decision-making without substantial upfront investment. The cloud MES system not only fills the technological gaps but also empowers SMEs to achieve sustainable growth in the competitive manufacturing sector.***

Keywords: Intelligent manufacturing workshop; Cloud MES system; Job management.

1. INTRODUCTION

Against the backdrop of economic globalization, manufacturing faces enormous challenges. Since Germany launched the "Industry 4.0" initiative, countries around the world have implemented plans for intelligent manufacturing transformation. China has also introduced the "Made in China 2025" strategy; through scientific deployment and implementation, the nation has gradually shifted from a manufacturing giant to a manufacturing powerhouse. However, due to limited technology and economic resources, as well as the characteristics of discrete order production, SMEs currently lag behind in this intelligent transformation. The disappearance of manufacturing dividends and rising operating costs have left many SMEs at a development bottleneck. Building a cloud MES system can help small and medium-sized manufacturers break through technological constraints. Therefore, studying the design scheme of a cloud MES system for intelligent manufacturing workshops is of great significance. Chen et al. (2023) pioneered a generative text-guided 3D vision-language pretraining framework for unified medical image segmentation, establishing a new paradigm for multimodal medical AI[1]. In biomedical signal processing, Ding and Wu (2024) provided a comprehensive systematic review of self-supervised learning techniques specifically applied to ECG and PPG signals[2]. Recommendation systems have evolved through sophisticated graph-based approaches, as demonstrated by Han and Dou (2025) who integrated hierarchical graph attention networks with multimodal knowledge graphs for enhanced user recommendations[3]. The advertising technology sector has witnessed innovative generative applications, including Hu's (2025) work on procedural playable 3D ad creation and subsequent research on few-shot neural editors for 3D SMEs[4,5]. Recruitment optimization has been transformed by Li et al. (2025) through their combination of generative pretrained transformers with hierarchical graph neural networks for resume-job matching[6]. Privacy concerns in advertising are addressed by Li, Lin, and Zhang (2025) through a novel framework incorporating federated learning and differential privacy for advertising personalization[7]. Security in IoT-based supply chains is enhanced by Miao et al. (2025) who developed a secure and efficient authentication protocol[8]. Peng et al. (2025) advanced 3D vision-language understanding through Gaussian Splatting techniques[9]. Digital advertising intelligence was improved by Tian et al. (2025) with their cross-attention multi-task learning approach for ad recall optimization[10]. Financial risk management has seen substantial innovation through Su et al.'s (2025) WaveLST-Trans model for anomaly detection and early warning systems in financial time series[11]. Tan (2024) explored AI application trends in automotive production, highlighting development trajectories in manufacturing intelligence[12]. Telecommunications testing was advanced by Tu (2025) through SmartFITLab, an intelligent execution and validation platform for 5G field interoperability testing[13]. Recommendation system robustness was addressed by Wang (2025) via joint training of propensity and prediction models using targeted learning for handling data missing not at random[14]. Finally, Wang et al. (2025) conducted an empirical study on the design and optimization of AI-enhanced intelligent financial risk control systems for multinational supply chains[15].

2. SYSTEM ARCHITECTURE DESIGN OF CLOUD MES FOR SMART MANUFACTURING WORKSHOPS

The cloud MES system for smart manufacturing workshops is built on cloud computing technology. Given cloud computing's characteristics of on-demand access and configurable shared resource pools, it can provide efficient and rapid computing services according to system requirements. The existing service models include SaaS (Software as a Service), PaaS (Platform as a Service), and IaaS (Infrastructure as a Service). This study focuses on the SaaS service model, which can develop personalized software systems based on user needs and deliver them through a rental model. Users simply connect to the network via a terminal to access the cloud-based software services, primarily targeting small and medium-sized enterprises. The system designed in this research is a general-purpose system with highly flexible functional modules. When different enterprises submit service requests, the system can be customized through secondary development before delivery, reducing software development costs while providing personalized services.

Cloud MES systems differ from traditional MES systems. In practical applications, there is no need to set up dedicated servers within the enterprise; instead, users can rent servers from cloud service providers and access them directly in the cloud, significantly reducing capital investment. Currently, common architectures in cloud MES system design include C/S and B/S. The former requires client installation, offering fast response times but higher maintenance costs. The latter centralizes core business logic on the server side, allowing direct use through a browser without separate client installation. Its advantages include strong compatibility and lower development and maintenance costs, though response speed is relatively slower. Considering the needs of small and medium-sized enterprises, B/S architecture was selected after comprehensive evaluation and designed as a three-tier structure: user layer, business layer, and data layer. The user layer consists of PC interfaces, mobile devices, tablets, etc., primarily for managing workshop production data and providing decision support for subsequent production operations. The business layer handles interactive request data from the user interface and performs appropriate database additions and deletions, serving as the core logic for each functional module. The data layer is responsible for storing basic workshop production data, workshop-collected data, and ERP interface data.

3. FUNCTIONAL MODULE DESIGN OF CLOUD MES FOR SMART MANUFACTURING WORKSHOPS

3.1 Basic Data Management Module

(1) Functional design

This module comprises four sub-modules: the Material Basic Definition module, used for information-based material modeling, supporting creation, editing, and deletion of material information and interfacing with other modules; the BOM Management module, covering finished-product BOM creation, editing, querying, and deletion, enabling production-plan compilation based on finished-product BOM data to provide a reliable basis for order production planning; the Routing Management module, which details every operation in the finished-product manufacturing process, allowing shop-floor personnel to determine operation sequences according to the production plan, assign each operation to the correct machine, and ensure rational shop-floor scheduling; and the Drawing & Document Management module, which stores shop-floor drawings and supports document upload, download, and viewing.

(2) Process design

After logging in, administrators enter the material management interface; once basic material data are created here, the defined materials are saved to the database. Next, in the BOM management interface, a finished-product BOM is created; by interfacing with the material-definition API, finished-product material data are obtained, represented with a children field, displayed on the BOM interface, and saved to the database together with the BOM data. In routing management, enter the routing number first, select the corresponding quality-inspection plan, fill in operation names and related equipment according to shop-floor needs, and finally store the created routing interface and routing in the database. On the drawing & document management page, drag and drop the files to be uploaded into the file area; files are saved to the database, and corresponding interfaces can be called for download or viewing.

3.2 Job Management Module

(1) Functional design

The Production Order Management module provides order creation, import, viewing, search, revision, and cancellation, and dynamically monitors order status, managing all users' production orders. The Production Plan Management module includes production-plan import, creation, modification, cancellation, viewing, and querying, managing shop-floor production plans set by production managers. The Production Scheduling module offers algorithmic scheduling, display of scheduling results, and manual scheduling, enabling efficient allocation of production resources, reducing resource waste, and guiding relevant production personnel. The Work Order Management module supports management, viewing, querying by number, modification, and deletion of work-order lists, managing all work-order tasks.

(2) Process design

After logging in, shop-floor personnel first enter the order management interface; after creating or importing production orders, they proceed to production-plan management, where corresponding production plans can be created based on order conditions. In the production-scheduling system, the algorithm interface is invoked based on production tasks, and already scheduled tasks are output. Finally, the system-generated work orders are dispatched to the corresponding production lines, guiding frontline personnel to complete product processing step by step according to work-order requirements.

3.3 Material Inventory Management Module

(1) Functional design

The inbound/outbound management module supports material scanning for inbound and outbound operations and allows real-time viewing of inbound/outbound information; it also supports querying material inbound/outbound records by inbound number. The inventory counting module can count newly added materials, mainly for periodic inventory checks to determine whether materials are being used arbitrarily; based on this information, material demand can be forecasted to facilitate timely procurement. The inventory inquiry module supports both exact queries by material number and location-filtered queries, ensuring up-to-date material inventory information.

(3) Process design

Inventory managers scan the material QR code with a mobile device, after which the inbound order is synchronized to the management system; the system promptly updates the inbound record and refreshes inventory data. During material management, the system can be used at any time to monitor the inventory status of all materials. During inventory counting, clicking "Add Inventory Count" synchronizes the latest count results to the management system, ensuring inventory information is updated in real time.

3.4 Equipment Management Module

(1) Functional design

In equipment ledger management, real-time updates of equipment additions and deletions are supported; relevant managers can retrieve equipment information via list views or number searches, and can also modify or delete equipment data, providing comprehensive management of workshop production equipment. The equipment inspection module mainly adds new inspection records and updates the inspection list, while supporting modification and deletion of inspection data for effective inspection record management. Equipment operation monitoring tracks equipment status in real time, obtains operating data promptly, and supports anomaly reporting to enable real-time monitoring of workshop production data.

(2) Process design

Equipment managers can create and modify ledger information for each device in the system's equipment ledger interface, use mobile devices to enter inspection data, and retrieve usage details of specific equipment by searching its number, ensuring accurate identification of potential faults. The dynamic monitoring data provided by the equipment operation monitoring system also assists in troubleshooting, keeping workshop equipment in stable operation.

3.5 Quality Management Module

(1) Functional design

The quality inspection plan management module manages all inspection plans in the workshop, providing accurate references and standards for inspection execution. Functions include adding, viewing, modifying, and deleting inspection plans, with support for queries by plan number. The quality traceability management module manages inspection records, enabling rapid location and tracing of quality issues. Functions include adding new inspection records and querying existing ones.

(2) Process design

Inspectors can create and modify relevant inspection plans within this module and adjust them effectively based on actual inspection execution, ensuring the plans fulfill their quality-control role. On the quality traceability interface, inspectors can view work-order inspection status at any time, monitor finished-product quality, and eliminate quality issues at an early stage.

3.6 Production Data Visualization Module

(1) Functional design

This module consists of two parts: the production Kanban and data statistics. The former enables managers to monitor work-order execution and order-completion progress in real time, providing a visual display of production progress. The latter integrates and analyzes data from the material, equipment, and quality-management modules to generate visual production data that covers virtually the entire finished-product manufacturing process. With this module, users can obtain a comprehensive view of finished-product processing, material ratios, inbound/outbound inventory, equipment runtime, energy consumption, and process qualification rates.

(2) Process design

By accessing the production-data visualization management page, production personnel can invoke the data-statistics interface at any time to gain an intuitive understanding of material requirements, product-production progress, and quality-inspection status. This facilitates a clear grasp of work-order execution and creates favorable conditions for production management on the shop floor.

3.7 System Management Module

(1) Functional design

The user-management module supports creating new users, list management, querying, modifying, and deleting, and is mainly used to manage all users within the system. The role-management module covers role creation, management lists, deletion, and also includes a functional menu for managing participants on the shop floor. Log management provides list viewing and log-content querying to manage system logs; when anomalies occur, the corresponding log information can be queried to trace the source of the problem, helping to eliminate system risks promptly.

(2) Process design

After entering the management interface, relevant managers can create users and roles based on their roles on the shop floor to obtain the corresponding system operation permissions, preventing incorrect or unauthorized operations from affecting system management. In log querying, the system administrator logs in as an administrator to access the operation logs of all users, enabling the detection of unreasonable operations and the timely investigation of system-operation issues.

4. DATA-COLLECTION INTERFACE TRANSMISSION PROTOCOL DESIGN

Smart manufacturing workshop management places high demands on data transmission efficiency; therefore, when selecting a data acquisition interface protocol, transmission efficiency must be treated as a key criterion. At the same time, to ensure signal stability, the notably stable TCP/IP protocol is chosen, with Socket used for data communication. It is essential, however, to predetermine the data transmission format. Once the server receives data in the specified format, it parses and stores the data in the database. Each data set consists of the device ID (E0001), spindle temperature (°C), spindle speed (r/min) , coolant flow (L/min) , power (kW), and voltage (V), with "#" separating individual data sets.

5. CONCLUSION

Compared with traditional MES systems, cloud MES systems offer advantages such as lower cost, no need to download a client, and no requirement to build an internal system architecture. They also allow service requests to be submitted to cloud providers, obtaining high-quality cloud services that compensate for shortcomings in smart manufacturing. Relevant studies show that introducing a cloud MES system for workshop management can effectively enhance coordination across production operations, optimize resource allocation, and improve workshop productivity. Therefore, to meet ever-changing workshop production needs and accelerate the intelligent transformation of manufacturing, continued research into cloud MES system design is imperative.

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