Research and Application of a Digital Management Platform for Steel Structure Production Systems

Shudan Dai[1,*], Qian Zhao[2,3], Xiao Xie[4]

[1]Guangzhou Construction Technology Industry Co., Ltd., Guangzhou, 511328, China
[2]Guangzhou Construction Co., Ltd., Guangzhou, 510030, China
[3]Guangzhou Construction Industry Development Co., Ltd., Guangzhou, 510520, China
[4]Guangzhou Research Institute of Construction Industry Group Co., Ltd., Guangzhou, 510520, China
*Corresponding author's e-mail: 2682937031@qq.com

Abstract. Based on steel structure production plants, this paper proposes a digital management platform for steel structure production systems by leveraging the precise data processing capabilities of digital technologies. A full-factor data-driven intelligent decision-making and visual control system has been constructed. Through the data middle-end, full-process and full-factor business data are integrated, and a standardized operational indicator system for steel structure production is established. Multi-dimensional visual presentation is realized via a BI data cockpit, with built-in machine learning models to achieve cost prediction, quality early warning, and schedule optimization. Compared with traditional production management modes, this platform demonstrates significant advantages. The research results can provide valuable references for the design of management platforms in other construction projects.

Keywords: steel structure manufacturing; digital platform; intelligent manufacturing; collaborative management; production informationization;

1 Introduction

Recently, with the mature development of BIM technology, industrial Internet of Things, cloud computing platforms, industrial big data, ERP, MES, RFID, AGV and other software and hardware technologies, the construction industry has ushered in an Internet-driven revolution. As the segment within the construction industry that is closest to large-scale manufacturing, the steel structure industry has been among the first to embrace this wave of transformation and upgrading[1-2]. The steel structure manufacturing sector should closely follow the technological development pace of Industry 4.0 and Made in China 2025, integrating mobile Internet, cloud computing, big data, and Internet of Things (IoT) technologies into steel structure manufacturing. At present, many domestic steel structure enterprises are poised to act, and the construction of digital steel structure factories has been elevated to the strategic level of enterprise development. By adopting the multi-variety, large-batch digital enterprise planning concept,

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the transformation and upgrading demands of the steel structure industry must be translated into concrete implementation paths and models without delay[3].

In recent years, domestic solutions have been proposed to address the problems of low production efficiency and inadequate lean management in steel structure workshops. For instance, Yang Liang et al. developed intelligent cutting and paperless production technologies for steel structure bridges, realizing intelligent cutting and paperless production for such bridges; Xu Zufeng et al. developed intelligent production equipment for steel structures and a corresponding MES execution system, and the related technical equipment has been applied in steel structure production bases with favorable results; Gao Baofu et al. developed a digital management system for assembly workshops that links business relationships among customers, production, and sales, facilitating the digital transformation of enterprises. Zhejiang Construction Group Co., Ltd. has developed a workshop production operation system with functions including project management, collaborative scheduling of production lines, intelligent nesting cutting, intelligent weight monitoring via smart scales, warehouse management, video monitoring, energy consumption monitoring, and production information summary and statistics[4].

At present, the main problem in the production management of steel structure enterprises lies in the contradiction between extensive management practices and the growing demand for intelligent construction[5]. Based on the requirements and actual production characteristics of steel structure factories, this paper takes the component production process as the main line of production management, integrates key technologies such as the Internet of Things, cloud computing, big data, and artificial intelligence, and develops a digital management platform for steel structure production systems. On the basis of the overall architecture design of the platform, research and functional design are carried out for ten major management modules, including orders, design, production, materials, equipment, personnel, monitoring, and logistics. The platform supports functions such as automatic production scheduling, data dashboards, and intelligent monitoring, and enables full life cycle quality traceability of products. It thus provides important guidance for the digital management and optimization of steel structure processing plants.

2 Overall Architecture Design of the Platform

The steel structure production management platform adopts a four-layer loosely coupled microservice architecture, which is divided from top to bottom into the application layer, core business service layer, resource layer, and storage layer. Each layer communicates via standardized interfaces, and the modules within the service layer achieve data interconnection and event-driven operations through a message bus. The overall architecture supports independent deployment and flexible scalability, with interactions between layers implemented through a lightweight communication mechanism. It is adaptable to the business requirements of steel structure manufacturing enterprises of different scales. The hierarchical description of the overall architecture is shown in Table 1.

Table 1. A table with the hierarchical description of the overall architecture.

Architecture level	Core module group	Core positioning
Application layer	PC end management application, mobile end applet/APP, workshop visualization board	Multi-terminal collaborative operation entrance, providing adaptive operation interface for different user roles
Core business services layer	11 core business modules	The core business of the system covers the whole business process of steel structure production, and each module is loosely coupled and independently deployed.
Resource layer	Micro-service framework, data platform, IOT data acquisition platform, message bus/rule engine, machine learning/BI module	System data carrier to realize safe storage and quick retrieval of all types of data
Storage tier	Relational database, time series database, distributed file storage	System data carrier to realize safe storage and quick retrieval of all types of data

The four-layer microservice architecture realizes network interconnection via the intranet and adopts standardized API interfaces for data interaction and docking, enabling real-time data interface updating. Specifically, the real-time data collected by the IoT data acquisition platform at the resource layer is transmitted over the intranet, and then delivered to the storage layer by invoking standard API interfaces to trigger real-time data writing and dynamic updating of the database.

3 Core Business Application Modules

The digital management platform for the steel structure production system is designed based on different roles and responsibilities, with dedicated operation or display interfaces developed for each. It mainly consists of two functional modules: production management (including PC terminal and mobile mini-program APP applications) and digital monitoring (including data visualization dashboards and intelligent video monitoring). The platform focuses on addressing long-standing issues such as information silos, inadequate safety supervision, and extensive cost control, thereby realizing collaborative management.

3.1 Production Management Application (PC Terminal/Mobile Mini-Program APP) for Business Administration

The production management application consists of a PC terminal and a mobile mini-program APP, dedicated to business administration. The PC version is mainly used for back-end production data summary and management, while the mobile mini-program is designed for on-site production information retrieval and entry. Centering on design, planning, cost, materials, production, quality, safety, and on-site operations, the platform conducts full-process management, realizing functions including order management, design management, production management, quality management, and cost statistics and analysis. It supports OCR recognition and online browsing of Tekla 3D models, and enables real-time monitoring of production progress, product quality, and equipment status.

The core business service layer consists of 11 independent microservice modules, the functions and interrelationships of each module are described as follows:

1) Order Management Module

Core functions: This module is responsible for the entry, verification, approval, and archiving of order and contract data. It realizes full-process tracking of orders from creation, dispatching, production, and transportation to closure, and supports refined management of customer information.

Inter-module relationships: As the starting point of the system workflow, approved order data are synchronized to the design management and cost management modules. The module receives order execution data from the production management and quality management modules and updates the order tracking ledger in real time.

2) Design Management Module

Core functions: Design task management, component and part BOM management, design approval management, and closed-loop management of design changes.This module creates design tasks based on orders, maintains BOM lists, completes design approval and change management, and realizes standardization of design data and full-module synchronization.

Inter-module relationships: The module receives order data from the order management module and synchronizes approved BOM data to the material management, planning management, and production management modules. Design change data are synchronized in real time to all associated modules to ensure data consistency.

3) Cost Management Module

Core functions: This module conducts full-life-cycle management of suppliers, performs project cost estimation, dynamic collection, deviation monitoring, and analysis based on order and BOM data, and achieves refined cost control.

Inter-module relationships: The module receives contract amount data from the order management module, BOM data from the design management module, procurement cost data from the material management module, and labor and manufacturing cost data from the production management module, then generates project cost ledgers. Cost overrun warnings are pushed to the order management module and project managers.

4) Material Management Module

Core functions: Material file management, material purchase application management, procurement management, inventory management, inbound and outbound management, and material shortage warning.This module establishes standardized material archives, generates material requirement plans based on BOMs, tracks materials throughout the whole process, and monitors inventory status in real time.

Inter-module relationships: The module receives BOM data from the design management module and generates material requirement plans. Purchase orders and inbound data are synchronized to the cost management module. Material arrival and inventory data are synchronized to the planning management and production management modules. Material shortage warnings are pushed to the production management module and purchasing personnel.

In this system, the BOM subsystem within the design management module adopts predefined unified and standardized interactive fields, covering core items including material code, material name and specification, quantity and unit, hierarchical level, and material attributes. Once the BOM list is finalized and approved in the design management module, the system automatically standardizes the BOM data format and synchronously transmits it to the material management module, realizing seamless automatic data synchronization between the two modules.

5) Plan Management Module

Core functions: This module formulates hierarchical production plans, realizes precise matching between work orders and resources through intelligent dispatching algorithms, and supports dynamic scheduling under abnormal conditions.

Inter-module relationships: The module receives basic data from the order, design, material, equipment, and personnel modules, and generates production plans and work orders. Work order data are synchronized to the production management module. The module receives work order execution data from the production management module and monitors the plan achievement rate.

6) Production Management Module

Core functions: Work order management, daily production report management, process management, operation order management, and real-time production progress tracking.This module executes and controls production work orders, collects on-site data via mobile terminals, monitors production progress in real time, and enables transparent control of the production process.

Inter-module relationships: The module receives work order data from the planning management module and BOM and process data from the design management module. Process execution data are synchronized to the quality management, planning management, and order management modules. Daily production data are synchronized to the production personnel management module for performance assessment. The module also receives resource data from the equipment and material modules to guarantee smooth production execution.

7) Quality Management Module

Core functions: Product quality inspection management, quality inspection report management, quality analysis, closed-loop management of non-conforming products, and full-life-cycle traceability of components.This module performs full-process quality inspection and control of components, establishes a unique component traceability system, and completes quality data analysis and closed-loop management of non-conforming products.

Inter-module relationships: The module receives work orders and process execution data from the production management module. Quality inspection results are synchronized to the production management and order management modules. Component traceability data are associated with full-dimensional data from all business modules. Quality analysis data are pushed to management and production departments.

8) Production Personnel Management Module

Core functions: Personnel file management, team management, attendance management, performance assessment, and training management.This module carries out full-life-cycle management of production personnel, realizes online attendance control, and completes performance assessment by integrating production data.

Inter-module relationships: Personnel skill, team, and on-duty rate data are synchronized to the planning management module to support intelligent order dispatching. The module receives daily production data from the production management module and conducts performance assessment. Attendance data are synchronized to the production management module for personnel on-duty monitoring.

9) Equipment Management Module

Core functions: Equipment ledger management, equipment maintenance management, equipment repair reporting management, and equipment operation status monitoring.This module implements full-life-cycle management of equipment, collects equipment operation data through the Internet of Things platform, and achieves closed-loop management of preventive maintenance and fault reporting.

Inter-module relationships: Equipment status and load data are synchronized to the planning management module for production planning. Equipment failure warnings are pushed to the production management module. Equipment operation and maintenance data are synchronized to the cost management module for recording related equipment costs.

10) Basic Management Module

Core functions: Factory and workshop management, process management, material category management, warehouse management, and production line management.This module maintains and manages basic system data and provides standardized basic data support for all business modules.

Inter-module relationships: It provides standardized basic data for all business modules to ensure consistency of business data across modules.

11) Data Analysis Module (Data Cockpit)

Core functions: Full-process data summarization, BI visual display, operation indicator monitoring, intelligent prediction, and decision-making suggestions.This module summarizes and analyzes all business data, displays core operational indicators through visual dashboards, and provides data-driven decision support for management.

Inter-module relationships: The module receives full-dimensional data from all business modules, performs data cleaning, analysis, and visual display. Decision suggestions and early warning information are pushed to corresponding business modules and managers.

3.2 Digital Monitoring Platform for Diverse Users

The digital monitoring platform comprises two core functional modules: a data cockpit and intelligent video monitoring. Through indicator-based monitoring and AI-powered intelligent analysis, it enhances data collection capabilities and fully unlocks data value.

The data cockpit integrates project-specific and company-wide full-process business data. Via the data cockpit, core operational indicators are visually presented, including project-specific order execution progress, total order volume, order delivery status, personnel attendance, real-time production status, equipment operation conditions, material shortage situations, and quality inspection results. Meanwhile, it generates predictive suggestions for project costs and schedules, which are pushed to management personnel.

The intelligent video monitoring module enables real-time detection of unsafe behaviors and risk events in key areas, such as failure to wear safety helmets, unauthorized entry into restricted zones, smoking, and open flames. Combined with AI intelligent video analysis technology, it can quickly trigger alarms and push danger warning notifications, effectively addressing the pain points of traditional workshop management—including information lag, slow abnormal response, and opaque processes. This further improves production efficiency, product quality stability, and on-site control capabilities.

4 Running Effect

The digital management platform has been formally applied at the Guangjian Science and Technology Steel Structure Intelligent Manufacturing Industrial Base. It fully utilizes an H-beam intelligent production line for component manufacturing and realizes digital closed-loop management and control throughout the entire process from order placement to product delivery. During platform operation, the production management level of the industrial base has been significantly improved. Through automatic production scheduling and full-process collaboration, the efficiency of design–production collaboration has been increased by 60%, the material procurement cycle has been shortened by 40%, the production plan fulfillment rate has reached 100%, the one-time acceptance rate of products has risen to more than 95%, and the project cost deviation has been controlled within 2%. The order delivery cycle has been shortened by 15%, with no occurrences of construction period delays, material shortages, or production shutdowns. Workshop safety production has been maintained in an orderly manner, and overall workshop production efficiency has been significantly improved.

5 Conclusion

This paper addresses current problems in the steel structure manufacturing industry, such as extensive production management, prominent information silos, and difficulties in cost control. By integrating digital technologies including the Internet of Things, cloud computing, and big data, a digital management platform for steel structure production based on microservice architecture is designed and developed. The main research conclusions are as follows:

(1) A distributed overall architecture of "application layer – service layer – resource layer – storage layer" is constructed, enabling independent development, deployment, and expansion of each layer, thus ensuring the flexibility and scalability of the system.

(2) Two core functional modules are designed, namely production management (PC terminal / mobile mini-program APP) and digital monitoring, covering all business links including orders, design, production, materials, equipment, and quality. The platform supports multi-department collaborative work, breaks down data silos in design, production, quality, logistics, and other processes, and achieves a data sharing rate of over 95%, solving issues such as low collaboration efficiency and delayed supervision in the traditional management mode.

(3) Through application verification at the Guangjian Kegong Steel Structure Intelligent Manufacturing Industrial Base, the platform can effectively reduce the loss rate of main materials and production energy consumption, improve production efficiency and safety supervision levels, and provide a feasible technical path and practical model for the digital transformation of steel structure enterprises.

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