ISSN 2706-655X Vol.6, Issue 2: 41-48, DOI: 10.25236/IJFET.2024.060206

Comprehensive High-Reliability Intelligent Tightening Control System

Lihui Pan, Duojin Wu, Bingqing Huang

Shandong CRRC Tonglida Intelligent Machinery Co., Ltd., Jinan, China

Abstract: *In the research of high-speed trains, our country's high-speed rail technology is at the forefront of the world. However, there has not been systematic research on the informatization of the assembly process of rail vehicles and components. The leading domestic manufacturers follow the manual assembly mode introduced in the early technology, although some enterprises have customized assembly tightening systems. These systems only collect the related tightening results and do not meet the quality management of the whole process with comprehensive control over people, machines, materials, methods, and environment. Therefore, considering the actual situation in the rail industry's assembly process, a highly reliable and intelligent tightening control system has been designed based on 4M1E. Under limited conditions, it addresses issues such as determining whether the working status of personnel is good. Whether users apply tools evenly, monitoring the operational status of the tools, assessing the effectiveness of production operations, and shielding the impact of noisy on-site environments on the feedback of tightening results.*

Keywords: *Railway Industry, Quality Management Theory, Industry Internet, Intelligent assembly, Tightening solution*

1. Introduction

According to the data released by the National Bureau of Statistics, there are more than 3.84 million manufacturing enterprises in our country, among which 373,000 are large-scale manufacturing enterprises, accounting for only 9.7%[1]. The overall situation of China's manufacturing industry features many enterprises but on a small scale. Major domestic rail vehicle manufacturers continue to use the manual assembly mode introduced with early technology in the assembly process of rail vehicles and parts. There has yet to be a systematic study on the informatization of the assembly process for rail vehicles and parts. Although some manufacturers have introduced relevant assembly tightening systems [2][3][4] to collect related tightening results, the analysis of this data has, to some extent, improved product quality. However, according to the five factors of man, machine, material, method, and environment in the theory of Total Quality Management that affect product quality, more than merely extracting tightening data is required. Nowadays, knowing how to use software theory knowledge to meet the requirements of Total Quality Management theory, integrating the existing manual digital display tightening equipment, and realizing a comprehensive and reliable tightening solution are crucial. A complete and reliable tightening solution will help small and medium-sized enterprises quickly achieve intelligent manufacturing, improve product quality, and reduce costs.

This article describes an intelligent tightening system applied to a project. This system is designed based on the theory of total quality management. It collects and conducts real-time comprehensive analysis of a series of data such as bolt tightening information, employee borrowing and returning tool records, and the status of the tightening equipment itself. The software part of this system is tool cabinet software, calibration software, PDA software, and server software. After completing the assembly at the industrial site, the tool cabinet, calibration car, and PDA software will accurately synchronize data to the server database in real-time. The server software's analysis module provides a data basis for managers to make decisions. A unified and standard software interface format is designed for each part to ensure the system's scalability. This software enables the quick addition of new functions to subsequent procedures, such as connecting to the enterprise's MES system.

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2. System Design

2.1. System Framework Design

The system network architecture mainly uses wireless (WIFI and Bluetooth) transmission methods to download orders and upload data. The system adopts the architecture shown in figure 1.

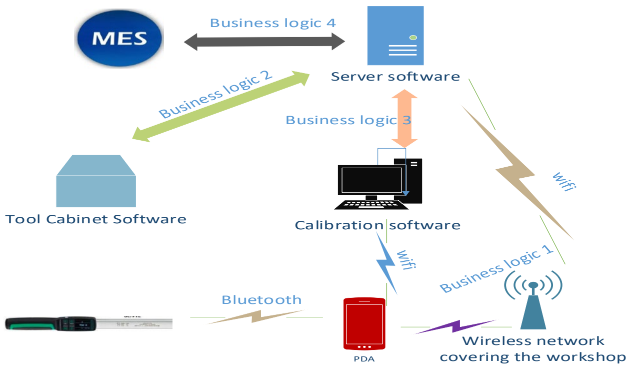

Figure 1: System functional framework diagram

The system divides its software components into server, PDA, calibration, tool cabinet, and server software. The system actively divides its software components into server, PDA, calibration, tool cabinet, and server software. The hardware part of the system consists of servers, tool cabinets, calibration vehicles, Bluetooth digital display wrenches, and PDA connected through wired and wireless networks. In addition to each set of equipment's software systems, there are also corresponding business logic between different software. Based on the above system architecture, we can derive (1) Data communication between the intelligent torque wrench and PDA. (2) Data communication occurs between the PDA and server and with the calibration software. (3) Data communication between calibration instruments and server. (4) Data communication between tool cabinet and server. (5) Data communication between the manufacturer's MES and the server (if the enterprise has an MES system).

2.2. System Functional Unit Design

This section will describe the main functions of server software, PDA software, tool cabinet software, and calibration bench software, respectively, as units.

2.2.1. Server Software

The server software acts as the central software of the entire system. It collects data from other software units and analyzes it according to the theory of Total Quality Management, drawing relevant conclusions. Therefore, the functions to be realized mainly include production management, user management, process editing definition, permission setting, equipment management, data analysis, etc., and the implementation of data docking function modules with PDA software, tool cabinet software, and calibration software.

2.2.2. PDA Software

The PDA software, built into industrial mobile phones, is the mobile client for the innovative tightening system, which automatically loads the app upon starting. Operators can log into the system using an account or employee card swiping. They can use the industrial mobile phone to view work tasks, start production, complete work reports, report exceptions, etc. Its built-in process information database matches work tasks with process information, providing operation steps, essential information, tightening quantity prompts, and displaying tightening results during production.

2.2.3. Tool Cabinet Software

The tool cabinet software is mainly used for intelligent tool retrieval, charging, and discharging, and intelligently guides operators in tool retrieval and displays tool status. When all tools of the same model are in use, the screen displays the names of the users. The software statistically analyzes tool usage rates, intelligently allocates means, and ensures balanced tool usage. When returning tools, the operator must calibrate the torque wrench on the required calibration device, and the calibration information is transmitted back to the system server. If the tool passes calibration, the operator can place it in the

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designated location in the tool storage cabinet. The system internally records the return time and tool model information and calculates the tool usage duration.

2.2.4. Calibration Software

The calibration software can calibrate manually operated digital display wrenches, inspecting their operational status. An electric wrench that continuously fails calibration must not return to the tool cabinet, and the operator should set the electric wrench as a repair status on the cabinet program. It is suitable for daily torque calibration of on-site tools and manages daily tool calibration. The system can store all calibration running data locally and upload it to the server software.

2.3. System Process Design

First, the artisans issue corresponding production tasks on the server software according to the technical requirements. The server software then decomposes the production tasks and assigns them to the workstation leaders' industrial mobile phones corresponding to each workstation. The workstation leader further breaks down the functions of their workstation to each worker's industrial mobile phone. The task distribution module includes two modes: automatic and manual distribution, allowing the workstation leader to choose the appropriate mode to distribute tasks to the specific workers according to actual needs. After the task distribution is complete, the workers swipe their cards at the tool management cabinet to collect tools. The cabinet, based on the assigned task information and the usage rate of tools calculated by the software, intelligently allocates means and automatically pops out the required type of tool to ensure balanced use of the devices. The cabinet software displays the occupier's name and other relevant information when using instruments of the same model.

After taking out the industrial mobile phone and tightening the equipment, workers swipe their cards or log in with their accounts on the mobile phone, connect the equipment via Bluetooth, and place the PDA in the workshop's wireless WIFI area to view the issued work tasks. Then, workers carry out the tightening operations according to the technical requirements of the production task. The PDA software provides assembly step navigation and visual technical guidance during the work. The tightening wrench collects data like torque value, rotation angle, and the tightening curve of each bolt, along with other process information and results, and sends this data via Bluetooth to the industrial mobile phone. Finally, the PDA software uses the workshop's WIFI to send the relevant data to the server. The PDA software has a wireless signal diagnostic function module; it quickly diagnoses when there are network fluctuations and immediately repairs any disconnections to ensure reliable data transmission. The software also optimizes the resume-from-breakpoint function. The system analyzes a network disconnection for safety reasons and alerts the workers. However, workers can continue working generally during tool disconnection periods. Once the industrial mobile phone reconnects to the workshop's wireless network, the PDA software immediately uploads the data collected during the disconnection to ensure the data transmission's reliability and that no tightening data is lost.

When returning tools, workers verify the torque wrench on the verification device. The verification software automatically compares the verification data to determine its qualifications. It then sends the verification data, re-inspection data, worker information, and tool information to the server. The cabinet software determines whether the recent verification data is qualified. Only if the verification passes, workers are allowed to place the tools back in the designated location in the cabinet; otherwise, they are prompted to set the wrench status to an abnormal state. Figure 2 below shows the system process.

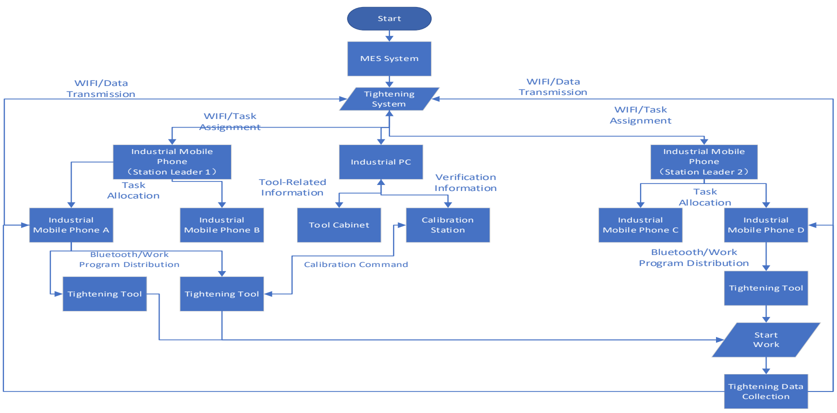

Figure 2: Design of the System Process

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3. System Interface Implementation

As this system has numerous functions that cannot all be listed, this section will analyze the system's relevant functions from the perspective of Total Quality Management theory.

3.1. Server Software-Related Interfaces

Server software, as the central software of this system - a data collection point, makes its data analysis module particularly important. The server software has developed related functions around the "human" factor, not only storing the basic information of the operational staff but also analyzing the state of the operational staff during the work process.

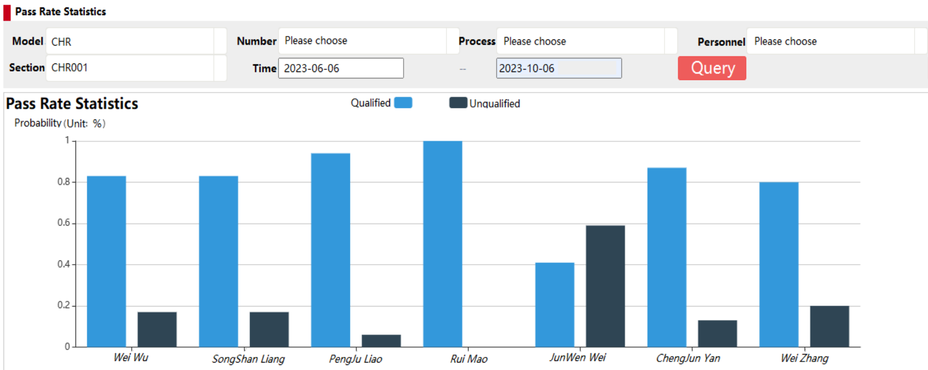
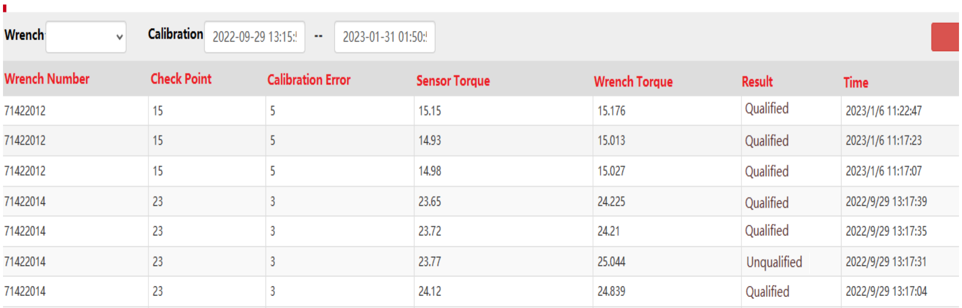


Figure 3: Personnel analysis in Pass Rate Statistics

Using the qualification rate statistics and analysis of personnel, figure 3 above can intuitively express the production efficiency of the operating personnel during specific periods or in some work processes. The server software has developed a checkout software docking interface around the 'machine' factor, as shown in figure 4 below.



Wrench Number	Check Point	Calibration Error	Sensor Torque	Wrench Torque	Result	Time
71422012	15	5	15.15	15.176	Qualified	2023/1/6 11:22:47
71422012	15	5	14.93	15.013	Qualified	2023/1/6 11:17:23
71422012	15	5	14.98	15.027	Qualified	2023/1/6 11:17:07
71422014	23	3	23.65	24.225	Qualified	2022/9/29 13:17:39
71422014	23	3	23.72	24.21	Qualified	2022/9/29 13:17:35
71422014	23	3	23.77	25.044	Unqualified	2022/9/29 13:17:31
71422014	23	3	24.12	24.839	Qualified	2022/9/29 13:17:04

Figure 4: Wrench calibration results

Using the function page displayed in figure 4, one can intuitively understand the current operating status of the tightening wrench. Workers can contact the manufacturer for repairs if the data shows multiple failures. The server software's solution to problems arising from the "material" factor is to display the data qualification rate analysis between different processes, as shown in figure 5.

Figure 5: Process analysis in Pass Rate Statistics

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By analyzing the qualification rates of different processes under a single task, it is possible to determine whether the overall operation of the study is sound. For the "method" factor, the server software's functionality module is to refine process variables and strictly set process conditions according to procedures, as shown in the following figure 6.

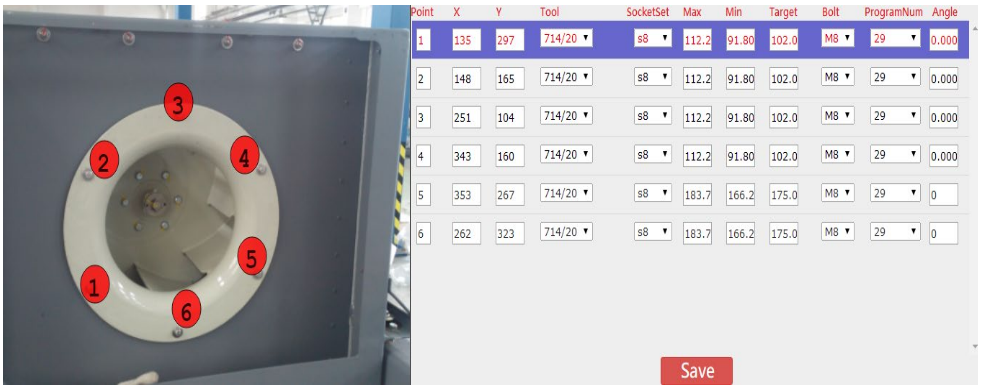

Figure 6: Process Parameter Editing

3.2. PDA Software Interface

The PDA software includes a built-in process information database, matching work tasks with process information. It provides operational steps, critical information, and tightening quantity prompts during production, displaying the tightening results. PDA software meets the requirements of the comprehensive quality management theory for the "method" factor. The PDA software equips a wireless signal diagnostic function module. It quickly diagnoses when there are network fluctuations and immediately repairs the network in case of disconnection, ensuring the reliability of data transmission. The PDA software has also optimized the breakpoint resumption function, avoiding the impact of harsh surrounding construction environments on wireless data transmission, which meets the requirements of the "environment" factor. The following figure 7 below shows task list and figure 8 below shows operational interface.

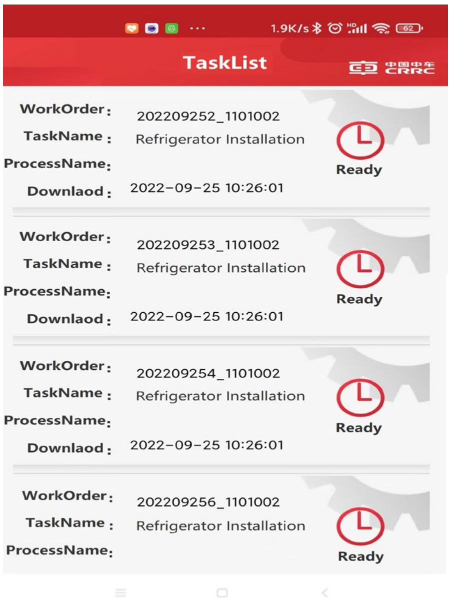

Figure 7: Task List Interface

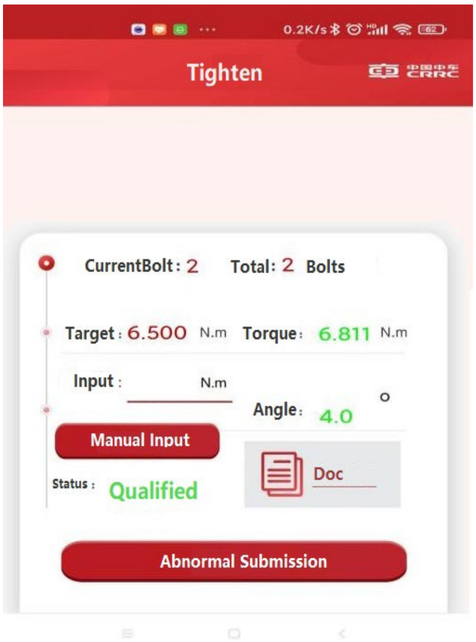

Figure 8: Operational Interface

3.3. Verification Software

The tool verification stand software can calibrate the equipped manual digital display torque wrenches, checking the wrenches' operational status. After calibrating, we send the data back to the server. Figure 9 below show operational interface in verification software.

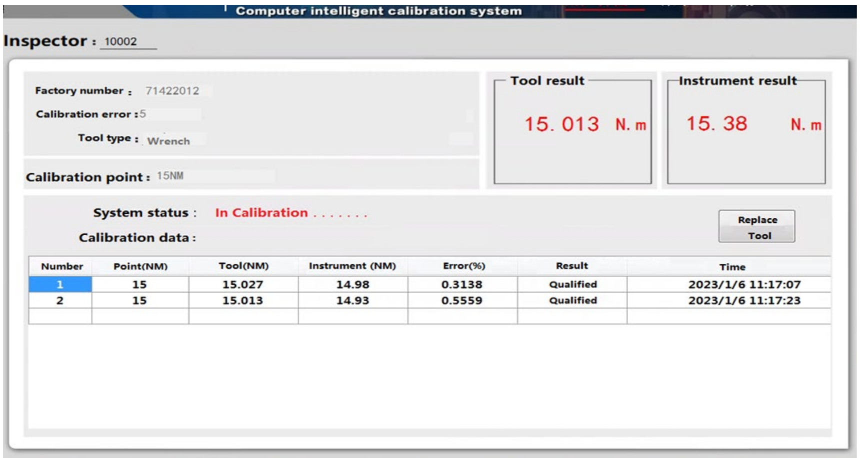

Figure 9: Verification Software

3.4. Tool Cabinet Software

The software for the tool cabinet primarily facilitates intelligent storage and retrieval of tools, enables smart charging and power disconnection, and provides corresponding tool information to server software. The following figure 10 shows task list in toolbox software and the following figure11 shows login interface in toolbox software.

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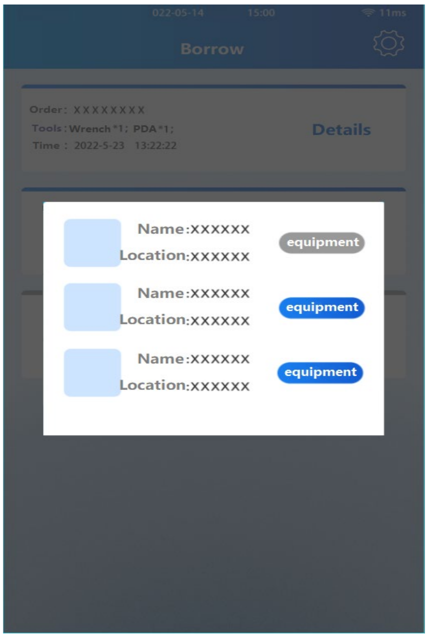

Figure 10: Task List in toolbox software

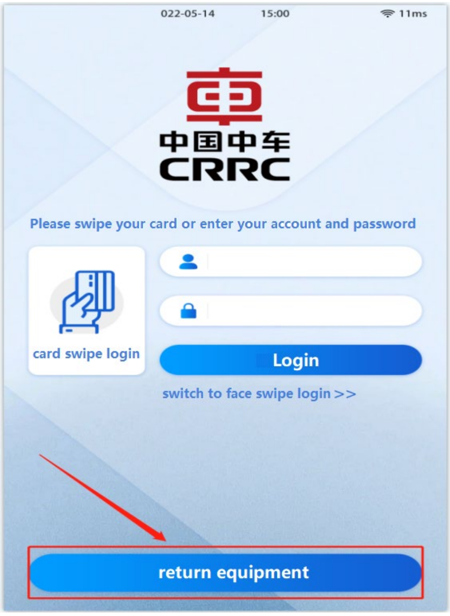

Figure 11: Login Interface in toolbox software

4. System Application Scenario

Considering the actual situation of some weak manufacturing industries at the current stage, this system has broken through the limitations of traditional tightening equipment software that only collects on-site operation data. The system meets the comprehensive quality management theory by collecting on-site data from multiple dimensions and analyzing it. Thus, it realizes a perfect and reliable tightening solution, ultimately enhancing the overall quality of the product's bolt connections. Figure 12 below illustrates the real-world tightening process, while figure 13 below depicts the data analysis interface on server.

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Figure 12: Tightening Porcess in reality

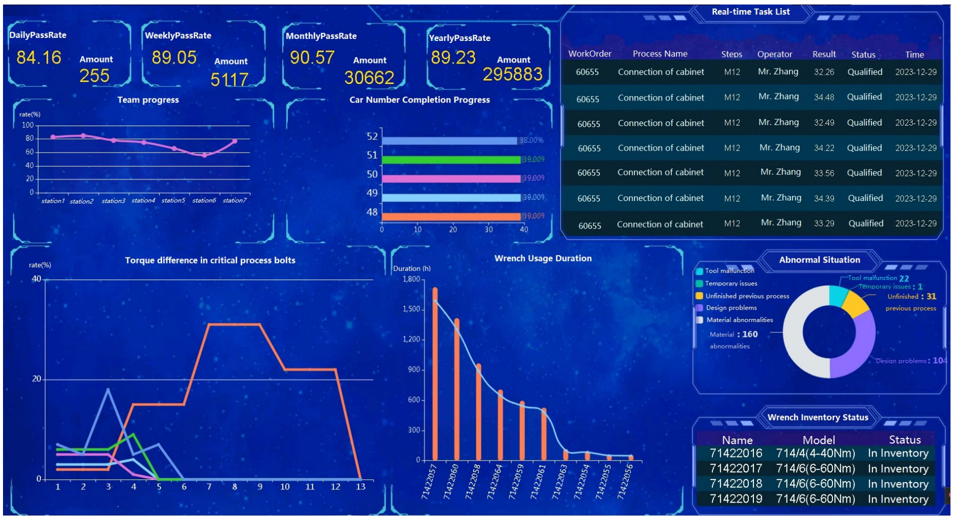

Figure 13: Data Analysis Interface on server

5. Conclusion

This system meets the five factors affecting product quality in the comprehensive quality management theory: human, machine, material, method, and environment. Utilizing software theory knowledge fulfills the complete quality management theory, integrates existing manual digital torque tightening equipment, monitors operators and equipment status, and provides information for managerial personnel to devise corresponding strategies promptly. The system helps small and medium-sized enterprises quickly achieve intelligent manufacturing, improve product quality, reduce costs, and realize a complete and reliable tightening solution.

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