Cooperative Control Mechanism of Key Objects and Key Nodes in Container Terminals

Hankun Shi¹, Xuelin Wang²*, Hongmao Zhou³

¹ China Waterborne Transport Research Institute, Beijing, China
² China Waterborne Transport Research Institute, Beijing, China
³ China Waterborne Transport Research Institute, Beijing, China
*Corresponding author’s e-mail: wangxuelin@wti.ac.cn

Abstract. This research starts from the operation process of the container terminal, constructs a technical route for the analysis of key objects and key nodes, summarizes the specific distribution of key objects and key nodes of the container terminal, and analyzes the process mechanism and interactive information of the container terminal. The cooperative control mechanism of key objects and key nodes creates a certain theoretical framework for the automation and intelligent design of container terminals.

1. Introduction

There are more than 30 automated container terminals built around the world. The ECT terminal in the Port of Rotterdam, the Netherlands was completed in 1993, marking the entry of the container terminal into the era of automation[1]. Subsequently, the Port of London in the United Kingdom, the Port of Kawasaki in Japan, the Port of Singapore, and the Port of Hamburg in Germany have successively built automated container terminals[2]. Since the Xiamen Yuanhai Automated Terminal was completed in March 2016[3], several newly built or renovated automated container terminals such as Shanghai Port, Qingdao Port and Tianjin Port have been built and put into operation one after another. Tianjin Port integrates the application of unmanned automated rail bridges, unmanned electric trucks, and remotely controlled unmanned and autonomous quay cranes[4-5]. The self-developed "intelligent horizontal transportation system" achieves the best overall efficiency. The intelligent production and real-time equipment scheduling system of Shanghai Port Yangshan Phase IV Automated Container Terminal has realized unmanned supervision of equipment operation execution, and the intelligent test of dual-cantilever AWMG container area has realized automatic container sorting, container turning and pre-turning Work, manual work intensity is greatly reduced[6-7]. The Qingdao Port Automated Container Terminal is highly integrated with new technologies such as the Industrial Internet, Internet of Things, and 5G[8-9]. It is the world's leading fully automated container terminal and the world's first "hydrogen +5G" smart green terminal[10], with a maximum operating efficiency of 52.1 natural containers/hour , Compared with the traditional terminal, the operating efficiency is increased by 30%, and the labor cost is reduced by 70%.

In short, the current problems in the direction of intelligent and automation of container terminals mainly include the following two aspects: the first problem is the uneven development of intelligent and automation technology of container terminals. It is mainly reflected in the unbalanced development of key technologies. For example, the upgrading of control technology can not catch up...
with the development of information technology, and the coordinated development between single machine equipment automation and system informatization is insufficient. The second problem is the lack of deep integration of emerging technologies. The integration of emerging technologies such as artificial intelligence, big data, blockchain, information physics system and automatic driving with port business scenarios and key equipment systems is far from enough to support the future development needs of container terminal intelligence and automation. Therefore, starting from the basic theory and overall architecture, it is particularly necessary to find the key objects and key nodes of the container terminal, and deeply analyze the cooperative control mechanism between them.

2. The technical route of analyzing key objects and key nodes of the container terminal

The characteristics of the operation process of the container terminal include: the loading and unloading operations in the container terminal are completely reversible; the operation machinery has cross-regional operations in the operation process; the operation machinery has obvious cooperation and correspondence in the operation process. Based on a comprehensive survey of major domestic automated container terminals such as Qingdao Port, Tianjin Port, Shanghai Port, etc., it analyzes the existing container moving operation process, sorts out the main ship loading and unloading processes, and studies the matching transportation methods. Finally, the key nodes and key objects in the container operation process are clarified. The key object and key node analysis technology roadmap is shown in Figure 1.

3. Distribution of key objects and key nodes in container terminals

The key objects of the automated container terminal are divided into four categories in terms of equipment types, namely terminal frontier loading and unloading equipment, terminal horizontal transportation equipment, terminal yard equipment, and in and out terminal loading and unloading equipment. The equipment under these four types of equipment together constitute the container terminal. The key objects are shown in Table 1. The organic cooperation between them determines the normal and orderly operation of container terminal production operations.
Table 1. Key Objects of Automated Container Terminal

| Wharf type     | Equipment type       | Equipment                                           |
|----------------|----------------------|-----------------------------------------------------|
| Container      | 1. Wharf apron handling equipment | Single trolley double 20ft box shore bridge          |
|                |                      | Single trolley double 40ft box shore bridge         |
|                |                      | Double trolley double 20ft box shore bridge         |
|                |                      | Double trolley 40ft box shore bridge                |
|                | 2. Wharf horizontal transportation equipment | Horizontal transportation truck                      |
|                |                      | AGV/IGV                                             |
|                |                      | Straddle carrier                                     |
|                |                      | Rail shuttle car                                     |
|                | 3. Wharf yard equipment | Rail mounted gantry crane                           |
|                |                      | Rubber tyred gantry crane                           |
|                |                      | Straddle carrier                                     |
|                | 4. Loading and unloading equipment in and out of the wharf | Container truck                                    |
|                |                      | Driverless container truck                          |

The key nodes of the container terminal are divided into four categories from the core system to which they belong, namely the terminal operating system, the support system, the equipment control system, and the remote control system. The subsystems under these four types of systems constitute the key nodes of the container terminal. As shown in Table 2. The coordination and interconnection between them assisted the normal operation of the key equipment of the container terminal, realized the business operation and the exchange and sharing of information and data, and improved the work efficiency and intelligence of the terminal to a certain extent.

Table 2. Key node of container terminal

| Wharf type | Core system | Subsystem                                                                 |
|------------|-------------|---------------------------------------------------------------------------|
| Container  | 1. Terminal Operation System | System management |
|            |             | Configuration management                                                  |
|            |             | Basic information management                                              |
|            |             | Appointment acceptance                                                     |
|            |             | Documentation and electronic data processing                             |
|            |             | Operation plan                                                             |
|            |             | Dispatching and monitoring                                                 |
|            |             | Gate control                                                               |
|            |             | Container information management                                           |
|            |             | Billing and settlement                                                     |
|            |             | Statistical analysis                                                       |
|            |             | Work terminal system                                                       |
|            |             | Dangerous goods management system                                          |
|            |             | CFS management                                                             |
|            | 2. Support system | Online business hall                                                        |
|            |             | Video monitoring system                                                    |
|            |             | Electronic chart system                                                   |
|            |             | Tally system                                                               |
|            |             | Ship safety information retrieval                                          |
|            |             | Meteorological information platform                                        |
|            |             | Remote monitoring system                                                  |
| Wharf type | Core system                      | Subsystem                                      |
|------------|----------------------------------|------------------------------------------------|
|            |                                  | refrigerated containers in storage yard        |
|            |                                  | Electronic map of port area                    |
|            |                                  | External truck navigation system              |
|            |                                  | Data center                                    |
|            |                                  | Large screen system                            |
|            |                                  | Access control system                          |
| 3. Equipment control system | Quayside container crane management system |                                               |
|            |                                  | Container gantry crane management system       |
|            |                                  | Horizontal transportation equipment management system |
| 4. Remote control system | Remote control system of quayside container crane |                                               |
|            |                                  | Remote control system of container gantry crane |

4. Cooperative Control Mechanism of Key Objects and Key Nodes in Container Terminals

Based on the above research content, combined with the container terminal material movement process mechanism and the container terminal material movement interaction information, from the frontier loading and unloading equipment of the terminal, the horizontal transportation equipment of the terminal, the terminal yard equipment, the loading and unloading equipment in and out of the terminal, and the level of key objects and the terminal operating system, starting from the level of key nodes such as the equipment control system, remote control system, and support guarantee system, we sort out the control logic structure required to achieve the remote real-time online material movement control function on the basis of ensuring the safe and stable operation of the terminal, as shown in Figure 2.

Figure 2. Logical structure of remote real-time material movement control

Combining the above control logic, the control mechanism of the coordination and cooperation between the key nodes and key objects of the container terminal is shown in Table 3. The interaction mechanism between the systems can open up the circulation path of decision-making information between the systems during the terminal operation. The interaction mechanism between devices can integrate the internal relationship between information flow and physical flow, and the interaction

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mechanism between devices can determine the optimal structure of the device in the geographical space layout.

Table 3. Cooperative control mechanism between key objects and key nodes of the container terminal

| Interaction category          | Information flow                   | Interactive information                                      |
|------------------------------|-----------------------------------|-------------------------------------------------------------|
| Interaction between systems  | 1       | A-B | Work order             | B-A | Work order execution status |
|                              | 2       | B-C | Work order             | C-B | Work status                 |
|                              |         | C-B | Work order execution status | Work intervention request |
| Interaction between system and equipment | 3       | B-a | Detailed work instructions |
|                              | 4       | a-B | Fault information      | b-B | Fault information           |
|                              |         | a-B | Work status            | b-B | Work status                 |
|                              |         | a-B | Work order execution status | Abnormal operation instruction execution |
|                              | 5       | B-c | Detailed work instructions |
|                              | 6       | c-B | Fault information      | c-B | Fault information           |
|                              | 7       | c-B | Work order execution status | c-B | Work status                 |
|                              | 8       | C-c | Remote operation instruction | c-B | Abnormal operation instruction execution |
|                              | 9       | C-c | Remote operation instruction                                                                 |
|                              | 10      | a-b | Driver identification information / vehicle number |
|                              |         | b-a | Positioning signal of wharf horizontal transportation equipment |
|                              | 10      | c-b | 3D scanning signal of wharf horizontal transportation equipment |
|                              |         | c-b | Positioning signal of wharf horizontal transportation equipment |

5. Conclusions
The analysis of the key objects and key nodes of the container terminal and the study of the control mechanism between them can lay a theoretical foundation for the construction of the container terminal control model and digital twin. On the basis of focusing on the material movement process mechanism and comprehensively grasping the material movement interactive information, combined with the actual operating conditions of each container terminal, in the future, we can create a system design plan and engineering application guidance specifically for automated container terminals.

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