Cooperative control mechanism of key objects and key nodes of dry bulk terminal

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Abstract. Based on the operation process of dry bulk terminal and according to the unique process characteristics of dry bulk terminal, this study combs the specific distribution of key objects and key nodes of dry bulk terminal. Based on the analysis of the process mechanism and interactive information of dry bulk terminal, the collaborative control mechanism of key objects and key nodes is studied, which creates a certain theoretical framework for the automation and intelligent design of dry bulk terminal.

1. Introduction
Foreign ports have advanced research and application concepts in dry bulk intelligent technology, and introduce advanced computer and information technology to reduce logistics costs and improve operation efficiency. For example, Newcastle port in Australia is the world’s largest coal export port[1]. Unmanned operation has been realized in the coal stacking link for a long time, so as to improve the coal stacking efficiency and reduce the operation cost. Rotterdam port in the Netherlands is committed to promoting the process of port digitization and improving port operation efficiency and service level through the application of modern information technology and artificial intelligence technology[2-3]. Rotterdam port uses Ethernet, cloud computing, mobile terminal equipment, Internet of things, GIS, video monitoring system, etc. to establish the port operation management system, realize the seamless connection between the information system instructions and the terminal machinery and equipment control functions, and make the efficient and reasonable allocation and scheduling of various port resources[4]. Shanghai Luojing phase II bulk cargo terminal has a set of full-automatic bridge grab ship unloader, full-automatic stacker reclaimers and full-automatic ship loader, all of which are remotely controlled through the central control room[5]. Huanghua port coal terminal has realized the operation of automatic coal terminal by integrating visualization system, monitoring and early warning system and emergency disposal system, and has become the first coal terminal in China to realize the whole process remote operation[6-7]. The remote operation system is introduced into the coal terminal of Huangye port to uniformly dispatch the dumper operation, stacker operation, reclaimer operation and loading operation of the coal terminal[8]. The Nanjiang bulk cargo terminal of Tianjin Port has completed the transformation of the automatic terminal, adopted a new automatic shipping system, scanned the hull through lidar, and then carried out the shipping work, so as to realize the automatic shipping operation under unmanned conditions[9-10]. It can be seen that in the future, the deep
integration of process flow, equipment, system and new technology is the core path for the construction and development of automatic dry bulk terminal.

After comparing and analyzing the intelligent technology application of several dry bulk cargo terminals, it is analyzed that the problems existing in the current intelligent and automation direction of dry bulk cargo terminals mainly include the following two aspects: the first aspect is that bulk cargo terminals have the characteristics of wide variety of goods, huge quantity and complex operation process. Many links need to rely on manual experience, and the degree of intelligence is low, the upgrading of control technology can not catch up with the development of information technology. The second aspect is the lack of deep integration between new technologies and traditional systems. The integration of emerging technologies such as artificial intelligence, big data, blockchain and information physics system 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 very important to find the key objects and key nodes of dry bulk terminal, and deeply analyze the cooperative control mechanism between them.

2. Distribution of key objects and key nodes of dry bulk terminal
Dry bulk terminal has the characteristics of rich types of equipment and systems, non centralized goods, complex technology and so on. Therefore, before studying the cooperative control mechanism of dry bulk terminal, it is particularly important to sort out the key objects and key nodes in many equipment and systems, complex processes. The key objects of dry bulk cargo terminal are divided into five categories from the perspective of equipment types, namely terminal loading and unloading equipment, terminal loading and unloading equipment, terminal yard equipment, terminal horizontal transportation equipment and terminal operation auxiliary equipment. The equipment under these five types of equipment together constitute the key objects of dry bulk cargo terminal, as shown in Table 1. The organic cooperation between them determines the normal and orderly operation of dry bulk terminal production.

| Wharf type               | Equipment type                      | Key object                                                                 |
|--------------------------|-------------------------------------|----------------------------------------------------------------------------|
| Dry bulk terminal        | Dock loading and unloading equipment| Mobile ship loader, swing ship loader, fixed ship loader, ship boom, ordinary gantry crane, bucket gantry crane, loading bridge |
|                          |                                     | Chain ship unloader, bucket wheel ship unloader, screw ship unloader, belt unloader, buried scraper ship unloader and pneumatic conveyor |
|                          | Dock loading and unloading equipment| Bridge crane grab, portal crane grab, loading and unloading bridge grab, single bucket loader, elevated bin hopper belt conveyor system, dumper, screw unloader, chain bucket unloader, bottom door dump truck, crane grab and simple push rod unloader |
| Wharf yard equipment     | Stacker, reclaimer, stacker reclaimer |                                                                            |
| Wharf horizontal transportation equipment | Belt conveyor, clamp belt conveyor, chain conveyor, buried scraper conveyor, screw conveyor, bucket elevator, bracket elevator |
| Auxiliary equipment for wharf operation | Electronic belt scale, funnel metering device, track scale, underground scale, water gauge measurement, bucket leveler, straight belt leveler, curved belt leveler, feeder, scraper, rake, shovel, bucket truck, wind and dust prevention net, |
sprinkler, hot air thawing device, steam heating pipe thawing device, gas or infrared thawing device, air blowing arch breaking device, arch breaking device of coal conveyor.

The key nodes of dry bulk terminal are divided into four categories from the core system, namely automatic control system, management information system, remote control system and support system. The subsystems under these four types of systems together constitute the key nodes of dry bulk terminal, as shown in Table 2. The cooperation and interconnection between them assisted the normal operation of the key equipment of the dry bulk terminal, realized the business operation and the exchange and sharing of information and data, and improved the work efficiency of the dry bulk terminal.

Table 2. Key nodes of dry bulk terminal

| Wharf type          | Core system                                      | Key node                                      |
|---------------------|--------------------------------------------------|-----------------------------------------------|
| Automatic control system | Automatic control system of bulk cargo handling machinery | Tally management system                      |
|                     | Automatic control system of bulk cargo conveying machinery | Stockpile management system                  |
|                     | Dust removal automatic control system             | Equipment management system                  |
|                     | Automatic lighting control system                 | Energy consumption management system          |
|                     | Operation information monitoring system           | Production and operation management system    |
|                     | Inventory information monitoring system           | Gate control system                          |
|                     | Equipment condition monitoring system             | Statistical analysis management system        |
|                     | Energy consumption monitoring system              | Basic information management system           |
| Management information system | Remote control system of wharf ship handling equipment | Wireless intercom system                    |
|                     | Remote control system of wharf yard equipment     | Port video surveillance system                |
|                     |                                                   | Ship dynamic monitoring system based on electronic chart |
|                     |                                                   | Meteorological information management system  |
|                     |                                                   | Positioning and navigation system             |
|                     |                                                   | Online service system                        |
|                     |                                                   | Large screen display system                   |
|                     |                                                   | Data center system                           |
| Remote control system |                                                   |                                               |
| Support system       |                                                   |                                               |

3. Cooperative control mechanism of key objects and key nodes of dry bulk terminal

On the basis of focusing on the material movement process mechanism of dry bulk terminal and fully mastering the material movement interaction information of dry bulk terminal, this study combs out the control logic structure required to achieve the remote real-time online movement control function on the basis of ensuring the safe and stable operation of the terminal, starting from the level of key objects and key nodes, as shown in Figure 1.
Figure 1. Remote real-time online material movement control logic of dry bulk terminal

Combined with the above control logic, the control mechanism of coordination and cooperation between key nodes and key objects of dry bulk terminal (between systems, between systems and equipment, between equipment and equipment) is shown in Table 3. The interaction mechanism between systems can open up the flow path of decision information between systems in the process of terminal operation. The interaction mechanism between system and equipment can integrate the internal relationship between information flow and physical flow, and the interaction mechanism between equipment can determine the optimal structure of equipment in geospatial layout.

Table 3. Cooperative control mechanism between key objects and key nodes of dry bulk 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                                              |
|                                        |                  | Work order execution status                                |
|                                        |                  | C-B Work status                                             |
|                                        |                  | Work intervention request                                   |
| Interaction between system and equipment| 3                | B-a Detailed work instructions                              |
|                                        |                  | a-B Fault information                                       |
|                                        |                  | Work status                                                |
|                                        |                  | Work order execution status                                 |
|                                        |                  | Abnormal operation instruction execution                     |
|                                        | 4                | B-b Detailed work instructions                              |
|                                        |                  | b-B Fault information                                       |
|                                        |                  | Work status                                                |
|                                        |                  | Work order execution status                                 |
|                                        | 5                | B-c Detailed work instructions                              |
|                                        |                  | c-B Fault information                                       |
|                                        |                  | Work order execution status                                 |
|   |       |
|---|-------|
| 6 | B-d   | Work status |
|   |       | Abnormal operation instruction execution |
|   | d-B   | Fault information |
|   |       | Work order execution status |
|   |       | Work status |
|   |       | Abnormal operation instruction execution |
| 7 | B-e   | Work order |
|   | e-B   | Fault information |
|   |       | Work order execution status |
|   |       | Work status |
| 8 | f-A   | Driver identification information, truck or train number |
| 9 | C-a   | Remote operation instruction |
|   | a-C   | Work status |
| 10| C-c   | Remote operation instruction |
|   | c-C   | Work status |
| 11| C-d   | Remote operation instruction |
|   | d-C   | Work status |

**Interactions between devices**

|   |       |
|---|-------|
| 12| a-b   | Interlocking control signal |
|   | b-a   | Interlocking control signal |
| 13| c-b   | Interlocking control signal |
|   | b-c   | Interlocking control signal |

4. Conclusions

The analysis of key objects and key nodes of dry bulk terminal and the corresponding cooperative control mechanism can lay a theoretical foundation for the construction of dry bulk terminal control model and digital twin. On the basis of focusing on the material movement process mechanism and fully mastering the interactive information of material movement, combined with the actual needs and process characteristics of each dry bulk terminal, a system design scheme and engineering application guidance for automated dry bulk terminal can be created in the future.

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