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SUPER ENGINEERING

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Fully automatic container terminals of Shanghai Yangshan Port phase IV

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Engineering Owner: Construction Headquarters of Yangshan Deep-water Port Phase IV Project of Shanghai International Shipping Center
Designer: CCCC Third Harbor Consultants Co., Ltd.
Civil Constructer: China State Construction Harbor Construction Co., Ltd.;
CCCC Third Harbor Engineering Co., Ltd.
Equipment Manufacturer: Shanghai Zhenhua Port Machinery Co., Ltd.
Software Developer and System Integrator: Shanghai Harbor e-Logistics Software Co., Ltd. of Shanghai International Port (Group) Co., Ltd.
Supervisor: Shanghai Far East Waterway Engineering Construction Supervision and Consultation Co., Ltd.;
Shanghai Donghua Construction Management Co., Ltd.;
Jinghua Engineering Supervision Co., Ltd. under CCCC Water Transportation Consultants Co., Ltd.
Operator: Shangdong Branch, Shanghai International Port (Group) Co., Ltd.

1 About Shanghai Yangshan Deepwater Port phase IV Engineering

Shanghai Yangshan Deepwater Port phase IV Engineering (hereinafter referred to as "Yangshan phase IV"), is located in Hangzhou Bay of Pudong New Area, Shanghai, China. Embanked by the East Sea Bridge in the north, the engineering is in the west most area of Yangshan Deepwater Port and sits on the reclaimed land along the Kezhushan Island – Great Turtle Island – Turtle Island line, covering 2.23×10^6 m^2 in total with a width of around 500 m. Coastline of the berths in the project stretches around 2770 m, including 2350 m for seven container ship berths and 350 m for auxiliary working ship berths. Total investment in the project is more than 14 billion yuan. The engineering has a planned capacity of 150000 deadweight tons (DWTs) for container berths (may be upgraded to 200000 DWTs in the future), and an annual throughput capacity of 4 million twenty-foot equivalent units (TEUs) in the preliminary stage, with 6.3 million TEUs planned in the longer term.

The terminals adopt the remotely controlled automated quay cranes (RC-AQCs) + automated guided vehicles (AGVs) + automated rail-mounted gantries (ARMGs) solution for container handling. The whole system incorporates three main types of heavy machinery and equipment for port operations, including 26 RC-AQCs, 130 AGVs and 88 ARMGs, all of which are electrically powered with no driver's cabs, featuring "unmanned" operations that are intelligently managed throughout the process.

With its construction commenced on Dec 23, 2014, Yangshan phase IV (as shown in Fig. 1) was launched for pilot operations on Dec 10, 2017 after almost three years of arduous construction and 18 months of meticulous and comprehensive equipment and system commissioning. The engineering owns, by far, the world's largest fully automated container quays with independent intellectual property rights, the highest level of automation and the highest penetration of intelligent technologies, featuring "China-made" across the board.

2 New layout model of intelligent yard at port

The automated yard in the Yangshan phase IV covers 945000 m^2, 2384.5 m in length and 210 to 446.5 m in width (averaged at 396.5 m), being the vastest area in the project. Yet compared with phases I, II and III projects, all of which are 900 m on average in land width, Yangshan

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Fig. 1 A glimpse of the fully automated terminals of Yangshan phase IV.

phase IV has a much smaller yard area subject to the limitation of its oblate terrain. To maximize the usable area of the automated yard, the site plan of Yangshan phase IV received dozens of revisions. Leveraging the fully automated handling solution, the full-framing layout of core zones of the automated yard, and the arrangement of rail-mounted gantry crane operating routes perpendicular to quays, high-density stacking has greatly boosted the utilization of land and deepwater quay while minimizing haul distances of horizontal transportation in the terminal (Fig. 2). Coupled with simulation and design optimization, the annual throughput capacity of the container terminals has increased from 5.3 to 6.3 million TEUs. Traffic in the port area flows from the east to the west, as entry gates are in the east while exit gates are in the west. After entering the gate of terminal, container trunks travel in one direction, and the entry and pickup operations of general purpose containers and refrigerated containers are completed in the landside interaction area of the yard. This arrangement effectively shortens the travel distances of external container trunks and their stays in the port area. The efficiency-oriented layout that adapts to local conditions has introduced a great leap in both the throughput capacity and the land utilization of Yangshan phase IV yard compared with traditional container terminals.

Fig. 2 The quay apron of Yangshan phase IV.

In port gate designs, the engineering pioneers a gates layout featuring three-tier entry, namely “pre-clearance, diversion and clearance”, setting up pre-clearing, diverting and clearing gates with a buffer parking lot for external container trunks between the diverting and clearing gates. The layout strengthens management over arriving vehicles, eases in-port traffic pressure and elevates the service quality and operational efficiency in the port area. The engineering also initiates an intensive layout for exit gates that integrates exit and inspection functions to enable full coverage of disinfecting spraying for containers from epidemic regions, which keeps the driveways of external container trunks and internal container shuttle trunks separate, enhancing the operating efficiency and ensuring smooth traffic flows.

In technical systems for the yard, the engineering has designed and developed a hybrid layout incorporating three types of automated rail-mounted gantry cranes (ARMGs) (Fig. 3), namely non-cantilever, unilateral-cantilever, and bilateral-cantilever gantry cranes, for the automated container yard. The layout, based on the “water-water transfer ratio” and the number of containers for inter-port-area dispatching, enables a rational allocation and hybrid layout of the three types of ARMGs adhering to an efficiency-volume balance principle. As a result, multiple problems, such as the imbalanced workloads for seaside and landside ARMGs in the yard, the higher requirements on seaside handling system efficiency against the ship upsizing context, the high handling cost of inter-port-area dispatched containers and the complicated traffic management, are effectively addressed, and the adaptability of the fully automated container terminals is also improved.

Fig. 3 A panorama of Yangshan phase IV project in equipment commissioning.

3 Packaged key technologies and innovations of ultra-large intelligent automation equipment at port

3.1 Ultra-large and ultra-heavy "unmanned" remotely controlled automated quay cranes (RC-AQCs or QCs) and packaged key technologies

Except the entry and exit operations of slings through ship hatches, which require manual remote control and manipulation, the QC (as shown in Fig. 4), with an elevating capacity of 65 tons and an outreach of 70 m, achieves fully automated operations covering all the operations and movements of the secondary trolley.

Signal hoist + tandem spreader + double trolley + transit platform. The transit platform is the area where the primary trolley interacts and connects with the gantry trolley. After mechanical arms and a conveyer are installed in place, container twist locks can be disassembled in a fully automated mechanical arm. There is no driver's cab on the QC, as it is fully automated except in the pickup of primary trolley and loading of containers on the ship side where manual intervention are required. Relying on the advanced Ship Profile Scanning System (SPSS), the QC scans the ship profile and builds a skeleton map in real time using the three laser cameras on the primary trolley to enable speed reduction and anti-collision protection during its automated operations. The gantry trolley is fully automated with superb accuracy and stability and monitors the bridge crane operation conditions online in real time to ensure the equipment reliability.

Fig. 4 Remotely controlled automated quay cranes (RC-AQCs).

Fig. 5 Automated rail-mounted gantries (ARMGs) in Yangshan phase IV.

3.2 Ultra-large and ultra-heavy fully automated rail-mounted gantry cranes (ARMGs) and packaged key technologies

The automated yard lies perpendicular to the quays and has total 88 units of ARMGs (as shown in Fig. 5) (one block with 2 ARMGs) for seaside operations of AGVs and landside operations of external container trunks. The ARMGs achieve fully automated operations controlled by the Terminal Operation System (TOS) and the Equipment Control System (ECS).

The engineering initiates a layout of three types of ARMGs (non-cantilever, unilateral-cantilever and bilat-

eral-cantilever, which are entirely electrically-powered) for joint operations, which is the first of its kind worldwide. To ensure container trunk operation safety, the landside ARMGs adopt an automated remote-control mode that supports manual intervention during handling operations, and implement full automation in all the rest operations. For seaside operations in the yard, the engineering initiates the arrangement of ARMGs with twice 20-foot spreader, improving the alignment between the operations of ARMGs and QCs while enabling fully automated and more efficient operations.

3.3 Intelligent automated guided vehicles (AGVs) and packaged key technologies

The in-terminal horizontal transport system comprises a total of 130 AGVs (as shown in Fig. 6) which move at a speed of 6 m/s with an elevating capacity of 65 tons. The system uses automatically-replaced lithium batteries and is controlled by the Terminal Operation System (TOS) and Equipment Control System (ECS) jointly in an "unmanned" and intelligent manner.

Fig. 6 AGVs using automatically-replaced batteries which supports automated lifting.

AGVs are important transporters in ship handling operations. Containers are transported by AGVs from the QCs to the seaside ARMGs or cantilever-type ARMGs in the yard blocks, or from the blocks to the QCs.

AGVs are powered by lithium batteries. Such pure electric vehicles, with state-of-the-art technologies currently available, cost less for maintenance, and have a high energy efficiency coefficient with less energy consumed and no waste gas produced, being green and environment-friendly. AGVs, apart from driverless operation, automatic navigation, route optimization and autonomous obstacle avoidance, support self-diagnosis of faults and self-monitoring on battery usage. With the help of wireless communication devices, the automatic scheduling system and the 60000-plus transponders installed under the ground, AGVs can achieve smooth and safe shuttling between busy quay sites and arrive at designated parking locations through precise positioning. Meanwhile, the project also launched a unique hydraulic lifting mechanism where the AGV lifting platform hoists and drops the fixed containers in the seaside interaction area of the yard. As a result, AGVs do not need to wait passively for the yard equipment to arrive for handling operations and rail-mounted gantry cranes also do not need to waste time waiting passively, solving the "de-coupled" problem between horizontal transport and depot operations and hence enhancing equipment utilization.

4 Intelligent management and control system and innovations

Orderly and efficient operation of an automated terminal requires not only automated equipment but also all-round collaboration, and the intelligence competency of systems has a direct bearing on the safety, capacity, cost and efficiency of terminal operation. The intelligent software system of Yangshan phase IV project is composed of the Terminal Operation System (TOS) and the Equipment Control System (ECS) (as shown in Fig. 7), which two forms the "brain" and "nerves" of the brand new terminal, respectively. In addition, the project has also developed a full-process management and control system integrating all elements for safety, security and environment protection at the port.

4.1 Intelligent terminal operation system at port – TOS

The TOS for intelligent operation management and control, independently developed by Shanghai International Port (Group) Co., Ltd., covers all business processes of the automated terminals and is connected to various data information platforms of Shanghai Port (including the business acceptance platform, the container trunk reservation platform, the data analysis platform, and the uniform scheduling platform). The TOS provides an intelligent production planning module, a real-time operation scheduling system and a process control system automatically monitored and adjusted. Taking into account the characteristics of the handling equipment in Yangshan phase IV project, the TOS develops an innovative instruction scheduling architecture platform which efficiently organizes production at the terminal through the equipment scheduling module and the collaborative process control system. With 57 scenarios, more than 1670 Tier-1 business processes, more than 5800 algorithm modules, and 35000 decision-making parameters, the TOS features extensive application and integration of Artificial Intelligence (AI), big data, the Internet of Things (IoT), intelligent modeling, evolutionary algorithms, and analogue simulation technologies, and enables intelligent online decision-making in real time for complex large systems under multiple business portfolios to facilitate collaboration among

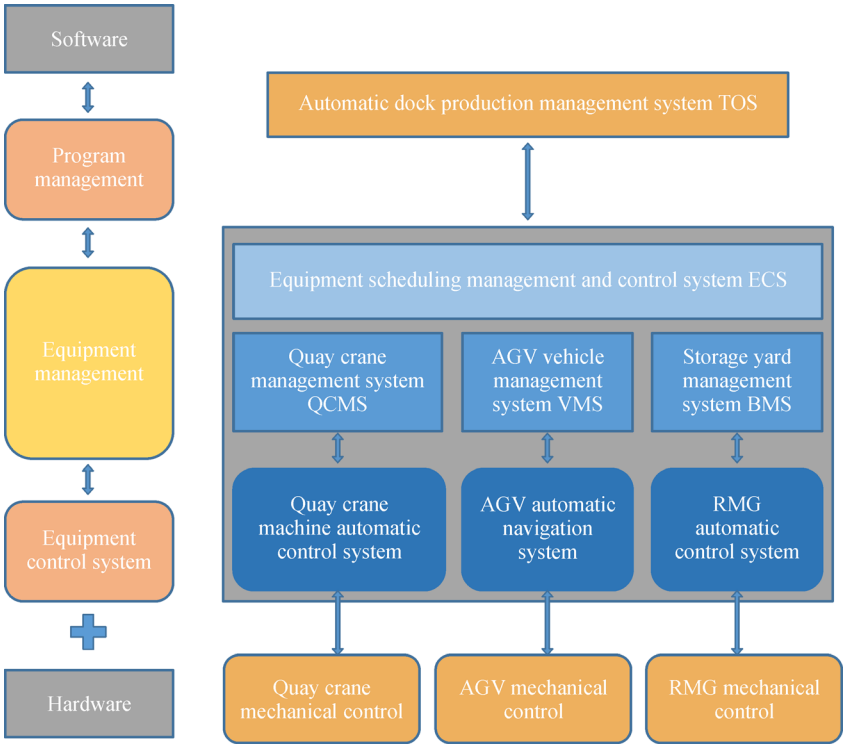

Fig. 7 Structures of TOS and ECS.

multiple equipment types at an ultra-large terminal. The TOS outperforms its international counterparts with monopolistic status by a wide margin.

4.2 Intelligent control system for automated equipment at port – ECS

The fully automated ECS of Yangshan phase IV was jointly developed by Shanghai International Port (Group) Co., Ltd. and Shanghai Zhenhua Port Machinery Co., Ltd. The ECS takes the place of the operators for traditional equipment and coordinates the equipment with the system in an organic manner to facilitate their close cooperation, so as to complete handling tasks assigned by the TOS automatically, efficiently and safely, and enable intelligent operations at the terminal as a whole. The ECS reduces the manpower cost at the terminal and manual interventions during production processes. In particular, it brings down the occurrence of safety accidents, improves the working environment for terminal operators, lowers down the labor intensity of terminal workers and improves terminal operational efficiency.

Primary features and technical innovations in the ECS are as follows: (1) AGV scheduling routes that run in parallel with the shoreline at the seaside; (2) AGV optimal routing algorithms; (3) AGV selection and collision avoidance control algorithms; (4) optimal route scheduling algorithms for rail-mounted cranes in the yard; (5) safety control algorithms for the double trolley quay crane platform; (6) real-time monitoring and remote-control operating system; (7) 3D simulation analysis system; (8) hot standby redundancy of automated terminal software systems; (9) target positioning and laser scanning systems of large mechanical equipment such as cranes; (10) automatic navigation and positioning technologies for AGVs; (11) wireless communication redundancy technologies of vehicles.

4.3 Intelligent full-process management and control system integrating all elements for safety, security and environment protection at the port

Automated areas of the Yangshan phase IV project (Fig. 8) include 61 automated rail-mounted hoisting box areas, AGV horizontal operation areas, the battery exchange stations, AGV maintenance and testing areas, and refrigerated container operation areas. These automated operation areas implement enclosed unmanned management and control by integrating an access control system to ensure safe and efficient organization of production, maintenance and emergency repairs in the areas. A total of four types of access control systems are designed tailoring to different needs, and interactive control processes are also diversified to match different production patterns. In addition, these automated access control systems also incorporate an intelligent face recognition access control system for automated equipment, an intelligent recognition management and control system

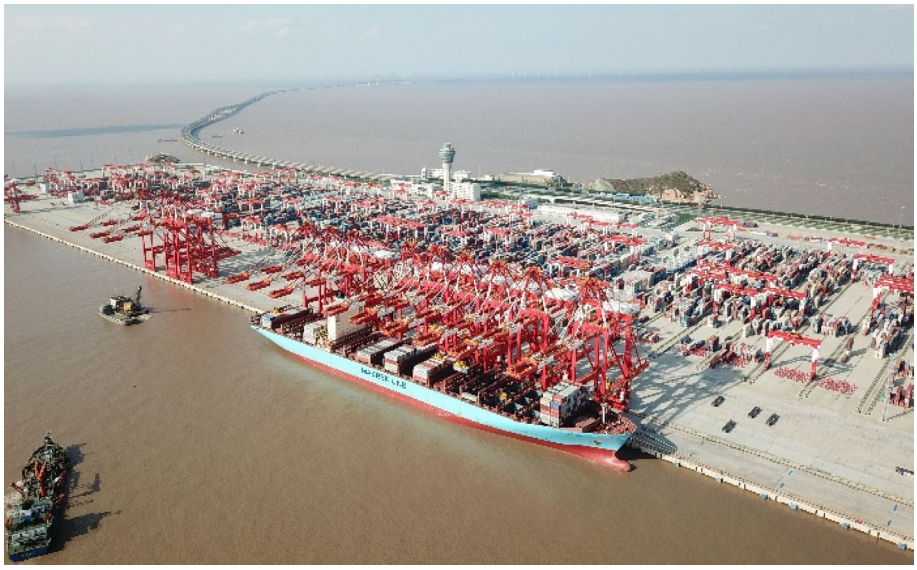

Fig. 8 Nine AQCs work together to handle a trip-E ultra-large ship.

for landside external container trunks at the port, a central control room access control system, an intelligent access control system for office areas, a positioning management and control system for quay apron personnel for border inspection purposes, an intelligent control system for unmanned monitoring and floodlight towers of the central substation, an intelligent entry and exit access control system for crossings, an intelligent management and control system for safety patrol and inspection in key areas, an intelligent management and control system for dangerous chemicals and awkward and lengthy containers handling areas, a meteorology, hydrology and air quality monitoring system, and an integrated intelligent safety and security system of the General Monitoring Center.