

Fig. 1. The layout of Automated container terminals.

### 3. Problem description and design

We consider all automated container terminals equipment including QCs, YCs and AGVs to handle the containers in the system at work in the port of Xiamen, China. The QCs are responsible for placing the container on the AGV from the ship or removing the container from the AGV. The AGVs are responsible for the horizontal transportation of containers from QCs to blocks or from blocks to QCs in a pattern of unilateral circulation. The efficiency of the roundabout is relatively low, so we increased the auxiliary roads in the roundabout path. On the front of each block is an AGV-mate; the YCs place the container from the AGV-mate to the corresponding storage location in the block. Each block is also equipped with two Rail-Mounted Gantry (RMG) cranes. The layout of the automated container terminal is shown in Fig. 1.

#### 3.1. Settings and hypotheses

The AGVs horizontal transportation of automated container terminals in this paper are assumed as follows:

- (1) The path-planning node map is established in Fig. 2, which is setting according to the region of AGVs horizontal transport. AGVs travel in a clockwise conformable path, it can reduce the conflict

and collision to some extent.

- (2) Each AGV can serve any QC or block, the operation sequence of the QCs is known.
  - (3) Set the path nodes in QCs, Blocks, turn points and intersections in horizontal transportation, such as in Fig. 2, {n14, n17, n20, n23} represents the nodes of QCs, {n2, n5, n8, n11} represents the nodes of Blocks, {n1, n12, n13, n24} are the turning nodes. And construct multiple crossing nodes {(n3, n15, n4, n16); (n6, n18, n7, n19); (n9, n21, n10, n22)} in intersections to facilitate modeling. That is, add the auxiliary roads (e.g. the node from n15 to n3 and n19 to n7).
  - (4) The capacity of each auxiliary road is restricted to no more than two vehicles to minimize traffic congestion and reduce the probability of collision/conflict between AGVs. The path of any third AGV that appears on the road will be reprogrammed (Fazlollahatabar & Hassanli, 2017).
  - (5) AGV-mates are equipped on the front of blocks to improve AGVs horizontal transport efficiency.
  - (6) AGVs driving at a safe distance (2 m) from each other throughout horizontal transport with “first-come, first-serve (FCFS)” rules imposed at the intersections (Nishi et al., 2011; Ji et al., 2017).
- (1) Set parameters  
 $I$ : set of import containers;  
 $E$ : set of export containers;

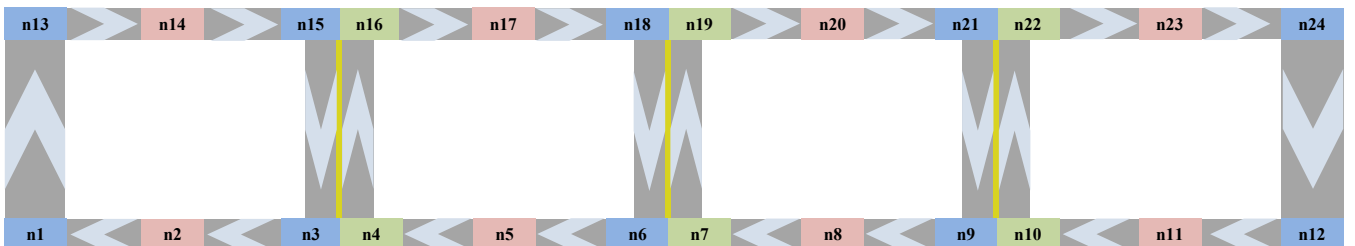


Fig. 2. Path-planning node map.