Research on ATS Route Control Based on the Binary Tree Algorithm

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***Abstract* — The Communication Based Train Control (CBTC) system has been widely employed in rail transit train control systems with its conspicuous technological advantages. As the brain of the CBTC system, the Automatic Train Supervision (ATS) system plays an important role. The route control function is one of the major functions of the ATS system. This article describes a route search algorithm with a binary tree generated in a directional non-ring diagram. Through the route control technology, it is possible to satisfy to the largest extent various operational demands in divergent complex operational scenarios of mixed large and small loops and Y-type loops, etc. and lay solid foundation for safe and highly efficient train operation.**

***Keywords* — Route search, binary tree, conflict detection, route control**

I. INTRODUCTION

In the CBTC system, it is necessary to obtain a route control sheet according to the signaling layout. Search for a route is the core to this. How to implement highly efficient and accurate search is an issue of concern. This article proposes a directional non-ring model based on analysis of a station / yard signaling layout and dynamically generates a binary tree in a directional and non-ring diagram. The final route is obtained by traversing of the binary tree.

II. CBTC SYSTEM OVERVIEW

The Communication Based Train Control (CBTC) system consists mainly of equipment such as the Automatic Train Supervision (ATS) system, the Zone Controller (ZC) system, the Computer Interlocking (CI) system, the Carborne Controller (CC), and the Data Communication System (DCS), in addition to a database storage unit, etc. The system implements supervision and control of train operational status, wayside signaling equipment status, and system operational control commands at the Operational Control Center by applying train location technology and bi-directional train-wayside communication technology, etc. and combining computer technology and communication network technology, thus reducing train tracking headway, effectively improving train passage capability, and greatly enhancing passenger transportation capacity and transportation efficiency of urban rail transit trains.

III. ESTABLISH THE MODELS OF ROUTE SEARCH

A. Binary tree

A binary tree is a set of a limited number of elements. When the binary tree is not blank, there is one element called the root. The other elements are grouped into two binary trees, named respectively left and right sub-trees. The most common way of describing a binary tree is a linkage storage structure, which refers to indicate a binary tree by a link table, the linkage of which is used to indicate logical relationship among the elements. The binary tree structure is illustrated in Figure 1 below:

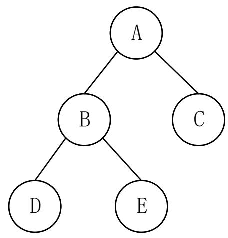

Fig.1 Binary Tree Diagram

B. Directional non-ring diagram

A directional diagram without a ring is called a directional non-ring diagram. It is a special directional diagram more general than a tree diagram. It has two characteristics: 1. Nodes in the diagram can be connected by a directional side; 2. If there is a directional path connecting Node A to Node B, there is definitely no directional path connecting Node B to Node A. Refer to Figure 2 below:

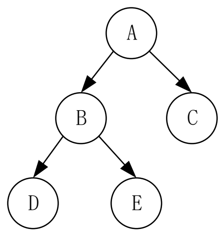

Fig.2 Directional Non-ring Diagram

C. *Station/yard layout analysis and modeling*

A typical station / yard signaling layout is shown in Figure 3 below. An equipment centralized station needs to establish logical relationship among signaling equipment including signals, switch machines, and track blocks, etc.

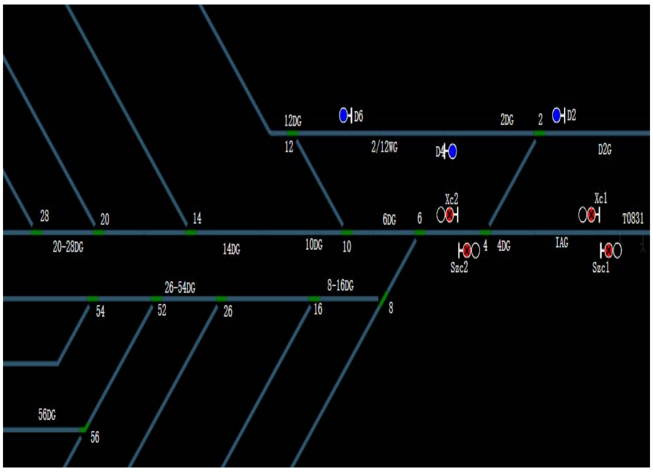

Fig.3 Typical Station / Yard Signaling Layout

By extracting key points in the switch machines, signals, and track blocks in the station / yard signaling layout, the station / yard diagram is simplified to a schematic as shown in Figure 4 below:

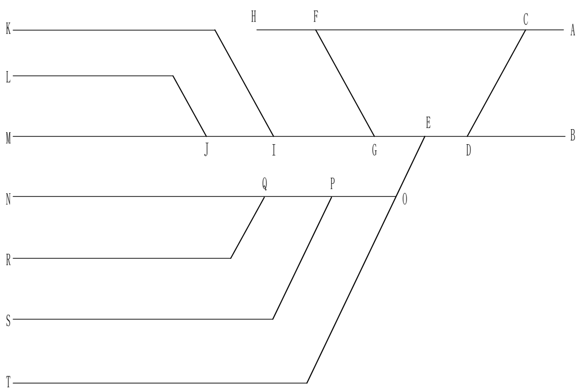

Fig.4 Abstracted Station / Yard Signaling Layout

Taking the above diagram as an example, a directional non-ring model can be built up with the key point in the diagram as the vertex and blocks and switch machines as arcs connecting the key point from the left turnback line / storage line, as shown in Figure 5 below. In this way, the route-search problem is equivalent to search of all possible paths from a vertex to the terminal point in a directional non-ring diagram.

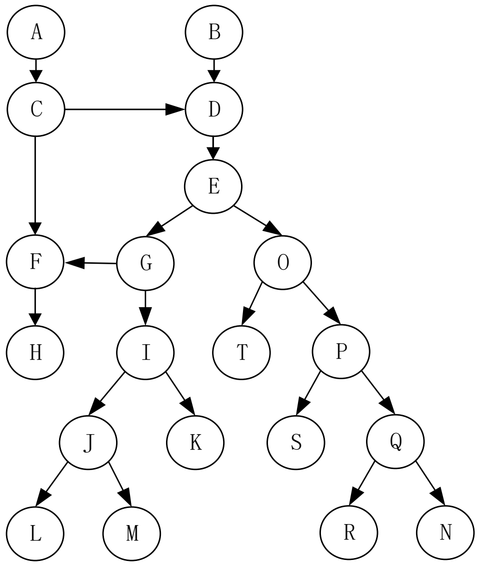

Fig.5 Directional Non-ring Diagram Model of Station / Yard Signaling Layout

Through observation, the degree of output of a vertex is no more than 2 in a directional non-ring diagram provided there is no three-way switch machine or any complex crossing equipment between two points in the directional non-ring diagram. Hence, the directional non-ring diagram has similarity and link with a binary tree. Therefore, searching of routes may be performed by dynamically setting up binary trees in the directional non-ring diagram and then traversing the binary trees to obtain all paths between the vertexes. Further, by conditional restrictions on some key nodes in the binary trees, adversary and conflicting routes may be identified effectively.

D. *Algorithm of route search*

The route search algorithm is explained here with departure from the turnback line / storage line above as an example. There are 3 sequences to traverse a binary tree: front traversing, intermediate traversing, and rear traversing. The algorithm here adopts the front traversing with the recursion process as follows: first, the root node is accessed. Then the left sub-tree of the root node will be traversed. Finally, the right sub-tree of the root node will be traversed until the binary tree is blank. Then the traversing is ended. The automatic route generation & search algorithm is the following:

1. Set up 1 blank stack for storage of the search path and set the root node as the current node;
2. Judge whether the binary tree is blank or not. If yes, the traversing will end;
3. Push the data of the current node into the top of the stack;
4. Judge whether the current node is a leaf node. If yes, store the content of the stack, which is then a route;

5. Access the left sub-tree of the node;
6. Access the right sub-tree of the node;
7. The stack-top element will go out of the stack.

Take the route from A to K and R as an example. The content of the stack is shown in Figure 6. Considering Figure 3, track blocks within the route can be understood as: D2G, 2DG, 4DG, 6DG, 10DG; D2G, 2DG, 4DG, 6DG, 8-16DG, 26-54DG.

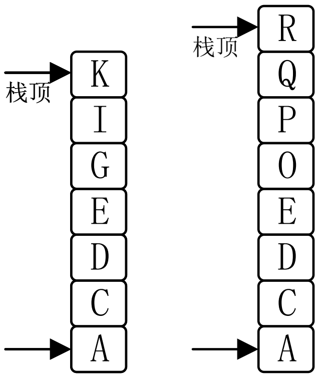

Fig.6 Content of a Stack

By applying the route search algorithm in actual scenarios of route conflicts at time of rail transit operation with small and large loops and Y-type loops, it is quite satisfactory to resolve the problem of setting a route in conflicting scenarios.

1) Route opening opportunity

In actual train operation, a train is run strictly in accordance with a planned operational train graph. However, the train is liable to be interfered with by various factors during train operation. As a result, the train may fail to run completely according to the schedule and cause earliness / lateness of the train. With consideration of small and large loops and branch lines, establishment of train routes will most likely cause unfavorable impact on train operation. To achieve the best efficiency of train operation and supposing establishment of train routes depend solely on train operational speeds and locations, selecting route opening opportunities according to train displacement can effectively avoid over-occupation of route resources, unintentional brake / stopping of the train between two adjacent stations, and waste of route resources due to lateness of the train. In this way, a model is set up of a route-triggering point:

Calculation of a route-triggering point:

$$Y1=A+V*t1 \tag{1}$$

$$Y2=A+V*(t1+t2) \tag{2}$$

Among these, Y1 is an emergency triggering point; Y2 is a general triggering point; V is the train speed; A is the location where the train starts decelerating due to the signal being not opened; t1 is the time needed to establish the route; t2 is a buffering period.

The system will calculate a general triggering point and an emergency triggering point according to the formulae above after acquiring the train location and speed. When the train runs to a general triggering point and the route opening conditions are fulfilled, the system will set the route. Otherwise, it will wait. When the train runs to an emergency triggering point, the system will start up an emergency-triggering mode to prevent the train from braking due to failure of route setting.

2) Scenario of route conflicts

An operating train is not an isolated individual but involves resolution of numerous route control issues during dynamic train operation. During the operational process, due to earliness and /or lateness of individual trains, competition for route resources arises as shown in Figure 7 below. The route resources to be deployed by the train T1 and the train T2 are conflicting and only one route may be set at a certain instant. Another route can be established only after release of the successfully set route. If in the operational train diagram, T2 is supposed to pass the switch block before T1 and T1 arrives on time but T2 is late due to interference from the outside world, the route set for T1 will render the route for T2 impossible to be set.

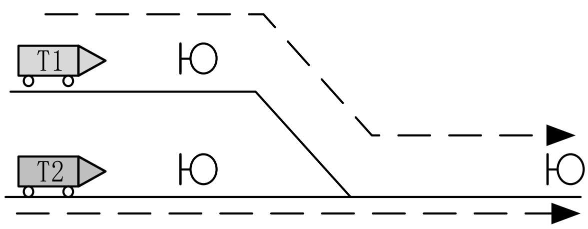

Fig.7 Scenario of Route Conflict

As train operation is continuous in time and space, that is, the train is at a definite location at each instant; in space, train displacement is also continuous, based on operational continuity of the train in space and exclusiveness of its location, correspondence can be set up between the train and elements it passes, that is, gradual occupation status demonstrated by the elements will reflect the train movement path.

Define the following parameters:

R is a set of route elements, $R = \{r_i \mid i=1, 2, 3, \ldots, n\}$, r_i being a specific element in the route.

G is a set of operating lines, $G = \{g_{i,j} \mid i=1, 2, 3, \ldots, n;\ j=1, 2, 3, \ldots, m\}$, $\{g_{i,j} \mid i=1, 2, 3, \ldots, n;\ j=1,$

2, 3, … , m} being an element passed and $g_{i,j+1}$ indicating Train j+1 passing Element r_i following Train j in the train operational schedule.

Define restrictional conditions between a train and elements it passes:

$$L(g_{i,j}) = \begin{cases} 0, \text{Train } j \text{ not passing Element } r_i \\ 1, \text{Train } j \text{ having passed Element } r_i \end{cases}$$

Define a target function:

$$F(R, j+1) = \prod_{i=1}^{n} L(g_{i,j}) = \begin{cases} 0, \text{Route } R \text{ cannot be set for Train } j+1 \\ 1, \text{Route } R \text{ can be set for Train } j+1 \end{cases}$$

From the above model, we can see for Train j+1 to pass through Route R in the operational schedule, it is necessary to detect that all trains scheduled to deploy the route resources relevant to Route R in the traffic schedule have completed deployment of the route resources. If this condition is met, the route can be set for the train. So, under the prerequisite of full compliance with the train diagram in operation, the conflicts due to train earliness or lateness may be resolved.

IV. RESULT OF ROUTE CONFLICT SIMULATION

In the CBTC simulation environment, a train schedule is assigned as shown in Figure 8 below. A train with a trip number 104 is running from the mainline (the blue color of the trip window arrow indicating that the train is currently in an earliness status). A train with a trip number 103 is turning back from the turnback line (the green color of the trip window arrow indicating that the train is currently in a punctual status). Both trains need to enter a platform corresponding to T0816. The routes of these two trains are conflicting. At this time, according to the schedule, Train 103 shall enter the platform first while Train 104 follows it closely. The system takes a schedule-first strategy by setting a route to the platform for Train 103. After Train 103 has left the platform, the system automatically sets a route for Train 104 to enter the platform.

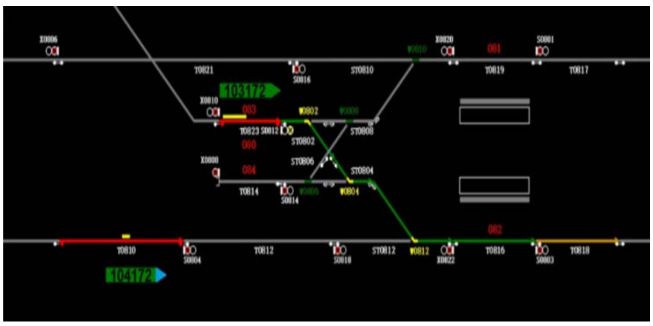

Fig.8 Simulation No. 1 of a Route Conflict Scenario

As shown in the following Figure 9, Train 551 is in an earliness status and Train 552 is in a puncture status. According to the schedule, Train 552 shall enter the station first while Train 551 shall follow it. Based on the schedule-first strategy, though Train 551 arrives at the turnback track first, the system automatically sets a route for Train 552 to enter the station first to avoid route conflict of the two trains.

Fig.9 Simulation No. 2 of a Route Conflict Scenario

V. CONCLUSION

As a core function of the ATS system, train route control is essentially regulation of the route control mode. In the mode of automatic triggering of routes, the train route control system automatically sets routes for operating trains, ensuring to the largest extent compliance with the schedule and operational efficiency while detecting conflicts between routes. If a conflict exists between routes, a pop-up window must be sent to the dispatcher in real time to generate a counter-strategy. The route-triggering opportunity is critical and route conflict detection plays a very important role in operational planning. Research on route control technology has profound significance to the creation of an intelligent rail transit control system.

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