Research on Heavy Haul Railway Dispatching System Based on Fuzzy Expert System

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Keywords: Heavy-haul railway, Transport organization, Expert system, Dispatching system.

Abstract. According to the transportation organization mode of Daqin Line, this paper proposes a heavy-haul railway dispatching system based on fuzzy expert system. This paper analyzes the conditions and transportation organization modes of Daqin Line, sums up and summarizes the actual experience of dispatchers, scheduling rules and strategies, establishes an intelligent dispatching system, realizes the real-time dispatching and adjustment of trains online, ensures the safety of trains, and improves the production efficiency of railway transportation.

Introduction

Realizing the intelligent of freight train dispatching command is an important link to reduce the work intensity of train dispatchers, ensure the safety of trains, and improve the production efficiency of railway transport.

The expert system (ES, Expert System) train scheduling system stores the knowledge and experience of the dispatcher, simulates expert reasoning and decision making process, and has the ability to handle uncertainty, inaccuracy, and heuristic decision making [1]. The ESTRAC developed by S. Araya et al. sets corresponding rules for adjusting various processes, and avoids "unreasonable phenomena" that do not satisfy constraints through heuristic knowledge [2]. K. Komaya et al. developed ESTRAC-III, which divided the entire solution process into two decision levels: upper and lower, through which the decision-making units of the two layers exchanged and completed the solution process step by step [3]. C. S. Chang and others proposed an event-driven fuzzy expert system, designed a two-level structure of the expert system of the control center and the local execution expert system, and made online adjustments to the rapid rail transit system in real time [4].

Based on the above research results, this paper proposes the Daqin Railway dispatching system based on the fuzzy expert system, summarizes the actual experience of the dispatcher, scheduling rules and strategies according to the line conditions of the Daqin Line and the integrated transport organization model of “Collecting, Distributing, and Transporting”. It realizes online real-time dispatching and adjustment of trains to ensure traffic safety and improve railway transportation production efficiency.

Dispatching Model of Heavy Freight Railway

Heavy-haul railway Daqin Line adopts the integrated transportation organization mode of “Collecting, Distributing, and Transporting”: organizing the cargo flow based on the strategic loading base’s consolidation mode; making the “distribution and transportation” integrated dispatching commander and transportation production system[5].

Set the heavy-haul railway dispatching network: $N(V, E, \psi, \phi, A, B, C)$, $V = (v_1, v_2, ..., v_m)$ represents the collection of all stations (vertices) on the road network; $E = (E^i_j) i, j = 1, 2, ..., m; k \in (k_1, ..., k_n)$, $\psi = (\psi^i_j) i, j = 1, 2, ..., m; k \in (k_1, ..., k_n)$ represents the daily average number of class k trains from station i to station j in the planned operation map; $\phi = (\phi^i_j) i, j = 1, 2, ..., m$ represents the passing capacity of
station i to station j; \( A = \{a^k\} \) indicates the loading capacity of the k-type train at the loading point i; 
\( B = \{b^k\} \) the daily average unloading capacity of the k-class train at the unloading point i; 
\( C = \{c^k\} \) the number of the trains that can be parked at the unloading point i to the departure line[6].

The goal of the system adjustment is to restore the plan map in the shortest possible time, that is, the sum of the delay arrival time of the train to the station and the delay departure time of the train from the station, Eq. 1:

\[ Z = \min \sum_{i=1}^{N} \sum_{j=1}^{M} \left( |EF_{i,j} - EF_{i,j}^0| + |ED_{i,j} - ED_{i,j}^0| \right) \]  

(1)

**Transport Organization of Heavy-haul Railway**

After many years of development, China’s heavy-haul railways have operated 5,000, 10,000 and 20,000 tons on the Datong-Qinhuangdao and Shuo-Huang Coal Lines, realized fast, efficient and low-cost transportation of bulk cargo. The transport organization of heavy-haul railways is mainly affected by three aspects: infrastructure, traffic organization, and cargo flow organization.

**Infrastructure**

The infrastructure mainly includes lines, stations, combination stations, loading points, and unloading points. Line passing capacity, station picking ability, combination station combination ability, loading point loading capacity, and unloading station unloading capacity play a strict restriction on the transportation of goods. According to the different loading capacity of the loading point, it can load 5,000 tons and 10,000 tons of trains and combine them into a 20,000-ton combined train or direct unloading station at the combined station. The total number of trains cannot exceed the capacity of the line:

\[ \sum_{i=1}^{k} x^k_{ij} \leq \phi_{ij} \]  

(2)

\[ \sum_{i=1}^{k} \sum_{j=1}^{M} x^k_{ij} + \zeta \leq \phi \]  

(3)

In the formula, \( x^k_{ij} \): the daily average number of k-type trains from station i to station j, trains/day; \( \phi_{ij} \): the capacity of trains from station i to station j, trains/day; \( \zeta \): the average number of vehicles entering the boundary port, trains/day; \( \phi \): average daily throughput capacity for heavy haul lines, trains/day; \( K \) is a collection of train types \( K = \{k_1, k_2, \ldots, k_n\} \).

Due to factors such as loading capacity, personnel and facilities, trains loaded at the loading point m cannot exceed loading capacity:

\[ x^k_m \leq a^k_m, \forall m \in M, k \in K \]  

(4)

In the formula, \( x^k_m \): the daily average number of k-type trains loaded at the loading point m, trains/day; \( a^k_m \): the loading capacity of the k-type train indicating the loading point m are listed.

The unloading point unloading capacity, personnel, facilities and stacking capacity of the open market are limited. The unloading point n can not exceed the sum of the unloading capacity and the arrival and departure line capacity:

\[ x^k_n \leq b^k_n + c_n, \forall n \in N, k \in K \]  

(5)

In the formula, \( x^k_n \): the number of k-type trains arriving at the unloading point n, trains/day; \( b^k_n \): the daily average unloading capacity of the k-type trains representing the unloading point n,
trains/day; \( c_n \): the number of trains that can be parked from the unloading point \( n \) to the departure line are listed.

The loading capacity of the loading point is limited. Heavy-load transportation usually runs 5,000 tons at the loading point and 10,000 tons of trains, then carries out 10,000 tons at the combined station, and 20,000 tons of trains are combined to run long and overweight large group trains. Affected by factors such as the number, length, combination of facilities, personnel, etc., the train portfolio cannot exceed the station combination capacity:

\[
y_i^k \leq \phi_i^k
\]  \hspace{1cm} (6)

In the formula, \( y_i^k \): the number of daily average combinations of the combined station \( i \) is shown in the trains/day; \( \phi_i^k \): the combined capacity of the combined station \( i \) is shown in the trains/day.

Due to factors such as the number of station-to-departure lines and station operating time, the number of trains receiving and dispatching at the station cannot exceed the capacity of the station's receiving and dispatching vehicles:

\[
\sum_{k \in K} z_i^k \leq \gamma_i
\]  \hspace{1cm} (7)

In the formula, \( z_i^k \): the daily average number of \( k \) trains arriving at station \( i \) is shown in trains/day; \( \gamma_i \): the number of daily average pick-up/drop cars in station \( i \) is shown.

**Traffic Organization**

The organization of traffic includes the organization of locomotives, vehicles, trains, and flight attendants. Heavy-haul railways use more than one type of locomotive at the same time to haul hundreds of vehicles into 10,000 tons and 20,000 tons of ultra-long and overweight trains. Affected by factors such as maintenance rate and in-transit rate, the locomotive and vehicle resources that can be used for loading vehicles should be less than the number of locomotives and vehicles.

\[
\sum_{k \in K} \sum_{i \in I, j \in J} \alpha_k x_{ij}^k \leq (1 - \lambda) \eta T_1
\]  \hspace{1cm} (8)

\[
\sum_{k \in K} \sum_{i \in I, j \in J} \beta_k x_{ij}^k \leq (1 - \omega) \delta T_2
\]  \hspace{1cm} (9)

In the formula, \( x_{ij}^k \): the daily average number of \( k \)-type trains at the loading point \( i \) to the unloading point \( j \), trains/day; \( \alpha_k \): the number of vehicles per train of class \( k \) trains; \( \lambda \): the vehicle maintenance rate; \( \eta \): the vehicle using rate; \( T_1 \): the total number of vehicles, Vehicles; \( \beta_k \): Denotes the number of locomotives per train of class \( k \) trains, Locomotives; \( \omega \): Indicates the maintenance rate of locomotives; \( \delta \): Represents locomotives using rate; \( T_2 \): Represents the total number of locomotives.

**Cargo Flow Organization**

The cargo flow organization includes transportation planning, source organization, and cargo unloading. The transport organization of heavy-haul railways must ensure that the annual transportation plan is completed. Adequate sources of goods and smooth unloading of freight cars will constrain transportation organization programs.

\[
\sum_{i \in I} \sum_{j \in J} \sum_{k \in K} x_{ij}^k g_{ij} \eta_k \geq G / 365
\]  \hspace{1cm} (10)
In the formula, $x_{ij}^k$: the daily average number of $k$-type trains at the loading point $i$ to the unloading point $j$, trains/day; $g_k$: the towing weight of the $k$-type vehicle, tons; $\eta_k$: the load factor of the $k$-type vehicle; $G$: the annual planned transportation volume, Ton.

**Train Dispatching Expert System**

Train scheduling refers to the dispatcher's scheduling and adjustment of the operation of the train according to the plan operation diagram, train formation plan, transportation plan, daily (class) plan and actual train operation conditions, and completes the operation indicators and ensures the safety of the train operation [6].

Figure 1. Schematic drawing. Figure 2. The basic structure of train dispatching expert system.

Train scheduling expert system stores knowledge of infrastructure, traffic organization, cargo flow organization, scheduling rules and adjustment strategies, inference engine simulation human experts search knowledge and rule base, real-time scheduling and adjustment of trains, to ensure traffic safety, improve Rail transport production efficiency. The system is mainly composed of man-machine interface, knowledge base, inference engine and other components:

**Knowledge Base**

Knowledge representation adopts production representation, which mainly stores basic data, scheduling rules, and adjustment strategies.

The underlying data is represented using triples (objects, attributes, values) or (relationships, object 1, object 2), such as: (Train, Type, 1) or (Compose, Train1, Train2), (Pass, Train3, Train4). The basic data is mainly divided into static data (including train information, station information, line information, plan operation diagrams, etc.), dynamic data (including dynamic information of trains, station dynamic information, dynamic information of line equipment), and intermediate states (Known static data and dynamic data deduced state of train, station, line data interaction adjustment).

Scheduling rules are a set of operations that the dispatcher performs on the train scheduling, and are expressed in the form IF<Prerequisite>THEN<Conclusions>CF, where <Prerequisite> is the condition to be satisfied by the rule, and <Conclusion> is the conclusion of the rule or Action, CF is the probability of occurrence. The rules are described using the Backus-Naur Form (BNF)[7]:

\[
< rule >::= < syntax > "\{" < express >\rightarrow < procedure > \}\"
\]

(11)

Where <express> is a determinant between information descriptions or relationships of trains, stations, and lines, and <procedure> is an action or process.

The dispatch strategy is the basis for train adjustments. Different adjustment strategies will have different adjustment effects. Due to the large number of factors affecting train operations. The choice of various adjustment strategies is an important aspect of train operation optimization. Operational adjustment measures mainly include: (a) increasing the load; (b) reducing the load; (c)
increasing the number of trains; (d) cancelling the train; (e) changing the combination method; (f) changing to the sending station; ) Change the unloading point; (h) Change the train arrival time; (i) Change the train arrival order; (j) Change the train station driving mode; (k) Change to the departure line.

**Inference Engine**

In this paper, the inference engine follows the depth-first principle, the direction of the forward chain, according to the input system state, matches the preconditions of the facts and rules, and then executes the action process. When multiple rules match, a sequential conflict reduction strategy is used to immediately execute the action of the matching rule and then match the next rule.

![Figure 3. Depth-first search chain of reasoning.](image1)

**Simulation Analysis**

As shown in Fig.4, the railway network is a simplified model for the heavy-haul railway of the Daqin Line and is mainly divided into the loading stations, the line, and the unloading stations. Among them, the Hanjialing Railway Station to the Qinhuangdao Liucun South Station is the main line. The west-zones railway stations and it’s connecting lines are the loading stations. The coal resources that are attracted mainly come from the Beitongpu Line, the Yungang Extension Line, the Kouquan Extension Line, the Dazhun Line, and the coal that is accessed through Gudiankou. The East-zones railway stations and it’s connecting lines are unloading ports, mainly ports, power plants along the boundary, and demarcation lines.

**Parameter Settings**

This article assumes that the loading capacity of each site is as shown in Table 1:

<table>
<thead>
<tr>
<th>Loading Station</th>
<th>Loading Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5000 tons</td>
</tr>
<tr>
<td>Dabao Line</td>
<td>6</td>
</tr>
<tr>
<td>Dazhun Line</td>
<td>4</td>
</tr>
<tr>
<td>Yungang Extension Line</td>
<td>6</td>
</tr>
<tr>
<td>Kouquan Extension Line</td>
<td>8</td>
</tr>
<tr>
<td>Beitongpu Extension Line</td>
<td>13</td>
</tr>
<tr>
<td>Datong Station</td>
<td>3</td>
</tr>
</tbody>
</table>
The unloading stations unloading capability is shown in Table 2:

Table 2. Unloading stations unloading capacity table.

<table>
<thead>
<tr>
<th>Unloading Stations</th>
<th>Unloading Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5000 tons</td>
</tr>
<tr>
<td>Jing-jin-tang Region</td>
<td>3</td>
</tr>
<tr>
<td>Tianjin Port</td>
<td>8</td>
</tr>
<tr>
<td>Caofeidian Port</td>
<td>6</td>
</tr>
<tr>
<td>Jingtang Port</td>
<td>8</td>
</tr>
<tr>
<td>Qinhuangdao East</td>
<td>13</td>
</tr>
<tr>
<td>Liuchun Village South</td>
<td>18</td>
</tr>
</tbody>
</table>

According to the summary on work and theoretical analysis, the target annual transportation volume is 400 million tons, the Daqin Line has a capacity of 100 tons, the average daily traffic volume is 1.1 million tons, and the train tracking interval times is \( t_1 = 11, t_2 = 12, t_3 = 14 \); the vehicles adopt C80 and C63 types, and the maintained quantity is 11,000 vehicles and 16,000 vehicles, and the number of vehicles of each type composed trains are \( m_1 = 210, m_2 = 110, m_3 = 50 \).

Traffic Organization Analysis

According to the constraints and scheduling strategies, the objective model is solved, and the traffic organization scheme is shown in Table 3.

Table 3. Traffic flow organization plan table.

<table>
<thead>
<tr>
<th>Traffic Flow Organization Plan</th>
<th>Plan 1</th>
<th>Plan 2</th>
<th>Plan 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5000 tons Trains</td>
<td>32</td>
<td>24</td>
<td>16</td>
</tr>
<tr>
<td>10,000 tons Trains</td>
<td>42</td>
<td>34</td>
<td>30</td>
</tr>
<tr>
<td>20,000 tons Trains</td>
<td>26</td>
<td>32</td>
<td>36</td>
</tr>
<tr>
<td>Average daily traffic (10 thousand tons)</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Trains</td>
<td>100</td>
<td>90</td>
<td>82</td>
</tr>
<tr>
<td>Vehicles</td>
<td>11680</td>
<td>11760</td>
<td>11660</td>
</tr>
</tbody>
</table>

According to the analysis of simulation results, all three plans achieved an annual transportation volume of 400 million tons and met the line transporting capacity; the use of vehicles was less than 12,000, and was calculated as half empty and half heavy vehicles to meet the vehicle ownership; and the 20,000-ton train was operated. The more vehicles there are, the fewer the number of vehicles that can drive; if calculated on the basis of the capacity of 100 trains, more annual transportation volume can be achieved.

Scheduling Strategy Analysis

Table 4. Adjustment strategy effect table.

<table>
<thead>
<tr>
<th>Adjustment Strategy</th>
<th>Personnel Maintenance A</th>
<th>Locomotives Rescue B</th>
<th>Decomposition of Train C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average delay time (minutes)</td>
<td>10</td>
<td>12.2</td>
<td>21.4</td>
</tr>
<tr>
<td>The longest delay time (minutes)</td>
<td>10</td>
<td>28</td>
<td>42</td>
</tr>
<tr>
<td>Total delay time (minutes)</td>
<td>10</td>
<td>61</td>
<td>107</td>
</tr>
<tr>
<td>Late trains (trains)</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Punctuality train number(trains)</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Number of adjustments (Num.)</td>
<td>1</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

According to the analysis of train adjustment scenes over the years, 70% of the scenes of locomotive failure zone parking, train delays, maintenance construction, and separation between
trains are accounted for. Take the locomotive failure zone parking scene as an example, compare the different effects of the different scheduling strategy under the same scenario. The simulation results are shown in Table 4.

From the simulation results, it can be seen that the dispatcher adopts different scheduling strategies in the same scenario, and the effects achieved are very different. In the dispatching strategy A, if the locomotive is quickly repaired, it does not substantially affect the operation of the subsequent train. If the locomotive cannot be repaired, the strategy needs to be adjusted again, but it takes more time. According to the analysis of statistical data over the years, Strategy B has adopted the most in the field and it is relatively well balanced.

Conclusion

The heavy-haul railway dispatching system based on fuzzy expert system adopts the optimized strategy in solving the target model based on constraints, event scenarios and adjustment strategies, which can quickly resolve conflicts and improve transportation efficiency. According to the simulation analysis, the heavy-haul railway dispatching system has a fast solution speed and good effect, and it can realize real-time scheduling and adjustment of trains online.

References


