Research on Case-Based Reasoning for Energy-Efficient Rail Transit Emergency Timetables

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Abstract. The continuous expansion of rail transit lines has led to a significant increase in energy consumption. Choosing an appropriate timetable based on external conditions of train operation can reduce energy consumption by more than 5%. When emergencies occur in rail transit, external conditions change, rendering the original timetable unable to meet energy-saving requirements. This paper primarily explores how to quickly determine an energy-efficient timetable based on historical energy-saving timetable data and current external conditions using case-based reasoning methods. The paper represents emergency event timetable cases using a framework approach, and then employs a retrieval algorithm based on the grey correlation degree method to search for cases. The energy-efficient timetable for the target case is selected from the retrieved source cases, considering the one with the lowest energy consumption.

Keywords: Emergency, Energy Conservation, Case-Based Reasoning, Similarity Calculation.

1. Introduction

Existing energy-saving schemes for train operation generally consider two aspects: hardware and software. Hardware upgrades involve continuous iteration and updating of facilities such as trains, tracks, and power storage devices to improve energy utilization. On the software side, selecting an appropriate energy-saving timetable when external conditions change is crucial for reducing energy consumption. Under normal circumstances, trains operate according to a pre-prepared energy-saving timetable. However, when emergencies occur, external conditions change, rendering the original timetable inadequate for operational and energy-saving requirements. Redrawing an energy-saving timetable from scratch takes several hours, and the subway company needs to quickly obtain the "optimal timetable" with lower energy consumption.

Therefore, this paper introduces case-based reasoning technology to address the selection of an energy-efficient timetable when trains resume operation after handling emergencies. The concept of Case-Based Reasoning (CBR) was first proposed by Schank[1], with the core idea of solving new problems based on the successful experience of solving past problems. The research team, in collaboration with the subway company for over a decade, has accumulated a large number of timetable cases under emergencies. By designing a reasonable case similarity calculation method, the paper can quickly find similar solutions from the case library that meet the subway company's energy-saving requirements.

In the field of energy-saving optimization for rail transit timetables, scholars have conducted extensive research on two energy-saving methods: reducing the idle time of a single train to lower traction energy consumption[2][3] and optimizing the continuous tracking train control strategy in the same power supply area to make full use of regenerative braking energy[4][5]. However, existing studies rarely consider the selection of energy-saving timetables under emergencies. This paper introduces the case-based reasoning method, using a framework approach for case representation and a retrieval algorithm based on grey correlation degree, significantly saving decision-making time.

2. Case Representation

The representation of cases is in the form of a triple: <A, B, C>, where A describes the current situation of the case, B is the energy-saving timetable used, and C is the energy consumption generated using this timetable under the given situation. The framework method is employed to represent knowledge for energy-saving timetable cases in rail transit emergency events, as shown in Table 1.

Table 1. Energy-efficient rail transit emergency timetable case representation

Framework name: Energy-efficient rail transit emergency timetable case		
Slot 1:emergency attributes	Facet 11:basic information	City Line Spot type Emergency type Date Time type
	Facet 12:influences	Emergency level Casualty Impact on line Impact on traffic
Slot 2:energey attributes	Facet 21:train attributes	Train's own weight Traction force Braking force
	Facet 22: operation organization	Number of departures Departure interval Maximum speed Average speed Average pause time Starting station Transfer stations
	Facet 23:external factors	Occupancy rate Passenger volume Hourly passenger volume
Slot 3: energy-efficient timetable	Facet 31:timetable number facet 32: energey consumption	

3. Case Retrieval Algorithm

The measure of the degree of correlation in the magnitude of factors between two systems, which changes over time or with different objects, is referred to as correlation. In the process of system development, if the trends of change in two factors are consistent, i.e., the degree of synchronous change is high, it can be considered that the correlation between them is high; otherwise, it is lower. Therefore, the grey correlation analysis method is a way to measure the degree of correlation between factors based on the similarity or dissimilarity of their development trends, namely "grey correlation," during the system's evolution. The grey correlation degree method believes that if the grey correlation degree between a compared case and a reference case is larger, their similarity is also greater. Thus, the magnitude of grey correlation degree can be used as one of the measures of case similarity [6]. The steps of case retrieval based on the grey correlation degree method are as follows:

(1) Determine the reference sequence (target case) and the comparison sequence (source case).

(2) Standardize the data to eliminate the influence of dimensions and magnitudes on the results; min-max normalization can be used.

(3) Calculate the correlation coefficients on each attribute.

(4) Calculate the grey correlation degree.

(5) Set a threshold and output the comparison sequences with grey correlation degrees greater than or equal to the threshold.

(6) Select the case with the lowest energy consumption from the output source cases and adopt the energy-saving timetable of that case.

4. Case Verification

This paper takes a subway vehicle failure emergency event case, referred to as case M, as an example to validate the effectiveness of the case library. The energy consumption attributes of each emergency event case are used as the feature attributes for case retrieval. Feature attributes A1-A13 represent the train's own weight, traction force, braking force, maximum speed, average speed, number of departures, transfer stations, starting station, average pause time, departure interval, occupancy rate, passenger volume, and hourly passenger volume, respectively. Setting the similarity threshold for the output cases to 0.79, we obtained 8 source cases that meet the similarity requirements, as shown in Table 2.

Table 2. Retrieved cases

Case-id	M	108	213	222	308	336	926	1780	1945
A1	37	37	37	37	35	37	35	37	38
A2	2380	2380	2380	2380	2380	2380	25000	2380	2380
A3	23500	18000	17000	16000	23500	17000	17000	23500	23500
A4	103	94	100	95	87	105	112	103	108
A5	35	34	39	35	36	34	45	42	38
A6	177	177	162	168	179	150	139	102	175
A7	327	308	310	326	358	345	364	378	362
A8	45	44	40	44	44	50	44	47	47
A9	59	47	58	55	60	45	47	62	88
A10	48	50	47	41	53	46	65	50	51
A11	0.362	0.561	0.554	0.548	0.444	0.564	0.515	0.524	0.418
A12	90020	80210	96193	97385	69697	89380	70129	78385	88607
A13	8819	8042	8867	8262	9122	8945	9087	8957	10131
Similarity		0.791	0.794	0.809	0.794	0.792	0.803	0.794	0.792
Energy consumption		**122823**	**125673**	**127098**	**121687**	**129712**	**129688**	**146577**	**149752**

From Table 2, it can be observed that all eight cases have a similarity exceeding 0.79 with case M. However, the case with case-id 308 has the lowest energy consumption value. Therefore, the timetable of case 308 is selected as the energy-saving timetable for case M at the current moment.

By comparing the actual energy consumption data of a certain subway under different timetables, it was found that in the event of a vehicle failure emergency, the energy consumption using the original timetable was 131,500 kW·h, while the energy consumption after implementing the timetable retrieved from case 308 was 125,800 kW·h, saving 5,700 kW·h, which is approximately 4.33% energy savings. This demonstrates the effectiveness of the method in addressing the selection of energy-saving timetables under emergencies.

5. Summary

This paper introduces the case-based reasoning method to determine the selection of energy-saving timetables for rail transit under emergencies. The grey correlation degree method is employed for case retrieval, filtering out cases from the past that are similar to the current situation, and adopting previously established energy-saving timetables. This enables the subway company to promptly restore rail transit operations and reduce train operating energy consumption. However, this paper focuses solely on energy saving as its objective. Future work could consider multi-objective decision-making, incorporating objectives such as passenger comfort, timetable variability, and other relevant factors into the consideration scope.

References

[1] Schank R, Abelson R. Goals and Understanding[M]. Erlbanum: Eksevier Science, 1977

[2] Asnis I A, Dmitruk A V, Osmolovskii N P. Solution of the problem of the energetically optimal control of the motion of a train by the maximum principle[J]. USSR Computational Mathematics and Mathematical Physics, 1985, 25(6): 37-44.

[3] Howlett P. An optimal strategy for the control of a train[J]. The ANZIAM Journal, 1990,31(4): 454-471.

[4] Zhao N, Roberts C, Hillmansen S, et al. A multiple train trajectory optimization to minimize energy consumption and delay[J]. IEEE Transactions on Intelligent Transportation Systems, 2015, 16(5): 2363-2372.

[5] Wang P, Goverde R M P. Multiple-phase train trajectory optimization with signalling and operational constraints[J]. Transportation Research Part C: Emerging Technologies, 2016, 69: 255-275.

[6] Wang Hongyu, Ni Zhiwei, Yan Jun,et al. Research on Application of Grey-Relational Theory in CBR[J]. Computer Technology and Development. 2010, 20(5): 96-99.