Study on GA-based Train Dispatching

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Abstract A GA-based train dispatching is presented in this paper. A model for the train dispatching on the lines with double tracks is established at first, the model can optimize train dispatching by adjusting the orders and times of trains’ departure from stations, and then the efficiency of the method is demonstrated by simulation at Guangzhou to Shenzhen high-speed railway.

Key Words  train dispatching _GA_intelligent decision-making .

1 Introduction

Train dispatching is a large-scale, combinatorial and optimal problem that has been argued to be NP-hard. Though this kind of problem can all get optimal solution by the enumerative method, but enumeration will cost a great lot of time. A lot of domestic and international scholars have been studying how to solve the train-dispatching problem rapidly and effectively. At present, the main methods for solving train dispatching mainly include operations research, artificial intelligence and discrete event dynamic system.

Operations research
Inspired by the achievement in the operations research on solving workshop dispatching, lots of scholars begun to solve train dispatching with operations research in the beginning of the Seventies [1][2][3][4]. Sauder[2], and others, proposed an optimal model for train-dispatching and studied the train dispatching problem along single track in 1983, applied Branch&Bound algorithm and enumerated all possible meeting points partly, in order to minimize total delay time in their research. This method does not permit overrun and demands a large amount of calculation time. Jovanovic[3] proposed a new algorithm that introduced heuristic searching function into Branch&Bound in 1989, which improved the computational speed to a certain extent. Caojiaming[4] had studied train dispatching problem along single track with linear programming method. But because the search space of this method was very extensive and easy to produce combinatorial explosion, it's difficult to meet the requirement for real time train dispatching under present requirement. In addition, since the actual operation was simplified, there are disaccords between the model and the actual operation.

Artificial intelligence
Two new research means, expert system and fuzzy decision-making, appeared in the end of the Eighties. Komaya[5], and others, proposed a train dispatching method based on expert system in 1989. Chengyu[6], Lipeng and Zhangyijun[7], and so on, worked over train dispatching with expert system too. This method expresses human expert's knowledge as a group of "If-Then" rules and has the advantage of easy maintenance and modification. But this kind of rules are very difficult to express those relations among complicated restraints, and it has been a bottleneck for expert system to acquire and formulate human expert's knowledge. In addition the knowledge acquisition tool and the machine-learning algorithm for solving this problem have not been available yet. The knowledge base will become very big with the increasing of problem scale to be solved, which will certainly reduce reasoning efficiency. Jialimin[8] proposed a train dispatching method based on fuzzy system in 1991. Because the fuzzy system can express human knowledge and experience as fuzzy rules, which should be a closer reasoning way to human. This method expresses imprecise factors that come from dispatcher's thinking and decision as a fuzzy set, and then regenerates train's departure priority at each station according to fuzzy operation rules. But establishing membership function in the fuzzy system has been a relatively difficult problem all the time. Traditional trial-and-error method costs long time and is difficult to obtain the optimized system. Although two kinds of methods above are able to get feasible solution, they cannot get the optimal solution for train dispatching.

Discrete event dynamic system
Zhouleishan[10] and Zhouwei[11] proposed a method to solve train dispatching with discrete event dynamic system in the middle of the 1990s. But because the research of discrete event dynamic system is just underway and still lack of the unified theoretical foundation, which can only deal with special problem, more studies in this field are needed.

In sum, existing train dispatching methods are difficult to cope with the requirement in real-time quality and optimizing property simultaneously, a more effective algorithm is needed to work out. In addition, it is
known that the progress of train dispatching method combines closely with intelligent technology. Every new achievement in intelligent technology usually leads to a new train dispatching method. This inspires us to solve this large-scale, combinatorial and optimal problem with the most advanced intelligent technology at present. Therefore the optimization-oriented GA is taken as the basis of the new dispatching scheme.

This paper describes the model of train dispatching on a double-track railway. On the basis of a concrete analysis for the drawbacks of the existing methods, a new method based on the Genetic Algorithms is presented. Simulation experiments at Guangzhou to Shenzhen railway confirm that the method is capable of creating feasible solutions rapidly for real-size problems in terms of total waiting time imposed on all trains involved.

2 The model of train dispatching

The train dispatching is a procedure that partly adjusting the train diagram in order to overcome traffic disturbance. Therefore train diagram is not only the basis of train dispatching but also the object of train dispatching. In the remainder of this paper, suppose that, \( G(t) \) represents the operation state of trains at moment \( t \), which is the train diagram at moment \( t \). Adjustment is done from moment \( t_0 \), and the operation state of trains is \( G(0) = G(t_0) \). According to the difference between \( G(t_0) \) and original schedule, train dispatching program makes a decision in order to change the operation state of trains at next moment \( t_1 = t_0 + \_ \) to \( G(1) = G(t_1) \). So the process of train dispatching is as following:

\[
G(0) \rightarrow G(1) \rightarrow \_ \rightarrow \_ \rightarrow G(p) \rightarrow \_ \rightarrow \_ \rightarrow G(n)
\]

where \( G(p+1) = G(p) + T \& G(j) \), \( j=0, \ldots, n \).

\( T \) is a state transition factor decided by train dispatching decision. During making train dispatching decision, consider not only time constraints such as the minimum headway of two trains in the same direction, the capacity of a section, etc., but also adjusting train diagram in order to approach original train diagram, i.e. \( \min G(j+1) - G(j) \). Represents a distance measure that describes the difference between two train diagrams. The definition for the target depends on the requirement of train dispatching. The typical evaluations include but not limited to: minimum total delay time, minimum total delay departure time, minimum time to finish journey, etc. It is noticeable that the feasible solution set for train dispatching includes finite points. There exists an optimal solution and can get it with comparison among the finite points in the set. So, train dispatching is a large-scale, dynamic, combinatorial and optimal problem with multi-constraint. The problem of this kind can be formulated to what follows in general:

State equation: \( G(j+1) = G(j) + T \& G(j) \)
With respect to:
Object: Obj1 and Obj2 ... and ObjN
Subject to:
Constraint: C1 and C2 ... and Cl, where \( N \) is an integer

A lot of decision-making problems can be formulated as this form in engineering, the differences among them consist in different constraints and objects. Therefore study on this kind of problems has comprehensive significance. This model can provide different matched forms for different research objects such as single track and double track. This paper gives an example for double track, auto-blocking railway lines to show the specific form of these problems. Suppose that there are \( M \) stations and \( M - 1 \) sections, the number of upstream and downstream trains are \( N_1, N_2 \) respectively.
2.1 object

\[ \text{Obj}_{\text{minimum total delay time}}. \]

\[ \max \left\{ \sum_{i=1}^{n} (A_{i,k} - D_{i,k}) + \sum_{j=1}^{m} (A_{j,k} - D_{j,k}) + \sum_{i=1}^{n} (D_{i,k} - D_{i,k}) + \sum_{j=1}^{m} (D_{j,k} - D_{j,k}) \right\} \]

Where \( A_{i,k} \) and \( D_{i,k} \) are the scheduled time of upstream train \( i \) arriving at and departing from station \( k \), respectively; \( A_{j,k} \) and \( D_{j,k} \) are the scheduled time of downstream train \( j \) arriving at and departing from station \( k \), respectively; \( A_{i,k} \) and \( D_{i,k} \) are the actual time of upstream train \( i \) arriving at and departing from station \( k \), respectively; \( A_{j,k} \) and \( D_{j,k} \) are the actual time of downstream train \( j \) arriving at and departing from station \( k \), respectively.

2.2 Constraints

2.2.1 Departure time constraints

\[ D_{i,1} \geq D_{i,1}^{'}, \quad D_{j,M} \geq D_{j,M}^{'} \]

Where \( D_{i,1}^{'}, D_{j,M}^{'} \) are scheduled time of upstream train \( i \) and downstream train \( j \) depart from station 1 and \( M \), respectively.

2.2.2 Stop time constraints

\[ D_{i,k} - A_{i,k} \geq S_{i,k}, \quad D_{j,k} - A_{j,k} \geq S_{j,k} \]

Where \( S_{i,k} \) and \( S_{j,k} \) are required minimum stop time of upstream train \( i \) and downstream train \( j \) at station \( k \), respectively.

2.2.3 Section running interval constraints

\[ A_{i,k} - D_{i,k} - (1-\gamma_{i,k})Q_{i,k} - (1-\gamma_{i,k})T_{i,k} \geq R_{i,k} \]
\[ A_{j,k} - D_{j,k} - (1-\gamma_{j,k})Q_{j,k} - (1-\gamma_{j,k})T_{i,k} \geq R_{j,k} \]

Where \( \gamma_{i,k} \) and \( \gamma_{j,k} \) are the job types of upstream train \( i \) and downstream train \( j \) at station \( k \), respectively. They are truth-value function, 1 indicates passing, and 0 indicates others. \( R_{i,k} \) and \( R_{j,k} \) are running time of upstream train \( i \) and downstream train \( j \) at section \( k \), respectively. \( Q_{i,k} \) and \( T_{i,k} \) are additional time for train starting and breaking at station \( k \).

2.2.4 Train running headway constraints

\[ |A_{i,k} - A_{j,k}| \geq \Delta T, \quad |D_{i,k} - D_{j,k}| \geq \Delta T \]

Where \( \Delta T \) is the minimum headway of two trains in the same direction. \( i,j = 1,2,\ldots,MI;i \neq j; j = 1,2,\ldots,Mj \).

3 Study on train dispatching based on genetic algorithm

3.1 The characteristics of GA

Genetic algorithms mimic the process of natural evolution, the driving process for the emergence of complex and well-adapted organic structures. Because it has succeeded in solving large-scale and complicated problems, it is used widely in many fields. Mainly, Genetic algorithm has the following compared with traditional optimization algorithms:

- It does not need derivative information of goal function, only needs to calculate the value of goal function, so has less dependence on questions.
- Optimization is started from multiple initial points, it is categorized in parallel problem-solving
paradigm, and so genetic algorithms can give attention to the request about real-time quality and optimizing nature.

Global search characteristics with flexibility and adaptability.

3.2 the process of GA-based train dispatching

Trains operation can be divided into operation in a station (departure, arrival and pass) and operation in sections. Usually trains operation in a section is described by running time, the only dispatching way is to reduce running time which only influences the time for the train arriving at the next station in a section and can be handled at the next station. So the key point for train dispatching is how to control trains operation in station, that is, to determine trains departure orders in each station in order to minimize total delay time. Therefore the objective of train dispatching based on genetic algorithms is minimum total delay time, and optimal parameters are trains departure order in each station. The GA based algorithms is illustrated with steps in what following:

Step1: population initialization.

- Determination of the genetic parameters: such as the size of population, maximum generation, the probability of crossover and the probability of mutation, etc.

- Generation of unique identifier for the serial number of the delaying train and the following trains, code trains departure order with real number and generate N individuals at random.

Step2: fitness calculation on every individual

The relative position of trains will be fixed as long as every individual that describes trains departure order is determined, so it can be determined that departure time for every train in the current station according to the listed constraints above.

- Calculating the departure time for the first train within an individual.

\[ D_{i,j} = \max(D_{ij}, A_{ij} + T_{i}^*) \]

Where \( T_{ij}^* \) is the minimum stop time of the first train at j station.

- Calculating the departure time for other trains.

\[ D_{i,j} = \max(D_{i,j}, A_{ij} + T_{i}^*, D_{i,j-1} + I^*) \]

Where \( I^* \) is the minimum interval between train k and k-1.

- Calculating the arrival time of trains arriving at the next station.

\[ A_{i+1,j} = \max(A_{i+1,j}, D_{i,j} + R_j^* \}

Where \( R_j^* \) is the minimum running time of train k at section j.

- Calculating the total delay time of trains.

The total delay time of trains is changed as the following function in order to transform the minimum problem to the maximum problem, and the following is the fitness function.

\[ f(k) = \left[ \sum_{i=1}^{N} \sum_{j=1}^{M} (A_{i,j} - A_{i,j}^*) + \sum_{i=1}^{N} \sum_{j=1}^{M} (D_{i,j} - D_{i,j}^*) + \sum_{i=1}^{N} \sum_{j=1}^{M} (D_{i,j} - D_{i,j}^*) \right] \]

Step3: selection.

Choosing individual by proportional selection mechanism, the probability to select individual k is as
Step 4: crossover.

Applying partly matched crossover mechanism to crossover two individuals, that is, generate two intersections at random first, then exchange the area between two fathers’ intersections and replace other areas which are out of the two intersections area according to the matching relations in the two intersections one by one. This is illustrated as fig1.

Step 5: mutation

Apply inversion mechanism to mutate an individual, i.e., choose two points at random, and then insert the character between two points to original position in the inverted sequence.

Step 6: calculating fitness for every individual according to step 2.

Step 7: Stopping calculating when the size of population is bigger than initial value, otherwise return to step 3.

4 The results of simulation experiments

This paper carried out simulation experiments on the background of Guangzhou to Shenzhen railway. Guangzhou to Shenzhen railway includes 14 stations and 250 trains with 4 categories. The simulation is carried out at the most severe situation when multiple trains are delayed. The result for multi trains’ 10 minutes delay is shown as fig3. The y-axis represents the total delay times for all trains that start from the current station, it’s unit is minute. The x-axis represents all stations from the first one to the last one within the region.

Fig3. the total delay time
5 Conclusion

This paper analyzed the advantages and the drawbacks of existing train dispatching methods, and put forward a new optimization method based on genetic algorithm. The experiments at Guangzhou to Shenzhen double track lines confirm that the method is capable of creating feasible solutions rapidly for real-size problems in terms of total waiting time imposed on all trains involved.

References

1 Szpigel B., Optimal train scheduling on single track railway, Operations Research, 1972(20)
2 SAUDER R.L. and EATERMAN M., Computer aided train dispatching decision support through optimization, Interfaces, 1983,13(24)
4 Cao Jia Ming, The optimal model and algorithms for single track lines, Railway transaction 1994, 16(3),72_78
7 Li Peng, et. al., Study on inner cooperative expert system for train dispatching, China railway sciences,1998,19_3_:1_9
9 Sun Zeng Qi, et. al., Intelligent control theory and technology, QingHua university,1996.4