Research on Generating Method of On-board Equipment Test Sequence in ATO System of High Speed Railway

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Abstract. With the development of railway technology, the Train control system of Beijing-Zhangjiakou high-speed railway, which was opened in 2019, applies CTCS-3+ATO (Automatic Train Operation) technology to realize automatic driving at 350km/h, including automatic train opening, automatic and precise parking, and the linkage between train doors and platform doors. To ensure the safety and reliability of train control system, it is necessary to test the system. In this paper, the test cases used in the testing work are concatenated into test sub-sequences according to certain principles, and the concatenation problems of test sub-sequences are converted into TSP (Travelling Salesman Problem) for solving. PSO (Particle Swarm Optimization) algorithm was used to obtain the test sequence of ATO system in high-speed railway, which provided guidance for the test work.

1. Introduction
In recent years, the rapid development of high-speed railway in China has brought great convenience to the people's travel. For high-speed railway, train control system is a safety demanding system, and its system safety cannot be ignored [1]. Before the opening of the line, it is necessary to conduct a comprehensive and full test of the system, and timely find the failure of the equipment to ensure the correctness and reliability of the system function, which is a crucial link for driving safety and efficiency. And the whole test is a time-consuming and laborious process, testing personnel also have certain requirements, so the generation of test sequence will not only make the test work comprehensively, reduce the occurrence of missed test and retest, but also can reduce manual labor, improve the test efficiency. Therefore, how to generate high quality test sequence is always a key technical problem to be solved in train control system testing, which has guiding significance for the whole test work.

The testing process is shown in figure 1. Laboratory test and field test are required after the completion of system development, and the quality of the test sequence determines the efficiency of the test. The laboratory simulation test is mainly to verify whether the ATO system of high-speed railway meets the design and functional requirements. The field test is to ensure the functional safety of ATO system of high-speed railway under the actual operating conditions. The functional requirements in the technical scheme of CTCS-3 train control system, the requirements specification for CTCS-3 train control system and the overall provisional technical specification for high speed
railway ATO system are extracted and analyzed, to generate a test sequence set for a high speed
railway ATO system [2]. The test sequence generation block diagram is shown in figure 2.

For the generation of test sequence of train control system, colored petri net and time automata are
usually used for modeling, and the generated model files are analyzed and delivered into test sequence
[4,5]. Alternatively, the test sequence generation problem can be converted to the Chinese postal route
problem and solved by genetic algorithm and ant colony algorithm [6,7].

2. ATO system of high-speed railway
On the basis of CTCS-2/CTCS-3 train control system, ATO unit is added to realize automatic driving
control, special precise positioning transder is set on the ground to realize accurate positioning, and
platform door control, data transmission between stations and train operation adjustment plan are
realized through GPRS (General Packet Radio Service) communication [8]. In addition, on the basis of
the original ATP (Automatic Train Protection) on-board equipment, TSRS (Temporary Speed
Limiting Server), CTC (Centralized Traffic Control), TCC (Train Control Center) and GSM-R (Global
System for Railway Mobile Communications) functions, related functions for ATO use are added.
ATO system of high-speed railway is mainly composed of ground equipment and vehicle-based
equipment. Vehicle-based equipment includes ATP, ATO unit, DMI (Driver-Machine Interface),
GPRS, GSM-R, TCR (Track Circuit Reader), BTM (Balise Transmission Module) and speed
measurement and ranging unit. Ground equipment includes TCC, TSRS, CTC, RBC (Radio Block
Center), track circuit, transponder, LEU (Lineside Electronic Unit), GSM-R communication interface
equipment.

3. Test sequence generation

3.1. Test the transformation of the sequence generation problem to the TSP problem
Since the operating mode of on-board equipment is an obvious state cut-off point, the transition
between each mode state is defined as a test framework. In addition to 11 vehicle-mounted modes
including CTCS-2 and CTCS-3 train control system, the vehicle-mounted equipment adopts the automatic mode when it is in automatic driving mode. Due to the complexity of on-board mode conversion relations, this paper only presents the conversion relations of several common on-board equipment working modes as directed graphs, as shown in figure 3. a1-a37 above the starting end of the line segment represents the test subsequence required for mode transformation, including AM (Automatic Mode), FS (Full Supervision Mode), SB (Standby Mode), OS (On Sight Mode), CO (Call On Mode), SH (Shunting Mode), IS (Isolation Mode), and TR (Trip Mode).

![Figure 3. Directed diagram of on-board equipment working mode conversion.](image)

Based on the test cases related to message integrity, speed monitoring, mode transformation and ATO function, the test sub-sequence is formed by concatenation in accordance with certain principles. The length of the test sub-sequence is shown in Table 1. For two vehicle-based modes that cannot be directly converted, Dijkstra algorithm is used to calculate the shortest path for mode conversion. For example, if SH cannot be directly converted to OS, the shortest path for mode conversion can be obtained as SH-SB-OS. Then, the path length is the sum of the path lengths from SH to SB and from SB to OS, that is, 3+3=6.

|       | AM | FS | SB | OS | CO | SH | IS | TR |
|-------|----|----|----|----|----|----|----|----|
| AM    | 0  | 2  | 11 | 11 | 10 | 10 | 6  | 8  |
| FS    | 9  | 0  | 6  | 9  | 7  | 4  | 4  | 5  |
| SB    | 13 | 4  | 0  | 3  | 2  | 3  | 2  | 2  |
| OS    | 13 | 4  | 2  | 0  | 2  | 2  | 2  | 2  |
| CO    | 15 | 8  | 2  | 5  | 0  | 4  | 4  | 5  |
| SH    | 16 | 7  | 3  | 6  | 5  | 0  | 5  | 3  |
| IS    | 16 | 7  | 3  | 6  | 5  | 6  | 0  | 5  |
| TR    | 22 | 13 | 9  | 12 | 11 | 12 | 6  | 0  |
Considering that the TSP problem requires that each city only pass through once, you need to convert the schema transformation digraph into a full graph. The specific operation is as follows: take the connecting lines of the digraph of vehicle-mounted device working mode conversion as vertices, and then connect the vertices so that any two vertices are directly connected only through a line segment. Figure 4 takes AM, FS, IS and TR as examples to describe the specific process of conversion. As long as all vertices are traversed, it is equivalent to traversing all the test subsequences in the onboard equipment working mode transformation digraph. Based on the above method, the sequence problems of AM, FS, SB, OS, CO, SH, IS and TR in the eight working mode transformation were transformed into asymmetric TSP problems in 37 cities.

3.2. particle swarm optimization

The algorithm was initially inspired by the regularity of bird cluster activities, and then established a simplified model using swarm intelligence [9]. The basic idea of particle swarm optimization algorithm is to start from the random solution, search for the optimal solution through iteration, evaluate the quality of the solution through fitness, and update the global optimal value through the currently searched optimal value [10]. The key to solving TSP problems through PSO algorithm is to define corresponding mathematical objects and operations, such as fitness function, particle speed, position and other parameters. The specific steps of the algorithm are as follows:

(1) Firstly, initialization is carried out to generate random particles, namely a random solution of TSP problem.

(2) Calculate the fitness value \( f(i) \) of each particle, that is, the total length of the current path.

(3) For each particle, the individual extreme value and the total extreme value are compared and retained and updated. The specific comparison process is as follows:

For each particle, the individual extreme value \( P_{best} \) and fitness value \( f(i) \) are compared. If \( f(i) > P_{best} \), then \( P_{best} = f(i) \). Compare the global extreme value \( G_{best} \) and fitness value \( f(i) \) for each particle. If \( f(i) > G_{best} \), make \( G_{best} = f(i) \).

(4) Update the particle position and velocity:

Particle position update formula:

\[
v_i(t + 1) = w \times v_i(t) + c_1 \times r_1 \times [P_{best} - P_i(t)] + c_2 \times r_2 \times [G_{best} - P_i(t)]
\]

Speed update formula:

\[
P_i(t + 1) = P_i(t) + v_i(t + 1)
\]

(5) Judge whether the iteration stop condition is met. If not, return step (2) to continue the iteration.

3.3. Sequence generation result

PSO algorithm is adopted to solve the above TSP problem, and the sequence with the minimum path of 138 is obtained. The optimal result is: a16-a23-a31-a5-a35-a7-a36-a15-a8-a1-a14-a33-a17-a32-a27-a9-a18-a34-a6-a19-a20-a30-a37-a29-a21-a10-a28-a27-a22-a24-a25-a11-a12-a4-a13-a3-a2. As the test sequence was too long, it was truncated at the working mode SB, and 7 test sequences were obtained, as shown in table 2. The 7 test sequences in table 2 can cover all test cases in the corresponding test subsequences of 37 test frameworks, and reduce the number of repeated test cases to achieve the generation of test sequences. Table 3 describes the comparison of the test sequence length between the initial solution generated by the PSO algorithm and the optimal solution.
Table 2. Test sequence table.

| serial number | Test sequence                                      |
|---------------|----------------------------------------------------|
| 1             | SB-a16-OS-a23-CO-a31-IS-a35-SH-a36-TR-a7-IS-a36-SB |
| 2             | SB-a15-FS-a8-AM-a1-FS-a14-TR-a33-SB                |
| 3             | SB-a17-CO-a32-TR-a27-FS-a9-SB                     |
| 4             | SB-a18-SH-a20-IS-a9-TR-a37-IS-a36-SB              |
| 5             | SB-a19-IS-a20-CO-a26-TR-a37-IS-a29-OS-a21-FS-a10-OS-a23-SB |
| 6             | SB-a10-OS-a20-TR-a22-SB                           |
| 7             | SB-a12-OS-a34-SH-a35-IS-a1-IS-a37-AM-a4-FS-a37-AM-a37-OS-a37-SB |

Table 3. Test sequence length comparison.

| The generated solution of PSO | path length |
|-------------------------------|-------------|
| initial solution              | 138         |
| optimal solution              | 206         |

4. Conclusion

By transforming the test sequence generation problem into TSP problem, particle swarm optimization algorithm is used to solve the TSP problem, and the test sequence of ATO onboard equipment of high-speed railway is finally obtained. Compared with the random solution generated by PSO algorithm, the path length is greatly reduced. How to further improve the length of the test sequence by optimizing the algorithm and make the generated sequence result better is the goal of the next optimization.

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