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Research on Stop-Addition Capability and Critical Distance of High-Speed Railway Trains under Speed-Up Conditions

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Abstract

To evaluate the feasibility of adding intermediate stops to high-speed railway trains under speed-up conditions, this paper takes a 300 km/h non-stop operation as the benchmark and investigates whether the running-time margin produced by increasing the operating speed to 350 km/h or 380 km/h can compensate for the time cost of added stops. Based on the acceleration, cruising, braking and station-stop processes of high-speed trains, evaluation indices are established, including speed-up time saving, stop-addition time cost, residual time margin, maximum feasible number of added stops and critical distance. The results show that the time cost of one added stop is much larger than the loss caused by speed-reduced pass-through at small and medium stations. Under 350 km/h and 380 km/h conditions, the total time cost of one added stop is approximately 282.04 s and 295.93 s, respectively, whereas passing through one station at 0.9 times the target speed increases the running time by only about 2.53 s and 2.60 s. The calculated critical distances for adding 1-4 stops are 178.06 km, 342.59 km, 507.12 km and 671.65 km under 350 km/h, and 131.97 km, 248.90 km, 366.20 km and 483.13 km under 380 km/h. The proposed evaluation method can provide a reference for stop-addition capability assessment and critical-distance determination under high-speed railway speed-up conditions.

Keywords

High-Speed Railway; Speed-Up; Added Stop; Time Cost; Critical Distance

1. Introduction

With the continuous improvement of the high-speed railway network, train operation organization has gradually shifted from simply pursuing high-speed direct services to coordinating speed improvement, service coverage and operational efficiency[1-2]. For existing high-speed railway lines, increasing the operating speed can reduce section running time and form a certain time margin. This margin may be used not only to shorten passenger travel time, but also to support additional stops at intermediate stations, thereby improving the service level of small and medium

stations along the line[3].

Although additional stops can improve service coverage, they also increase total train running time. One station stop does not only involve fixed dwell time; it also includes approach braking, re-acceleration after stopping, and additional losses caused by the reconstruction of the speed profile[4-6]. Therefore, the feasibility of stop addition after speed-up should not be estimated simply by dividing distance by speed. Instead, it should be evaluated through the compensation relationship between speed-up time saving and stop-addition time cost[7].

When high-speed trains pass through small and medium stations without stopping, pass-through speed reduction may also occur. Preliminary calculations show that, under a 0.9 speed-reduction coefficient, the additional time for a train passing through one such station is only about 2.53 s at 350 km/h and 2.60 s at 380 km/h. This is far smaller than the hundred-second-level cost of one added stop. Accordingly, this paper treats speed-reduced pass-through as a running-time correction factor, while focusing on stop-addition time cost and critical distance.

2. Model and Evaluation Indices

2.1. Operating Schemes

The 300 km/h non-stop operation is selected as the benchmark scheme, and its running time is denoted by T0300(L). When the train operates at 350 km/h or 380 km/h without additional stops, the running time is denoted by T0v(L), where v belongs to {350, 380}[8]. When n intermediate stops are added under the speed-up condition, the running time is denoted by Tnv(L).

2.2. Evaluation Indices

The speed-up time saving is defined as:

$$\Delta T_v(L) = T^0_{300}(L) - T^0_v(L)$$

The stop-addition time cost is defined as:

$$C^n_{stop}(L) = T^n_v(L) - T^0_v(L)$$

To judge whether added stops are feasible after speed-up, the residual time margin is defined as:

$$R^n_v(L) = T^0_{300}(L) - T^n_v(L)$$

When R^n_v(L) is not less than zero, the total running time of the speed-up stop-addition scheme does not exceed the 300 km/h non-stop benchmark, indicating that the scheme is feasible in terms of time. The maximum feasible number of added stops is defined as:

$$N_{max}(v,L) = \max\{n \mid R^n_v(L) \geq 0\}$$

For a given speed level v and number of added stops n, the critical distance is defined as:

$$T^n_v(L_{crit}) = T^0_{300}(L_{crit})$$

This equation indicates that the speed-up stop-addition scheme has the same running time as the 300 km/h non-stop benchmark at the critical distance. When the route length is greater than the critical distance, the time saving produced by speed-up can compensate for the corresponding stop-addition cost; otherwise, the scheme is infeasible.

3. Analysis of Stop-Addition Time Cost

According to the train operation calculation, under the 350 km/h condition, the time required for the train to decelerate from cruising speed to a stop is about 162.04 s, and the time required to re-accelerate to cruising speed is also about 162.04 s. The corresponding braking and acceleration distances are both about 7.88 km, and the total distance of the speed-changing stages is about 15.75 km. With a fixed dwell time of 120 s, the total time cost of one added stop is approximately 282.04 s.

Under the 380 km/h condition, the braking and re-acceleration times are both about 175.93 s. The corresponding braking and acceleration distances are about 9.28 km each, and the total distance of the speed-changing stages is about 18.57 km. Considering the fixed dwell time, the total time cost of one added stop is approximately 295.93 s.

Table 1. Time cost of one added stop

Item	350 km/h	380 km/h
Cruising speed (km/h)	350	380
Maximum acceleration (m/s^2)	0.6	0.6
Maximum deceleration (m/s^2)	0.6	0.6
Fixed dwell time (s)	120	120
Braking time for stop (s)	162.04	175.93
Re-acceleration time after stop (s)	162.04	175.93
Braking distance (km)	7.88	9.28
Acceleration distance (km)	7.88	9.28
Total speed-changing distance (km)	15.75	18.57
Total increase including dwell time (s)	282.04	295.93

Table 1 indicates that the time cost of an added stop is significantly higher than the fixed dwell time itself. A station stop consumes not only the 120 s dwell time, but also substantial time associated with braking and re-acceleration. Therefore, one added stop should not be treated as only a fixed 120 s penalty when evaluating stop-addition capability.

By contrast, the time loss caused by speed-reduced pass-through at small and medium stations is limited. Under a 0.9 speed-reduction coefficient, the pass-through speeds are 315 km/h and 342 km/h for the 350 km/h and 380 km/h schemes, respectively.

Table 2. Time cost of speed-reduced pass-through

Item	**350 km/h**	**380 km/h**
Cruising speed (km/h)	350	380
Reduced pass-through speed (km/h)	315	342

Reduction coefficient	0.9	0.9
Station influence-zone length (m)	800	800
Deceleration time for pass-through (s)	16.20	17.59
Re-acceleration time after pass-through (s)	16.20	17.59
Speed-changing distance for pass-through (km)	2.99	3.53
Total time increase for pass-through (s)	2.53	2.60

As shown in Table 2, the time loss caused by speed-reduced pass-through is only 2.53 s at 350 km/h and 2.60 s at 380 km/h. Compared with the 282.04 s and 295.93 s costs of one added stop, the order-of-magnitude difference is obvious. Therefore, speed-reduced pass-through is not the dominant factor affecting stop-addition capability, but is mainly treated as a running-time correction factor.

4. Critical Distance and Stop-Addition Capability

4.1. Critical Distance Results

Using the proposed model, the critical distances under different speed levels and numbers of added stops were calculated. Under the 350 km/h condition, the critical distances for adding 1 to 4 stops are 178.06 km, 342.59 km, 507.12 km and 671.65 km, respectively. Under the 380 km/h condition, the corresponding values are 131.97 km, 248.90 km, 366.20 km and 483.13 km.

Table 3. Critical distance under different speed levels and numbers of added stops

Speed level	Added stops	Critical distance (km)	300 km/h non-stop time (s)	Speed-up stop-addition time (s)
350 km/h	1	178.06	2275.57	2275.52
350 km/h	2	342.59	4249.94	4249.88
350 km/h	3	507.12	6224.32	6224.24
350 km/h	4	671.65	8198.69	8198.59
380 km/h	1	131.97	1722.56	1722.12
380 km/h	2	248.90	3125.65	3125.75
380 km/h	3	366.20	4533.30	4532.98
380 km/h	4	483.13	5936.39	5936.61

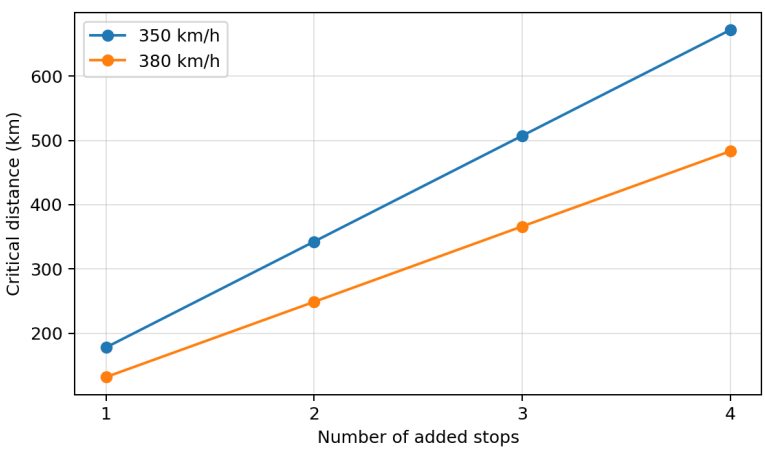


Figure 1. Critical distance of speed-up stop-addition schemes under different numbers of added stops

The results show that the critical distance increases as the number of added stops increases. This indicates that multi-stop addition requires a longer route length to accumulate sufficient speed-up time saving. For short-distance sections, even when the operating speed is increased, the time saving is still insufficient to compensate for one added stop; for medium- and long-distance sections, the time saving gradually increases, and stop addition becomes feasible.

Table 4. Increment of critical distance

Speed level	Change in number of stops	Increase in critical distance (km)
350 km/h	1 to 2 stops	164.53
350 km/h	2 to 3 stops	164.53
350 km/h	3 to 4 stops	164.53
380 km/h	1 to 2 stops	116.92
380 km/h	2 to 3 stops	117.30
380 km/h	3 to 4 stops	116.92

Under the current parameters and stop layout, the critical distance shows an approximately linear increase with the number of added stops. This is because each additional stop introduces relatively stable fixed dwell time, approach braking loss and re-acceleration loss, which require additional route length to accumulate sufficient speed-up time saving.

4.2. Stop-Addition Capability under Different Route Lengths

Table 5. Examples of the maximum feasible number of added stops under different route lengths

Route length (km)	350 km/h	380 km/h
100	0	0
150	0	1
200	1	1
300	1	2
400	2	3
500	2	4

Table 5 shows that the higher speed level has a clear effect on stop-addition capability. Under the same route length, the 380 km/h scheme can generally support more added stops. For example, when the route length is 300 km, the 350 km/h scheme can support at most one added stop, whereas the 380 km/h scheme can support two added stops. When the route length reaches 500 km, the 350 km/h scheme can support two added stops, while the 380 km/h scheme can support four added stops.

Table 6. Running time and residual margin for a 200 km route

Speed level	Added stops	Total running time (s)	Margin relative to 300 km/h non-stop (s)	Feasibility
350 km/h	0	2227.49	311.40	Feasible
350 km/h	1	2507.45	31.44	Feasible
350 km/h	2	2787.41	-248.52	Infeasible
380 km/h	0	2079.39	459.50	Feasible
380 km/h	1	2373.13	165.76	Feasible

380 km/h	2	2666.88	-127.99	Infeasible

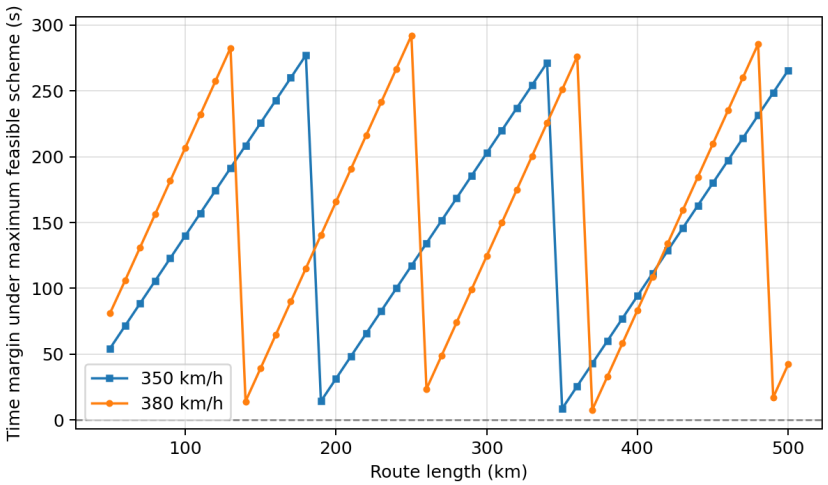


Figure 2. Time-margin variation under the maximum feasible stop-addition scheme

For the 200 km route, both the 350 km/h and 380 km/h schemes can support one added stop, but neither can support two added stops. However, after adding one stop, the 380 km/h scheme still retains a residual time margin of 165.76 s, while the 350 km/h scheme retains only 31.44 s. This indicates that, under the same number of added stops, the 380 km/h scheme has a more sufficient time margin.

5. Conclusions

This paper takes the 300 km/h non-stop operation as the benchmark and studies the feasibility of adding intermediate stops under 350 km/h and 380 km/h speed-up conditions. Evaluation indices including speed-up time saving, stop-addition time cost, residual time margin, maximum feasible number of added stops and critical distance are established. The main conclusions are as follows.

First, the time cost of an added stop is much larger than the time loss caused by speed-reduced pass-through at small and medium stations. Under 350 km/h and 380 km/h conditions, the total time cost of one added stop is approximately 282.04 s and 295.93 s, respectively, whereas passing through one station at 0.9 times the target speed increases the running time by only about 2.53 s and 2.60 s. Therefore, stop-addition time cost is the dominant factor affecting stop-addition capability, while speed-reduced pass-through is mainly a correction factor.

Second, different numbers of added stops correspond to different critical distances. Under the 350 km/h condition, the critical distances for adding 1 to 4 stops are 178.06 km, 342.59 km, 507.12 km and 671.65 km, respectively. Under the 380 km/h condition, the corresponding critical distances are 131.97 km, 248.90 km, 366.20 km and 483.13 km. Critical distance can therefore serve as an important basis for stop-addition capability assessment under speed-up conditions.

Third, the 380 km/h scheme has stronger stop-addition capability than the 350 km/h

scheme. For the same number of added stops, the 380 km/h scheme requires a shorter critical distance; for the same route length, it generally supports more added stops or retains a larger running-time margin.

Fourth, the calculation for a 200 km route shows that both 350 km/h and 380 km/h schemes can support one added stop but cannot support two added stops. Among them, the residual margin after adding one stop is significantly larger under 380 km/h, indicating that a higher speed level may not only increase the maximum feasible number of added stops, but also improve the time margin of near-critical schemes.

In summary, speed-up time saving can be converted into stop-addition capability under certain route-length conditions. However, the effect is jointly influenced by route length, speed level, number of added stops and stop-addition time cost. The proposed critical-distance and maximum-stop-addition evaluation method provides a reference for analyzing train stop-addition capability under high-speed railway speed-up conditions.

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