

Development of Station Capacity Models Considering Route Combinations

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This research proposed headway-based capacity models considering route combinations of trains. These models were validated by the network of Taiwan high-speed rail. Users can use these models to evaluate the capacity of intermediate and terminal stations.

(*Keywords* : Station capacity, route combinations of trains, intermediate station, terminal turn-back station)

1. INTRODUCTION

In recent year, railway transportation system has become more and more popular owing to its high transportation capability⁽¹⁾⁻⁽³⁾, and it is usually considered as the key answer to solve the transportation problem in both urban and intercity. Despite the above-mentioned advantages, railway system is characterized by huge amount of construction cost; Besides, a large part of the cost will be viewed as sunk cost, which means paid and irretrievable or repurposed, as a result, the assessment of the supply capability of the system at the planning stage is a critical issue. In the field of rail transportation research, capacity, as an indicator or concept, is to measure the supply capability of a railway system. Different capacity analysis methods among past related studies can be roughly categorizing them into three group: Analytical model, Simulation model, and Optimization model⁽²⁾⁽⁴⁾⁽⁵⁾. The former is usually assessing capacity by analyzing the headway in consideration of different operating conditions⁽⁴⁾⁽⁶⁾, which doesn't need to determine the timetable in advance. However, the latter two usually require an initial timetable as the input⁽³⁾⁽⁷⁾⁽⁸⁾, and they will take longer time to solve the problem⁽⁴⁾.

This research develops a simulation model based on headway-based concept, which means the headway between two consecutive trains is treated as the measure to assess capacity. Moreover, we determine the headway according to the routes, which the trains go through respectively, and the "motions", which the trains happen in the station respectively. It is expected to avoid the complex utilization barrier when capturing some randomness of train operation, and maintain a valid capacity assessment. The high-speed rail (HSR) system in Taiwan (THSR) is selected as the target for analyzing, including two kinds of spatial reference points: intermediate stations and terminal (turn-back) station.

2. CAPACITY MODEL FOR THE INTERMEDIATE STATION

The intermediate station is specifically defined as the station located along the line except for the endpoints, and the HSR trains will not terminate their service at these stations. That is, according to different operating arrangements, some of trains will stop at the

station and then keep their journey subsequently, while the other will directly pass through the station.

2.1 Combination of Route-Motion

The headway between two trains will be influenced by the routes they go through at the station and their stopping situation. Therefore, all possible combination of "Route-Motion" of trains, which each kind of combination is treated as a headway individually, is needed to figure out. The route is determined according to the track used by the train at the station. As for motion, there are a total of three motions defined in the models for intermediate station and they can be defined by the stopping situation of the trains: A train stopping at a station has two motions which are "Arrive" and "Depart", while a train passing through a station (not stopping) has one motion which is "Pass". To sum up, the models will determine the headway through the routes and motions between two trains, which is defined as "Combination of Route-Motion". Then, the combination of "Route-Motion" can be further deduced through the correspondence between the preceding train and the following train in terms of routes and motions. Previous mentioned work for a common station of THSR is illustrated in Figure 1 for example. Finally, each combination will be viewed as a kind of possible headway.

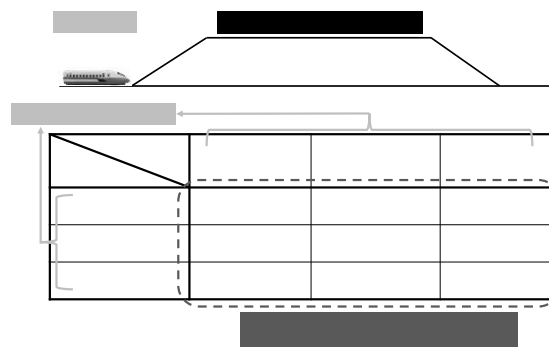


Figure 1 Illustration of Headway for the Intermediate Station

2.2 Framework of the Capacity Model

The simulation model tries to generate a series of train according to the ratio of train type. Train type in this model is defined by the route used by the train along with the stopping situation of the train at the station. The simulation process of simulation model for

intermediate station is shown in Figure 2.

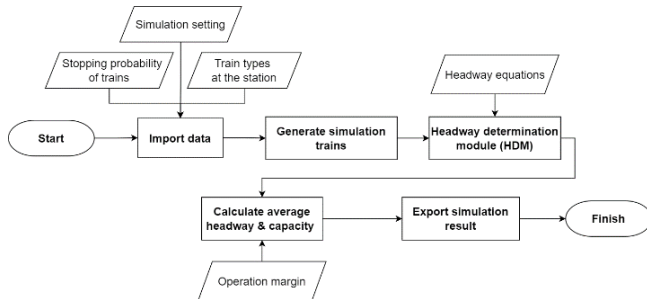


Figure 2 The Flowchart of Capacity Model for Intermediate Stations

The basic simulation mechanism of this model is to generate a series of simulation trains, and then it will arrange arrival and departure times for each train one by one according to the headway between two trains at the station (The arrival and departure time for passing train is viewed as the same). The headway determine module (HDM) is responsible for performing related processes from now on. The detailed flowchart of HDM is shown as Figure 3.

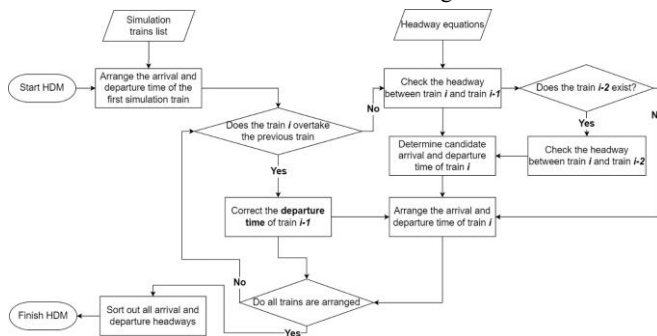


Figure 3 The Flowchart of HDM

In the process of arranging arrival and departure time, the arrival and departure time of the train is usually affected by the adjacent trains, that is, the preceding train and the headway between them determine the arrival and departure time of the following train. This relationship is sequential and one by one. However, when overtaking and refuging occur, it would break the above-mentioned rule and make the situation become complicated. Moreover, this situation also affects the determination of trains' arrival and departure headways at intermediate stations. Owing to the special situation as the overtaking, the arrangement of the arrival and departure time of a train is needed to check not only the relationship between the previous train but also the train prior to the previous train. Similarly, determination of the actual arrival and departure headways will also encounter the problem. The HDM is going to sort out the actual arrival and departure headway according to the arrival and departure time of the simulation train after the previous checking process.

3. CAPACITY MODEL FOR THE TERMINAL TURN-BACK STATION

The terminal turn-back station is specifically defined as the endpoint station of both sides of the line, where the HSR train will

terminate their service temporarily and prepare to turn around for the next trip or even stay at the station for the need of operation dispatching. In contrast to the intermediate station under double tracks operation, the routes for trains to enter or leave the terminal turn-back station may exist conflicts due to the operation of turnaround. Moreover, the turnaround time, which is referred to as the time interval from a train fully stopping at the station to it leaving the station, is much longer than the train dwell time for an intermediate station.

3.1 Combination of Route-Motion

Due to being the endpoint over the line, there are two kinds of train motions at the terminal turn-back stations: enter (get into the station) and leave (get out of the station). In addition, we assume that entering and leaving are alternate. The situation is that a train gets into the station, next a train gets out of the station, then a train gets into the station, and so on. However, for the terminal turn-back stations, we define headway as the time interval between two consecutive trains arriving at the station (There is another one leaving train between the two entering trains). Moreover, we also assume that the time interval between two consecutive trains arriving at the station is the same as the time interval between two consecutive trains leaving from the station.

To sum up, according to the above assumption and the definition of headway here for the terminal turn-back stations, the model determines the headway by considering the "Combination of Route-Motion" among three trains, which are entering, leaving and entering. Previously mentioned work is illustrated in Figure 4. Finally, each combination will be viewed as a kind of headway.

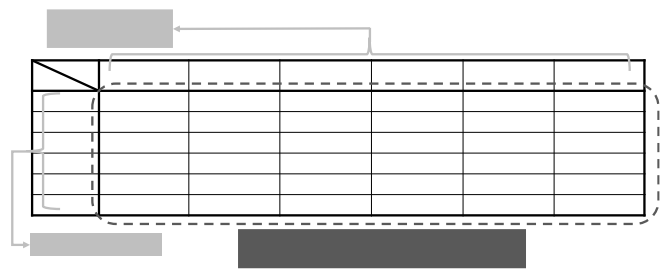


Figure 4 Illustration of Headway for the Terminal Turn-back Station (partial)

3.3 Framework of the Capacity Model

The simulation model generates the entering train and the leaving train alternately. The process of simulation model for terminal turn-back stations is shown in Figure 5.

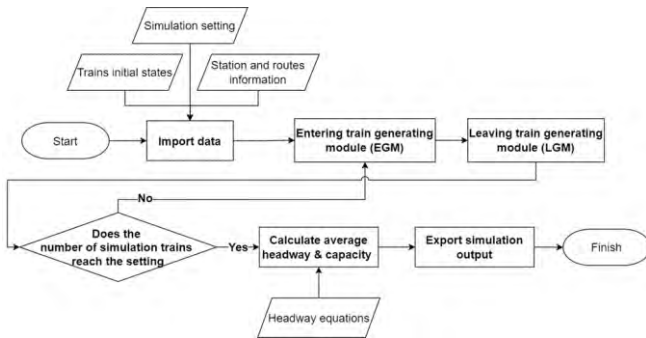


Figure 5 The Flowchart of Capacity Model for Terminal Turn-back Stations

The entering train generation module (EGM) determines an entering train to get into which tracks by considering the occupancy situation and using ratio. Also, EGM needs to determine the headway when the simulation trains form a “entering-leaving-entering” (or referred to as “in-out-in”) combination. The detailed flowchart of EGM is shown as Figure 6.

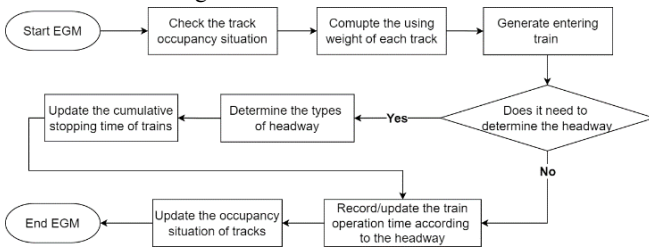


Figure 6 The Flowchart of EGM

The leaving train generation module (LGM) determines a leaving train to leave from which tracks by considering the occupancy situation, using ratio and cumulative stopping time for the trains staying at the station. If there is no train’s cumulative stopping time fulfills the turnaround time, LGM will adjust the cumulative stopping time to ensure that there is at least one train fulfilling the turnaround time. The detailed flowchart of LGM is shown as Figure 7.

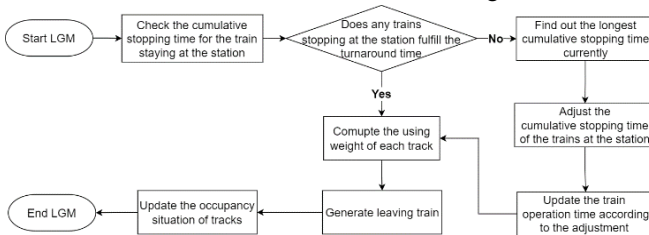


Figure 7 The Flowchart of LGM

4. MODEL VALIDATION AND OPERATION MARGIN

This research validates the proposed models by comparing the capacity analysis result of the proposed models and the practical value. This comparison is viewed as a validation of our models, and also the criteria to measure the operation margin for the proposed models. The results of headway for the proposed models and the practical value are summarized in Table 1 (*h* stands for headway, while *C* stands for capacity).

Table 1 The Comparison Results of the Two Stations

Station	Proposed Models	Practical Value	Percentage Error
Taichung station	<i>h</i> : 233.56 (s) <i>C</i> : 15.4 (trains/hr)	<i>h</i> : 300 (s) <i>C</i> : 12.0(trains/hr)	28.45%
Nangang station	<i>h</i> : 232.72 (s) <i>C</i> : 15.5 (trains/hr)	<i>h</i> : 300 (s) <i>C</i> : 12.0(trains/hr)	28.91%

Based on the comparison, the differences in headway between model result and practical value for both intermediate station and terminal turn-back station are less than 30%, which is under a reasonable range⁽⁹⁾. In addition, this difference is treated as the operation margin to fulfill the gap between theoretical capacity and practical capacity⁽⁴⁾.

5. CASE STUDY

We apply the two models to an actual case to evaluate the average headway and capacity. THSR is selected as the object of case study for this research, and the track layout of the stations is illustrated in Figure 10. We will identify the bottleneck over the line, and attempt to analyze the cause. Then, a further analysis of the influence on capacity due to the change in key factors will be illustrated.

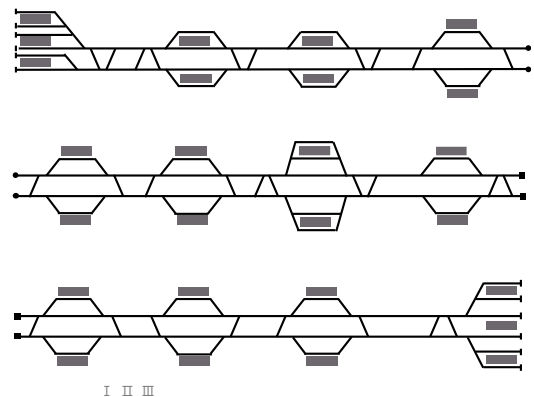


Figure 8 Track Layout of the Stations over THSR Line

The capacity analysis result of THSR analyzed by capacity simulation mode is summarized in Table 2. The expected maximum headway (minimum capacity) over the whole line occurs at Taipei station. The reason is speculated to be the longest dwell time among all intermediate station, and all of trains are needed to stop at Taipei station. Therefore, the impact of dwelling time on capacity will be significant when the ratio of stopping trains is in the majority.

Table 2 The Capacity Analysis Result of THSR

Station	Nangang	Taipei	Banqiao	Taoyuan	Hsinchu	Miaoli
Capacity (trains/hr)	11.9	9.9	14.8	11.4	12.4	16.5
Station	Taichung	Changhua	Yulin	Chiayi	Tainan	Zuoying
Capacity (trains/hr)	11.9	16.5	16.5	11.7	11.3	11.9

According to the analysis result, we take Taipei station to further

evaluate the effect of dwell time on capacity for the intermediate station, while other conditions and factors are still the same. The evaluation result is presented in Table 3. The longer dwell time means that the stopping trains need to spend longer time staying at the intermediate station. It will lengthen the time intervals between two consecutive trains arriving at and departing from the station. Therefore, it leads to a reduction in the capacity for the intermediate station.

Table 3 The Effect of Dwell Time on Capacity (Taipei Station)

Dwell Time (s)	180	120	90	60
Capacity (trains/hr)	9.9	11.9	13.1	14.7

As for the terminal turn-back station, there are basically two critical factors included in the proposed model, namely turnaround time and number of trains participating in turnaround operation, have significant effect on capacity for the terminal turn-back station. Here we take Nangang station to examine the influence of the two factors and the result is shown in Figure 9. The shorter turnaround time means that the train doesn't need to stay for a long time at the terminal turn-back station after it entered the station. If there are more trains ready to depart at the station initially, it means that additional waiting time is not needed when the train is about to leave, thereby reducing the headway between trains.

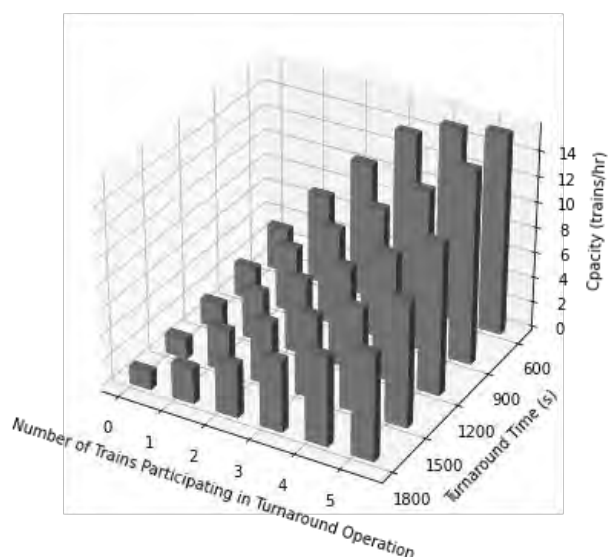


Figure 9 The analysis result of turnaround time and number of trains participating in turnaround operation on capacity for the turn-back station

6. CONCLUSION

This research, focusing on the HSR system, develops capacity simulation models in consideration of the headway between trains under different route combinations to evaluate the capacity for intermediate station and terminal turn-back station, respectively. The

case study validates gap between the theoretical capacity derived from the proposed model and practically sustainable capacity lies in a reasonable range, displays the application of the models to a real HSR line, and summarizes the relationship between several key factors and capacity.

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