

# *Design of Simulation Software Based on Suburban Railway Turn-round Track's Safety Distance*

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**Abstract:** Turn-back capacity of the turn-back station is the key point which affects the operating capacity of the suburban railway. The design of the turn-round track in station is the prime factor which affects the turn-back capacity. Meanwhile, the length of turn-round track is partly determined by its safety distance, so the safety distance may enhance or decrease the turn-back capacity of the station. On account of the perspective of signal systems, the simulation software for the Turn-round Track safety distance has been designed based on the characteristics and design specifications of the suburban railway. According to the braking model laid down by IEEE 1474.1, the influence of the safety distance on the train operation under the circumstance of the automatic turn-back control was analyzed by a safety distance calculation model on CBTC(Communication Based Train Control System).The mileage-time diagram was drawn by the entire turn-back simulation process. Based on the influence of safety distance to turn-back capacity, the optimal turn-round track safety distance within simulated scenario was obtained. Finally, a typical turn-back operation after station on the Fuzhou Airport Line was taken as an example for simulation. The results indicated that the turn-back capacity and operating efficiency was improved by the reasonable setting of the safety distance.

## 1. Introduction

Suburban railway refers to a railway passenger transportation system in a developed and densely populated urban area, with the main urban area as the center, connecting the central urban area with the suburbs or the central city with satellite cities<sup>[1]</sup>. At present, the turn-back station type mixed the turn-back operation after station and the turn-back operation before station was used by suburban railway. It not only reduces the difficulty of operation and ensures the passengers' comfort, but also reduces the distance with other lines transfer. According to the current design standards and construction conditions, the design of the safety distance of the turn-round track of the turn-back

station would be limited by the construction foundation and cannot fully meet the requirements in the "Standard for Design of suburban Railway". At the same time, the turn-back capacity of the turn-back station was largely determined by the safety distance. An excessively long safety distance will affect the length of the terminated line after station and increase unnecessary construction costs; an excessively short safety distance is destructive to control the train safety driving of the signal system. According to the specification, the safety distance of the terminated turn-round track is 50 meters, and the safety distance of the through-type turn-round track is 60 meters<sup>[2]</sup>. Whether there is a safety margin in the specification is worthy of further study.

According to the actual operating conditions, the safety distance in actual construction is generally not less than 40 meters, so the discussion in this article does not consider the turn-back capacity under the extremely short situation of safety distance. At present, there are lots of research results on the safety distance and turn-back capacity of urban rail transit turn-round track. The influence of the safety distance length on the turn back capacity before station was analyzed by the literature<sup>[3][4]</sup>, and proposed a scheme which can shorten the safety distance by optimizing the ATO operation strategy. The turn-back capacity was improved by optimizing turn-back station safety line project configuration in the literature<sup>[5][6]</sup>. From many aspects, such as signal system, turnout speed limit, train formation, the turn-back capacity was enhanced about 7.1% by proposing the condition that choosing No. 12 switch and the train in six-carriage-marshalling in the literature<sup>[7]</sup>. However, there are few simulation software for the safety distance calculation of the turn-back station. In this paper, The simulation software designed can not only greatly improve the work efficiency, but also can simulate the various train operation of the turn-back stations. It is an effective technical method to study the influence of safety distance on turn-back capacity, and to determine safety distance design in engineering design.

## 2. The Influence Analysis of the Safety Distance on the Turn-round Track

The typical braking model developed by IEEE1474.1 and the safety braking model under CBTC defined by the CBTC system standard are shown in Figure 1<sup>[8]</sup>. Based on the fundamental model, the calculation model of the turn-round track safety distance established in this paper.

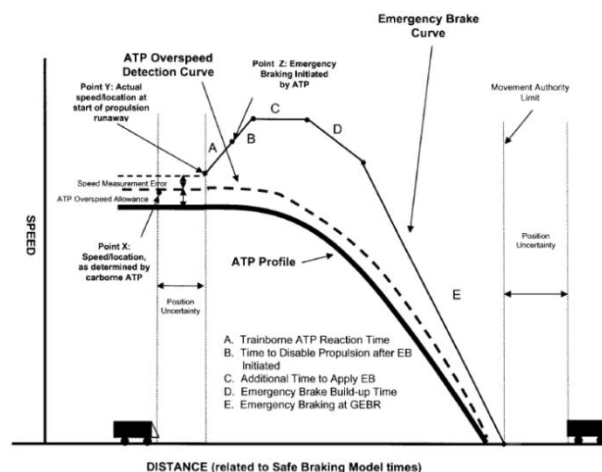


Figure 1: IEEE 1474.1 safe braking model.

From Figure 1, it can be seen that the train will trigger emergency braking in the most unfavorable situation (Service braking cannot make the train stop before the ATO parking point), so that the determination of the safety distance needs to consider the Service braking distance and

emergency braking in the same mileage. The relationship between them has been shown in Figure 2.

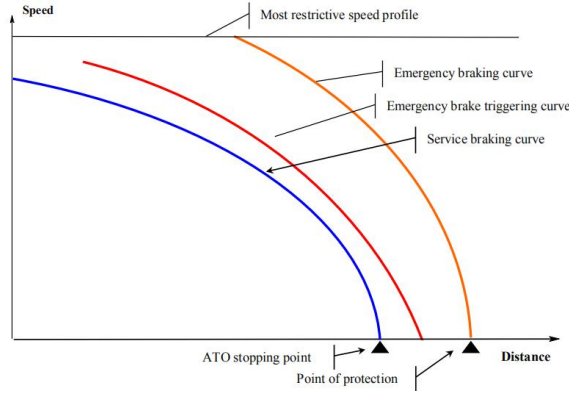


Figure 2: Schematic diagram for the safety distance of turn-round track.

Service braking is the braking process under ATO control. ATO is used with a constant braking rate in this calculating model. The formula of service braking distance is:

$$S_{Service\_brake} = \frac{v_{ATO}^2}{2(a_{s\_brake} + a_{other})} \quad (1)$$

Among these parameters,  $v_{ATO}$  is the ATO's protection speed of the current position,  $a_{s\_brake}$  is the braking rate outputted by service braking, and  $a_{other}$  is the extra acceleration which caused by the slope or other factors.

The process of emergency braking is combined with four processes which include the ATP equipment reaction phase, traction removal phase, emergency braking establishment idle phase, and braking phase. If the emergency braking rate GEBR under the most unfavorable conditions of the emergency braking model is set to be constant, the calculation formula of emergency braking distance of the entire process is:

$$\begin{aligned} S_{Emergency\_brake} &= \frac{(v_0 + t_q a_q)^2 - v_0^2}{2(a_q + a_{other})} \\ &+ \frac{(v_0 + t_q a_q + t_o a_{other})^2 - (v_0 + t_q a_q)^2}{2a_{other}} \\ &+ \frac{(v_0 + t_q a_q + t_o a_{other})^2}{2(a_{e\_brake} + a_{other})} + S_b \end{aligned} \quad (2)$$

Among these parameters,  $v_0$  is the ATP's protection speed at the current position,  $a_q$  is the maximum traction acceleration during the train's operation,  $a_{e\_brake}$  is the acceleration of the train's emergency braking,  $t_q$  is the traction delay from the ATP reaction to the traction removal, and  $t_o$  is the establishment of the brake to the idling time of the emergency braking Delay.  $S_b$  is the distance to the nearest transponder and the measurement error.

From formula (1) and (2), the formula for calculating the safety distance is:

$$S_{safety} = S_{Emergency\_brake} - S_{Service\_brake} \quad (3)$$

In the controlling mode by CBTC, there is a fixed speed constant difference between the ATO limiting speed and the ATP emergency braking speed, which named as:

$$v_{ATO} = v_0 - \Delta v \quad (4)$$

Substituting formula (4) into formula (3) can obtain the calculation model of safety distance. It can be known from the formula that since the performance parameters of the train itself are constant, the parameters which affect the length of the safety distance are the service braking rate of train and the ATO controlling speed.

## 2.1. Analysis of Factors Affecting Safety Distance

### 2.1.1. Service Braking Rate

The braking rate of the train during approaching platform is mainly related to the train's performance parameters, passenger conditions, operating mode and passenger comfort.  $a_{s\_brake}$  of the train is appropriately adjusted by the on-board system during the operation. On normal circumstances, the braking rate output during the braking process of a train entering the station decreases as the speed decreases. A decrease in the braking rate will result in increasing the braking distance. The parameters involved in the emergency braking distance model are fixed parameters of ATP, which are constants. Therefore, the emergency braking distance for a categorical point is immutable. From formula (3), it can be known that when the output of the service braking rate becomes large, the safety distance becomes shorter, on the contrary the result will be the opposite. Therefore, shortening the safety distance can ensure the safety of operation by increasing the braking rate when the train enters the station.

### 2.1.2. ATO Speed

ATO controlling speed is mainly determined by the limited speed on track, including limited on switch or set by MRSP for current conditions. From formula (3), it's known that when  $a_{s\_brake}$  is a constant, the length of safety distance is totally determined by  $v_{ATO}$ , and  $S_{safety}$  is a quadratic function about  $v_{ATO}$ . In order to obtain the optimal value of the safety distance, find the second derivative of formula (3) about  $v_{ATO}$ , it can be seen that  $S''_{safety}$  is always greater than zero, which means there is a minimum value for the safety distance; and when  $S'_{safety}$  is equal with zero,  $v_{ATO} < 0$ , it also means the safety distance decreases as the speed limit decreases while  $v_{ATO} \in (0, +\infty)$ . Therefore, shortening the safety distance can ensure the safety of operations by reducing the speed limit.

## 2.2. Analysis of Influence of Safety Distance on Turn-back Capacity

The turn-back capacity of a Suburban railway is defined as the maximum number of trains that a turn-back station can finish in a unit time. In calculation process, it is performed according to the

formula as  $N_{turnback} = \frac{3600}{T_{interval}}$ .  $N_{turnback}$  is the maximum number of trains that can finish turn-back operation per unit time, and  $T_{interval}$  is the turn-back interval<sup>[9]</sup>. The turn-back interval refers to the departure interval between the completion of the turn-back operation of the front and rear trains. It mainly includes the time of the train to enter, stop, exit the station, enter the turn-round track and handle the route. The calculation of the specific turn-back capacity and the effect of the safety distance on the turn-back capacity are described in turn according to the classification of turn-back before and after the station.

### 2.2.1. Turn-Back Before the Station

The typical station type of turn-back before the station is shown in Figure 3. The safety distance section is behind the platform, and the train turn-back period is short. After the train enters the station, the turn-back work is completed on the crossover line outside the platform.

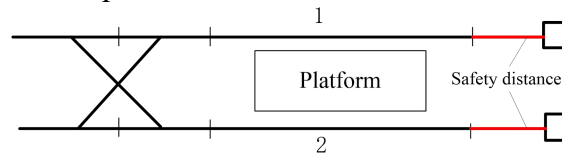


Figure 3: Typical station type of turn-back before.

The process of single-line turn-back before the station is as follows: (1)The first train stops at the station. (2)Stop and disembark, then handle the exit route of the first train. (3)The first train clears the platform section. (4) Handle the second train. Turn-back interval time equal to the following formula  $T_{interval} = t_{1\_enter} + t_{1\_stop} + t_{1\_exit} + t_{handle}$ . When the safety distance is shortened, a straight pit stop needs to reduce the pit stop speed or increase the pit stop braking rate, which will cause an increase in the pit stop time, and increase the turn-back interval; the side pit stop takes into account the speed limit by switch, the safety distance required to enter the station at a lower speed below the limiting speed is shorter than that of the straight approach, so it is considered that shortening the safety distance of the train entering the station within a certain range does not affect the turn-back interval.

The process of double-line turn-back is as follows:(1)The first train has already departed from platform 1 and the third train has entered the platform 1 and stopped at the side. (2)Admire and operate the second train at platform 2. (3)The second train leaves the station sideways. (4)Handle the lateral approach of the fourth train. Turn-back interval time equal to the following formula  $T_{interval} = t_{3\_enter} + t_{2\_handle} + t_{2\_exit} + t_{4\_handle}$ . If the safety distance is shortened, the impact on the double-line turn-back is similar to that of the single-line side stop, and it will not affect the turn-back interval.

### 2.2.2. Turn-back after the Station

The typical station type of turn-back after the station is shown in Figure 4. Different from the last station, the platform tracks and the turn-round tracks are set separately. The safety distance protects the trains entering the turn-round track section, and it can accommodate multiple trains to turn-back at the same time.

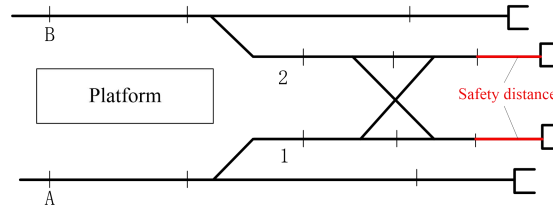


Figure 4: Typical station type of turn-back after.

Compare with last type of station, this station type is divided into the platform line and turn-round track. A is the inbound point and B is the outbound point. The single-line turn-back process is divided into the pick-up process: (1)The first train enters platform A. (2)The first train stops and disembarks and handles the route to the first turn-round track. (3)The first train clears platform A. (4)Handle the second train into platform A; turn-back process: (1)The first train enters the first turn-round track. (2)Handle the way for the first train to leave the turn-round track. (3)The first train clears the turn-round track section. (4)Handle the second train into the first turn-round track; the departure process: (1)The first train enters platform B. (2)The first train stops to pick up passengers. (3)The first train leaves the platform section B of the clearing platform. (4)Handle the route for the second train to enter the platform B. Turn-back interval time equal to the following formula  $T_{interval} = \max\{t_{enter}, t_{turnback}, t_{exit}\}$ . When the safety distance is shortened, the speed limit of entering the turn-round track needs to be reduced, and the time required for the turn-back process is increased. However, in a large number of engineering surveys, the time of the turn-back process is less than the running time of the inbound and outbound stations so that there is little influence to turn-back interval. Double-lines process may be the same as that of the single-line. The only difference is that the turn-back process of the second train will enter the second turn-round track to complete the turn-back. Therefore, the turn-back interval of the double line is the same as the calculation method of the single line. Since the entry the second turn-round track is on the side, a proper shortening of the safety distance does not affect the time of the turn-back process, so the shortening of the safety distance does not affect the turn-back interval of the turn-back after the station.

In summary, the shortening of the safety distance will reduce the turn-back capacity to a certain extent for the direct turn-back before the station; the turn-back capacity for the side-stop turn-back before the station and the turn-back after the station will not make an impact.

## 3. Structure and Function of Software

### 3.1. Composition

The software uses Visual Studio 2013 as the development environment, combined with the Access 2010 database software, and uses ODBC technology to realize the interactive operation of the data for both. C++ is selected as the programming language for it is commonly used in the preparation of interlocking interfaces. The entire software is divided into a user operation layer and a data storage layer[10]. It has the identification of various typical turn-back stations, the calculation of safety distances, and calculating the turn-back capabilities with different turn-back methods and

length of safety distances. Software structure is shown in Figure 5.

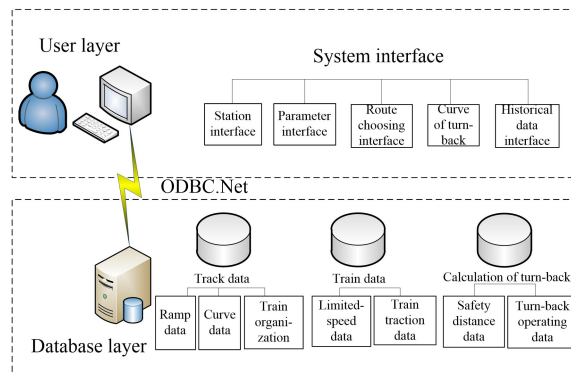


Figure 5: Structure of software.

### 3.2. Function Implementation

According to the functional design in Section 3.1, the functional diagram of the software is shown in Figure 6.

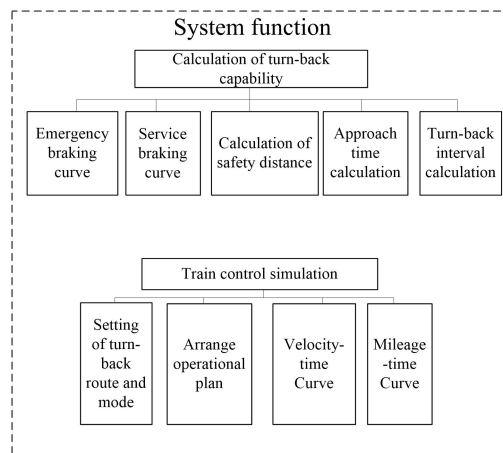


Figure 6: Functional diagram of software.

The entire software flow can be roughly described as the process of traction calculation for each segment of turn-back process. According to the type of turn-back station input by the user and the selection of the turn-back mode, the software internally searches for the route corresponding to the selected mode according to the station, stores the route number in order, and issues a departure instruction again. The train calculates the traction of the corresponding route according to the turn-back operation plan, and completes the calculation of the safety distance. Compared with the safety distance designed on site, if the calculation result is longer than the on-site value, the setting safety distance cannot guarantee operation safety, otherwise it means that the currently set safety distance design has an optimized margin. As entering the station at the maximum speed, user could get simulation result this time is the optimal safety distance. In multiple simulations, the relationship between the safety distance and the turn-back capacity can be obtained by changing the parameters which could affect the turn-back capacity (braking rate or limited speed limit); and the user can obtain the velocity-mileage curve chart and history of the safety distance simulation record according to their requirements. The software flow chart is shown in Figure 7.



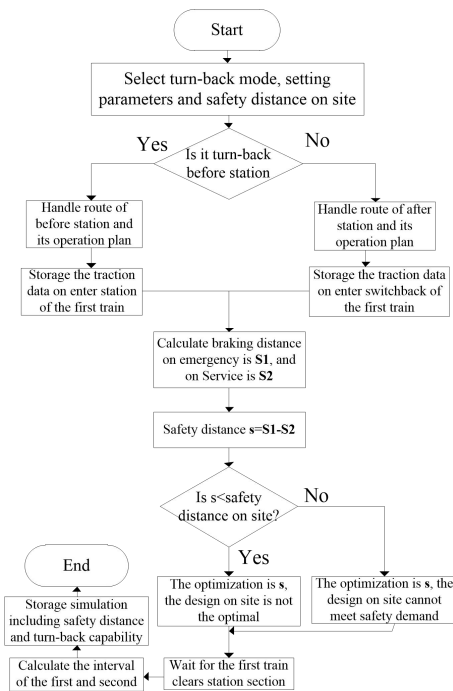


Figure 7: Flow chart of software.

## 4. Simulation

### 4.1. Simulation Station and Parameters

Take Dahe station of Fuzhou airport line as an example in experiment. Dahe station is a typical turn-back station. The software interface of the station is shown in Figure 8. The turn-round track adopts No. 12 switch, and the side speed limit of turnout is 50km/h. When calculating the turn-back capacity, a little margin should be considered, Therefore, the driving speed is calculated as 45km/h. At present, the safety distance of its turn-round track is set as 55 meters. The trains expected to be put into operation are the 6-section-marshalling and Type A locomotives. Table 1 lists the data of track and parameters of train in the station required for traction calculation.

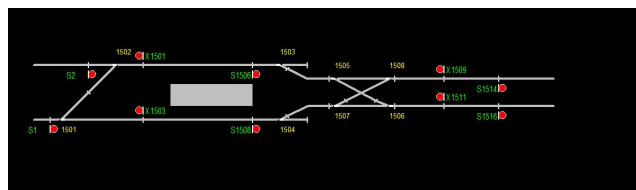


Figure 8: Software interface of Dahe station.



Table 1: The track data of Dahe station and vehicle parameters.

Parameter(unit)	Value
Slope(%)	1
Radius of curve(m)	1500
Tunnel length(m)	0
Speed limit(km/h)	80
Total train mass(T)	335.4
Train length(m)	140
Train resistance parameter <sup>a</sup>	2.7551
Train resistance parameter <sup>b</sup>	0
Train resistance parameter <sup>c</sup>	0.004286

In order to conduct multiple simulations and analyze the relationship between safety distance and turn-back capacity, the software sets user-defined dynamic parameters, which are shown in Table 2. The entering speed and braking rate are the key independent variables to research the relationship between them.

Table 2: Dynamic parameters to simulation.

Parameter(unit)	Value
Stop time (s)	40
Authorization switching time(s)	5
Route handling time(s)	13
Arrival/turn-back speed(km/h)	60
Braking ratio of train(m/s <sup>2</sup> )	1.2

## 4.2. Simulation Results

According to the specification and actual operation requirements, as well as the variables involved in the model, the optimal safety distance should give consideration to the turn-back capacity and driving safety, the braking distance should not exceed the length provided by the safety distance, and the turn-back capacity should not be less than 30 pairs per hour. According to the type of station, it can be divided into direct or lateral direction to the turn-round track, and the calculated results are shown in Table 3 and table 4(All the results has been rounded up to an integer).

Table 3: Result of direct direction to the turn-round track.

Arrival speed/(km/h)	Arrival braking rate/(m/s <sup>2</sup> )	Safety distance /m	Turn-back capacity /(pair /h)
60	1.2	41	29
70	1.2	55	29
80	1.2	73	30
60	1.1	43	29
60	1.0	46	29
60	0.8	49	28

Table 4: Result of side direction to the turn-round track.

Arrival speed/(km/h)	Arrival braking rate/(m/s <sup>2</sup> )	Safety distance /m	Turn-back capacity /(pair /h)
50	1.2	31	28
40	1.2	20	26
30	1.2	11	26
40	1.1	23	25
40	1.0	26	25
40	0.8	29	24

It can be seen from the simulation results that when the limited speed decreases and the braking rate increases, the safety distance decreases, and the effect of pit stop speed is greater than the braking rate. According to the operating standards of Fuzhou airport line and considering the maximum limited speed, 49 meters should be selected as the optimal safety distance in case of the decrease of the maximum reduction of the acceptance turn-back capacity. This not only guarantees operation safety and efficiency, but also saves construction costs.

## 5. Conclusions

The safety distance of suburban railway turn-round track simulation software based on Visual Studio development environment, according to the qualitative relationship between the safety distance and turn-back capacity, taking the speed and braking rate as variables, considering the actual operation requirements comprehensively, taking into account the train operation safety and turn-back capacity, therefore the calculation model of safety distance is established, then the simulation software suitable for the design of safe distance of turn-back line of regional railway is developed. The simulation software takes Dahe station as an example to simulate the safety distance and turn-back capacity. The simulation results are accurate and reliable. It has a good reference value for the future construction of suburban railway and urban rail transit.

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