Method for Identifying Global Structural Risk Bottleneck of Regional Rail Transit Based on Sensitivity Analysis

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Abstract. The characteristics of multi-standard rail transit systems coexistence of regional rail transit increase the risk probability of rail transit network. At the same time, the interaction between multi-standard systems and the integrity of the rail transit network increase the risk impact area and the risk consequences. Therefore, the risk bottleneck identification for regional rail transit is of great significance to realize targeted protection and optimization of key risk points and effectively reduce the global risk of the transportation system. In view of the fact that the existing risk assessment methods of rail transit network mostly use index fusion, which cannot reflect the global structural risk and cannot effectively evaluate the global risk bottlenecks of the rail transit network, this paper proposes a method for identifying global structural risk bottlenecks of regional rail transit based on sensitivity analysis. First, an assessment index for the global structural risk of the rail transit network is established, and then sensitivity analysis is used to assess the impact of the failure and optimization of station or section on the global structural risk of the rail transit network, so as to provide decision support for the protection and optimization of the rail transit network risk bottlenecks. Finally, the regional rail transit in Chengdu-Chongqing area is taken as an example to verify the effectiveness of the method.

1. Introduction
Regional rail transit refers to a comprehensive rail transit system that is formed to meet the needs of regional economic integration and includes a variety of rail transit systems such as high-speed railway, intercity railway, monorail, and subway. With the rapid development of the regional economy and the formation of urban circles, regional rail transit is facing the development requirements of more safety, more efficiency and more comfort, embodying the characteristics of heterogeneity, integrity, interaction and synergy.

The multi-standard systems coexistence of regional rail transit has increased the convenience of residents, but also brought more risks. At the same time, the interaction between multi-standard systems and the integrity of the rail transit network have increased the risk impact area and the risk consequences. Therefore, the identification of risk bottlenecks is of great significance to the realization of targeted protection and optimization of key risk points in regional rail transit systems, and to effectively reduce the global risks. However, many existing related researches on global risk assessment of rail transit network use the method of index fusion. Although it is possible to evaluate and rank risk factors, because it contains more subjective factors, it cannot reflect the global structural risk.
risk from the perspective of transport capacity, and it cannot effectively evaluate the global risk bottleneck of the rail transit network. Each part in the rail transit network has different impacts on the global risk of the rail transit network. The failure of some parts will greatly increase the rail transit network risk, and the optimization of some parts will greatly reduce the rail transit network risk. Based on the assessment of the global structural risk of the rail transit network, this paper uses sensitivity analysis to evaluate the impact of the failure and optimization of station or section on the global structural risk of the rail transit network, so as to provide decision support for the protection and optimization of rail transit network risk bottlenecks. The main contributions of this paper are as follows:

1) A method for assessing global structural risk of regional rail transit is proposed: Based on the global transport capacity risk (not the global structural risk) assessment of regional rail transit, the optimal passenger flow assignment is used to eliminate the impact of non-structural factors on the global transport capacity risk of rail transit network, thereby assessing the effect of the rail transit network structure on the global transport capacity risk.

2) Sensitivity analysis is introduced to the identification of risk bottlenecks: Through two types of sensitivity analysis, the impact of optimization and failure of key parts on the global structural risk of rail transit network was evaluated, and the identification of the global structural risk bottleneck of rail transit network was realized.

2. Related Works
At present, there are many literatures on the global risk assessment of rail transit. Most of them analyze the rail transit risk factors from multiple levels and perspectives and evaluate the global rail transit risk through index fusion. For example: Literature [1] used the improved DS / AHP method to identify and evaluate the danger sources of urban rail transit and determined the order of different danger sources. Literature [2], from the perspective of system engineering, based on a comprehensive analysis of urban rail transit operation risk factors, combined with fuzzy analytic hierarchy process, established an evaluation model for urban rail transit operation risk factors. Reference [3] established a multi-factor comprehensive safety assessment model of urban rail transit networked operation based on extension theory, divided the safety risk factors affecting urban rail transit networked operation into five categories, and established a comprehensive safety risk assessment index system for networked operations. Reference [4] based on the rail transit network topology structure, taking system functions and passenger flow as the main line, by constructing a dynamic and weighted rail transit network model and transportation network model for urban rail transit, analyzed the risk of network operation of urban rail transit from different aspects such as heterogeneity, vulnerability, connectivity, and passenger flow distribution. These literatures analyze risks from multiple aspects and can assess multiple aspects of rail transit network risks. However, some methods are greatly affected by subjective factors, and most methods do not take the transport capacity risk of rail transit network as the leading factor and do not consider the relationship between transport capacity risk and single-point risk to establish a global risk assessment system, making it difficult to use a single indicator to truly assess the global risk of the rail transit network.

For the road network structural risk, the existing researches mostly focus on the assessment of road traffic structure risk. Reference [5] defined the risk and classification of the highway network structure through the vulnerability analysis of the road network, and established the evaluation index and quantitative evaluation method applicable to the highway network structure balance risk, proposed a general model for comprehensive risk assessment of highway network structure, and formed a method system for highway network structural risk analysis. Reference [6] constructed the road network structural risk measurement index from three types of measures: the basic road network non-uniformity measure, connectivity measure, and indestructibility measure. However, at present, there are few structural risk assessments of rail transit network from the perspective of transport capacity risk and OD requirements, and there are few literatures that evaluate the impact of rail transit network structure optimization on the risk, so it cannot provide sufficient support for the optimization of risk bottlenecks.
At present, there are a lot of researches on identifying the bottlenecks of rail transit network capacity. Reference [7] conducted research on the transport capacity of rail transit-related equipment and facilities, and identified equipment and facilities with weak transport capacity. Reference [8] proposed two types of bottleneck identification models based on the network components and the theory of constraints (TOC): a capacity bottleneck identification model based on the passenger flow prediction model, a service bottleneck recognition model based on capacity bottleneck identification result and comprehensively considered supply and demand evaluation indicators. Reference [9] studied static bottlenecks and dynamic bottlenecks respectively: in the analysis of static bottlenecks, a method for locating and ranking static bottlenecks based on constraint theory is proposed; in the analysis of dynamic bottlenecks, passenger flow allocation is first performed on urban rail transit networks, based on this, the bottlenecks are identified and ranked according to the expert's score or according to the urgency. Reference [10] pointed out that urban rail transit networks should separate capacity-based technology bottlenecks from service-level service bottlenecks and proposed network bottleneck identification, analysis, and resolution methods. Reference [11] first carried out an idealized network passenger flow allocation, and based on this, constructed a station dynamic bottleneck identification method based on service level and an improved line dynamic bottleneck identification method based on a passenger flow density model. However, the above research mainly focuses on bottlenecks in transport capacity itself or in one aspect of the rail transit network, and lacks a method for identifying bottlenecks in the global structural risk of the rail transit network with transport capacity as its core.

To sum up, the existing researches on the global risk assessment of rail transit mostly use the analytic hierarchy process, which evaluates the risk through the fusion of indicators, and is greatly affected by subjective factors. At present, there are few assessments of the global structural risk of the rail transit network, and few literatures assessing the impact of the optimization of the rail transit network structure on the global transport risk. In terms of risk bottleneck identification, there is little literature that combines sensitivity analysis with rail transit risk bottleneck identification.

3. Assessment Method for Global Structural Risk of Regional Rail Transit

3.1. Assessment Method for Global Transport Capacity Risk of Regional Rail Transit

Here, the “global transport capacity risk” is not the “global structural risk”, and the “global transport capacity risk” is the basis for calculating the “global structural risk". The overall risk of regional rail transit is reflected in two aspects: transport capacity risk, personnel and equipment loss risk. Transport capacity risk is determined by many factors, which will be described in detail below. Factors such as people / equipment / environment / management in stations and sections cause a single point of risk, which ultimately creates a risk of loss of personnel and equipment in the rail transit network. There is an interaction between transport capacity risk and single point risk. Single point risk will affect the transport capacity risk of the rail transit network by reducing the capacity of the stations or sections, while high transport capacity risk (which represents high passenger flow load, detailed explanation will be carried out in the following) may cause new single point risk. Since the single-point risk does not have much relationship with the global structure, for the assessment of the global structural risk, this paper will focus on the transport capacity risk and take the global transport capacity risk as the global risk indicator of rail transit network.

When the traffic capacity of the rail transit network station / section cannot meet the travel needs of passengers, it will inevitably cause congestion at the station / section, which will bring transport capacity risk. Here, the ratio of passenger flow demand to traffic capacity of rail transit network is referred to as the passenger flow demand load, as a core element for calculating transport capacity risk. With the increase of passenger flow demand load, the transport capacity risk also increases accordingly. The transport capacity risk of each station and interval can be summed to obtain the global transport capacity risk of the rail transit network. The global transport capacity risk of rail transit network is mainly related to the OD demand, the traffic capacity (which includes the impact of single-point risk) of each part of the rail transit network, and the passenger flow assignment strategy. OD demand which is constrained by the traffic capacity constraints of rail transit network, forms the passenger flow (demand) load distribution of station and section after the passenger flow assignment,
and then determines the transport capacity risk of the entire rail transit network. Based on the above ideas, the global (transport capacity) risk calculation of the rail transit network is as follows.

$$s(t) = \sum_{i=1}^{N} w_i(t) * f \left( \frac{x_i(t)}{c_i(t)} \right)$$

(1)

Here, $x_i(t)$ represents the passenger flow demand (unit: person number/hour) of station (or section) $i$ at time $t$. $c_i(t)$ represents the traffic capacity (unit: person number/hour) of station (or section) $i$ at time $t$. $x_i(t)/c_i(t)$ represents the passenger flow demand load of station (or section) $i$ at time $t$. $f(x)$ is the probability function of transport capacity risk, which is used to map the passenger flow demand load to the probability of occurrence of transport capacity risk, and $w_i(t)$ represents the transport capacity risk consequence of station (or section) $i$ at time $t$. For easy understanding, Table 1 lists the related concepts and symbols for global transport capacity risk assessment of regional rail transit.

**Table 1.** Related concepts and symbols for global transport capacity risk assessment of regional rail transit

| Concepts | Symbols | Unit | Explanation |
|----------|---------|------|-------------|
| passenger flow demand of station (or section) $i$ | $x_i(t)$ | person number/hour | the number of passengers that need pass through a station or section within a unit of time |
| traffic capacity of station (or section) $i$ | $c_i(t)$ | person number/hour | the maximum number of passengers that can safely pass through a station or section within a unit of time |
| passenger flow demand load of station (or section) $i$ | $x_i(t)/c_i(t)$ | no unit | the ratio of passenger flow demand to traffic capacity of a station or section |
| probability function of transport capacity risk | $f(x)$ | no unit | used to map the passenger flow demand load to the probability of occurrence of transport capacity risk |
| consequence of transport capacity risk of station (or section) $i$ | $w_i(t)$ | no unit | consequence of transport capacity risk of a station or section |
| transport capacity risk (i.e. passenger flow demand load risk) of station (or section) $i$ | $w_i(t) * f \left( \frac{x_i(t)}{c_i(t)} \right)$ | no unit | transport capacity risk of a station or section |
| global transport capacity risk of regional rail transit | $s(t)$ | no unit | global transport capacity risk of a regional rail transit network |
| global structural risk of regional rail transit | $s^*(t)$ | no unit | global structural risk of a regional rail transit network |

The transport capacity risk probability function $f(x)$ takes the passenger flow demand load as an input, and considers that as the passenger flow demand load increases, the risk probability should first remain low and increase slowly, and then enter a stage of rapid growth, after which the risk probability reaches a high level and quickly approaches 1. Based on the above considerations and parameter calibration, $f(x) = \frac{1}{1 + e^{ax+b}}$ is selected as the risk probability function. After a station or section has a risk, its risk consequences are related to its actual passenger flow. Here, the risk consequence value is
set to the smaller of the traffic capacity of the station / section and its passenger flow demand:

\[ w_i(t) = \min(x_i(t), q_i(t)) \]

3.2. Assessment Method for Global Structural Risk of Regional Rail Transit

The above regional rail transit global transport capacity risk is determined by three factors (as shown in Figure 1): (1) OD demand, (2) rail transit network (station / section) traffic capacity, (3) passenger flow assignment strategy. Among these factors, (1) is the external condition, (2) is the inherent structural factors in the rail transit network, and (3) are non-structure factors (dynamic dispatching strategy). To realize the global structural risk assessment of the rail transit network, the evaluation results should truly reflect the impact of the inherent structural factors of the rail transit network, so the non-structure factors need to be removed.

Based on this idea, this paper takes factor (3) as an optimization variable, and minimizes the global transport capacity risk of the rail transit network through the optimal passenger flow assignment [12], thereby removing the influence of the non-structure factor. This paper defines the minimum global transport capacity risk of the rail transit network as the global structural risk of regional rail transit, as shown in equation (2).

\[ s^*(t) = \min_{\text{passenger flow assignment}} s(t) \]  

Figure 1. Determinants of global transport capacity risk in regional rail transit network

According to Reference[12], the model for minimizing the global transport capacity risk of rail transit networks is as follows. The graph \( G(V,E) \) represents the regional rail transit network, where \( V \) is the set of all stations in the rail transit network and \( E \) is the set of all sections in the rail transit network. There are \( S \) stations and \( T \) sections in the rail transit network, \( v_i \) represents the i-th station, \( e_k \) is the k-th section, where \( i = 1, \ldots, S \) is the station number and \( k = 1, \ldots, T \) is the section number.

In this paper, the station is divided into three parts: entrance channel, transfer channel and exit channel:

\[ \sum_{i} p_{ai} + \sum_{i} p_{ib} + \sum_{i} p_{ic} \]  

Where \( v_i \) is the i-th station in the rail transit network, \( a \) is the station entrance, \( b \) is the station exit, and it is assumed that each station has only one entrance and one exit. \( c, d \) are the boarding and alighting locations of each station, that is, the platform. \( p_{ac} \) is the entrance channel from entrance \( a \) to platform \( c \) in station \( i \), \( p_{bc} \) is the exit channel from platform \( c \) to exit \( b \) in station \( i \), \( p_{cd} \) is the transfer channel from platform \( c \) to platform \( d \) in station \( i \). In order to simplify the processing, it is considered that there are only two opposite channels between each pair of endpoints in the station, and each channel in the station is independent of others.

Table 2 lists the related symbols for optimization model of global transport capacity risk.
Table 2. Related symbols for optimization model of global transport capacity risk

| Symbols | Unit | Explanation |
|---------|------|-------------|
| $q_{ij}$ | person number/hour | OD demand from station i to station j |
| $p_{ij}^m$ | no unit | the m-th simple path from station i to station j |
| $x_{ij}^m$ | person number/hour | decision variable, represents the OD demand allocated to path $p_{ij}^m$ |
| $p_{ac}^i$ | no unit | Channel from a to c in station $v_i$ |
| $q_{ac}^i$ | person number/hour | OD demand of channel $p_{ac}^i$ |
| $C_{ac}^i$ | person number/hour | capacity of channel $p_{ac}^i$ |
| $q_{k}$ | person number/hour | OD demand of section $e_k$ |
| $L_k$ | person number/hour | capacity of section $e_k$ |

$a$ is a channel or a section of rail transit network, $p$ is a simple path. If $a$ is on the path $p$, then $g(a, p)=1$, otherwise $g(a, p)=0$.

$g(a, p)$ no unit probability function of transport capacity risk

$w_{ac}^i$ no unit consequence of transport capacity risk of channel $p_{ac}^i$

$w_k$ no unit consequence of transport capacity risk of section $e_k$

Because there are many loops in the regional rail transit network, an OD demand may correspond to many feasible paths. This article only considers the first 5 shortest simple paths, and these first 5 shortest simple path is calculated by the graph tool in python. The objective function is minimizing the global transport capacity risk of the rail transit network:

$$ S = \min \left\{ \sum_{i} f \left( \frac{q_{ac}^i}{C_{ac}^i} \right) \cdot W_{ac}^i + \sum_{i} f \left( \frac{q_{ch}^i}{C_{ch}^i} \right) \cdot W_{ch}^i + \sum_{i} f \left( \frac{q_{cd}^i}{C_{cd}^i} \right) \cdot W_{cd}^i + \sum_{i} f \left( \frac{q_{k}}{L_k} \right) \cdot W_{k} \right\} $$

(3)

The constraints are:

$$ q_{ac}^i = \sum_{j} (x_{ij}^m \cdot g(p_{ac}^i, p_{ij}^m)) $$

(4)

$$ q_{ch}^i = \sum_{j} (x_{ji}^m \cdot g(p_{ch}^i, p_{ji}^m)) $$

(5)

$$ q_{cd}^i = \sum_{j,m} (x_{ij}^m \cdot g(p_{cd}^i, p_{ij}^m)) $$

(6)

$$ q_{k} = \sum_{j,m} (x_{ij}^m \cdot g(p_{k}, p_{ij}^m)) $$

(7)

$$ x_{ij}^m \geq 0 $$

(8)

$$ \sum_{m} x_{ij}^m = q_{ij} $$

(9)

(4) is used to calculate the inbound passenger flow of the station, (5) is used to calculate the outbound passenger flow of the station, (6) is used to calculate transfer passenger flow of the station, (7) is used to calculate the section passenger flow, (8) (9) represents the passenger flow assignment constraints. The model is calculated by genetic algorithm.
4. Identification Method of Structural Risk Bottlenecks in Regional Rail Transit Based on Sensitivity Analysis

The purpose of risk assessment is to understand the global risk level of the system on the one hand, and on the other hand, to identify the risk bottleneck of the system, in order to protect or optimize the key risk point. For different purposes, different methods should be used for risk identification. The first type of method addresses the need for optimization of risk bottlenecks. It is necessary to find the section or station transfer channel that reduces the global risk the most at the same level of optimization. This is the bottleneck point for safety optimization of the rail transit network, which needs to be optimized as focus. To meet the needs of the risk bottleneck point protection, it is necessary to find the section or the station transfer channel that increases the global risk the most under the condition of channel failure, which is the bottleneck point for safety protection of the rail transit network and requires focused protection.

4.1. The First Type of Sensitivity Analysis: Optimization Sensitivity

After taking optimization measures to improve the traffic capacity of the rail transit network structure, global structural risk of the rail transit network will change; and after different rail transit network structures have been equally optimized, the reduction degree of the global structural risk of rail transit network will differ. Partial derivative of the global structural risk of rail transit network to the traffic capacity of each channel is used to calculate the optimization sensitivity of each channel:

$$\alpha_{cd}^{iv} = \frac{\partial S}{\partial C_{cd}}$$

Where $S$ is the global structural risk of the rail transit network, $\alpha_{cd}^{iv}$ is the optimization sensitivity of channel $p_{cd}^{iv}$, and $C_{cd}^{iv}$ is the traffic capacity of channel $p_{cd}^{iv}$. The channel optimization sensitivity can intuitively show the reduction of the global structural risk of the rail transit network after the traffic capacity of this channel is improved.

This paper uses the difference method to solve this partial derivative in the calculation:

$$\alpha_{cd}^{iv} = \frac{S(C_{cd} + \Delta C_{cd}) - S(C_{cd})}{\Delta C_{cd}}$$

Where $\Delta C_{cd}$ is a small change in $C_{cd}^{iv}$. In this paper, $\Delta C_{cd}^{iv}$ is taken as one tenth of $C_{cd}^{iv}$.

4.2. The Second Type of Sensitivity Analysis: Failure Sensitivity

When a station channel in the rail transit network fails, the rail transit network will redistribute passenger flow. At this time, the global structural risk of the rail transit network is recalculated, and the ratio of the global structural risk of the rail transit network after and before the change of the channel capacity is used to measure the impact of channel failure on the global structural risk of rail transit network. Due to the failure of some channels, some places will not be accessible. Considering that there is a certain capacity of non-rail transit, this paper adjusts the capacity of these channels to a smaller value (rather than set to 0), so as to avoid the infinite situation in the calculation.

$$\beta_{cd}^{iv} = \frac{S}{S'}$$

Where $\beta_{cd}^{iv}$ is the failure sensitivity of the channel $p_{cd}^{iv}$, $S'$ is the global structural risk of the rail transit network after the capacity changes, and $S$ is the global structural risk of the rail transit network before the capacity changes.

5. Case Study

The data source in the case study is from “Chongqing Rail Transit Group's official website”[13], and the “Chongqing Urban District Transportation Development Annual Report 2018”, which was
5.1. Scenario and Data Sets
This paper uses the regional rail transit in Chengdu-Chongqing area as an example to conduct an example study. Figure 2 is the topological diagram of Chongqing regional rail transit lines. Only the departure station, terminal station and transfer station of each line of regional rail transit are retained. In total, there are 10 lines, 42 stations, 55 sections, 63 entrance channels, 63 exit channels, 56 transfer channels and four kinds of rail transit systems, which are high-speed railway, intercity railway, monorail, and subway. The following content mainly provides OD demand data and data used to calculate the rail transit network flow.

1) Calculation basis for station traffic capacity
In this paper, the stations are divided into three types: large station, medium station and small station. The division basis of this paper is as follows: according to the line planning of Chongqing rail transit stations, the stations with three or more lines are large stations, the stations with two lines are medium stations, and the rest are small stations. The capacity of the channels of the three type stations is shown in Table 3.

| Type of Channel                  | Type of Station | Large Station | Medium Station | Small Station |
|----------------------------------|-----------------|---------------|----------------|--------------|
| Entrance channel capacity        |                 | 12800         | 9600           | 6400         |
| Exit channel capacity            |                 | 12800         | 9600           | 6400         |
| Transfer channel capacity        |                 | 9600          | 6400           | none         |

2) Calculation basis for section traffic capacity
According to literature[12], the transport capacity of each line in the rail transit network is obtained by the type of train, the maximum number of trains, and the minimum departure interval of each line. Information on Chongqing rail transit lines is shown in Table 4. According to the data, the Chengdu-Chongqing passenger train model is CRH380D, the number of seats is 1328, the departure interval is
20min, the Yuwan railway train model is CRH2A, the number of seats is 623, and the departure interval is 50min.

Table 4. Chongqing rail transit line data

| Line   | Train Type | Number of Trains | Capacity | Minimum Departure Interval |
|--------|------------|------------------|----------|---------------------------|
| Line 1 | Subway B   | 6                | 1440     | 3min10s                   |
| Line 2 | Straddle   | 6                | 1320     | 3min                      |
| Line 3 | Straddle   | 8                | 1760     | 2min30s                   |
| Line 4 | Subway As  | 6                | 2322     | 10min                     |
| Line 5 | Subway As  | 6                | 2322     | 8min                      |
| Line 6 | Subway B   | 6                | 1440     | 3min30s                   |
| Line 10| Subway As  | 6                | 2322     | 4min                      |
| Line loop| Subway As | 6                | 2322     | 6min                      |

3) OD demand data
The typical OD demands of Chengdu-Chongqing regional rail transit is shown in Table 5.

Table 5. OD demand

| NUM | Origin          | Destination          | OD Demand(persons/hour) |
|-----|-----------------|----------------------|-------------------------|
| 1   | ShaPingBa       | JianYangNan          | 4800                    |
| 2   | JiaoChangKou    | ZiZhongBei           | 3600                    |
| 3   | JianYangNan     | ShaPingBa            | 4800                    |
| 4   | ZiZhongBei      | JiaoChangKou         | 3600                    |
| 5   | RanJiaBa        | WanZhouBei           | 3600                    |
| 6   | WuLiDian        | ChangShouBei         | 2400                    |
| 7   | WanZhouBei      | RanJiaBa             | 3600                    |
| 8   | ChangShouBei    | DaPing               | 2400                    |
| 9   | JianDingPo      | XiaoShiZi            | 10310                   |
| 10  | JiaoChangKou    | JianDingPo           | 8184                    |
| 11  | YuDong          | Jiangbei Airport T2  | 16156                   |
| 12  | YueLai          | SiGongLi             | 13842                   |
| 13  | SiGongLi        | ShaPingBa            | 7164                    |
| 14  | Chongqing       | JiaoChangKou         | 6504                    |
| 15  | XiaoShiZi       | YuDong               | 4662                    |
| 16  | YuDong          | JiaoChangKou         | 5004                    |
| 17  | HaiXiaLu        | HongQiHeGou          | 13334                   |

5.2. Calculation Process
Based on the traffic capacity and OD requirements of rail transit network, this paper uses the optimal passenger flow assignment method in reference[12] to remove the impact of passenger flow assignment on the global risk calculation of the rail transit network, thereby obtaining the global structural risk calculation result of the rail transit network. The value of the global structural risk in this paper is the sum of the risks of all entrance channels, exit channels, transfer channels, and sections in the rail transit network under the optimal passenger flow assignment. When solving the second type of sensitivity, the channel capacity after the failure is taken as one tenth of the original channel capacity. After each change of the channel capacity, the optimal passenger flow assignment method will be used to distribute passenger flow and the optimal passenger flow assignment problem is solved by genetic algorithm(GA). The setting parameters of genetic algorithm in this paper are: the number of
iterations is 1500 and the population size is 2000. The calculation flowchart is shown in Figure 3. The parameters used in the calculation are shown in Table 6.

Table 6. Related parameters

| Parameters | Description |
|------------|-------------|
| Traffic Capacity | Traffic capacity in channels and sections |
| OD Demand | 17 typical OD demands |
| Number of OD paths | Consider 5 shortest paths per OD |
| Difference method variable | The small change in the channel traffic capacity used by the difference method to solve the partial derivative is one tenth of the original capacity |
| Traffic capacity after failure | Traffic capacity after channel failure, the value is one tenth of the original traffic capacity |
| Genetic algorithm parameters | 1500 iterations, 2000 population size |

Figure 3. Calculation flowchart

5.3. Result Analysis

Two types of sensitivity analysis are performed on the transfer channels in the rail transit network, and the optimization sensitivity and failure sensitivity of each transfer channel are obtained. The top ten transfer channels with the most influence are shown in Table 7 and Table 8.

Table 7. Optimization sensitivity

| Num | Station | Transfer Channel | Optimization Sensitivity |
|-----|---------|------------------|--------------------------|
| 1   | Chongqing North Station South Square | Line 3-Line loop | -12.295 |
| 2   | HongQiHeGou | Line 3-Line 6 | -8.014 |
| 3   | Chongqing North Station North Square | intercity railway - Line4 | -6.711 |
| 4   | Chongqing North Station South Square | Line 3-Line 10 | -6.112 |
| 5   | WuLiDian | Line loop-Line 6 | -5.368 |
| 6   | ShangXin Street | Line 6-Line loop | -3.267 |
| 7   | DaPing | Line 2-Line 1 | -3.243 |
| 8   | Chongqing North Station North Square | intercity railway -Line 10 | -1.923 |
| 9   | MinAn Avenue | Line loop-Line 4 | -1.875 |
| 10  | Chongqing North Station South Square | Line 10-Line 3 | -1.272 |

The optimization sensitivity indicates the degree of change in the global structural risk of the rail transit network with the increase of the capacity of a channel (negative values indicate reduced risk). The smaller the value (that is, the greater the absolute value), the greater the contribution of the corresponding channel's optimization to reducing the global structural risk.
Table 8. Failure sensitivity

| Num | Station                                      | Transfer Channel               | Failure Sensitivity |
|-----|----------------------------------------------|--------------------------------|---------------------|
| 1   | Chongqing North Station South Square Line 3-Line 10 |                                | 1.353               |
| 2   | MinAn Avenue Line loop-Line 4                |                                | 1.178               |
| 3   | Chongqing North Station North Square Line 10-high-speed railway |                      | 1.158               |
| 4   | XiaoShiZi Line 6                           |                                | 1.155               |
| 5   | ShangXin Street Line loop-Line 6            |                                | 1.135               |
| 6   | Chongqing North Station North Square Line 10-intercity railway-Line 10 |                       | 1.134               |
| 7   | HongQiHeGou Line 6                         |                                | 1.125               |
| 8   | Chongqing North Station North Square high-speed railway-Line 10 |                      | 1.122               |
| 9   | ShangXin Street Line 6-loop                   |                                | 1.121               |
| 10  | Chongqing North Station North Square Line 10-intercity railway |                        | 1.116               |

The failure sensitivity indicates the degree of change in the global structural risk of the rail transit network with the failure of a channel capacity (values greater than one indicate increased risk). A larger value indicates a greater contribution of the failure of the corresponding channel to the increased global structural risk.

It can be seen from the results that the transfer channel of Chongqing North Station South Square from Line 3 to Line loop needs to be optimized urgently. The transfer channel of Chongqing North Station South Square from Line 3 to Line 10 needs to be protected urgently. In addition, Chongqing North Station South Square, Chongqing North Station South Square, ShangXin Street, and HongQiHeGou all have many transfer channels of great impact on global structural risk, which require optimization or protection measures.

6. Conclusion

On the basis of constructing the global structural risk assessment index of regional rail transit, this paper evaluates the influence of the rail transit network structure optimization / failure on the global structural risk of the rail transit network through sensitivity analysis, so as to provide decision support for the optimization and protection of the important rail transit network structure. Firstly, this paper analyzes the global risk assessment system of regional rail transit, considering three factors of the risk: external conditions, rail transit network structure factors and rail transit network non-structure factors (dynamic adjustment strategy). Then, through the optimal passenger flow assignment, the non-structure factor of rail transit network is eliminated, and the global structural risk assessment index is established. Afterwards, this paper addresses two types of actual needs, and through sensitivity analysis, evaluates the impact of rail transit network structure optimization / failure on global structural risks, so as to provide decision support for the optimization and protection of important rail transit network structures. Finally, the Chengdu-Chongqing regional rail transit is taken as an example for analysis and verification, and the key station transfer channels in the Chengdu-Chongqing regional rail transit network that need to be optimized and protected are identified. The next research should consider the impact of cascading failure caused by a station/section failure on the rail transit network on the global structural risk.

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