Study on the Scheme of Three Branch Interchange

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Abstract: In cities with a "ring+radiations" road network structure, a three Branch intersection is formed at the connection between the inner ring and radiations. Common three branch interchanges include T-shaped, Y-shaped, trumpet shaped, leaf shaped, pear shaped interchanges, etc. Shenyang City plans a "two verticals and three horizontals+four rings+seventeen radiations" urban expressway network. This article takes the three-branch intersection formed by Chongshan Road, Tawan Street, and Yuanjiang Street in Shenyang City as an example to analyze its traffic characteristics and predict traffic demand. Based on this, three interchange selection schemes are proposed, and recommended schemes are obtained through multi angle comparison. This article provides ideas for the selection of three branch interchanges. In addition, because this project is located in the built-up area and the surrounding land is tight, this article also explores the problems and solutions of the overpass renovation in the built-up area, providing reference for similar projects.

Keywords: Interchange Selection; Three-Branch Interchange; Road Reconstruction; Urban Expressway Nodes; Urban Transport

1. Introduction

Three branch interchanges can be divided into T-shaped, Y-shaped, trumpet-shaped, leaf-shaped, and pear-shaped interchanges, etc. according to the shape. Among them, T-shaped and Y-shaped interchanges are often used in hub interchanges and general interchanges with large turning traffic volume. Y-shaped interchanges require separation of the main line, occupy more land, have short left turn ramps, strong evacuation capacity, and higher cost; T-shaped interchanges do not require separation of the main line, occupy less land, slightly more ramp land, long left turn ramps, slightly worse evacuation capacity than Y-shaped interchanges, and lower cost[1].

Trumpet-shaped, leaf-shaped, and pear-shaped interchanges are often suitable for general interchanges. Trumpet-shaped interchanges have a simple plane form, low cost, suitable for setting up a centralized toll station, and the traffic volume of the circular ramp in the interchange is low; leaf-shaped interchanges are suitable for general interchanges with small left turn traffic and can be extended to become all cloverleaf interchanges in the long term; pear-shaped interchanges are suitable for general interchanges with equivalent left turn traffic and limited main line side land[2-3].

Interchanges, according to the crossing form of traffic flow lines, can be divided into fully interchangeable interchanges and planar intersection type interchanges. Fully interchangeable interchanges have a three-dimensional crossing between all traffic flow lines, and the above T-shaped, Y-shaped, trumpet-shaped, leaf-shaped, and pear-shaped interchanges are all fully interchangeable interchanges. In practice, due to actual conditions or because some turning traffic is small, some directions are connected through ground signal intersections, forming a planar intersection type interchange. Engineers have accumulated a lot of experience in interchange selection based on project characteristics[4-10].

By summarizing the “ring+radiations” road network structure of cities in China, we can find that, the three branch interchanges formed at the connection between the inner ring and the radiations have different traffic characteristics and surrounding conditions, and their selection covers various forms of interchanges, which have also derived some forms of variation. In addition, in the selection of interchanges in cities, while considering the connection method of the main road, it is also necessary to consider the connection method

of the auxiliary road and the requirements of the slow traffic system. For example, the Yuxi Road interchange in Hefei City forms a Y-shaped interchange with the main road of the East First Ring Road, the main road of the South First Ring Road, and the elevated Yuxi Road, achieving rapid connection of the main line. The ground auxiliary road forms a light controlled intersection, as shown in Figure 1; while, in the interchange between East First Ring Road and Changqing Street in Shenyang city, Changqing Street viaduct is only connected to the northern section of the East First Ring by a ramp, and turns through a ground signalized intersection with the southern section of the East First Ring, forming a planar intersection type interchange, as shown in Figure 2; the connection of Beijing North Second Ring and Xizhimen North Street is relatively special, the main road and auxiliary road of Xizhimen North Street cannot directly connect with the northern section of the North Second Ring, and needs to be directional converted through the southern Xizhimen interchange, as shown in Figure 3.

Figure 1. Yuxi Road Interchange in Hefei City

Figure 2. The Interchange between East First Ring Road and Changqing Street in Shenyang City

Figure 3. The Interchange between Beijing North Second Ring Road and Xizhimen North Street in Beijing

2 Project Overview

Shenyang city plans to establish a "two verticals and three horizontals+four rings+seventeen radiations" urban expressway network. Currently, the urban expressway network framework has been basically built, but some sections and nodes have not yet been planned. The project we discuss is located at the intersection of Northwest First Ring Road (Chongshan Road, Tawan Street) and Northwest Radiation (Yuanjiang Street). The project is of great significance as it connects to the rapid North First Ring Road to the east, extends to the West First Ring Road to the south, forms a new radial fast track to the northwest, and extends to the Northwest Second and Third Ring Roads. The geographical location of the project is shown in Figure 4.

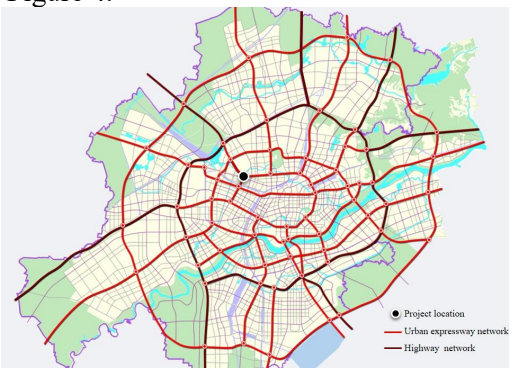

Figure 4. The Geographical Location of the Project

2.1 Analysis of the current situation of the project

The Chongshan East Road and Chongshan Middle Road are rapid roads. The main line of

Chongshan Middle Road is designed at a speed of 60km/h, with 5-6 lanes in both directions. The ground auxiliary road is designed at a speed of 50km/h, with 8 lanes in both directions. Chongshan West Road (Nujiang Street Tawan Street) is currently an urban main road with a design speed of 60km/h. The current section is a two lane road with ten lanes in both directions, and the outermost side is a bus lane with a red line width of 60m.

The current situation of Tawan Street is an urban main road with a design speed of 60km/h. The current section of Tawan Street (south of Chongshan Road) is in the form of a single road, with ten lanes in both directions and a central dividing guardrail. The slow traffic system is a pedestrian non shared board, and the width of the red line is 50m.

Yuanjiang Street (west of Xianggong Street) is currently a highway with a design speed of 60km/h, a two-way four lane road, and a slow traffic system with hard shoulders on both sides. The width of the red line is 40m. Yuanjiang Street (Jinshui North Street Xianggong Street) is currently in the form of a single road, with a road width of 6m. At present, Yuanjiang Street is a dead end road on the east side of Jinshui North Street and is not connected to Tawan Street.

Chongshan Road, Tawan Street, and Yuanjiang Street are planned as urban expressways. Chongshan Road and Tawan Street are part of the First Ring Road, while Yuanjiang Street serves as the northwest radiation. Currently, Chongshan West Road, Tawan Street, and Yuanjiang Street have not been planned.

The surrounding Huanggutun, Tawan, and Minglian areas of the project are mainly residential land, with a small amount of commercial and educational land. The construction land in the Korean and Dingxiang areas radiating northwest from Yuanjiang Street is mainly residential land.

2.2 Engineering control conditions

The main restrictive factors of this project involve land conditions, rail transit, and rivers, as shown in Figure 5.

(1) The area around the intersection where the project is located is all built-up areas, making demolition difficult. Currently, the red line only considers planar intersections, and the land conditions for interchange renovation are extremely limited.

(2) Chongshan Road and Tawan Street are not orthogonal and intersect at an angle of about 65 °, which is not conducive to ramp layout.

(3) Part of the subway line 10 is arranged along Chongshan Road, and the project is located adjacent to the section of line 10 and Tawanjie Station (integrated development), which has an impact on the layout of bridge piers.

(4) The north side of the project is the Xinkai River, which is not conducive to the layout of bridge piers. The Xinkai River is a manually excavated irrigation canal with a total length of about 27km and a width of 30-25m. Currently, there is a a river crossing bridge on Tawan Street.

Figure 5. Analysis of Engineering Construction Conditions

3 Traffic prediction and functional positioning

3.1 Current Traffic Analysis

Conduct a survey on the travel characteristics and operational status of the traffic system in the surrounding area of the project, and analyze the current traffic characteristics, we can find that:

(1) The expressway network is not fully formed and the traffic capacity is not matched. For the perspective of the expressway network, currently the rapid development of Chongshan Road in the North First Ring Road is only implemented to Changjiang Street. After the main road of Chongshan Road crosses Changjiang Street and lands, the main and auxiliary roads mix, and the expressway directly connects to the main road. In addition, the one-way traffic volume during peak hours of the road section is close to 4000 pcu/h, resulting in mismatched traffic capacity. The transit traffic for long-distance travel cannot be separated from the arrival traffic developed in the surrounding area, which is prone to

congestion.

In the "Ring+radiations" type expressway network structure, the number and spacing of rays determine the ability of the inner ring traffic to connect with the outside. At present, only the main road in the northwest direction is connected to the outside, resulting in severe congestion on the main roads entering and exiting the city during peak hours, and there is an urgent need for expressways to connect to the outside.

(2) East and south directions are the main traffic directions. For this intersection, due to the current nature of land use and road network connectivity in the northern part of the node, the Tawan Street (north of Chongshan Road) section mainly serves the surrounding communities and parks along the Xinkai River, with relatively low traffic demand. Therefore, the traffic volume at the north entrance and north exit of the intersection is relatively small. The main traffic directions are the right turn from Chongshan Road east to south and the left turn from Tawan Street south to east, accounting for about 80% of the total traffic volume at the intersection.

(3) Poor road network connectivity and high pressure on surrounding road networks. At present, due to the fact that Yuanjiang Street has not yet been planned and is not connected to Tawan Street, vehicles can only detour Kunshan West Road and Xianggong Street, causing excessive traffic pressure on the surrounding road network during morning and evening rush hours, and serious congestion at intersections.

3.2 Traffic Demand Prediction

The four stage method was used for traffic prediction, and the results are shown in Figure 6. Based on the traffic prediction results, the following conclusions can be analyzed:

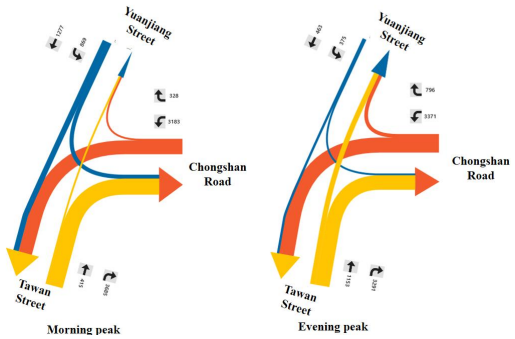

Figure 6 Traffic Volume Prediction Results (Unit: pcu/h)

(1) The first ring road is the main traffic direction. In the node area of this project, the mutual conversion traffic between the North First Ring Road and the West First Ring Road is the maximum traffic volume. There are obvious tidal characteristics in the traffic between the Northwest Radiation and the First Ring Road, and the traffic demand between the Northwest Radiation and the West First Ring Road is slightly higher than that with the North First Ring Road.

(2) The new channel brings a larger scale of transfer traffic volume. With the construction of the road network, especially the backbone expressway network, it will have a significant impact on traffic flow distribution. Due to the connection between Yuanjiang Street and Tawan Street, it provides a convenient passage between the residential area in the northwest area and the first ring road, bringing about a large scale of transfer traffic volume. After the traffic flow is redistributed, it effectively alleviates the pressure on the surrounding road network during morning and evening peak hours.

4 Research on Interchange Scheme

The interchange scheme should comprehensively consider factors such as urban road network planning, intersection road properties, land use control conditions, underground structures, surrounding buildings, and landscape effects. While meeting functional requirements, the interchange form should be simplified as much as possible, the number of interchange floors should be reduced, demolition land occupation should be reduced, and project investment should be saved. At the same time, a reasonable selection of interchange structure should be made, fully considering the location of rail transit stations and sections, to ensure the feasibility of the plan. Based on the above principles, we compare and select interchange schemes.

4.1 The Interchange Scheme A

According to the traffic prediction results, Chongshan Road and Tawan Street, as part of the first ring expressway in the city, have the most important traffic volume from east to south and from south to east. Although the land conditions in the southeast quadrant are tight, the two-way connection between the two directions is still completed according to the

design standards of the "main line", to ensure the rapid and smooth flow of the main traffic direction, avoid the formation of new bottlenecks and congestion points in the expressway renovation.

According to the traffic characteristics, there are obvious tidal features in the traffic between the northwest radiation and the first ring road. In terms of ramp setting, it is considered to add two ramps for bidirectional connection between the northwest radiation and the West First Ring Road. However, due to the overall traffic pressure of the North First Ring Road being greater than that of the West First Ring Road, especially the high traffic pressure on Chongshan Middle Road and Chongshan East Road, it is not recommended to directly enter the main road of the North First Ring Road on a large scale during morning peak hours; During the evening rush hour, in order to alleviate the traffic pressure on the first ring road, it is recommended that vehicles quickly exit the first ring road and head towards various radiation directions, reflecting the overall design concept of "fast exit and slow entry" between the peripheral area and the first ring road. Therefore, it is recommended to increase ramps in the east-north direction, and no longer set up separate ramps in the east-north direction. Turning can be achieved through ground level intersections; To avoid a large amount of traffic entering the West First Ring Road in the short term during morning rush hours, one lane merges into the North South direction. Therefore, the selection of interchange in scheme A is a partial-connect interchange, as shown in Figure 7.

Figure 7 Interchange Scheme A

Considering the impact of existing buildings in the surrounding area, while meeting traffic needs, efforts should be made to avoid or reduce demolition. In Scheme A, due to the obtuse angle between the "east" and "south" directions, which is conducive to the layout of the line, "east" and "south" are the main connecting directions. Therefore, the design speed of "east" and "south" is 60km/h, which is consistent with the accelerated part of Chongshan Road to avoid congestion caused by local speed limits; The sharp angle between the "east" and "north" directions is not conducive to the layout of the ramp, in order to avoid the impact of the ramp on the current residential buildings in the northeast quadrant. The design scheme has been adjusted and optimized, reducing the design speed of the east to north ramp from 40km/h to 25km/h and reducing the turning radius to 35m.

For the interchange level, Chongshan Road and Tawan Street auxiliary road are located on the ground level; An elevated bridge is set up on the main roads of Chongshan Road and Tawan Street, located on the second floor. At the same time, the east to north ramp (Ramp A) and the north to south ramp (Ramp B) are located on the second floor; The south to north ramp (Ramp C), located on the third floor, crosses the elevated main roads of Chongshan Road and Tawan Street.

4.2 The Interchange Scheme B

Considering the connection between Yuanjiang Street and Shenying Expressway will greatly enhance the connection between the northwest radiation and the West First Ring Road. Therefore, in scheme B, the north-south direction will be designed as the main line, and based on the transportation concept of "fast exit and slow entry", ramps will no longer be separately arranged from north to east. Vehicles will complete the left turn in the north east direction through the ground auxiliary road to avoid excessive pressure on the peak of the North First Ring Road from west to east. Therefore, the selection of interchange in scheme B is a partial-connect interchange, as shown in Figure 8.

Considering the good shape of the north-south and north-south lines, and the future connection between Yuanjiang Street and Shenying Expressway, the radial line will bear a significant increase in traffic volume. Therefore, the design speed for north-south and north-south directions is 60km/h. The design speed of the east-west south and south-west east ramps is 40km/h, while considering

avoiding the demolition of residential buildings in the northeast quadrant, reducing the linear indicators, turning radius, and design speed, the east to north ramp adopts a speed of 25km/h.

Figure 8 Interchange Scheme B

For the interchange level, Chongshan Road and Tawan Street auxiliary road are located on the ground level; An elevated bridge is set up on the main roads of Chongshan Road and Tawan Street, located on the second floor. At the same time, the east to north ramp (Ramp A), the east to south ramp (Ramp B), and the south to east ramp (Ramp C) are located on the second floor, too; The main line from south to north and from north to south is located on the third floor, crossing ramps of Chongshan Road and Tawan Street.

4.3 The Interchange Scheme C

Considering the connection between Yuanjiang Street and Shenying Expressway in the planning, and the significant enhancement of the connection between Chongshan Road，Tawan Street, and the northwest radiating Yuanjiang Street, scheme C is designed as a complete interchange, connecting Chongshan Road, Tawan Street, and Yuanjiang Street through ramps to form a Y-shaped interchange, as shown in Figure 9.

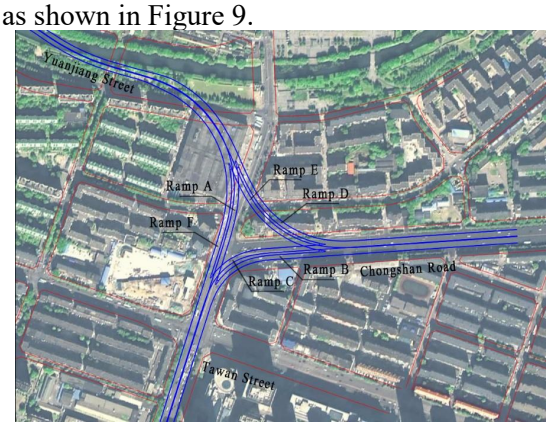

Figure 9 Interchange Scheme C

This scheme takes into account the strongest evacuation capability and strives to maintain a smooth line shape in all directions. The design speed of ramps in all directions is 40-60km/h, and the minimum turning radius is 110m. This plan requires the demolition of residential buildings in the northeast quadrant and supermarkets in the northwest quadrant.

For the interchange level, Chongshan Road and Tawan Street auxiliary road are ground level roads located on the ground level; The main line of Tawan Street from south to north, the main line of Yuanjiang Street from south to north, the main line of Chongshan Road from east to west, and the south to north ramp (Ramp A)， the south to east ramp (Ramp B) are located on the second floor; The main line of Tawan Street from north to south, the main line of Yuanjiang Street from north to south, the main line of Chongshan Road from west to east, and the east to south ramp (Ramp C) , the north to south ramp (Ramp F) are located on the third floor; The east to north ramp (Ramp D) and the north to east ramp (Ramp E) connect the second and third floors.

In the above three schemes, according to traffic organization analysis, a pair of entrances and exits are set up on Chongshan Road, Yuanjiang Street, and Tashan Road respectively. Motor vehicles can enter and exit the main road through these entrances and exits. The elevated main road serves long-distance transit traffic, while the ground auxiliary road mainly serves short distance travel and surrounding land parcel arrival and departure traffic. In Scheme A and Scheme B, the turning traffic from north to east is completed by detouring the ground road. The slow traffic system can use ground lights to control crossing at intersections.

4.4 Scheme Comparison and Selection

The above three scheme are compared and selected, as shown in Table 1. Taking into account technical standards, traffic capacity, actual land conditions, and investment costs, scheme A is recommended.

Table 1 Scheme Comparison and Selection

	scheme A	scheme B	scheme C
Type of Interchange	Partial-connect Interchange	Partial-connect Interchange	Complete Interchange Y-shaped
Ramp	Lack of	Lack of	All ramps

setting	north - east ramp	north - east ramp	
Technical standards	Lower, the design speed of the east-north ramp is 25km/h	Lower, the design speed of the east-north ramp is 25km/h	Higher, ramp design speed 40-60km/h
Traffic capacity	The capacity of the east-north ramp is relatively small	The capacity of the east-north ramp is relatively small	Balanced traffic capacity in all directions
Demolition	No need	No need	The northeast quadrant housing and northwest quadrant supermarket need to be demolished
Investment	Minimum	Relatively high	Maximum

5 Summarize

In the "ring+radiations" road network, for the interchange node renovation project formed between the inner ring and the radiations, the selection and research of interchange schemes should be based on traffic characteristics analysis, and fully consider the traffic organization form of the surrounding road network, the carrying capacity of the connecting road network, etc. Finally, the appropriate interchange form should be selected based on multiple factors.

The renovation projects implemented in built-up areas, where land is tight and cannot be demolished, can be optimized as a design solution by appropriately reducing the ramp alignment indicators and reducing the design speed, while meeting transportation needs.

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