Research on Beijing Urban Rail Transit Network Based on Traffic Efficiency

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**Abstract.** The coordination between urban rail transit network and city spatial functional distribution plays an important role in the process of urbanization. This paper, based on an empirical analysis, studies the characteristics of the Beijing urban rail transit network from the perspective of time and space. Then, according to statistical analysis, a series of reasonable evaluating indicators and comparison among the typical cities in the world, we summarize the obvious problems existing in the network. At last, we draw the conclusions that the network needs improvement and we put forward six suggestions aiming to increase the transport efficiency and optimize the network layout.

**Introduction**

Beijing is in the stage of adjusting its city spatial layout to “two-axis, two-belt and multiple centers” according to The General Plan of Beijing (2004-2020). The non-capital core functional industries will be moved to suburban regions and the core-functional industries will be strengthened, aiming to achieve balanced development. With the adjustment of Beijing population and industrial distribution, the demand for transport shows new features. The key method to solve the traffic problem is to build urban transport system coordinated with the overall development plan of the city. The urban rail transit network, as the backbone network system, plays an important role in adjusting the urban development and spatial layout.

Urban rail transit is a product of the development of industrialization and urbanization at a certain stage, which mainly consists of key services with specific characteristics and the wheel-rail technology such as subway, light rail, suburban railway and so on. It is a special transportation different from the intercity rail transportation and high-speed railway. The urban rail transit uses the technology of wheel-rail. It has many advantages such as environmental protection, large capacity, and high speed which can easily meet the demand of travelers in the city.

The development of urban rail transit has a high correlation with the population agglomeration, land exploitation and spatial formation of the city. Besides, it has important economic and social influences on the development of the city. Furthermore, it can enhance the value of land comprehensive development. In recent years, Beijing urban rail transit has been entered the network era. More and more lines are being constructed or planned. Meanwhile, under the situation of adjusting Beijing spatial layout, the urban rail transit network demonstrates some new features, and will provide a more and more convenient and efficient environment for travelers.

**Literature Review**

Zhao Jian considers that there are complex interactions between urban transport and the city’s form. Specific requirements of a specific urban form are needed to be adaptive to the urban transport mode. Besides, urban transport also has the functions of guiding the development of urban form and shaping the city’s form [1]. Cao Zhong-ming and Gu Bao-nan summarized five basic network structures and properties of urban rail transit from the perspective of sustainable development, and then analyzed the impact of improvement of network structure on the urban structure in big cities of
the country [2]. ChenFeng, Liu Jin-ling and Shi Zhong-heng believe that the evolution of a city’s form is equivalent to the evolution of urban transport and integrated land use. It is the interactive development between urban transport and land use that leads to a city form [3]. Guo Qian, Wu Dian-ting and Bao Jie found that the index of Beijing transfer efficiency showed a downward trend before 2011, and then kept increasing after doing a research on the influences of changes of the network on the transfer efficiency in 8 different periods. They consider that this is due to too much emphasis on the expansion, while ignoring the efficiency [4]. Guo Qian, Wu Dian-ting and Li Rui did a research on the accessibility of Beijing rail network and drew a conclusion that the accessibility in the central areas is better than the peripheral lines due to the number of the transfer stations and the distance between stations. Besides, the high density of station and the difficulties of transferring weaken the accessibility [5]. Wang Bo, Zheng Xiao-wei and Li Shi-min showed that the level of function is the core issue of transport development model. Improving the transport network supply and demand relationship requires a combination of networks, operation optimization and so on to manage the traffic distribution comprehensively and coordinately [6]. Li Pu and Wu Zi-han have analyzed the features of the network model based on the rail transit of Beijing, Shanghai and Guangzhou [7]. Liu Zhi-qian and Song Rui used the complex network theory to analyze the impact of the reliability of rail transit network on the enhancement of accessibility and the operational efficiency. They used the space L method for modeling and analyze the node degree, clustering co-efficiency and average path length [8]. Duan Jie and Li Jiang showed that the topology level of rail transport network could act as an index of measuring the size of city and the form of space [9]. Zeng Ming-hua and Li Xia-miao studied the structure optimization of the network from the perspective of basic features of itself. Zhang Ming [10], Xu Rui-hua and Yang Ke analyzed the practical problems when the management change from single line to the network in the rail transport and then give the advice of paying more attention to the necessities of organizing and coordinating the network [11].

In summary, researches of domestic and international focused on transportation network architecture, network operations and transport efficiency and so on. Most researches on traffic network structure mainly focused on the methods and means, morphology, structure optimization, etc. However, the study of the spatial structure of urban rail transport network is relatively rare. Research on urban rail transit network operation focused on traffic and other characteristics, such as operational organization and management level, but the network level is rarely involved. There are many studies on transport efficiency, but most considered the evaluation and transport efficiency factors. The affecting factors, taking into account the spatial structure research networks and layout, are rare yet to be seen considering the construction sequence of study.

**The Situation of Beijing Urban Rail Transit Network**

Recently, with the expansion of the urban spatial scale and the adjustment of urban functions in Beijing, the management of the urban rail transit develops rapidly and shows increasing features, which offers more convenient and comfortable environment for citizens. This part will give a comprehensive discussion about the situation of Beijing urban rail transit network.

**The Level of Beijing Urban Rail Transit Network**

By the end of 2015, The Beijing urban rail transit network has 18 lines, with 554km and 287 stations, covering 11 districts. Particularly, there are 53 transfer stations, accounting for 18.5% of all the stations in the network. The basic skeleton network has already come into formation. This paper uses the line density as an indicator to measure the level of Beijing urban rail transit as Table 1.
Table 1. Indicators of Beijing urban rail transit network (2008-2015).

<table>
<thead>
<tr>
<th>Year</th>
<th>Mileage (km)</th>
<th>The line density of land (km /(10^2 \times \text{square km}))</th>
<th>The line density of population (km /(10^3 \times \text{people}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>200</td>
<td>1.22</td>
<td>1.18</td>
</tr>
<tr>
<td>2009</td>
<td>228</td>
<td>1.39</td>
<td>1.30</td>
</tr>
<tr>
<td>2010</td>
<td>336</td>
<td>2.05</td>
<td>1.71</td>
</tr>
<tr>
<td>2011</td>
<td>372</td>
<td>2.27</td>
<td>1.84</td>
</tr>
<tr>
<td>2012</td>
<td>442</td>
<td>2.69</td>
<td>2.14</td>
</tr>
<tr>
<td>2013</td>
<td>465</td>
<td>2.83</td>
<td>2.20</td>
</tr>
<tr>
<td>2014</td>
<td>527</td>
<td>3.21</td>
<td>2.45</td>
</tr>
<tr>
<td>2015</td>
<td>554</td>
<td>3.38</td>
<td>2.55</td>
</tr>
</tbody>
</table>

**The Structure of Beijing Urban Rail Transit Network**

Fig. 1 shows 3 types of line shape of Beijing rail transit network structure. The annular line runs through the four directions of the city and offers internal service for passengers, such as line 2 and line 10. The grid lines include horizontal and vertical line offers cross-region service, such as line 1 and line 4. The ray line is the branch line, which connects the central urban districts and the suburban areas.

![Figure 1. Structure of Beijing urban rail transit network.](image)

**The Operations of Beijing Urban Rail Transit Network**

With the improvement of Beijing urban rail transit network, passengers have more alternative routes to reach to their destination. The accessibility of the whole network has been increased. During the
period of 2008 to 2015, the scale of passenger traffic flow is increasing faster than that of the network scale. The total passenger traffic volume in the whole year of 2015 is up to 32.5 billion, which accounting for 44.95% in the public transport. The goal of “double 50” -green travel, i.e., public transportation accounting for 50% of the total traffic and the rail transportation accounting for 50% of the public transportation, will realize. On December 31, 2015, the passenger volume is 1194.69 million, which reaches the maximum ever and the Beijing urban rail transit network has been the busiest in the world.

**The Transport Efficiency of Beijing Urban Rail Transit Network**

Efficiency refers to the ratio of input and output. From the view of planning, construction, operation and transport efficiency respectively mean operating efficiency, passenger efficiency and cost efficiency. In this paper, transport efficiency means passenger efficiency, which equals to total passenger volume divided by operating mileage. Table 2 shows the transport efficiency of Beijing urban rail transit from 2007 to 2015.

<table>
<thead>
<tr>
<th>Year</th>
<th>Mileage (km)</th>
<th>Total passenger volume (million persons)</th>
<th>Transport efficiency (million persons/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>142</td>
<td>650</td>
<td>4.58</td>
</tr>
<tr>
<td>2008</td>
<td>200</td>
<td>1210</td>
<td>6.05</td>
</tr>
<tr>
<td>2009</td>
<td>228</td>
<td>1420</td>
<td>6.23</td>
</tr>
<tr>
<td>2010</td>
<td>336</td>
<td>1840</td>
<td>5.48</td>
</tr>
<tr>
<td>2011</td>
<td>372</td>
<td>2180</td>
<td>5.86</td>
</tr>
<tr>
<td>2012</td>
<td>442</td>
<td>2460</td>
<td>5.57</td>
</tr>
<tr>
<td>2013</td>
<td>465</td>
<td>3210</td>
<td>6.90</td>
</tr>
<tr>
<td>2014</td>
<td>527</td>
<td>3410</td>
<td>6.47</td>
</tr>
<tr>
<td>2015</td>
<td>554</td>
<td>3250</td>
<td>5.87</td>
</tr>
</tbody>
</table>

**Existing Problems of Beijing Urban Rail Transit Network**

In recent years, Beijing urban rail transit has played an important role to alleviate traffic congestion pressure and facilitate citizens to travel. However, there are some outstanding problems in the process of construction.

**Smaller Scale and Lower Degree of the Network**

According to the national practice, the operating mileage of an urban rail transit system up to 400km is the mark of entering the Network Age. However, although Beijing urban rail transit has already formed a network, the scale is smaller and the degree is lower than many famous cities in the world (table 3).
Table 3. The Degree of urban rail transit network in Typical Cities (2015).

<table>
<thead>
<tr>
<th>City</th>
<th>Operating mileage (km)</th>
<th>Population (10^6)</th>
<th>Land area (km²)</th>
<th>The line density of land (km/km²)</th>
<th>The line density of population (km/10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York</td>
<td>1056</td>
<td>840</td>
<td>789</td>
<td>1.34</td>
<td>1.26</td>
</tr>
<tr>
<td>Tokyo Metropolitan Area</td>
<td>2500</td>
<td>3800</td>
<td>13400</td>
<td>0.19</td>
<td>0.66</td>
</tr>
<tr>
<td>Seoul</td>
<td>597</td>
<td>1053</td>
<td>605</td>
<td>0.99</td>
<td>0.57</td>
</tr>
<tr>
<td>London</td>
<td>420</td>
<td>828</td>
<td>1577</td>
<td>0.27</td>
<td>0.51</td>
</tr>
<tr>
<td>Paris</td>
<td>220</td>
<td>1190</td>
<td>105</td>
<td>2.09</td>
<td>0.18</td>
</tr>
<tr>
<td>Shanghai</td>
<td>617</td>
<td>2415</td>
<td>6340</td>
<td>0.10</td>
<td>0.26</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>215</td>
<td>730</td>
<td>1104</td>
<td>0.19</td>
<td>0.29</td>
</tr>
<tr>
<td>Beijing</td>
<td>554</td>
<td>2171</td>
<td>16410</td>
<td>0.03</td>
<td>0.26</td>
</tr>
</tbody>
</table>

The Discordance between Network and Urban Development

The urban rail transit, as a large capacity and high speed public transport system, plays an important role in the process of urban development and special adjustment. There is complex interaction mechanism between urban transportation and urban form. Specific urban form requires specific urban transportation, and urban transportation has the function to shape the city and lead the development of the city form. Due to the different function and layout of each line and node, the network has different spatial and functional hierarchy.

However, in the process of planning and constructing Beijing urban rail transit, the interaction between transport and urban development is ignored, which leads to the disequilibrium among different lines. Table 4 shows the passengers volume proportion of each line in a week of the whole network, which proves the conclusion above.


<table>
<thead>
<tr>
<th>Line’s Name</th>
<th>Proportion</th>
<th>Line’s Name</th>
<th>Proportion</th>
<th>Line’s Name</th>
<th>Proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jichang line</td>
<td>0.32%</td>
<td>Line 15</td>
<td>2.58%</td>
<td>Line 8</td>
<td>3.44%</td>
</tr>
<tr>
<td>Fangshan line</td>
<td>1.15%</td>
<td>Line 14</td>
<td>2.72%</td>
<td>Line 5</td>
<td>8.28%</td>
</tr>
<tr>
<td>Yizhuang line</td>
<td>1.82%</td>
<td>Line 13</td>
<td>7.47%</td>
<td>Line 2</td>
<td>10.09%</td>
</tr>
<tr>
<td>Changing line</td>
<td>1.89%</td>
<td>Line 10</td>
<td>16.13%</td>
<td>Line 1</td>
<td>10.98%</td>
</tr>
<tr>
<td>Batong line</td>
<td>2.86%</td>
<td>Line 9</td>
<td>4.61%</td>
<td>Line 4</td>
<td>11.62%</td>
</tr>
<tr>
<td>Daxing line</td>
<td>3.22%</td>
<td>Line 7</td>
<td>3.34%</td>
<td>Line 6</td>
<td>7.47%</td>
</tr>
</tbody>
</table>

Low Degree of Connection between Lines

The transfer station is the line intersection, playing an important role to evacuate passengers. Therefore, the design of transfer stations directly influences the transport efficiency. In 2015, the ratio of average transfer passengers in the total volume is more than 85% in Beijing urban rail transit. Besides, with the expansion of the network, the ratio will continually increase. However, in the network, it is very inconvenient to transfer between lines.

First of all, the proportion of transfer stations is low. There are 53 transfer stations, which accounts for 18.5% only. Besides, the special distribution is disequilibrium. The northern is more...
convenient than the southern and the western is more convenient than the eastern. Then, from the view of transfer time, passengers spend too much time on transferring from one line to the other through the corridor. Based on the survey about transfer time of each transfer station in Beijing urban rail transit network, the statistical results show in figure 2.

Figure 2. Statistical Results of Proportion Based on Transfer-Time.

Last but not least, in the aspect of transfer mode, most of the transfer modes between two lines is from the station on the ground to underground, lacking in the mode of within the transfer stations. As a result, traffic congestion always happens in certain stations, which increases the total traffic time.

Unreasonable Distribution of Station

The distribution of each station reflects the area service level. The density of station and the average distance between stations are two important indicators to weigh the rationality of each station.

This paper draws a conclusion of unreasonable distribution of stations from two aspects discussed above. On one hand, in China, urban rail transit chooses the developed mode of high-volume and low density. Therefore, the average distance between stations within 1km is the best. However, in Beijing urban rail transit, the average distance of station is 1.55km. On the other hand, the distributions in different areas should reflect the hierarchy, i.e., the average distance between stations in different areas should adjust upon the traffic demands. In Beijing urban rail transit, this principle is ignored in the planning and construction as can be seen from table 5.

Table 5. Density of station in different hierarchical area in 2015 of Beijing urban rail transit network.

<table>
<thead>
<tr>
<th>Hierarchical area</th>
<th>Station’s number</th>
<th>The station density of land</th>
<th>The station density of population</th>
</tr>
</thead>
<tbody>
<tr>
<td>The core functional area</td>
<td>55</td>
<td>0.60</td>
<td>0.25</td>
</tr>
<tr>
<td>Urban function extended area</td>
<td>164</td>
<td>0.13</td>
<td>0.15</td>
</tr>
<tr>
<td>Urban new area</td>
<td>75</td>
<td>0.01</td>
<td>0.14</td>
</tr>
<tr>
<td>Administrative area</td>
<td>287</td>
<td>0.02</td>
<td>0.10</td>
</tr>
</tbody>
</table>
Unscientific construction schedule

The planning for urban rail transit includes special-planning and timing-planning. The construction schedule for each line not only has an influence on the operability, but also affects the transport efficiency in the whole network. Because different lines offer different service for passengers, the construction schedule should be considered. However, in the process of constructing Beijing urban rail transit, many lines in suburban are built before the central area lines. However, the traffic demand in central areas is stranger than suburban regions. For example, the Beijing West Railway Station is one of the busiest traffic hubs. There has been large passenger volume every day since 1996. However, no urban rail transit is conducted in this area until the year of 2012. This is quite beyond imagination! Before the year of 2012, Beijing has already conducted and operated more than 400km and most of the lines are constructed in suburban areas. However, in these areas, the demand travel by subway is very small. Most of the time, the full-load ratio is very low.

Reason analysis

This part will analyze some reasons for the problem above from three aspects.

1) Beijing is the first city to build urban rail transit in China. At the beginning of planning the whole network, the relative theories and principles are deficient. The only way to do is to refer to the lessons and experience from the foreign countries. However, these theories are usually not coordinated with Beijing specific situation. As a result, many lines and stations are constructed unreasonable.

2) The planning of the network is unreasonable.

In the process of planning each rail line, people usually consider more information of the scale other than the function. This always leads to a lower transport efficiency and frangible network structure. With the development of the city, the gap between the city construction and rail network grows larger and larger.

Ignoring the long-term urban planning but only focusing on the short-term economic benefits is a potential hidden trouble. Once the city expands, some lines will be operated with lower efficiency. For example, the subways in many areas with strong traffic demand are constructed later. As a result, the effect to solve the congestion pressure of the whole rail transit system is not notable.

3) The investment mode is too single. The funds of urban rail transit totally depend on the government currently due to huge demand for capital. The deficiency of capital is one of the most difficult problems during the process of construction. How to finance from social capital is a considerable issue.

Conclusions and suggestions

Empirical analysis above shows that there are many problems in Beijing urban rail transit network. First, the total scale of Beijing urban rail transit is lower than the mainly developed cities. Second, the layout of rail network and urban function is not coordinated. The supply in areas with strong demand for transport, such as core function districts and transportation hubs, is not adequate. Third, the network has fewer transfer stations, that is to say, the proportion of transfer station is very low. What’s more, passengers usually need to walk a long transfer corridor, which increases the total travel time. Fourth, the average distance between stations is longer. All of these issues directly reduce the transport efficiency of the whole network.

Six proposals, which aim to improving the transport efficiency and optimizing the layout of Beijing urban rail transit, have been given as follows.

1) From the aspect of network degree, the network scale and service scope should be increased to a higher level firstly. Second, the distribution of transport resource must be in accordance with the demand in different areas, in order to alleviate the traffic congestion.
2) The urban rail transit network development should be coordinated with the city spatial and functional layout, which will promote the network to play the full leading role in the process of urban function adjustment.

3) More transfer stations are needed especially the stations connecting three or more different lines. If possible, stations transferring on the same stage are also in need to realize the seamless transfer, which could greatly improve the efficiency of the rail transit.

4) The subway should work together with other means of transportation such as bus, taxi, coach and so on. This can help to build a whole perfect rail transit system based on the subway with high transfer efficiency. Besides, the distance between stations should consider the environment and future development around the lines.

5) Using other rail transit means to the network hierarchy is a good idea. This can render the aim of resource sharing and advantage complementation. Recently, the rail transit in Beijing is mainly based on the subway which is in a single-mode. Although suburban railway such as S2 has been in using, its utilization rate is low. Therefore, different rail transits should be constructed according to different areas such as suburban railways, city fast track sand so on. This will feature the whole rail transit system with multi-connected, diversity, multi-hierarchy.

6) Considering the construction sequence of network, it should give priority to the line construction in central districts which have a higher density of population and then expand outward gradually.

References


