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Research Article

Coherent Network Optimizing of Rail-Based Urban Mass Transit

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An efficient public transport is more than ever a crucial factor when it comes to the quality of life and competitiveness of many cities and regions in Asia. In recent years, the rail-based urban mass transit has been regarded as one of the key means to overcoming the great challenges in Chinese megacities. The purpose of this study is going to develop a coherent network optimizing for rail-based urban mass transit to find the best alternatives for the user and to demonstrate how to meet sustainable development needs and to match the enormous capacity requirements simultaneously. This paper presents an introduction to the current situation of the important lines, and transfer points in the metro system Shanghai. The insufficient aspects are analyzed and evaluated; while the optimizing ideas and measurements are developed and concreted. A group of examples are used to illustrate the approach. The whole study could be used for the latest reference for other megacities which have to be confronted with the similar situations and processes with enormous dynamic travel and transport demands.

1. Introduction

An efficient public transport is more than ever a crucial factor when it comes to the quality of life and competitiveness of many cities and regions. Rail-based urban mass transit is the backbone of modern transit systems [1], as their inherent characteristics such as exclusive right-of-way, automated guidance, and electric propulsion allow them to carry large numbers of passengers with speed, convenience, and safety.

Projects of rail-based urban mass transit are often a top contender to meet the rapidly increasing travel demand, especially in many Asian cities [2]. As high population density requires an efficient transport system to facilitate mobility and economic development of the territory. On the other hand, this high density provides the essential condition for the development of a mass transit type of public transport. Furthermore, this kind of transit system is bound to grow. The world is constantly urbanizing, creating megacities that rely more and more on public transportation.

Indeed, the development of rail-based urban mass transit has been one of the key objectives of the transport policies and strategies over the past few decades. As the population size of Chinese city increases, the use of a rail-based system becomes more appealing. Since 2003, 28 cities have done their plans of this system network. 2700 km among the planned lines have been constructed after that. This means, above 250 km line track per year have been brought into operation, which is quite faster than the construction speed of in western world in 70′s last century with 160 km per year.

Despite the recent remarkable achievements, the development of rail-based urban mass transit system in China still faces a lot of problems [3]. Especially, this kind of remarkable development causes insufficient aspects, such as deficiency and inconsistency. Some plans have to be changed. The other must even go through fundamental revision.

Transit networks, although being structurally simpler than many other networks, present some specific challenges. The network planning of rail-based urban mass transit is influenced and restricted by a series of factors, such as nature environment, social system, economic condition, and construction technique, so that its concepts are normally multifarious with different emphasizes [4].

First of all, there are a number of surveys of the empirical literature on demand and capacity of network. There is, therefore, no contribution to be made by providing an extensive literature survey here.

Secondly is about the evaluation of network planning, which is difficult to measure, and while there is no consensus within the literature on a single appropriate proxy variable, three approaches could be defined that are most commonly used: (1) number of vehicles/trains in operation and train kilometers operated [5] (as these figures increase per passenger or per route length, service frequency also increases and there is less crowding), (2) some measure of time or money [6] (for instance in vehicle time or waiting time through a value of time factor), and (3) other quality factors that are not directly measurable in terms of time or money [7] (such as service reliability, infrastructure quality, and ventilation).

Some approaches have also used simulation models that are constructed to describe the relationship [8]. Normally the simulation model is a generic model that can be changed to adapt the influencing factors, such as rate of carriage fullness or length of time periods [9]. By running the model, several what-if questions can be replied to make revisions.

Finally, the importance of intermodal connectivity at stations [10], which had been argued and was also confirmed by many studies. Providing good feeder bus services in both origin and destination stations at all time periods considerably enhanced ridership [11]. At the same time, the walk ability for pedestrians in station proved to be important for increasing ridership.

But analysis in a multimodal network is more complicated than the investigation of pure vehicular or bus trips. It involves combinedmode trips in which travelers choose not only the routes, but also the transport modes and the kinds and locations of transfers [12]. Some studies have demonstrated that combining this framework with sensitivity and game theoretic approaches form a platform for analyzing the competition between operators as well as for studying the case of regulation [13, 14]. Furthermore, considering high demand for metro systems, a service disruption may lead to significant degradations in a city’s public transportation system. That is why establishing alternative means of transportation for passengers usually using buses is undertaken by transport authorities [15].

While traditional transit planning methods consider such characteristics as demand, demography, geography, time, and others, none seem to address the network design in a direct manner, which becomes increasingly important as systems grow. Till now, the most

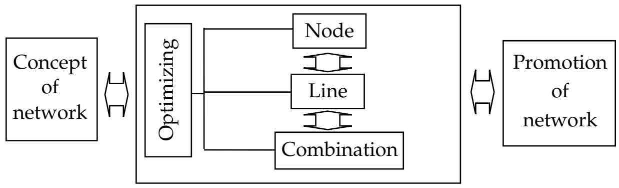

Figure 1: Coherent constituent parts of optimizing.

applied optimizing methods have been struggling to include too many influences and variants. Lacking of an efficient and effect optimizing system for the network planning should be the one of the main reasons of this dilemma situation. This paper could shed light on it.

2. Efficient and Effect Optimizing

According to the philosophy of planning, the character of process should be emphasized, especially during the phase of planning revelation. As conventional assessment approach normally focuses on picking out the best one among all candidate concepts at the last phase of network layout, while an efficient and effect optimizing contrarily attends to value every main elements of network during the whole planning step by step.

It is worthy to mention, the principle of this coherent network optimizing is to achieve the biggest accumulated net contribution, which is equal to total profit mines total cost. Profit results from ticket and increment of land value, while cost will be calculated not only with construction investment, but also operation expense as well as passenger mobility time.

This optimizing consists of main three constituent parts; they are node and line as well as combination of network (see Figure 1). As mentioned before, this process should be infiltrated into every course of network planning, so that planner could benefit through planning coupling to promote the quality of every concept and finally to achieve more valuable and sustainable network plan in respects of different aspects of point, line, and surface.

2.1. Optimizing of Main Node

It is crucial in convenience and possibility of transfer, as node plays an important roll to form the whole network. It decides the level of accessibility and flexibility for whole network. At the same time, it also influences the cost and construction tempo, especially when they are directly located in the central city.

Because of the limited space and density buildings in these areas, potential space is always limited. Besides the above necessity analyses, its layout and construction cost should be good investigated in each concept which can be multiplied the sum of prognostic passenger by its unit price of mobility time.

2.2. Optimizing of Line

It determines the form and difficulty level of network. The terrace of line affects mostly the construction feasibility, so that it decides the correlative construction cost finally. The needs of operation, such as park place of wagon maintenance place, and, should be also considered by the choice of route.

If the line needs to be taken by special construction measure, its cost will be raised with several times. For this reason, it is worthy through quantitative analysis of the demand about space, technique, and expense during the planning carefully.

2.3. *Optimizing of Combination*

Combination means the mechanics of network. It overlaps with the front two aspects and covers the capacity and capability of the transit network. According to the transfer times and its time cost, the final layout of different lines, either crossing or parallel, can be set up though breaking, remarking, and interweaving.

Nevertheless, a group of operation index such as passenger flow, volume of circular flow, and rate of flow in different directions can be regarded as criteria to arguer the efficiency of network operation.

Capacity is a quite vital important for network planning, as it refers to the adaptability of the present and future transport volumes. Absolutely it is the biggest challenge rising in planning of rail-based urban mass transit in China, where the urbanization, modernization, and motorization generate rapidly and enormously. These kinds of dramatic development bring gigantic demand and stress of passenger flow to the rail-based urban mass transit, so that they are definitively among the main reasons of deficiency and insufficiency of network planning mentioned at the beginning of this paper.

3. Application of Coherent Optimizing and Measurement

In order to give prominence to these mentioned aspects, some examples and cases shall be written in detail as follow.

As one of the Chinese megacities, public transport Shanghai has been challenged by overload of passenger volume day after day. According the last population census at the end of 2010, there are more than 2.3 million inhabitants in Shanghai. Obviously, it exceeds the prediction sum of population 2020 stated in the master plan with the total amount of 1.6 million, which was however quoted as basic reference date for the plan of whole system.

So it is not difficult to understand, why the lines are quite overloaded and crowded during peak hours, and why the network can still not meet the huge demand even after rapid construction in last decade years.

By means of the elevated ring streets, the network of the rail-based urban mass transit Shanghai can be divided into three parts (see Figure 2). Part one is the core area which covers the city center with about a radius of 3 km. In this area, there are 64 km lines and 34 metro stations. Secondly, part two is the area between core area and inner ring, which circular is the rest part of the central city without above mentioned core area. Here are located altogether 208 km lines and 108 stations. Finally, part three is the third one of network, which is outside of the inner ring street and stretches in the city periphery.

In this fall, the service radius of network is, respectively, 500 m in core area and 600 m in central area, which is closer and longer than the normal recommended value in other world cities. However, the service radius directly affected the mobility time and accessibility as well as the efficiency of whole network.

So as a measurement is called, the density of node and lines inside both of the core area and central area should be further completed. Especially near the present huge hubs, which are often overloaded, could be through addition of stations to ease the satiation degree.

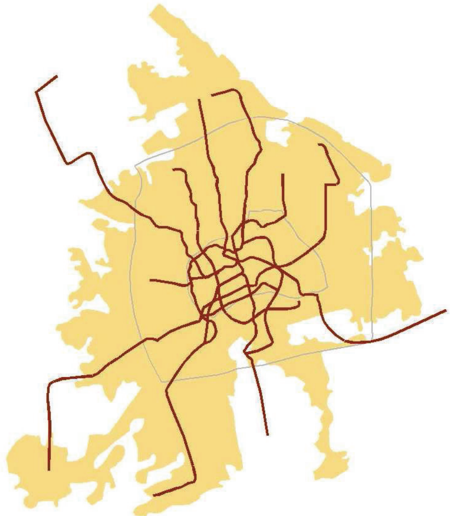

Figure 2: Shanghai rail-based urban mass transit (in red) and inner- and outside ring streets (in grey) as well as urban constructed area (in yellow).

Example 3.1 (transfer of node). In the station of People's Square, where is the super center of administration, culture, and business in Shanghai, there are 3 metro lines concentrated under the ground, in addition with more than 40 bus lines above the ground (see Figure 3). The station of People's Square is in the mitten crossing of line 1, 2, 8. All of them combine the biggest traffic hub for the urban and region. The volume of passenger and transfer passenger altogether accounts for 900 thousand per day, which is quantitatively equal to the dimension of population in a big city.

With the urbanization and development of real estate in suburb areas, more and more people remove from central city to outskirts of the city. At the same time, the central city has won more and more area to be redeveloped and reconstructed. Therefore, the connection between central city and suburb has become more important than before.

During peak hour, most of this kind of connection has relied on rail transit system, especially the radial pattern lines. Although, this phenomenon is accord with the classic economic geography theory, but it is also confronted with typical Chinese feature, namely, masses of passengers. One reason for that is over speeding sprawl of the city and excessive development of real estate around rail lines.

Example 3.2 (radial pattern of line). Since 1995, the line 1 goes from south-west via center to north as first operated line in Shanghai and binds new developing zone via developed city center to the main railway station. With the development of rail-based urban mass transit network, the average rate of growth of passenger volume in each year is about 16% from 2001 to 2011, after the other main lines have also been operated in business inside of city area.

But the growth rates for every station along line 1 are quite different. In south-west are more than 50%, because of density development of new residential areas. These growth rates with value higher than 20% are originated near the new shopping center or new business center, which are located between city center and new residential area. Most stations have experienced growth about 10%–20% rate. Few of them have been increased less than 5%. And very few are even gone down (see Figure 3).

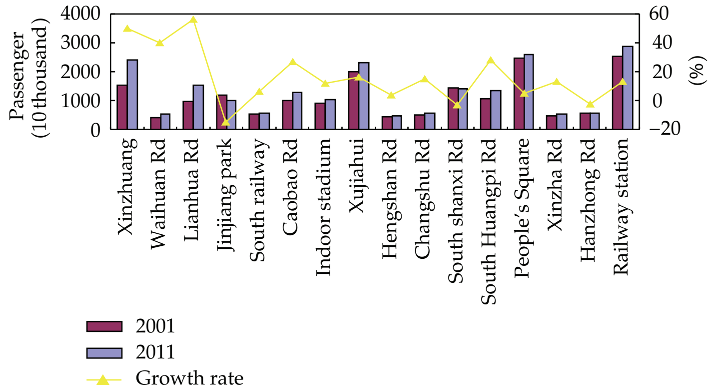

Figure 3: Growth rate of passenger flow of line 1.

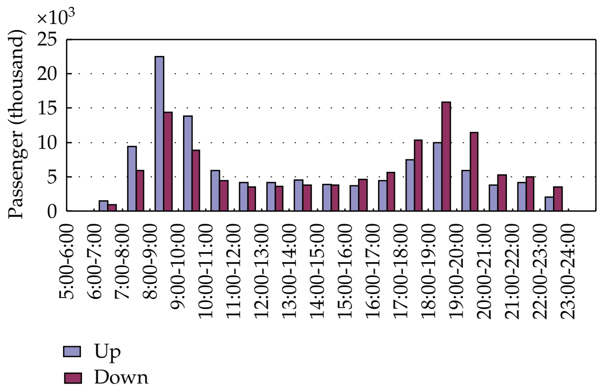

Figure 4: Daily Passenger flow in two ride directions of line 8 in 2010.

For another example, line 8 is overloaded with rapid growth rate because of the connection of large scale of residential communities in two ends. During peak hour at normal day, some sections of this line have to withstand the full-load ratio 175% (see Figure 4).

Example 3.3 (seamless link between city and region). Another main reason goes to the restriction of network density in outside of the city. There are only 8 lines among 18 radial pattern lines, which extend to the distance longer than 30 km. The last stations of other 10 lines break down less than 20 km outward from the city center (see Figure 2).

Incidentally, the distance with 30 km is about the bound line by rail-based urban mass transit system for commuter traffic. With the normal speed of 30–40 km per hour, rail-based urban mass transit can be as the best suitable traffic modal to give passenger about 1 hour trip within this region.

If the capacity of commuter traffic between city center and suburb could not keep the same step with the increase demand, its advantages, such as express, reliable, and massive, would not be exerted. Furthermore, it would result in more and more private motorized trip and would bring worse unhealthy modal split.

Tracing to the development of rail transit system in advanced world cities, the measurement is strongly recommended to add long radial pattern lines with 30 km distance at least to 20 lines. In that fall, it can achieve 2 lines in same direction for every periphery area, and avoid the service problem rising from the interval space between two radial pattern lines.

The third measurement to increase the capacity and capability can be realized by establishment of regional express line. Regional express line distinguishes rail-based urban mass transit with its relative longer interval distance between stations, faster speed and bigger capacity. When it is introduced to the network, it can improve the long connection between central city and periphery as passenger corridor.

At the same time, it can also reduce the almost to satiation volume pressure inside of the central area. Moreover, it can promote the impact power of Shanghai in the Yangtze delta area, so that it is quite reasonable to be built for not only for the reason of transport, but also for the future of region development.

4. Conclusions

The coherent network optimizing is useful to promote the quality of network plan. The analysis of four aspects, namely, node, route, formation, and capacity conduce to assess each concept comprehensively and abjectly, especially when the principle of efficiency about net contribution is in every course compared.

Last but not least, it is also, facility to be applied in comparison not only for the whole of network, but also for some sectors. These examples in Shanghai have shown, that both of central area and periphery area should be emphasized in network planning, especially during the phase of urbanization.

And urbanization has been a worldwide phenomenon since last century. By 2050, above 70% of the world population will live in urban areas, although the figure is right now about the half of them. Shanghai is the typical example in China, which has made fast pace of urbanization particularly and continually for the past three decades.

All of urban growth, urban sprawl, and increased motorization have brought significantly the demand of transport and require major adaptation of the urban infrastructures, in particular public transport. In this context, an important goal has to be made to reach a high modal share of public transport requires. This study offers an initial step toward that direction.

It has been demonstrated, that rail-based urban mass transit can be as the backbone of public transport to meet the actual mobility needs and to inform the choices ahead for future urban mobility. The promotion of its network planning through coherent network optimizing will be useful to capitalize on mutual benefits. So, it could be used as the latest reference for other megacities which have to be confronted with the similar situations and processes with enormous travel and transport demands.

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