Discussion on the Development of Modern Trams in China

Zhang Haijun[1] ， HU Junhong[2,3]

[1] Jiangsu Transportation Institute Nanjing Jiangsu 210017, China

[2] School of Transportation, Southeast University, Nanjing 210096, China

[3] School of Transportation, Nanjing Tech University, Nanjing Jiangsu 210009, China

KEYWORD: Modern tram, functional orientation, development and application, planning and design

ABSTRACT: Modern tram has been gradually applied to the public transportation in China due to its humanity, efficiency, ecology and environment-friendly. In the initial stage of development, however, numerous problems occurred in terms of function-orientation, route selection during initial implementation, construction standards and project cost because of the lack in practical experience, and guidance in technical standards and criteria. Based on the analysis and thinking on modern trams that have been built or are being built in China, this paper provides discussion on key problems having occurred in the development and application of trams and puts forward its development trend.

Development history of trams

The first prototype of tram was the horse-drawn tram rolling on tracks in 1800, U.K. After steam engines were invented, the first electricity-powered tram was put into operation in 1881 by Siemens AG, cooperated with Lichterfelde government. From then on, trams had rapid development in Europe and even in the whole world.

In 1930s, due to the dramatic increase of private cars and other forms of public transportation, urban road square was in great shortage. Old trams together with other vehicles were running at the same time at a really low speed but with big noise. What's worse, they occupied a lot of road resources. As a result, the trams were gradually replaced with private cars and meanwhile lots of tram lines were removed in many cities.

In 1970s, with the rapid rise of car ownership, a number of problems occurred, such as traffic jam, environment pollution and energy crisis, which compelled those developed countries in Europe and United States to give priority to trams as the dominate mode of public transportation. According to the statistics from the European Transportation Association, 137 cities had put trams in good operation by 2010 with an annual increase of 5%. In our country, the operation of tram has been retained only in Dalian, Changchun and Hong Kong. However, in recent years, planning and research on modern tram has been carried out in cities such as Beijing, Tianjin, Shanghai, Nanjing and so on and the modern trams have been gradually put into operation.

The characteristics and function-orientation of modern trams

Technical characteristics of modern trams

The modern trams are developed and modified from the conventional trams with technological upgrading. Compared with the conventional ones, they are not only more beautiful in appearance but also optimized in performance. What's more, they have the great advantages of large volume, easy transfer, fast speed and low noise etc.

The development and application of modern trams in China

The first tram line was built in 2006, in Binhai New District, Tianjin, with its total length of 7.86km. It was a new type of tram with signal-track guide, rubber-wheel-driven and 750V DC power supply produced by Raul Company, France. It can accommodate 167 passengers. Another similar tram line was put into service in 2009, in Zhangjiang High-Tech Park, Shanghai.

In August 2013, four tram lines were built in Hunnan New District, Shenyang, with its total length of 60km and an investment of about 4.82 billion Yuan. The trams were dependently developed by Changchun Car Manufacturer, with two kinds of 70% and 100% low floor, and 750V DC contact line power supply.

Tram Line No. 1 was opened to traffic in August 2014, in Hexi New District, Nanjing, of which the total length is 7.76km. The trams adopted Bombardier's technology of Flexity Ⅱ 100% low floor by China CSR Nanjing Puzhen Railway and used on-board energy storage (battery units) as power supply.
In October 2014, tram Line No. 1 in Suzhou was put into trial operation. It spanned Suzhou Hi-Tech Zone and ended at Suzhou Entertainment Park, connecting Rail No.1 and No.3, with its total length of 18.19km. It adopted 100% low floor, which was of the same type but with different appearance compared with those in Nanjing.
Tram lines that are under construction include Qilin Science and Innovation Park (Nanjing), tram Line No.1 in Huai'an, Guangzhou-Haizhu line and tram Line No.1 in Zhuhai and so on. According to incomplete statistics, 4000km tram line will be built in the next 20 years.

The functional orientation of modern trams

With reference to the development history and practical application of modern trams in and abroad, its functional orientation includes as follows:
Firstly, it takes the part of density-increase, supplement and extension of rail transportation in big cities.
First of all, in some big cities with metro systems, tram lines, being taken as the density-increase lines, connect suburban area with metro lines. For example, tram Line No.1 in Hexi New District, Nanjing, lies on the main road of Jiangdong road, connecting with subway Line No. 2, No. 10 and intercity Line S3, with 4 bus stops transferring with subway stations. Such layout sets up a multi-mode comprehensive public transportation system, which can link different traffic modes.
Second, tram lines usually lie at the destination of subway lines, which provide extension service for subways and save a lot of investment on the basis of assuring service quality. Madrid in Spain is a typical city, which adopts the mentioned mode above. There are 3 tram lines in Madrid, two of which connect the destination of subways. They depart at the same station and one extends to southwest and the other to northwest.
Secondly, it acts as the backbone of public transportation in new urban districts or small- medium cities.
As the development intensity and population density in new urban districts have not reached a certain level, the construction of MRT or LRT will lead to low investment efficiency at high construction costs due to low passenger flow in these areas. Therefore, the construction of tram lines, being taken as the backbone of public transportation in the new urban districts, can solve the traffic problem in these areas and form a certain scale of line network, connecting with both suburb rail and downtown of the new city area and thus can ease the conflicts between supply and demand of the development in new urban districts and reflect the transportation-orientated function.
The planned construction of tram lines in Qilin Science and Innovation Park (Nanjing) is based on the above-mentioned principles. The lines are built on the main passenger flow corridors, by connecting with Maqun passenger transportation hub, subway Line No. 2, Line No. 12 and intercity Line S6 as well as dozens of bus routes linking to the central city and other directions.
Thirdly, it takes on the function of tourism and business in some regions with special requirements.
It acts as special mode of transportation in some landscape areas or regions with special requirements such as tourist spots, entertainment park, film and television base. For example, Reims in France is the world-famous city of champagne. Trams in the ancient city of Notre Dame take power supply from third rail without contact line and the front of which is shaped like champagne glass. These trams fit in well with the ancient city as the chief carrier of the ancient city culture and modern civilization.

Problems occurring in the development of modern trams

In view of the practical operation of modern trams, many problems occur in the development of modern trams due to the fact that we don't have any successful experience and standard guidance.
Firstly, trams in revenue service can not meet the expected target.Table 1 lists relevant data of trams in the early years of operation in Hunnan (Shenyang), Hexi (Nanjing) and Line No.1 in Suzhou.

Table 1. Relevant operation parameters of trams in our country

Key index	Line No. 1 in Hexi, Nanjing	Line No.1 in Suzhou	Lines No.1, 2 and 5 in Hunnan
Line mileage (km)	7.76	18.19	48.1 (12.2/14.8/21.1)
Speed (km•h-1)	12-13	25-27	17/18/23
Running time (min)	35	38-41	57/47/55
Departure interval (min)	30-40	15	14-20
Average daily passenger flow(person•day-1)	0.3-0.5	0.8-1	3-4
Cost per kilometer (ten thousand yuan)	1.56	1.73	0.803

Data in the table show that trams in Hexi (Nanjing) and Hunnan (Shenyang), run at the lowest speed of 12-13 km•h-1, which is slower than conventional buses. The departure interval in these three districts is more than 15 minutes, among which the departure interval in Nanjing is more than 30 minutes. The daily passenger flow intensity of these three lines is less than 1000 persons •km^{-1}. The investment to Line No.1 in Suzhou is the most with 0.173 billion Yuan •km^{-1}. The average cost is 110,000,000 Yuan •km^{-1}. Why does it fail to achieve the expected operation benefit with high investment?

Secondly, the places where tram lines should be built are not clear. Trams lines in Europe, are located in the center of the city, taking on as the backbone of urban public transportation. However, tram lines in China have to be built on the outskirt of the city rather than in the central city due to the special situation of too much population in the central city, too many private cars and too much shortage of road resources inside the city. Figure 1 is a draft layout of tram lines network in a city, south of China. The square of the city is 2900$km^{2,}$ with a population of 3,500,000. The planned 443km of tram lines lie basically on the outskirt of city. However, the problems of few passenger flow and low operation efficiency will occur at the initial operation period.

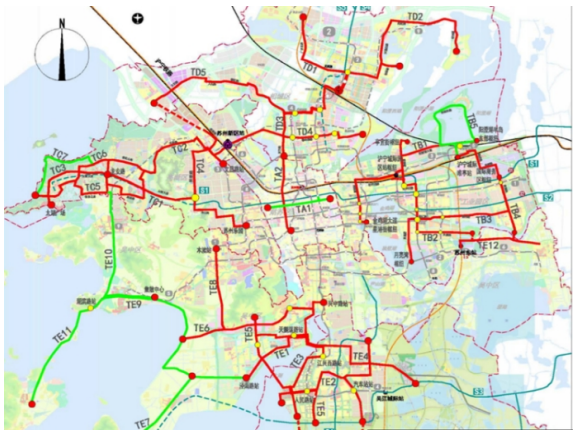

Figure 1 layout of tram lines

Thirdly, should modern tram be developed in the direction of subways or conventional buses?

In order to ensure fast and safe operation of trams, we usually take many engineering measures to isolate the interference between social traffic and trams, which, on the one hand, can greatly improve the operation efficiency and safety of trams and on the other hand, increase the engineering and maintenance cost. MRT or LRT enjoys exclusive right of way, and the departure interval is so short (the minimum interval is less than one minute) that its operation efficiency is high. Trams, however, is a rail transportation based on roads. If we decrease the departure interval, it will seriously affect traffic in intersection roads. Therefore, the problem that in which direction should tram lines be developed should be discussed.

The above-mentioned problems lead to the irrational development of trams in our country for being lack of research on functional orientation and passenger demand, which will not only result in the waste of social resources but also strangle the new modes of transportation that meets the development demands in new urban districts.

Thinking on the development and application of modern trams

Reasonable function-orientation and scientific line layout

(1) Define the reasonable commercial speed target

The commercial speed means the average speed of trams in the section including the stopping time and additional time of stopping and starting. It is a comprehensive index involving running speed, the right of road selection, way of passing intersections and operation organization.

As ground rail transportation, the commercial speed of trams will be affected by many key factors including the highest running speed of trams, the distance between stops and the number of intersections. Other factors will also affect the commercial speed of trams, such as acceleration value of trams, distribution of road-right, layout of cross section, intersection passing method and ticket selling as well as ticket examining.

The reasonable commercial speed of trams should be 12-25km•h^{-1} according to relevant simulation. If it is close to the lower limit, it should be oriented as conventional transportation and if it is close to the upper limit, it should be oriented as rapid transportation.

In the process of planning, reasonable commercial speed should be defined with reference to the functional orientation to choose the reasonable engineering plan and measurements.

(2) The appropriate operation length of trams

Since the highest running speed of tram is 50-70km•h^{-1} and the commercial speed is 12-25 km•h^{-1}, the operation time and operation length of a signal line should be in an appropriate range as ground public transportation. Taking tram lines set up on the main road of 30km as an example. If we assume that stops are set at every 1 km and there is an intersection at every 1km. The simulated operation data of trams and private cars are shown in Table 2.

Table 2. Margin settings for A4 size paper and letter size paper.

Project	Highest design speed (km•h^{-1})	Max. acceleration (m/s^2)	Running speed on main line (km•h^{-1})	Stop time (min)	Time delay in crossing(min)	Running time (min)	Average commercial speed (km•h^{-1})
Tram	70	1.33	50	26.5	13.2	67.6	26.6
Car	120	2.3	60	-	10.5	40.6	45

Due to the stopping and delay at intersections, it takes 67.6 minutes for a tram to cover 30km while it only takes 40 minutes for a car. Therefore trams had no advantage in the choice of travel mode. So the operation length of tram should be within 20km and running time should be less than 60 minutes.

(3) Effective selection of initial implementation line

It is also a key to the functional orientation for trams to select an effective operation line. The opening and operation of trams should ensure moderate passenger flow and play the function of service and guidance.

It has been proved that selection of effective operation line should be based on the coverage of passenger flow. Preliminary study shows that if the daily passenger flow intensity recently is less than 3000 person•km$^{-1,}$ it should not be taken as preliminary implementation line. If future daily passenger flow intensity is less than 3000 person•km$^{-1,}$ it should not be planned as medium volume line.

Exert the tram's advantage as the ground public transportation

Trams in Dalian have been in service for almost a hundred years adopting old trams and new trams with 70% low floor, which becomes an important part of characteristics in Dalian. Trams in Dalian, starts from northern commercial center adopting mixed right of road selection. The minimum dis-

tance between intersections is 50m. At the Jiefang Square in downtown, trams are running harmoniously with pedestrians and social cars, carrying more than 200,000 passengers everyday

Be simple and practical and reasonably reduce engineering cost

The domestic construction cost of trams, built in recent years, is more than 0.1 billion yuan per kilometer and the construction cost of recently-built trams is more than 0.15 billion yuan per kilometer. Although it is only 1/4—1/5 of that of subway in construction cost, it is roughly equal to the construction of a main road in cost. If it only carries 10,000-20,000 passengers per day with such an expensive investment, the benefit of which is far below that of a main road. Therefore, a reasonable reduction of engineering cost will be good to promote and enhance the use value of trams

Optimized connection and foster and guide the passenger flow

Lying in the middle level or as the backbone of traffic modes in the system of urban public transportation, trams should, on the one hand, be connected with urban rail transportation and on the other hand, be transferred with conventional buses. Bus routes in the operation lines of trams should be optimized before trams are put into operation in order to reduce parallel routes and increase the density of intersection, which can transfer passenger flow to trams and thus develop an integrated comprehensive transportation system.

Modern tram Line No.1 in Hexi, Nanjing, connects with trams, subways, buses and public bicycles at the Olympic Stadium East stop. It is a typical model for multi-mode and multi-level transferring system. Connection between trams and main passenger flow passage as well as distribution terminal, such as airport and CRH stations, should be taken into consideration before planning the layout of tram lines in order to ensure and improve passenger flow.

Figure 2 Tram connection and transferring

Build a line network operation system with "One Track, Multiple roads"

Compared with conventional buses, trams usually have an independent right of way in its section and have sharing right of way at intersections, which can increase its commercial speed and ensure its operation punctuality. However, we have to set up network operation system with "One Track, Multiple Roads" at main passages in order to improve its operation efficiency and utilization rate of passage resources. In Croydon, a city in the south of London, there are 3 tram lines, which connect national railway network in London. They are the backbone line network of public transportation in the city. The operation mileage of trams in Croydon covers 28km and rail track mileage only 16.5km.

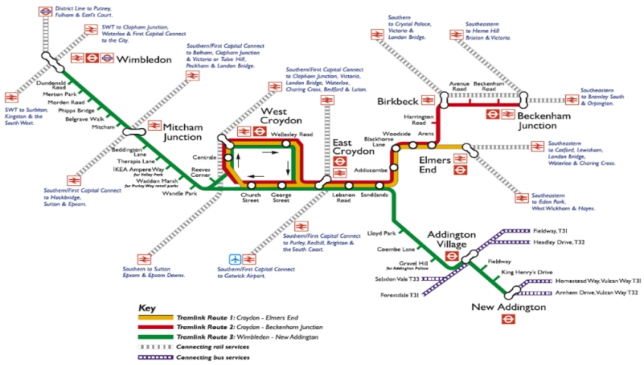

Figure 3 Line network of trams in Croydon

Therefore, at the stage of tram-line planning, we should focus on the selection of main passenger-corridors. In the recent planning, we can add branch lines at both ends of main passages to increase passenger flow, while in the future planning, we should set up a network operation system according to the main passenger-corridors to improve its utilization rate

Conclusion

As ground-rail transportation with medium traffic volume, modern trams meet the demands of urban development in China in terms of ecology and environment. It boasts energy saving, environment-friendly, safe and comfortable features with flexible operation and appropriate cost. They are emerging in China with a prosperous future.

In the development of modern trams, we should stick to the concept of scientific orientation, local condition tailor and prudence and implement the design principles of simple, practical and low cost. It is recommended that systematic research on the application of modern trams in urban public transportation should be done in order to draft the development strategy of the industry and set up the planning of urban public transportation to ensure its reasonable layout and the sustainable development of modern trams in urban public transportation.

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