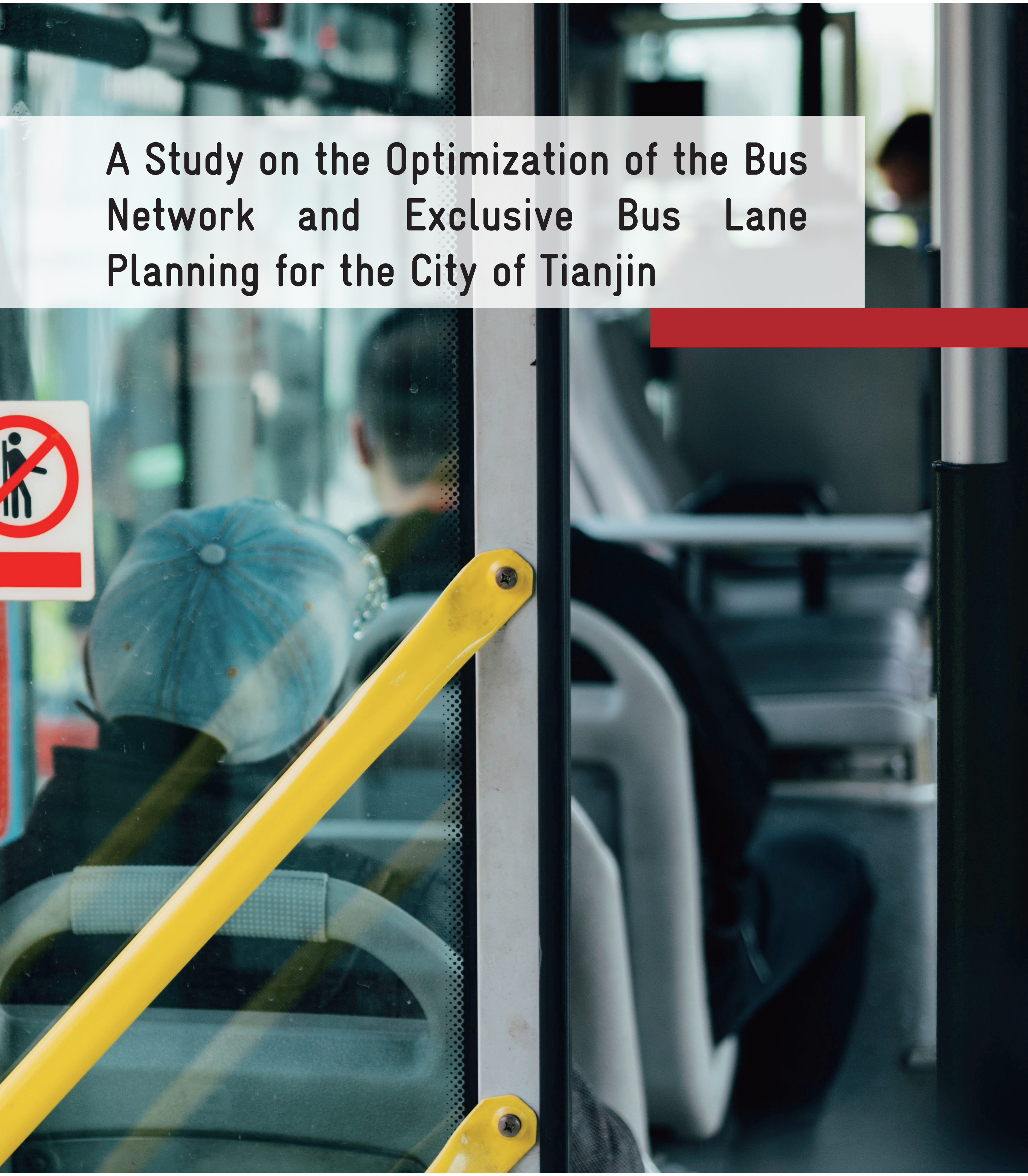
A Study on the Optimization of the Bus Network and Exclusive Bus Lane Planning for the City of Tianjin



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Beijing, 2022

Glossary

Battery electric bus (BEB)	A bus that is powered by an on-board battery and an electric motor.
Bunching	Appears when multiple buses of the same line enter a station at the same time and cause an overflow.[1]
Bus bay	A bus bay is a designated spot along a road where buses can leave the traffic flow to board or drop off passengers.
Bus corridor	Bus corridors are areas with a high concentration of bus travel, as well as commercial activity and other urban functions. They are characterized by large passenger flows, the establishment of delineated bus lanes, and ultimately, higher transport speed and efficiency.
Bus lane	A lane in which only buses are allowed to pass during designated hours.[1]
Bus passenger flow	The boarding number of passengers for one vehicle or bus line within a certain period.
Carbon emission factor	The coefficient of carbon emissions in an energy-consuming process.
Carrying coefficient	Average number of passengers per vehicle.
Coverage	The length of the public bus and tram line network as a proportion of the length of urban roads within a certain area of the city.[3]
Delay time	The waste of travel time caused by traffic interference and control facilities.
Departure interval	The interval between two adjacent buses of the same line leaving a platform.[1]
Driving time	Time that a bus spends driving on the road, excluding time spent waiting at intersections or at stations.
Exhaust emissions	The gaseous waste products produced during material conversion processes.
Flat fare	A ticket fare that is the same regardless of the distance travelled in a single journey.[4]
Green wave	Occurs when traffic lights are coordinated to provide vehicles green lights through multiple intersections.
Hub	Urban passenger transport hubs are places where passengers arrive and transfer, and where transport modes and lines are changed. A public transport hub mostly refers to a comprehensive municipal facility with a collection of multiple bus lines and different modes of transport, with the necessary service functions and control equipment.[5]
In-line roadside platform	Bus stops that are arranged along the sidewalk and non-motorised lanes without a bus bay.[6]
Load rate	The ratio of passenger volume to rated full passenger capacity.[1]
Marking rate	The ratio of the delineated length of a bus line to the total length of the bus line.
Maximum red-light monitoring mechanism	During the implementation of a bus priority system, this mechanism monitors the maximum red-light time and cycle length of other phases in order to minimise the negative impact on other traffic flows.[2]

Modal share	The ratio between the number of passenger trips of a certain mode of transportation and the total number of passenger trips.
New energy bus	A bus powered by an energy source other than traditional petroleum fuels (petrol or diesel fuel).
New energy vehicles	A vehicle powered by an energy source other than traditional petroleum fuels (petrol or diesel fuel).
Non-motorised transport	Umbrella term for all forms of human powered transportation (e.g., walking, cycling, skating, etc.).
On-demand buses	A one-stop direct shuttle from the community to the company and from the company to the community, also known as a business shuttle.
Operating mileage	The total mileage travelled by a vehicle, including distances with and without passenger transport.[1]
Passenger volume per km	Yearly vehicle passenger volume / yearly vehicle operating mileage.
Peak hours	The hours of the day with the most traffic.[1]
Signal phase	At intersections with traffic lights, one signal phase is one state of a pre-set signal scheme at an intersection, displaying different signals to give right of way to vehicles or pedestrians in different directions. It is not a single indication, but the relationship between several signals. (e.g. one signal phase would be a time window where traffic participants of one direction receive a green light, while others have to wait).
Plug-in hybrid bus	A bus whose battery can be charged both via an on-board combustion engine or a power plug.
Right of way	The right to move onto or across a road before other vehicles or pedestrians.
Repetition rate	The ratio of the total length of bus lines to the length of the line network in a certain area of the city.[3]
Shuttle bus	An operating vehicle that runs in a designated section of a bus line.
Standby rate	The ratio of buses kept in reserve to the total number of buses in a bus fleet.
Travel time	The total time a vehicle takes to travel a part of a road, including driving time, traffic light waiting time, and delay time.
Vehicle use intensity	The mileage a vehicle drives within a certain time unit (e.g., the average vehicle use intensity of private cars in Tianjin is 32 km per day).
Well-to-wheel emissions	A well-to-wheel analysis is the evaluation of the environmental impact of a particular energy source from its extraction to its conversion into kinetic energy.

Content

1 Introduction 6

1.1 The City of Tianjin 7

1.2 Origin of the Study 9

1.3 Objective and Structure of the Study 10

2 Evaluation of the Bus Network Optimisation Plan of Tianjin 11

2.1 Background 12

2.2 Research Objective and Structure 12

2.2 Evaluation of the TMEDI Plan 12

2.1.1 Introduction to the TMEDI Plan 12

2.1.2 Evaluation and Suggestions for the TMEDI Plan 13

2.2 Conclusion 19

3 Optimisation of Bus Operation Capacity Allocation 20

3.1 Background 21

3.2 Research Objective and Structure 21

3.3 Status Quo of Bus Operation Capacity Allocation 22

3.3.1 Issues of the Bus Network Structure 22

3.3.2 Issues of the Operating Model 27

3.4 Suggestions on Capacity Allocation 29

3.4.1 Optimize the Bus Network Structure 29

3.4.2 Establish Diversified Bus Operation Methods 31

3.4.3 Optimize Peak and Off-Peak Schedules and Vehicle Configurations 33

3.4.4 Optimize the Subsidy Model of Bus Operation 35

3.4.5 Establish an Intelligent Bus Dispatching System 35

3.4.6 Optimize the Fare System 35

3.5 Specific Issues and Suggestions for Fleet Electrification 36

3.5.1 Development Status of Electric Buses in Tianjin 36

3.5.2 Challenges Brought by Electric Buses to Bus Network Optimization 37

3.5.3 Suggestions 37

4 Bus Corridor Analysis 39

4.1 Research Objective and Structure 40

4.2 Evaluation of Bus Corridors in Tianjin 40

4.2.1 Overview 40

4.2.2 Speed 40

4.2.3 Continuity of Bus Lanes 44

4.2.4 Delay Times 47

4.2.5 Platform Design 50

4.2.6 Summary of Issues 51

4.3 Bus Corridor Optimization Strategy 51
4.3.1 Coordinated Development of Bus and Subway Transit Services 51
4.3.2 Reduction of Unnecessary Bus Corridors 52
4.4 Optimization of a Bus Corridor Case Study 55
4.4.1 Case Study Selection 55
4.4.2 Suggestions for the Placement of Bus Lanes 55
4.4.3 Suggestions for Improving the Continuity of Bus Lane Markings 55
4.4.4 Suggestions to Strengthen the Signal Optimization of Key Corridors 57
4.4.5 Suggestions for the Optimization of Bus Stops 58
4.5 Conclusion 60

5 Carbon Emission Estimation of the Middle Ring Corridor 61
5.1 Background 62
5.2 Significance of Carbon Emission Reduction 62
5.2.1 New Technologies Promote Industrial Emission Reduction 62
5.2.2 Transformation of the Mobility System 64
5.3 Calculation Method of Carbon Emission Reduction 64
5.4 Carbon Emission Calculation 64

6 Conclusion 66
6.1 Summary of the Report 67
6.2 Outlook 67

Appendix 68
Ways to Set Up Bus Lanes at Intersections 69
Advantages and Disadvantages of Different Approaching Lanes 72

References 75

1 Introduction

1.1 The City of Tianjin

Tianjin (天津) is a municipality and a coastal metropolis located on the shore of the Bohai Sea in Northern China. Being only 120 kilometres southeast of Beijing, it is part of the Jing-Jin-Ji (Beijing-Tianjin-Hebei) Urban Agglomeration (See Figure 1-1). As one of the four municipalities[1] under the direct administration of the Central Government of China, Tianjin is at the highest administrative level of Chinese cities. With a total administrative land surface of 11,916.88 m^2,[2] it is home to 13,860,000 habitants.[3]

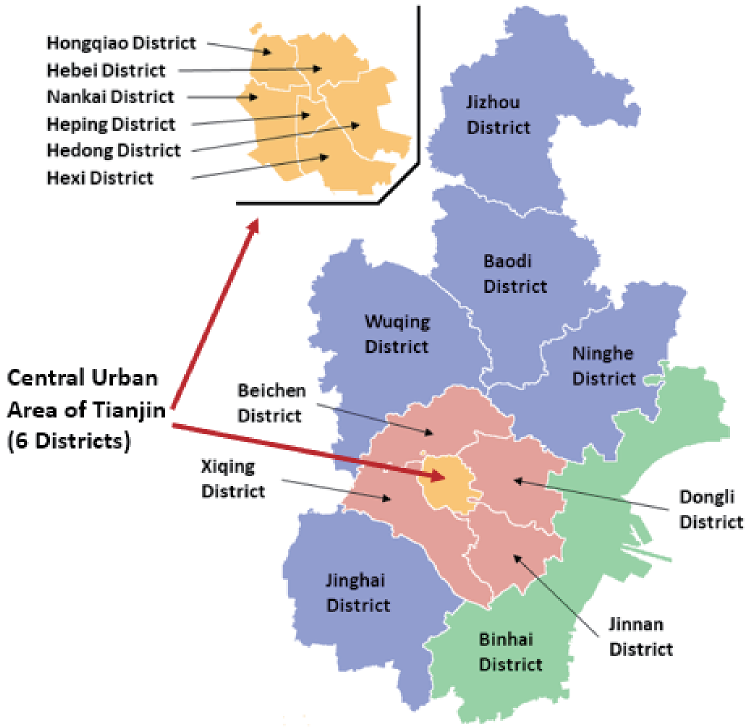
The city consists of four areas covering 15 districts, divided as follows (See Figure 1-2):

- The Central Urban Area includes six districts: Heping District (和 平 区), Hexi District (河 西 区), Nankai District (南开区), Hebei District (河北区), Hongqiao District (红桥区), and Hedong District (河东区)
- The Surrounding Area includes four districts: Dongli District (东丽区), Jinnan District (津南区), Xiqing District(西青区), and Beichen District (北辰区)
- The Suburban Area includes four districts: Ninghe District (宁 河 区)， Jinghai District (静 海 区)， Baodi District (宝坻区)， and Wuqing District (武清区), Jizhou District (蓟州区)
- Binhai New Area (滨海新区) is comprised of one District, which is a National Level Special Economic Zone.

Figure 1-1: Location of Tianjin in China

[1] The four municipalities under the direct administration of the Central Government are Beijing, Tianjin, Shanghai, and Chongqing.
[2] Official Introduction of Tianjin http://www.gov.cn/guoqing/2013-03/20/content_5046146.htm
[3] The 7th National Census Communiqué of China (3rd Report) Chapter on Provincial Population http://www.stats.gov.cn/tjsj/tjgb/rkpcgb/qgrkpcgb/202106/t20210628_1818822.html

■ **Figure 1-2: Administrative Divisions of Tianjin**



In 2020, the Gross Domestic Product (GDP) of Tianjin was CNY 1.4 trillion,[4] ranking 2nd among cities in Northern China. Its main industries include petrochemical industries, textiles, car manufacturing, mechanical industries, and metalworking. The Tianjin Port, located in the Binhai New Area, is the largest port in Northern China and the main maritime gateway to Beijing.

Even before China announced its goal to achieve carbon neutrality by 2060 and carbon emissions peaking before 2030,[5] Tianjin had already been one of the forerunners of emission reduction in the urban transport sector. The city has been playing a key role in the implementation of the 2013 "Air Pollution Control of the Jing-Jin-Ji Area"[6] program and the 2018 "Blue Sky Protection Campaign"[7] by China's State Council. Both programmes include comprehensive air pollution control measures with quantified targets on PM 2.5 levels as well as emission reduction ratios for the transport sector. According to the "2018-2020 Announcement on the New Energy Bus Action Plan"[8] of Tianjin's Transport, Industrial Development, and Development & Reform Authorities, the city retired all traditional diesel buses and replaced them with New Energy Buses by the end of 2020.

[4] The 2020 Tianjin Statistic Report http://www.tj.gov.cn/sq/tjgb/202103/t20210315_5384328.html
[5] The 2030 and 2060 climate goals were announced by Chinese President Xi Jinping at the end of 2020 and submitted as updated Nationally Determined Contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC) secretariate on 28 October 2021.
[6] http://www.gov.cn/gongbao/content/2013/content_2541901.htm
[7] http://www.gov.cn/zhengce/content/2018-07/03/content_5303158.htm
[8] All Buses in Tianjin Will be Replaced with New Energy Buses by the end of 2020 http://news.72177.com/2020/0426/4529738.shtml

1.2 Origin of the Study

Funded by the International Climate Initiative (IKI), the Sino-German Cooperation on Low Carbon Transport (CLCT) project is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, in partnership with the Ministry of Transport of the People's Republic of China (MoT). The project aims to strengthen cooperation between Germany and China in the field of climate protection in the transport sector and to provide Chinese policy makers and relevant governmental authorities on national, provincial, and local levels with effective and efficient implementation strategies to further develop a low carbon transport sector in China.

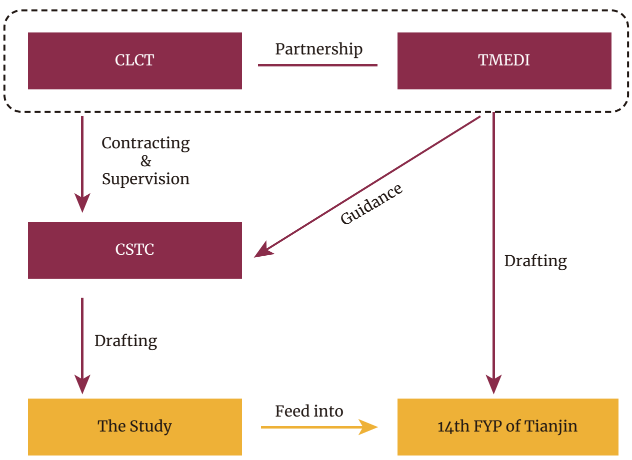
Within the scope of urban passenger transport, the CLCT project conducted two research studies on the topic of new energy buses. Firstly, the New Energy Buses in China Overview on Policies and Impact project, in collaboration with the China Automotive Technology and Research Center (CATARC) outlines the development course and policy landscape of China's new energy bus industry. Secondly, the Research on Technical System of the Life Cycle of Battery Electric Buses project, in collaboration with the China Academy of Transportation Sciences (CATS) focuses on the technical system that covers all aspects of Battery Electric Buses (BEB) from their procurement, operation, and maintenance to the development of supporting infrastructure, as well as battery decommissioning and vehicle scrapping initiatives.

Bus electrification is a systematic programme encompassing not only the procurement of buses, but also the adjustment and optimisation of related bus networks, their operation capacity allocation, as well as the design, construction, and operation of needed charging infrastructure. Covering, amongst other initiatives, all of these aspects relevant to bus electrification, Tianjin's 14th Five-Year-Plan (FYP) for the 2021 – 2025 period will set the objectives, road map, and indicators that will guide the development of Tianjin's fully electrified urban bus system, in coordination with other modes of transport. Commissioned by the municipal government, the Tianjin Municipal Engineering Design & Research Institute (TMEDI) conducted research on the transport sector plan of Tianjin's 14th FYP, the Bus Network Optimisation Plan, and also looked at sub-studies on bus operation and bus corridor management.

While the CLCT project strives to provide targeted recommendations to support Chinese cities to develop a low carbon transport sector, the 14th FYP preparation for Tianjin presented a perfect window of opportunity for the fostering of international technical cooperation on bus network optimisation and operation improvements. These issues are unique to Tianjin, as the city just fully electrified its bus fleet at the end of 2020, which puts it ahead of most cities worldwide. The challenges and lessons learned from Tianjin will be valuable not only for other cities in China, but also those globally that aspire to develop electric bus systems.

Following the collaboration between TMEDI and the CLCT project, the China Sustainable Transportation Center (CSTC) was selected through open tendering to conduct the research presented here, and draft this report (Figure 1-3).

Figure 1-3: Cooperation structure



1.3 Objective and Structure of the Study

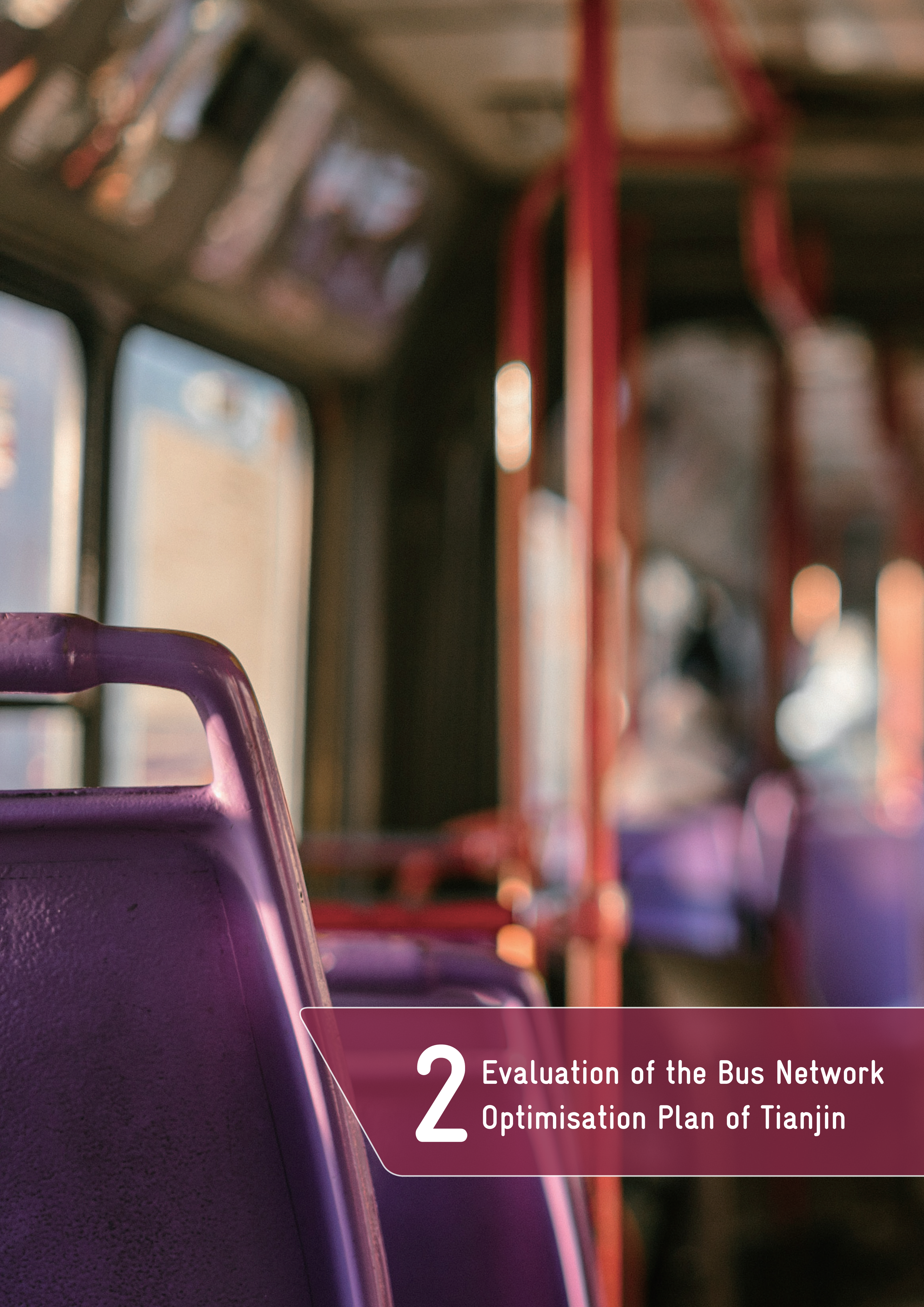
The objective of this study is to assist the transport authorities of Tianjin to comprehensively improve the service level of Tianjin's bus system through bus network and bus lane planning, and thus improve the efficiency and climate friendliness of the city's public transit network. The study assesses identified problems related to Tianjin's bus network and operation, and then proposes macro development strategies as well as detailed optimization suggestions to tackle these, for the 2021-2025 period. To support TMEDI's research for the preparation of Tianjin's 14th FYP in the most effective manner, the CSTC team worked as a parallel team with TMEDI, providing evaluations relating to TMEDI's research tasks and conducting independent analysis on other topics as requested by TMEDI. The content of this study is divided in this report as follows:

- **Part 1. Evaluation of the TMEDI Bus Network Optimization Plan.** The CSTC research team acted as an external reviewer of the Bus Network Optimization Plan drafted by TMEDI and provided an overall assessment of the plan, as well as and related suggestions for its improvement.

- **Part 2. Optimization of Bus Operation Capacity Allocation.** Research provided an analysis not only of the operational issues of the bus network itself, but also of other relevant operational issues, such as the input capacity for peak and off-peak hours, bus scheduling, fare setting, subsidies, and further related considerations.

- **Part 3. Bus Corridor Analysis.** The study provides an analysis of the exclusive bus corridors of Tianjin, evaluating their efficiency from the aspects of overall operation, bus speed, bus lane continuity, delay times, platform design, and other related issues. To provide targeted suggestions, a specific bus corridor was selected as a case study for detailed analysis. Recommendations on related operational aspects of the case corridor were provided to support its optimization.

- **Part 4: Emission Reduction Potential Estimation.** The study concludes with the presentation of findings from a carbon emission reduction estimation, which was conducted for selected case bus corridors. The estimation reflects the vast potential in the reduction of carbon emissions, if Tianjin could continue to improve its public transit system and reduce the transport modal share of cars.



2 Evaluation of the Bus Network Optimisation Plan of Tianjin

2.1 Background

By the end of 2020, Tianjin had 566 bus lines in operation, with a total length of 13,671.5 km[9] of bus routes. The city had a total of 7,353 operational buses with 4,081 reserved diesel buses available for emergency use[10]. As one of the pioneer Chinese cities for bus fleet electrification, Tianjin's bus fleet includes 5,017 battery electric buses (BEBs) and 1,618 Plug-in hybrid buses in its central urban area (see Table 2-1).

Tianjin's urban transit system has seen a key development of a rapid expansion of its urban rail transit system. Currently, Tianjin has six operating subway lines, with a total mileage of 232 km. Tianjin's target is to achieve 500 km of urban rail transit by the year 2025. However, the network overlap between the city's urban rail transit and bus networks has led to competition between the two systems, and a decrease of passenger volume for buses. Along with the new challenges brought by the bus fleet's electrification, the city is also facing a systematic and holistic adjustment of its overall bus network – which has been unchanged for over a decade.

Commissioned by the municipal government of Tianjin, TMEDI and Tianjin Bus[11] have developed a Bus Network Optimization Plan (TMEDI Plan). The TMEDI Plan serves as a sub-study for Tianjin's 14th FYP and will guide the city's bus network development with both strategic guidance and detailed suggestions for implementation. The final version of the TMEDI Plan was finished in May, 2021.

Table 2-1: Bus composition in Tianjin

	Central urban area	Whole city
Total number of e-buses	6,635	7,353
Battery electric buses	5,017	7,353
Plug-in hybrid buses	1,618	
Standby diesel buses	2,752	4,081

(Source: TMEDI)

2.2 Research Objective and Structure

The research objective of this study are divided into two specific assignments:

1. Evaluation of the TMEDI Plan and identification of key aspects to improve, and;
2. Concrete suggestions for improving the TMEDI Plan.

In accordance with the research objective, the study evaluates three aspects of the TMEDI Plan: 1. The status quo analysis; 2. The optimization goals, and; 3. The bus network structure. In addition, the study provides suggestions for improvement stemming from relevant literature and best practice cases. A special focus is also placed on suggestions relating to the electrification of Tianjin's bus fleet. The study will conclude with a summary of findings.

2.3 Evaluation of the TMEDI Plan

This chapter first briefly introduces the contents of the TMEDI Plan. Based on this outline, three aspects of the plan are subsequently evaluated, and suggestions for further improvement are provided.

2.3.1 Introduction to the TMEDI Plan

The TMEDI Plan is compromised of four parts: 1. A status quo analysis; 2. A general optimization concept; 3. Concrete design solutions, and; 4. An impact prediction. Each of these parts will be introduced in this section.

Five aspects relating to the status quo of Tianjin's current bus network are examined by this evaluation: 1. The service level of the bus network; 2. Bus passenger flows; 3. The relationship of the bus network with subway transit; 4. The allocation of station resources, and; 5. The main features of bus lanes. In summary, the study's analysis

[9] Source: TMEDI
[10] The number of buses were calculated in early 2021.
[11] Tianjin Bus 天津公交集团 (tjbus.com) is a public enterprise for the bus operation of Tianjin

of the TMEDI Plan's status quo offers multiple findings. Regarding its service level, in the central urban area of Tianjin, the bus network has a relatively high coverage rate. At the same time, these routes are overlapping and often involve detours. In suburban areas, bus network coverage has been found to be insufficient. While 100% of central urban areas are served by a 500-meter bus station coverage rate, only 70% of suburban areas have the same service. In relation to bus passenger flows, 53% of current passengers take buses for commuting purpose, while a much smaller proportion of 23% of current passengers take buses for private trips, such as for shopping or other personal needs.

In terms of the relationship of the bus network with subway transit, there is a general lack of coordination between the two systems, and a low transfer ratio. In regards to infrastructure, bus stations were found to lack supporting services for electric buses, especially charging facilities. Furthermore, an overall suggestion that arose was that the quality and efficiency of existing bus corridors could be enhanced.

The TMEDI Plan therefore proposes an optimization concept, based on balancing the relationship between the network's structure and function, costs and services, supply and demand, and the needs and infrastructure of both bus and subway lines.

Concrete solutions designed in the Plan propose five major actions:

1. A reduction of overlap in existing services;
2. An optimization of overall bus service by reducing bus routes in densely distributed areas, and increasing them in areas requiring more services;
3. The splitting of long bus lines into several shorter lines;
4. The straightening of existing routes and setting up of traffic hubs in areas where bus lines have been found to be densely distributed and overlapping, and;
5. Establishing short, medium, and long-term plans relating to the adjustment of the overall bus network of the city. For example, in the short term, 51 routes will be accordingly adjusted (of which 9 have already been changed), in the medium term (by the end of 2023), 69 additional routes will be adjusted, and in the long term (by the end of 2025), an additional 42 will be adjusted.

Overall, the TMEDI Plan is expected to enable a reduction of the average bus line length by 1.74 km (shortening it to 22.4 km), cut down the overlapping rate of bus routes and stations, scale down the overall number of buses, and strengthen the connection of bus routes with subway stations.

2.3.2 Evaluation and Suggestions for the TMEDI Plan

a) Status Quo Analysis

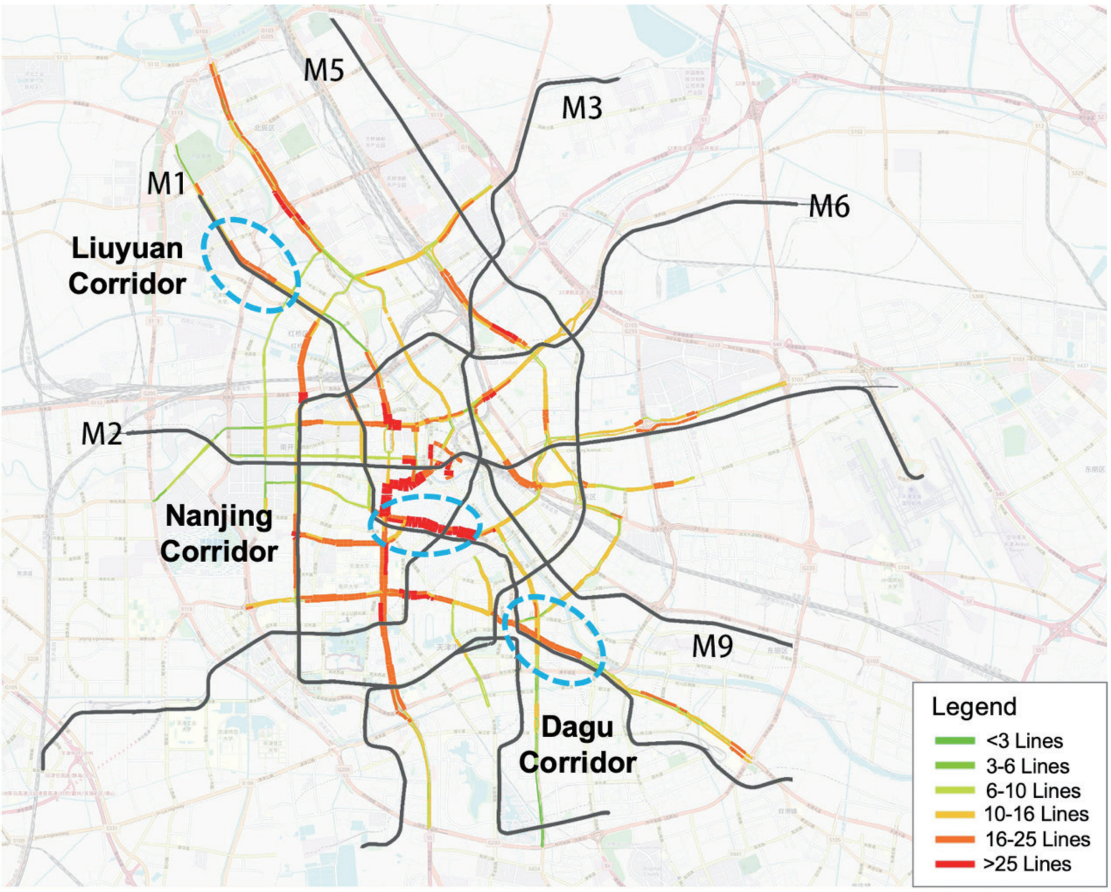
The status quo analysis of the TMEDI Plan has comprehensively surveyed the service levels of bus networks, bus passenger flows, the bus network's relationship with the subway transit network, and the allocation of station resources, amongst other considerations. One of the main issues found by this analysis was the negative impact of the overlapping of bus and subway network coverage. The research produced statistics on the number of overlapping lines and stations (see Table 2-2) but the issue is more clearly understood when the overlaps are presented in a spatial visualization, such as that presented in Figure 2-1..

As is shown in Figure 2-1, Tianjin's Metro Line 1 has the largest overlap with coverage provided by bus lines, with it's coverage being partially replicated by a total of 16 bus lines in the Liuyuan and Dagu corridors and over 25 lines in the Nanjing corridor. According to the National Report on Urban Passenger Transport Development by the MoT, the annual subway passenger flow in Tianjin in 2019 was 525 million [11], which was lower than the national average of 612 million (see Figure 2-2). One reason for Tianjin's lower flow of metro passengers was determined to be the high overlap in coverage between bus and subway networks.

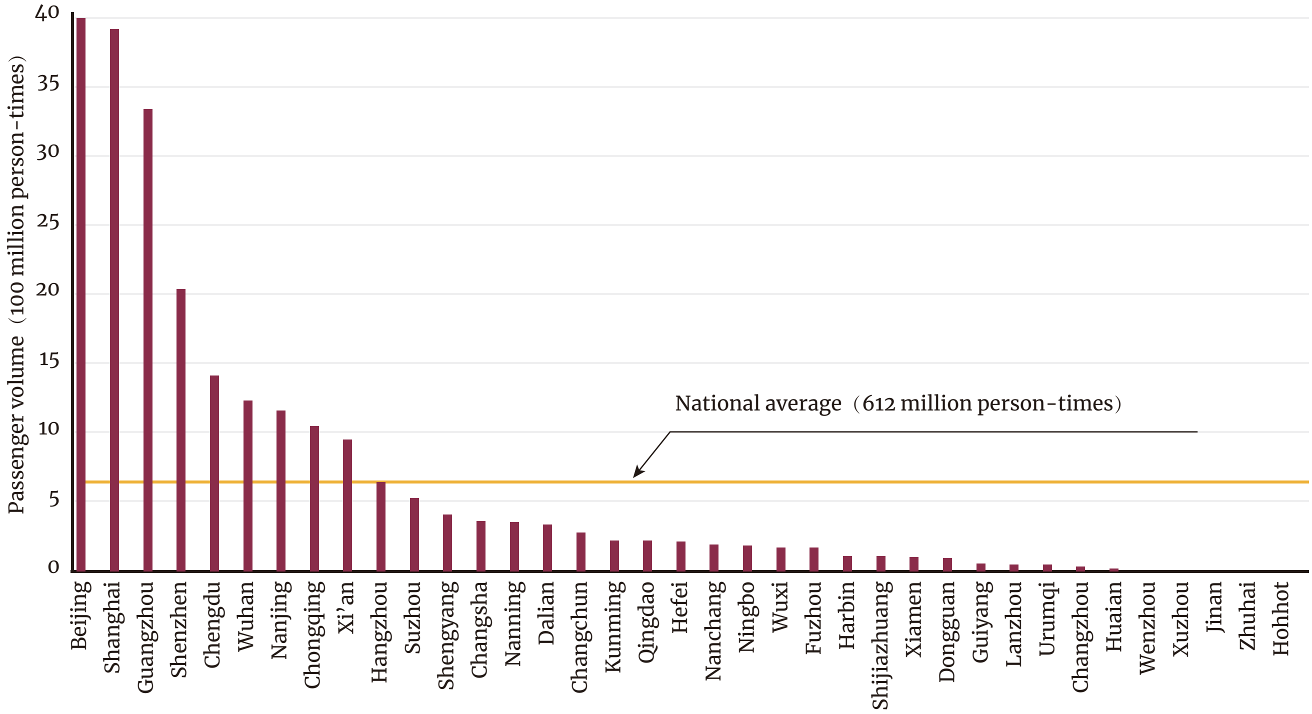
Table 2-2: Overlapping bus and subway transit coverage in Tianjin

	Quantity
Bus lines with subway overlap	383
Bus stations with subway overlap	1,606
Average number of parallel stations per line	4
Lines with over 10 Parallel stations	21
Lines with 6-10 Parallel stations	97
Lines with 1-5 Parallel stations	265

Figure 2-1: Distribution and overlapping of Tianjin's subway and bus networks



■ **Figure 2-2 : Subway passenger volume of China's major cities in 2019**



b) Development Targets

In order to determine the role that bus transit might play in fulfilling the city's transport development targets as stated in the TMEDI Plan, a further clarification of the role that bus networks play in the overall transport system of Tianjin is needed. This chapter will therefore first discuss the current and possible future states of bus transit in Tianjin, and then provide suggestions on how the city's bus networks might be improved so that they can support the fulfilment of Tianjin's overall transport development goals.

To analyse the role that bus transit plays in the transport system of Tianjin, basic indicators of travel behaviour (e.g., number of trips per capita per day, average travel time per capita) as well as the modal share of bus transit of Tianjin are compared with five other cities of a similar scale (namely Beijing, Shanghai, London, Seoul, and Hong Kong). As shown in Table 2-3, in Tianjin, the average number of trips by any mode of transport, per person per day is 2.4, with an average travel time of 30 minutes, and an average travel distance of 4.8 kilometres. The vehicle ownership rate in Tianjin is 0.42 vehicles per household, with a vehicle-use intensity rate of 32 kilometres per day. There is no major difference in the average number of trips taken per capita per day between Tianjin and the other comparative cities, with the exception of Hong Kong. While the average number of trips per person in Hong Kong is 1.8 times/day, people in the other five cities take an average of over 2 trips per day.

In a comparison of the average time of travel for a single journey, Tianjin and London were found to have the shortest travel time per capita among the examined cities, with an average duration of each trip of 30 minutes. The average travel time in the other cities ranged from between 40-60 minutes. Similarly, Tianjin and London have – compared to the other cities – shorter average travel distances of 4.8 and 3.8 kilometres per capita. Similar to Hong Kong and Shanghai, the private car ownership rate and motor vehicle use intensity in Tianjin are not yet very high, which demonstrates that the city is not highly dependent on private cars.

Based on these characteristics, Tianjin is in a perfect position to lead its residents to travel green, provided that the government will introduce effective and timely policies to curb private car ownership, and in parallel, vigorously build an efficient and convenient public transit system. Furthermore, comparing the transport modal share of the five cities, the proportion of active mobility (walking and cycling) accounts for 69% of total trips in Tianjin, which is much higher than that of Shanghai (50%). However, the modal share of bus transit of Tianjin is the lowest amongst all cities, accounting for only 9%, which implies ample room for improvements.

Figure 2-3 shows the average daily travel distances of individuals by rail, bus, and bicycle in Tianjin. The average travel distance of trips by rail transit is 12.6 km, which is suitable for those needing to travel longer distances. The average travel distance of bus trips is 8.3km, which is suitable for medium and long-distance travel. Bicycles, which are suitable for short-distance trips, already have an average travel distance of 1.8km, in Tianjin. With a high proportion of active mobility already in its modal share, the question of how to improve the attractiveness of subway and bus travel – while maintaining the popularity of active mobility – has become a core issue for Tianjin. With the continuous improvement and expansion of the Tianjin subway network, the contradiction between the development of the subway and bus networks has become more and more prominent. Keeping the development requirements of the city and its transport sector in mind, a further integration of the bus and subway networks should be promoted. In this regard, bus networks can work in a complementary manner with rail networks within the overall public transport system of Tianjin in two main ways:

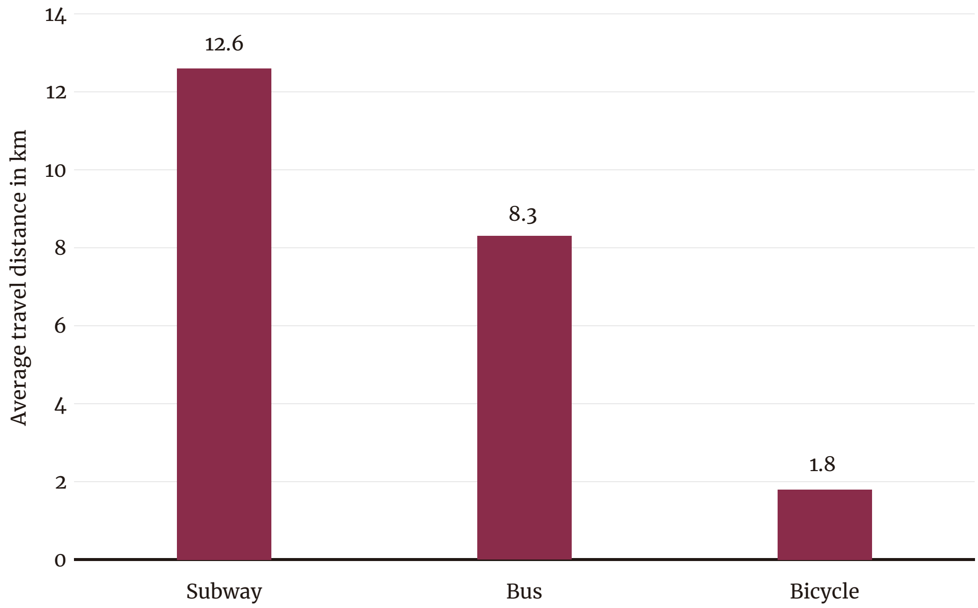
(1) In urban areas, buses should serve corridors with major passenger flows that are not already covered by subway transit networks, and bus lines that overlap with subway coverage should be reduced.

(2) In suburban areas, buses should function as a supplement to the subway transit network and play the key role of connecting and feeding passengers from their homes and destinations to subway stations.

Table 2-3: Comparison of travel behavior in selected cities

Indicators		Tianjin	Beijing	Shanghai	London	Seoul
Number of trips per capita per day		2.4	2.8	2.4	2.2	2.6
Travel time per capita in minutes		30	52	47	30	41
Travel distance per capita in km		4.8	12.2	6.9	3.8	-
Private car ownership rate per household		0.42	0.84	0.42	0.80	0.67
Motor vehicle use intensity per day in km		32.0	41.5	39.0	27.7	-
Mode share	Walking	36%	31%	22%	37%	22%
	Bicycle	33%	9%	28%	4%	1%
	Subway transit	1%	14%	9%	16%	15%
	Bus and tram	9%	20%	13%	18%	22%
	Taxi	5%	4%	6%	2%	9%
	Private car	16%	22%	22%	23%	30%

Figure 2-3: Average distance of individual subway, bus, and cycling trips in Tianjin



The TMEDI Plan includes optimization targets regarding an adjustment of the structure of transport networks, a reduction of usage costs, further regulation of capacity, and a strengthening of connections between different forms of transport. However, these targets are all qualitative in nature. To ensure a smooth implementation of the plan, it is highly recommended to add quantitative targets as well. As outlining concrete and feasible quantitative targets is a resource-intensive process, due to the limited scope of this research, this study does not propose any specific quantitative targets to be added to the TMEDI Plan. However, for the purpose of illustration, some examples of quantitative targets used as central elements of planning in other cities in China and globally are provided here:

1. The Jinan Urban Bus Transport Plan states that the proportion of bus transit to other modes of travel should reach 30% in the long-term (by 2020) and should account for more than 60% of the city's motorized travel. The average commuting time should not be longer than 45 minutes. Also by 2020, the coverage rate of bus stops every 300 meters should reach 75% and a passenger satisfaction rate of at least 80% of bus transport users should be achieved.[7]

2. The Master Plan of Shanghai City (2017-2035) includes a plan to build a comprehensive transportation system that is "safe, convenient, green, efficient and economical". By 2035, bus transit in central urban areas should account for about 50% of the total modal share of transport options, the proportion of green transport modes should reach 85%, and the 600-meter coverage rate of central urban subway transit stations should reach 60%.[8]

3. London aims to increase the modal share of bus transport to 34% and non-motorized transport to 30% by 2031.[9]

4. Singapore proposes to improve the quality of the experience of using bus transit networks, prioritize road rights relating to bus transit, and expand the urban rapid transit network and its overall capacity. According to the plan, by 2030, Singapore's modal share of bus transit will reach 75% and the 500-meter coverage rate of bus stations will reach 80%.[10]

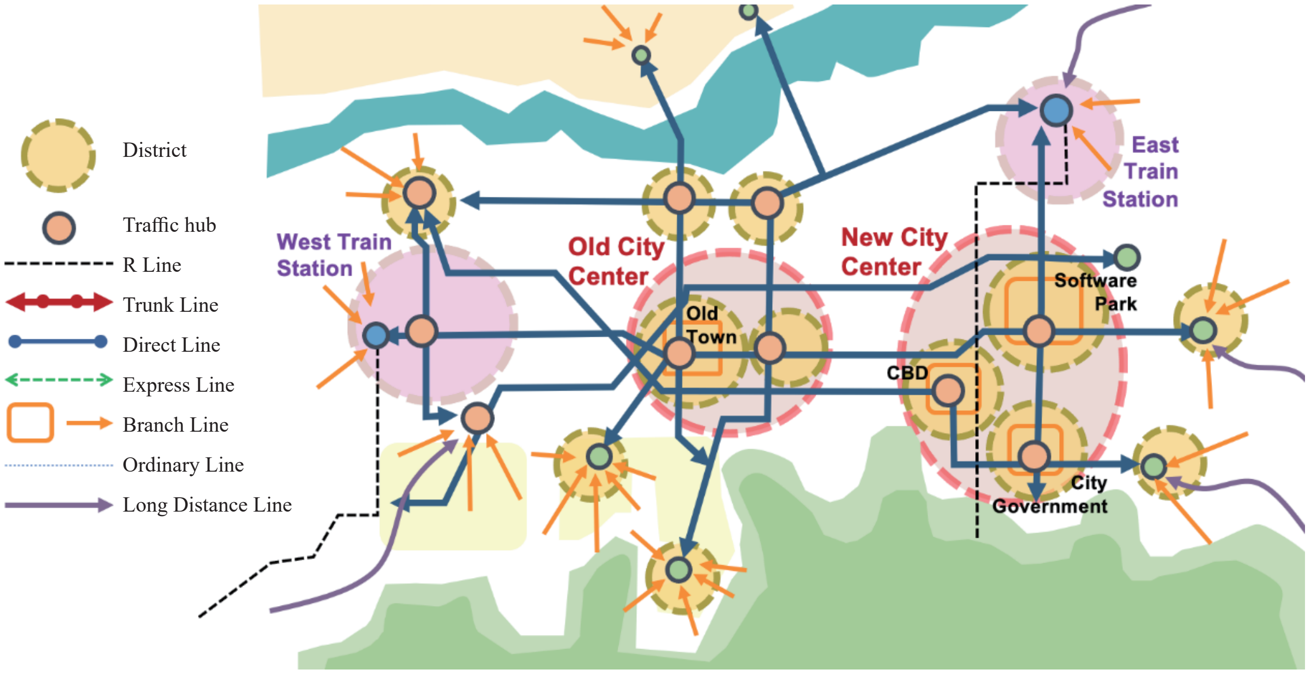
c) Bus Network Structure

An understanding of Tianjin's overall bus network structure needs to be further developed. The TMEDI Plan divides bus lines into four categories: 1. Trunk lines; 2. Ordinary lines; 3. Branch lines, and; 4. Suburban lines (see Table 2-4). While the plan does outline the functional description and structural proportions of each type of line, it could be complemented by a more thorough discussion of the possible overall restructuring of the bus network and a visual presentation of it. A spatial visualization of the bus network and the subway network in relation to the overall public transport system would be a useful planning tool. It is thus suggested that a visualization of the new bus network structure, illustrating its relationship with the subway network, the bus line network at all levels, and the main nodes and hubs in the Tianjin central urban area should be added. An example of the type of mapping diagram that could be drafted is provided in Figure 2-4.

Table 2-4: Structural classification of Tianjin's bus network

Line Type	Description of Line Function	Structural Proportion (# of bus lines/Total # of bus lines)
Trunk line	Service area: Between administrative areas in the central urban area. Main features: Bus lines that mainly serve medium and long-distance travel, with a large passenger flow and go directly to the destination. Trunk lines are arranged along the main passenger corridors in the central urban area, taking into account the four districts around the city, connecting the main hub nodes. The route direction should be misaligned with that of subway transit as far as possible, with a minimal bypass coefficient.	15%
Ordinary line	Service area: Within and between administrative areas. Main features: Ordinary lines rely on some trunk corridors, connect secondary hub nodes, fill the service gap of subway and bus trunk networks, and are focused on making riding convenient to users.	55%
Branch line	Service area: Within administrative areas. Main features: Branch lines connect the function points of schools, hospitals, shopping and transportation hubs, subway stations, etc. Their one-way length of travel is short, and their bypass coefficient is not limited.	15%
Suburban line	Service area: Connecting Binhai New Area and the five new districts (Baodi, Ninghe, Jinghai, Wuqing, Jizhou). Main features: Suburban lines connect the central urban area with Binhai New Area and the five new districts, giving due consideration to the connection function between the central urban area and the four surrounding districts (Dongli District, Jinnan District, Xiqing District, Beichen District), and create connections between these hubs as thoroughly as possible.	15%

■ **Figure 2-4: Example of a bus node diagram**



(Source: Jinan bus line network reconstruction project)

2.4 Conclusion

The TMEDI Plan analyses the status quo of the Tianjin bus network, puts forward optimization targets and suggestions for network optimization, provides a staged adjustment scheme, and outlines the expected impacts of the plan's implementation. This research considers the structure and findings of the plan to be reasonable, and its content to be comprehensive and detailed. However, in the interest of making the plan as effective as possible, to strengthen it further, we propose the following suggestions:

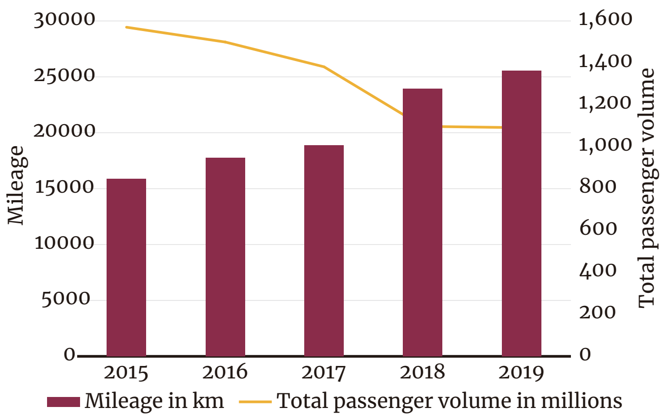
- To set an overall objective of enhancing the attractiveness of Tianjin's urban rail and bus transit options, while still maintaining the high modal share of active mobility.
- To add quantitative indicators and milestones to the bus network optimization objective to measure its goals and ensure its smooth implementation.
- To differentiate Tianjin's optimization goals for the central urban area and the rest of the city.
- To add route maps with detailed spatial analyses that demonstrate geographic overlaps and relations between different bus lines and possible ways to adjust them accordingly.

3 Optimisation of Bus Operation Capacity Allocation

3.1 Background

By 2019, the total mileage of bus lanes in Tianjin had surged to 14,951.7 kilometres, - this was an increase of 2,101.5 kilometres from 2018. Over the same year, the total operating distance increased by 137,000 km, reaching 1.336 million kilometres miles covered. However, in spite the increase in bus lanes, the total passenger volume of bus travel went on a downward trend, dropping from 76.54 billion in 2015 to 69.18 billion in 2019. From 2015 to 2019, the bus operating distance increased, but the bus passenger volume shrank (Figure 3-1). The main reasons for this trend were found to be the competition that bus transit faced from the expanding subway system, as well as a series of issues of the design and operation of the bus network itself.

■ **Figure 3-1: Bus mileage and passenger volume in Tianjin from 2015 to 2019**



(Source: TMEDI)

3.2 Research Objective and Structure

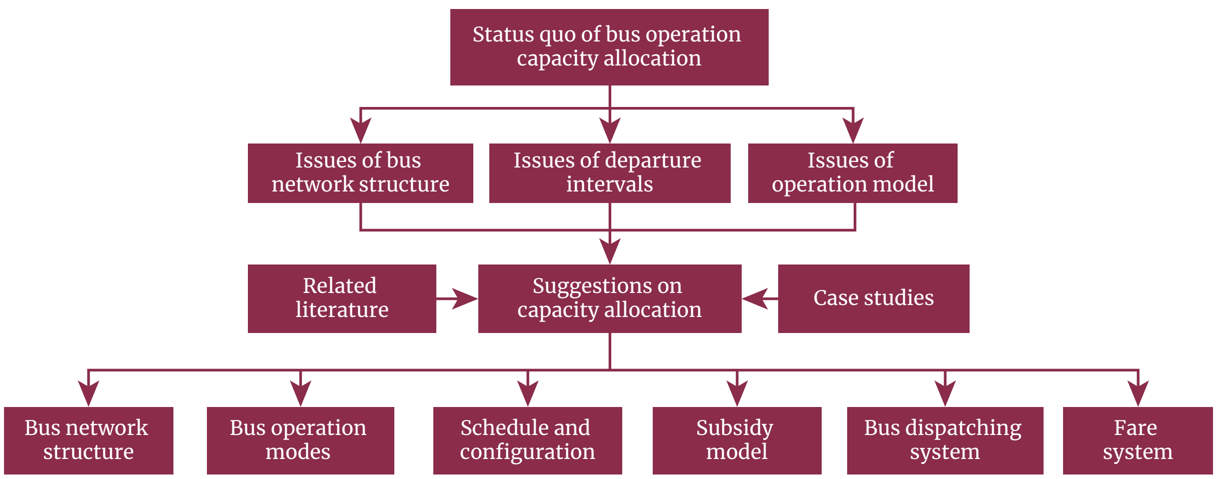
Findings from research discussed in Chapter 3 can be separated into two main outcomes:

1. An evaluation of the status quo of bus capacity allocation in Tianjin: This chapter first discusses the most urgent issues related to the structure of the bus network, departure intervals, and general operating model of bus transit in Tianjin.

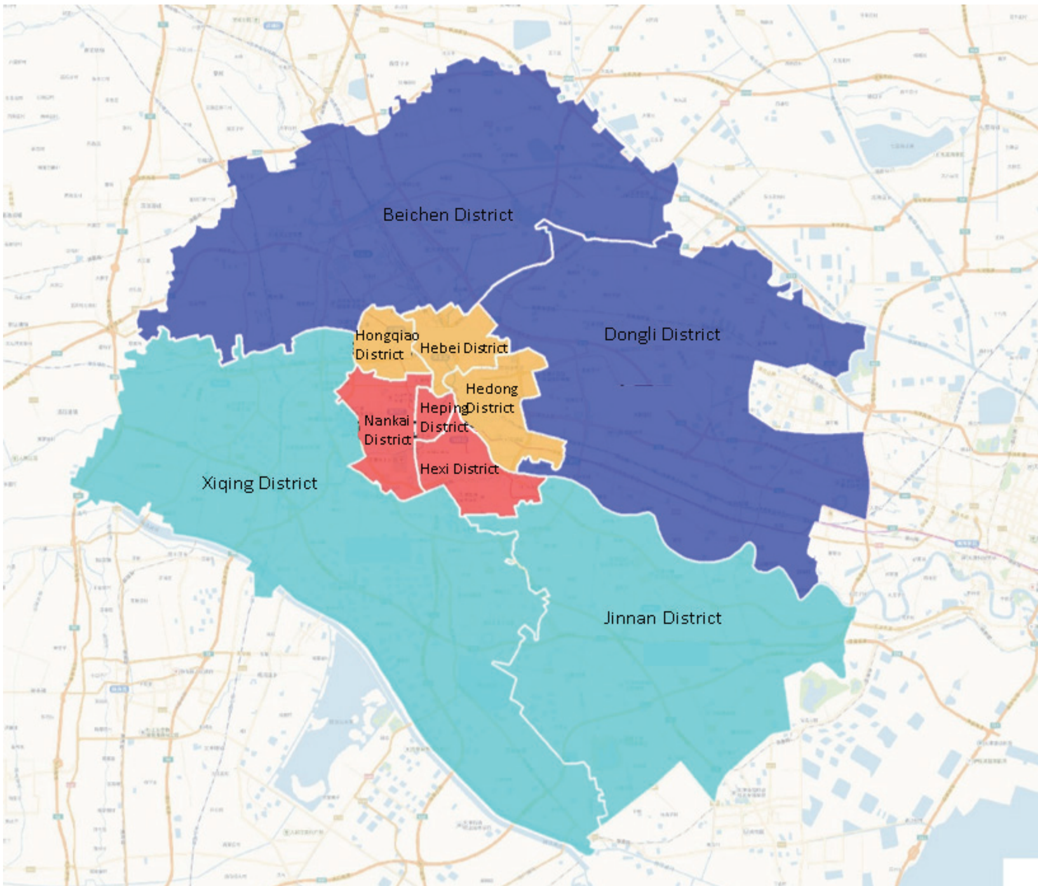
2. A provision of suggestions for the optimization of bus capacity allocation in Tianjin: To address identified challenges, the chapter will discuss comprehensive suggestions, based on findings from relevant case studies and literature. The findings will be summarized in a conclusion at the end of this sub-study.

A general outline of findings of the research outlined in this chapter is presented in Figure 3-2. Again, the research scope of the study is the central urban area of Tianjin, including the downtown area with its six districts (Heping, Hexi, Hebei, Nankai, Hedong, and Hongqiao) and its four surrounding ring districts (Jinnan, Dongli, Xiqing, and Beichen). The geographic scope of this research is presented in Figure 3-3.

■ **Figure 3-2: Research structure**



■ **Figure 3-3: Geographic research scope (Source: TMEDI)**



3.3 Status Quo of Bus Operation Capacity Allocation

This chapter section addresses the main issues related to the capacity allocation of Tianjin's bus network. Areas which have been identified as needing attention in order to better strengthen the network include issues with the structure of the bus network, departure intervals, and the system's overall operating model.

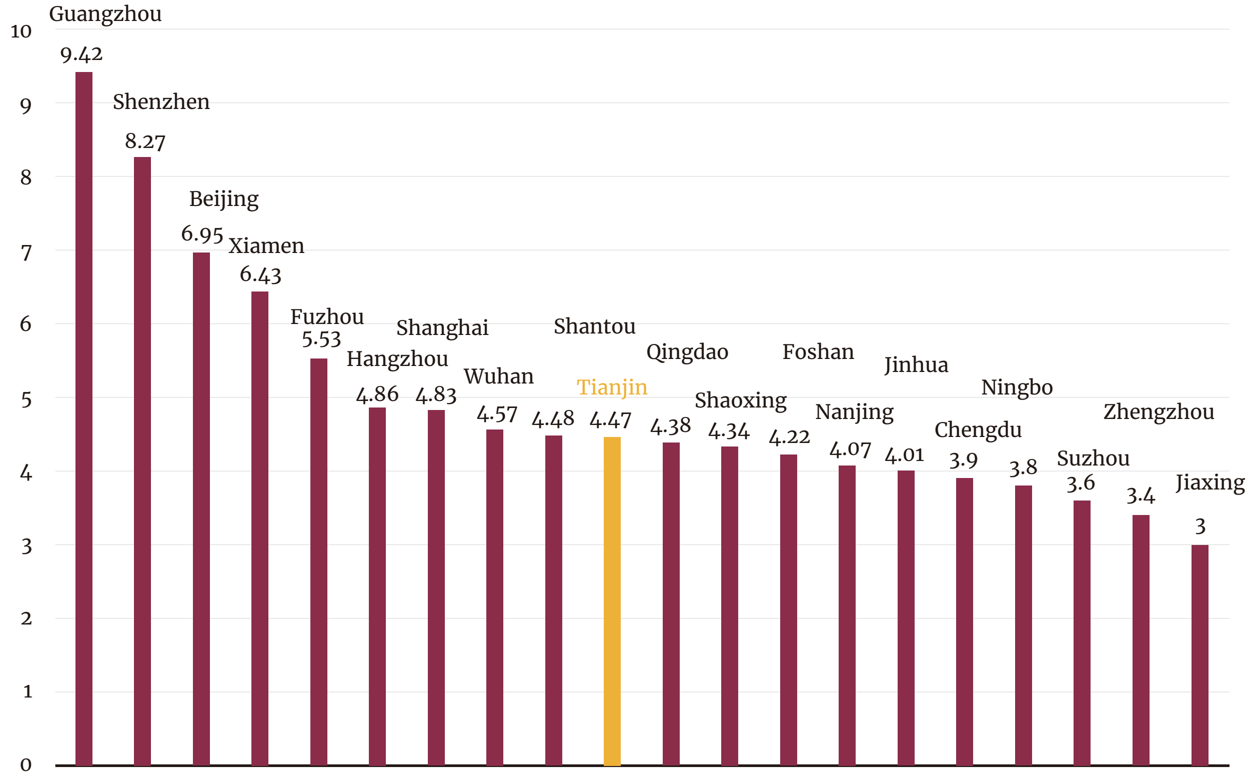
3.3.1 Issues of the Bus Network Structure

a) High Line Repetition Rate

The length of the bus network covering the central urban area of Tianjin is 1,699 kilometres, while the total length of all bus lines is 7,593 kilometres. The repetition rate of bus lines in Tianjin is 4.47, which, compared with that of other Chinese cities of similar size and population, is considered to be high. As shown in Figure 3-4, the repetition rate in Tianjin is higher than that of Qingdao, Nanjing, and Foshan, but lower than that of mega cities like Beijing, Shanghai, Guangzhou, and Shenzhen.

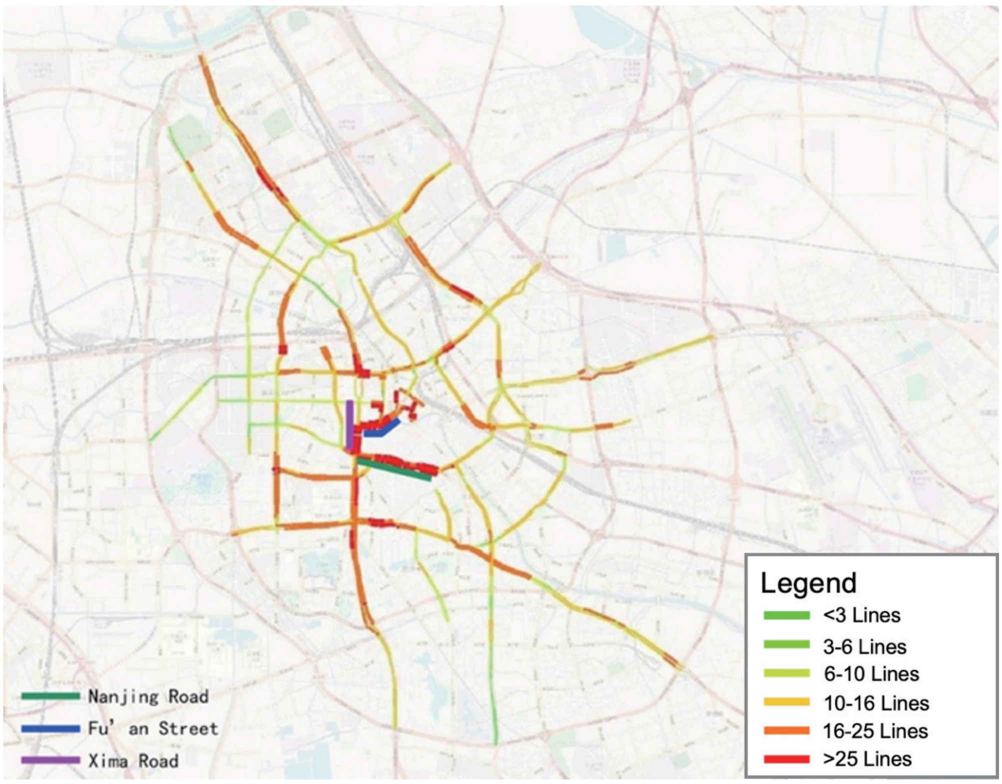
Figures 3-5 and 3-6 analyse the number of bus lines running on dedicated bus lanes, and the number of bus lines passing by each bus stop respectively. There are more than 25 bus lines along Nanjing Road, Fu'an Street, and Xima Road Corridor. These bus lines all pass through the same stations, resulting in a high number of buses stopping at the same point. As an example, 35 different bus lines are passing through Beimen Station and 14 through Xiangjiang Station (Figure 3-6), resulting in an increase in bus queuing times and bus delays. Buses running on different shifts catch up with, and overtake each other, creating a bunching of waiting buses at these stations, particularly during morning and evening peak hours. Such a high repetition of bus lines and stations leads to a waste of public transport capacity, and works against its own progress, resulting in lower passenger flows on each bus line in spite of the running of a high number of vehicles.

Figure 3-4: Comparison of bus line repetition rates of major cities in China



(Source: Amap 2017, Big Data Analysis Report of Public Transport in Major Cities in China)

Figure 3-5: Statistical diagram of the number of bus lines in dedicated lanes



(Source: TMEDI)

■ Figure 3-6: Total number of bus lines (two-way statistics) passing by bus stops

(Source: TMEDI)

b) Lengthy Bus Lines

Currently, there are 538 bus lines covering the central urban area of Tianjin. The distance of each bus line ranges from 10 to 50 km, with an average running length of 25.13km. As shown in Figure 3-7, in 2019, Tianjin ranked as the third city in China with the highest average of length of bus lines, amongst 36 benchmark municipalities, with Lanzhou and Haikou ranked at the top of the list.

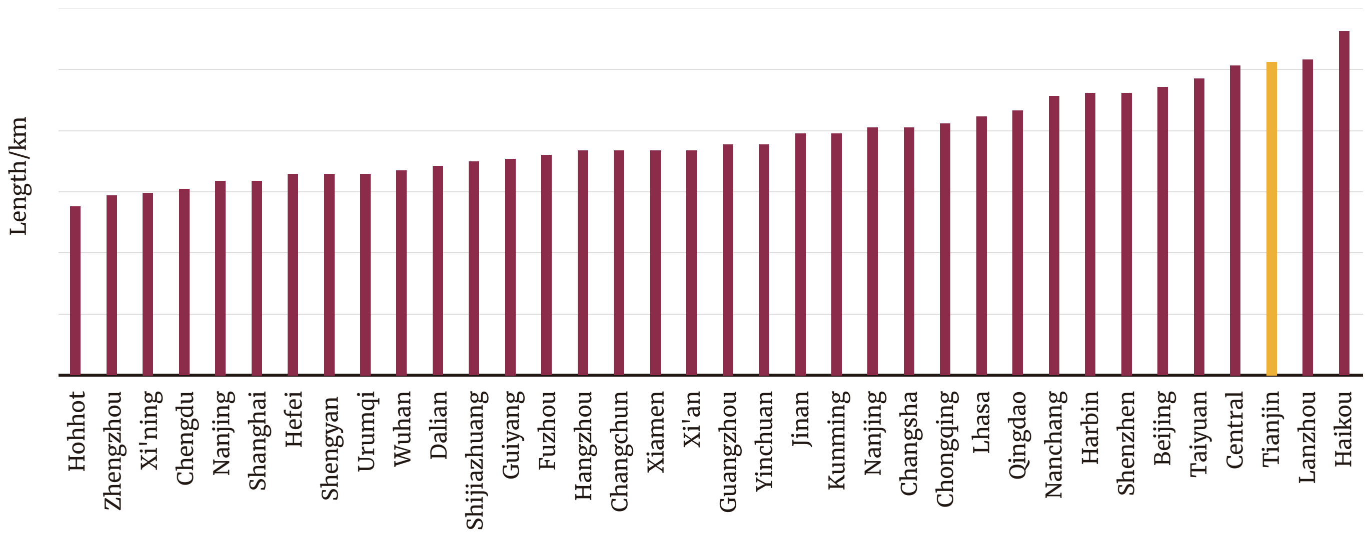
As specified in the “Rules for the Setting and Adjustment of Bus and Tram Network (Draft for Soliciting Opinions)”[12], the length of urban express lines should be 15-30km, trunk lines should be 12-25km, and branch lines should be 8-15km. Longer bus lines are inefficient for cities, as they can easily lead to high operation times, low punctuality rates, and poor reliability, which negatively affects the overall user experience.

The longer the distance of a bus line, the longer the operation time becomes and the number of buses required to meet passenger demands becomes higher. Long routes have many bus stops along the way, which increases the risk that – along parts of the route – buses will have low passenger flow, thus not allowing the vehicles to operate at their full capacity.

Comparing the line length by average number of vehicles used in Tianjin, Figure 3-8 shows that the average number of buses used for bus lines covering 30-50 km is 15, while the average number of buses used for the shorter 8-15 km lines is only 5.

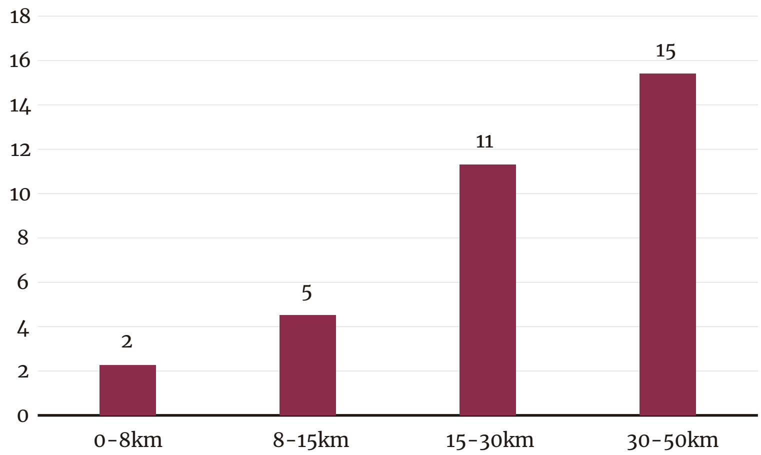
As shown in Table 3-1, there are a total of 97 bus lines that overlap with more than 6 subway stops. Higher levels of overlap between subway and bus network coverage leads to waste of both bus and subway network capacity.

Figure 3-7: Average distance of bus lines in cities in 2019



(Source: China Urban Passenger Transport Development Report)

Figure 3-8: Number of vehicles allocated on different length bus lines in Tianjin



(Source: TMEDI)

Table 3-1: Overlaps of bus and subway networks in Tianjin (Source: TMEDI)

	Quantity
Bus lines with subway overlap	383
Bus stations with subway overlap	1,606
Average number of parallel stations per line	4
Lines with over 10 parallel stations	21
Lines with 6-10 parallel stations	97
Lines with 1-5 parallel stations	265

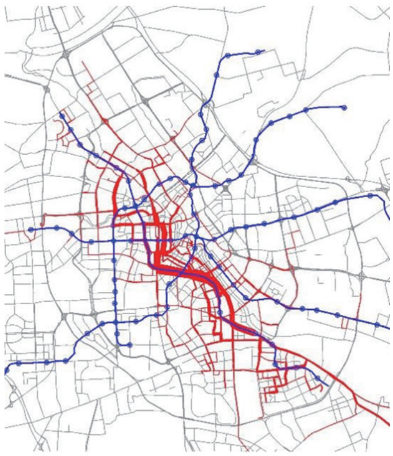
[12] National Standard Number: GB/T 37114-2018/《公共汽电车线网设置和调整规则（GB/T 37114-2018）》

c) Lack of Targeted Departure Interval Setting for Peak and Off-Peak Periods

There is a significant difference in bus passenger flows between off-peak and peak travel hours. As shown in Figure 3-10, the peak of passenger flows in Tianjin is between 7:00 and 8:00 a.m., accounting for 12% of the total number of bus trips of the day, followed by 5:00 to 6:00 p.m., accounting for 9% of the total number of bus trips of the day.

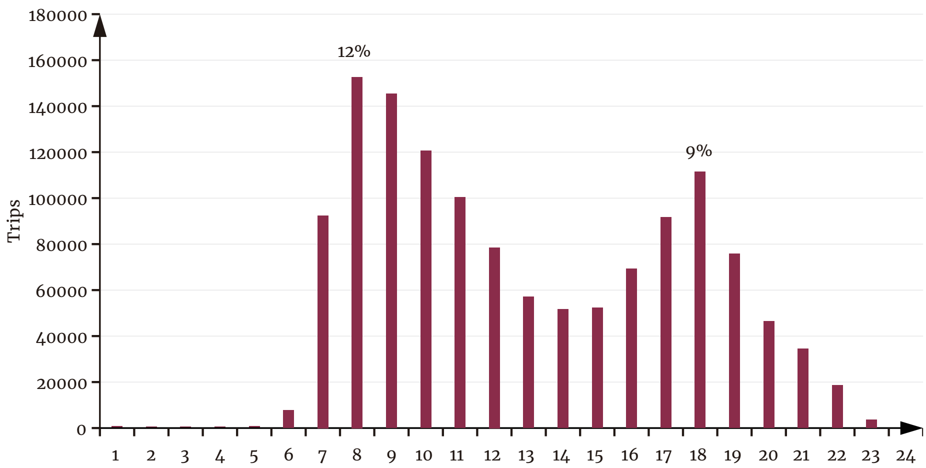
Bus capacity allocation, in terms of departure intervals between peak and off-peak hours, is not correlated to passenger flows, which creates inefficiencies during peak hours and a waste of capacity during off-peak hours. As shown in Figure 3-11, during peak hours, 11% of lines depart every 6-11 minutes, 43% depart every 11-20 minutes, and 47% have a departure interval of over 20 minutes. During off-peak hours, 8% of bus lines depart every 6-11 minutes, 37% depart every 11-20 minutes, while 56% have a departure interval greater than 20 minutes. This comparison confirms that, while bus passenger flows during peak and off-peak hours significantly differ, bus capacity allocation is not being adjusted in accordance with customer demand. Matching the peak and off-peak hours departure intervals with the actual passenger flows will greatly increase the efficiency of the Tianjin bus network. With over 30% of lines having a departure interval of more than 30 minutes during peak hours, the average departure interval of bus lines in Tianjin is rather long. Such long departure intervals decrease the reliability of bus lines, while increasing waiting time and uncertainty for passengers. This may lead to an unpleasant customer experience and a subsequent decrease in demand for bus services.

Figure 3-9: Distribution map of bus corridors that overlap with Subway Line 1



(Source: TMEDI)

Figure 3-10: Passenger flows during peak and off-peak hours in Tianjin



(Source: TMEDI)

3.3.2 Issues of the Operating Model

a) Ticket Price Setting is not Cost-Effective

At present, the Tianjin bus fare system is using a flat fare. Single journeys for bus lines in the urban area cost CNY 2 (EUR 0.25), and passengers can receive a 5% discount if they travel using a bus card. This current single-fare system forces short-distance passengers to subsidize long-distance passengers, which is not only unfair but also fails to reflect the relationship between fares and actual operating costs. As explained in the previous chapter, the geographic length of bus lines in Tianjin tend to be too long. If the single fare system were to be maintained if long bus lines were divided into several lines, some passengers would have to pay twice. In addition, the single fare system is not conducive to supporting passengers to cost-effectively transfer between bus and subway services, because Tianjin's subway system currently implements a distance-based ticket fare system. This means that based on cost, passengers have an incentive to travel longer distances by bus rather than the subway. Furthermore, there is no discount for passengers who wish to interchange between bus and subway lines on their journey, which negatively affects the integration of the two systems.

b) Low Passenger Volumes per Kilometre

The value of passenger volumes per kilometre represents transport efficiency. As shown in Figure 3-12, in comparison with 36 benchmark municipalities, the volume value of Tianjin (2.07 passengers/km) is lower than the average volume value (2.5 passengers/km), which shows that the efficiency of bus transportation in Tianjin offers room for improvement. The city of Xining has the largest bus passenger volume per kilometre (3.99 passengers/km). Regarding China's 1st tier cities[13], the passenger volume per kilometre in Beijing is the highest, with 2.44 passengers/km, while Shenzhen is at the lowest level (1.38 passengers/km). The rates in Shanghai (1.96 passengers/km), Guangzhou (1.99 passengers/km), and Tianjin are about the same level, ranking in the lower half of the list.

As can be observed in Figure 3-13, the passenger volume per kilometre in Tianjin reaches a maximum value of 3.00 for bus lines between 20km and 30km length. On an average, for lines with a length above 30km, the value drastically declines as line length increases. Lines with a length below 20km are slightly less efficient on average. Overall, this shows that bus transit in Tianjin is less efficient on longer routes than shorter distances.

c) Ineffective Subsidy Policy

According to the latest regulations[14], subsidies for energy consumption, warranties, tires, and any other operating expenses are currently determined based on the operating mileage of a bus line, instead of its passenger volume. Such a type of subsidizing policy can have a negative effect on the efficiency of bus companies, as it may incentivize them to blindly extend bus operating distances.

[13] In China, cities are classified into tiers based on their level of social-economic development. Even though there are no Government-issued classification standards, it is widely acknowledged that the four 1st tier cities are: Beijing, Shanghai, Guangzhou, and Shenzhen. 2nd tier cities are generally the better performing provincial capitals cities.

[14] Tianjin City Bus Operating Cost Regulation Measures (Trail) / 天津市公共汽车运营成本规制办法（试行）

Figure 3-11: Proportion of bus departure interval lengths in the central urban area of Tianjin, in minutes (Data source: TMEDI)

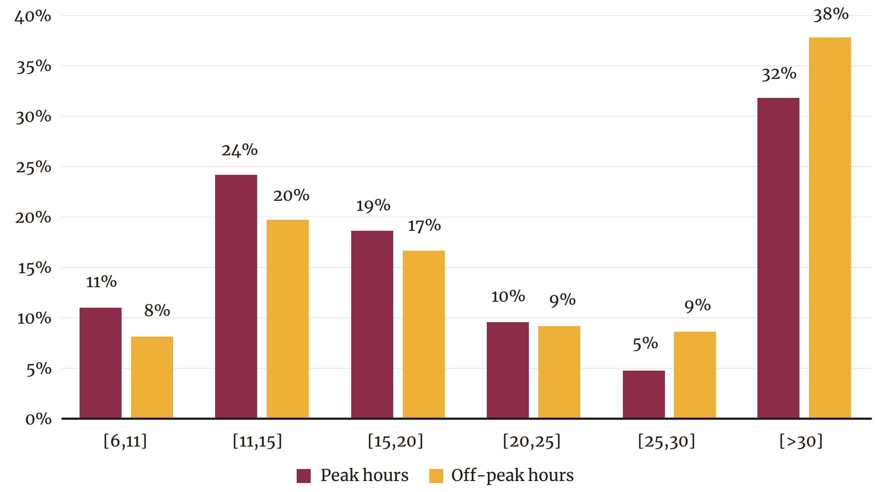
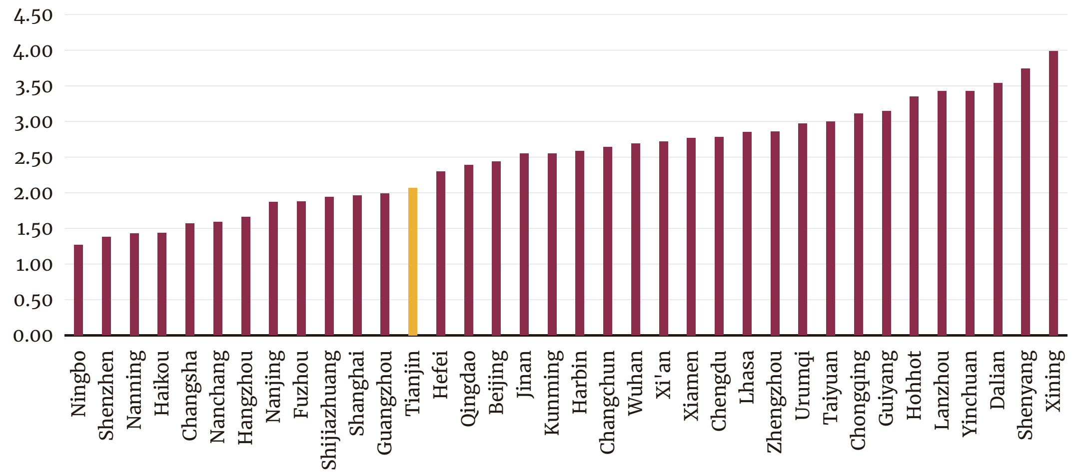
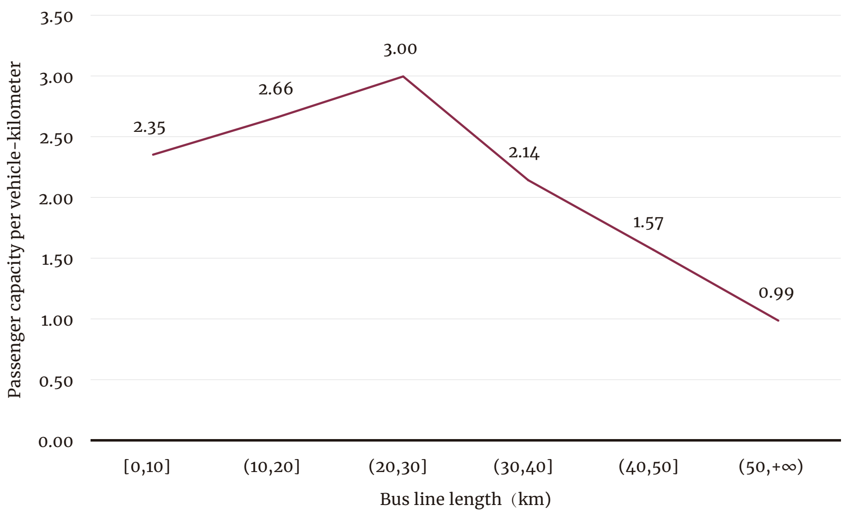


Figure 3-12: Passenger volume per kilometre in Chinese cities in 2019



(Source: [11])

Figure 3-13: Comparison of passenger volume per km at different line lengths in 2019



(Data source: TMEDI)

3.4 Suggestions on Capacity Allocation

Based on the issues relating to capacity allocation identified in this research, this chapter section will provide suggestions on how these challenges might be effectively dealt with.

3.4.1 Optimize the Bus Network Structure

a) Establish a Multi-Layered Network Line System

The structural problems of a high repetition rate, lengthy lines, and untargeted departure intervals show the necessity to optimize bus line networks and restructure bus transport system capacity allocation. To solve those problems, it is suggested to divide the bus line network into four levels (see Figure 3-14):

1. Trunk lines. Trunk lines are mainly arranged along the corridors. They connect all levels of hubs and fulfil the majority of travel demand.

2. Direct lines. Based on the general trend of passenger flow, "zigzag" direct lines are added to further improve the service level for passengers and reduce transfers. Most of the direct lines run within the corridors, while a small part of the ends of lines may extend beyond the corridors.

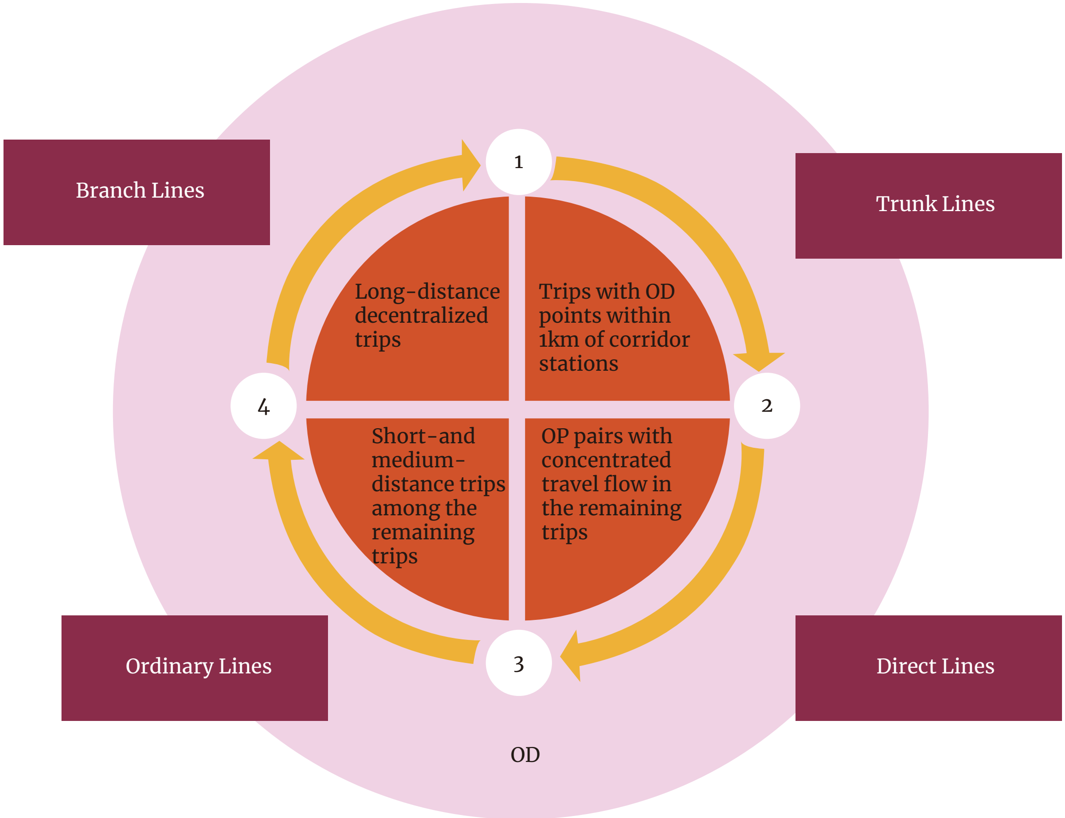
3. Ordinary lines. Ordinary lines are mainly located in between main corridors to cover areas that lack public transport services, and serve the demand of medium- and short-distance travel.

4. Branch lines. Branch lines can be divided into two types. One type connects the main residential areas with the periphery hubs of the main corridors, serving as connection travel from homes to transport hubs. The other type connects the main corridors and commercial areas, providing service to passengers who travel from main corridors to offices.

5. Long-distance lines. Long distance lines connect the central areas of new towns to peripheral and/or large residential areas with external transfer nodes in central area.

The key to establishing a multi-layered bus network is the effective use of passenger Origins and Destinations (OD) data. OD data can be used to plan the effective operation of bus networks, if specific steps are followed. First, out of all passenger trips, the ones with OD points within 1 km range of corridor stations shall be identified and connected through trunk lines. Second, find OD pairs with concentrated travel flows in remaining trips and serve them through direct lines. Third, continue to screen short- and medium-distance trips among the remaining trips and serve them through ordinary lines. Finally, for decentralized long-distance trips, provide services in the form of branch and trunk lines. Finally, OD data should be correlated with data on lines with problems such as frequent stops with no passenger flows, lines without effective connections or supplemental duties to subway networks, lines taken with circuitous routes, or extensively lengthy lines, and these routes should be reduced or integrated into other relevant lines.

Figure 3-14: Schematic diagram of line service types at different levels



(Source: Pre-Feasibility Study for the Shandong Spring City Sustainable Urban Mobility Development Project, September 2016)

b) Optimization of Bus Line Management

The current operation mode of the Tianjin bus network poses certain obstacles to the adjustment and optimization of the line network. The main obstacle is that the operation system lacks efficient exit mechanisms. Once a bus line is put into operation, it is difficult to cancel or shorten the line, and it can only be retained or extended. There are three causes for this issue:

1. Due to the operating history of the public bus company, there are systematic challenges in setting up a performance-based market mechanism for bus line operation and alteration.

2. Current subsidies are provided without consideration of the actual passenger volume of bus lines. Therefore, there is no financial incentive for bus companies to cancel lines with low passenger volume.

3. As bus companies are faced with punishment measures when citizens file complaints, they fear to abolish even bus lines with low passenger flow, as this might lead to angry passengers.

Bus lines operating with very few passengers are a huge waste of bus capacity. Therefore, it is recommended to learn from the experience of other cities to establish a performance-based evaluation system that encourages operation efficiency, and allows for the cancellation or alteration of lines as needed.

In 2011, the city of Shenyang introduced an exit mechanism for the cancellation of bus lines. This mechanism forced bus lines with serious levels of unpunctuality, long departure intervals, and high complaint rates to stop operation. Underperforming lines had contracts cancelled, and bus companies could then relaunch an open bid for the operation of new lines. This mechanism was made possible because of the city authority's determination to improve bus line management as well as its desire to establish an effective monitoring system for bus services. Not only were under-performing lines forced to exit inefficient contracts, but bus companies also lost the operation permission for such lines.

The city of Foshan operates its bus system through the mode of "three-layer-management" (i.e., a city government layer, a bus company management layer, and a bus company operation layer). At the city government level, the transport authority provides policy guidance and strategic decision making. At the level of bus company management, Foshan established the Foshan Public Transport Management Co., Ltd. (Foshan TC) with district-level operation and management sub-centres. The Foshan TC is responsible for the development of a unified ticket and fare system, and a dynamic and adjustable operation mechanism. The Foshan TC manages and coordinates all bus companies. At the level of bus company operation, the Foshan TC conducts supervision, assessment, and evaluation of the bus companies on a monthly base, according to the terms and conditions in the service contracts signed with them. The comprehensive assessment is carried out in accordance with the city's special regulations.[15] Rewards and penalties are issued to the bus companies based on the assessment conducted by the Foshan TC.

3.4.2 Establish Diversified Bus Operation Methods

With the continuous improvement of Tianjin's subway network, the traditional bus operation mode with fixed lines, fixed stations, and fixed departure times is not competitive to the subway system. Regular bus transit should find different methods to meet the diverse and personalized travel needs of residents to improve the overall operating efficiency of the bus system. For example, it would be purposeful to establish diversified and flexible bus operation line systems such as on-demand buses, direct lines, special group service lines, and responsive buses.

a) On-Demand Buses

"On-demand Buses" are a high-end bus service provided for middle- and high-income groups during morning and evening peak hours. They are usually used for commuting purposes that connect popular residential areas and business centres by direct lines or to the subway. Such buses are punctual, direct, and comfortable with reserved seats. The fare for these buses is market-based and is usually much higher than that of conventional buses. For example, the Shanghai Hongqiao Business Area is located over 2 km away from the nearest subway station. Based on large demand, an on-demand bus line operates two new energy buses that run every 10 minutes between the Hongqiao Business Area and the nearby public transit station.

b) Bus Pooling

Bus pooling is an upgraded version of on-demand buses. Similar to carpooling, passengers can set up temporary travel demands, and a bus will be provided when a certain number of passengers can be ensured. Passengers can set their routes according to their needs and would not be limited to using fixed bus lines. Bus pooling mainly meets the provisional travel demands of passengers. Its largest advantage is dynamic service, and is similar to online car-hailing businesses, but has a larger carrying capacity. Because its capacity is greater, bus pooling needs to rely on accurate algorithms or advanced technology to provide quality and affordable service to the public.

The "online reservation and travel via bus pooling" service run by the Beijing Public Transport Corporation provides bus pooling services from large residential communities to business districts and major transport hubs. These bus lines utilize intelligent public transport and big data platforms to create a diversified and comprehensive public transport service network. When requests are received from the interactive platform, a new shuttle bus can be provided. To ensure comfort and punctuality, seats are reserved in advance.

The "Shenzhen E-Bus" (E-Bus) program by the Shenzhen Eastern Bus Group, is a bus pooling service that follows the "online reservation and one seat per person" principle. Passengers can forward their demands online, then the operating enterprise plans routes according to the aggregated demand and then provides buses. The differences between this program and service provided by regular bus lines are: 1) Shenzhen Eastern Bus is a private enterprise and adopts a B2C[16] operation mode; 2) E-Bus shares their drivers, buses, and other resources with public transport companies to revitalize existing public assets and seeks to achieve a "lightweight" operation mode, and; 3)

[15] "Methods of Foshan for Assessing Service Performance of Buses and Trams" and "Methods of Foshan for Assessing Service Quality of Buses and Trams".
[16] Business to Customer

Fare policies are separated from those of regular buses and the service is self-sufficient, relying on operation efficiency and management innovation.

c) Non-Stop Express Lines

Non-stop express lines are similar to regular buses, but have fewer stops and higher speeds. Passengers can swipe cards and take the bus at fixed times and stations without reservations.

A good example of a non-stop express line is the N^X of San Francisco.. The Light Rail Line N^X is the busiest line of the San Francisco light rail network, with an average daily passenger flow of more than 40,000 people. To alleviate congestion and reduce passenger delays, the non-stop express bus line is available in the morning (6:00-9:00 a.m.) and evening (4:00-7:00 p.m.) every day. Running on an interval of 10 minutes, the non-stop line has 36 shifts throughout the day and provides transport service from residential areas to the central business district (CBD), with an average daily passenger flow of more than 1,400 passengers (Figure 3-15).

The CBD of Beijing has a total of 17 non-stop express lines run by the Beijing Public Transport Corporation. The fee collection method for this service is relatively fixed, and the lines are often available during morning and evening peaks from Monday to Friday, and mainly serve commuters. The lines stop at several stations near the final stops, have very few stops near the middle of the route and often have a long length. The non-stop express lines of the CBD have addressed the commuting demands of some passengers from remote areas, and as a kind of bus transit service with special stations and lines, their routes and times are more fixed than on-demand buses.

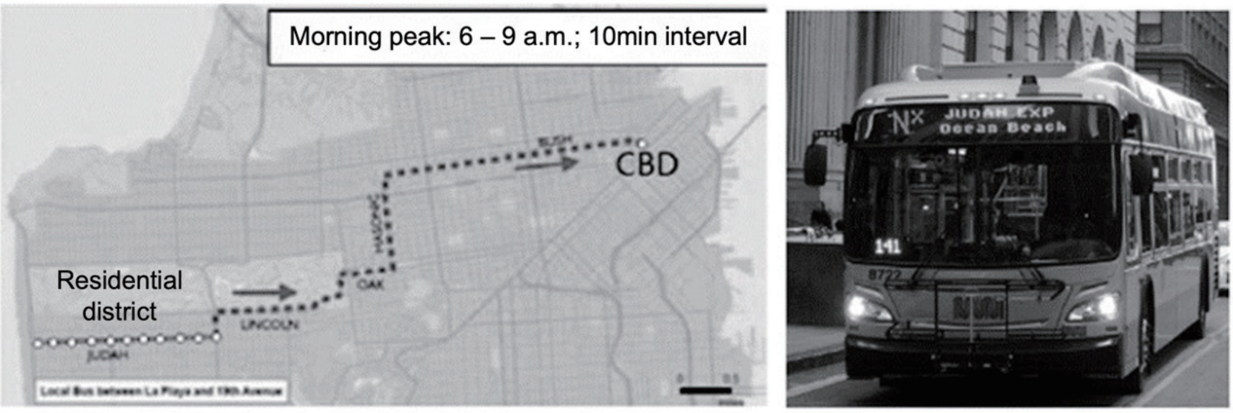
d) Non-Stop Buses to Shopping Malls

In Jilin, non-stop bus lines driving directly to shopping malls have been introduced. The Jilin Public Transport Group investigated and analysed cluster areas with "night economy" activities and planned six non-stop bus lines to night markets. This has stimulated the vitality of the "night economy" of the city and created safe and convenient conditions for citizen's to travel at night. These bus lines are mainly centred on three major areas with well-developed "night economy" markets and form a wide range of coverage.

e) Buses for Vulnerable Groups

Buses for vulnerable groups may have small passenger flows and high costs due to their special designs and equipment, but they also have high significance in terms of social security. Special government subsidies are required to relieve the fiscal pressure on enterprises and give them a further incentive to provide transport services for groups with special needs, including door-to-door bus travel services to remote areas with low population densities that may not even support regular or high-frequency bus lines. Vulnerable groups needing pick-up and drop off transport support include a wide range of citizens, from children who require school buses and other services, to older adults and disabled people that might need to travel to access medical care, shopping centers, and social activities.

■ Figure 3-15: N^X non-stop express line during morning peak hours (left) and non-stop express bus on N^X-Judah Street during morning peak hours (right)



(Source: Chenjing, The Direction and Suggestion of Diversified Development of Ground Bus in Beijing, 13th China Intelligent Transportation Conference, 2018)

An example of a special bus service for vulnerable groups is the ADA Paratransit Auxiliary Transport Service in Chicago. This service offers transportation options for people with disabilities who are unable to use regular, fixed-route services. Only those individuals obtaining a certification letter from the local transport bureau are eligible to take ADA Paratransit. ADA Paratransit must be available in the same service areas and during the same hours of operation as the rest of the transit system, and the service operates in the Greater Chicago Area covering Chicago and the surrounding six counties. The current ticket fare for the ADA auxiliary bus is USD 3.25 (EUR 2.8).

f) Community buses

As a "bus at the door" service, community buses are designed to meet the last mile demand of travellers, providing convenient transport options to community residents for their trips to surrounding schools, hospitals, commercial districts, public activity centres, subway transit stations, bus transfer hubs, and other destinations. Shanghai is currently using community buses to meet the diversified travel demands of urbanized areas. Community buses adopt the operation mode of a "half-hour shift with three minibuses". The Shanghai community bus network covers twelve residential areas, which include entertainment and cultural centres, community hospitals, and other service points in the Hongqiao district. Community buses are an effective way to alleviate the last mile problem which often comes with public transit services.

3.4.3 Optimize Peak and Off-Peak Schedules and Vehicle Configurations

By optimizing the departure interval of bus lines during peak and off-peak hours and configurating the vehicle size needed at different times of the day, it is possible to match passenger demand and flows with the correct frequency and size of buses. During peak hours, it is better to increase the frequency of buses and use larger vehicles to meet high passenger flows. However, in off-peak hours, smaller buses can be used which run with a reduced departure frequency. Bus line schedules should therefore be developed to strictly correspond with variations in passenger flows on the line throughout the day and week.

Zhangjiakou City operates bus lines with schedules and vehicles used in accordance to flow demands. An example bus line from Zhangjiakou has a total length of 15km and a one-way running time of 27 minutes. The peak hours of the line are 8:00 to 10:00 a.m. and 6:00 to 9:00 p.m. The off-peak hours of the line are 6:00 to 8:00 a.m. and 10:00 a.m. to 6:00 p.m. (see Figure 3-17). The highest passenger flow during peak hours is 162 passengers/hour, and passenger flow during off-peak hours is about 100 passengers/hour. The buses operated on this line are the Foton 6650 series battery electric bus with a capacity of 36 people. This type of bus needs to be charged every 60 kilometres, with a single charging time of 40 minutes. Considering passenger flow demand and charging time needs of the line at peak and off-peak hours, it is estimated that the example line needs to be equipped with 10 buses. During peak hours, the departure interval will be every 12 minutes, and the one-hour capacity is 180 people/hour, which meets the demand of passengers during peak hours. During off-peak hours, as the passenger flow decreases, the departure interval would be adjusted to 24 minutes, and the one-hour capacity would be 90 people/hour (see Figure 3-18).

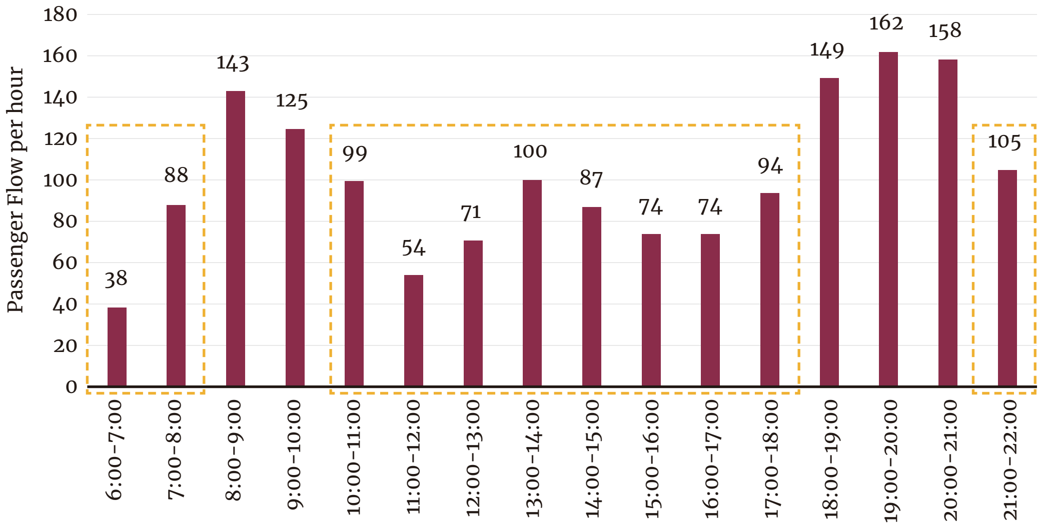
Realizing the optimal configuration of vehicle models that should be used at different times of the day can effectively save capacity and improve efficiency. To effectively adjust service provision to traffic demands, it is necessary to compare passenger volume changes between peak and off-peak hours, adopt a size matching method that promotes the use of large vehicles at peak hours to provide sufficient capacity and comfort, ensure road traffic efficiency, and reduce driver costs. It is more efficient to use smaller vehicles during off-peak hours, which ensures that the demand can be met, but that buses travel with a reasonably full load rate, with buses running at flexible yet appropriate frequencies of departure to ensure the attractiveness of using bus transit routes over other types of transport.

Developing a unified resource base which could serve to coordinate all buses and staff of different bus lines would support a more holistic and efficient dispatch system. This base could analyse the varied distribution characteristics of passenger flows in different location and on different lines at the same time, and then determine which buses should be allocated where and at what times, to more effectively use transport resources. This would additionally help keep service levels and customer satisfaction rates high.

Figure 3-16: ADA Paratransit Auxiliary Transport Service

(Source: https://www.pacebus.com/ada)

Figure 3-17: Passenger flows during peak and off-peak hours on Zhangjiakou City's bus lines



(Source: Transit transfer implementation plan for Donghuayuanbei high speed railway station, 2019)

Figure 3-18: Full-day schedule of bus lines in Zhangjiakou City

Zhangjiakou Bus Line in District 203										
Station No.	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
1	7:30	8:42			13:54	15:06	17:06	18:18	20:18	21:30
2		8:54	10:54	12:06				18:30	20:30	
3	7:54	9:08			14:18	15:30	17:30	18:42	20:42	21:54
4	8:06	9:18	11:18	12:30				18:54	20:54	
5	8:18	9:30			14:42	15:54	17:54	19:06	21:06	
6	8:30	9:42	11:42	12:54			18:06	19:18		
7		9:54				16:18		19:30		
8		10:06		13:18				19:42		
9						16:42		19:54		
10		10:30		13:42				20:06		

Off-peak time　　Peak time

(Source: Transit transfer implementation plan for Donghuayuanbei high speed railway station, 2019)

3.4.4 Optimize the Subsidy Model of Bus Operation

As previously noted in this study, financial subsidies for Tianjin's bus lines are based on a lines operating mileage, and has no relation with actual passenger volumes. This means that bus operators are not financially incentivized to attract more passengers, and long and inefficient routes are not eliminated or changed over time. To find ways to solve this problem, Tianjin can learn from the following experience of Guangzhou and Shenzhen.

1. Tianjin should add a consideration of indicators of service quality and profit levels when deciding subsidy provisions. In Shenzhen, buses are dependent on government subsidies, but the costs of the public enterprises and the service quality of bus lines are also considered. The government provides subsidies for public-benefit tasks, increased fuel prices, and lowered bus fares. When the profit margin of the enterprise is higher than 6%, 30% of the exceeding profit can be used for the enterprise's development, and 70% will be put into special funds to make up for any deficiency. Furthermore, the enterprise can receive full subsidies only if levels of bus service quality reach a set standard, otherwise, the amount of overall subsidies will be deducted.

2. Tianjin should include passenger flow as an assessment indicator, when considering how to provide subsidies. In Guangzhou, the financial subsidy funds for the transport industry are allocated according to the principle of "fact verification, balanced distribution of responsibilities and benefits, and reasonable allocation". After giving priority to subsidies for reduced ticket prices, subsidies to vulnerable groups, and policy-based subsidies, the rest of the subsidies will be granted based on the actual passenger flow. In practice, subsidies shall be granted based on the proportion of the actual passenger volume of each bus company to the total passenger volume of the industry.

3.4.5 Establish an Intelligent Bus Dispatching System

To improve Tianjin's mismatch between the city's bus schedules and passenger flows, it is recommended to implement an intelligent bus scheduling system. As accurate real-time passenger flow data is the basis of such system, the digitization of the public transport system of Tianjin should be accelerated. In this context, the mining and analysis capabilities for GPS and IC-card data should be enhanced to better analyse historical and real-time data of all bus lines, thereby creating accurate data sources for the intelligent bus dispatching system to use when creating schedules. Capabilities for automatic scheduling and automatic dispatching also need to be improved. Based on passenger flow data, the system will automatically generate a bus schedule which includes the routes of on-demand buses, non-stop direct buses, and other forms of specialized bus modes. This makes it possible to meet travel demands in a fast and accurate manner, therefore increasing the overall efficiency of the bus network. Furthermore, through feeding vehicle GPS data as well as vehicle camera footage into the intelligent dispatching system, the visibility as well as the intelligence of bus operation management will be improved. Digital maps can enable the convenient tracking of the location and speed of buses at any time. Through this application of smart monitoring technology, operation personnel can also track the utilization rate of buses and the distance between vehicles, to effectively adjust the capacity of different routes at different times, and better meet the travel demands of passengers.

3.4.6 Optimize the Fare System

The single fare system in Tianjin needs to be adjusted as soon as possible, and ideally before the optimization of the Tianjin bus line network is undertaken, so that customers pay a fare that is appropriate to their own journey and do not have to continue to bear the negative impact of the current fare context. As mentioned previously in this study, the average length of bus lines in Tianjin are too long. As the optimization plan suggests to divide certain lines into two separate lines, if the fare system is not adjusted, some passengers will be forced to pay double the price they originally paid for a single journey, which is not conducive to the promotion of line network optimization or customer satisfaction. More reasonable fare systems that take into account the travel demands and average income of passengers should therefore be considered. It is recommended to reform the fare system alongside the bus network optimization process and implement a distance-based pricing mechanism. Specific fare standards should be defined after an in-depth study of the costs of travel and available government subsidies. Eventually, the fares should be closely linked to actual costs of travel, and pricing mechanisms should also consider an interchange discount to encourage customers to make use of good interchange connections between bus and subway lines.

3.5 Specific Issues and Suggestions for Fleet Electrification

3.5.1 Development Status of Electric Buses in Tianjin

The main BEB types used in Tianjin are issued by BYD and Yinlong (see Figures 3-19 and 3-20). The BYD buses are 10.5 meter long with both slow charging and fast charging variations. A slow charge of a BYD buses takes 2-2.5 hours, while a fast charge takes 40 minutes. A fully charged BYD bus can run 200 km. Generally, BYD buses can be charged at night, and do not need additional charges during the daytime. The Yinlong buses are also 10.5 meter long, and have fast charging capacities. When fully charged, Yinlong buses can run for 50 km (see Table 3-2). The common challenge for both bus types is the impact of cold weather on mileage covered when charged. In winter, the mileage both buses can cover when fully charged may decrease by over 50%, with buses also requiring increased charging time and experiencing the occasional charging failure and other related emergencies due to cold temperatures. In the case of Tianjin, there is a high probability of the need for the emergency dispatching of standby buses due to emergencies like power failures and charging failures. Therefore, the standby rate of electric bus lines is generally 20%, while that of traditional fuel line buses is much lower, at generally 5%.

Currently, there are 730 charging piles in the central urban area of Tianjin. As the charging piles need to be installed within bus stations/depots, they take a large amount of space that was previously used for parking. As a result, around 5% of the buses that used to be pared inside the bus station now need to be parked at distant bus stations or other locations, which increases amounts of deadhead mileage. According to TMEDI, charging piles are required to be built within 3 km of bus station, which unfortunately causes some vehicles to be driven empty for 3 km or more simply to be able to be park.

■ **Figure 3-19: Yinlong battery electric bus**

(Source: www.1904bus.com)

■ **Figure 3-20: BYD battery electric bus**

(Source: www.news.cn)

■ **Table 3-2: Technical indicators of battery electric buses in Tianjin**

	BYD	Yinlong
Length	10.5m	10.5m
Type of charging	DC charging[17]	DC charging
Charging time	2.5h/40 min	0.5h
Range after full charging	200 km	50 km
Procurement model	Procurement of the whole bus including the battery with full ownership, loans are paid through municipal public budget	
Main challenge	Climate (cold weather)	

[17] Direct Current charging

3.5.2 Challenges Brought by Electric Buses to Bus Network Optimization

Based on communications with TMEDI, electric buses bring the following two challenges to overall bus network optimization efforts:

a) Increasing Operational Challenges for Lengthy Bus Lines

The operating mileage of Yinlong buses at full capacity is only about 50 km, while the average length of a Tianjin bus line is 25.13 km. If there is a charging pile at only one end of a bus line, the bus needs to be charged every time it runs back and forth. Due to the constraints of operational mileage, Yinlong buses can therefore only be used for shorter bus lines. Compared with Yinlong buses, BYD vehicles have a mileage of 200 km, which is more suitable for lengthy bus lines that connect different districts (such as the Jin-bin line, which connects the central urban area to the Binhai New Development Zone).

b) Pressure on the Installation of Charging Infrastructure

To carry out the implementation of optimized bus networks, charging infrastructure needs to be installed in at least one end of the bus line. However most cities face issues with installing this infrastructure due to the high demand for usable land surfaces and limited space to add these within bus stations. This problem is significantly challenging in city center areas.

3.5.3 Suggestions

Due to the limited mileage that can be covered by electric buses, a core recommendation is the segmenting of lengthy bus lines. Additionally, two operational measures are recommended as follows:

a) Charging Arrangement and Coordination

Plans for the timing and location of charging stations need to take into account the operation schedules and organization of bus routes. For example, for short-distance lines, charging can be arranged from 11:00 p.m. to 7:00 a.m. of the next morning by the order of the finishing time of buses (see Table 3-3). For long lines, daytime charging should be arranged from 11:00 a.m. to 2:00 p.m. and from 4:30 a.m. to 5:00 p.m. if possible. Charging volume should meet the demands of the remaining operational tasks of the day and the capacity that each bus needs to return to its charging station. Additionally, it is recommended to separately dispatch buses during peak hours, increase departure intervals during off-peak hours, and consider setting up shuttle buses and express buses (with fewer stops on the same line) to ensure sufficient transport capacity where needed.

b) Enrich the Bus Arrangement Mode of Bus Lines

To ensure that the needs of bus lines are met, and ensure the sufficient capacity of transport networks, steps can be taken to effectively make up for the operational shortages of battery electric buses. Tianjin Bus can consider combining battery electric buses with plug-in hybrid buses or traditional diesel buses to meet fleet needs, or could increase the number of battery electric buses deployed on lines simultaneously, to allow time for vehicle charging. Three possible arrangement modes to optimize bus deployment are outlined here:

1. The first mode is to only use battery electric buses in a bus line. This mode is suitable for lines with sparse shift density as well as short bus operation lines Buses can be charged during shift intervals, and this mode would be convenient for overall line management and vehicle maintenance. For example, the Branch bus line could give preference to battery electric bus operation (Figure 3-21).

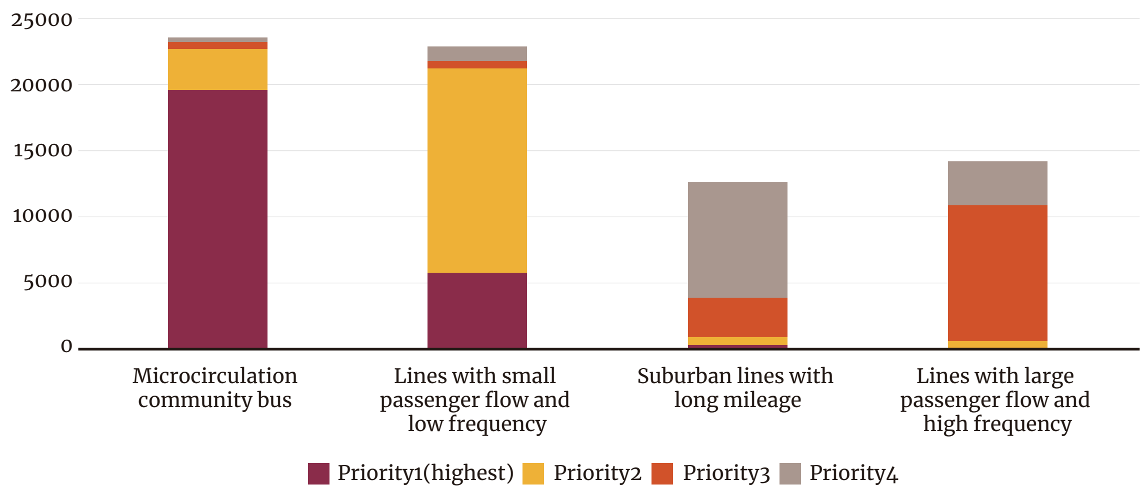
2. The second suggested arrangement mode is a rotated combination, where the entire bus line (or part of it) uses battery electric buses, and the number of battery electric buses available is one or two more than the number of drivers. After driving back to the terminal, one driver changes to drive another vehicle that has been charged in the station, and the vehicle that the driver just drove to the station stays in the station for charging until the next driver arrives. In this mode, drivers often change and drive different buses. This mode however is not conducive to long-term familiarity with bus performance or the formation of compatibility between drivers and buses. It also makes it difficult to assess the income and cost of single buses, as only the income and cost of the whole line can be assessed.

3. The third arrangement mode is a decentralized charging circuit, where charging piles are set up at both ends of the original and the terminal stations of bus lines. This arrangement would effectively double the bus mileage that can be travelled, so that battery electric buses could be put into operation also on long lines.

■ Table 3-3: Charging and replenishing strategy considering operation and dispatching modes for battery electric buses[4]

Line length	Charging and replenishing strategies	Operation and scheduling organization
Short	Charging should be arranged from 11:00 p.m. to 7:00 a.m. the next day according to the order of the finishing time of buses	Same as conventional fuel vehicle lines.
Long	• Use BYD buses on long distance lines • For Yinlong buses, equip one charging station at least at one end of the line, and only charge the buses with enough capacity to complete the next lap to reduce charging time	• Set up shuttle buses, and express buses (with fewer stops on the same line) to ensure sufficient transport capacity as appropriate • Increase departure intervals during off-peak hours • Separately allocate buses during peak hours • Replenish batteries in off-peak hours

■ Figure 3-21: Priority of bus line layout for battery electric buses [10]



(Source: CSTC)

4 Bus Corridor Analysis

4.1 Research Objective and Structure

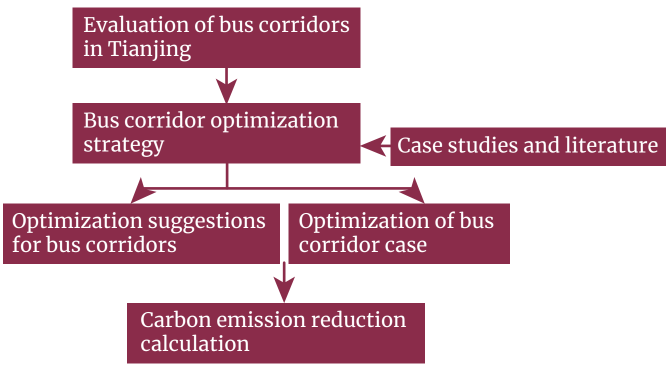
The research objective of this section is divided into two goals:

1. Introduce a bus corridor optimization strategy and improve the overall bus corridor service level.

2. Propose a bus corridor optimization scheme to alleviate traffic congestion and minimize greenhouse gas emissions, .along with outlining a supporting bus corridor case study.

In accordance with these goals, this section first identifies the most urgent issues affecting the operation of bus corridors in Tianjin (see Figure 4-1). Based on these problems, a comprehensive strategy to optimize the effectiveness of bus corridors will be presented. This strategy will be supported by discussing a case study of a Tianjin bus corridor. Finally, a potential calculation for carbon emissions reduction will be discussed, based on suggestions for the optimization of the bus corridor in the case study. Findings will then be summarized in the section's conclusion.

Figure 4-1: Research structure



4.2 Evaluation of Bus Corridors in Tianjin

Based on a field trip to Tianjin in November 2020, including a site visit to Tianjin's current bus corridors and workshops with the local Tianjin bus company and TMEDI, the main issues of Tianjin's bus corridors were identified by the research team. These will be summarized below, preceded by a brief introduction on the state of Tianjin's bus corridors. The research team evaluated the state of the slow average traffic speed inside bus corridors, the long travel time of bus lines, the lacking continuity of the bus lane markings along the road, and the lacking of platform design.

4.2.1 Overview

As can be observed in Figure 4-2, there are twelve main bus corridors in Tianjin with a total of 194 km of bus lanes. The bus companies operate 566 bus lines with a total length of 13,671.5 km. The fleet of 6,800 operating vehicles in Tianjin is fully electrified.

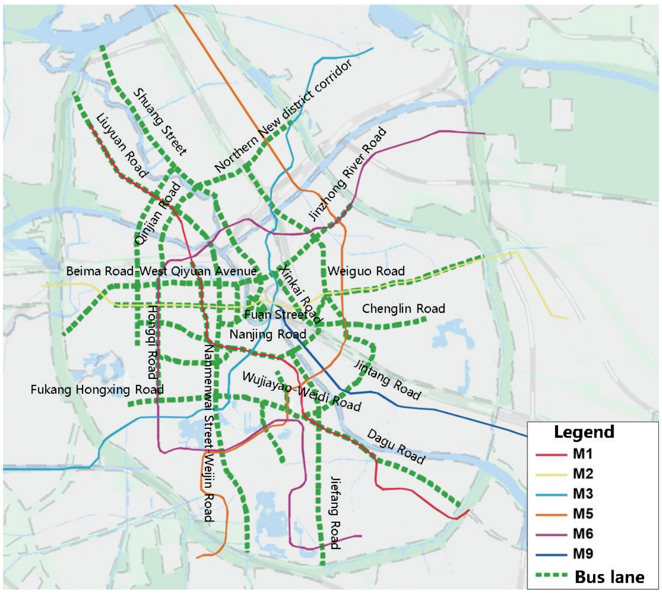
4.2.2 Speed

There is little difference in average bus speeds between the morning and evening peak hours in Tianjin, with the average bus speed during the morning peak hours being only slightly lower than that of the evening (see Figure 4-4 and 4-5). The average speed on the bus corridors changes depending on the location of bus lines, going from slower to faster progressing outwards from the inner ring road (see Figure 4-3). The speed on inner ring road corridors is about 15 km/h, with only a few road sections at less than 10 km/h, the speed on middle ring road corridors is 16-18 km/h and the speed on the bus corridors in the outer ring road is higher than 20 km/h. However, the speed of cars driving in other lanes of the same bus corridors is faster than the speed of the buses. Generally, cars drive at 30 km/h on the inner ring road and 50 km/h on the outer ring road, which is about twice the speed of buses (see Figures 4-6 and 4-7).

To further study the impact of bus lanes on bus speed, bus lanes in five 1^{st} tier and 2^{nd} tier[18] cities, namely Jinan, Beijing, Shanghai, Shenzhen, Chengdu, and Nanjing, were selected for a comparative analysis with Tianjin. To increase the reliability of the data, one section of a bus corridor in the central urban areas of each comparative city and seven bus corridors in Tianjin were selected.

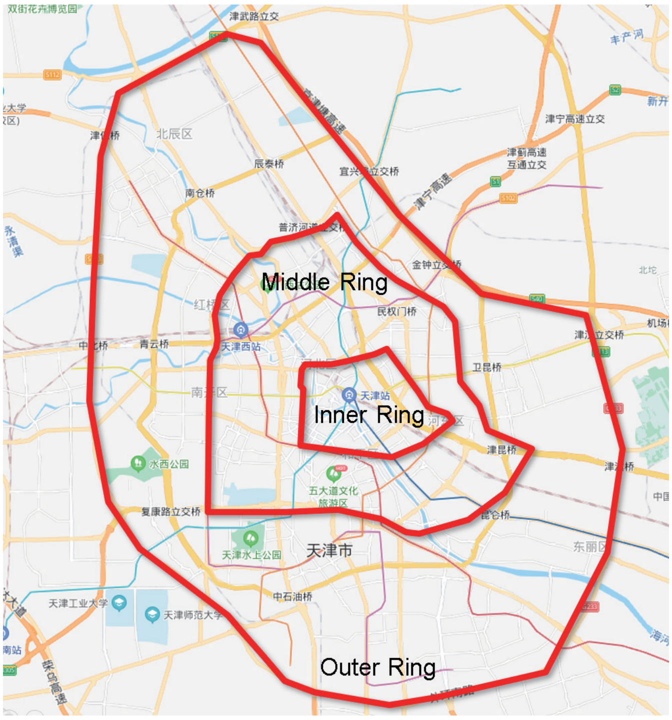
Using the function of Baidu Maps to automatically calculate the travel time for a certain route, the average travel time of buses and cars between two points of the selected bus corridor at 5:30 p.m. was recorded. Bus waiting time was excluded from travel time estimates. The comparison of the data shows that in bus lanes of the six benchmarked cities, the speed of buses during the evening peak was slightly higher than the speed of cars (see Table 4-1). In Tianjin, only some city sections, such as Jintang Road, Qinjian Road, and Hongqi Road, had a slightly higher bus speed than car speed. In the other sections, again as shown in Table 4-1, car speeds were much higher than bus speeds. A longitudinal comparison with other cities showed that the speed of both buses and cars was higher in Tianjin. This observation determined that 1) Tianjin's buses can't compete with cars in terms of speed, and; 2) Tianjin's bus corridors have comparably low congestion levels, and both buses and cars move relatively smoothly.

■ Figure 4-2: Distribution of Tianjin's bus corridors and subways



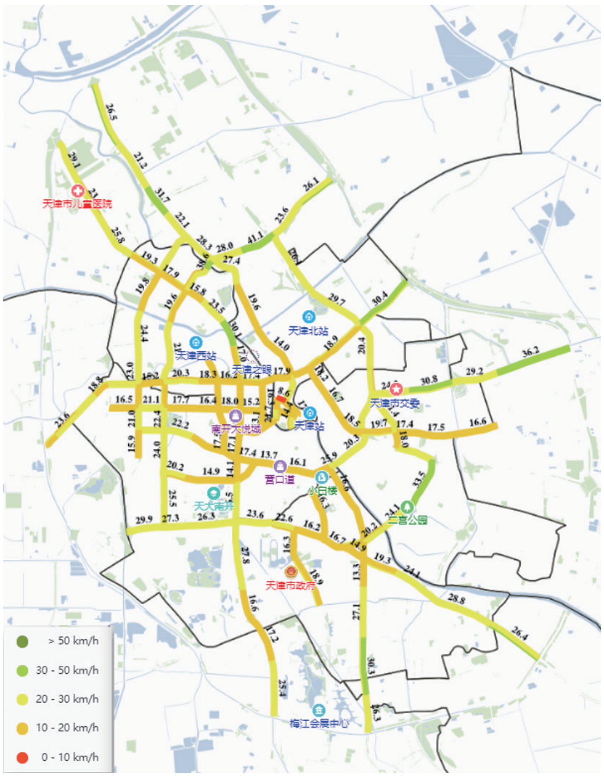
(Source: CSTC)

■ Figure 4-3: The location of Tianjin's three ring roads



(Source: CSTC)

■ **Figure 4-4: Speed of buses on bus lanes in the morning peak (11/11/2020, 8:00 a.m.)**



(Source: TMEDI)

■ **Figure 4-5: Speed of buses on bus lanes in the evening peak (11/10/2020 5:00 p.m.)**

(Source: TMEDI)

■ Figure 4-6: Speed of cars in the morning peak (11/11/2020 8:00 a.m.)

(Source: TMEDI)

■ Figure 4-7: Speed of cars in the evening peak (11/10/2020 5:00 p.m.)

(Source: TMEDI)

Table 4-1: Comparison of the speed of buses and cars in selected bus corridors

City	Road	Start-end station	Length (km)	Speed (km/h)		Bus speed/ Car Speed
				Bus	Car	
Jinan	Jingshi Road	Keyuan Road- Bayi Bridge Station	5	12.0	11.1	1.1
Beijing	Changan Street	Ritan-Xidanlukoudong Station	5.3	14.5	12.7	1.1
Shanghai	Xizang Road	Beijingdong Road- Renmin Guangchang Station	1	12.0	10.0	1.2
Shenzhen	Huafu Road	Huafu Road-Shihua Mansion Station	1	10.0	8.6	1.2
Chengdu	Shudu Street	Zongfu Road-Shuangqiaozi Station	3	13.8	12.9	1.1
Nanjing	Zhongshan Street	Xinqiao-Xinjiekou South Station	2	13.3	10.0	1.3
Tianjin	Jieyuan Street	Beimen-Xiqing Station	4.03	19	25	0.8
	Nanmenwai Street	Haiguangsi- Beimen Station	2.3	13.5	15.4	0.9
	Jintang Road	Jingshiyi Road- Jingshiwu Road Station	1.8	6.8	13.5	0.5
		Jianfu Street- Daqiao Street Station	0.6	9.4	16.8	0.6
		Longtan Road-Huzhu South Street station	0.6	12.0	12.0	1.0
		Zhongshanmen No.1 Road- Quangning Road Station	0.5	7.7	11.4	0.7
	Weiguo Road	Taixing Road- Weikunqiao West Station	1.6	16.0	21.8	0.7
	Jinzhong River Road	Jinshajiang- Waihuan Station	1.5	9.0	30.0	0.3
	Pujihe-Qinjian-Hongqi Road	Yixingfu-Pujihe Station	2.9	19.3	19.1	1.0
		Pujihe-Qinjian Street Station	3.7	20.2	26.0	0.8
		Dingzigu No.0 Road-Honghu North Road Station	2.6	13.0	11.5	1.1

4.2.3 Continuity of Bus Lanes

According to the standards for bus lanes in Beijing and Shandong Province, a dedicated entrance lane for buses must be established at urban intersections when a certain number of lanes or passenger flow is reached.[12][13] Bus lanes in Tianjin are not currently marked at intersections, which means that all types of vehicles are permitted to use intersection bus lanes. . Also, on some streets, markings for bus lanes have been removed due to construction works or other reasons (see Figures 4-8 and 4-9). As a result, the marking of bus lanes is often interrupted in Tianjin. According to Table 4-2, the marking rate of bus lanes in Beijing, Shanghai, Shenzhen, Chengdu, and Jinan is above 80%. In addition, Jinan, Shanghai, Shenzhen, and Chengdu have designated bus lanes at every intersection (see Figure 4-10). In Beijing and Nanjing however, bus lanes are only partly marked at intersections.

To calculate the continuity of the bus lanes, 18 sections of bus lanes in Tianjin were selected to be examined for markings. The result of this marking survey showed that the continuity of the marking of bus lanes in Tianjin was rather low. The most continuous sections of bus lanes were found to be on Jintang Road (the section between Longtan Road and Guangning Road) and Hongqi Road (the sections between Huanghe Road and Weishui Road and between Yuanyang Road and Wangdingdi), with continuity rates of about 70% - 80%. The continuity of other sections was low, from 20% - 40%. Except for the roads mentioned above, no bus lanes were marked at intersections. Figure 4-11 shows the speed of bus traffic during the morning peak hours. The reason for volatile bus speeds could be the discontinuity of bus lanes, as bus speeds were found to be low when streets did not have a delineated bus lane.

City	Road	Start-end station	Length (km)	Speed (km/h)		Bus speed/ Car Speed
				Bus	Car	
Tianjin	Pujihe-Qinjian-Hongqi Road	Ziyahe-Xiqing Road Station	2.0	10.0	20.0	0.5
		Xiqing- Anquan Road Station	1.4	8.4	10.5	0.8
		Huanghe-Weishui Station	1.0	12.0	14.0	0.9
		Yibin-Yaan Street Station	0.5	10.0	15.0	0.7
		Yuanyang-Wangdingdi Station	2.2	15.8	14.8	1.1
		Wangdingdi -Binyue Bridge Station	2.2	12.0	15.3	0.8
	Chenchang-Dingzigu No. 3 Road	Jinbao Bridge-Jiaqing Street Station	5.1	21.9	22.2	1.0
		Xianyang Road- Qinjian Road Station	3.3	16.5	17.4	1.0

(Source: CSTC)

■ **Figure 4-8: Status quo of un-delineated approaching lanes at intersections (the bus lane should be yellow)**

(Source: CSTC)

■ **Figure 4-9: Status quo of un-delineated approaching lanes**

(Source: CSTC)

Table 4-2: Bus lane marking continuity in different cities

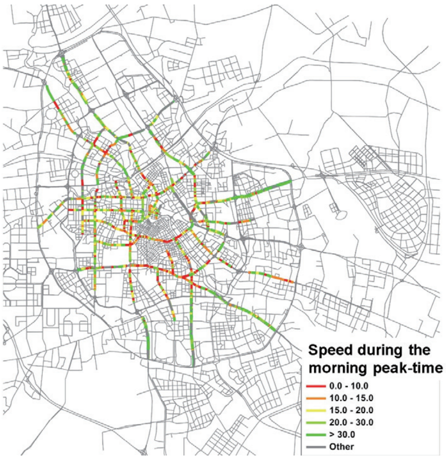
City	Road name	Start-end station	Length in km	Continuity of Bus lane	Bus lane marked at intersections?
Jinan	Jingshi Road	Keyuan Road- Bayi Bridge Station	5	90%	Yes
Beijing	Changan Street	Ritan-Xidanlukoudong Station	5.3	80%	Partly yes
Shanghai	Xizang Road	Beijingdong Road- Renmin Guangchang Station	1	95%	Yes
Shenzhen	Huafu Road	Huafu Road-Shihua Mansion Station	1	80%	Yes
Chengdu	Shudu Street	Zongfu Road-Shuangqiaozi Station	3	85%	Yes
Nanjing	Zhongshan Street	Xinqiao-Xinjiekou South Station	2	50%	Partly yes
Tianjin	Jieyuan Street	Beimen-Xiqing Station	4.03	40%	No
Tianjin	Nanmenwai Street	Haiguangsi- Beimen Station	2.3	30%	No
Tianjin	Jintang Road	Jingshiyi Road- Jingshiwu Road station	1.8	30%	No
Tianjin		Jianfu Street- Daqiao Street station	0.6	65%	No
Tianjin		Longtan Road-Huzhu South Street station	0.6	70%	No
Tianjin		Zhongshan Men No.1 Road-Guangning Road station	0.5	60%	No
Tianjin	Jinzhonghe Road	Jinshajiang- Waihuan Station	1.5	30%	No
Tianjin	Pujihe-Qinjian-Hongqi Road	Yixingfu-Pujihe Station	2.9	60%	No
Tianjin		Pujihe- Qinjian Road Station	3.7	20%	No
Tianjin		Dingzigu No.0 Road- Honghu North Road station	2.6	30%	No
Tianjin		Ziyahe- Xiqing Road station	2.0	30%	No
Tianjin		Xiqing- Anquan Road Station	1.4	40%	No
Tianjin		Huanghe-Weishui Station	1.0	70%	No
Tianjin		Yibin-Yaan Street Station	0.5	60%	No
Tianjin		Yuanyang-Wangdingdi Station	2.2	80%	No
Tianjin		Wangdingdi -Binyue Bridge Station	2.2	60%	No
Tianjin	Chenchang-Dingzigu No. 3 Road	Jinbao Bridge-Jiaqing Street Station	5.1	60%	No
Tianjin		Xianyang Road-Qinjian Road Station	3.3	60%	No

(Source: CSTC)

■ **Figure 4-10: Bus lane in Chengdu**

(Source: Baidu Maps)

■ **Figure 4-11: Bus speed on bus corridors during the morning peak**



(Source: TMEDI)

4.2.4 Delay Times

The travel time of a bus line is composed of three parts: 1. The driving time, 2. the delay time at intersections, and 3. the delay time at stations. To analyse the travel time of buses in Tianjin, four bus lines with high passenger flows from the central urban area, namely the lines 830, 832, 855, and 907, were observed. According to data recorded on-site by CSTC[19], it was found that driving time of the lines 830 and 907 accounted for 51% and 54% of overall total travel time, respectively, while driving time of line 832 accounted for 69% of total travel time, and driving time of line 855 accounted for about 43% of total travel time. On average, the driving time of these bus lines accounted for 54% of the total travel time. For comparison, in the travel time composition of bus line 117 in Jinan, driving time accounted for a similar 52% of the total travel time.

Analysis of delay times at intersections on observed lines showed that an average of 36% of travel time was spent waiting at intersections and 10% was spent with buses being at bus stops, which meant that delays in travel time mainly occurred at intersections. Line 117 in Jinan had a total time spent at stations of 27% and delays at intersections accounted for 21% of total travel time. Thus, when comparing the composition of delays of bus lines in Tianjin and Jinan, it was be observed that intersections in Tianjin accounted for a significantly larger proportion of delay times than in Jinan (see Table 4-3 and Figures 4-12 and 4-13.

To understand the source of remaining delay times on the same four lines discussed above, the number of intersections and bus stops passed by during journeys was counted for each line, and the distance between intersections and bus stops was calculated (see Table 4-4). It was been found that the distance between intersections in Tianjin was smaller than in Beijing and Jinan. Additionally, the calculation of the proportion of delay time that was at intersections versus delayed at stations showed that the proportion of intersection delay in Tianjin accounted for about 70% - 85% of total delay time. This was found to be much higher than intersection delays in Beijing and Jinan, where their proportion was only 45% - 60% of total delay time. Reasons for this difference were found to be the high density of both road networks and intersections in Tianjin, as well as low passenger flows at stations (see Table 4-5). Results therefore demonstrate that in Tianjin, the delay time at stations accounts for a smaller proportion of overall delay time than that spent at intersections.

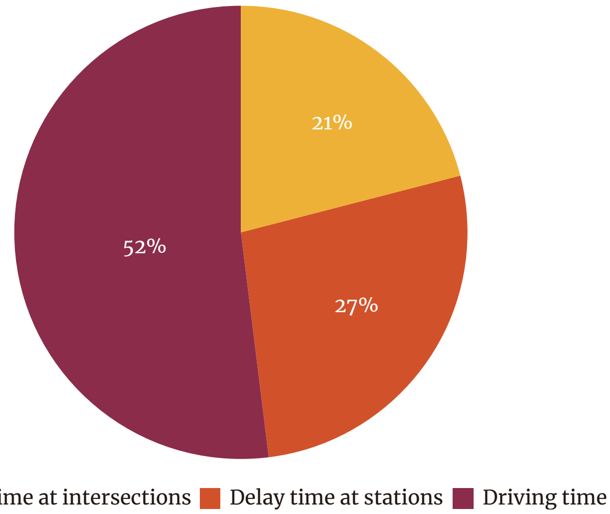
If Tianjin succeeds in optimizing traffic and reducing bus delay times at intersections, overall delays in bus operation will be significantly reduced, which will improve the service level of the entire bus system.

Table 4-3: Composition of bus line travel time, collected during the morning peak

City	Tianjin					Jinan
Bus line	No. 830	No. 855	No. 832	No. 907	Average value	No. 117
Delay time at intersections	42%	48%	21%	32%	36%	21%
Delay time at stations	7%	10%	10%	14%	10%	27%
Driving time	51%	43%	69%	54%	54%	52%

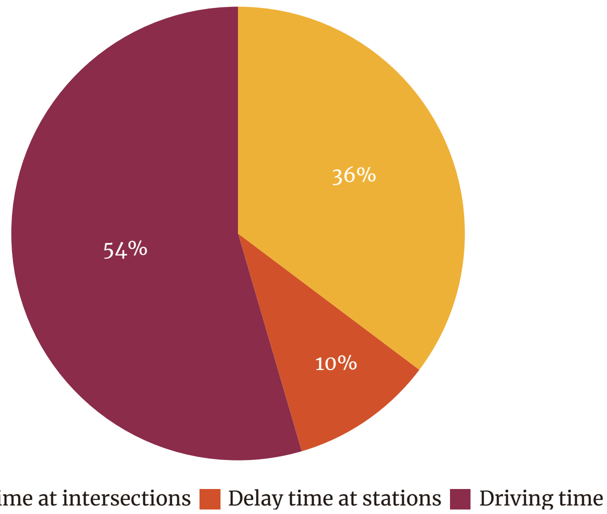
(Source: CSTC, based on [14])

Figure 4-12: Travel time of bus line 117 in Jinan



(Source: CSTC)

Figure 4-13: Average travel time of four example bus lines in Tianjin



(Source: CSTC)

[19] 2020 Tianjin during morning peak; 2018 Jinan during morning peak

Table 4-4: Basic statistics of compared bus lines

City	Route	Start-end station	Length / km	Num. of intersections	Average distance between intersections in m.	Num. of bus stops	Average distance between bus stops in m.
Tianjin	No. 830	Central park- Xiangjiang Street Station	5.71	27	211	8	714
Tianjin	No. 855	Shengan Street-Guyi Street Station	2.3	7	328	5	460
Tianjin	No. 832	Tianjin-Haiguangsi Station	4.25	12	377	9	472
Tianjin	No. 907	Beimen- Xiqingdao Station	4.03	8	504	7	576
Jinan	No. 117	Lashan Bridge- Second ring Road station	12.8	20	640	24	533
Beijing	K1	Demaozhuang-Qianmen Station	15.3	24	638	17	900

(Source: CSTC)

Table 4-5: Bus stop activity within 5 minutes during the morning peak

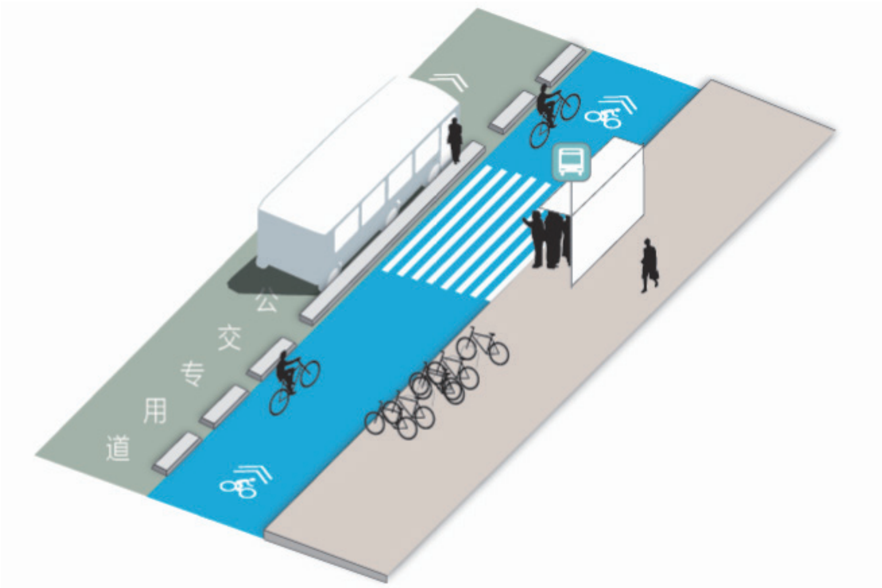
Bus stops	Number of buses	Number of passengers getting on the bus	Number of passengers getting off the bus
Haiguangsi	11	7	11
Beimen	15	18	31
Xiangjiangdao	6	9	7

(Source: CSTC)

4.2.5 Platform Design

Currently, most bus platforms in Tianjin are in-line roadside platforms, where buses stop directly on the roadway instead of entering a bus turnout (Figure 4-14). This type of bus stop shortens time spent at bus stops, improves passenger flow efficiency, and minimizes delays at stations. However, this model is more suitable for small passenger flows at platforms. When passenger flow is high, conflict between passengers and other road users (such as bicycles) can be aggravated, leading to greater safety risks. As shown in Figure 4-15, in-line roadside platforms in Tianjin do not get too crowded and are efficient for low passenger flow, but conflicts between passengers and non-motor vehicles can still be observed.

■ **Figure 4-14: Common bus stop design in Tianjin – In-line roadside platform**



(Source: CSTC)

■ **Figure 4-15: Passengers entering/leaving a bus at an in-line bus stop in Tianjin**

(Source: CSTC)

4.2.6 Summary of Issues

This chapter evaluated the four following key aspects of Tianjin's bus corridors: 1. Variations in bus and car speeds in bus corridors; 2. A lack of continuity in bus lane markings; 3. Travel time composition of bus lines and related delays;, and 4. Design styles of bus platforms. Four main conclusions are drawn from this evaluation:

1. In Tianjin's bus corridors, the speed of buses in bus lanes is usually lower than the speed of the cars in other lanes, indicating that the design of the bus lanes may not be adequate and needs to be improved.

2. The continuity of bus lane markings in Tianjin's bus corridors is low. The average marking rate in Tianjin's bus corridors is 50%, which is far below that of bus corridors in other cities.

3. The delay time of buses in Tianjin is longer at intersections than at stations, and Tianjin's delay time at intersections is far larger than delay times at intersections in other cities. This implies that markings and related services at intersections along bus corridors could be improved to reduce delay times.

4. There are primarily in-line roadside platforms in Tianjin, which have a high efficiency in boarding passengers but are more suitable for low passenger flows. Once the passenger flows are increased, potential conflict between bus passengers and other road users will become more prominent unless the type of platform used is changed.

4.3 Bus Corridor Optimization Strategy

This chapter section proposes a range of suggestions for the optimization of bus corridors in Tianjin. After first outlining general suggestions, specific suggestions for improvement based on the bus corridor case study will be provided, with a view to showcase concrete benefits of an optimization of bus corridors in Tianjin.

4.3.1 Coordinated Development of Bus and Subway Transit Services

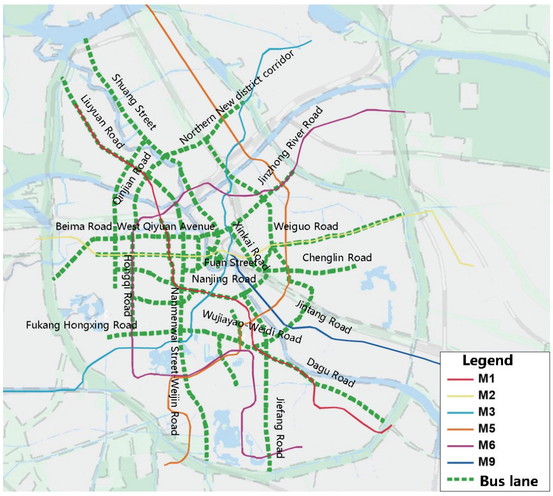
Subway networks have certain advantages over bus transit lines, such as a larger passenger capacity, no risk of congestion, and high punctuality. This makes the subway suitable for servicing corridors with large passenger flows. Moreover, the subway system is more appropriate for meeting the needs of residents with medium and long travel distances. Bus corridors could therefore be aligned with the subway network in a complementing manner, to support consumers to get the best out of both systems. Bus systems can make up for the subway's insufficient coverage of areas with medium and low passenger flows. Table 4-6 and Figure 4-16 demonstrate the current overlap of the bus corridors and the subway networks in Tianjin. It is found that the bus corridors of Liuyuan, Nanjing, and Dagu have an overlap ratio of 60% with the subway line M1. Huanghe and Weiguo bus corridors have an overlap ratio of 70% with the subway line M2, and the Hongqi bus corridor has an overlap of 30% with the subway line M6. Research should be therefore conducted to verify the necessity of running each of these overlapping bus corridors.

Table 4-6: Statistics of bus corridors overlapping with subway lines

Subway line	Overlapping bus corridors	Overlap ratio
M1	Liuyuan, Nanjing, Dagu bus corridors	60%
M2	Huanghe Road, Weiguo Road bus corridors	70%
M3	No overlap	0
M5	No overlap	0
M6	Hongqi bus corridor	30%
M9	No overlap	0

(Source: CSTC)

■ **Figure 4-16: Overlapping layout between bus corridors and subways**



(Source: TMEDI)

4.3.2 Reduction of Unnecessary Bus Corridors

Traffic congestion in Tianjin is caused by the increase of urban vehicle ownership and limited road space resources. As vehicles with large capacity, high efficiency, relatively low investment costs, lower demands on road resources per capita, and less pollution, buses are a well-proven mode of transport in major cities and an important tool for reducing traffic congestion. Bus lanes can further guarantee that road space resources are used exclusively by buses, again improving operation efficiency, ensuring a high rate of punctuality, enhancing the comfort of the passengers, increasing the modal share of bus transit, and ultimately relieving road congestion. To have optimal efficiency, possible speeds of travel based on volume, and passenger flow requirements need to be considered when setting bus corridor routes and placing bus lanes. Bus corridors that do not meet the needs of passengers by not having appropriate speeds and travel flows should be removed.

a) Bus Corridor Placement Should Meet Certain Speed Requirements

As shown in Table 4-7, the average speed of express roads in the central urban area of Tianjin is 31.4 km/h. It is recommended to set up bus lanes on express roads where the average speed is lower than 31 km/h. In the central urban area, the average speed on arterial roads is 13.8 km/h. It is therefore recommended to set up bus lanes on arterial roads where the average speed is lower than 13 km/h.

b) Bus Corridor Placement Should Meet Certain Passenger Flow Requirements

With the goal of serving more passengers, the establishment of bus lanes reallocates road space at the expense of private vehicles. Only when placed along the primary passenger flow corridors, bus lanes will be of benefit to consumers. Therefore, before establishing a bus lane, the following requirements need to be met:

1. Measured by the number of passengers passing through a single lane, the bus passenger flow should not be smaller than that of private vehicles.

2. Measured by the proportion of bus passenger flows in the whole corridor, bus passenger flows should not be smaller than the average passenger flow of the total lanes within the corridor.

Tables 4-8, 4-9 and 4-10 outline recommended threshold values that can be used for planning bus corridor placement based on passenger flows. Figure 4-17 illustrates current levels of congestion on roads used as bus corridors in Tianjin. Table 4-11 outlines daily passenger flow numbers in Tianjin, including a breakdown by corridor and morning and evening flow times.

■ **Table 4-7: Recommended bus speed threshold for bus lanes**

Road type	Average speed in the central urban area (km/h)	Recommended threshold (km/h)
Express roads	31.4	≤31
Arterial roads	13.8	≤13

(Source: Green Transport Development Strategy Research (Phase I) in Tianjin Downtown)

Table 4-8: Recommended threshold values of bus passenger flows and traffic flows for bus lanes

Road type	Bus passenger flow (person/hour)	Bus vehicle flow (vehicle/h)
Express roads	≥3,000	≥100
Arterial roads	≥1,500	≥50

(Source: Green Transport Development Strategy Research (Phase I) in Tianjin Downtown)

Table 4-9: Car capacity of express and arterial roads per lane

Road type	Passenger flow p/h	Capacity vehicle/h
Express roads	2,250	1,500
Arterial roads	1,200	900

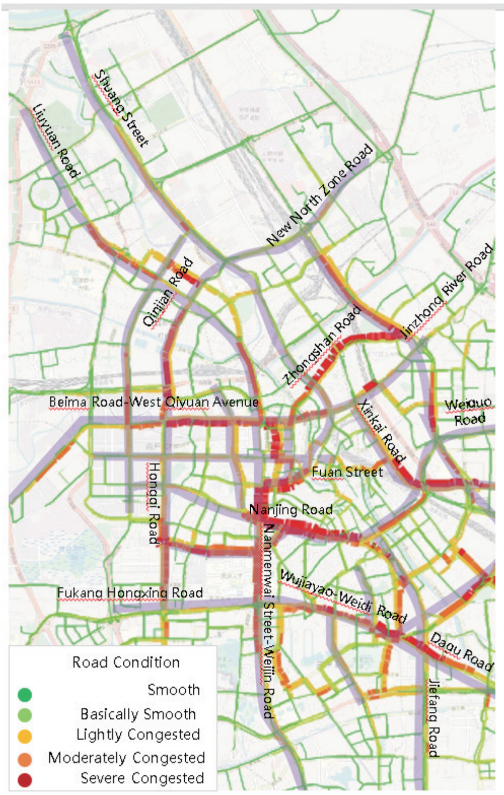
(Source: Green Transport Development Strategy Research (Phase I) in Tianjin Downtown)

Table 4-10: Recommended threshold values of bus passenger proportion in the bus lane

Road type	Recommended threshold (%)
Express roads (num. of lanes in one direction ≥4)	≥20%
Arterial roads (num. of lanes in one direction ≥3)	≥30%

(Source: Green Transport Development Strategy Research (Phase I) in Tianjin Downtown)

Figure 4-17: Level of congestion along bus corridors in Tianjin



(Source: TMEDI)

Table 4-11: Bus passenger flow of major bus corridors

	Daily passenger flow	Morning peak passenger flow	Evening peak passenger flow
Nanmenwai Street bus corridor	25,066	3,008	2,256
Dagu bus corridor	23,455	2,815	2,111
Beima Road bus corridor	23,080	2,770	2,077
Fuan- Pingan Street bus corridor	22,293	2,675	2,006
Wujiayao-Weidi Road bus corridor	22,001	2,640	1,980
Jintang Road bus corridor	21,622	2,595	1,946
Nanjing bus corridor	20,433	2,452	1,839
Xinkai Road -Chenglin Roadbus corridor	17,322	2,079	1,559
Zhongshan Road bus corridor	17,077	2,049	1,537
Weijin Road bus corridor	13,270	1,592	1,194

(Source: TMEDI)

Table 4-12: Bus Corridors to be removed based on conditions of congestion and speed

Number	Name of the corridors	Road level	The average speed	The peak single-line passenger flow of a segment
1	Northern New District corridor	Express road	56 km/h	1,000 passenger/h
2	Jinzhong River corridor	Arterial road	30 km/h	800 passenger/h
3	Shuang Street corridor	Arterial road	32 km/h	1,200 passenger/h
4	Weiguo corridor	Express road	64 km/h	600 passenger/h
5	Jiefang Road corridor	Arterial road	34 km/h	1,100 passenger/h

(Source: CSTC)

c) Remove Redundant Bus Corridors

Congestion and speed levels vary for different bus corridors in Tianjin (see Table 4-12). Bus corridors where the average speed on arterial roads is more than 13 km/h, the average speed on express roads is more than 31 km/h, and the peak single-line passenger flow of a segment is less than 1,500 passengers/h are inefficient for travel, and should be cancelled. Suggested bus corridors to be reduced in Tianjin according to this criteria are the corridors of Northern New District, Jinzhong River, Shuang Street, Weiguo, and Jiefang Road. The average speed and the section bus passenger flow of these corridors are again outlined in Table 4-12.

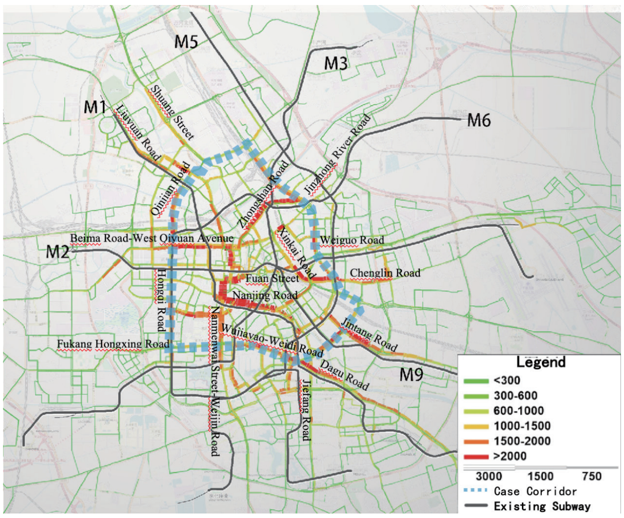
4.4 Optimization of a Bus Corridor Case Study

4.4.1 Case Study Selection

The selection of a bus corridor case study for this research was based on three criteria: 1. The bus corridor needed sufficient passenger flow; 2. Overlap of the corridor with the subway network needed to be as small as possible, and; 3. The corridor was not to be impacted by construction work for the subway or roadworks.

After a comprehensive analysis, it was found that the Middle Ring Road of Tianjin met all criteria for selection, and was therefore chosen for the case study. The average passenger flow of the Middle Ring Road at morning peak hours was found to be approximately 2,000 persons per hour, which made it one of the main passenger flow corridors in Tianjin. Moreover, the proportion of overlap of the corridor with the subway network was low, except for a small section overlapping with the M6 metro line. Consisting of express roads and arterial roads, the total length of the Middle Ring Road was found to be approximately 34 km. An outline of the corridor is illustrated in Figure 4-18.

■ **Figure 4-18: The Middle Ring Road bus corridor case**



(Source: CSTC)

4.4.2 Suggestions for the Placement of Bus Lanes

Two types of bus lanes can be used in bus corridors; they can be placed either in the middle lane, or on the side of the road. For the case study of the Middle Ring Road, it was recommended to establish bus lanes on the side of the road, due to three main reasons:

1. Passenger flow: Placing the bus lane in the centre of the street is useful for streets with high passenger flow. Normally, the peak of one-way passenger flow needs to be more than 5,000 passengers/h. In comparison, the segment with the average passenger flow of the Middle Ring Road was found to have a flow of 2,000 passengers/h, which did not meet the conditions for the placement of a dedicated lane in the middle of the road.

2. Circular design of the Middle Ring Road: Only a few bus lines were found to operate across the entire case study corridor, and it was found to be common that buses entered and exited the bus corridor after a few kilometres. Dedicated lanes on the roadside were suggested, as they are more adaptable to the pattern of buses entering and exiting bus corridors.

3. Already partly existing roadside bus lanes on the Middle Ring Road: To make use of existing resources, it was found that using roadside bus lanes was more effective than setting up new bus lanes in the middle of the road, for this case study.

4.4.3 Suggestions for Improving the Continuity of Bus Lane Markings

Intersections are generally considered to be bottlenecks in road networks. The flow capacity of an intersection usually is less than that of road sections. Optimizing the traffic organization of intersections is key to improving the overall traffic organization of a road network. Similarly, intersections are also essential for improving the efficiency of bus lanes. As shown in Table 4-2, bus corridors with a high marking rate also usually have bus lane markings at intersections, such as in Beijing, Shanghai, Shenzhen, or Chengdu. Good bus corridors not only guarantee continuity along the road but also ensure the right of way of buses at intersections.

There are three possible directions for bus lanes at intersections: 1. Straight bus lanes; 2. Left-turn bus lanes, and; 3. Right-turn bus lanes (see Appendix 1). The relationship between these lanes and advantages and disadvantages to their selection is further discussed in Appendix 2. For the purpose of the case study of this research, a section of the Middle Ring Road bus corridor (from Wujiayao Station to Xinan Building Station) will again be examined to determine which directions of bus lanes would be appropriate to set up to improve traffic flows (see Figure 4-19).

The Middle Ring Road section from Wujiayao Station to Xinanlou Station is 2.5 km long, has eight intersections and an average distance of 357 m between every two intersections. As can be observed in Figure 4-20, the marking rate on this section of the case study route is less than 50% for each direction. With such a low marking rate, the benefits bus lanes have on the service level of bus transit become limited. In view of the high density of Tianjin's road network and small spaces available at intersections, it only continuous bus lanes can necessarily be set up in these locations. Marking and setting up bus lanes at intersections will reduce delays at intersections and enhance the function of bus corridors. Continuous bus lanes can be set up once flow directions and information on how traffic enters and exits each intersection is understood. Different intersections may require different type of planning, as is outlined in Table 4-13.

■ **Figure 4-19: Wujiayao Station - Xinanlou Station**

(Source: Baidu Maps)

■ **Figure 4-20: Bus lane markings along Middle Ring Road bus corridor**

(Source: CSTC)

Table 4-13: Recommended bus lane types at intersections

No.	Intersection	Number of approaching lanes (Eastern direction)	Bus lane type
1	Wujiayao-Meteorological Station Road intersection	6 lanes	Left side of the right turn lane
2	Wujiayao-Guizhou Road intersection	6 lanes	Left side of the right turn lane
3	Wujiayao-Machang Road intersection	7 lanes	Left side of the right turn lane
4	Weidi Road-Youyi Road intersection	5 lanes	Left side of the right turn lane
5	Weidi Road-Liwan Road intersection	4 lanes	Shared use of straight bus lane
6	Weidi Road-Yuexiu Road intersection	4 lanes	Shared use of straight bus lane
7	Weidi Road-Baiyun Road intersection	4 lanes	Shared use of straight bus lane
8	Weidi Road-Guangdong Road intersection	4 lanes + 1 right turn lane	Left side of the right turn lane

(Source: CSTC)

4.4.4 Suggestions to Strengthen the Signal Optimization of Key Corridors

As shown in chapter 2.4 of this study, intersection delay is a major issue in Tianjin's bus corridors. The efficiency of bus corridors will therefore be significantly improved if delays at intersections are reduced. Case studies of cities inside and outside China show that bus priority systems can help to reduce the delay time of buses at intersections, improve their punctuality rate, and enhance residents' willingness to travel by bus. In a system that prioritizes bus networks, traffic signals are adjusted in a way that prioritizes bus movements and flows at the expense of other vehicles. Tianjin currently has no bus priority system in place, and implementing such a system would better improve the efficiency of the bus network as well as overall flows of traffic for all vehicles.

a) Level Division of Bus Priority Systems

Bus priority signal systems can be divided into six levels. [15] The higher the level, the higher the precision of bus signal priority controls for buses over other traffic. Higher levels of bus priority systems have significant requirements for hardware and software that the city needs to invest in. Different signal systems have varying levels of signal precision and higher levels are therefore more challenging to implement. In particular the highest levels of signal systems, from 4-6, are challenging to implement and are currently not suitable to be used in the context of Tianjin.

Level 1 signal systems are useful when traffic flows and bus flows are low and not very volatile, and can be used to help bus flows in simple circumstances. Under such circumstances, priority for the movement of buses is achieved through specially designed signal control parameters. For example, buses are given as much green light time as possible, and the frequency of signal phases that prioritize buses is increased. At this level, equipment for bus detection or communication facilities are not required, but overall benefits to traffic flows are limited.

Level 2 signal systems offer the most basic type of dynamic bus signal priority control. Before arriving at a station, buses can forward a priority request to accommodate their arrival, and will receive a response. To send a request, each bus needs to have special equipment installed. This type of signal system is common, but not suitable for intersections with high traffic volume, as frequent priority requests may overwhelm the overall transit system.

Level 3 signal systems have both red-light monitoring mechanisms and a bus detection mechanism, and additionally, introduces a competition mechanism for bus priority requests. The competition mechanism allows for the coordinating of traffic demands between individual buses, as well as between buses and other vehicles and road users, including pedestrians. Level 3 signal systems are therefore suitable for intersection clusters used by buses that also have large flows of pedestrians and private vehicles.

The city of Jinan uses signal systems to improve the speed and efficiency of its bus transit system by optimizing signal timing and installing 225 sets of dedicated bus signals at 118 intersections on 17 main traffic roads. It has implemented green wave control at 328 intersections on 34 bus-intensive arterial lines, so that buses encounter fewer red lights and more green lights, thus reducing delays at intersections. At 11 intersections along Jingqi Road, Yingxiongshan Road, East 2^{nd} Ring Road, and West 2^{nd} Ring Road, signal lights relating to buses are controlled in advance, so that buses can be a step ahead when the red light turns green (see Figure 4-21).

Another example of signal systems in use can be observed in the US state of Rhode Island. To improve the speed and efficiency of its R line, the Rhode Island Public Transit Authority (RIPTA) has introduced the state's first Transit Signal Priority (TSP) system. The TSP system keeps the traffic lights green for public transit with the goal of improving the speed and punctuality of buses. With the implementation of this system, intersections generate fewer delays, because buses have priority to pass them faster. The TSP system better synchronizes series of intersections simultaneously, which allows all traffic to move down the corridors more fluently. According to estimations by RIPTA, the TSP system saves about 30 service hours every working day. In a year, the cost saved reduces the service time required to complete the same amount of work by approximately 7,650 hours. This saves RIPTA nearly USD 7,000,000 per year, which can be then used to subsidize services needed on routes with high passenger capacity.

The final example of a city that uses signal systems is the Welsh city of Cardiff. In Cardiff, to avoid frequent traffic jams and bus delays, traffic control departments installed signal control devices on traffic lights at intersections and sensors at different locations on roads operated by buses. The sensors monitor bus movements in relation to the overall schedules of different bus routes. If a bus fails to arrive on time due to congestion, the sensors automatically send signals to the traffic light control devices at intersections to extend the green light time, and ensure that the lights change only after the delayed bus passes by, so as to cut the waiting time of behind-schedule buses at red lights.

b) Bus Priority Suggestions for the Middle Ring Road Bus Corridor

After examining challenges in Tianjin, and lessons learned from other cities, the following recommendations are suggested for the case study location of the Middle Ring Road bus corridor:

1. Tianjin needs to establish a system to prioritize the movement of buses throughout the city. It is crucial to carry out relevant research as soon as possible to determine what steps need to be made (dedicated lanes, markings, intersection infrastructure, signal systems, etc.) to make Tianjin's bus travel system more efficient.

2. Bus signal priority control needs to be coordinated with considerations of both space and time, linking traffic signal control and intersection planning to traffic flows and route demand. Tianjin needs a bus signal priority systems that considers not only the smooth operation of bus vehicles on the whole line, but also the demands of users and the spatial context of each individual intersection. The impact that bus priority systems have on other forms of transport should as positive and unobtrusive as possible.

3. Since different levels of bus priority systems can be implemented, depending on needs and resources, and higher levels of signal systems have a much more significant impact on overall transport systems, before implementing a bus priority system in Tianjin, it is necessary to set a clear target first. Then, to avoid application problems, the extent of bus priority signal systems used should be determined and then implemented.

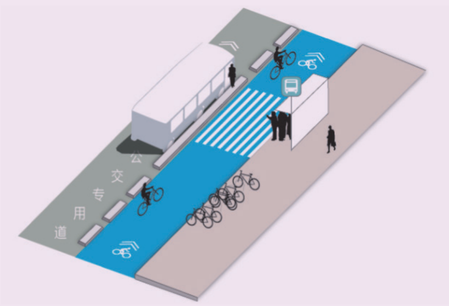
4.4.5 Suggestions for the Optimization of Bus Stops

Currently, the main type of bus platform used in Tianjin is the in-line roadside platform, which provides a high parking efficiency in the context of low bus and pedestrian traffic. For stations with high passenger flows, it is recommended to adjust the type of bus stops used, and construct bus bay platforms for pedestrians to safely board stopping buses.

■ Figure 4-21: Dedicated bus signals in Jinan

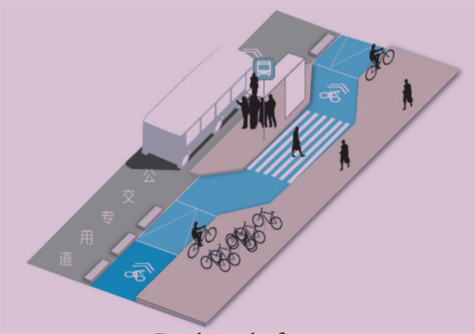
(Source: CSTC)

■ Figure 4-22: Types of bus platforms



In-line roadside platform

This platform design is suitable for small passenger flows. The boarding of passengers is executed from the roadside. It requires little road space. However, passengers might get stressed when boarding buses, as the crossing of the bicycle path contains a risk of collision.



Bus bay platform

Bus bay platforms are suitable for high passenger flows. The boarding of passengers is executed from a dedicated boarding space. It requires sufficient road space. Passengers can safely cross the bicycle path before the bus arrives. Passengers getting off the bus are exposed to a reduced risk of collision with vehicles on the bicycle path.

(Source: CSTC)

4.5 Conclusion

This chapter first analysed the overall context and functions of bus transit in Tianjin based on the relationship between bus, subway, and non-motorized transport. Using Tianjin's Middle Ring Road corridor as an example, suggestions regarding bus corridor optimization were provided. These findings and suggestions are summarized below:

1. Function and positioning of bus transit in the context of the overall public transport system of Tianjin: In the central urban area, the bus system should serve passengers on routes that are not covered by the subway. In the outer areas of the city, bus transit should serve as a supplement to the subway, feeding passengers to the closest subway lines.

2. Complementary development of bus and subway transit: Bus corridors should be developed integrally and complementarily to the subway network to compensate for the subway's insufficient coverage, satisfying travel corridors with low-to-medium passenger demand.

3. Simplifying bus corridors: Bus corridors should be simplified by removing unnecessary bus lanes – in particular bus lanes that overlap with the subway system should be cut.

4. Increase the continuity of bus lanes: The allocation of new bus lanes should be executed in proportion to passenger volume and the number of lanes. On uncongested roads or roads with low passenger volume and sufficient lanes, there is no need to set up dedicated bus lanes.

5. Optimization of the Middle Ring Road pilot bus corridor: The Middle Ring Road corridor of Tianjin should be selected as the location of a pilot project to test the effectiveness of the implementation of proposed optimization steps for bus transit in the city. Therefore, in this pilot location, the continuity of bus lanes should be improved, a bus priority system should be implemented, and bus stops with large passenger flow should be transformed to bus bay platforms. Outcomes should be closely monitored to determine their effectiveness and appropriateness to be subsequently rolled out in other areas of the city as required.

5 Carbon Emission Estimation of the Middle Ring Corridor

5.1 Background

This chapter first elaborates on the significance benefits resulting from carbon emission reduction, and the challenging steps that need to happen for this process to occur. Afterwards, a calculation method for carbon emission reduction potential will be introduced. Finally, the carbon emission reduction potential that an optimization of the Middle Ring Road bus corridor case study could carry will be calculated.

5.2 Significance of Carbon Emission Reduction

Greenhouse gas emissions cause global warming, which is a cause for attention and concern for the international community. With its large energy consumption, China is duty-bound to further strengthen energy conservation and emission reduction efforts. In 2020, Xi Jinping solemnly announced at the general debate of the 75th session of the United Nations General Assembly that China will adopt more powerful policies and measures in this field, striving to achieve the peak of carbon dioxide emissions before 2030, and carbon neutrality before 2060.[16] The transportation sector plays a significant role in the reduction of carbon emissions. In 2018, the carbon emissions of the transportation sector in China accounted for around 10% of total national emissions, and the aims for carbon emission reduction, including within the transport sector, are very ambitious.[16] There are two main approaches to reducing carbon emissions from the transport sector: 1.The application of new technologies, and; 2. the Transformation of the mobility system.

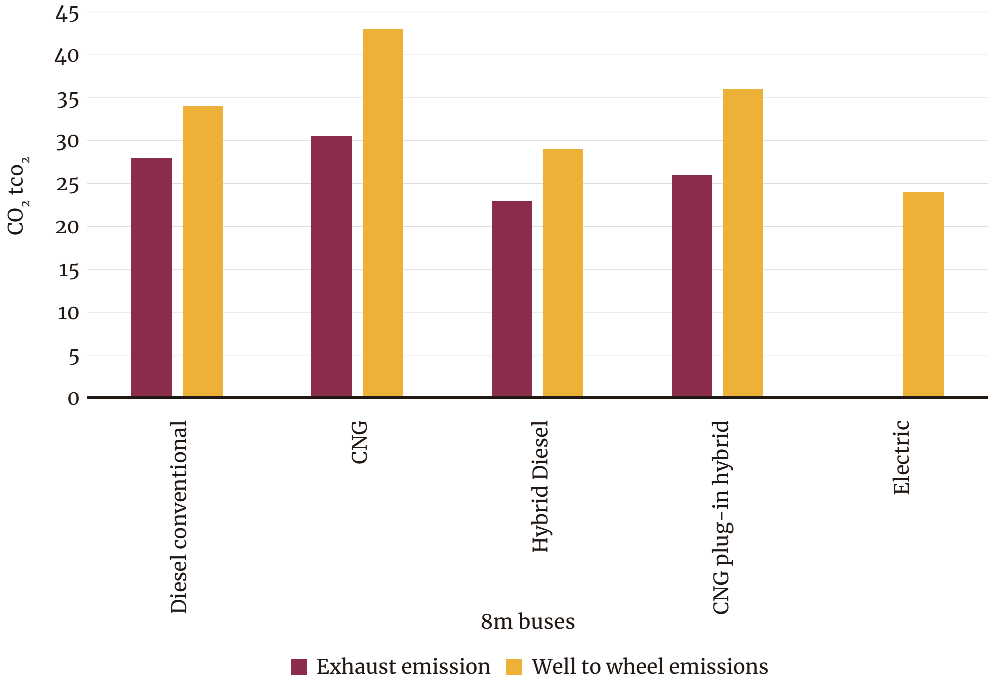
5.2.1 New Technologies Promote Industrial Emission Reduction

The development and use of New Energy Vehicles (NEVs) is a national strategic measure to tackle climate change and promote green development in China. In 2012, the "Energy Saving and New Energy Vehicle Industry Development Plan (2012-2020)" was released, which "takes battery electric vehicles as the main strategic direction for the development of new energy vehicles and the transformation of the automotive industry". By the end of 2019, China's battery electric buses accounted for 99% of the global total. According to the "New Energy Vehicle Industry Development Plan (2021-2035)" issued by the Ministry of Industry and Information Technology (MIIT, 20 October 2020), China will strive, by 2035, to make battery electric vehicles become the mainstream type of transport used, realize the commercial application of fuel cell vehicles, and fully electrify vehicles in the public field. Battery electric buses are continuously becoming more connected, intelligent, light-weight and less carbon-intense. Charging technology is being developed to become more powerful and intelligent as well, although most charging systems are still mainly based on conventional charging types, with fast charging stations only availably as supplements. In terms of vehicle performance, the driving range, safety, comfort, aesthetics, and intelligence levels of battery electric vehicles continue to improve as related technology is developed and refined.

A 2019 study by the World Research Institute (WRI) compared the exhaust emissions and well-to-wheel emissions of different energy types of buses. It was found that the well-to-wheel carbon emissions of battery electric buses are the lowest among all models. They emit 31% ~ 38% less CO2 than traditional diesel buses, 42% ~ 45% less than natural gas buses, and also have less emissions than various hybrid models (see Figures 5-1 and 5-2).[17]

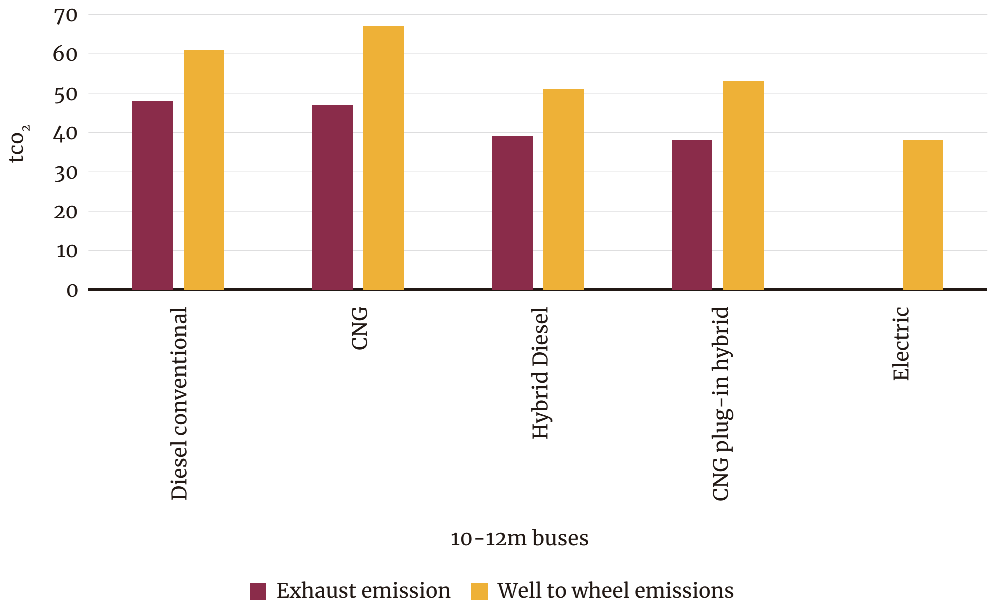
The Ningbo Beilun Bus Company monitored the energy consumption of battery electric buses operating on the city's 703 line. It was found that, in comparison with combustion engine powered buses, pure Liquified Natural Gas (LNG) buses, and gas-electric hybrid buses with the same passenger capacity, battery electric buses can save 41%, 42%, and 18% respectively in energy consumption. If powered by renewable energy, the operation of battery electric buses produces zero emissions and can reduce carbon emissions by 107 tons per vehicle per year compared with combustion engine powered buses. Switching to battery electric buses would therefore having a significant impact on the overall decarbonization of the transport sector.[18]

■ Figure 5-1: Comparison of carbon emissions among conventional diesel, hybrid and battery electric buses (buses with 8m length)



(Source: World Resources Institute, 2019)

■ Figure 5-2: Comparison of carbon emissions among conventional diesel, hybrid and battery electric buses (buses with 10-12m length)



(Source: World Resources Institute, 2019)

5.2.2 Transformation of the Mobility System

In 2021, the "Outline of the National Comprehensive Three-dimensional Transport Network Plan" issued by the Central Committee of the Communist Party of China and the State Council proposed to accelerate green and low-carbon development and ensure that carbon dioxide emissions from the transport sector peaked as soon as possible. The Central Financial and Economic Commission also clearly required that the transportation sector should accelerate the formation of green and low-carbon transportation modes. Shifting from private cars to public transportation can effectively reduce carbon emissions. By transforming the mobility system and reducing the share of private vehicles, while encouraging green travel modes, national greenhouse gas emissions can be significantly reduced.

5.3 Calculation Method of Carbon Emission Reduction

By the end of 2020, Tianjin achieved the full electrification of its 6,800 operating buses, which emit zero CO2 in their operation. This study therefore focuses on the calculation of the reduction in carbon emissions resulting from the optimization of the bus corridors, which attracts more passengers to take buses and thereby reduces the number of emissions-producing private vehicles currently in use.

The calculation method used to determine the possible reduction in carbon emissions that could result from the optimization of bus corridors combines data on population, travel modes, travel distances, and other supporting variables, to predict the future annual amount of carbon emissions of certain types of transport modes. The actual formula used is as follows:

Future annual carbon emission of chosen transport mode = population *
modal share * travel rate * travel distance/carrying coefficient *
carbon emission factor * 365.[19]

5.4 Carbon Emission Calculation

This report uses Tianjin's Middle Ring Road bus corridor as a case study. By improving the continuity of bus lanes on the Middle Ring Road bus corridor on roads and at intersections, and adopting a bus signal priority strategy, the speed, punctuality and efficiency of public transportation will be improved. Compared with private cars, buses will have a continuous and independent right of way and a higher priority on roads, which will make the convenience of public transportation higher than that of using a private car. With faster bus speeds, shorter waiting times for passengers, and more convenient public transportation choices available on public transit corridors, people's willingness to take public transportation will be greatly increased, ultimately changing residents' travel habits and increasing the modal share of bus transit.

A 2018 survey in Tianjin showed that the modal share of buses in motorized travel was 27% and that of cars was 40% (see Table 5-1). In contrast, in cities that have successfully developed dedicated bus lanes, such as Beijing, Shanghai, London, Seoul, or Hongkong, the average modal share of both buses and cars is 34%. In downtown Tianjin, the modal share of bus transit in motorized travel will reach 30% by 2030, according to the Green Transport Development Strategy Research (Phase I) of the Word bank.[20]

For the calculation of projected carbon emissions, it is assumed that after the optimization of the bus corridors, the modal share of bus travel would increase by 6%, reaching 33%, whereas the modal share of cars would drop to 34% by 2030.

Table 5-1: Motorized travel modal share of cars and buses in selected cities

Modal share	Tianjin	Beijing	Shanghai	London	Seoul	Hongkong
Year	2017	2010	2010	-	-	-
Bus	27%	33%	26%	31%	29%	52%
Car	40%	37%	44%	39%	39%	13%

(Source: TMEDI, CSTC 2017)

With an increasing number of residents taking the bus, per capita carbon emissions will be reduced. Therefore, this section calculates the reduction in carbon emissions after the optimization of the Middle Ring Road bus corridor according to the formula provided above. The Tianjin Middle Ring Road bus corridor serves an area that includes surrounding lands that are located a maximum of 600 m distance from roads. Hence, the service area of the Middle Ring Road bus corridor is about 52 km^2 and the population density of the affected area is 12,000 people per km^2. The population of the service area is 624,000.

The average travel rate in Tianjin is 2.4 trips per person per day, with an average travel distance is 4.8km and a carrying coefficient of 1.5. The private car carbon emission factor is 203g/km. Based on the formula and these values, as of 2021, the annual carbon emission of cars in the evaluated area of Tianjin is 142,034 tons CO_2. If the modal share of cars is – as described above – reduced to 34% by 2030, the annual carbon emissions in the evaluated area may be reduced to 120,729 tons. Therefore, attracting more citizens to use bus transit can reduce carbon emissions by approximately 21,305 tons annually between 2021 and 2030.

Conclusion 6

6.1 Summary of the Report

After the systematic analyses of ways to optimize Tianjin's bus network, overall bus operations, and bus corridor management, the study concludes with the following recommendations.

The recommended overall objective from study findings is to enhance the attractiveness of Tianjin's urban rail and bus transit networks while maintaining the city's already high modal share of non-motorized transport. Tianjin's bus system is well positioned within the city's overall transport system to become an efficient and popular choice amongst travellers, particularly if the recommended steps to optimize the flow and function of the network are taken. Focusing on the bus network itself, it is highly recommended to differentiate the optimization goals for the network's central urban area and rest of the city, to better facilitate the coordinated development of bus routes with the coverage of the subway network. In particular, bus service levels should be improved in the central urban area in geographic areas not reached by the subway. In the rest of the city, the bus network should serve as a connecting service to the subway. TMEDI's overall approach to bus network optimization that aims to rectify the issues of overlapping and redundant bus and subway lines, and having bus lines that are too lengthy, is deemed by this study to be both rational and feasible.

At the operational level, this study recommends implementing a multi-tiered bus network system that corresponds to the different needs of passengers (including routes, scheduling, fares and accessibility). The management mechanism of bus lines could be enhanced by moving towards a market-driven model with financial incentives being adjusted, so that under-performing bus lines could be evaluated and forced to improve. Other specific measures to improve the overall bus network operation include:

- The diversification of bus line types based on the varied needs of passengers
- The provision of different scheduling, dispatching, and bus configuration strategies for peak and off-peak hours
- The creation of a passenger-flow based subsidy model that incentivizes operation efficiency and is not based on the length of lines
- The application of an intelligent dispatching and bus monitoring system
- The application of a more cost-effective ticket/fare model
- The harmonization of bus and rail travel schedules and routes

Regarding the management of bus corridors, issues of low speed, incoherent bus lanes, a lack of clear and consistent lane markings, delays at intersections, and inefficient station design were identified. To tackle these issues, the study recommends:

- The reduction of unnecessary bus corridors
- The reduction of delays by ensuring bus lane continuity and bus signal priority at intersections
- For stations with high passenger flows, the adjustment of types of bus stops and an increase in pedestrian crossing facilities

With the goal of generally understanding the carbon emission reduction potential through enhancing the bus system of Tianjin, a rough estimation was made based on a mathematic model. The calculation was based on an assumption that the modal share of buses will be increased by 6% (to a similar level of Beijing) and the modal share of private vehicles will drop by 6% by 2030, and includes indicators of population, modal shares, travel rates and distances, and carbon emission factors. The result of the estimation is that over 20,000 tons of carbon emissions annually could be reduced by optimizing only the Middle Ring Road bus corridor alone.

6.2 Outlook

The development path set by the 14th FYP will determine the future of carbon emissions in the transport sector in the city of Tianjin. While this study focused on the issues of optimizing the city's bus network and operations, other aspects of Tianjin's E-Bus operations, such as the installation of charging infrastructure, the coordination between charger locations and bus line settings, e-bus maintenance, issues of battery degradation, battery recycling and other related issues will also affect the day-to-day performance of the city's bus system. The overall outlook for the rolling out of a more efficient and environmentally sustainable transit system in Tianjin, driven by the promotion of a responsible and adaptive bus network, is positive, particularly when such a plan will be unrolled in the midst of China's broader development strategies.

Appendix

Ways to Set Up Bus Lanes at Intersections

There are three types of bus lanes that can be set at the approaching lanes of intersections, namely straight bus lanes, left-turn bus lanes, and right-turn bus lanes.

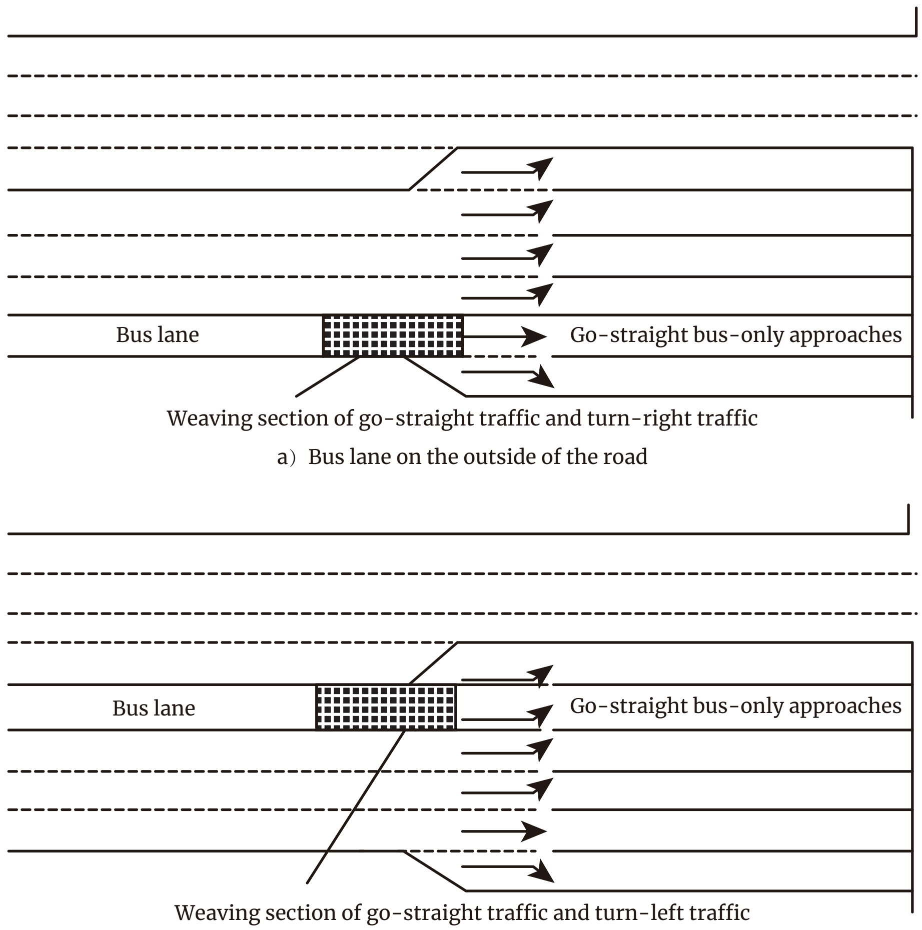
(1) Approaching lanes for straight-moving buses

Due to limited space, most intersections can only provide approaching lanes for buses moving in a straight direction, as adding left- and right-turn lanes is very space-intensive. Depending on the relative position of the approaching lane and the road section of the bus lane, approaching lanes for straight-moving buses can be further divided into three types: straight, staggered, and mixed with other turning vehicles.

a) Straight approaching lanes

This type of approaching lane is applied when a bus moves straight, but an additional turning lane is added before the intersection for other turning private vehicles. In this case, the bus lane extends to the stopping line. An interweaving section is established in front of the approaching lanes, which allows other turning private vehicles to pass through the bus lane and enter their dedicated turning lane. At the intersection, the private vehicles can leave the road, while the bus can continue to move straight. Straight approaching lanes have the least impact on traffic flows, which is especially beneficial to the movement of straight-going buses because they do not need to change lanes. The design of straight approaching lanes has to be adjusted depending on if the bus lane is located along the inner or the outer lane of the road. A visualization of both lane types can be found in Figure 6-1.

Figure 6-1: Dedicated approaching lanes for straight-going buses



a) Bus lane on the outside of the road

b) Bus lane on the inside of the road

(Source: CSTC)

b) Staggered approaching lanes

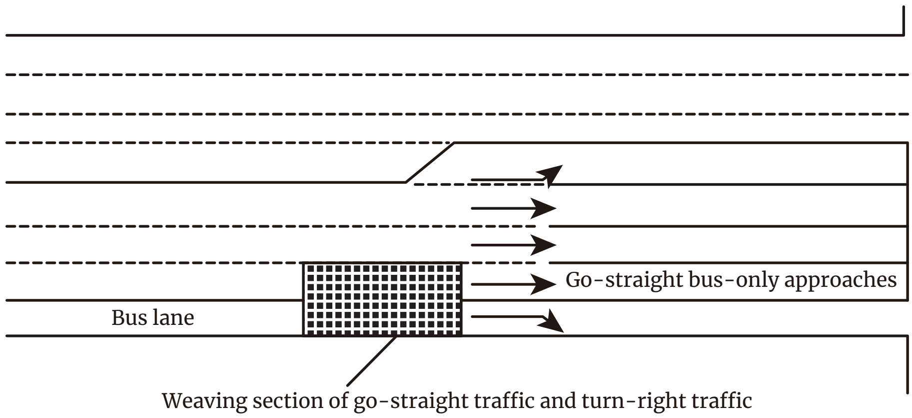
This type of approaching lane is applied when a bus is moving straight and there is a high number of other turning private vehicles, but the road and traffic conditions do not allow for an additional approaching lane for to accommodate these turning private vehicles. Under these circumstances, the bus lane is moved inwards by one lane, and an interweaving section is established in front of approaching lanes to allow straight-moving buses and other turning private vehicles to change lanes.

Staggered approaching lanes are demanding for drivers of both public transit vehicles and other private vehicles because both need to change lanes when approaching the intersection, which can lead to traffic congestion in the interweaving process. The design of staggered approaching lanes has to be adjusted depending on if the bus lane is located along the inner or the outer lane of the road. A visualization of both types of lanes can be seen in Figure 6-2.

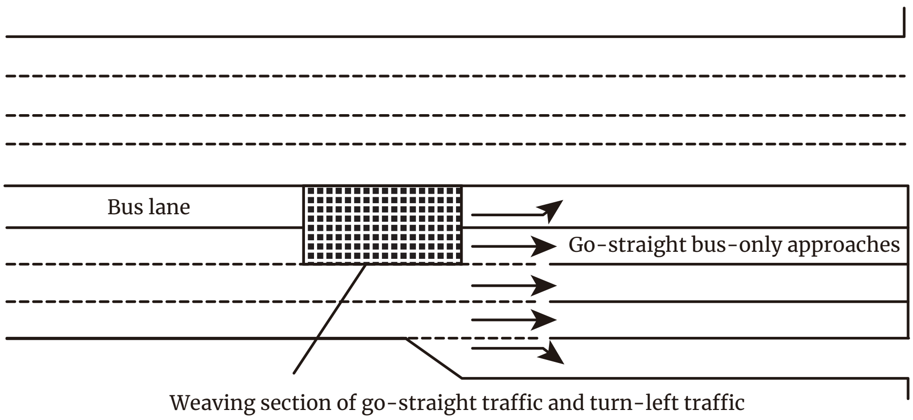
c) Shared approaching lanes

This type of approaching lane is used when straight-moving buses and turning private vehicles share the same approaching lane and signal phase and the volume of other turning private vehicles is relatively low. In this case, an interweaving section is established in front of the approaching lanes, which allows other turning private vehicles to enter shared approaching lanes. Such lanes are unfavourable for traffic flows, as the differing demands of both groups may lead to congestion. The design of shared approaching lanes has to be adjusted depending on if the bus lane is located along the inner or the outer lane of the road. A visualization of both types of lane can be seen in Figure 6-3.

Figure 6-2: Staggered approaching lanes



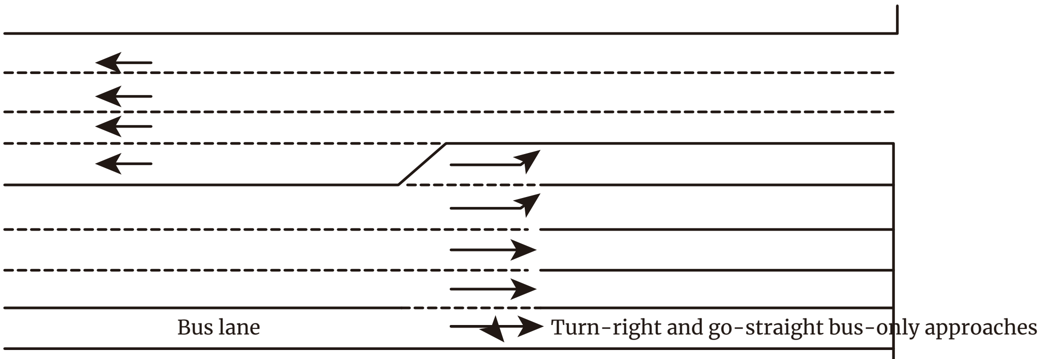
a) Bus lane on the outside of the road



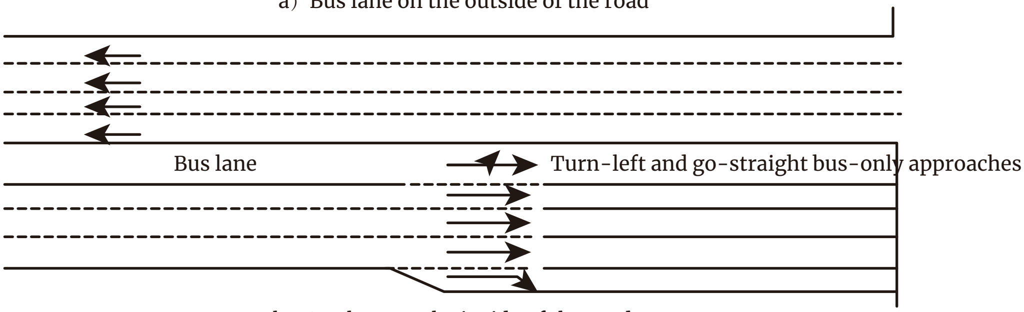
b) Bus lane on the inside of the road

(Source: CSTC)

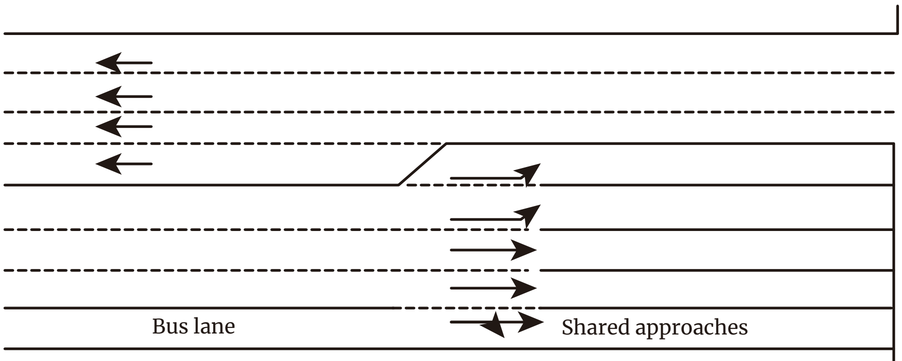
■ Figure 6-3: Shared approaching lanes



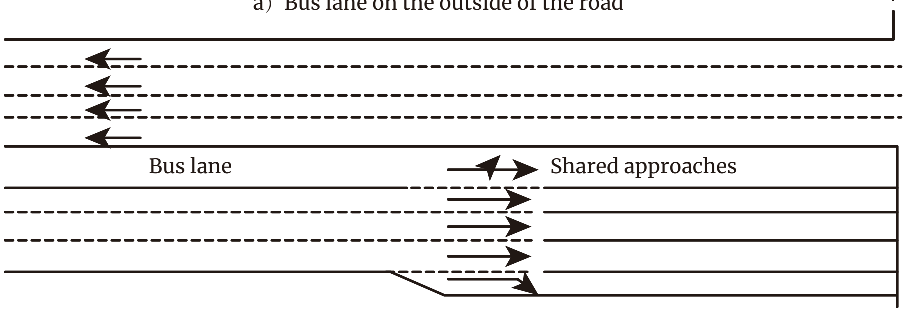
a）Bus lane on the outside of the road



b）Bus lane on the inside of the road



a）Bus lane on the outside of the road



b）Bus lane on the inside of the road

(Source: CSTC)

(2) Approaching lanes for left-turning buses

When the volume of left-turning buses at an intersection is high, a dedicated approaching lane for left-turning buses on the left-turning lane of the intersection could be implemented. To avoid chaos caused by the interweaving of left-turning buses and left-turning private vehicles passing through the intersection, the approaching lane for left-turning buses must correspond to the respective departing lane. The placement principles for these lanes are:

a) If the departing lane is located along the outer lane, the left-turn approaching lane should also be located along the outer lane;
b) If the departing lane is located along the inner lane, the left-turn approaching lane should also be located along the inner lane;
c) If the departing lane is in the middle, the left-turn approaching lane should be located along the outer lane.

(3) Approaching lanes for right-turning buses

When a right-turn lane is provided with traffic lights or when the traffic flow of right-turning buses is high, the setting up of a dedicated approaching lane for right-turning buses could be considered. To avoid chaos caused by the interweaving of right-turning buses and right-turning private vehicles passing through the intersection, the approaching lane for right-turning buses must correspond to the respective departing lane. The placement principles for these lanes are:

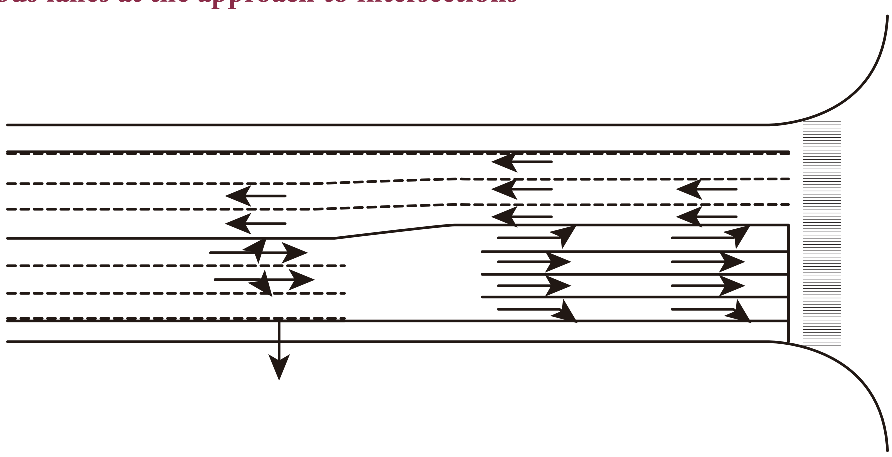
a) If the departing lane is located along the outer lane, the right-turn approaching lane should also be located along the outer lane;
b) If the departing lane is located along the inner lane, the right-turn approaching lane should also be located along the inner lane;
c) If the departing lane is in the middle, the right-turn approaching lane should be located along the inner lane.

Advantages and Disadvantages of Different Approaching Lanes

To illustrate the advantages and disadvantages of different types of approaching lanes, into the relationship between approaching lanes for straight-moving buses and right-turn lanes as examples can be examined. Five different contexts to consider are illustrated in Figures 6-4, 6-5, 6-6, 6-7 and 6-8. The advantages and disadvantages of each of these the five types of approaching lanes are then summarized in Table 6-1.

(1) No bus lane

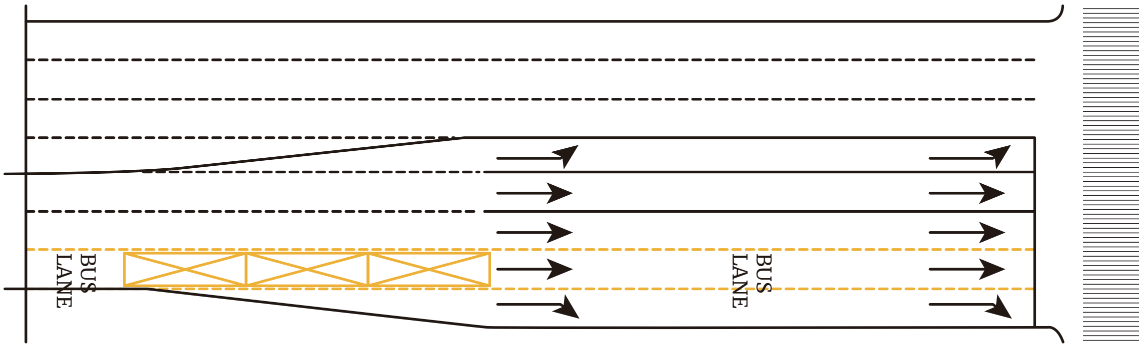
■ **Figure 6-4: No bus lanes at the approach to intersections**



(Source: CSTC)

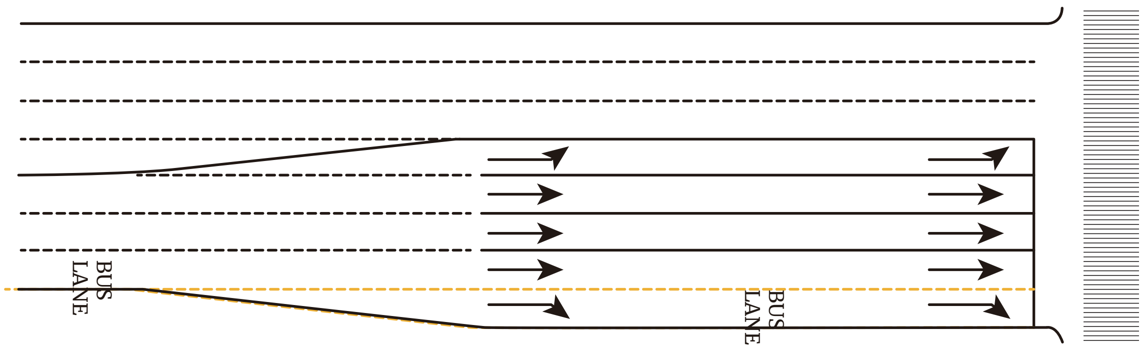
(2) Bus lane is set on the left side of the right-turn lane

■ **Figure 6-5: Bus lane is set on the left side of the right-turn lane**



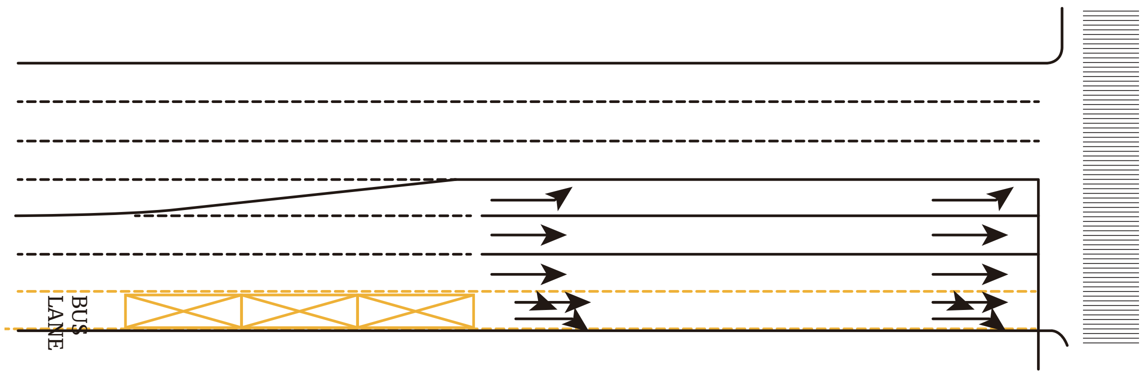
(3) Bus lane is set on the right side of the right-turn lane

■ **Figure 6-6: Bus lane is set on the right side of the right-turn lane**



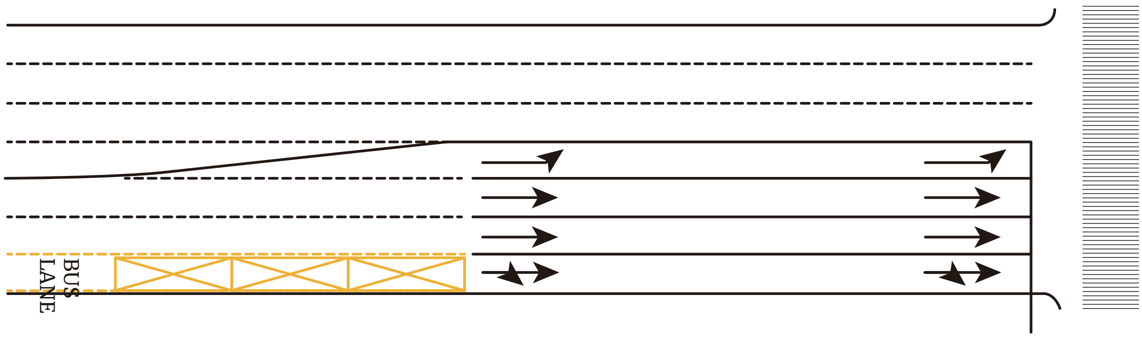
(4) Shared use of straight bus lane

■ **Figure 6-7: Shared use of straight bus lane**



(5) Shared use of right-turn lane

■ **Figure 6-8: Shared use of right-turn lane**



■ **Table 61: Advantages and disadvantages of different types of approaching lanes**

Lane type		Application requirements	Advantages	Disadvantages
No bus lane		There are less than six approaching lanes and the traffic volume is high.	Nether bus nor private car flow is limited, which helps to improve the overall traffic efficiency of the intersection.	The efficiency of bus transit at the intersection is not significantly improved.
Bus lane	To the left of the right-turn lane	There are more than five approaching lanes and the distance between adjacent intersections does meet the length requirements of the interweaving section.	Exclusive approaching lane for buses and no need to change lanes.	One lane of private car use must be changed to a bus lane, which reduces the traffic efficiency of private vehicles. The right-turning vehicles need to cross the bus lane, which increases the risk of accidents.
	To the right of the right-turn lane	There are more than five approaching lanes and the distance between adjacent intersections does not meet the length requirements of the interweaving section.	Exclusive approaching lane for buses.	One lane of private car use must be changed to a bus lane, which reduces the traffic efficiency of private vehicles. The right-turning vehicles weave with the bus flow, which can more easily lead to accidents.
Shared use of straight bus lane		There are less than six approaching lanes and the volume of right-turning vehicles is low.	Straight-moving buses and right-turning private vehicles share a dedicated approaching lane, they don't have to change lanes, which improves the overall traffic efficiency.	Straight-moving buses and right-turning vehicles have interfering travel demands, reducing efficiency and increasing security risks. Right-turning private vehicles should give ways to straight-moving buses.
Shared use of right-turn lane		There are less than six approaching lanes and the volume of straight-moving buses is high, while the volume of right-turning vehicles is low.	Straight-moving buses use the right-turn approaching lane, allowing them not to have to change lanes, which improves the overall traffic efficiency.	Straight-moving buses and right-turning vehicles have interfering travel demands, reducing efficiency and increasing security risks. Straight-moving buses should give way to the right-turning vehicles.

(Source: CSTC)

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