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Application Readiness of Fuel Cell City-bus in China

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Summary

In recent years, fuel cell city-buses (FCCBs) application in urban public transport have been rapidly developed in China that over 20 cities have operated more than 1300 FCCBs by 2019. We use the readiness to analyse development of FCCB application in different cities. Factors affecting the readiness are classified by four dimensions, from which a model is constructed by survey, analytic hierarchy process (AHP), and etc. Based on the model, we calculate cities' readiness and cluster cities into different types. For each type of city, suggestions to increase their readiness or improve preparation for FCCB application are put forward.

Keywords: Bus, Fuel Cell Vehicle/Hydrogen Vehicle, Market Development, Public Transport, Business Model

1 Introduction

Urban public transport (UPT) has been required as the breakthrough and the former part of new energy vehicle (NEV) application in both national and local level NEV strategy in China because it is a public welfare providing basic public transport and the priority area for green and low-carbon mobility in the country. Under strong support and relevant policies from the governments, UPT has always been the area with the highest NEV penetration rate and the largest number of participating cities in China.

In China, NEV penetration rate in UPT up to 2019 and in 2019 are over 51% and 90%, respectively, while NEV penetration rate in all other areas are around 2% up to 2019 and 5% in 2019. With the rapid development of fuel cell electric vehicle (FCEV) as one of the important technical routes of NEV both in the world and in China, the application of fuel cell electric bus (FCEB), especially fuel cell city bus (FCCB) in UPT has become the most promoted NEV type in China. More and more cities have engaged in FCCB application with booming enthusiasm in the past two years [1]. By the end of 2018, the number of city-buses in mainland China is about 670,000, with an average of 250 million people travelling by public transport every day. Among the city-buses, the number of new energy city-buses (NECBs) has exceeded 340,000, with a penetration of 51% in the total number of the city-buses in China, and ranks top in the world. In 2019, about 76,000 NECBs were newly added, which accounted for about 95% of the annual total number of replaced and newly added buses in UPT. Among the 660+ Chinese cities, more than 330 prefecture-level, above-level and county-level cities combined have adopted NEVs in UPT by the end of 2019.

Since 2015, the application of new energy bus power technology routes in China's UPT has obviously changed. From 2016, battery electric city-buses (BECBs) became the new main bus type that replaced the previous hybrid-buses (HEBs). The BECBs accounted for nearly 90% of the newly added NECBs by 2019 [2-3], but the growth rate of FCCBs has accelerated significantly since 2018. In recent two years, FCCBs have been adopted by an increasing number of Chinese cities due to their higher application subsidies, shorter charging time and stronger durability. In 2018, only 10 cities added 300^{+} FCCBs each while in 2019, there were around 15 new cities adding more than 1,000 FCCBs.

We found in surveys that FCCB application differs in progress in different cities, and cities applying FCCBs present different development features from those applying BECBs. The previous advanced BECBs application cities such as Shenzhen in Guangdong Province, cities in Hunan Province, or even metropolises like Beijing and Shanghai with both large scale of BECB and pilot FCCB application in the United Nations Development Program (UNDP) project, have not kept their leadership in FCCBs application. Instead, some lower-level cities, i.e., prefecture-level cities, such as Foshan in Guangdong Province, Zhangjiakou in Hebei Province, and even smaller county-level cities such as Jiashan County in Zhejiang Province, stand out in FCCB application scale. The scale difference in FCCB application among cities naturally leads to the following questions that deserve investigation: what are the different characteristics among these FCCB application cities? What are the key factors affecting their development levels? How should the existing FCCB application cities learn from each other? How do cities newly entering the race choose more appropriate development path based on experience from pioneer cities?

With the above questions in mind, we use the parameter of readiness to compare degree of development and analyse key influencing factors of FCCB application in UPT in different cities. Thereafter, we classify cities by cluster analysis to open their path of application and suggest for future strategies. The study shall be performed under deep understanding of the overall background of NECBs promotion and application in Chinese cities.

2 Application Status of FCCB in China

In general, there are four bus types according to the type of energy power, i.e., traditional internal combustion engine bus (ICEB), hybrid bus (HEB), battery electric bus (BEB) and fuel cell electric bus (FCEB). With different application scenarios and size of vehicle, FCEB can be further divided into fuel cell group bus (FCGB), fuel cell city bus (FCCB) and fuel cell light bus (FCLB).

2.1 Main Types and Application Scenarios of FCEB

Similar to other types of energy power buses, the FCEB has multiple types and application scenarios, as shown in Table 1. By the end of 2019, FCCB applied in UPT has the largest application scale, the longest operation time and the largest number of cities in China among all the three FCEB types. The number of FCCBs applied in the UPT accounts for about 70% of the total number of FCEBs.

Table1: Main type and application scenario of FCEB in China

Application scenario	Type of FCEB	Case and corresponding picture	
UPT	FCCBs mainly used, and a few FCLBs used	 	
Urban-rural passenger transport	A few FCCBs used	Jiashan: Xiamen Golden Dragon FCCBs	
Rural passenger transport	No FCEBs used yet	-	
Customized passenger lines	FCLBs mainly used	Wuxi: SAIC MAXUS FCV80s are put on the customized passenger line from Airport to Bus stop	
Chartered bus transport	Large FCGBs mainly used	Beijing: FOTON AUV 8.5 m FCEBs serve China EV100	
Tourist bus transport	Medium FCGBs mainly used	Foshan: 8.5 m FCEBs in the 4A tourist area	
Commuter bus transport	FCLBs mainly used, and some medium-large FCGBs used	Shanghai: Chemical Industry Park uses SAIC MAXUS FCV80s for employees to commute	
		Wuhan: Xiamen Golden Dragon FCGBs	

2.2 Promotion and Application History and Status of FCCB

Generally speaking, the FCCB promotion and penetration in UPT among Chinese cities include two main stages by 2019. The first stage is demonstration operation in 2006-2015. By participating in the UNDP global FCEB demonstration project in 2006, Beijing and Shanghai were the first to start FCCB operation among Chinese cities. Subsequently, Beijing and Shanghai successively carried out demonstration operation with a total number of around 10 FCCBs through the UNDP/ Global Environmental Fund (GEF) project practice, as well as major events and activities in China such as the Beijing Olympic Games (2008), China's NEV "10 cities and 1,000 vehicles" pilot city project (from 2009), Shanghai World Expo (2010) and Guangzhou Asian Games (2010). The second stage is 2016-2019, in which FCCB application have generally entered the stage of small-scale commercial operation, with nearly 30 cities applying a combined 1,300 FCCBs. In 2016-2018, five Chinese cities, including not only Beijing and Shanghai but also Foshan in Guangdong Province, Zhengzhou in Henan Province and Yancheng in Jiangsu Province, have successively participated in the third phase of the UNDP/GEF project and operated 36 FCCBs in total. In addition to the five demonstration cities, an increasing number of other Chinese cities have launched FCCB applications in the past two years, driven by the national and local supporting policies.

The national level policies that promote the rapid development of FCCBs mainly include improving the infrastructure for hydrogen production and hydrogenation, and increasing purchase subsidies for high-power and high-mileage FCCBs while reducing subsidies for BECBs. The subsidy standard for each FCLB and truck is 300,000 Yuan, and for each large-medium FCCB is 500,000 Yuan. In recent years, local governments have intensively issued relevant policies, which have directly promoted the quick development of FCCBs in some cities. Only in 2019, 57 provinces and cities in China issued over 60 hydrogen related plans and 26 subsidy policies, including 31 special policies for hydrogen energy and fuel cell.

In addition, the improving FCEB industrial support capacities and accelerating hydrogenation infrastructure are also important factors for the rapid development of FCCB application in cities. By 2019, around 20 vehicle enterprises can provide FCCB products on a large scale with continuously maturing technology and market service. In terms of infrastructure construction, China has built 18 hydrogen refuelling stations in 2015-2018, and 28 in 2019 [4]. By 2019, 61 hydrogen refuelling stations have been completed and 52 of them have been put into operation, distributing in 36 cities of 18 provinces and mainly serving FCCBs.

2.3 Regional Distribution of FCCB Application

According to statistics of China National Monitoring and Management Center for NEVs [5], by 2019, 3,712 of the total 6,000$^+$ FCEVs sold in China have been connected to the Center. The 3,712 national-platform connected FCEVs are distributed in 14 provincial-level markets in the Chinese mainland, including 12 provinces and 2 municipalities directly under the central government. Figure 1 shows the percentage of each FCEV type. 39.4% (1,462) of the total number of FCEVs connected to the platform are FCEBs, and of which the most widely applied are FCCBs, accounting for 63.1% (923) of the total FCEBs.

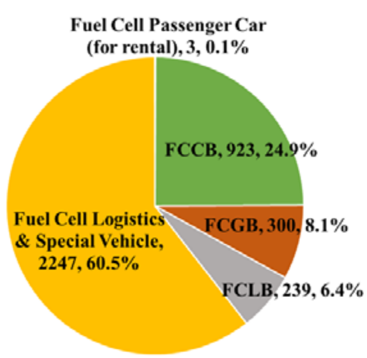

Figure 1: Distribution of FCEV types connected to platform

From the perspective of regional distribution, 14 provincial-level markets with FCEVs applied in 27 cities covering all seven regions in the mainland of China. As shown in Table 2, although the number of fuel cell logistics vehicles is the largest among FCEVs, they have only entered less than 20 cities in 10 provinces. Instead, FCEB application has wider regional coverage with 21 cities in 13 provincial-level markets, and its hottest segment is FCCB with 19 cities engaged in the application. The other two cities, Wuxi (Jiangsu Province) and Fushun (Liaoning Province) only applied FCLBs (SAIC Maxus FCV80) in commuting service rather than FCCBs in UPT. In addition to cities shown in Table 2, cities such as Lu'an in Anhui Province, Nanning in Guangxi Province and Wuhan in Hubei Province, each started with 1-3 FCCBs promoted in the last month of 2019 [6].

Table 2: Regional distribution of FCEB and FCCB application in China by 2019

Coverage area	Province-level Market (FCEB number)	FCCB application city number and FCCB number in each city
East China	Shanghai (355)	1 city: **Shanghai** (8)
	Jiangsu (55)	4 cities: Suzhou (35, including **Changshu** (20)), Nantong (6), Yancheng (10), Wuxi (0)
	Zhejiang (18)	2 cities: Jiaxing (including **Jiashan** (18)), Huzhou (0)
	Shandong (70)	4 cities: **Weifang (**30), Liaocheng (30), Jinan (10), Dezhou (0)
North China	Beijing (145)	1 city: **Beijing** (5)
	Hebei (174)	1 city: **Zhangjiakou** (174)
South China	Guangdong (335)	5 cities: **Guangzhou** (2), Shenzhen (0), **Foshan** (320), Zhuhai (0), Yunfu (10)
	Fujian (2)	1 city: **Fuzhou** (2)
Central China	Henan (95)	2 cities: **Zhengzhou** (23), Nanyang (72)
	Hubei (33)	2 cities: **Wuhan** (23), Shiyan (0)
Southwest China	Sichuan (45)	1 city: **Chengdu** (45)
Northwest China	Shanxi (70)	1 city: **Datong** (70)
	Shaanxi (0)	1 city: Xi'an (0)
Northeast China	Liaoning (40)	1 city: Fushun (0)

2.4 Selection of Typical Cities for FCCB Application City Readiness

The FCCB application in China is evaluated through cities. Table 2 not only reflects the difference of the overall scale and segment of FCEV promotion in each city, but also preliminarily reflects the level and regional distribution characteristics of FCCB application in cities. Among the 19 FCCB application cities, there are 2 municipalities directly under the central government (Beijing and Shanghai), 6 provincial capitals (Guangzhou in Guangdong Province, Fuzhou in Fujian Province, Zhengzhou in Henan Province, Wuhan in Hubei Province, Chengdu in Sichuan Province and Jinan in Shandong Province). Besides, there are 11 prefecture-level cities also applied FCCBs, even including lower-level cities such as the county-level city Changshu in Suzhou of Jiangsu Province and the county of Jiashan in Jiaxing of Zhejiang Province. These facts indicate that different levels of Chinese cities have the power and conditions to promote and apply FCCBs. In order to further investigate the development level of FCCB application among different level cities, we will select 14 out of the 19 cities from the all four levels as representatives to analyse. Due to the large number of prefecture-level cities, we plan to select Zhangjiakou, Foshan, Datong (in Shanxi Province) and Weifang (in Shandong Province) as the representatives of the prefecture-level cities according to the number of FCCB applications and the representativeness of regional distribution. Meanwhile, for the other three levels of cities, we will select all the cities regarding that the number of these cities is small and the cities have high representativeness themselves. After selecting 14 representative cities from all the four different levels of cities, we will further analyse the development level of FCCB application in these cities. The concept of readiness will be used to reflect FCCB application development in cities and an evaluation model will be constructed to analyse the key development power.

3 City Readiness of FCCB Application

3.1 Measure Model of the Readiness

City readiness of FCCB application is a comprehensive concept that reflects the development level of the city's FCCB application in UPT with rich connotations. Before establishing measure model of the readiness, we should establish an indicator system that can reflect the main aspects of FCCB application in order to make a basic judgment on the FCCB development level. Based on the authors' long-term surveys on NEV application mechanism in Chinese cities, especially with field investigation of cities' FCCBs application in recent years and sorting references of domestic and international research achievements [7], this paper constructs an indicator system of city readiness of FCCB application with four dimensions, including local condition, policy environment, supporting facilities, and vehicle operation and maintenance, as illustrated in Figure 2.

Primary indicator (dimension A_i)	**Secondary indicator (secondary dimension B_{ij})**	**Tertiary indicator (index layer C_{ijk})**	**Indicator calculation and source**	**Comprehensive weights(w_i)**
Local condition A_1	Economic level B_{11}	Real GDP per capita C_{111}	Urban statistical yearbook	1.12%
	Natural foundation B_{12}	Climatic condition C_{121}	Temperate monsoon climate mainly	0.46%
		Hydrogen supply C_{122}	Wind, solar and other natural resources	1.84%
	Traffic condition B_{13}	Scale of city-bus C_{131}	Public information collation	0.25%
		Electric rate of city-bus C_{132}	Number of NECBs/total number of buses	0.73%
	Industrial base B_{14}	Electric rateC_{141}	Research and public information collation	1.40%
		Layout of fuel cell enterprises C_{142}		3.19%
		Industrial chain integrity C_{143}		1.22%
	Major event B_{15}	Government project C_{151}	Research and public information collation	2.28%
		Sport event C_{152}		0.69%
		Enterprise investment C_{153}		1.26%
Policy environment A_2	Vehicle promotion B_{21}	Scale of promotion C_{211}	Policies, planning documents, etc.	10.05%
		Demonstration operation C_{212}		3.35%
	Hydrogen refuelling station construction B_{22}	Scale in plan C_{221}		1.57%
		Service capacity C_{222}		1.00%
		Regional distribution C_{223}		2.01%
		Preferential policy C_{224}		0.66%
	Fiscal and tax policy B_{23}	Fiscal subsidy for vehicle C_{231}		2.91%
		Tax reduction and exemption C_{232}		0.72%
		Fiscal subsidy for station C_{233}		2.73%
		Fiscal subsidy for enterprise C_{234}		1.64%
	Hydrogen energy development goal B_{24}	Industrial financial target C_{241}		3.21%
	Public service platform construction B_{25}	Public service platform construction C_{251}		1.07%
		Other platforms construction C_{252}		1.07%
Supporting facilities A_3	Hydrogen production capacity B_{31}	Layout of hydrogen production enterprises C_{311}	Research, expert interviews, etc.	3.58%
		Hydrogen production scale C_{312}		1.79%
	Hydrogen refuelling station construction B_{32}	Start time of construction C_{321}	Research and public information collation	1.99%
		Construction scale C_{322}		7.20%
		Regional distribution C_{323}		6.54%
	Hydrogen refuelling station service capacity B_{33}	Storage capacity C_{331}	Storage capacity of hydrogen (kg)	1.60%
		refuelling pressure C_{332}	MPa	0.88%
		refuelling quantity C_{333}	refuelling quantity (kg/day)	2.90%
	Cost of hydrogenation B_{34}	Hydrogen refuelling cost C_{341}	Research, expert interviews, etc.	9.56%
	Hydrogen refuelling station operation & maintenance B_{35}	Operational subject C_{351}	Research, expert interviews, etc.	1.55%
		Innovation mode C_{352}		1.55%
Vehicle operation and maintenance A_4	Fleet operation B_{41}	Vehicles' number in operation C_{411}	Research and public information collation	1.67%
		Start time of operation C_{412}		0.67%
		Operational coverage area C_{413}		1.06%
	Vehicle technical level B_{42}	Vehicle performance C_{421}	Comprehensive evaluation of vehicle endurance, speed, fuel cell power, etc.	1.28%
		Failure rate C_{422}	Research and platform data collation	0.64%
	Fleet operation capacity B_{43}	Average vehicle mileage C_{431}	km	1.99%
		Vehicle mileage between two refuelling acts C_{432}	km	0.76%
		Average online rate C_{433}	Number of operating vehicles/vehicles connected to platform	3.46%
	Vehicle maintenance capacity B_{44}	Maintenance condition C_{441}	Research, expert interviews, etc.	0.80%
		Maintenance subject C_{442}		0.32%
		Vehicle maintenance timeliness C_{443}		0.70%
	Business model B_{45}	Fleet operational subject C_{451}	Research, expert interviews, etc.	0.54%
		Innovation mode C_{452}		0.54%

Figure 2: Indicator system of city readiness for FCCB application

•Local condition: Being the basic support for city's FCCB application, the major local conditions to facilitate FCCB application include the city's economic level, traffic conditions, especially conditions of public transport, and industrial layout related to FCEBs. In addition, we also found that some major events, such as important government projects, sport events and enterprise investment are often direct factors and key driving forces to kick off the city's FCCB application in the early stages. For example, the main driving force behind the application of FCCBs in Zhangjiakou is the city being the major hosting location for the 2022 Winter Olympics. The city views FCCB application as the important contributor to the expected low-carbon green winter Olympics. Meanwhile, Zhangjiakou has been approved to build China's only national-level renewable energy demonstration zone since 2015, which is another key driving force for Zhangjiakou to apply FCCBs to promote hydrogen production with renewable energy.

•Policy environment: This refers to the series of policies set by the city to support FCCBs application. The policies include fiscal and tax ones such as subsidies and tax deduction/exemption for NEV promotion, and non-financial ones such as constructing hydrogen refuelling stations, setting targets for FCCB promotion market, scale of hydrogen refuelling stations, hydrogen energy industry and public service platform.

•Supporting facilities: Besides hydrogen refuelling station construction for FCCB operation, supporting facilities also include upstream hydrogen energy supply capacity, which indicates whether the city can provide low cost and abundant hydrogen to meet demand of FCCB operation.

•Vehicle operation and maintenance: This reflects the city's FCCB operation level. In addition to FCCB scale and application scenario, it also includes other factors such as vehicle technical level, service and maintenance capacity and business models.

Based on scientific, highly representative, hierarchical and practical principles, as well as understanding of city readiness of FCCB application, this paper selects 48 specific indicators from 4 dimensions to evaluate city readiness of FCCB application, as shown in Figure 2.

The measurement method of city readiness of FCCB application is learned from the evaluation system for high-quality urban economic development or evaluation model for smart city construction level of Zhang Zhen (2019), He Qin (2019) and other scholars [8-9]. Based on the research results, this paper builds a comprehensive indicator evaluation model for city readiness of FCCB application by the following steps. First, we construct judgment matrices of the three level indicators by judging the importance of indicators within the same level and calculating the indicator weight. Second, we make a consistency check on judgment matrices with Equation 1. Third, based on the principle that all the weights add up to 100%, we multiply the indicators of different levels correspondingly and adjust the results to get the comprehensive weights w_i, as shown in the last column of Figure 2.

$$CR = \frac{CI}{RI} < 0.1 \quad (1)^*$$

*Note: In Formula 1, *CI* is the consistency index, *RI* is the random consistency index, and *CR* is the consistency ratio

According to comprehensive weights w_i and normalized scores (scores are recorded as x_{ijk} with a maximum of 5 points) assessed by resources relevant to the fourth column in Figure 2, we build a measurement model of city readiness of FCCB application with multi-objective linear weighted sum method, as shown in Equation 2. In Equation 2, *R* represents city readiness of FCCB application and x_{ijk} are scored with data from field research, expert interviews and public information collation, etc. Indicators such as the number of FCCBs in operation can be scored directly and objectively. Indicators such as business model cannot be scored objectively, of which we take the average value from the assessments by experts in the field.

$$R = \sum_{i=1}^{48} w_i \cdot x_{ijk} \quad (2)$$

3.2 City Readiness and Classification

3.2.1 Calculation and Analysis of City Readiness

The readiness of the selected 14 cities is be calculated by Equation 2. With a maximum value of 5, *R* is positively related to FCCB promotion and application scale, which means that the greater *R* is, the better condition it is for the city to promote and apply FCCBs. Each city's score of the *R* value and their ranking are shown in Table 3. The average *R* value of all 14 cities is 2.9083.

Table 3: Cities score and ranking of readiness

	Beijing	Shanghai	Guangzhou	Fuzhou	Zhengzhou	Wuhan	Chengdu
Score	2.6210	3.7824	2.7120	1.6819	2.5422	3.1746	3.2403
Ranking	11	2	10	14	12	6	5
	Jinan	Zhangjiakou	Foshan	Datong	Weifang	Changshu	Jiashan
Score	1.8907	3.3885	3.9724	2.7820	2.7767	2.8487	3.3025
Ranking	13	3	1	8	9	7	4

In the 14 cities selected, Foshan, Shanghai and Zhangjiakou rank the top three in their city readiness of FCCB application, with score of 3.97, 3.78 and 3.39, respectively. Among the top three cities, only Shanghai is a municipality, while the other two, Foshan and Zhangjiakou, are both prefecture-level cities. Moreover, the six capital cities performed behind the prefecture-level cities on average. These six capital cities rank the 5th, 6th, 10th, 12nd, 13rd and 14th, respectively, with an average score of 2.5403, which is lower than the 14 cities' average score of 2.9083. Although Changshu and Jiashan are not prefecture-level cities, with Jiashan being only a county under the jurisdiction of Jiaxing, the two cities' readiness rank high due to their strong policy support. Changshu also benefits from the fact that Toyota, the world's leading hydrogen fuel cell enterprise, launched a research and development base in the city, and put the driving effect on the support of local FCCBs and hydrogenation facilities.

To further analyse characteristics of FCCB application in each city, we calculate and rank scores of the 4 dimensions affecting the 14 cities' readiness shown in Table 4. The average scores of local conditions, policy environment, supporting facilities and vehicle operation and maintenance are 3.2, 3.0, 2.6 and 3.1, respectively. Among them, supporting facilities have the lowest scores, with a large gap from the other three dimensions. It reflects that pressure on supporting facilities of hydrogen refuelling is still relatively high and hinders the FCCB application in most cities.

Table 4: Score and ranking of the 4 dimensions of cities*

	Beijing	Shanghai	Guangzhou	Fuzhou	Zhengzhou	Wuhan	Chengdu
Local condition	3.6(6)	3.7(5)	2.8(10)	2.1(14)	2.4(13)	3.0(9)	3.9(1)
Policy environment	1.7(14)	3.4(5)	3.3(7)	2.3(12)	2.8(9)	3.0(8)	3.8(2)
Supporting facilities	2.7(8)	4.2(1)	3.2(4)	0.5(13)	2.1(12)	3.3(3)	2.5(10)
Vehicle operation and maintenance	3.5(3)	3.5(3)	0(14)	2.9(13)	3.2(9)	3.4(5)	3.3(8)
	Jinan	Zhangjiakou	Foshan	Datong	Weifang	Changshu	Jiashan
Local condition	3.1(8)	3.9(1)	3.8(4)	2.5(12)	3.9(1)	2.7(11)	3.4(7)
Policy environment	2.4(11)	3.4(5)	4.0(1)	2.8(10)	2.0(13)	3.5(4)	3.8(2)
Supporting facilities	0.5(13)	3.0(5)	3.8(2)	2.6(9)	2.8(7)	2.3(11)	2.9(6)
Vehicle operation and maintenance	3.2(9)	3.8(1)	3.8(1)	3.4(5)	3.4(5)	3.2(9)	3.1(12)

*Note: number in round brackets is cities' ranking of 4 dimensions

Chengdu, Zhangjiakou and Weifang score the top three in local conditions. Besides Zhangjiakou, which has good conditions for holding the Winter Olympics and owning the only national new energy demonstration zone, Chengdu has a complete and strong hydrogen energy industry chain [10]. Moreover, abundant resources such as hydropower in Chengdu ensure hydrogen supply. Although Weifang has relatively weak economic status, its traditional industry is strong. As a strong leader in transition from traditional engine enterprise to hydrogen engines enterprise, Weichai (Weichai Holding Group Co., Ltd.) in Weifang has a powerful impetus for local fuel cell industry cluster and market application.

Foshan, Chengdu and Jiashan are the top three in policy environment. The three cities have broad policy coverage, as well as specific measures and strong support from policies.

Shanghai, Foshan and Wuhan are the top three in supporting facilities, among which Shanghai has the most prominent advantages. Shanghai has the largest number of hydrogen refuelling stations in the country, resulting from the early start of their constructions ahead of other cities. By 2019, eight hydrogen refuelling stations, including two oil-hydrogen mixed stations and a power-hydrogen mixed station has been opened in Shanghai. The power-hydrogen station can supply 1,000 kg hydrogen daily, achieve 70MPa refuelling pressure in the future, and supply hydrogen to the other stations as a master station. Although the FCCB fleet scale promoted in Shanghai is not large at this stage, its industry, policy and infrastructure foundation are advanced for the future.

Zhangjiakou and Foshan are the top two in vehicle operation and maintenance. They each has large scale FCCB application. For example, number of FCCBs in Foshan exceeds 300 and the operation rate reaches 98.8%. Also, the FCCBs run crossing multiple areas in Foshan, including Nanhai, Shunde and Chancheng. Moreover, the FCCBs enjoy a professional maintenance location. Foshan Automobile Group can supply multiple services in the company’s parking lot including maintenance, washing, hydrogen refuelling, and etc.

3.2.2 Cluster Analysis of Cities Based on City Readiness

In order to further study different development levels of China’s cities FCCBs application, we use SPSS22.0 to cluster evaluate results of the 14 cities’ FCCB application readiness with a systematic clustering method. As shown in Figure 3, levels of cities’ application readiness are divided into five types by systematic clustering. Type Ⅰ includes Beijing and Weifang. Type Ⅱ includes Zhengzhou, Wuhan, Datong and Changshu. Type Ⅲ includes Shanghai, Chengdu, Zhangjiakou, Foshan and Jiashan. Type Ⅳ includes Fuzhou and Jinan. Type Ⅴ only includes Guangzhou. Classification results of these 14 cities are similar to the measurement results of the city readiness evaluation system. The five types of cities are sorted into the four echelons, as listed in Table 5.

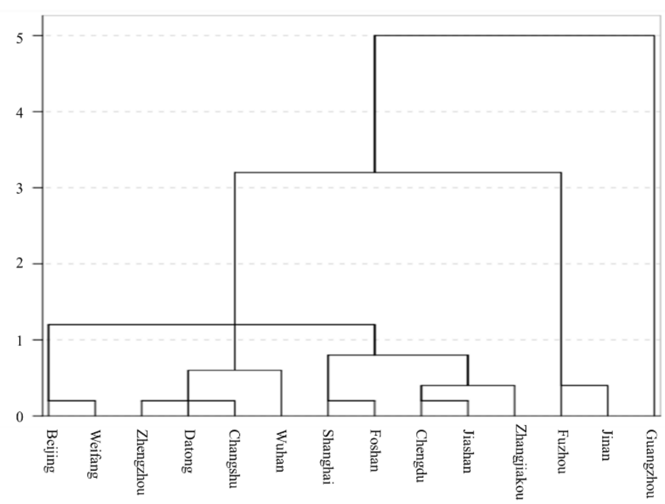

Figure 3: Cluster pedigree of application readiness of FCCB in China

Table 5: Classification of cities

Echelon	City	Type
Echelon Ⅰ	Foshan, Shanghai, Zhangjiakou, Jiashan, Chengdu	Type Ⅲ
Echelon Ⅱ	Wuhan, Changshu, Datong, Zhengzhou	Type Ⅱ
Echelon Ⅲ	Weifang, Guangzhou, Beijing	Type Ⅰ and Ⅴ
Echelon Ⅳ	Jinan, Fuzhou	Type Ⅳ

Cities of echelon Ⅰ have the highest level of promotion and application of FCCBs and their fleet operations are leading in China at the current stage, including Foshan, Shanghai, Zhangjiakou, Jiashan and Chengdu. Among the five cities, Foshan has the highest readiness score and scored more than 3.5 in all the four dimensions. Except for the score of local condition, which ranked the fourth, the remaining dimensions were all ranked first or second. The overall coordinated development of four dimensions of echelon Ⅰ is relatively good. However, high-tier and large cities still don't have large enough scale of FCCB promotion like Shanghai and Chengdu. Application scale needs to be expanded for the large or high-level cities, and sustainable development of FCCB application needs to be enhanced in small and medium size cities such as Foshan, Zhangjiakou and Jiashan.

Cities of echelon Ⅱ currently have high level of FCCBs promotion and operation in China, including Wuhan, Changshu, Datong and Zhengzhou. The overall development level of these cities is generally good, but there exist weak dimensions of these cities. Take Wuhan as an example, Wuhan and Shanghai both started FCCB operation in 2018 while Wuhan's local condition and policy environment ranked lower and the overall development level lagged behind Shanghai. However, Wuhan has advantages in other aspects such as more FCCB operation lines and wider coverage areas.

FCCB operation in cities of echelon Ⅲ are at a medium level, including Weifang, Guangzhou and Beijing. There are certain constraints in vehicles promotion of this type of cities that some dimensions score low. For example, Guangzhou's vehicle operation and maintenance ranks the last in the 14 cities. Compared with cities of echelon Ⅰ or Ⅱ, the cities of echelon Ⅲ may have prominent individual dimensions, but the overall development advantage is not obvious. This type of cities should pay more attention to complementing the shortcomings, promoting coordinated development and improving the overall development level in FCCB application.

FCCB promotion in cities of echelon Ⅳ started late and fleet operation level is still low. For instance, Fuzhou and Jinan both started FCCBs operation in November, 2019. Due to the late start, the comprehensive supporting conditions in this type of cities are not perfect yet. The echelon Ⅳ cities can learn from experience of the cities of echelon Ⅰ or Ⅱ to quickly expand development space and narrow the gap with pioneering cities.

4 Conclusion and Discussion

Based on investigation of rapid growing FCCB application in UPT in China, and learning from domestic and international research results, the paper builds an evaluation indicator system of city readiness of FCCB application, which includes 4 primary dimensions, 20 secondary dimensions and 48 indicators. These four dimensions are local condition, policy environment, supporting facilities and vehicle operation and maintenance. Based on subjective and objective weighting method, the measure model of city readiness is constructed and used to calculate application readiness of the cities selected. Furthermore, we use cluster analysis method to classify the 14 representative cities, which are divided into four development types. Main conclusions are as follows:

(1) Generally speaking, the development level of FCCB application in cities still needs to be improved. Also, development levels and paths among cities are quite different. In the 14 cities selected, Foshan, Shanghai and Zhangjiakou rank the top three for city readiness of FCCB application, followed by Jiashan, Chengdu, Wuhan, Changshu, Datong, Zhengzhou, Weifang, Guangzhou, Beijing and other cities. However, there is still no model city which has the absolute lead in all dimensions nor whose development path can be completely copied by

other cities. Operations in the two provincial capitals, Fuzhou and Jinan, are relatively weak and still in the initial stage.

(2) Specifically, the 14 selected cities are divided into four echelons by using system clustering with SPSS22.0. Cities of echelon Ⅰ are Foshan, Shanghai, Zhangjiakou, Jiashan and Chengdu. This type of cities has a leading level of FCCB operation and balanced development in all dimensions. They should pay attention to maintenance and upgrade, as well as how to innovate business models, improve operation quality and achieve sustainable development without government's high subsidies or driving forces of major events. Echelon Ⅱ cities include Wuhan, Changshu, Datong and Zhengzhou. This type of cities has certain advantages in fleet promotion while some individual dimensions are relatively weak. It is urgent for them to make up for the shortcomings and develop to a high level in FCCB application. Echelon Ⅲ cities include Weifang, Guangzhou and Beijing. FCCB operation in cities of this echelon are at a medium level and scores of some dimensions are low. They should focus on the use of comparative advantages, such as industrial foundation advantages of Weifang, and economic and market advantages of Guangzhou or Beijing. Also, these cities should learn from each other and focus on comprehensive development. Cities of echelon Ⅳ include Jinan and Fuzhou, which are provincial capital cities and are in the initial stage of operation. These cities should learn from development experience of advanced pioneering cities, take advantage of local conditions of provincial capitals, and play a leading and demonstrative role for the lower-tier cities in their own provinces.

(3) Comparison of cities' FCCB application in different regions shows that regional development is obviously uneven. Cities with good FCCB application are mainly distributed in the Beijing-Tianjin-Hebei region, the Yangtze River Delta region and the Pearl River Delta region, among which the Yangtze River Delta region have better overall development. Also, there is no strict relationship between FCCB application and the city's economic condition or level. Different cities all have opportunities to apply FCCBs by adjusting measures to local condition, learning from similar cities and avoiding promotion blindly.

Development of cities' FCCB application is a complex project that evaluation indicator system of city readiness is relatively large and data is hard to obtain, which significantly constraints the evaluation. Regarding this, we adjust indicators of secondary dimensions when constructing the indicator system, but the system still needs to improve. In addition, influencing factors and development paths of FCCB applications are quite different at different stages. In future research, it is necessary to make up for these shortcomings by using corresponding data statistics and collection techniques. Most cities that apply FCCB are demonstration cities at the present stage. More about identification of key influencing factors and choice of development path at the stage of transition to market-oriented dominance. Furthermore, different types of cities can cooperate and complement with each other to build an integrated, green and intelligent ecosystem of transportation in a low-carbon and zero-emission way.

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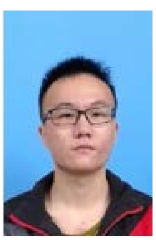

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