

Article

Sustainable Distribution Organization Based on the Supply–Demand Coordination in Large Chinese Cities

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Abstract: In large Chinese cities, inefficient logistics organization, a rapid increase in freight demand, and the spreading of city logistics space have jointly contributed to the urban problems related to goods movement, such as spatial conflicts, traffic congestion, and air pollution. To address these problems and improve urban sustainability, we proposed a new spatial organization model of supply–demand coordination. We used the data from the Third China Economic Census and online point-of-interest (POI) for China’s four direct-controlled municipalities and 13 sub-provincial cities. We found that: (1) the freight supply and demand in China’s large cities are both spatially decentralized and clustered. However, there is a significant spatial mismatch between freight supply and demand in most of the studied cities. (2) The 17 studied cities can be divided into three types—highly unbalanced, unbalanced, and balanced—in light of the spatial mismatch between freight supply and demand. (3) The capacities of road surface and logistics nodes spatially differ. The supply capacity of the road systems in Beijing, Shanghai, and Guangzhou can only accommodate 18.4%, 35.5%, and 32.2% of the demand, respectively, while the supply capacity of the logistics nodes is more than twice that of the actual demand in these cities. Based on the findings, this paper proposed a differentiated method of demand management in different areas of the cities. To achieve the goals of low-carbon and sustainable development in logistics distribution, policy makers may consider planning urban freight activities along metro lines and intercity rail lines. Thus, this paper will provide a new perspective for understanding the urban freight distribution and management in large Chinese cities.

Keywords: distribution mode; supply and demand; sustainable development; city logistics

1. Introduction

Goods in cities are generally delivered in small batches, at multiple frequencies, and within a very limited time. Such distribution activities in cities incur the highest costs while tending to have the lowest efficiency in the organization of logistics chains. In addition, city distribution is largely and continuously impacted by many factors such as city freight management, city production, consumption, and circulation space reconstruction, resulting in traffic congestion, air pollution, and space conflict, which are harmful to the sustainable development of the cities [1,2]. Large cities, in which an increasing number of logistics enterprises and facilities concentrate, generally serve

as the gateway and hub and become the core of distribution organization and management [3–5]. In metropolis cities such as London and Paris, the volumes of goods generated by city distribution account for a quarter of those cities' traffic volumes, about 20% to 30% of vehicle kilometers [1]. To reduce the impact of logistics activities on the environment, logistics facilities gradually sprawl from downtown to the suburbs. In Paris, Los Angeles, and Toronto, the average distance of these facilities from the urban center increased by nine km, while the same tendency is also apparent in both Tokyo and Atlanta. City logistics sprawling has intensified the separation between logistics activity space and service objects, and, as a result, freight handling activities increase significantly. In the metropolises of developing countries such as India and Brazil, transportation planning focuses more on passenger transportation and intercity freight, and less attention is paid to logistics demands within the cities. The insufficient planning of city logistics space makes it difficult to deal with the “last mile” distribution [6–9].

With the promotion of information technology and intelligent manufacturing, smart logistics and smart city concepts have emerged, and new equipment such as unmanned vehicles, fully electric vehicles, and locker boxes are widely used [10,11]. At the same time, new organizations and business models, such as joint distribution, matching platforms between vehicles and cargos, and freight forwarder, keep on surfacing and effectively reduce the waiting time and labor input of city distribution. Through the implementation of the innovative logistics system, CO₂ emissions in several cities in Europe have decreased by 84%, and the environmental pollution is mitigated, but the long-term effect of city distribution management still needs to be tested [12–15]. Research on the European Union (EU) shows that city logistics management is so difficult that in 60% of EU cities, 55% of vehicle emissions are caused by goods distribution, and 40% of cargo are shipped to the downtown areas for reasons such as its larger population and commercial density; meanwhile, differences between city logistics service requirements and spatial separation have intensified the imbalance between freight supply and demand [10,16].

There are 30 cities with more than eight million permanent residents in China in 2017. The increase in customers' demand for quality and the timeliness of logistics services has accelerated the changes in the number, types, and functions of service providers, and to a certain extent prompted the disorderly spread of logistics activities. In addition, China, entering a critical period of urbanization, is inevitably facing the huge challenge of sustainable development [17,18]. Several large cities in China have issued the development plans for the logistics industry since “The 10th Five-Year Plan”, but the focus in those plans was on large-scale logistics nodes such as logistics parks and logistics centers without adequate consideration given to the layout of city distribution facilities and terminals for end consumers and supermarkets, such as distribution centers and warehouses [2,19]. Therefore, distribution problems have become a hot spot of social concern and pressure point in the logistics field [20–23]. The rapid expansion of the e-commerce consumer market has further fragmented and personalized distribution demands, thanks to the e-platforms such as Alibaba and JD. Take Chinese express delivery industry as example; in 2016, the industry used approximately 3.2 billion woven bags, 6.8 billion plastic bags, and 8.6 billion packaging boxes [24–26]. However, it is difficult to accurately present the characteristics of city distribution supply and demand, and reveal the diversity of logistics distribution space between different cities, as the logistics data available are not systematic and comprehensive enough in China; population mobility and city space expansion are fast [18,27].

In view of the above, (1) this paper has integrated the data of government's economic census and POI on the internet to better present the status quo of the logistics industry in China. After considering the influence of various factors and complex internal relations between supply and demand, analogy methods are used to estimate the city distribution demand and supply; (2) this paper has revealed the spatial pattern of supply and demand space in differentiated areas of different cities, which can help illuminate the influence of spatial structure and its differences on the design of city distribution management mode [16]; (3) the authors took into consideration the efficient rail transportation system, the relatively concentrated distribution demands in large Chinese cities, and proposed sustainable

distribution strategies from the perspective of spatial differentiation such as city distribution based on a metro rail network, the layout of joint distribution centers and dedicated distribution lanes, and the application of electric trucks and green packaging, which can reduce distribution costs, improve logistics land-use efficiency, and reduce air pollution.

2. Literature Review

To build a link between the existing literature and this research work, we developed a structured literature browsing method that mainly consists of four key steps [28,29]:

- (1) Search for articles in databases and other sources, such as Scopus, CJFD (China Academic Journals Full-text Database), Web of Science, and so on.
- (2) Reduce the number of articles by reading the abstract and identifying the main topic and keywords.
- (3) Retrieve additional articles by tracking the research cited in some studies and supplementing the key Chinese articles.
- (4) Divide the main categories, discuss the key scientific results, and identify the scientific gaps, and bottlenecks.

Firstly, we referred to the Scopus database, because it contains the main journals from this research work. The following list of keywords (and their combinations) were used to search for the studies: city or urban logistics (distribution, delivery) and sustainability; supply and demand; demand forecasting; logistics sprawl. In order to reflect the latest research trends, we decided to include English language journal articles from 2008 to 2018 only. Initially, 364 articles were identified. The search was conducted in August 2018. Secondly, the entire set of selected articles was reduced to 25 articles by restricting the topic area and reading the abstracts and keywords.

As demonstrated in Figure 1, the number of the selected articles has increased in the last years, which means that this research field is getting more and more attention.

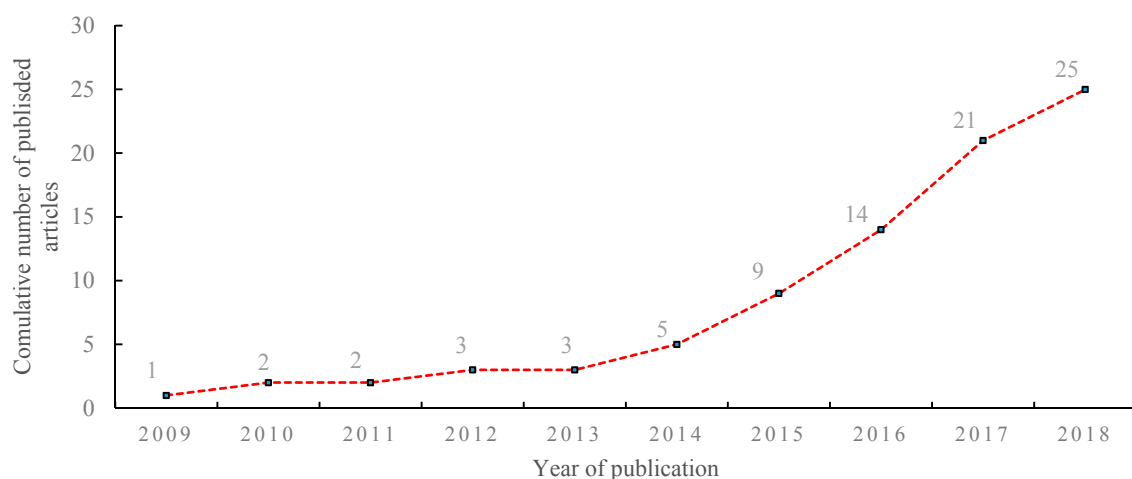


Figure 1. Classification of articles by year of publication.

The selected article uses a lot of similar keywords, and some keywords are rarely used. The most frequently used keywords (greater than or equal to four times) are depicted in Figure 2. Freight activities and logistics are closely linked. To mitigate the environmental impact of urban logistics and freight activities, diversified distribution facilities and strategies are widely mentioned, such as for example: fully electric vehicles, cargo tricycles, off-hour delivery, cycle transport, non-motorized transport, mobile depot, and joint distribution center [30–33]. The question of how to effectively control the increasing demand for urban distribution has become the core of urban

distribution management. A series of models and algorithms for demand analysis and prediction has become one of the research hotspots [34,35].

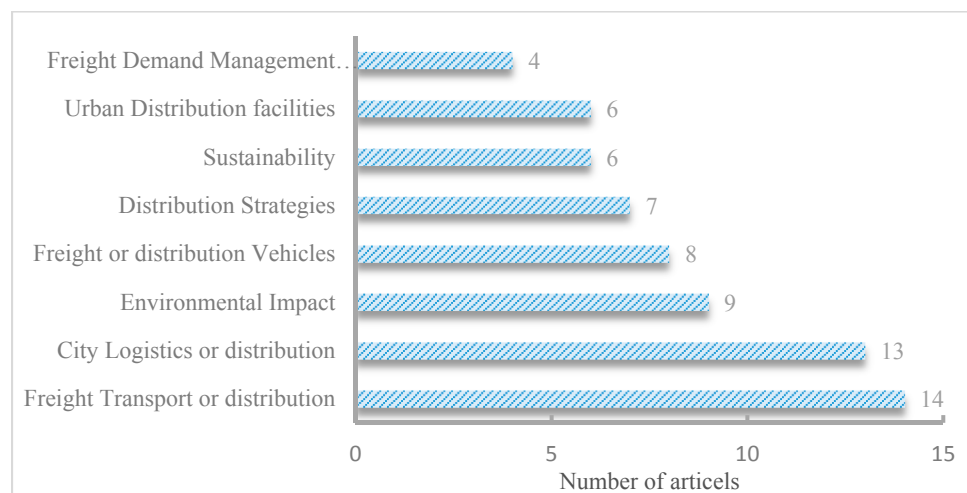


Figure 2. Classification of articles considering the used keywords.

By analyzing the most cited articles, we can further understand the direction of research in this field (see Figure 3). In the implementation of logistics policy, it is necessary to consider differentiated distribution patterns, characteristics of freight demand, and socio-economic characteristics [36]. The sustainable development of urban distribution faces enormous challenges, featuring restrictive measures of local authorities, rapid increases in demand, and lower vehicle utilization efficiency as key restrictions [35,37]. The effective coordination of the interests of multiple stakeholders and anticipation of new technologies are very critical approaches [38].

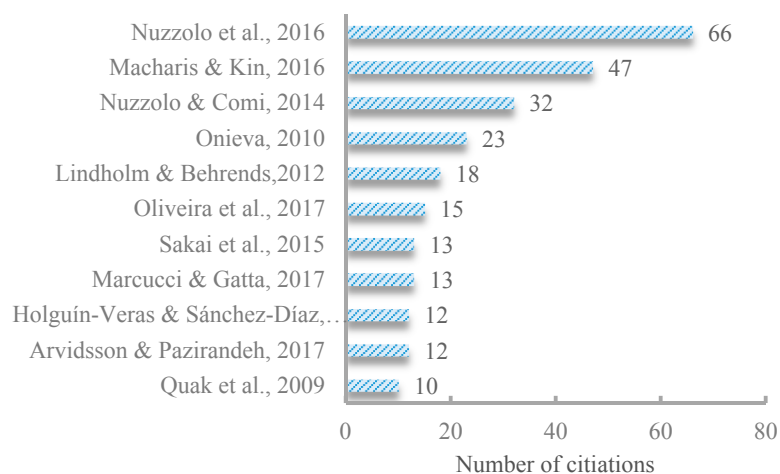


Figure 3. The most cited articles based on a search in the Scopus database.

In order to make up for the shortcomings of the Scopus database, and fully consider China's national conditions, we have added more than 20 additional articles by tracking the research cited in the selected 25 articles in the first stage. At the same time, more than 10 Chinese papers and books are selected in CJFD. According to the research theme, the above articles are divided into the following three categories for detailed discussion.

2.1. Characteristics and Influencing Factors of Distribution Demand and Supply

The city distribution system is defined as the interaction between two components: supply and demand [39–41]. As a derivative demand, city distribution is affected by the population and growth rate, economic development level, and supply chain system [11,12,42]. Its specific manifestations including packs of consumer goods, city construction materials, waste, postal parcels, and other related items according to customer requirements [1,18]. New business model and distribution strategies help match supply and demand for distribution services [43,44]. With the gradual diversification of city space, some scholars have proposed the concept of freight landscape, using spatial distribution, freight demand density, and freight flow indicators to explain the spatial distribution characteristics of freight activities and intensity in metropolises [16]. The supply of city distribution is reflected by warehousing and logistics facilities, vehicles, operational efficiency, etc. [41,45]. It can also be described by the number of freight trucks, the per capita storage area, the distance from the distribution center to the central business districts, and the service level of roads [5,46]. Although the demand and supply of city distribution are decentralized, most of the demands arise from downtown areas. The investment intensity, population density, and freight management strategy of city transportation logistics land have aggravated the contradiction between supply and demand, highlighting the important role of government in city distribution management [47]. The accurate understanding of urban distribution supply and demand characteristics is the key to the sustainable development of distribution [36,48].

2.2. City Freight Demand Analysis and Forecasting

The demand analysis of city freight activities is influenced by multiple participants such as consumers, producers, wholesalers, and retailers. Accurate prediction is very difficult [49]. The traditional freight demand models seem to be more suitable for regional and national planning than for the city one. Some scholars have proposed forecasting demand from different commodity types and final consumer demand [50,51]. The microsimulation models representing explicit tours and individual shipments are difficult to apply to the analysis of the total demand of distribution [29].

Generally speaking, four major types of methods are used to analyze and forecast freight demands. The first type, prediction methods based on traditional statistics, mainly include the Markov chain, elastic coefficient method, input–output model, freight intensity method, clustering method, grey theory model, regression analysis method, etc. [52–54]. The disadvantage of these methods is that they require a long period of historical data and are based on linear regression. The second type of method, artificial intelligence-based prediction methods, covers artificial neural networks, expert system inference rules, and so on. Although this type of method improves the accuracy of prediction to some extent, it is difficult to ensure the accuracy and determine the value of parameters [55]. The third type of method consists of prediction methods based on the four-phase method [40]. Some scholars present a general modeling framework to estimate the quantity, delivery, and vehicle units' OD (origin–destination) matrices [34]. Some scholars divide data into the three categories of variability, reliability, and source. They are static, dynamic, deterministic, probabilistic (random), ambiguous, public, and private [56]. Among this type of method, the data acquisition methods include enterprise surveys, vehicle observation surveys, parking surveys, driver surveys, commodity flow surveys, GPS (global positioning system) surveys, vehicle traffic statistics surveys, etc. The fourth type of method is prediction methods involving special correlation. Some scholars use the spatial interaction gravity model to predict the dynamic logistics generation in downtown areas [57]. When dealing with the status quo of the logistics industry in China, scholars have to face the lack of basic data on city distribution in China and the significant change in distribution demand, and have to take into their account many influencing factors. In this regard, the first two methods are not effective. Demand analysis and forecasting based on OD and spatial analysis are highly accurate, but require huge volumes of survey data [35].

2.3. City Distribution Spatial Patterns and Differences

The spatial pattern is manifested in three aspects: space sprawling, spatial concentration, and recentralization. (1) Space sprawling refers to the process of expansion and decentralization for warehousing and distribution activities from city centers to suburbs. For example, cities such as Atlanta, Los Angeles, Chicago, Tokyo, and Beijing have followed the trends of warehousing activities expansion and related W&D (warehouse and distribution) decentralization [6,58,59]. (2) Spatial sprawling is also accompanied by the centralization of logistics activities. For example, Cidell surveyed 47 cities in 50 United States (US) city agglomerations from 1986 to 2005, and revealed the suburbanization and centralization trends of warehousing and logistics-related activities from the county scale [60]. The MIT (Massachusetts Institute of Technology) Transportation and Logistics Research Center has paid attention to logistics companies clustering in geospatial space for a long time. Their related researches focused on the formation of logistics industry clusters in Zaragoza, Rotterdam, Memphis, Louisville, and Napoli, as well as the spatial layout characteristics of logistics clusters formed by US logistics establishments [61,62]. As a core facility for logistics activities, some researches have shown that storage facilities are closer to the edge of city commercial centers, such as the empirical studies in Ahmedabad, India, and Beijing, China. Limited by available land, storage facilities are still dispersed to suburbs [7,18,20]. (3) The suburbanization of logistics activities has led to a reduced ability in rapid distribution, and some logistics companies have chosen to recentralize their locations. Some scholars have conducted empirical research on the metropolitan area of Paris [63]. In general, the differentiation trend in the distribution pattern of different cities has been quite significant. However, the existing research has focused on supply facilities such as warehousing and distribution, and paid little attention to the difference between supply and demand, which is not conducive to the formulation of distribution management strategies.

3. Data and Methods

3.1. Research Objects, Data Sources, and Processing

The collection of data on distribution in large cities is the basis for the recognition of the spatial distribution and the interaction of distribution supply and demand. Most of the data from the existing studies in the US is acquired through the statistics of transport, courier, post, distribution, handling, and 27 other sectors in the North American Industrial Classification System [62,64]. At present, China has not yet classified the logistics industry in national economic industries or industrial statistics, and most researchers currently use the statistical data on transportation, warehousing, and postal services, or questionnaires, business registration information, and the yellow pages to obtain logistics data [24]. POI is the core data of location-based services on the map, including the names, categories, and coordinates of all of the merchants, government agencies, streets, etc. In recent years, online map service platforms represented by Baidu, Tencent, and Autonavi Navigation have stored a large number of POIs of corporate and node facilities. Such POI data has been widely used in spatial analysis in the fields of retail, residential, and logistics, etc., and has proven to be very reliable [18,65,66]. In this study, a web crawler tool was built and programmed to call the API (application programming interface) platform and collect POIs (see Figure 4).

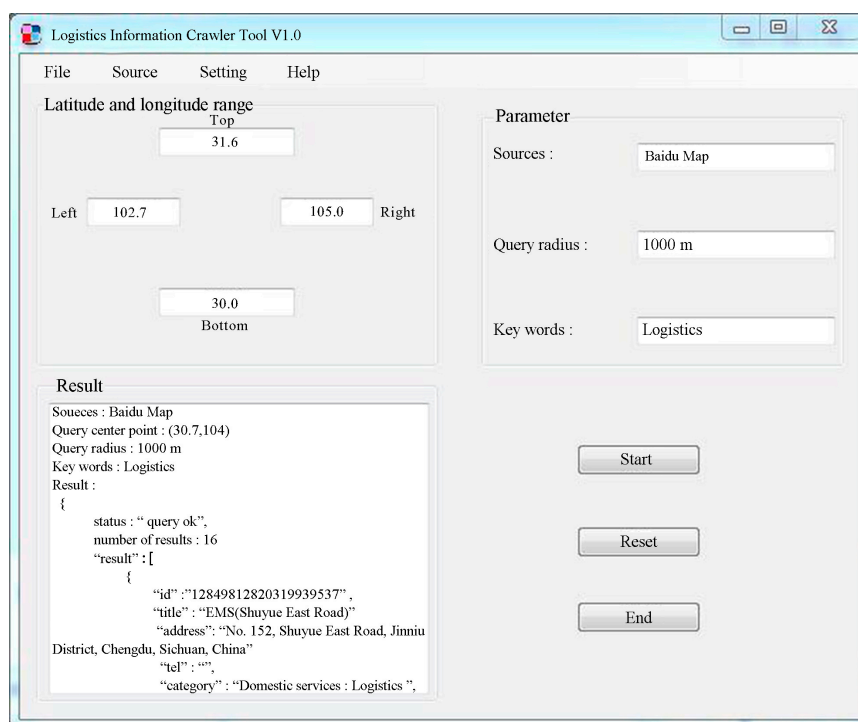


Figure 4. The collection process of point-of-interest (POI) by the web crawler tool.

First, the authors determined the keywords and selected “logistics”, “shopping”, and “real estate community” in the manuscript. Second, we use the “search nearby” tool to obtain the primary attributes, including the name, latitude, and longitude, address, and contact number via the Baidu Map API, within a search radius of 1000 m. The literature has been added to disclose more technical details [67,68]. In this way, logistics data can be acquired more efficiently, and the problem of heterogeneity of data can be solved [27,66]. China’s directly controlled municipalities and sub-provincial cities generally have the problems of high population density, strong distribution demand, and serious traffic congestion. In consideration of the availability of data, the authors selected 17 Chinese cities as the research objects, and collected, from the Baidu map API platform, POIs as well as China’s third economic census data on wholesale and retail trade, transportation, warehousing and postal services, and real estate development and management enterprise corporate units (see Table 1). These two types of data acquired both online and offline are the combination of macro-statistical and micro-facility data, and they are considered to be the main factors affecting city distribution demand and supply [26,55,64]. Due to the different acquisition methods and sample objects, the data results of the two are quite different. Furthermore, the authors also collected data on major logistics nodes, industrial parks, and wholesale markets in Beijing and Chengdu to better demonstrate the distribution of logistics demand in typical cities [18].

Table 1. Data of POI and the Third China Economic Census for logistics, businesses, and households.

City	Logistics/Unit: pcs		Business/Unit: pcs		Residential District/Unit: pcs	
	Method 1	Method 2	Method 1	Method 2	Method 1	Method 2
Beijing	3450	14,290	3582	190,704	11,113	3426
Shanghai	7780	15,003	3825	145,668	20,534	3766
Tianjin	1709	10,247	1311	66,133	4057	1491
Chongqing	2212	4890	2454	80,577	1223	3279
Guangzhou	3564	5766	3058	65,154	1156	1373
Shenzhen	3668	9149	2802	84,245	5250	787
Shenyang	1642	2784	1178	35,801	1311	1413
Dalian	1028	3926	1066	32,284	2389	1615
Wuhan	1498	3325	1599	40,849	1828	1891
Chengdu	3089	2661	2787	22,346	5202	1954
Xi'an	1111	1404	1466	24,205	2242	1626
Jinan	937	1373	861	32,093	1002	754
Qingdao	1699	5600	1219	52,523	2238	1302
Hangzhou	1845	3660	2053	68,329	2522	1723
Ningbo	1680	3750	1044	41,753	696	999
Harbin	863	1542	789	17,803	391	1035
Xiamen	1398	2523	890	25,761	314	650

Source: Data from Baidu Map (method 1) in October 2014 and China Economic Census Yearbook 2013 (method 2).

3.2. Research Methods

3.2.1. City Distribution Demand Estimation Method

Existing studies mostly use the volume of freight traffic or freight turnover to replace logistics demand [6,58]. The logistics demand, including transportation, warehousing, distribution, and other operations, is difficult to estimate [17,42]. Distribution demand in cities are generally raised by city residents [59]. It has not been included in the statistical index system, and lacks an effective estimation method [69,70]. Currently, the distribution demands of large cities in China are generated in both online and offline shopping, and the demand for online shopping is directly related to the scale of e-commerce in the city, especially the courier parcel volume and the total volume of postal services [17]. Offline shopping is directly related to the scale of the wholesale and retail industry in the city, and the total retail sales of consumer goods as well. Both demands are related to the per capita disposable income of city residents and the influence of the city resident population [2,71]. A small number of cities represented by Guangzhou have carried out surveys on city distribution, which provides an important benchmark for estimating the distribution demand data of other large cities [72]; the analogy calculation method of the city distribution demand is as follows:

$$D_i(x) = \left(\alpha_i \times x' \times \left(\frac{k_i}{k} \times \frac{\rho_i}{\rho} \right) + (1 - \alpha_i) \times x'' \times \left(\frac{m_i}{m} \times \frac{n_i}{n} \right) \right) \times p_i \times \frac{\lambda_i}{\lambda} \quad (1)$$

where $D_i(x)$ represents the distribution demand amount of city i , which consists of online and offline markets. The city resident population and per capita disposable income of city residents are the major factors [2,11,12]. The explanation and data sources of the indexes in Formula (1) can be shown in Table 2.

Table 2. Explanation and data sources of the indexes.

Index	Symbol	The Data Source or Calculation Method
The proportional proportion of online shopping	α_i	$\alpha_i = \frac{e_i}{m_i}$
Annual online shopping distribution amount per capita in Guangzhou/kg	$x' = 360$	Source: [72]
Annual offline shopping distribution amount per capita in Guangzhou/kg	$x'' = 3240$	
Online shopping transaction amount of city <i>i</i> /hundred million yuan	e_i	China Post Industry Statistics Report
Courier business amount of city <i>i</i> or Guangzhou/ten thousand pieces	k_i, k	
Retail sales of social consumer goods of city <i>i</i> or Guangzhou/hundred million yuan	m_i, m	
Number of legal person units in the wholesale and retail industry	n_i, n	China Statistical Yearbook
The number of city resident population/ten thousand	p_i	
Per capita disposable income of city residents in city <i>i</i> or Guangzhou/yuan	λ_i, λ	
City Online Shopping Index	ρ_i, ρ	aEDI (Alibaba E-commerce Development Index)

The rationality of the formula is guaranteed in several aspects. (1) First, it considers that China's city distribution is composed of two parts, online and offline, and the ratio of the two can be directly calculated through statistical data. (2) The influencing factors of online and offline distribution are determined on the basis of actual survey work and the related literatures. (3) After considering the availability of data, Guangzhou's distribution volume of 32.03 million tons in 2011 was used as benchmark data to verify the validity of Formula (1) [72]; the main verification process is as follows:

- (1) The proportional amount of online shopping is calculated, and $\alpha_i = 0.05$. Therefore, it can be concluded that in 2011, the annual distribution of the city's annual online shopping distribution amount was 1.6 million tons, and the annual offline shopping distribution amount per capita was approximately 130 kg, while the annual total distribution amount per capita was approximately 2470 kg.
- (2) According to the scale and growth rate of China's online shopping market in 2011–2013 [73], the annual growth rate of 50% is determined, and $\alpha_i = 0.1$. Furthermore, it can be calculated that in 2013, the annual online shopping distribution amount per capita was 360 kg, and the annual offline shopping distribution amount per capita was approximately 3240 kg. In 2013, the total distribution volume in Guangzhou was 46.54 million tons, with an average annual growth rate of 21%.
- (3) After comparing the above calculation results with the 44.49 million tons of total distribution volume in the results of the distribution survey performed by Guangzhou City, a difference of only 2.05 million tons occurs, and the error rate is -4.6% , which fully demonstrated the reliability and validity of Formula (1).

Considering that all of the indicators in Formula (1) can be collected through statistical yearbooks and aEDI, the distribution demand in different cities can be estimated.

3.2.2. City Distribution Supply Capacity Estimation Method

The balance between logistics supply and demand is the main goal of the logistics system operation [39,40]. The existing research studies have focused on the forecast and analysis of logistics demand, and the capacity and length indicators of the transportation infrastructure are mostly used in the evaluation of the logistics supply level [53,54]. The distribution system capacity is the combined effects of city road capacity and facility capacity. City road resources represent road capacity. The authors take into their account the current city truck management in China, the number of passenger cars owned in the city per person, and the impact of the number of trucks with city pass [2]. The node capacity is mainly characterized by city warehousing and logistics land resources. The layout of the large logistics parks and logistics centers within the city, as well as the distance to areas with concentration of distribution demands, all exert a strong influence on how the node capacity is efficiently converted into road capacity [18]. Based on the calculation of the capacity of city roads and the method of calculating the scale of storage and logistics land use [74,75], the estimation formula of the city distribution supply capacity is as follows:

$$S_i(y) = \frac{s_i}{3.5l_i} \times y_i \times \gamma_i \quad (2)$$

where $S_i(y)$ represents the road capacity of city i , which is determined by the road area and length, the traffic flow, and the number of commercial trucks and personal cars.

$$S'_i(y') = s'_i \times y'_i \times \sigma_i \quad (3)$$

where $S'_i(y')$ represents the node capacity of city i , which is determined by the logistics and storage area, the logistics processing capacity, and total distribution demand.

These calculation methods have been widely adopted in the planning and design department of China for city logistics nodes and channel layouts. The node capacity and road capacity can ultimately be converted into the number of box vans in cities to evaluate the matching degree between city supply and demand. The explanation and data sources of the indexes in Formulas (2) and (3) can be shown in Table 3. Since all of the indicators in Formulas (2) and (3) can be collected through statistical yearbooks and industry standards, the distribution supply capacity in different cities can be estimated.

Table 3. Explanation and data sources of the indexes.

Index	Symbol	The Data Source or Calculation Method
Road area in city i	s_i	China City Statistical Yearbook
Road length in city i	l_i	
Average daily traffic capacity of one lane in city i	y_i	Source: [75]
Truck road resources occupation ratio in city i	γ_i	$\gamma = \left(\frac{q_i}{q_i + q'_i} \right) \times \xi$
The number of standard truck	q_i	China City Statistical Yearbook
The number of private-owned cars	q'_i	
Reduction coefficient	ξ	The value is 0.2–1 according to the freight traffic management method
Logistics and storage area in city i	s'_i	China City Statistical Yearbook
Annual logistics processing capacity per mu (Ten thousand tons/mu)	y'_i	
The proportion of city distribution in freight traffic	σ_i	$\sigma_i = \frac{D_i(x)}{Q_i}$
	Q_i	China City Statistical Yearbook

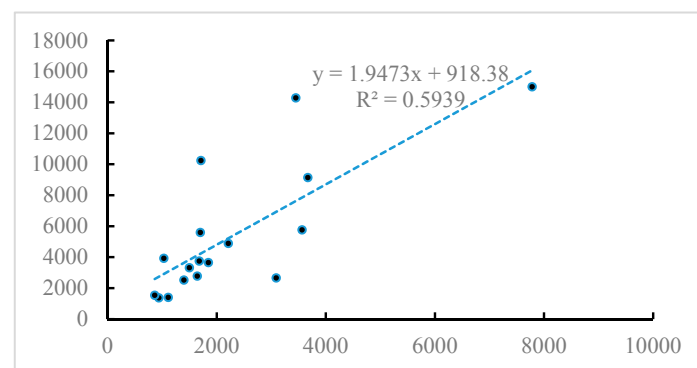
4. Spatial Pattern of Distribution Supply and Demand in 17 Typical Cities

Based on the data sources and research methods in Part 2, the POI and the third economic census data were tested for correlation. The distribution demand and supply estimation methods were

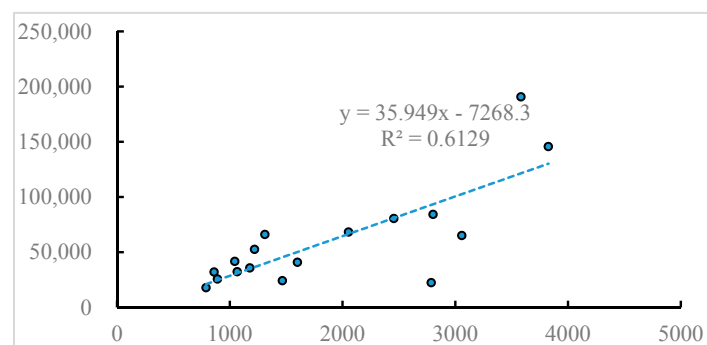
used to reveal the distribution characteristics of supply and demand in typical cities. These results can lay the foundation for coordinated supply and demand distribution management models for sustainable development.

4.1. Distribution Spatial Patterns and Characteristics in Typical Cities

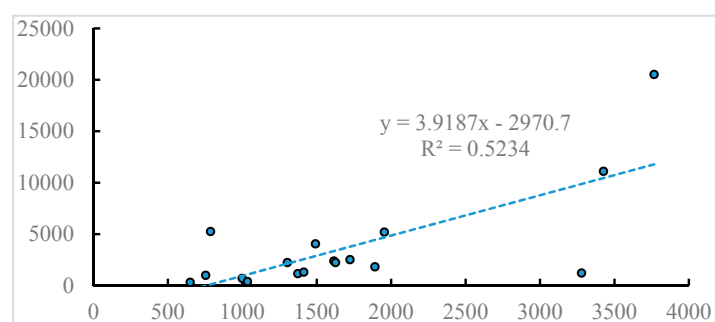
To verify the validity of online and offline data, the correlation analysis between the POI data and the third economic census data in Table 1 is shown in Figure 5.



a. The correlation of logistics data.



b. The correlation of business data.



c. The correlation of residential district data.

Figure 5. Correlation analysis between the POI data and the third economic census data.

As seen from Figure 5, the correlation of retail and wholesale businesses is relatively high, and the online map service platform focuses on providing information on food, entertainment, shopping, etc. However, the correlation between logistics data and residential district data is slightly lower, since the relevant data collected from the transportation, warehousing, and postal industries contains a large amount of passenger transport enterprise data, and the corresponding POI data are not collected. As is known to all, the scales of the real estate development companies differ substantially, not to

mention the sizes and magnitudes of their residential projects. To solve the current problem of data missing in China's logistics industry, the use of POI data for analysis of distribution spatial patterns has strong practical significance, and the effectiveness has also been fully tested [18,66]. Therefore, the authors extract POI data, such as 4476 pieces of distribution-related data (accounting for 11.43% of total logistics data), 31,984 pieces of shopping data, and 63,468 pieces of residence data. Simultaneously, we collected the logistics, transportation, and business planning text, in an attempt to uncover the spatial distribution pattern of the supply and demand of the distribution.

First of all, Beijing and Chengdu, which have regular logistics development planning and complete logistics statistics and survey data, are selected as typical cases, and their spatial patterns of supply and demand are further analyzed (see Figures 6 and 7).

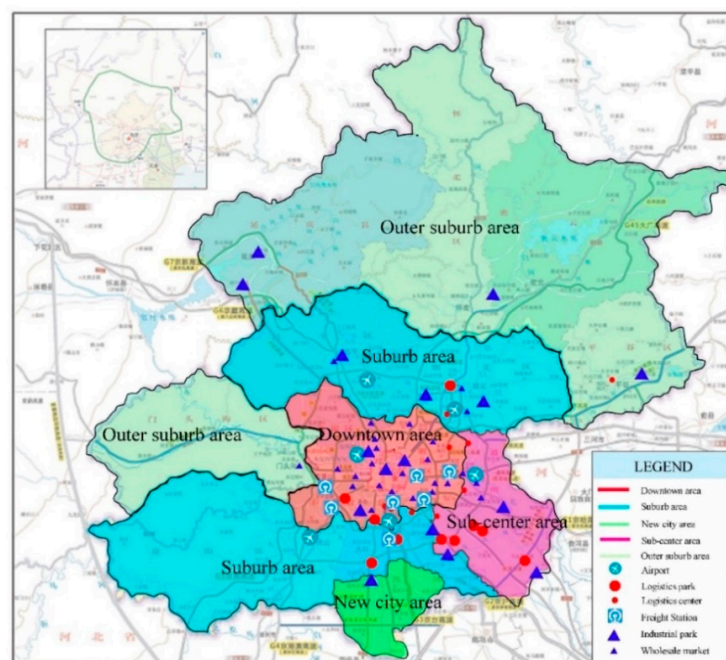


Figure 6. The spatial pattern of supply and demand in Beijing, China.

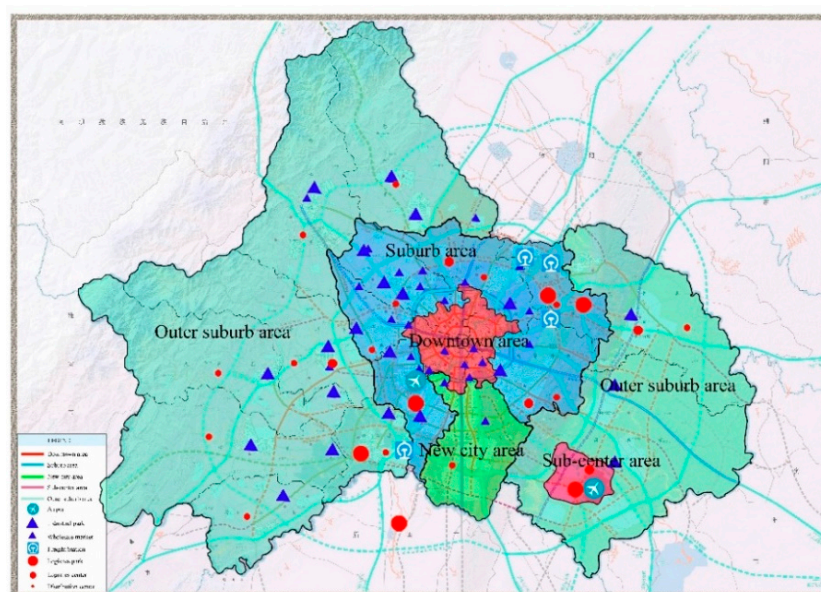


Figure 7. The spatial pattern of supply and demand in Chengdu, China.

In Figures 6 and 7, the authors divide the city into its downtown area, suburb area, outer suburb area, new city area, and subcenter area. The main distribution supply points are the logistics parks, logistics centers, and distribution centers, and the main distribution demand points are the industrial parks and wholesale markets [18,76]. Since the spatial structures of these typical cities and existing research results are similar, the main features of supply and demand are as follows:

(1) Suburbanization and multicenters: Most of the 17 sampled cities have established new city areas, subcenters, or satellite cities. Some of the new city areas have become national-level new areas, e.g., Binhai New Area, Liangjiang New Area, Xixian New Area, Tianfu New Area, etc. [77]. In the process of function adjustment and the spatial expansion in the cities, the relocation of logistics distribution facilities is inevitable. For instance, in the coordinated development of Beijing–Tianjin–Hebei, the relocation of the Beijing logistics function into Hebei is a major work. Statistically, in non-port cities, the logistics distribution facilities have been moved nearly 15–30 km away from the city center in nearly 10 years. The suburbanization of distribution facilities exceeds that of residence in both scale and speed, and such a trend has manifested in many large cities in European countries, the United States, and Japan [78]. In certain port cities, such as Shanghai, Tianjin, Chongqing, and Shenzhen, the logistics distribution facilities are 40–60 km away from the city centers, because most of the ports are located away from the city center [2].

(2) Interdependence and differentiation: The spatial interdependence is reflected in that city distribution facilities are located close to a large city's residential areas and large commercial complexes, and they coexist in a region. The spatial variation is reflected in that the downtown area is still the business center, and its population density is higher than that of the suburban and new city areas. Thanks to the adjustment of city functions and spatial distribution, the distance between distribution facilities and the downtown areas is farther and farther, and the distribution demand of the downtown areas cannot be met in a timely and effective manner, resulting in obvious spatial variation. For instance, the distance between the distribution centers and allocating centers built by Beijing enterprises is 21.957 km, outside the fifth ring road of Beijing, while the main demands of city distribution are concentrated on the areas circled by the fourth ring road. With the increase in distribution demands from e-commerce activities, the government has begun to consider the centralization of the distribution facilities [18].

Based on a summary of typical cases and general spatial characteristics, it is obvious that the expansion of space in China's big cities is accelerating, and the suburbanization trend of logistics space is unavoidable [2]. China's larger cities have common problems such as excessive population growth, commercial concentration, large distribution demand, road congestion, and similar road networks; so, the authors can summarize the general characteristics of the distribution demand and supply space pattern of central cities in China as follows based on Figures 6 and 7 (see Figure 8).

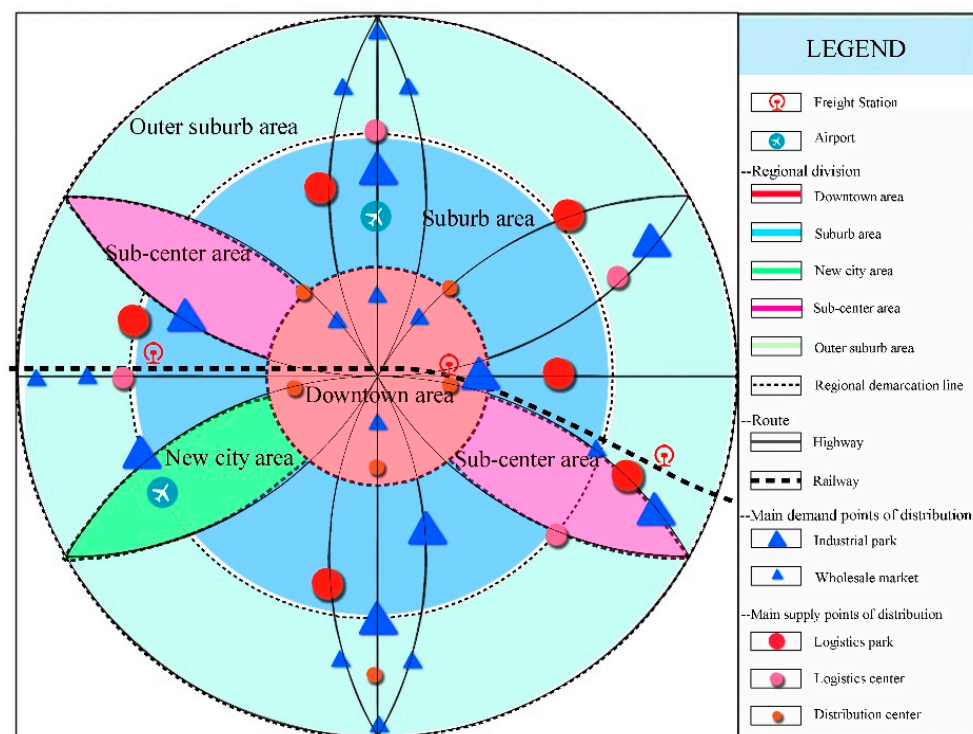


Figure 8. The general characteristics of the distribution pattern of large cities in China.

4.2. Supply and Demand Characteristics and Type Division in 17 Typical Cities

The authors calculated the distribution demand amount, point distribution supply capacity, and road distribution supply capacity in 2013 for the 17 sampled cities by using the computational Formulas (1)–(3) (see Figure 9). The main data are shown in Appendix A. In the calculation process, the average daily traffic capacity of one lane is 20,000 according the CJJ 37-2012 *Code for design of City Road Engineering*. The node and road capacity are transformed through a 1.5-ton standard truck.

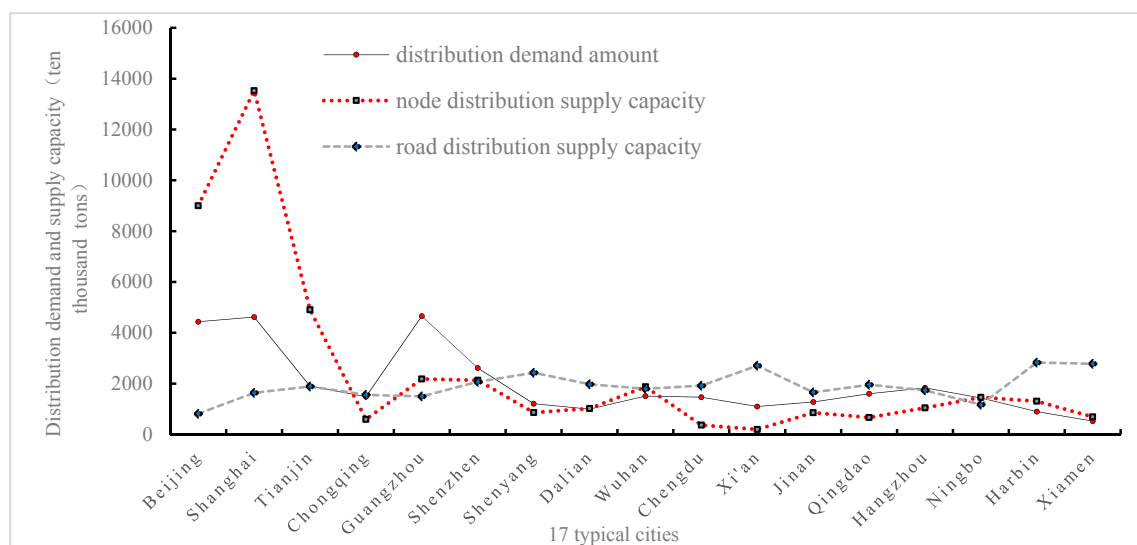


Figure 9. Distribution demand and supply capacity in 17 typical cities.

Based on the results of Figure 9, D signifies the distribution demand amount; S signifies the road distribution supply capacity, and S' signifies the node distribution supply capacity. The 17 typical cities

can be divided into three categories of areas, namely, highly unbalanced, unbalanced, and balanced ones, in light of the matching degree of supply and demand. The division results are shown in Table 4.

Table 4. Division results based on the matching degree of supply and demand. D: distribution demand amount; S: road distribution supply capacity, and S': node distribution supply capacity.

Category	Standards	Results
Highly unbalanced areas	$S'/D > 2$, or S/D and $S'/D < 1$	Beijing, Shanghai, Guangzhou, Shenzhen, Tianjin, Hangzhou
Balanced areas	S/D and $S'/D > 1$	Dalian, Wuhan, Harbin, Xiamen
Unbalanced areas	—	Chongqing, Chengdu, Shenyang, Xi'an, Ji'nan, Qingdao, Ningbo

- (1) Highly unbalanced areas: This category of areas is located in Beijing, Shanghai, Guangzhou, Shenzhen, etc. in the Pearl River Delta, Yangtze River Delta, and Beijing–Tianjin–Hebei region, respectively. In these areas, the supply capacity of its distribution roads is far from meeting the demands of the city distribution. Especially in the three traditional first-tier cities (Beijing, Shanghai, and Guangzhou), the road supply capacity only meets 18.4%, 35.5%, and 32.2% of the demand, respectively, and the three metropolises have huge permanent resident populations, high per capita disposable incomes, high urbanization levels, good e-commerce development environments, and relatively strong radiation abilities. Moreover, the supply capacities of distribution points at Beijing, Shanghai, Tianjin are respectively 2.03, 2.93, and 2.58 times of the distribution demand amounts, which is consistent with the four cities' roles as centers of the regional economy, commerce, and trade, and their respective functions as port cities.
- (2) Unbalanced areas: These areas are located in Chongqing, Chengdu, Xi'an, Ji'nan, etc. in West China, the Liaodong Peninsula Area, and Northeast China, respectively. In this category of areas, the configuration of node and road capacities is uncoordinated. For instance, in such major cities in West China as Chongqing, Chengdu, and Xi'an, their node capacities account for 40.2%, 25.3%, and 18.3% of the city distribution demands, respectively, while their road capacities exceed the distribution service demands. It indicates that the city distribution network systems in the above areas are not yet fully developed, and the shortage of their point capacities restricts their road capacities, failing to promote their roles of radiation and motivation in the surrounding areas. In the above cities, their urbanization levels are low, they have medium per capita disposable income, their logistics efficiency is not high, and they have less technical equipment.
- (3) Balanced areas: These areas are located in such cities as Wuhan, Xiamen, and Dalian in Central China, and the coastal areas in the southeast and northeast parts of China, respectively. In these cities, the node and road capacities are complementary to each other and close to the demands. With relatively complete city distribution network systems, the cities with ports have sufficient land resources logistics. They have a sparse permanent resident population and multiple city centers. For instance, the resident populations of Dalian and Xiamen are 694 million and 373 million, respectively, ranking the penultimate first and second among 17 central cities in China. Although the population of Wuhan exceeds 10.22 million, it is scattered in three areas: Wuchang, Hankou, and Hanyang.

In the downtown areas of the 17 cities, the population and commercial densities are much higher than their respective averages of the whole cities [48]. For example, the densities in the downtown areas are 22.76 times that of the average in Tianjin, 19 times that of Beijing, and more than 10 times that of Shenyang, Jinan, and Qingdao; and the number and scale of commercial facilities in the downtown areas accounted for more than 95% of these cities' total. As a result, the distribution supply in downtown areas is still far from meeting the demand, and it is difficult to effectively

solve the distribution problems in the short-term [2]; new management methods and strategies are urgently needed.

5. Sustainable Distribution Model Design

From the perspective of the supply–demand theory in economics and the supply–demand analysis of transportation systems [79,80], the core of distribution problems in large cities lies in the imbalance between supply and demand. Its impact on city sustainable development is reflected in:

(1) The number of delivery trucks and increase in energy consumption during the distribution process. The increased demand for distribution, as well as the service characteristics of multi-frequency and small-volume in delivery, has led to a sharp increase in the number of distribution trucks [25]. Under the strict cargo management policy of large cities, large trucks are difficult to enter downtown areas during the daytime, and a large amount of goods are transferred to small box trucks, which not only increases the loading and unloading times, but also easily leads to the idling of the vehicles [19].

(2) The conflict between distribution space and living space has intensified. Due to the increase in land prices and the reduction of logistics land in downtown areas, distribution supply facilities are gradually decreasing [47]. At the same time, distribution demands are concentrated in city centers, which leads to the existence of large number of non-compliant distribution spaces, being a serious safety concern in the living space. These safety hazards are extremely likely to cause major accidents.

(3) Unreasonable and over delivery has been around for a long time. Poor communication leads to the widespread of a large number of non-real needs. Secondly, delivering returned goods from impulsive consumption and the amplification of real distribution demands have put tremendous pressure on the existing supply facilities. In addition, a lack of comprehensive understanding of distribution needs and road network conditions stimulate problems such as vehicle idling and excessive delivery, which are reflections of the imbalance between supply and demand [81].

Under the circumstances that the road supply capacities in China's bigger cities are basically saturated and the distribution demand is growing rapidly, it is difficult to solve the problems of distribution in a short period of time [2]. From a spatial differentiation perspective, this paper propose a sustainable distribution model based on supply and demand coordination.

5.1. Demand Management Based on Type and Area Differentiation

Through the establishment of a large data platform for the collection and monitoring of distribution demand of terminal customers (residential and commercial facilities, etc.), the authors can better understand the amount, type, time, source, and service object of demands, and clarify their spatial and temporal distribution characteristics. For different types of demands in different areas of the city, the differentiating management measures are as follows:

(1) Downtown and suburb areas: These areas need to meet the basic living demands; control and limit hedonic demand; reduce the demands for redundant construction, excessive greening, and excessive lighting; and restrain other demands derived from the residents' leisure and entertainment. Some living consumption and business service demands in downtown and suburb areas need to be gradually transferred to the outer suburb and subcenter areas, which is an important way to reduce traffic pressure and pollution problems in the downtown and suburb areas.

(2) Subcenter areas and new city areas: These areas have ample logistics land, and land prices are relatively low. An excessive concentration of demand and supply can be avoided through planning in advance. Hedonic and business service demands in downtown and suburb areas can be transferred to subcenter and new city areas, where logistics nodes and transportation hubs can be built, and new industrial parks and wholesale markets can be established.

(3) Outer suburb areas: Commercial facilities and terminal distribution nodes shall be planned and established to increase the satisfaction rate of demand over time. To attract population and commercial facilities, the level of distribution service in the outer suburb areas will be enhanced. In the future, the outer suburb areas will be dedicated to the satisfaction of industrial demand and become the

transit area for intercity distribution needs. Large distribution centers will be planned and built here. Establishing differentiated demand management methods for different areas of the city helps reduce demand density, improve demand management efficiency, and improve distribution service levels.

5.2. Supply Management Based on Technology, Model Innovation

Without a significant increase in the existing distribution supply capacity, how to solve the imbalance between the supply and demand of distribution with modern technology and model innovation remains a problem [82,83]. In this process, the government should issue policies to guide the development into proper channels [48]. Enterprises should actively explore new service models and invest in new technical equipment. For example, through the real-time acquisition and dynamic monitoring of status indicators such as the capacity and speed of key facilities and main roads, the point-to-road capability can be quickly promoted, and supply efficiency can be improved. The main strategies include the following:

(1) Platform strategy: Firms and enterprises should be encouraged to establish truck and cargo matching platforms and terminal distribution platforms represented by “Truck alliance”, “Huolala”, “Ishansong”, etc. With dynamic matching models and algorithms for supply and demand, the status of real-time supply can be monitored, and the amount of demand can be forecast dynamically. This will help reduce the problem of vehicle idling and space underutilization caused by information asymmetry, and provide exemplary models for the layout and adjustment of terminal distribution facilities.

(2) Collaboration strategy: With the implementation of the pilot collaborated distribution projects sponsored by the Ministry of Commerce and Ministry of Finance, different cities should formulate action plans for collaboration in distribution in accordance with their actual conditions, in which enterprises should play the leading role. The governments’ favorable policies shall be made use of in purchasing public services, and the public–private cooperation model shall be established. With incentives given to the establishment of distribution alliances among companies in the same industry and across industries, distribution supply capacity can be maximized for the convenient and effective movement of vehicles in distribution activities.

(3) Green strategy: Taking advantage of existing high-speed rail freight and large-scale metro network in Chinese large cities [84,85], the feasibility of adding special trains for distribution in metro lines and intercity rail lines can be explored, and the use of vans in downtown areas can be reduced. Moreover, the efficiency of supply can be significantly improved with the introduction and wider application of new energy trucks, unmanned vehicles, and drone distribution, and green recyclable packaging can also greatly cut down the energy consumption of distribution.

The goal of supply management is to improve quality and efficiency, increase the real-time responsiveness to demand, and reduce environmental pollution and the waste of resources in the service process. The main guiding strategies for different types of requirements in different spaces, as well as the platform, collaboration, and green strategies, are shown in Figure 10. The results include a reduction in the number of traditional freight trucks and increase in green packaging and new energy trucks. The demands for distribution in suburban and new city areas will concentrate, while those in the downtown areas will decrease.

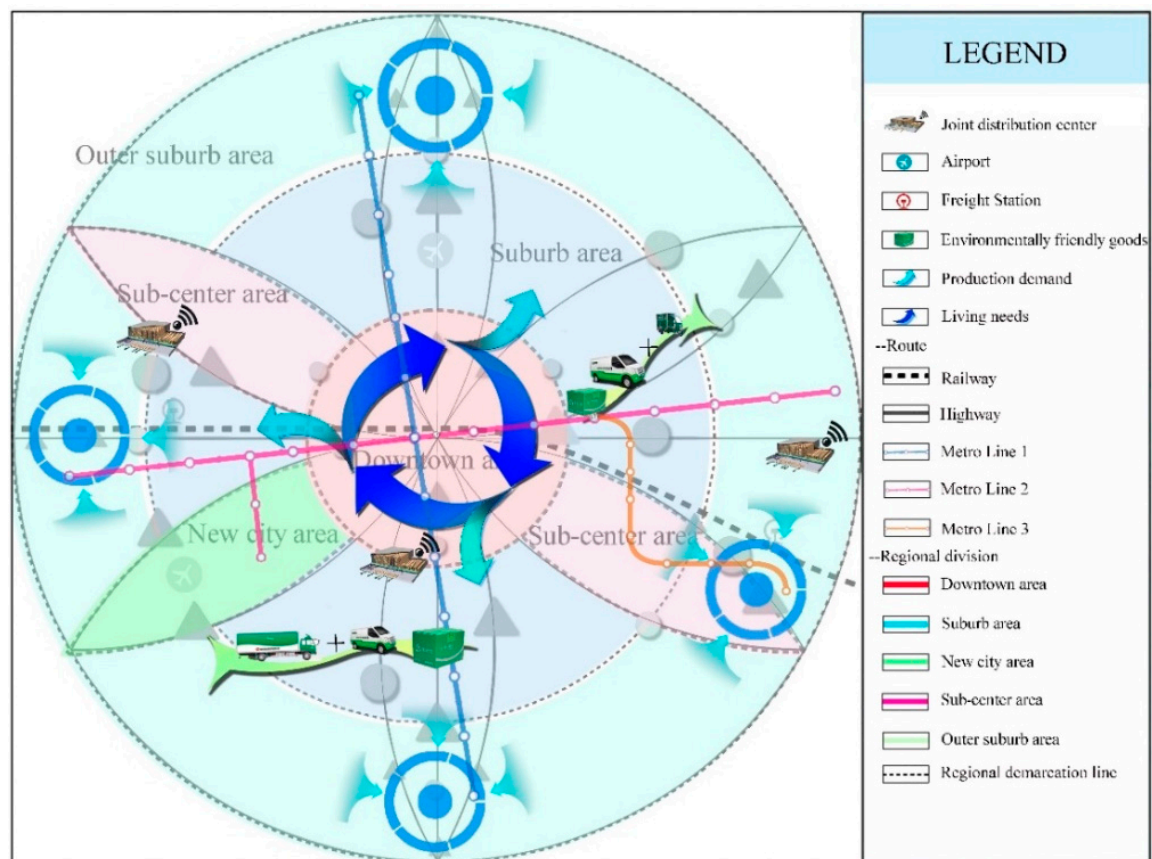


Figure 10. Sustainable distribution model design based on supply–demand coordination.

The expected goals after the implementation of the supply and demand management strategies include:

(1) If 10% of the 17 sample city's distribution demand (about 35,000 tons) is borne by new energy vehicles and metro lines and intercity rail lines, it is expected to reduce the number of transports of box trucks (loading capacity: 3.5 tons) by 10,000 times. This is also effective in reducing energy consumption and carbon emissions, while the pressure of urban road traffic is mitigated [30,86]. To achieve this goal, the Ministry of Transport, Commerce, and Public Security of China have organized 22 cities including Tianjin, Shijiazhuang, and Chengdu to develop themselves into Pilot Cities for Green Freight Distribution in 2018. At the same time, JD and Alibaba also released a green smart logistics vehicle plan and planned to purchase a large number of new energy trucks. By 2017, a total of 34 cities in China's mainland have completed the construction of 5021.7 km of city rail transit routes, and such routes in the 17 sample cities accounted for more than 80% of the total. This provides an important foundation for city distribution, and its technical, economic, and environmental feasibility has been fully justified [85,87].

(2) In 2011, the Ministry of Commerce of China began to implement a joint distribution action plan, which proposed that the core city's joint distribution (including unified distribution) network coverage rate should reach 40%, and freight volume by truck decrease by 30%. Under this circumstance, the 17 sample cities were included in the joint distribution of pilot cities. If the joint distribution accounts for 5% (about 15,000 tons) of the total distribution demand, the number of transports of box trucks (loading capacity: 3.5 tons) is expected to reduce by 5000 times. This is in full compliance with the needs of China's online retail development, but how to set up a common distribution center will become a key issue to be solved urgently [33,88].

(3) Consider that the population and commercial density of the downtown areas of China's big cities are 5–10 times that of the entire city [2]; tremendous pressure is thus imposed on the last mile distribution [10,48], and it also brought serious shortages of road resources and space conflicts [89]. If 10% of the distribution demand of the downtown areas is shifted to the suburb areas and subcenters of the city, the annual distribution will be reduced by 20,000 tons, and the number of transports of box trucks (loading capacity: 3.5 tons) will be reduced by more than 5700 times.

Of course, the implementation of the above-mentioned strategies requires the government to coordinate the interests of the participating entities, formulate an annual action plan in accordance with the goals of sustainable development and low-carbon constraints, and encourage enterprises to actively fulfill their social responsibilities.

6. Conclusions and Discussion

Under the multiple constraints of population, resources, and the environment, the issue of sustainable development in big cities has received widespread attention, which is inevitably influenced by important factors such as the equilibrium of economic development, social welfare, resource consumption, environmental pollution, and governance. As a derivative demand for social and economic development, urban distribution plays a positive role in ensuring the consumption of urban and rural residents and promoting the city's economic growth. However, environmental pollution, traffic congestion, resource consumption, and other problems of urban distribution have been restricting sustainable urban development, and can never be ignored. This paper selected 17 typical cities with some major difficulties in distribution in China as the empirical study objects, identified the characteristics and spatial differences of distribution and supply in China's big cities, and provided a new perspective for the world's observation of China's urban distribution management.

The innovation of this study is the integration of online data and economic census data. Through correlation analysis, the study shows the reliability of the data and overcomes the deficiency in distribution data in China. With the existing demand forecast and the evaluation indexes of supply capacity, the calculation methods of distribution demand and supply are developed, and the interactive relationship between supply and demand in different cities is quantified. From the perspective of spatial differentiation, the authors designed an innovative distribution management mode based on supply and demand coordination in large Chinese cities.

6.1. Conclusions

(1) The spatial distribution of logistics space in large cities in China displays a multicenter pattern, featuring scattered demand and relatively concentrated supply. The freight generation activities and supply infrastructure are located in different parts of the cities. For example, the distribution centers are mainly located between the downtown and suburban areas, while larger logistics facilities such as logistics centers and parks are farther away from the city centers. This is consistent with the trend of logistics sprawl in cities in Europe and the United States. The dynamic changes in logistics space are also subject to the development of subcenters and new urban areas in China's large cities, and such changes can help alleviate the contradiction between supply and demand of distribution through space management.

(2) The contradiction between supply and demand is prevalent in the 17 sample cities. The higher the rate of economic growth, the more prominent the single-center pattern of cities, and the more significant the contradiction between supply and demand becomes. As the focus of urban distribution management, central cities are the key to measuring the effectiveness of distribution management. Since existing urban road resources are seriously insufficient, the priority is given to passenger transport, and restrictions on the shipping time and area of freight traffic are inevitable. The multicentered supply and demand space of urban distribution provides a new way to mitigate the conflict between urban supply and demand.

(3) In the design of sustainable distribution model, the authors of this paper propose that governments should start with differentiated demand management, promote the gradual transfer of living demand to the suburb areas, and transfer the productive demand to the new city areas and subcenter areas. This will effectively reduce the non-compliant distribution space and the density of distribution demand in the downtown areas. With the implementation of platform development, collaboration, and green strategies, supply efficiency and capacity will be improved, distribution costs will be reduced, and space conflicts between the urban distribution, production, and living activities can be pacified. This management model innovation draws on the useful experience of foreign city distribution management, which not only conforms to China's national conditions, but also effectively utilizes advanced technological means.

6.2. Discussions

(1) Existing researches show that the distribution problems faced by large cities in developed countries are mainly traffic congestion, environmental pollution, and late deliveries. The strategy is to use information technology to rationally optimize the distribution route, reduce the use of trucks in the distribution process, and achieve the punctuality of distribution. At present, there are more technological innovations for the "last-mile distribution". As an emerging developing country, the essence of China's large city distribution problem lies in the serious imbalance between supply and demand, especially in different areas of the city, which requires a new perspective in distribution management. With the redistribution of demand and the improvement of the supply technology level, new supply and demand balance points can be found in different areas of the city.

(2) China is relocating its rural population into large cities and accelerating the reconstruction of large cities. This poses a huge challenge to city distribution management. At the same time, the rapid flow of population, resources, and production elements, as well as the swift growth of the internet economy, especially the integration of online and offline consumption, provides an important opportunity to optimize city distribution management and control demand effectively. A large number of empirical studies have shown that there are similar spatial patterns in major bigger cities around the world. Thus, the distribution space pattern developed and the differentiated demand management strategies proposed in this paper are significant for the distribution management of metropolises in developed countries.

(3) Since China's logistics industry has not entered the industrial classification codes to date, the national statistical data are not complete, and the data that characterizes the distribution supply and demand mainly comes from consulting companies and big data logistics companies. The POI data and national economic census data can be used to quantify the relationship between supply and demand. This study primarily adopts cross-section data rather than long-period panel data, which will also have a certain impact on the understanding of the evolution law and intrinsic mechanism of supply and demand characteristics. The shortcomings of the above research need to be further explored in the next stage of work. With the continuously increasing environmental pressures, it is particularly important to quantify the efficiency of the new technology and business model innovation to improve the supply capacity and efficiency.

(4) At last, in order to test the effectiveness of the sustainable distribution strategy proposed in this paper, significant further empirical research is needed. This is very important for the big cities in China in the process of rapid urbanization. It can also provide exemplary models for urban distribution management in Brazil, India, and other countries.

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Abbreviations

The following abbreviations are used in this manuscript:

BESTUFS	Best urban freight solutions
POI	Point of Interest
OD	origin–destination
GPS	Global Positioning System
W&D	Warehouse and distribution
MIT	Massachusetts Institute of Technology
API	application programming interface
aEDI	Alibaba E-commerce Development Index
CJFD	China Academic Journals Full-text Database

Appendix

Table A1. Basic data of demand and supply of distribution in 17 typical cities.

City	m_i	n_i	p_i	λ_i	ρ_i	s_i	l_i	q_i	q'_i	s'_i	Q_i
Beijing	8375.1	190,704.0	2114.8	40,321.0	42.9	13,884.0	7931.0	25.7	518.9	35.0	25,889.0
Shanghai	8019.1	145,668.0	2415.2	43,851.0	38.4	9932.0	4865.0	20.1	235.1	85.5	43,809.0
Tianjin	4470.4	66,133.0	1472.7	32,658.0	25.2	12,440.0	6933.0	24.3	216.6	55.0	31,985.0
Chongqing	4511.8	80,577.0	2970.0	25,216.0	17.0	12,723.0	6221.0	31.7	389.9	19.3	71,842.0
Guangzhou	6882.9	65,154.0	1292.7	42,066.0	46.0	10,241.0	7127.0	27.6	247.7	18.5	59,142.0
Shenzhen	4433.6	84,245.0	1062.9	44,653.0	50.2	11,496.0	6364.0	31.6	258.1	12.1	22,242.0
Shenyang	3186.1	35,801.0	825.7	29,074.0	22.2	7777.0	3527.0	14.7	125.3	10.0	20,957.0
Dalian	2526.5	32,284.0	694.3	30,238.0	31.5	8384.0	3025.0	15.5	106.2	18.0	26,276.0
Wuhan	3878.6	40,849.0	1022.0	29,821.0	29.0	7443.0	4833.0	14.6	132.1	20.7	25,023.0
Chengdu	3752.9	22,346.0	1429.8	29,968.0	28.8	7017.0	2707.0	19.4	256.0	7.2	42,537.3
Xi'an	2548.0	24,205.0	858.8	33,100.0	24.9	7452.0	3081.0	20.7	163.5	6.0	49,243.0
Jinan	2743.4	32,093.0	699.9	35,648.0	24.3	7859.0	4749.0	13.7	121.4	7.9	17,570.0
Qingdao	2904.3	52,523.0	896.4	35,227.0	46.4	5426.0	4334.0	17.5	152.5	6.6	23,720.0
Hangzhou	3531.2	68,329.0	884.4	39,310.0	32.2	2869.0	2479.0	17.3	204.7	9.1	23,884.0
Ningbo	2635.7	41,753.0	766.3	41,729.0	31.5	8384.0	1582.0	9.8	142.1	12.1	17,790.0
Harbin	2728.3	17,803.0	1065.6	25,197.0	17.3	5767.0	2761.0	14.5	100.5	8.8	9007.0
Xiamen	974.5	25,761.0	373.0	41,360.0	38.6	3570.0	1777.0	10.0	67.7	8.2	9393.0

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