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How does COVID-19 pandemic impact cities' logistics performance? An evidence from China's highway freight transport

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ABSTRACT

The pandemic COVID-19 which has spread over the world in early 2020 has caused significant impacts not only on health and life, but also on production activities and freight work. However, few studies were about the effect of COVID-19 on the performance of cities' logistics. Hence, this study focuses on the Belt and Road Initiative (BRI) and compares the changes in logistics performance from a spatial perspective caused by COVID-19 that are reflected on the highway freight between its 18 node cities in 2019 and 2020 of the same periods for 72 days. This study uses the entropy weight method to reflect the impact that COVID-19 has caused to the logistics level. Based on the modified gravity model, the impact on the logistics spatial connection between node cities was analyzed. These two aspects have been combined to analyze the logistics performance. The results show that the node cities have been affected by COVID-19 dissimilarly, and the impact has regional characteristics. The logistics level and spatial connection of Wuhan are the most seriously declined. The decline in logistics level has the same spatial variation law as the confirmed cases. The logistics connection between Wuhan and the surrounding node cities and the three-node cities in the northeast of China are also severely affected by the pandemic because of the expressway control policies. The regional distribution of logistics performance has differences, and the correlation of the logistics level and logistics spatial connection decreases. Besides, this study puts forward different recovery suggestions and policies for different belts in the BRI, such as focusing on restoring areas and giving full play to the role of the Chengdu-Chongqing urban agglomeration and logistics corridor. Finally, further provides corresponding suggestions for reducing the impact of emergencies from the perspectives of logistics hubs.

1. Introduction

The COVID-19 pandemic that began at the end of 2019 has undergone a rapid and complex development process in 2020, which has seriously impacted human health, economic production, and social operations on a global scale. A non-optimistic fact is that such a severe global public health challenge has formed an extremely complicated pattern due to the differences in the pandemic prevention strategies of various countries and regions in the world. Under this pattern, the original production activities, spatial flow, and social order have undergone significant changes.

While the fields of medicine and life sciences are actively working to deal with the COVID-19 itself (Shamsoddin, 2020), many studies in other fields have also explored the impact of the pandemic from various points of view. The discussions carried out include the impact of the COVID-19 pandemic on economic development (McKee and Stuckler, 2020; Walker et al., 2020; You et al., 2020), the change in population shifting caused by the shift in human activity patterns (Choi, 2020; Kraemer et al., 2020; Zhang et al., 2020), and the difference in regional product supply and demand caused by social isolation and blocking strategies (Grida et al., 2020; Ivanov, 2020), etc. As a supporting system for maintaining economic operation and circulation of production and living factors, how the logistics system should deal with the impact of the pandemic has a significant research necessity. Unlike other general social production activities, logistics activities have important spatial variability attributes, and therefore have a complex relationship with the spread and impact of the pandemic. Thus, observing how changes in logistics performance from a spatial perspective are affected by the

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pandemic will help explain in depth the impact of the pandemic on the spatial abnormality of logistics activities.

There have been many studies on the relationship between logistics activities and the pandemic. Still, they mainly focus on how the pandemic affects logistics production activities and how the suppression of logistics activities by the pandemic affects the guarantee of living supplies, such as how pharmaceutical logistics and food logistics respond to the challenges brought by the pandemic, etc. However, on a macro scale, there is still a lack of research to observe the shrinkage and evolution characteristics of regional logistics performance under the impact of the pandemic. Hence, the research work carried out in this study will focus on one specific question: how the logistics level and logistics spatial connection of the city-based logistics performance are affected by the pandemic. With the pessimistic reality that the pandemic has evolved into a long-term event on a global scale, regional-scale logistics network reconstruction, logistics performance recovery, resilience enhancement, and model transformation will become essential issues in the development of the logistics industry.

In the above context, the research work of this study will be based on a mesoscale, that is, to observe how the logistics performance of node cities is affected by the pandemic from the logistics level, logistics spatial connection. In terms of research methods, researches on cities' logistics performance based on the spatial perspective often face more significant difficulties; the reason is that it is challenging to obtain inter-city mobility data accurately. This study selects a typical part of logistics activities-highway freight transportation, and uses the refined data analysis of freight vehicles between cities to interpret the changes in the logistics performance between cities after being affected by the pandemic.

This study selects a region affected by a clear development strategy-the Belt and Road Initiative (BRI) (Wang et al., 2020; Zhou et al., 2021) within China. As the first country affected by the pandemic, China suffered a massive blow in the first quarter of 2020. With a series of practical measures against the pandemic, China's social operation and national economy have slowly recovered. The BRI, as a regional development strategy formulated at the national level in China, has a significant impact on the production relations and circulation activities of the node cities within its scope. Therefore, this study analyzes the impact of the pandemic on the cities' logistics performance from a spatial perspective through the analysis of the logistics performance within the BRI, including logistics level and logistics spatial connection.

The framework is as follows, data and methodology are described in Section 3, the results and discussion are presented and discussed in Section 4, and Section 5 gives the summary and conclusion.

2. Literature review

To find out the impact of COVID-19 on the logistics performance of node cities in the BRI, the literature review focuses on the impact of COVID-19 on logistics and other industries such as transportation and environment, as well as the related research on logistics performance, the logistics in the BRI.

Previous studies on the impact of COVID-19 focused on transportation modes (Beck and Hensher, 2020; Michail and Melas, 2020), transportation cost (Hensher et al., 2021) and transport systems (Arellana et al., 2020), and the environment (Cole et al., 2020; Fu et al., 2020), etc. Few studies researched the impact of COVID-19 on logistics, with the focus being macro logistics systems. Singh et al. (2020) constructed a simulation model of the public distribution system to demonstrate the impact of COVID-19 on the food supply logistics system, emphasizing the importance of a resilient logistics system during a pandemic. Liu et al. (2020b) assessed the development trend and driving forces of China's logistics industry in the post-COVID-19 era and summarized some potential impacts of COVID-19 on China's logistics industry, including five aspects: logistics demand declines sharp, insufficient transportation capacity, interruption of the logistics

network, and so on. Bylen (2020) used a diagnostic interview survey and statistical data analysis method to analyze Poland's logistics service market under COVID-19. It was found that the market had different impacts on different industries during the pandemic. Loske (2020) used regression analysis and system dynamics to analyze the impact of the pandemic on the transport volume in German retail logistics, revealed the changes in the volume and capacity of food retail logistics in road transportation. Yang et al. (2021) evaluated the dynamic impacts of the COVID-19 epidemic on the regional express logistics by using statistical and econometric analysis. Based on the results, they proposed short-term policy implications and long-term policy implications. Some scholars focused on transportation and logistics supply chains (Narasimha et al., 2021; Zhang and Dong, 2021). Our study further complements the literature on the external shock, including natural disasters and other epidemics on logistics performance, due to less literature on the impact of COVID-19 on logistics. The impact of natural disasters on logistics like a hurricane (Shen and Aydin, 2014; Fialkoff et al., 2017; Arabi et al., 2021), severe winter weather (Roh et al., 2015). Other epidemics on logistics focused on epidemics control and logistics operations (Dasaklis et al., 2012; Büyüktahtakın et al., 2018). These studies on the impact of COVID-19 and external shock on logistics concentrated on the whole logistics system, seldom paying much attention to the impact on individual factors in the logistics system like cities and connection.

Logistics performance has been commonly discussed as early as 1985 at a seminar in Netherland (Bakar et al., 2014), then the research on logistics performance was gradually expanded, which has been widely used in various logistics research (Chow et al., 1994; Caplice and Sheffi, 1995). The definition of logistics performance differs among different organizations and links. Logistics performance is defined as the performance of time and cost in the supply chain and supply chain network (Beamon and Balcik, 2008; Blecken et al., 2009; Banomyong and Supatn, 2011). Logistics performance is a metric used to quantify an organization's efficiency and effectiveness (Neely et al., 2005). This study proposed that logistics performance is composed of logistics level and logistics spatial connection (GAO et al., 2021) from a spatial perspective based on the previous definition of logistics performance, aiming at the freight transportation in cities' logistics.

The literature on logistics in the BRI analyzed the logistics supply chain (Liu et al., 2018; Chan et al., 2019), its impact on logistics (Chhetri et al., 2018; Lau et al., 2018), and logistics optimization problems (Wei and Dong, 2019). Jiang (2020) used a three-stage DEA model to evaluate the logistics efficiency of 29 node cities in the BRI from 2013 to 2018 and found that the logistics efficiency of coastal node cities by the Maritime Silk Road is relatively high. Sun and Chen (2016) evaluated the logistics competitiveness of Xi'an, Xiamen, Quanzhou, Urumqi, Lanzhou, and Haikou based on the entropy weight method and comprehensive evaluation index method. Their results showed that Xi'an and Xiamen had strong logistics competitiveness. However, these studies on the logistics level of the node cities started from evaluating the logistics level, separating the logistics connection between node cities. Most of them evaluated the logistics level of a single node city, and few took different belts in the BRI into account.

In summary, few studies researched the impact of COVID-19 on cities' logistics performance, and existing studies concentrated on the whole logistics system. There is little research on the impact of COVID-19 on the cities' logistics performance in the BRI. In order to supplement this research gap, this study explores the impact of COVID-19 on the cities' logistics performance, including logistics level and logistics spatial connection of node cities in the BRI.

3. Data and methodology

3.1. Data source and description

COVID-19 put pressure on global supply chains in the BRI (Buckley,

2020), causing us to be subject to the data itself when observing the logistics performance of the BIR. Due to the impact of the pandemic, the complete data of international orders and the changing process of logistics activities cannot be accessed and observed. Therefore, this study focuses on important Chinese node cities of different belts in the BRI to get the complete data of logistics performance and logistics connections between them. The selection of node cities in the BRI is based on the latest map of BRI, Vision and Actions on Jointly Building Silk Road Economic Belt and 21st-Century Maritime Silk Road and (Jiang, 2020). This study studies three belts (Wang et al., 2018; Cui and Song, 2019), each corresponding to one group of cities that are located in the BRI. The north belt: Harbin, Changchun, Shenyang, Hohhot, and Yinchuan; the central belt: Hefei, Nanchang, Changsha, Wuhan, Zhengzhou, Xi'an, Chongqing, Chengdu, Lanzhou, Xining, and Urumqi; the south belt: Nanning, Kunming, and Lhasa. Because of the lack of data in Lhasa, this study researches the remaining 18 node cities in the BRI. Fig. 1 shows the node cities and three belts, where the blue line presents the north belt, the green line presents the central belt, and the pink line presents the south belt.

This study has selected a total of 72 days' (from 25 of the 12th lunar month to 8th of the 3rd lunar month in the following lunar year) activity data from 2020 of the highway freight networks as the research data set. The activity data of the highway freight network of the same period from 2019, which serves as a control, are also prepared in this study. Considering the influence of the Chinese Spring Festival, we used the lunar calendar and not the Gregorian calendar. Using the lunar calendar as a control group can align the period in obtaining more reliable estimation results (Ming et al., 2020; Silver et al., 2020; Zhang et al., 2021). Fig. 2 shows the period when COVID-19 had an impact on China. Unknown pneumonia cases occurred in Wuhan at the end of December 2019. COVID-19 began to appear in several provinces of China on January 19, 2020 (25th of the 12th lunar month). COVID-19 had been initially controlled in several provinces on March 31, 2020 (8th of the 3rd lunar month in the following lunar year). Wuhan city was completely lifted lockdown on April 8, 2020 (16th of the 3rd lunar month).

All data are provided by the National Highway Freight Data Management Platform of the Ministry of Transport of China. The data set is based on days and records the trajectories of 647,502 highway freight vehicles. The data mainly includes fields such as vehicle id, load, total mileage, average speed, stopping city, and passing city. A passing city is different from a stopping city. A passing city is where data are recorded as long as a vehicle passes through a city. A stopping city is where a vehicle stops for more than 4 h before the data is recorded. The distance of highway transportation between cities is obtained from the highway transportation network.

3.2. Methodology

Comparing the impact of COVID-19 on the logistics performance of node cities in the BRI has two steps. Firstly, measures the logistics level of each node city in the BRI. Secondly, the modified gravity model is used to calculate the gravitational value and analyze the logistics spatial connection.

3.2.1. Measuring logistics level

Measuring the logistics level has two steps. The first step is constructing an evaluation indicator system of logistics level, based on highway freight transport from a spatial perspective. The second step is measuring logistics level by using relevant methods.

For the first step, the evaluation indicator system is based on data fields and referenced by (Yang, 2010; Li and Yin, 2011; Peng et al., 2018). The specific dimensions and indicators in Table 1 construct an evaluation system from a spatial perspective with three dimensions: the scale of highway freight, the external connection of highway freight, and the efficiency of highway freight. The scale of highway freight includes

traffic, the number of active vehicles,[1] turnover, and freight transport volume. The strength of external connections consists of the number of connected cities and the strength of the connections between cities. The number of connected cities is a summary of connections between one city and other stopping cities, the strength of the connections between cities is the product of the number of connected cities and its number of vehicles. Fig. 3 shows the example of the number of connected cities and the strength of the connections between cities, the number of connected cities for A is 2, and the strength of the connections between cities for A is 400 by definition. The efficiency of highway freight includes average speed and average mileage.

The primary method to measure the logistics level is the analytic hierarchy process, fuzzy comprehensive evaluation method, and entropy weight method. The subjectivity of index weight by analytic hierarchy process and fuzzy comprehensive evaluation method are stronger, but the entropy weight method does not, so that its result of the evaluation is more objective. The entropy weight method is an evaluation method to calculate the objective weight by the movement of indicators, in logistics was used by (He et al., 2010; Yan et al., 2020). Therefore, the entropy weight method is selected to calculate the logistics level of node cities in the BRI. The steps of the method are as follows:

(1) Min-max normalized the data.

$$Z_{ij} = \frac{X_{ij} - min(X_{ij})}{\max(X_{ij}) - min(X_{ij})} \tag{1}$$

where Z_{ij} is the normalized value of the indicator, X_{ij} is the original value of the indicator, $min(X_{ij})$ is the minimum of all values of indicator, $max(X_{ij})$ is the maximum of all values of the indicator.

(2) Calculate the information entropy value of the indicator j.

$$Y_{ij} = \frac{Z_{ij}}{\sum_{i=1}^{m} Z_{ij}} \tag{2}$$

$$e_j = -\frac{\sum_{i=1}^{m} Y_{ij} * ln Y_{ij}}{lnm} \tag{3}$$

where Y_{ij} is the weight for calculating Z_{ij}. m is the number of cities, which equals 18.

(3) Calculate the weight of each index.

$$w_i = \frac{1 - e_i}{k - \sum_{i=1}^{k}(1 - e_i)} \tag{4}$$

where k is the number of the index, which equals 8.

(4) Calculate the logistics level.

$$P_i = \sum_{j=1}^{k} w_i Z_{ij} \tag{5}$$

where P_i is the logistics level of city i.

3.2.2. Modified gravity model

The gravity model originated from universal gravitation in physics and was widely used in physics research. It was used to analyze urban space in the middle of the 20th century (Zipf, 1946). In recent years, it has been widely used in economic research (Bikash Ranjan and Pabitra Kumar, 2019; Sun et al., 2019; Ulucak et al., 2020). The basic gravity

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[1] traffic with more than 14 days and operating mileage more than 20 km in a month.

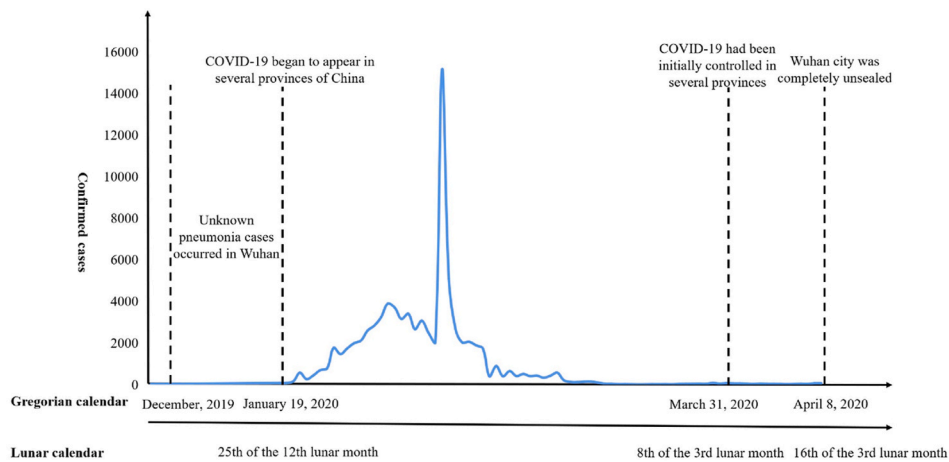**Fig. 1.** The BRI node cities and three belts.

Fig. 2. The period of COVID-19 outbreak in China.

Table 1
The evaluation index system of logistics level of node cities in the BRI.

Target layer	Dimensions	Three-level index
Logistics level (Highway freight transport)	Scale	Traffic
		The number of active vehicles
		Turnover
		Freight transport volume
	External connections	The number of connected cities
		The strength of the connections between cities
	Efficiency	Average speed
		Average mileage

model (G_{ij}) is calculated by:

$$G_{ij} = k \frac{Q_i Q_j}{D_{ij}^{\beta}} \qquad (6)$$

where G_{ij} is the spatial attraction between cities i and j. Q_i, Q_j represents the quality of cities i and j. D_{ij} represents the distance of i and j, β is the distance attenuation coefficient, β is based on (Taaffe, 1962), and concludes that b is equal to 2. k is gravitational adjustment coefficient.

Quality should represent the logistics level of cities. Therefore, Q in (6) is replaced by the logistics level of each node city (Qi et al., 2016; Zhao et al., 2016). Since this study focuses on highway freight transport, D_{ij} indicates space distance of highway. Due to the unequal logistics connections between the two cities (Tang et al., 2013), k is corrected by proportion. k is as follows:

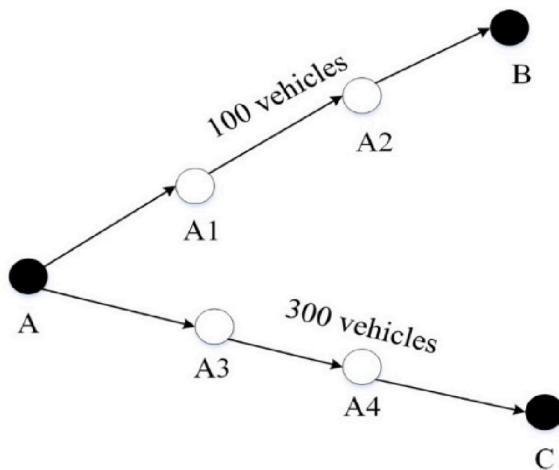$$k = \frac{F_i}{F_i + F_j} \qquad (7)$$

Fig. 3. The example of the number of connected cities and the strength of the connections between cities. (A, B and C are all the stopping city, A1-A4 are all the passing city; a total of 100 vehicles pass through A to B, and A to C has 300 vehicles).

where F_i , F_j indicates freight transport volume of cities i and j, $F_i + F_j$ indicates the sum of freight transport volume of cities i and j.

Thus, modified gravity model (g_{ij}) is:

$$g_{ij} = \frac{F_i}{F_i + F_j} * \frac{L_i L_j}{D_{ij}^2} \tag{8}$$

where L_i, L_j represents the quality of node cities i and j in the BRI, D_{ij} represents highway distance between node cities i and j in the BRI, F_i , F_j represents freight transport volume of node cities i and j in the BRI.

Then using (8) to calculate the gravitational values of 72 days in 2019 and 2020.

4. Results and discussion

4.1. Comparison of differences in logistics level of node cities affected by COVID-19

The comparison between the logistics level of node cities is composed of two aspects: numerical comparison, the spatial variation law (Tu et al., 2018; Liu et al., 2020c). The results of the logistics level in node cities for 2019 and 2020 (from 25th of the 12th lunar month to 8th of the 3rd lunar month in the following lunar year) are shown in Tables 2 and 3, as well as the three secondary indicators, logistics level, and its ranking.

The logistics level in all node cities in the BRI is affected by COVID-19, resulting in different degrees of decrease, with Wuhan experiencing the most serious decline. Apart from Wuhan, other node cities with higher logistics level are still at the top of the list. COVID-19 has caused a pandemic in Wuhan and spread to the whole country, shaking the national economy. The Chinese government has implemented a set of strict control measures, including placing the city of Wuhan under lockdown (Min et al., 2020), suspending all public traffic within the city (Lin et al., 2020). These have led to a 90% drop in Wuhan's highway freight transport scale and an 84% drop in Wuhan's external connections, further leading to a sharp decline in the logistics level, with the ranking of Wuhan falling from the top to the bottom. The logistics level ranking of each node city in 2019 in this study is in line with *CCCL* (Competitiveness of City Logistics in China), where Chongqing, Chengdu, Wuhan, Zhengzhou, Xi'an, Changsha are at the forefront of the list. Shenyang is not at the top of CCCL's report, but it still ranks high compared to the other node cities. Compared 2019 and 2020, Shenyang's logistics level is still at the forefront despite being affected by the COVID-19.

Table 2
The logistics level in 2019.

City	Scale/Rank	External connection/Rank	Efficiency/Rank	Logistics level/Rank
Hohhot	0.179/15	0.275/16	0.761/1	0.330/12
Shenyang	0.575/4	0.886/5	0.367/4	0.615/5
Changchun	0.327/9	0.452/12	0.000/18	0.289/14
Harbin	0.244/14	0.417/14	0.120/17	0.263/15
Hefei	0.353/8	0.556/9	0.273/10	0.390/8
Nanchang	0.248/13	0.468/11	0.370/3	0.333/11
Zhengzhou	0.531/7	0.979/2	0.353/7	0.615/4

City	Scale/Rank	External connection/Rank	Efficiency/Rank	Logistics level/Rank
Wuhan	0.704/3	0.929/4	0.192/14	0.654/3
Changsha	0.564/5	0.705/7	0.291/8	0.542/7
Nanning	0.305/10	0.510/10	0.367/5	0.373/10
Chongqing	1.000/1	0.937/3	0.139/15	0.795/1
Chengdu	0.720/2	1.000/1	0.254/11	0.696/2
Kunming	0.300/11	0.593/8	0.282/9	0.376/9
Xi'an	0.539/6	0.773/6	0.363/6	0.564/6
Lanzhou	0.140/16	0.403/15	0.235/12	0.231/16
Xining	0.063/18	0.202/18	0.121/16	0.112/18
Yinchuan	0.251/12	0.423/13	0.221/13	0.290/13
Urumqi	0.075/17	0.217/17	0.380/2	0.178/17

Table 3
The logistics level in 2020.

City	Scale/Rank	External connection/Rank	Efficiency/Rank	Logistics level/Rank
Hohhot	0.081/14	0.129/16	1.000/1	0.292/8
Shenyang	0.297/3	0.550/2	0.520/7	0.414/3
Changchun	0.153/8	0.258/11	0.126/18	0.174/15
Harbin	0.087/12	0.215/14	0.340/14	0.175/14
Hefei	0.159/7	0.342/8	0.555/4	0.294/7
Nanchang	0.086/13	0.283/10	0.652/2	0.261/11
Zhengzhou	0.170/6	0.491/4	0.553/5	0.340/4
Wuhan	0.059/15	0.148/15	0.231/17	0.119/16
Changsha	0.264/4	0.430/6	0.407/11	0.339/5
Nanning	0.142/9	0.316/9	0.546/6	0.279/9
Chongqing	0.425/1	0.546/3	0.254/16	0.419/2
Chengdu	0.341/2	0.631/1	0.344/13	0.420/1
Kunming	0.138/10	0.374/7	0.417/10	0.262/10
Xi'an	0.203/5	0.443/5	0.519/8	0.336/6
Lanzhou	0.035/16	0.216/13	0.560/3	0.197/13
Xining	0.005/18	0.019/17	0.273/15	0.065/18
Yinchuan	0.114/11	0.230/12	0.361/12	0.198/12
Urumqi	0.006/17	0.000/18	0.467/9	0.102/17

The consistent spatial variation law is shown in Fig. 4. The closer to Wuhan, the more cases and the more serious the decline in logistics level. The Pearson coefficient of the declining value of logistics level and the cumulative number of confirmed cases in node cities is 0.7. This may be explained by the relationship between the spread of confirmed cases and the logistics level (Vaillancourt and Haavisto, 2016). The node cities
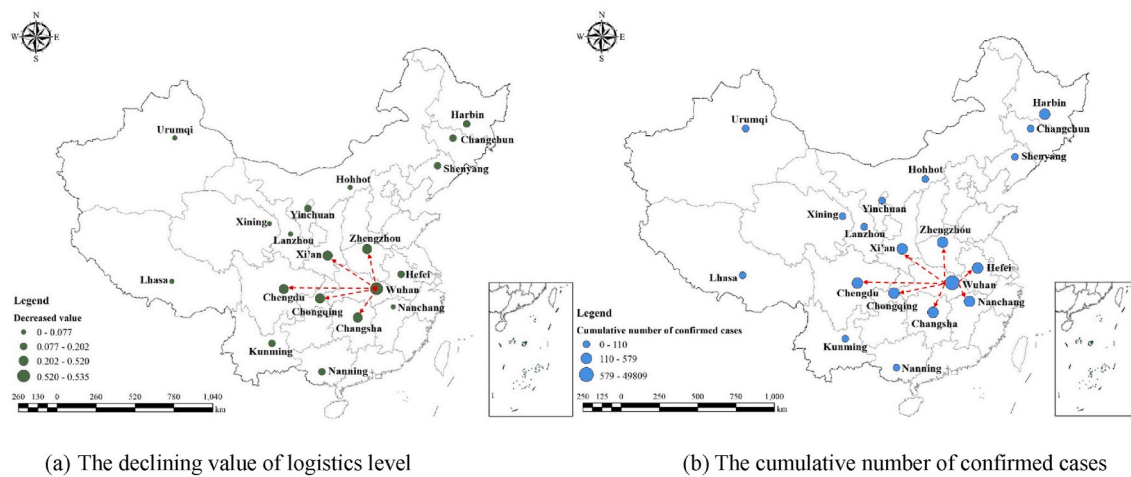
(a) The declining value of logistics level   (b) The cumulative number of confirmed cases

Fig. 4. The declining value of logistics level and the cumulative number of confirmed cases in node cities.

closed to Wuhan were affected by the spread of the pandemic in Wuhan, resulting in more confirmed cases, as shown in Fig. 4(b). These node cities reduced more logistics activities and connections to prevent the spread of the pandemic, which has led to the decline of highway freight transport scale and external connections. Then, this further led to a drop in their logistics level, as shown in Fig. 4(a). For example, the cumulative number of confirmed cases of Zhengzhou, Xi'an, Chengdu, Chongqing, and Changsha near Wuhan is more than 100. Their logistics level has dropped by more than 0.2. But Xining, Urumqi, and Lanzhou are northwest China, with the cumulative number of confirmed cases in the bottom three and far away from Wuhan, so they were not severely affected. Under the pandemic, the logistics level of these cities has dropped by less than 0.1. Based on our findings, it can be concluded that logistics level changes are highly associated with the cumulative number of confirmed cases and the distance between the city and Wuhan.

However, it's interesting that Hefei and Nanchang are not conformed to this law. They have many cases and are close to Wuhan, but the logistics level has decreased less. Therefore, it is necessary to explore further the impact of other factors, including the time of different public health emergency response level (Lei et al., 2020) and no cases on the

logistics level. The time of different public health emergency response level and no cases in node cities located border Hubei province is shown in Table 4. We can be observed in Table 4 that the duration of public health emergency response and no cases of Hefei and Nanchang are earlier than other node cities. The level of public health emergency response and the timing of no cases influences, to some extent, the tightening or loosening of freight control and lockdown policies. Their shorter duration of public health emergency response and earliest no case suggest a decline in the severity of their pandemic, followed by a shift towards looser control policies. This may cause an earlier release of control on their freight transport, allowing their logistics activities to flow normally as early as possible. Mitigating the impact of the pandemic on their logistics level creates an earlier opportunity for a normal resumption of logistics. This might lead to their logistics level being better than other node cities under the pandemic though they are also on the border of Hubei Province, their logistics level is in the middle and did not decline much during the period.

4.2. Comparison of differences in logistics spatial connection of node cities affected by COVID-19

This study visualized the gravity value (logistics spatial connection) between each node city by comparing the logistics spatial connection in 2019 and 2020. Figs. 5 and 6 show the results of the logistics spatial connection between node cities and the overall logistics spatial connection of each city in the BRI in 2019 and 2020.

In terms of the overall logistics spatial connection in individual cities, the overall logistics spatial connection of all node cities had decreased; the ranking of Wuhan has changed dramatically. Wuhan's lockdown blocked its logistics connection with other node cities in the BRI, resulting in its rank dropping from the 3rd in 2019 to the 9th in 2020. Therefore, it is necessary to focus on restoring Wuhan's logistics connection. The mass infection of COVID-19 had led to halting public transportation between many cities in China (Liu et al., 2020a). Thus, the overall logistics spatial connections of all node cities were weakened in 2020.

However, although Chongqing, Chengdu, Zhengzhou, Changsha, Shenyang, and Xi'an are affected by the pandemic, they are still closely linked with other node cities. Their ranking of overall logistics spatial connection has little changed by comparing with other node cities, improving or returning to 0–2 rankings. Although Shenyang is less strongly logistics spatial connection than the other six cities, Shenyang is still the city with the highest spatial connection of the other node cities in the north region. The external connections in the logistics level of these six cities ranked in the top seven in 2019 and 2020, especially Shenyang, which rises from fifth to second. Different regions have their
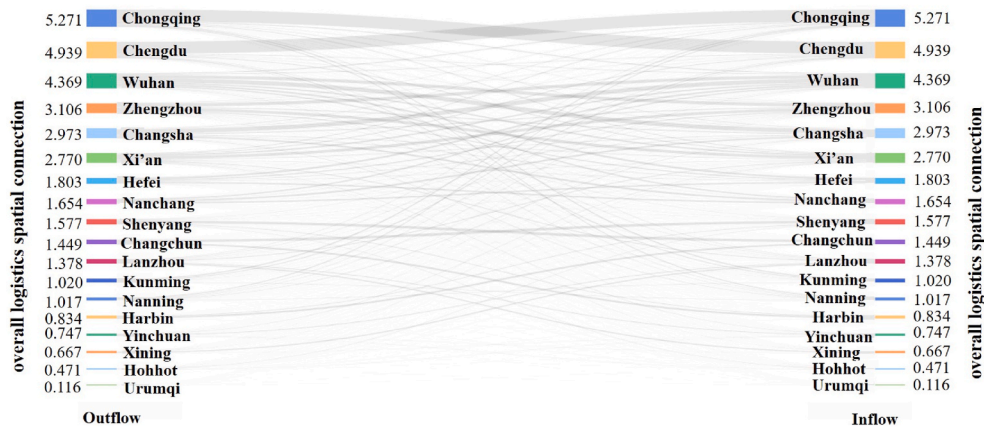
Table 4
The time of different public health emergency response levels and no cases in node cities located border Hubei province.

Node cities	Level I public health emergency response[a]	Level III and IV public health emergency response	Duration of public health emergency response (days)	No cases[b]
Wuhan	January 24	June 13	140	April 26
Zhengzhou	January 25	May 6	101	March 4
Changsha	January 23	March 31	67	March 14
Chongqing	January 24	March 25	60	April 23
Chengdu	January 24	March 25	60	April 23
Nanchang	January 24	March 20	55	March 12
Hefei	January 25	March 15	49	March 8
Xi'an	January 25	February 28	34	March 27

[a] According to the nature, severity, and scope of impact, public health emergencies are classified into four levels (I, II, III, and IV), with severity decreasing from Level I to Level IV.

[b] No caspes is that all confirmed cases are returned to zero.

Fig. 5. Logistics spatial connection between node cities in the BRI in 2019. (the larger the rectangle, the greater the logistics spatial connection of the node city; and the thicker the curve between the two-node cities, the greater the logistics spatial connection strength).
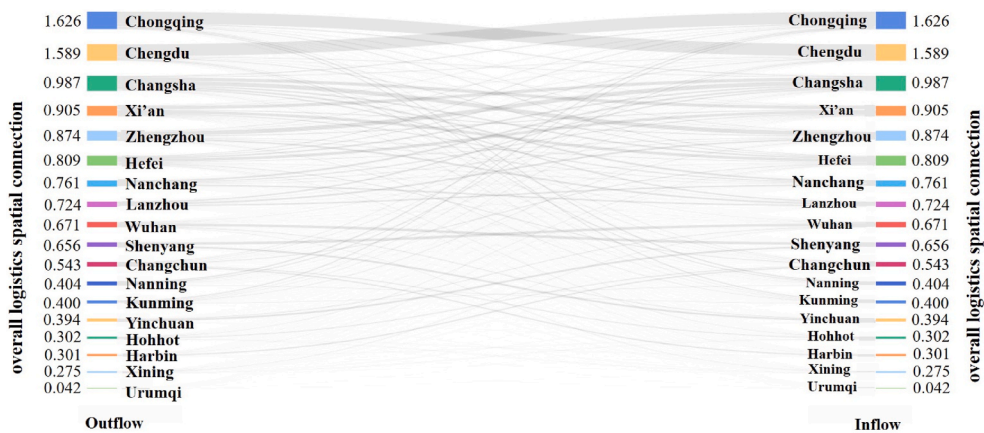

Fig. 6. Logistics spatial connection between node cities in the BRI in 2020. (the larger the rectangle, the greater the logistics spatial connection of the node city; and the thicker the curve between the two-node cities, the greater the logistics spatial connection strength).

hub cities in the BRI from the external connection and logistics spatial connection of different regions. The central and western hub role of Zhengzhou and Chongqing was increasingly prominent (Walcott and Fan, 2017; Jiang, 2020). Zhengzhou still ranks high in the external connection and logistics spatial connection in 2020, so it is natural to replace Wuhan in the central region. The hub cities of the southwest region are Chongqing and Chengdu, Xi'an is the hub of the northwest region, and Shenyang is of the north. We must continue to make full use of the logistics radiation and agglomeration effects of these six cities in the BRI, in order to resume from pandemic as soon as possible.

From the logistics spatial connection between node cities, the pandemic greatly impacted the logistics connection between Wuhan and other node cities. In 2019, Wuhan was the node city with the strongest logistics connection between Changsha, Hefei, and Zhengzhou, but in 2020 only Changsha. This shows that the pandemic has weakened Wuhan's logistics hub and radiation function. COVID-19 has not changed the closest logistics connections between the BRI's node cities: Chongqing and Chengdu. A possible explanation is that they are bordered on each other and belong to Chengdu-Chongqing Urban Ag-glomerations that is centered on Chongqing and Chengdu. The Chengdu-Chongqing logistics corridor plays an important role that has an effect on Chengdu-Chongqing Urban Agglomerations by "Corridor Effects" (Mao and Yu, 2013).

Fig. 7 plots the decline of logistics spatial connection between any two cities, divided into three levels. The serious decline of logistics spatial connection is divided into two regions: the surrounding area of Wuhan and the northeast. The expressway control policies in some node

cities whose logistics spatial connection declined seriously is shown in Table 5. It is seen in Table 5 that there are two types of expressway control policies: traffic control and set up the quarantine stations. The traffic controls include temporarily closing some toll stations and monitoring vehicles near Hubei province or expressway to Hubei province. These traffic controls will result in the unsmooth flow of freight transport, and reduce the number of freight transport. For instance, Chongqing and Chengdu are most closely linked. There are more expressways between Chongqing and Chengdu to Hubei province and are controlled by traffic controls. Temporarily closing some toll stations on some expressways such as Chengdu-Chongqing Expressway and Shanghai-Chengdu Expressway could block the freight transport between them, further has led to a 70% drop in the logistics connection. Setting up the quarantine stations is to perform procedures such as temperature testing, document checking, questioning and verification, which will increase the passage time and thus reduce the flow of freight. This may result in the decline in logistics connection between Nanchang, Hefei, and Wuhan.

Although some node cities are affected by the expressway control policies, the decline of their logistics connection is lower than other node cities of the second level. Therefore, it is necessary to further explore the relationship between expressway control policies and decline. Fig. 8 presents the relationship between the declining level of the two regions and the duration of policies. The two regions are seen in comparison, the logistics spatial connection between Changsha, Zhengzhou and Wuhan fell twice as much as between Changchun and Harbin, Shenyang. This may be because the duration of expressway
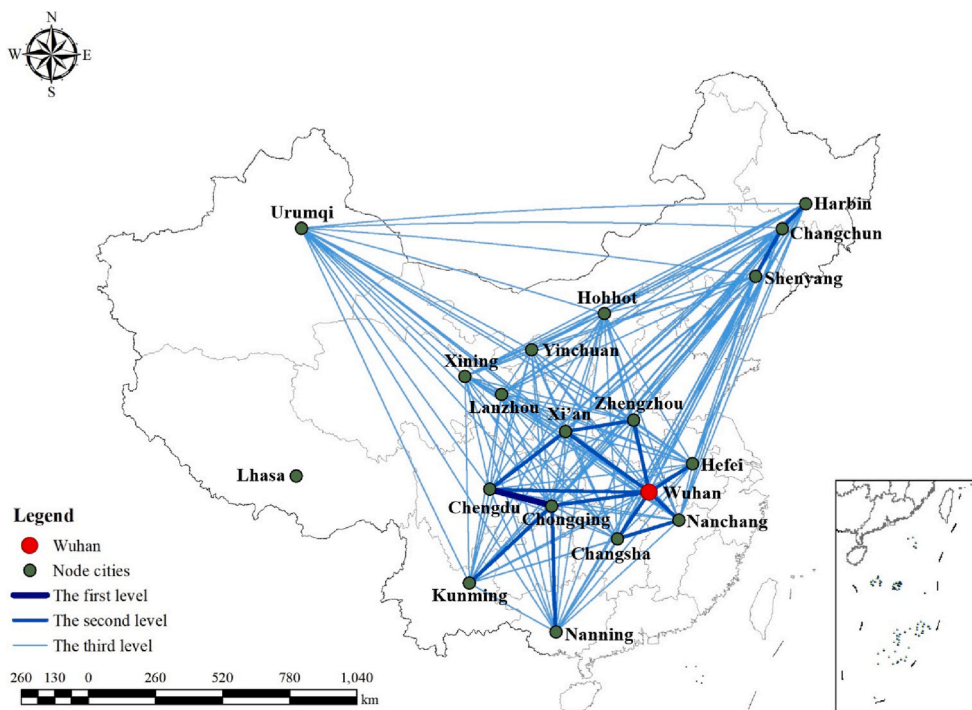
Fig. 7. Decline level of logistics spatial connection between node cities in the BRI.

control policies in Changchun and Shenyang is shorter than Changsha and Zhengzhou. The shorter duration of expressway control policies can improve the efficiency of freight transport on the expressway and reduce the time of freight transport, thus further restoring logistics spatial connection.

4.3. Comparison of differences in logistics performance of node cities affected by COVID-19

At last, this study comprehensively analyzed the impact of the COVID-19 pandemic on the BRI cities' logistics performance. Fig. 9 and Fig. 10 show the logistics performance of node cities in the BRI in 2019 and 2020, divided into four levels composed of low-low, low-high, high-low, and high-high according to the average value of logistics level and logistics spatial connection.

It is found that the distribution of logistics performance in 2019 is more concentrated, and most node cities are distributed in low-low while none is in high-low, but each region is distributed in 2020, which indicates that the pandemic has affected the overall distribution of logistics performance in node cities. This can also be explained by the correlation between logistics level and logistics spatial connection, decreasing from 0.89 to 0.74. Recovering and improving future logistics performance requires us to eliminate the impact of the pandemic on the distribution of logistics performance and make it more concentrated.

Logistics performance is composed of logistics level and logistics connections. Wuhan has been dramatically impacted in both aspects, so whose logistics performance is also affected the most: high-high in 2019, but in 2020 fell into low-low. Therefore, from the point of restoration of the most severe node cities, the government should focus on restoring the logistics performance of Wuhan. However, the node cities with high-high distribution in 2019 and 2020 belong to the central belt with Wuhan, showing that although affected by COVID-19, the logistics performance in the central belt is still better than that in the other two belts. This may be explained by most node cities with good logistics and economic foundations being in the central belt. The logistics performance of Nanchang and Hefei in the central belt has changed from low-low to high-high due to their shortening of the pandemic prevention

policies.

5. Conclusion

This study explored the impact of the COVID-19 pandemic on the BRI cities' logistics performance from a spatial perspective, including logistics level and logistics spatial connection, taking China's highway freight transport as the starting point. Firstly, this study employed the evaluation indicator system of the logistics level from a spatial perspective, and the entropy weight method was used to calculate the logistics level of 18 node cities in 2019 and 2020. Secondly, the modified gravity model was used to calculate the logistics spatial connection of node cities. Then comprehensively analyzed the impact of the COVID-19 pandemic on the BRI cities' logistics performance. Finally, this study gave some suggestions about restoring logistics performance.

The results show that the logistics performance of node cities in the BRI has been affected by COVID-19 dissimilarly, and the impact has regional characteristics. The impact on the logistics level is reflected in two aspects related to Wuhan. Wuhan implemented strict traffic control policies and city lockdown, which has led to the logistics level, logistics spatial connection seriously declining. The decline in the logistics level affected by the pandemic is also regional and divergent, the same as the cumulative number of confirmed cases, concentrated in the node cities that are bordered on Wuhan. However, Nanchang and Hefei are not conformed to this law due to earlier public health emergency response time and no cases. The impact on the logistics connection is also regional. The logistics connection between Wuhan and the surrounding node cities, the three-node cities in the northeast of China was also heavily affected by expressway control policies. The distribution of logistics performance changed from centralized in 2019 to decentralized in 2020, which can also be explained by the correlation coefficient.

In addition to the above conclusions, there are still policy implications worth further in-depth consideration. The public policies under the pandemic might have a negative impact on logistics. During the beginning of the COVID-19 outbreak, the Chinese government has implemented strict lockdown policies in China. This has seriously blocked logistics activities between cities, especially Wuhan and the cities

Table 5

Expressway control policies in some node cities during the COVID-19 pandemic.

Node cities	Start Time	End Time	Control policies
Nanchang	January 25	February 14	Fully set up checkpoints for cross-provincial passages (especially all intersections on the provincial borders of Hubei Province). Implement temporary traffic control.
Hefei	January 27	February 24	
Zhengzhou	January 27	February 25	Traffic control at some expressway toll stations connected to Hubei Province, for example, some toll stations at G4 Beijing-Hong Kong-Macao Expressway[a].
Changsha	January 26	February 24	Focus on monitoring vehicles from Hubei Province, especially Wuhan entering and exiting various toll stations. Traffic control at some expressway entry/exit e. g. G0422 Wuhan-Shenzhen Expressway.
Chengdu	February 7	February 24	Temporarily close some toll stations on the G93 Chengdu-Chongqing Expressway.
Chongqing	January 29	February 25	Implement temporary traffic control on the expressway in multiple districts and close some toll stations, such as G42 Shanghai-Chengdu Expressway[b] in Wanzhou district (Sun Jia) toll station. Set up some quarantine stations.
Xi'an	January 27	February 25	Temporarily control measures and vehicle license control at some toll stations on the expressway. Temporarily close some toll stations on the expressway.
Harbin	February 1	February 24	Temporarily close some expressway toll stations and adopt temporary control and traffic adjustment, for example, G1 Beijing-Harbin Expressway, G1212 Shenyang-Jilin Expressway, and G1211 Jilin-Heihe Expressway.
Changchun	February 3	February 9	
Shenyang	February 5	February 22	

[a] Beijing-Hong Kong-Macao Expressway passes through Beijing, Hebei Province, Henan Province, Hubei Province, Hunan Province, and Guangdong Province.

[b] Shanghai-Chengdu Expressway passes through Shanghai, Jiangsu Province, Anhui Province, Hubei Province, Chongqing, Sichuan Province.

around Wuhan. Since the expressways are the lifeblood of freight activities, the expressway control policies and duration are important factors influencing logistics performance. The expressway control policies also have a negative impact on logistics. Traffic control and setting quarantine stations may cause disruptions to freight transport and increase transport times. The length of the control policies is positively related to the decline in logistics performance. The more time spent controlling the policy, the more severe the decline in logistics performance. Wuhan had the longest closure policy during the pandemic, so it had the most significant drop in logistics performance. This is because the shorter duration of control policies can improve the efficiency of freight transport and reduce the time of freight transport. In addition, the reaction time to policy restrictions is also an important factor. Wuhan is located in a concentration of outbreaks, so the reactivity of control policies in Wuhan and surrounding cities is faster. Then, this could lead to a serious decline in logistics performance.

To help the logistics performance of the node cities along the BRI to get out of the impact of the pandemic as soon as possible, this study gives targeted policy recommendations for different belts along the BRI. The north belt should focus on restoring the logistics level and logistics connection of the three-node cities in the northeast of China by playing to Shenyang's radiant leading role. The central belt should focus on restoring Wuhan's logistics activities and connections with other surrounding node cities and continue to leverage the logistics radiation and agglomeration effects of Chongqing, Chengdu, Zhengzhou, Changsha and Xi'an. We should also restore the connection between Chengdu and Chongqing as soon as possible so that the urban agglomeration and logistics corridor between these two cities shall fully play their role in logistics activities. Further, to reduce the impact of emergencies like other similar pandemics and diseases on the BRI in the future, it is necessary to set up logistics hubs in different regions: southwest (Chongqing and Chengdu), northwest (Xi'an), central (Zhengzhou), and north (Shenyang).

Author statement

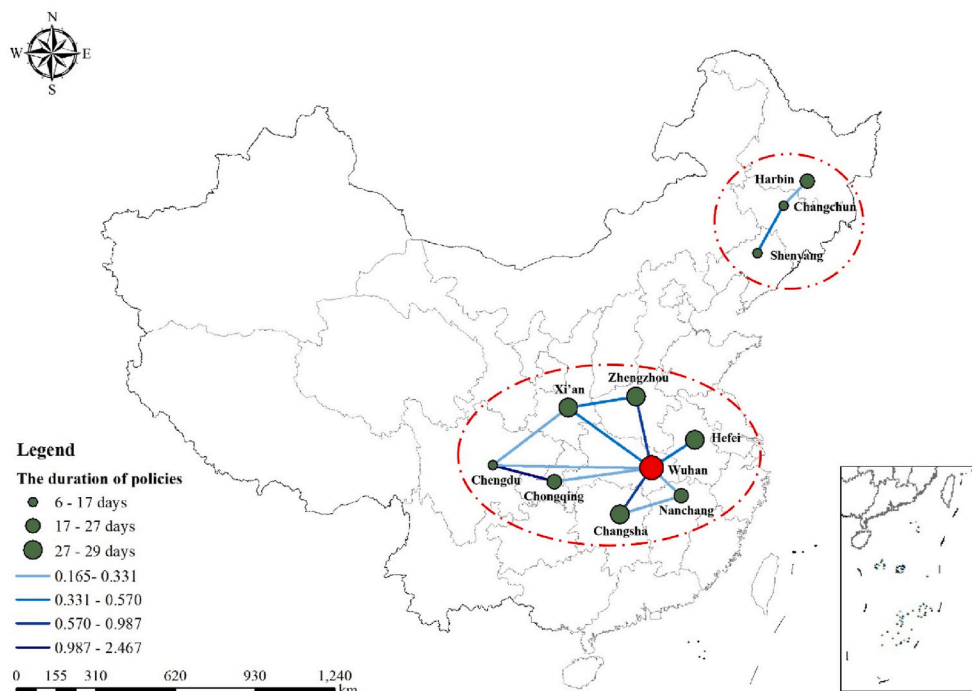Zhiwei Cui: Conceptualization, Investigation, Writing-Original draft preparation.

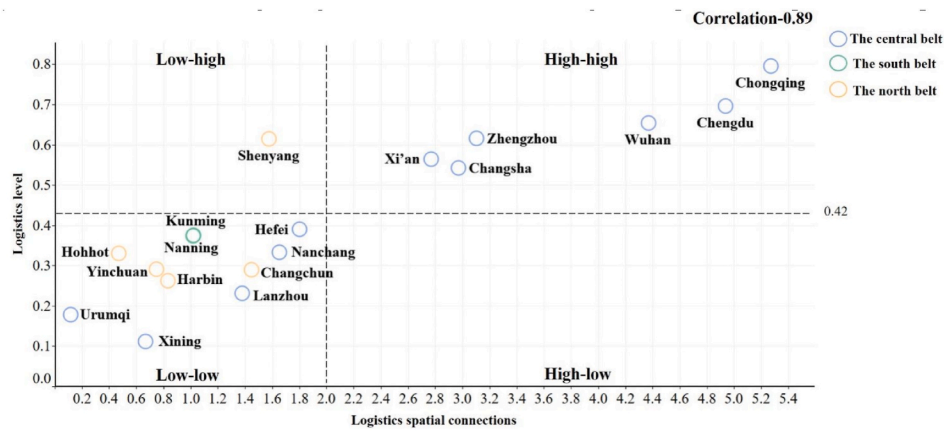**Fig. 8.** Decline level of the two regions and the duration of policies.

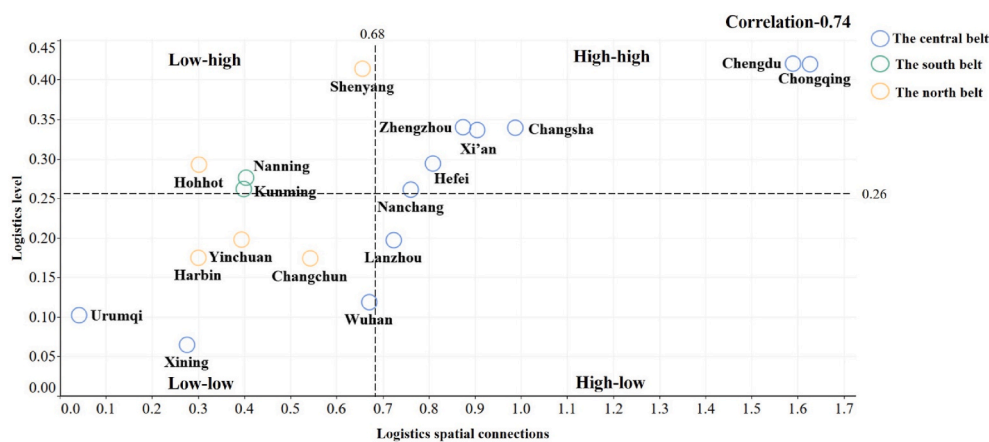**Fig. 9.** Logistics performance of node cities in the BRI in 2019.

Fig. 10. Logistics performance of node cities in the BRI in 2020.

Xin Fu: Methodology, Software, Funding acquisition.
Jianwei Wang: Writing-Reviewing, Supervision.
Yongjie Qiang: Investigation, Data curation.
Ying Jiang: Validation.
Zhiyou Long: Editing, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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