Research of multimodal transport potential of major cities in China based on the satellite remote sensing

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Keywords: Multimodal transport potential index, road-rail transport, road-air transport, satellite remote sensing, territorial spatial planning.

Abstract

By two or more modes of transportation to connect with each other and complete the transport process, multimodal transport could significantly improve transport efficiency, reduce costs, while promote energy conservation and emission reduction, compared with the traditional single mode of transport. Therefore, the multimodal transport development reflects the level of national or regional economic development to some extent. In this study, multimodal transport potential index was built to evaluate the possibility of multimodal transport. Remote sensing images from satellites were used to extract roads, railway stations and airports. A method was proposed to derive the road-rail transport potential index and road-air transport potential index, and then for the analysis of multimodal transport potential in 36 cities. Results show that there is a big gap among 36 cities on the development potential of road-rail and road-air transport. Compared with the road-rail transport potential index, the distribution of road-air transport potential index is more consistent among and within the seven regions. Index values of megacity and super cities are much higher than type I and II big cities. Moreover, in the 36 cities, there is a positive correlation between the multimodal transport potential index and GDP. The research results could be used to quantitatively evaluate the development of transport infrastructure, consequently provide more solid and reliable basic information for the planning, design and scheme adjustment of multimodal transport, thus comprehensively improve the efficiency and quality of multimodal transport, serve the territorial spatial planning.

1. Introduction

Urban traffic facilities are the foundation support of human activities. Scientific territorial spatial planning and improvement of transportation network could promote urban development, stimulate urban vitality and enhance residents' travel happiness. In China and many other countries in the world, considerable proportion of transport capacity is carried out by road system, which is the most fundamental transport infrastructure. Meanwhile, with rapid development of modern urban technology nowadays, transport and travel by rail and air are more convenient and comfort. At the same time, the radius of human activity is larger and larger. Obviously, modern transport industry needs effective, while single mode of transport mode could not meet the demand of timeliness, as well as multiple needs of faster, more convenient, lower cost any more.

High quality comprehensive transport is inseparable from the realization and development of multimodal transport. The germination of the idea of multimodal transport in European and American countries can be traced back to the end of the 1830s, but the emergence of modern multimodal transport in the real sense in the United States was in the 1920s. By two or more modes of transportation to connect with each other and complete the transport process, multimodal transport could significantly improve transport efficiency, reduce costs, while promote energy conservation and emission reduction, compared with the traditional single mode of transport (Islam et al., 2005; Si et al., 2011; Harris et al., 2015; Luan et al., 2019; Xu, 2023; Zhang et al., 2023).

Multimodal transport includes multiple stages and requires multi-sectoral coordination, which demonstrates the level of regional economic development, infrastructure construction capacity, and transportation management efficiency (Mo et al., 2015; Liu and Zhang, 2023; Yin et al., 2023). In recent years, with the implementation of major national development strategies in China, such as a country with strong transportation network, the coordinated development of the Beijing-Tianjin-Hebei Region, the Yangtze River Economic Belt, the Belt and Road Initiative, the Guangdong-Hong Kong-Macao Greater Bay Area, and the new land-Sea Corridor in the West, multimodal transport has achieved significant economic and social benefits in terms of improving transport efficiency, reducing cargo damage and cargo gap, as well as reducing transportation costs.

However, although multimodal transport has many advantages, there are still some problems, such as the connection between different modes of transport is not smooth, insufficient information sharing, transport organization is not optimized, etc. Therefore, recent researches on multimodal transport pay more attention to how to solve these problems to improve transport efficiency, reduce logistics costs, and better serve the national major development strategy (Schiller et al., 2010; Ramani et al., 2016; Li, 2020; Jian et al., 2023).

Among these key issues, the connectivity of railway station, airport and road is the fundamental guarantee for the realization of multimodal transport, and the key to solving the problem of the “last mile” (Zhang and Chen, 2015), while there is a lack of relevant research. Therefore, in this study, the multimodal transport potential index was defined to measure the connectivity of road and railway station, as well as road and airport, in the 36 major cities of China. Moreover, multimodal transport potential distribution was discussed from various perspectives, such as city level, geographical location, city scale level, and economy.

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https://doi.org/10.5194/isprs-archives-XLVIII-1-2024-111-2024

2. Study area and data sources

2.1 Study Area

The study area is 36 major cities in China. They are the most important cities in the country, which develop faster and with higher urbanization rate. The 36 cities include 4 municipalities (Beijing, Tianjin, Shanghai and Chongqing), 5 cities specifically designated in the state plan (Dalian, Ningbo, Xiamen, Qingdao and Shenzhen) and 27 provincial capitals (Shijiazhuang, Taiyuan, Hohhot, Shenyang, Changchun, Harbin, Nanjing, Hangzhou, Hefei, Fuzhou, Nanchang, Jinan, Zhengzhou, Wuhan, Changsha, Guangzhou, Nanning, Haikou, Chengdu, Guiyang, Kunming, Lhasa, Xi'an, Lanzhou, Yinchuan, Xining and Urumqi). Most of the 36 cities are in the eastern part of China.

The city scale was determined by population size. Megacity, supercity, type I large city and type II large city have population of more than 10 million, 5-10 million, 3-5 million and 1-3 million, respectively. Information of the 36 major cities is shown in Table 1 as follows.

Table 1. List of 36 major cities in China

No.	City	Province	Region	City scale
1	Beijing	Beijing	NC	Megacity
2	Tianjin	Tianjin	NC	Supercity
3	Shijiazhuang	Hebei	NC	Type II Large City
4	Taiyuan	Shanxi	NC	Type I Large City
5	Hohhot	Inner Mongolia	NC	Type II Large City
6	Shenyang	Liaoning	NE	Supercity
7	Dalian	Liaoning	NE	Type I Large City
8	Changchun	Jilin	NE	Type I Large City
9	Harbin	Heilongjiang	NE	Type I Large City
10	Shanghai	Shanghai	EC	Megacity
11	Nanjing	Jiangsu	EC	Supercity
12	Hangzhou	Zhejiang	EC	Supercity
13	Ningbo	Zhejiang	EC	Type II Large City
14	Hefei	Anhui	EC	Type I Large City
15	Fuzhou	Fujian	EC	Type II Large City
16	Xiamen	Fujian	EC	Type I Large City
17	Nanchang	Jiangxi	CC	Type II Large City
18	Jinan	Shandong	EC	Type I Large City
19	Qingdao	Shandong	EC	Supercity
20	Zhengzhou	Henan	CC	Supercity
21	Wuhan	Hubei	CC	Supercity
22	Changsha	Hunan	CC	Type I Large City
23	Guangzhou	Guangdong	SC	Megacity
24	Shenzhen	Guangdong	SC	Megacity
25	Nanning	Guangxi	SC	Type II Large City
26	Haikou	Hainan	SC	Type II Large City
27	Chongqing	Chongqing	SW	Supercity
28	Chengdu	Sichuan	SW	Supercity
29	Guiyang	Guizhou	SW	Type II Large City
30	Kunming	Yunnan	SW	Type I Large City
31	Lhasa	Xizang	SW	Type II Large City
32	Xi'an	Shaanxi	NW	Supercity
33	Lanzhou	Gansu	NW	Type II Large City
34	Yinchuan	Ningxia	NW	Type II Large City
35	Xining	Qinghai	NW	Type II Large City
36	Urumqi	Xinjiang	NW	Type I Large City

(Abbreviation of Regions:
NE: Northeast, NC: North China, EC: East China, CC: Central China, SC: South China, SW: Southwest, NW: Northwest)

Accordingly, the transportation of 36 cities represents the most well-developed city-level infrastructure system in the whole country, therefore, this study uses the transport resource information of the 36 cities to calculate the multimodal transport potential and discusses the spatial distribution of multimodal transport potential index, as well as the relationship of the index and economy.

2.2 Data Sources

Urban transportation infrastructure, such as road, railway station, airport was introduced to build the index of multimodal transport potential.

In order to objectively express the spatial transportation infrastructure, remote sensing images were used to obtain the vector information. In the study, the information of roads, airports and railway stations of the 36 major cities was extracted by 2-meter resolution satellite remote sensing images such as ZY-3 and GF-1 (Table 2), with the support of AI technology. Examples of extracted results of Roads, railway station and airport are shown as Fig. 1 and Fig. 2.

Table 2. Satellite parameter of ZY-3 and GF-1

Satellite	Launch date	Sensor	GSD	Swath width
ZY3-01	9-Jan-2012	Nadir panchromatic	2.1m	50 km
		Nadir multispectral	5.8m	52 km
GF-1	26-Apr-2013	GF(HR) camera	Panchromatic Image:2m Multispectral Image:8m	60km
		Wide-swath camera	Multispectral Image:16m	800km
ZY3-02	30-May-2016	Nadir panchromatic	2.1m	50 km
		Nadir multispectral	5.8m	52 km

Satellite remote sensing images, population and GDP data of 2019 were used to maintain consistency.

Figure 1. Example of railway station and the roads of 5km around extracted from satellite remote sensing images

Figure 2. Example of airport and the roads of 5km around extracted from satellite remote sensing images

3. Methodology

In order to quantitatively measure the multimodal transport possibility, the multimodal transport potential index (*MMTPI*) was built. The multimodal transport potential index includes two parts, which are road-rail transport potential index and road-air transport potential index. The road-rail transport potential index distributes the potential of transport conversion between road and railway, while the road-air transport potential index represents the potential of transport conversion between road and air.

Further, the road-rail and road-air transport potential index was calculated by the road density, derived by formula (1), within a radius of 5km based on the locations of railway station and airport.

$$MMTPI=\sum l_i/S \quad (1)$$

Where *MMTPI* is multimodal transport potential index, l_i, S are length of i road, area of the 5km circle, respectively.

Any city has more than one railway station and/or airport, the road-rail and/or road-air transport potential index would be the average of all the road densities in each 5km-circle. Apparently, the higher the index is, the more possible the city multimodal transport becomes. Meanwhile, the higher index indicates more convenient transfer potential from one transport mode to another, or even more modes of different stages.

Then the potential level of multimodal transport was discussed from the perspectives of different cities, seven geographical regions, four city scales and the correlation with economic development step by step, to study the characteristics of multimodal transport potential in China. The flowchart of the study is shown by Fig. 3.

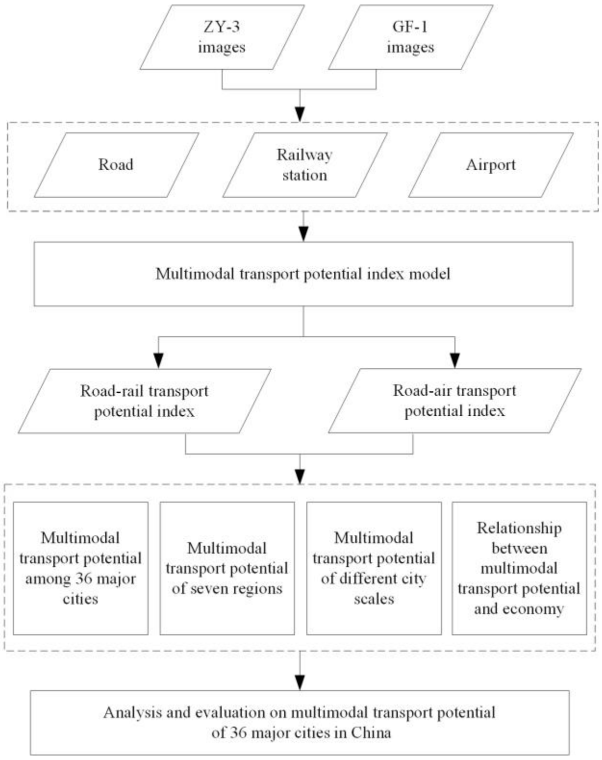


Figure 3. Flowchart of multimodal transport potential research

4. Results and Discussions

4.1 Differences of Multimodal Transport Potential among 36 Major Cities

The multimodal transport potential index of 36 major cities has obvious difference. Either road-rail transport potential index range or road-air transport potential index range spans relatively large, while the range of road-rail transport potential index is larger than road-air transport potential index. The minimum value of road-rail transport potential index is lower than the minimum value of road-air transport potential index, however, the maximum values of the two are very close.

4.1.1 Road-rail Transport Potential Index of 36 Cities: Among them, road-rail transport potential index is between 1.2 and 5.6, with an average of 3.2. In all the 36 cities, road-rail transport potential index of 20 cities is no less than the average, and 16 cities have lower index than the average. As Fig. 4 shows, road-rail transport potential index of the 36 cities could be separated into 1.2-1.9, 1.9-2.6, 2.6-3.4, 3.4-4.1, 4.1-4.8, and 4.8-5.6. The numbers of cities in the group of 1.9-2.6 and 3.4-4.1 are the most, and both of them have 10 cities. In the group of 2.6-3.4, the number of cities is 9. While other three groups only have 7 cities in their ranges.

The top three cities with higher road-rail transport potential index are Hangzhou, Ningbo and Zhengzhou, all of which are above 5.0. The last three are Lhasa, Nanning and Xining, all lower than 2.0. It could be found that, the highest index of road-rail transport potential is more than 4.5 times of the lowest.

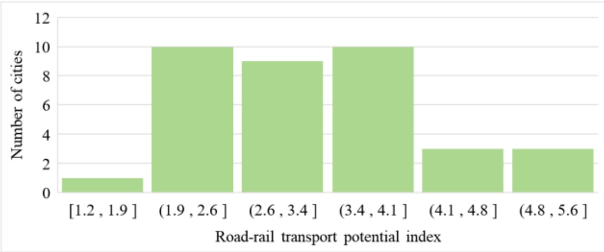


Figure 4. Road-rail transport potential index distribution histogram of 36 cities

4.1.2 Road-air Transport Potential Index of 36 Cities: The road-air transport potential index for 36 major cities is between 1.7 and 5.5, with an average of 3.4. As could be seen from Fig. 5, road-air transport potential index of the 36 cities could be divided into six groups, which are 1.7-2.4, 2.4-3.0, 3.0-3.6, 3.6-4.2, 4.2-4.9 and 4.9-5.5. Both of the city numbers in 2.4-3.0 and 3.6-4.2 are 12, more than other four groups. The group of 2.6-3.4 has 9 cities, while the group of 4.1-4.8, 4.8-5.6 and 1.2-1.9 only have just one or two cities.

Among them, road-air transport potential index of 16 cities is no less than the average, and 20 cities have lower index than the average. The top three cities with higher road-air transport potential index are Ningbo, Nanchang and Chengdu, all of which are greater than 4.4; The last three are Lhasa, Kunming, Hohhot and Fuzhou, all below 2.6. It could be seen that the highest index of road-air transport potential is more than 3.2 times of the lowest.

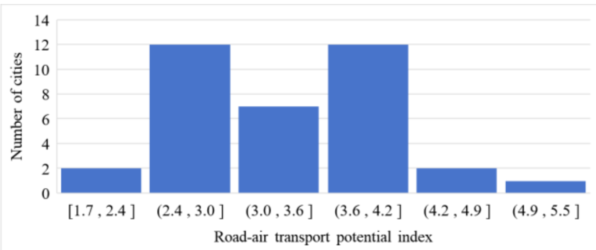


Figure 5. Road-air transport potential index distribution histogram of 36 cities

4.2 Development Levels of Multimodal Transport Potential of Seven Regions

Seven geographical regions are widely used in spatial distribution discussions of researches on geography. In this study, 36 cities were grouped by their locations into the seven regions to compare the multimodal transport potential in and among the regions.

From the perspective of location, the potential index of multimodal transport in the seven regions is very unbalanced, as showed in Fig. 6. The multimodal transport potential of North China, East China and Central China is better than that of Northeast China, Northwest China, Southwest China and South China (Table. 3).

The mean values of the road-rail transport potential index in seven regions are 4.1 in Central China, 3.8 in East China, 3.5 in North China, 3.1 in Northeast, 2.6 in South China, 2.5 in Northwest and 2.5 in Southwest. Meanwhile, the mean values of the road-air transport potential index are 3.7 in Central China, 3.6 in East China, 3.5 in South China, 3.4 in North China, 3.2 in Northeast, 3.2 in Northwest and 2.8 in Southwest. The overall trend shows that regions with greatest multimodal transport potential are Central and East China, and the trend decreases to the north and south respectively.

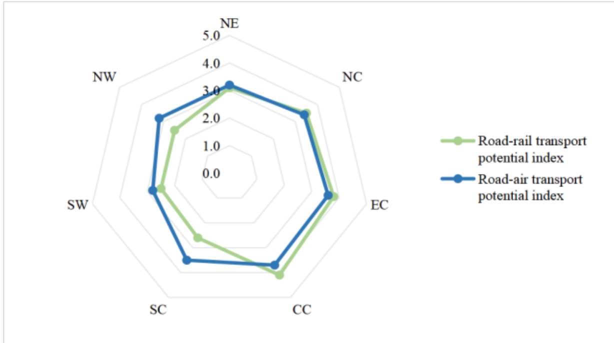


Figure 6. Multimodal transport potential index of seven regions

Within the same region, the potential degree of road-rail transport in the Northeast and Northwest is the most balanced, and the standard deviation is 0.5. While the worst is East China, where the values vary widely among the 9 cities, with a standard deviation of 1.2. The standard deviation values of road-rail transport potential in Central China, North China, South China and Southwest are 0.6, 0.7, 0.8 and 0.9, respectively.

On the other hand, Northwest region has the most balanced road-air transport potential index among the cities with a standard deviation of 0.4. On the contrary, road-air transport potential index values in East China and Southwest are the most unbalanced, with a standard deviation of 1.0. The standard deviation of index values in Northeast, North China and South China are all about 0.6, and that of Central China is 0.8.

Compared with road-rail transport potential index, the distribution of road-air transport potential index is more consistent among and within the seven regions.

Table 3. Statistics of multimodal transport potential index of seven regions

Region	**Road-rail transport potential index**		**Road-air transport potential index**	
	AVE	**STD**	**AVE**	**STD**
NE	3.1	0.5	3.2	0.6
NC	3.5	0.7	3.4	0.6
EC	3.8	1.2	3.6	1.0
CC	4.1	0.6	3.7	0.8
SC	2.6	0.8	3.5	0.6
SW	2.5	0.9	2.8	1.0
NW	2.5	0.5	3.2	0.4

4.3 Influences of City Scale on Multimodal Transport Potential

The standards of city scale were set to meet the needs of population and urban management more scientifically. Thus the 36 cities were grouped according to their population size to four levels, which were megacity, supercity, type I large city and type II large city.

Results show that, the multimodal transport potential index of different city scales has distinct grades, as Fig. 7 shows. Among the four scales, the average of road-rail transport potential index in megacity is 3.5, that in supercity is 3.9, and the average values of type I large city and type II large city are 3.0 and 2.7, respectively.

The average of road-air transport potential index in megacity is 3.9, that in supercity is 3.6, and the values of type I large city and type II large city are 3.2 and 3.0, respectively.

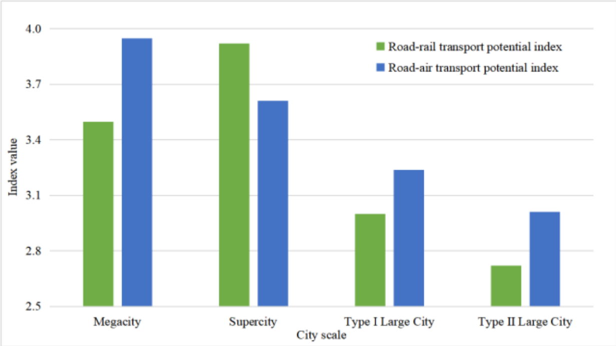


Figure 7. Multimodal transport potential index of four city scale levels

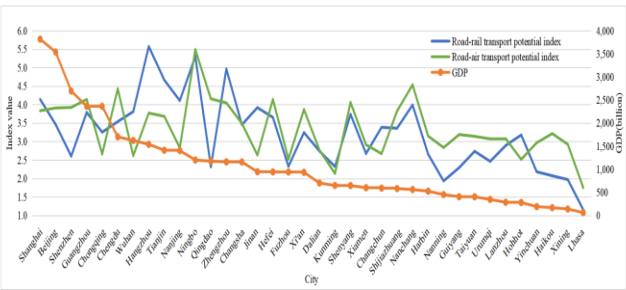
It could be seen from Table 4 that, among the cities of the same scale, the multimodal transport potential development of megacity and type I large city is more balanced than that of supercity and type II large city. On the whole, road-air transport potential index shows more balance than road-rail transport potential index within the same level of cities.

Table 4. Statistics of multimodal transport potential index of four city scale levels

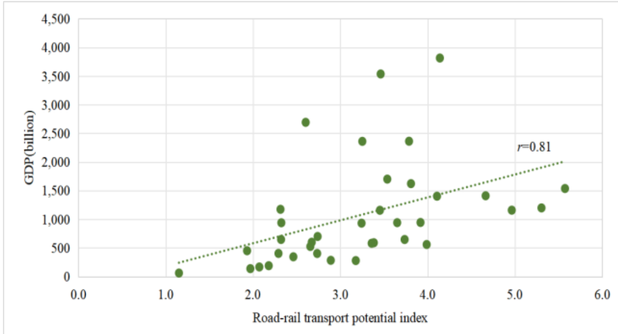
City scale	Road-rail transport potential index		Road-air transport potential index	
	AVE	STD	AVE	STD
Megacity	3.5	0.7	3.9	0.1
Supercity	3.9	0.9	3.6	0.7
Type I Large City	3.0	0.6	3.2	0.5
Type II Large City	2.7	1.1	3.0	1.0

4.4 Relationship between Multimodal Transport Potential and Economy of 36 Cities

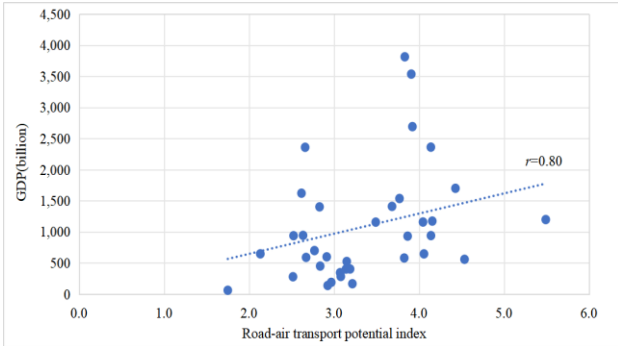
GDP is the most intuitive indicator to measure the economic status and development level of a country or region. From Fig. 10, correlation analysis of multimodal transport potential and GDP shows that the road-rail transport potential index and the road-air transport potential index in 36 major cities has a certain positive correlation with GDP. The higher GDP indicates the greater potential of multimodal transport, and the higher degree of multimodal transport will also help growth of GDP. Compared with road-air transport potential index, the correlation between road-rail transport potential index and GDP is better.



(a)



(b)



(c)

Figure 8. Relationship between multimodal transport potential and economy of 36 cities
(a. Line chart of multimodal transport potential index and GDP,
b. Scatter diagram of road-rail transport potential index and GDP,
c. Scatter diagram of road-air transport potential index and GDP)

5. Conclusions

By introducing remote sensing data of domestic satellites, this study proposes a method for measuring multimodal transport potential. Further, the multimodal transport potential index was taken to two parts, which were road-rail transport potential index and road-air transport potential index.

The results show that the multimodal transport potential index of 36 major cities is obviously different. There is a big gap among different cities on the development potential of road-rail and road-air transport. From the perspective of location, the distribution of multimodal transport potential index among the seven regions is disequilibrium. Compared with the road-rail transport potential index, the distribution of road-air transport potential index is more consistent among and within the seven regions. On the other hand, there is positive relation between multimodal transport potential index and city scale. The larger the city scale is, the higher the multimodal transport potential index is. Index values of road-rail transport potential index and road-air transport potential index in megacities and supercities are much higher than type I and type II large cities. Moreover, in the 36 cities, there is a positive correlation between the multimodal transport potential index and GDP, which indicates the local economic development to a certain extent.

The research results also indicate that, as a convenient and widely used data source, remote sensing images could be applied to the information extraction of roads, railway stations, airports and many other transport infrastructures, while for the analysis and discussions further. Meanwhile, the mainly mode of multimodal transport is road-rail at present, and other modes like road-air, as well as rail-water are vigorously promoted at present. Accordingly, remote sensing monitoring of the comprehensive layout of the transport system should be carried out regularly in key cities to objectively, comprehensively and quantitatively reflect the construction and development of highway, railway, airport, water transport, logistics park and other infrastructure, consequently provide more solid and reliable basic information for the planning, design and scheme adjustment of multimodal transport, thus comprehensively improve the efficiency and quality of multimodal transport, serve the territorial spatial planning.

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