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# Development of a 250-m Grid Dataset for Travel Resilience Spatial Differentiation within the Sixth Ring Road of Beijing (2020)

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**Abstract:** Travel resilience refers to the process of restoring residents' travel to the original state of balance between supply and demand or establishing a new equilibrium state after experiencing negative disturbances. It characterizes the interactions between residents' travel, disturbances, urban space, and transportation systems in terms of process, continuity, and dynamics. The key measurement of travel resilience lies in the ability of transportation demand to recover to pre-disturbance levels or achieve a stable state during long-term coupling with a disturbance. Using the K-means clustering method and cell phone signaling data from Beijing between February and September 2020, the authors calculated a spatial differentiation dataset of travel resilience within Beijing's Sixth Ring Road. The dataset includes (1) cluster factors and resulting data in points, including the unique identification ID for each 250 m grid (GID), travel recovery speed (25rate) and magnitude (29rate) under the epidemic disturbance, clustering results indicating travel toughness (Kmeans_clu), and (2) kernel density values with 250-m resolution. This dataset was archived in a previous study. shp and .tif formats and consists of 47 data files with a data size of 5.32 MB (compressed to one file of 1.01 MB).

**Keywords: travel; COVID-19 pandemic; mobile signaling data; resilience; clustering analysis**

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**Dataset Availability Statement:**

The dataset supporting this paper was published and is accessible through the *Digital Journal of Global Change Data Repository* at: https://doi.org/10.3974/geodb.2023.10.04.V1 or https://cstr.escience.org.cn/CSTR:20146.11.2023.10.04.V1.

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## 1 Introduction

Resilience is a critical attribute that reflects the capacity of a system to recover, and has been widely discussed and used in various disciplines such as ecology, psychology, economics, and engineering[1–4]. In geographical research, the concept of resilience has been applied to analyze the dynamic adaptive capacity of regions for disaster prevention, mitigation, and preparedness[5,6], the self-adaptive processes of trade networks during negative disturbances such as financial crises and economic recessions[7–9], the recovery, transformation, and renewal of regional economies under external shocks[10–13], and the dynamic equilibrium and anti-interference capabilities of urban systems[14–18]. Overall, resilience is an important indicator of sustainable development in complex systems, representing the ability to adapt to disturbances and maintain functionality with dynamic and phased characteristics.

The application of the concept of resilience in the context of transportation systems helps deepen our understanding of the robustness and reliability of transportation networks, thereby promoting the modernization and high-quality development of transportation systems. However, existing studies on transportation resilience have mainly focused on the resilience of infrastructure supply networks[19–22], with limited discussion on the resilience of transportation demand, that is, the recovery and adaptation of residents' travel during disturbances. Therefore, this study analyzed the changes in residents' travel within the Sixth Ring Road of Beijing during the initial period of the COVID-19 pandemic using continuous mobile signaling data collected over eight months. By establishing a conceptual framework for travel resilience, proposing measurement methods, and considering the impact of the pandemic, this study summarizes the patterns of travel resilience and four resilience models in Beijing. This study contributes to enriching the understanding of resilience, complementing transportation resilience theory from the demand side, and providing insights into the sustainable development of transportation systems.

## 2 Metadata of the Dataset

The metadata of the Dataset of Travel resilience spatial differentiation within the Sixth Ring Road of Beijing city of China (2020)[23] is summarized in Table 1. This includes the full name, short name, authors, year of the dataset, temporal resolution, spatial resolution, data format, data size, data files, data publisher, and data-sharing policy, etc.

## 3 Methods

This dataset consists of 250 m grid covering the area within the Sixth Ring Road of Beijing. The data used in this dataset include the following:

1. Grid-to-grid travel data based on China Unicom mobile signaling data, sourced from Wisdom Footprints Company[1].
2. Boundary data of the Sixth Ring Road of Beijing, sourced from the Chinese Academy of Sciences Resource and Environmental Science and Data Center[2].

### 3.1 Algorithm

In unsupervised learning algorithms, K-means clustering is widely applied, is relatively mature, and highly operational. Furthermore, K-means clustering allows specification of the number of clusters in the clustering result. Therefore, this study selected the K-means algorithm

[1] Wisdom Footprints Company. http://www.smartsteps.com/.
[2] The Chinese Academy of Sciences Resource and Environmental Science and Data Center. https://www.resdc.cn/.

**Table 1** Metadata summary of the Dataset of travel resilience spatial differentiation within the Sixth Ring Road of Beijing city of China (2020)

| Items | Description |
|---|---|
| Dataset full name | Dataset of travel resilience spatial differentiation within the Sixth Ring Road of Beijing city of China (2020) |
| Dataset short name | TravelResilienceBeijing2020 |
| Authors | Fan, W. Y. JFJ-3237-2023, Institute of Geographic Sciences and Natural Resources Research, fanwenying21@mails.ucas.ac.cn<br>Huang, J. CVH-4108-2022, Institute of Geographic Sciences and Natural Resources Research, huangjie@igsnrr.ac.cn<br>Wang, J. E. AAD-5237-2020, Institute of Geographic Sciences and Natural Resources Research, wangje@igsnrr.ac.cn |
| Geographical region | Within the Sixth Ring Road of Beijing city |
| Year | 2020 |
| Temporal resolution | Monthly |
| Spatial resolution | 250 m |
| Data format | .shp, .tif |
| Data size | 1.01 MB (after compression) |
| Data files | Travel resilience pattern 250-m grid vector data |
| Foundations | National Natural Science Foundation of China (42121001); Youth Innovation Promotion Association of Chinese Academy of Sciences (2021049) |
| Data publisher | Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn |
| Address | No. 11A, Datun Road, Chaoyang District, Beijing 100101, China |
| Data sharing policy | (1) ***Data*** are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use ***Data*** subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute ***Data*** subject to written permission from the GCdataPR Editorial Office and the issuance of a ***Data*** redistribution license; and (4) If ***Data*** are used to compile new datasets, the 'ten per cent principal' should be followed such that ***Data*** records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[24] |
| Communication and searchable system | DOI, CSTR, Crossref, DCI, CSCD, CNKI, SciEngine, WDS/ISC, GEOSS |

for the unsupervised classification of travel resilience zones.

The K-means clustering algorithm partitions data into a predefined number of clusters (k) by minimizing the error function using distance as the similarity measure. It assumes that two objects are more similar if their distances are smaller. Here, "distance" does not necessarily refer to the physical distance in the entity space but rather the distance in the coordinate space, with its actual meaning determined by the data content.

The primary steps of the K-means clustering algorithm are as follows:

(1) Randomly select k initial cluster centers from n sample data points.

(2) Calculate the distance of each sample from each cluster center and assign the sample to the cluster with the closest distance.

(3) Once all the samples were assigned, the centers of the k clusters were recalculated.

(4) The newly calculated centers were compared with previous centers. If the center of any cluster has changed, return to step (2); otherwise, proceed to step (5).

(5) The algorithm terminates and outputs the clustering results.

The core of executing the K-means clustering algorithm is to minimize the sum of squarederrors (SSE) for the given dataset $D=\{x_1,x_2,\cdots,x_m\}$, with respect to the cluster partition $\{E_l \mid l=1,2,\cdots,k\}$ obtained by clustering. The formula for calculating the SSE is as follows:

$$SSE=\sum_{l=1}^{k}\sum_{x\in E_l} dist\left(\mu_l, x\right)^2 \tag{1}$$

where $k$ is the number of clusters, $E_l$ represents the $l$-th cluster, $x$ is a sample and $\mu_l$ is the centroid of cluster $E_l$.

### 3.2 Data Processing

The data processing is as follows:

(1) Collection of administrative boundaries and ring road boundary data for Beijing.

(2) The mobile signaling data are cleaned by removing trips outside the Sixth Ring Road and constructing an origin–destination (OD) matrix for trips within the Sixth Ring Road.

(3) Calculate travel recovery indicators, including “recovery speed” and “change magnitude,” using MATLAB.

Specifically, “recovery speed” is calculated according to the following formula:

$$Sp_{ij} = \sum_{k=i}^{j-1} \frac{P_{k+1} - P_k}{P_{k+1}} / (j-i) \tag{2}$$

where $Sp_{ij}$ represents the average recovery speed of trips from month $i$ to month $j$, and $P_k$ represents the total number of trips in month $k$.

The change in magnitude" is calculated using the following formula:

$$Sc_{ttl} = \frac{P_s - P_0}{P_s} \tag{3}$$

where $Sc_{ttl}$ represents the overall change in the number of trips from the start of the disturbance to the period of overall stability. $P_s$ denotes the total number of trips in stable month and $P_0$ represents that in the initial month.

(4) Use travel recovery indicators to perform k-means clustering on the grid data, resulting in travel resilience spatial differentiation data.

(5) Conduct a kernel density analysis of the clustering results to identify spatial patterns of travel resilience.

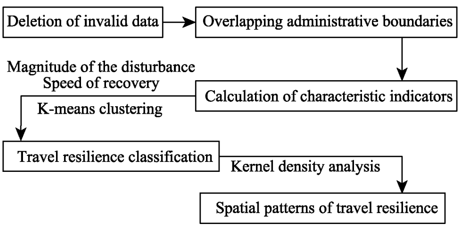


**Figure 1** Dataset development technology roadmap

## 4 Data Results and Validation

### 4.1 Data Composition

The dataset for the spatial differentiation of travel resilience within the Sixth Ring Road of Beijing (2020) includes 47 data files: (1) resilient spatial distribution in four categories, archived in a point feature format (.shp), and (2) kernel density analysis results stored in. tif format. The attribute table includes the following: (1) unique identifier (GID) for each 250-m grid; (2) “Recovery Rate” (25rate) and “Magnitude of Change” (29rate) for travel recovery under epidemic disruption; (3) spatial pattern of travel resilience, i.e., clustering results for grid cells, divided into four categories represented by the numbers 0–3, wherein the magnitude of the number is arbitrary and only serves to differentiate categories (field name: kmeans_clu). The values in the raster files represent the kernel density within each cluster type for four raster files.

### 4.2 Data Products

According to calculations based on mobile signaling data from February to September 2020, within the Sixth Ring Road in Beijing, the lowest total travel volume occurred in February, with 4.339 million trips. Conversely, the highest total travel volume was observed in September, with 20.008 million trips. The average travel distance ranged from 7.74 km to 8.49 km, and this distance distribution remained relatively stable across different travel volumes.

Based on the overall magnitude of change and recovery rate of travel volume, Beijing's travel resilience can be categorized into four types:

Type I: Small change in travel volume and slow recovery rate.

Type II: Small change in travel volume and fast recovery rate.

Type III: Large change in travel volume and slow recovery rate.

Type IV: Large change in travel volume and fast recovery rate.

The dataset results revealed that Type III was the most prevalent type, accounting for 36.1% of the spatial distribution, whereas Type I was the least common, representing only 9.6%.

**Table 2** The proportions of the four resilience regions

| Types | Labels | Disturbance magnitude | Recovery speed | Proportions (%) |
|---|---|---|---|---|
| Type I | 0 | Little | Slow | 9.6 |
| Type II | 1 | Little | Quick | 19.8 |
| Type III | 2 | Large | Slow | 36.1 |
| Type IV | 3 | Large | Quick | 34.5 |

The spatial distribution of the four resilience areas on the map of the Beijing City Ring Road, along with kernel density analysis, provides an intuitive view of the differences and basic characteristics of these four resilience areas (Figure 2)[25]. Type I: Areas with small changes in travel and slow recovery were localized in the southern and eastern regions between the Fifth and Sixth Ring Roads. These areas are predominantly green spaces and parks. Type II: Areas with small changes in travel but fast recovery were mainly clustered in the eastern region between the fifth- and sixth-ring roads. These areas are characterized by residential communities with abundant amenities such as schools, shopping malls, and office buildings. Type III: Areas with large changes in travel and slow recovery are concentrated within the Fourth Ring Road and extend outward along the radial transportation lines. Additionally, areas near the Beijing Capital International Airport were categorized as Type III resilience areas. Type IV: Areas with large changes in travel but fast recovery are primarily clustered around large employment centers, such as Zhongguancun, Shangdi, and the Central Business District (CBD). The distance from the city center did not significantly affect the distribution of these areas.

The spatial characteristics of the combination patterns of resilience zones are as follows:

Within the Fourth Ring Road, the line of the northern of the area connecting the Yuegezhuang Bridge and Siyuan Bridge primarily comprises the third (large changes, slow recovery) and fourth resilience zones (large changes, fast recovery). In the southern part of this region, there is a mixture of the Third Resilience Zone (large changes, slow recovery), Fourth Resilience Zone (large changes, fast recovery), and Second Resilience Zone (small changes, fast recovery), with some localized concentrations of the Second Resilience Zone, which often corresponds to areas with more parks and green spaces.

In the Tongzhou area, the second (small changes, fast recovery) and third resilience zones (large changes, slow recovery) predominated, with very few instances of the Fourth Resilience Zone (large changes, fast recovery).

In areas where manufacturing factories are concentrated in the south, the Fourth Resilience Zone (large changes and fast recovery) is accompanied by the distribution of the Second Resilience Zone (small changes and fast recovery). By contrast, in areas where the information industry is concentrated in the north, the Fourth Resilience Zone (large changes, fast recovery) is accompanied by a Third Resilience Zone (large changes, slow recovery).

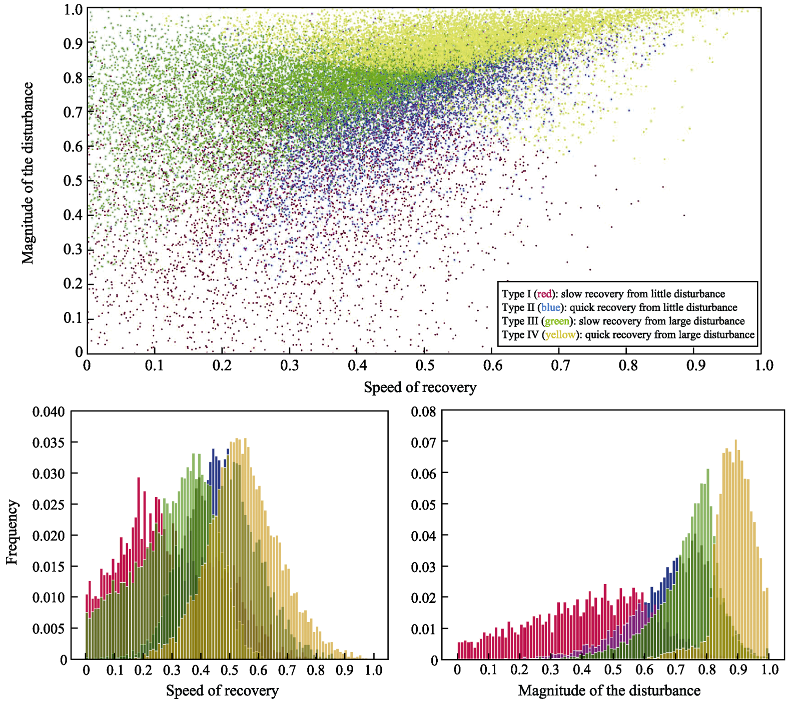


**Figure 2** The clustering results for travel resilience

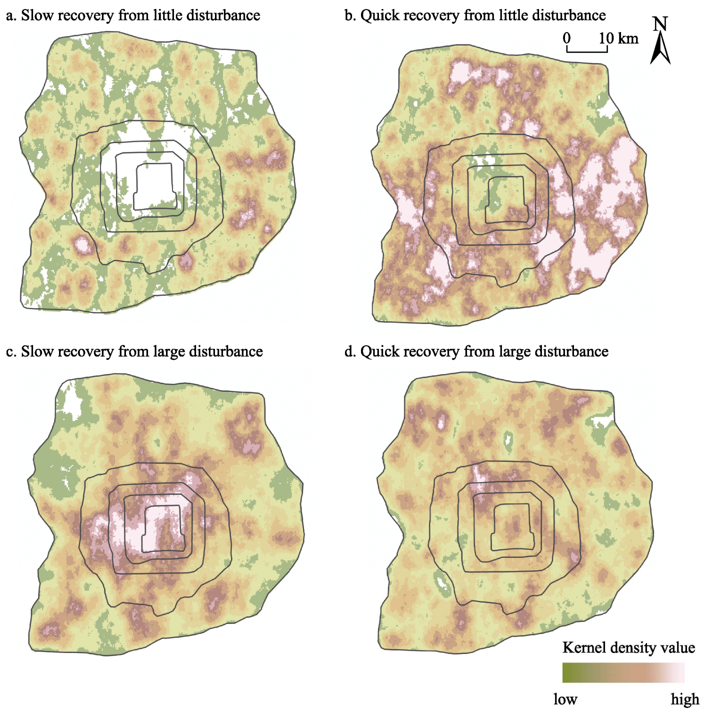


**Figure 3** Maps of the kernel density analysis results for the spatial differentiation of travel resilience in Beijing

The First Resilience Zone (small changes, slow recovery) was often adjacent to the Second Resilience Zone (small changes, fast recovery) and was primarily distributed between the Fifth and Sixth Ring Roads.

## 5 Discussion and Conclusion

This study introduces a method for measuring travel resilience and calculates its characteristic indicators of travel resilience for Beijing based on continuous 8 months of mobile signaling data. It combines unsupervised machine learning and kernel density analysis to analyze the spatial patterns of travel resilience, providing insights and references for research related to travel resilience.

Furthermore, based on the spatial distribution characteristics and differences in travel resilience, this study discusses the practical significance of the four resilience zones.

(1) First Resilience Zone (small changes, slow recovery): this zone is primarily located outside the Fourth Ring Road and has relatively low travel volumes. After sudden events, there was little overall change in the travel volume in these areas. This suggests that people's activities in these areas are less spatially affected. However, recovery is slow, indicating that the relationship between people and space is stable, but not tightly connected. The land use functions in this zone are not highly important to residents' lives, and their functional influence has limited reach.

(2) Second Resilience Zone (small changes, fast recovery): predominantly found in the eastern and southern parts, with fewer occurrences within the Fourth Ring Road than outside. These areas had lower travel volumes. This resilience zone is characterized by stable functionality, minimal impact of sudden events, and a strong and stable connection between people and space. Residents' lives depend on the physical spaces in these areas.

(3) Third Resilience Zone (large changes, slow recovery): concentrated within the Fourth Ring Road and extending outward along radial transport routes, similar to the distribution pattern observed in September with high travel volumes. This resilience zone is significantly affected by sudden events and requires longer to reach a new stable state. Therefore, it directly reflects the overall recovery of a city and should be the focus of urban management monitoring.

(4) Fourth Resilience Zone (large changes, fast recovery): concentrated in areas between the North Fifth Ring Road and North Third Ring Road, between the East Fourth Ring Road and East Fifth Ring Road, and outside the Fifth Ring Road. This zone includes research institutions, residential areas, wholesale markets, and factories. These areas can be managed efficiently and exhibit significant changes but with quick recovery. The differences in recovery speed depend on the management decisions.

The division of resilience zones in this study was based on clustering results, using recovery speed and change magnitude as indicators. Unsupervised machine learning methods do not require specific predefined values for resilience, allowing for multiple interpretations of results based on a specific urban context. However, there are commonalities, with resilience zones reflecting different patterns of interaction between people and spaces in the city, providing a new perspective for understanding urban dynamics.

### *Author Contributions*

Fan, W. Y. designed the algorithms, contributed to data processing and analysis, and drafted the data paper. Huang, J. collected mobile signaling data and reviewed, guided, edited, and improved the data. Wang, J. E. reviewed and guided the data processing and paper writing.

### *Conflicts of Interest*

The authors declare no conflicts of interest.

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