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Discussions

A New Method for Calculating Highway Blocking due to High Impact Weather Conditions

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Abstract: Fog, rain, snow, and icing are considered to be the high-impact weather events often lead to the highway blockings, which in turn causes serious economic and human losses. At present, there is no clear calculation method for the severity of highway blocking which is related to highway load degree and economic losses. Therefore, the goal of this work is to develop a method to be used to assess the high impact weather effects on the highway blocking. Based on the K-means cluster analysis and the CRITIC (Criteria Importance through Intercriteria Correlation) weight assignment method, we analyze the highway blocking events occurred in Chinese provinces in 2020. Through cluster analysis, a new method of severity levels of highway blocking is developed to distinguish the severity into five levels. The severity levels of highway blocking due to high-impact weather are evaluated for all weather types. As a part of calculating the degree of highway blocking, a new method is proposed for China, and the highway load in each province is evaluated. The economic losses resulting from highway-blocking events caused by dense fog are specifically assessed. Results suggested that the highway losses caused by dense fog was the main contributor for highway blocking conditions and occur at about 43%.

1 Introduction

High-impact weather conditions negatively affect the transportation safety, mobility, and reliability (Das and Ahmed, 2022; Hammit et al. 2018; Dehman and Drakopoulos, 2017; Yu et al. 2015), even causing delays in the delivery of goods and materials (Jaroszweski et al., 2015). Many agencies have set enhancing traffic safety on highways as the main goal to improve transportation efficiency and safety (Ali et al. 2021; Das et al. 2021; Ratanavaraha and Suangka, 2014).
Weather-related road accidents have a significant seasonal pattern as the high-impact weather is common in different seasons (Edwards, 1999; Keay and Simmonds, 2005; Bergel Hayat et al., 2013). Fog, heavy rain and snow usually have the most

adverse impact on transportation (Yang et al. 2021). Due to slippery road conditions or hydroplaning on rainy days (Kim et al. 2021), road accidents are two to three times more likely than in dry weather (Brodsky and Hakkert,1988) and the overall accident risk was found to be 70% higher than the value of normal conditions (Andrey and Yagar, 1993). Fog usually occurs in winter and has a great impact on transportation (Li et al., 2019; Liu et al., 2016; Shen et al., 2022). Low visibilities because of fog can affect the drivers' behavior and the road safety (Hassan and Abdel-Aty, 2011), and vehicle rear-end collisions on the highway commonly occur in foggy weather (Huang et al. 2020). Therefore, driving in foggy weather is a potentially dangerous activity for road blocking conditions (Yan et al. 2014).

The high-impact weather conditions can also lead to traffic delays, economic loss, or increased pollution effects (fog case). The road surface with snow or icing can lead to slower vehicle speeds and a decrease in fuel combustion efficiency (Hallegatte 2008; Min et al., 2016). The work of Min et al. (2016) showed that when 10% improvement occurs in road surface conditions, 0.6–2% reduction in air emissions amount can occur. The weather forecasting products, if used, the road transportation sectors can generate great economic benefit. Frei et al. (2014) found that 75.1-91.2 million U.S. dollars can feed into to the national economy in Switzerland (cost/benefit ratio of around as 1:10).

Highway Blockings are usually caused by human or natural causes of highway traffic interruption, and they are generally divided into the two types (Niu et al. 2015; Song et al. 2021): 1) due to highway maintenance construction, reconstruction and expansion construction, major social activities and other planned events and 2: due to natural disasters (including geological disasters, extreme weather, etc.), accidents, disasters, public health events, social security events, and other reasons caused by unexpected events.

Many researchers have studied the influence of adverse weather on highway traffic blocking (Song et al., 2021; Niu et al., 2015). Song et al., (2021) found that the correlation coefficients between the length of highway blocking and the meteorological impact indices of fog, typhoon and snowfall are significantly positive. However, there are few studies on the damage caused by highway blocking due to high impact weather (Andrey et al. 2003; Chapman 2015; Chen et al., 2016; Manish et al., 2005; Pregnolato et al., 2017). In this respect, the current work will further help to improve HIW events effects on road blocking. By 2021, the total length of highways in China has reached 169,100 kilometers, ranking first in the world. The ability to estimate highway traffic demand caused by the highway blocking during adverse weather events; therefore, it is critically needed.

In this study we describe and evaluate the main high impact weather (HIW) factors (fog, rain, snow, and icing), their temporal and spatial distribution characteristics, highway load, and losses affected by the highway blocking. Based on this analysis, a new method how to assess the HIW impact on road blocking is proposed. Findings from the paper will provide transport institutions with a practical guidance for systematically investigating the weather effect on highway blocking damage.

This manuscript is organized as follows: The data and methods are described in section 2. The highway blocking features, temporal and spatial distribution, and damage caused by the highway blocking are given in section 3. Discussions are given in Section 4 and the conclusions are provided in section 5.

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2. Data and methods

2.1 Chinese highway network and study area

In this study, the highway distribution in 2020 issued by the Ministry of Transport of the People's Republic of China is adopted, with a total mileage of 155,000 km (Fig. 1a). According to the differences in geographical environment and climatic characteristics of China, 32 provincial administrative regions in China (Taiwan, Hong Kong and Macao are not included in this study due to the lack of data) are divided into 8 main regions (Fig. 1b), i.e., Northeast China (Heilongjiang, Jilin and Liaoning Provinces and northeastern Inner Mongolia Autonomous Region), North China (Beijing and Tianjin Municipalities, Hebei, Shanxi and Shandong Provinces and central Inner Mongolia), East China (Jiangsu, Anhui and Zhejiang Provinces, and Shanghai Municipality), Central China (Henan, Hubei, Hunan and Jiangxi Provinces), South China (Guangxi, Guangdong, Fujian and Hainan Provinces), Northwest China (Xinjiang Autonomous Region, Gansu Province, Ningxia Hui Autonomous Region, Shaanxi Province and western Inner Mongolia), Qinghai-Tibet region (Tibet Autonomous Region and Qinghai Province), and Southwest China (Sichuan, Yunnan and Guizhou Provinces).

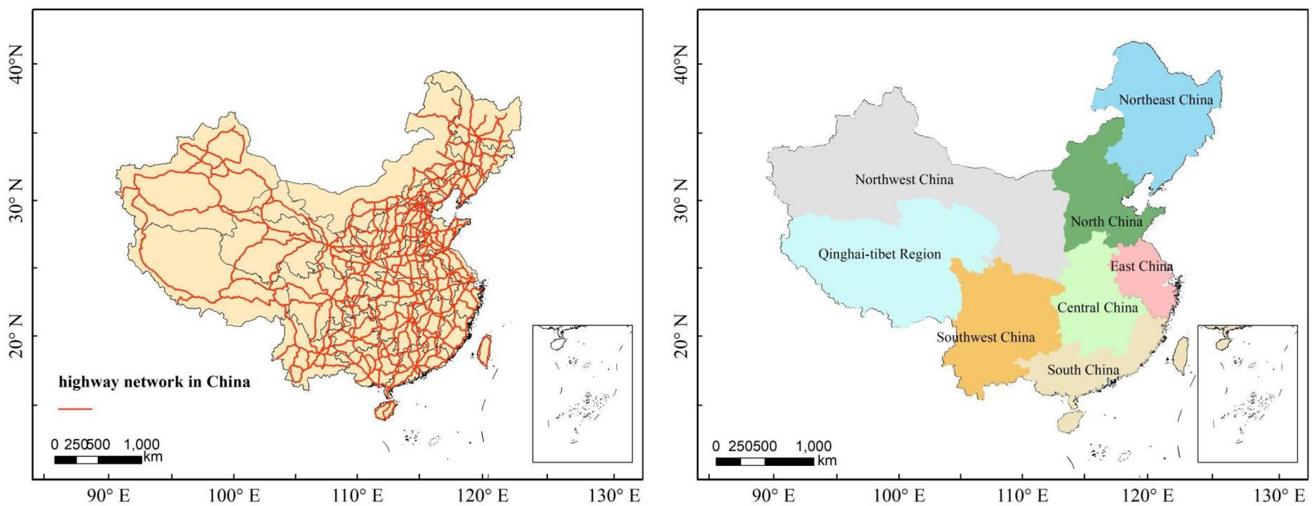

Figure 1. The distribution of highway network (a) and the regional division (b) in China.

2.2 Data sources

2.2.1 Highway-blocking events data

The highway-blocking events data obtained from the Ministry of Transport of the People's Republic of China (Fig. 1a) follow the criteria of the Highway Traffic Blocking Information Submitting System of the Ministry of Transport of the People's Republic of China (2018, No. 451). The dataset contains 16 indicators: province name, submitting department, route name, route number, starting and ending pile number (Highway pile numbers are usually combined with the milestone system and are expressed in K kilometers ± meters. That is, along the direction of the road, the pile number at the starting point is k0+000,

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and one pile number is marked every certain distance (such as 100 meters), and the corresponding place is marked), reasons of highway blocking, blocking mileage (the distance of the highways blocking), status, blocking type, information event classification, site description, disposal measure, time of finding blockage, submitting time, expected recovery time, and actual recovery time. Since highway blocking information is submitted by manual statistics, there is a possibility of manual statistical errors. Therefore, all data were corrected in advance for spatio-temporal sequences, and the quality control was then carried out according to blocking causes and site descriptions, etc. 95% of the valid data is filtered out.

2.2.2 Meteorological observations

The meteorological observation data used in this research is obtained from the National Climate Center of the China Meteorological Administration, and its variables include temperature, pressure, wind direction and speed, rainfall, snow depth and visibility. We designate March–May as spring, June–August as summer, September–November as autumn and December–February as winter.

The weather cause of the blockage is recorded in the highway blocking data. We can find the relevant meteorological elements of the nearest weather station in this period according to the road section and time period of the blockage.

2.2.3 Transportation-related economic data

The transportation-related economic data are derived from the National Bureau of Statistics for transportation and post item and national economic accounting item (2020 data). The transportation and postal item contain the transport mileage, Highway Technology Status, passenger capacity, freight capacity, civilian automobile ownership and express business. The national economic accounting includes the added value of gross domestic product (GDP) generated by transportation. The industry classification of transportation is based on the industry classification of national economic activities (GB/T 4754–2017; https://data.stats.gov.cn/easyquery.htm?cn=C01).

2.3 Analytical method

2.3.1 K-means clustering analysis

K-means clustering is an unsupervised machine learning method without prior knowledge (that is, no classification criteria is given before classification). For the classification of unlabelled data into groups and determining cluster centers. One chooses the desired number of clusters, and the K-means procedure iteratively moves the centers to minimize the total within-cluster variance. Specifically, the criterion is minimized by assigning the observations to the K clusters in such a way that within each cluster the average dissimilarity of the observations from the cluster mean, as defined by the points in that cluster, is minimized (Hastie et al., 2009).

Consider a set of n-dimensional vector {xi} = {xi1, xi2, …, xin}, and the dissimilarity measure follows the squared Euclidean distance.

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$$\mathrm{d}(\mathrm{x}_i, x_{i'}) = \sum_{j=1}^{n}(x_{ij} - x_{i'j})^2 = \|\mathrm{x}_i - x_{i'}\|^2 \quad (1)$$

The objective is to find

$$\mathrm{argmin}\, \frac{1}{2}\sum_{k=1}^{K}\sum_{C(i)=k}\sum_{C(i')=k}\|\mathrm{x}_i - x_{i'}\|^2 = armin \sum_{k=1}^{K} N_k \sum_{C(i)=k}\|\mathrm{x}_i - \bar{x}_k\|^2 \quad (2)$$

where N_k is the number of points in cluster k, $\bar{x}_k$ is the center of cluster k, $C(i)$ = k indicates x_i belongs to cluster k. Given an initial set of centers, the K-means algorithm alternates these steps:

(1) For each center we identify the subset of training points (its cluster) that is closer to it than any other center;

(2) The means of each feature for the data points in each cluster are computed, and this mean vector becomes the new center for that cluster. These two steps are iterated until convergence.

Typically, the initial centers are randomly chosen observations from the training data. Details of the K-means procedure, as well as generalizations allowing for different variable types and more general distance measures, are given in Hastie et al. (2009).

2.3.2 CRITIC weight assignment method

The CRITIC (Criteria Importance through Intercriteria Correlation) method is an objective weight assignment method (Diakoulaki et al. 1995; Wei et al. 2020), which is commonly used for the analysis of data with strong correlations of indicators and also considers the variability among indicators. By objectively calculating the indicators of data, each item is assigned a different weight, and the calculation steps are as follows.

Contrast intensity, expressed as a standard deviation, indicates the dispersion degree of an indicator. The larger the standard deviation is, the greater the dispersion degree is, the larger the differences between samples are, and the larger the assigned corresponding weights are. The standard deviation *S* can be expressed in Eq. (3).

$$S_j = \sqrt{\frac{\sum_{i=1}^{p}\left(x_{ij} - \frac{1}{n}\sum_{i=1}^{n} x_{ij}\right)^2}{n-1}} \quad (3),$$

where x_{ij} denotes the data processed by standard deviation, S_j the standard deviation of the jth indicator, n the total number of samples, and p the total number of indicators.

Correlation is expressed as the correlation coefficient between indicators. The stronger the correlation between indicators is, the higher the repetition rate of information expression. Therefore, the corresponding weights of the indicators can be reduced to a certain extent. The correlation coefficient *R* can be expressed in Eq. (4).

$$R_j = \sum_{i=1}^{p}(1 - r_{ij}) \quad (4),$$

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where, R_j indicates the correlation coefficients of the jth indicator with the other indicators, and r_{ij} denotes the correlation coefficient of the ith indicator with the jth indicator.

The weight of indicator (W) can be written as Eq. (5).

$$W = \frac{S_j \times R_j}{\sum_{j=1}^{p} S_j \times R_j} \quad (5).$$

2.3.3 Calculation method of highway load

In this study, the traffic data indicators with a high correlation with transportation are chosen to assess the highway load in each province. The larger the corresponding highway load is, the greater the economic losses are when highway blocking event occurs due to high-impact weather. Based on the statistical data issued by the National Bureau of Statistics, the data of mileage, passenger capacity, freight capacity, express capacity, the added value of transportation and civilian automobile ownership are selected as the basic reference. Since the area, altitude and topography in different regions affect the distribution of highways, and the degree of highway utilization varies in different regions due to the differences in economic development, we perform a comprehensive assessment by referring to the highway density (highway length in a specific unit area and the highway load under the unit length).

The correlations between data items are higher because some of the data items are obtained by performing calculations from other data items. Additionally, subjective weight assignment methods, such as the gradation classification method and the analytic hierarchy process, are not objective enough, while we prefer to obtain objective analysis from the data in this study. Thus, the CRITIC weigh method is chosen. Specifically, data normalization is firstly performed for all traffic indicators, where Z is the normalized data, calculated by $Z = \frac{Z_{\mathrm{i}} - Z_{\mathrm{min}}}{Z_{\mathrm{max}} - Z_{\mathrm{min}}}$, and then the weights are assigned to each normalized data by using the CRITIC weight method to obtain the weight value of each indicator. So we develop an equation (Eq. (6)) to calculate the degree of highway load.

$$\mathrm{HW_{load}} = H_{\mathrm{d}} * \alpha + \Delta\mathrm{TF_{load}} * \beta + \mathrm{GDP_{trans}} * \gamma + \Delta P_{\mathrm{load}} * \delta + \mathrm{VD} * \varepsilon + \mathrm{EP} * \epsilon + \mathrm{TF_{load}} * \theta + P_{\mathrm{load}} * \vartheta + V_{\mathrm{private}} * \mu \quad (6),$$

where $\mathrm{HW_{load}}$ denotes the highway load, H_d the highway density, $\Delta\mathrm{TF_{load}}$ the load capacity of freight transport for per kilometer, $\mathrm{GDP_{trans}}$ the added value of the GDP generated by transportation, ΔP_{load} the number of people for per kilometer, VD the vehicle density, EP the number of express packages, $\mathrm{TF_{load}}$ the total freight transport, P_{load} the number of people, and V_{private} the number of private vehicles. α, β, γ, δ, ε, ϵ, θ, ϑ and μ are the corresponding coefficient values of each parameter.

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3. Results

3.1 Highway blocking features

From figure2 we can see that, fog is the main weather factor which causes highway blocking in China (Fig. 2), with a proportion of 48%. The next largest contributor is rainfall (road slippery), accounting for 33% of the total. The highway blocking caused by snowfall (snow cover) and icing also accounts for 17% and 2%, respectively. In addition, there are hail, gale, snowdrift (Wind blowing snow), typhoon, high temperature, dust and other weather factors.

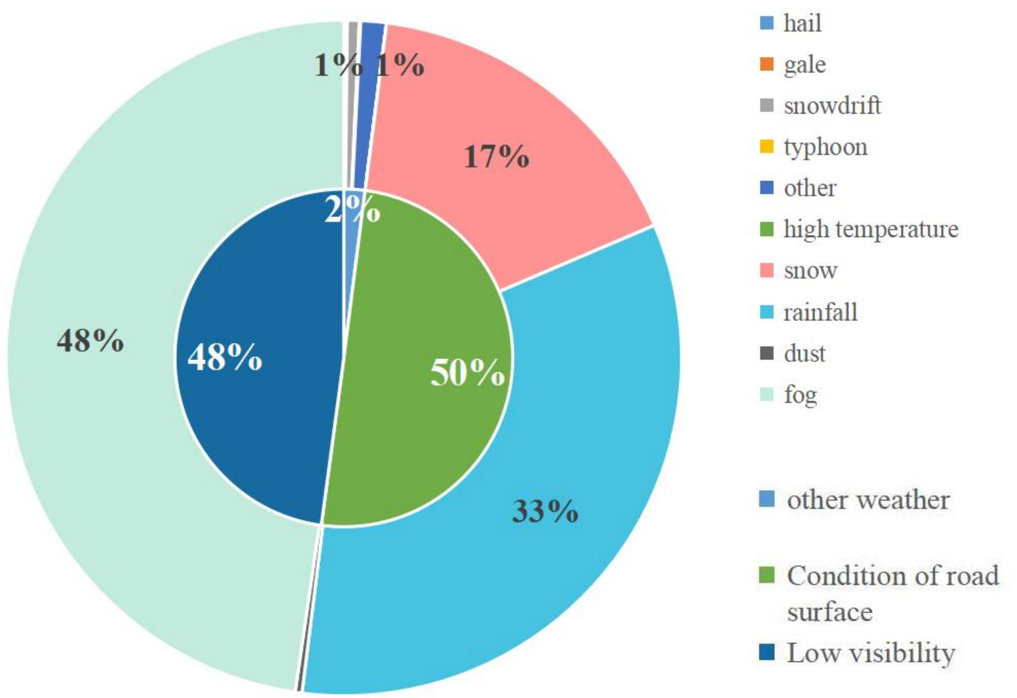

Figure 2 main weather factors affecting highway blocking in China

The main factors affecting highway blocking (Fig. 3a and Table 1) vary among provinces. In several provinces of Northeast China, Northwest China and the Qinghai-Tibet region, the main weather factors affecting highway blocking are snowfall and icing, followed by dense fog. In several provinces of North China, East China and Central China, the main weather factor is dense fog, followed by snowfall or rainfall. The main weather factor in several provinces of South China is rainfall, followed by dense fog. The main weather factors in Yunnan and Guizhou Provinces of Southwest China are icing and snowfall, while it is dense fog and rainfall in Sichuan Province.

Although the main weather factors affecting highway blocking differ in different provinces of China (Fig. 3b and Table 1), the provinces with a higher frequency of highway blocking are Sichuan Province, Henan Province, Hebei Province, Shanxi Province, Hunan Province, Jiangsu Province and Chongqing Municipality. The rainfall in Sichuan, Chongqing and Shanxi

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causes more blocking than dense fog. However, the blocking caused by dense fog is more than that caused by rainfall in Henan, Hebei, Hunan and Jiangsu Provinces. The blocking events due to both dense fog and rainfall are much more in Sichuan Province than in other provinces.

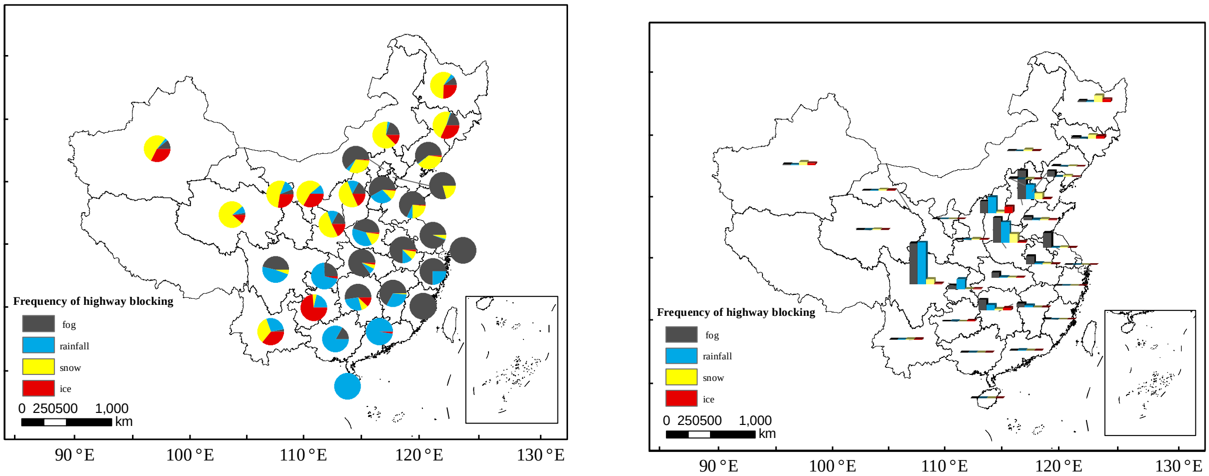

Figure 3 High impact weather types leading to highway blocking in different provinces of China (a: proportion, b: number)

3.2 Spatio-temporal distribution features of highway blocking

There are large seasonal differences in highway blocking in various regions of China due to differences in geographical environment and climatic characteristics (Fig. 4a), and high-impact weather types (Fig. 4b), such as dense fog, snowfall (snow cover), rainfall (road slippery) and icing, are also various. As shown in Fig. 4, the highway-blocking events are the most in Southwest China, reaching 8692 (29.6% of the total blocking events in China), followed by North China (8331). In Central China, the highway-blocking events also reach 7347.

The highway blocking in Southwest China is concentrated in summer and winter, with 3891 events (46.0%) and 3196 events (37.8%), respectively. The highway-blocking events in spring and autumn account for just 16.2%. The blocking events in Southwest China are mainly caused by rainfall (50.0%) and dense fog (42.5%), while those caused by snowfall and icing are much less, accounting for no more than 8% of the total.

In North China, the highway-blocking events are also concentrated in summer and winter, with 2526 events (44.4%) and 2058 events (25.1%), respectively. The proportions of highway-blocking events in spring and autumn are 16.0% and 14.4%, respectively. The highway-blocking events in North China are mostly caused by dense fog (3760 events, 45.1%), followed by rainfall (2536 events, 30.4%). In addition, snowfall causes more blocking events in North China (1,833 events, 22.0%) than in Southwest China. Like North China, the highway-blocking events caused by dense fog and rainfall in Central China are the most frequent, i.e., 3757 events (51.1%) and 2366 events (32.2%), respectively.

There are 2283 highway-blocking events in East China, mainly concentrated in winter (43.5%) and spring (37.7%). Among them, 85.5% of blocking events are caused by dense fog, which is the highest proportion for all types resulting in blocking events in a single major region.

A total of 1828 highway-blocking events occur in Northeast China, evenly distributed in spring, autumn and winter, with a proportion of about 30% in these three seasons. Only 1268 blocking events occur in Northwest China, mainly in winter (nearly 50%). The highway-blocking events caused by snowfall account for nearly 50% in Northeast and Northwest China, followed by the events caused by icing. The difference is that there are more dense fog-caused blocking events in Northeast China than those in Northwest China.

The highway-blocking events in the Qinghai-Tibet region and South China are just 159. Among them, there are only 88 events in South China, most of which are concentrated in summer. However, the highway-blocking events in the Qinghai-Tibet region are concentrated in autumn and winter. The blocking events are mainly caused by snowfall in the Qinghai-Tibet region but rainfall in South China.

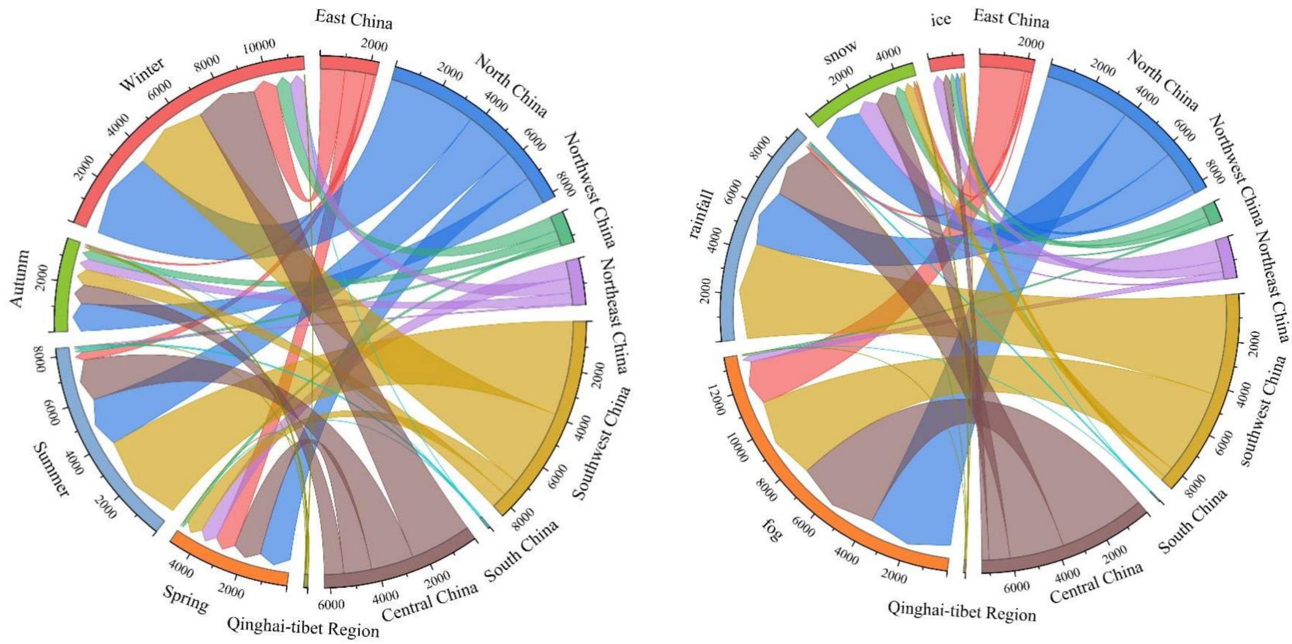

Figure 4 Seasonal characteristics (a) and the main high impact weather (b) affecting the highway blocking in different areas of China

From the ten-day distribution of highway-blocking events in different provinces of China (Fig. 5), it can be found that the regions where highway blocking occurs throughout the year are Chongqing and Sichuan of Southwest China and Henan, Hebei and Shanxi of North China. The peak of highway-blocking events differs in different provinces. The blocking events in Chongqing and Sichuan peak in late July, while those in the other provinces peak in November–December. The highway-blocking events in most provinces of China decrease noticeably from late August to early September. In Henan and Hebei

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Provinces, there are window periods in late March and middle to late September, which are two transition periods between winter and spring and between summer and autumn, with markedly reduced blocking events. In Sichuan and Chongqing, the window periods for blocking events are in late February and early March, especially in early March.

The diurnal variation of highway-blocking events in different provinces of China (Fig. 5b) suggests that they mostly occur from 17:00 BJT to 08:00 BJT in the following day, and fewer events appear at other time. Highway-blocking events appeared throughout the day in Chongqing, Xinjiang, Sichuan, Shanxi, Heilongjiang, Henan and Hebei, which is basically consistent with the ten-day variation result.

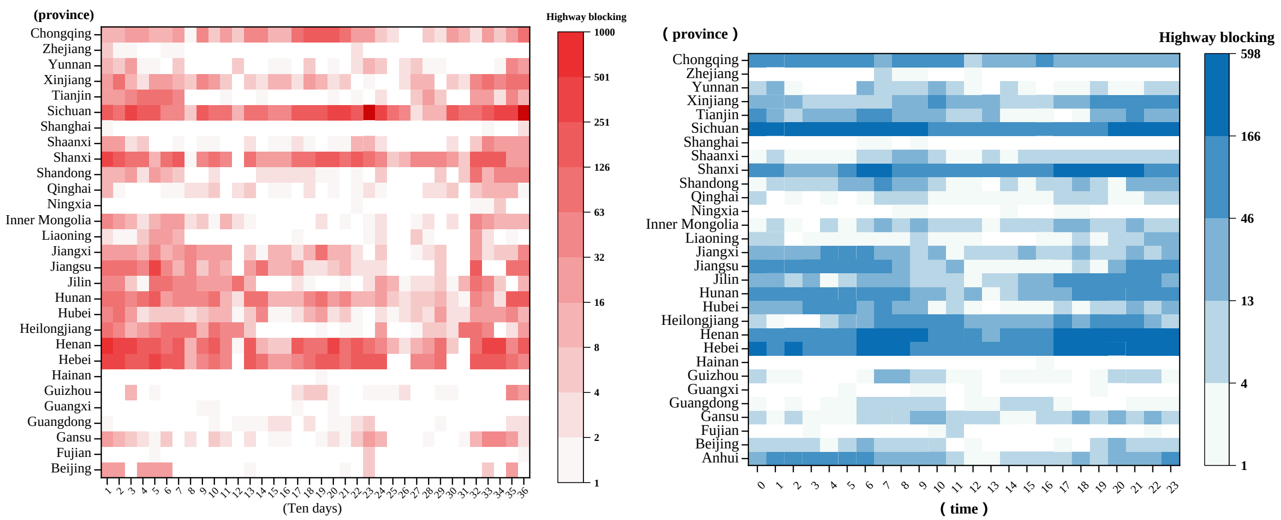

Figure 5. The changing characteristics of highway blocking every ten days (a) and Diurnal variation (b)

3.3 Highway blocking levels

To investigate the severity of highway blocking, we select the blocking mileage (the distance of the highways blocking), blocking time and response time as the most crucial reference indicators. This study only considers the evaluation of road traffic by the blockage itself, and does not consider the basic resources of the road network and the impact of secondary disasters. If the road network resources are large, then the blocking may have little impact on the local road network, which is not considered in the blocking degree.

Firstly, the blocking mileage is used as the initial judgment condition of severity. Then, the blocking events caused by different meteorological factors are clustered. Finally, the severity of the blocking events is determined according to the size of the clustering centers.

Data normalization is performed for all severity levels of highway blocking due to meteorological factors. Then, the severity levels are judged according to the location and size of the cluster centers of the clustered mileage. The severity (S) of highway-blocking events is expressed as the equation:

$$S = L \times T \quad (7),$$

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where L indicates the blocking mileage (km), and T denotes the blocking time (h). The severity of highway blocking is classified into five levels for clustering. The higher the level is, the more serious the blocking is. Furthermore, all highway-blocking events are classified according to the five clustering centers, and the distribution of the five levels of highway-blocking events is obtained (Table 2).

Table 3 shows the distribution of highway-blocking levels for the eight main regions in spring and summer. The regions with a severe level (level 4) and above in spring are mainly in Northeast China and North China, and the main high-impact weather for highway blocking is snowfall, fog, rainfall and icing in these areas. The blocking events with a moderate level can be found in most parts of China in spring, highly affected by snowfall, icing, dense fog and rainfall. The only blocking factors of dust and snowdrift appear in spring in Northwest China, while the blocking events in the Qinghai-Tibet region are caused by snowfall only. The levels in six regions of North China, Central China, South China, East China, Northwest and Southwest China all reach the severe level (level 4) in summer, and the main high-impact weather is rainfall. The moderate-level blocking events appear in most parts of China, mainly caused by rainfall and dense fog. In addition, there are blocking events caused by dust in Northwest China.

The distribution of highway-blocking levels in the eight major regions in autumn and winter (Table 4) indicates that the regions with blocking events at the severe level (level 4) and above in autumn are mainly in Northeast China, North China, Central China, Northwest China and the Qinghai-Tibet region, and these events are mainly influenced by snowfall, rainfall, fog and icing. The blocking events at the moderate level can be found in most parts of China and are also mainly caused by snowfall, rainfall, fog and icing. The most blocking events occur in winter. In this period, six regions of Northeast China, North China, Central China, South China, East China, Northwest China and Southwest China have the blocking events reaching the severe level (level 4), and the main high-impact weather is snowfall. The blocking events with a moderate level occur in most parts of China, mainly caused by dense fog, icing, snowfall and snowdrift. No blocking event occurs in South China throughout the winter. In contrast, the icing-caused blocking events increase in Northeast China and Central China. The snowdrift-caused blocking events and increased icing-caused blocking events can be observed in Northwest China. Compared with East China, no dense fog-caused blocking event appears in Northwest China.

Figure 6 presents the relationship between highway blocking levels and high-impact weather in China. Highway-blocking events are the highest frequency in Southwest China, and most of them are at slight (level 1) levels, of which 87.6% are at level 1. The blocking events with slight (level 1) and normal (level 2) levels are relatively fewer in Northern and Central China; the blocking events at level 1 account for only 64.1% in North China and 62.6% in Central China. The percentages of blocking events at level 1 in Northwest and Northeast China are less than 50%.

The highway-blocking events at level 1 are the most, 50.3% of which are caused by dense fog. The percentages of blocking events caused by rainfall (road slippery) and snowfall (snow cover) reach 34.7% and 11.4%, respectively. Less than 5% of the blocking events at level 1 are caused by icing. In terms of the blocking events at lower levels (levels 1–3), the percentage of dense fog-caused blocking events increases with the severity level of blocking. For the blocking events at higher levels (levels

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4–5), the proportion of blocking events caused by rainfall (road slippery) and snowfall (snow cover) is higher, especially at the highest level (level 5, exceeding 80%).

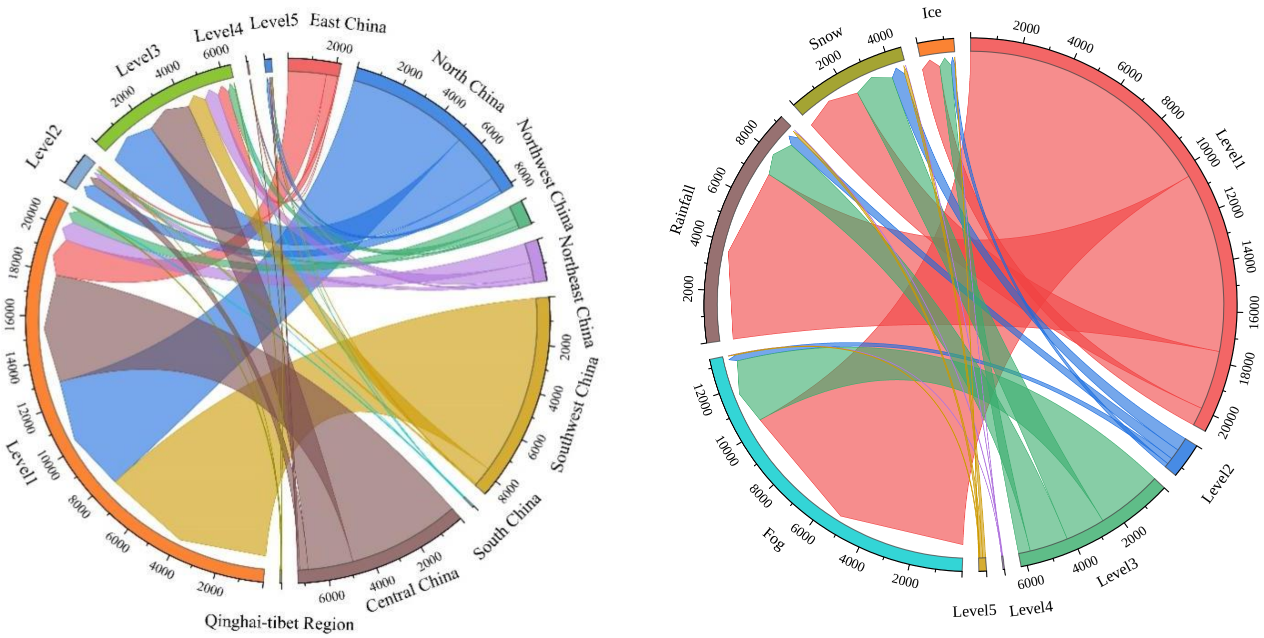

Figure 6. The level of highway blocking (a) and relationship with high impact weather (b)

3.4 Losses due to highway blocking

In this study, the economic indicators, H_d, ΔTF_{load}, GDP_{trans}, ΔP_{load}, VD and EP, are selected from the statistical data issued by the National Bureau of Statistics as the basic reference. Then, the economic volume per kilometer of ΔTF_{load}, GDP_{trans}, ΔP_{load} and EP in different provinces of China is calculated by combining the highway mileages of different provinces (Table 5). Next, the data normalization is performed for the selected economic indicator data. Furthermore, the CRITIC weigh method is used to assign weights for each normalized data, as shown in Table 6. The highway load in China calculated using Eq. (6) as below (Eq. (8)):

$$HW_{load} = H_d * 0.115 + \Delta TF_{load} * 0.1123 + GDP_{trans} * 0.1002 + \Delta P_{load} * 0.1174 + VD * 0.1079 + EP * 0.0984 + TF_{load} * 0.1267 + P_{load} * 0.1190 + V_{private} * 0.1033 \quad (8),$$

The highway load of each province in China (Fig. 7) indicates that it shows an overall decreasing trend from the eastern coast to the inland. The high load is concentrated in Jiangsu, Shandong and Guangdong Provinces, and the highway load in Jiangsu Province is the highest in China. In the inland provinces, Sichuan Province has a higher highway load than its neighboring provinces due to its unique geographical location and economic development level in Southwest China. The overall highway load in Hainan Province is lower because of it is an island. Fujian Province has the lowest highway load among the coastal provinces.

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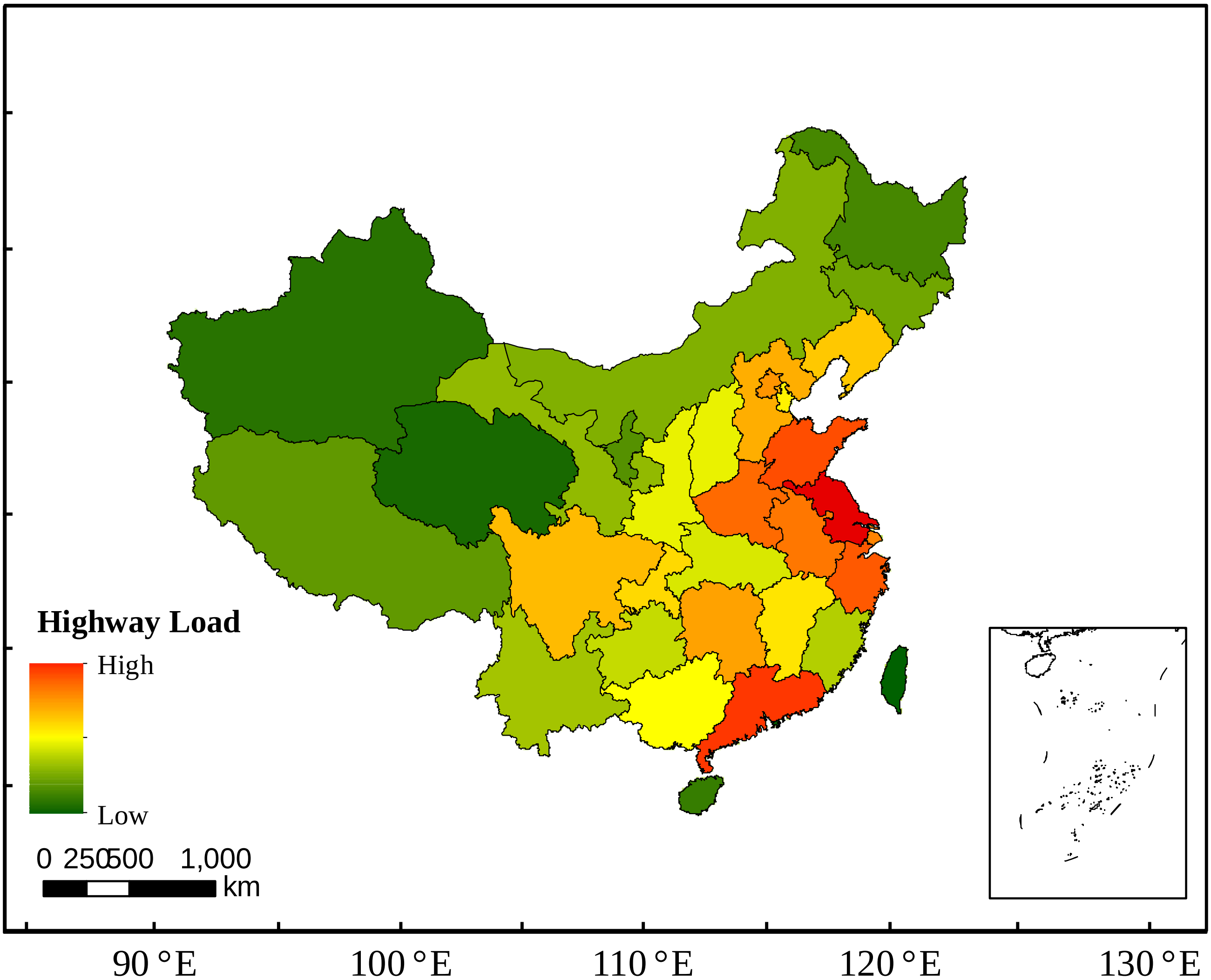

295 **Figure 7 the Highway Load in China**

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Through the above analysis, we can find that the highway blocking caused by high-impact weather is related to the weather and climate conditions in different regions, and has regional and seasonal characteristics. However, as the differences of the economic indicators, H_d, ΔTF_{load}, GDP_{trans}, ΔP_{load}, VD and EP, there are great difference for the highway load in difference
300 area. When a highway-blocking event occurs, the higher the load is, the greater the losses and impacts are.

The definition of highway load proposed in sec 2.3.3 can provide a better assessment condition for understanding the highway losses due to high-impact weather in each province. Fog is the main weather factor which causes highway blocking in China.

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In the following, the impact caused by dense fog is assessed based on the load conditions of different provinces. The highway losses caused by each blocking event are calculated to obtain the TF_{load}, GDP_{trans}, P_{load} and EP in different provinces of China. Figure 8 shows the highway losses caused by dense fog. From the figures we can see that the highway losses caused by dense fog are mainly concentrated in North China, East China and Sichuan Province (especially in Jiangsu, Sichuan, Hebei and Henan Provinces), followed by Central China and Northeast China. However, the losses are remarkably low in Northwest China, South China and the Qinghai-Tibet region. No highway-blocking events caused by dense fog occur in Guangdong Province, Hainan Province, Guizhou Province and Tibet Autonomous Region throughout the year.

Dense fog can cause highway blocking, making highway traffic delayed or affected. As shown in Table 7, due to dense fog, there are more than 1 million passengers delayed or affected in Hebei, Jiangsu, Anhui, Henan, Hunan and Sichuan Provinces and Tianjin Municipality. Three provinces, namely Jiangsu, Henan and Sichuan, are the most serious, with about 6.67 million, 6.39 million and 4.55 million passengers affected by dense fog weather in highway traffic.

The provinces with more serious delays in freight transportation caused by dense fog are Hebei, Henan, Jiangsu, Sichuan and Anhui, and the delays in freight transportation are more than 10 million tons. Freight transportation in three provinces, namely Hebei, Henan and Jiangsu, is affected the most, with 33.8 million, 26.7 million and 17.2 million tons, respectively. The express business in China is more developed, and most express packages are transported through highways. Therefore, the delays of express packages due to dense fog are also serious. More than ten million packages in Jiangsu Province, Hebei Province, Henan Province, Sichuan Province, Anhui Province and Tianjin City are delayed due to dense fog (Table 7), especially in Jiangsu (68.8 million packages), Hebei (59.0 million packages) and Henan (42.8 million packages). This result is basically consistent with the situation of freight transportation.

GDP_{trans} is also affected by dense fog. There are 14 provinces with GDP_{trans} losses of 100 million yuan or more (Table 7), especially in Hebei (4.43 billion yuan), Henan (3.93 billion yuan), Jiangsu (3.14 billion yuan), Sichuan (1.52 billion yuan) and Tianjin (1.37 billion yuan).

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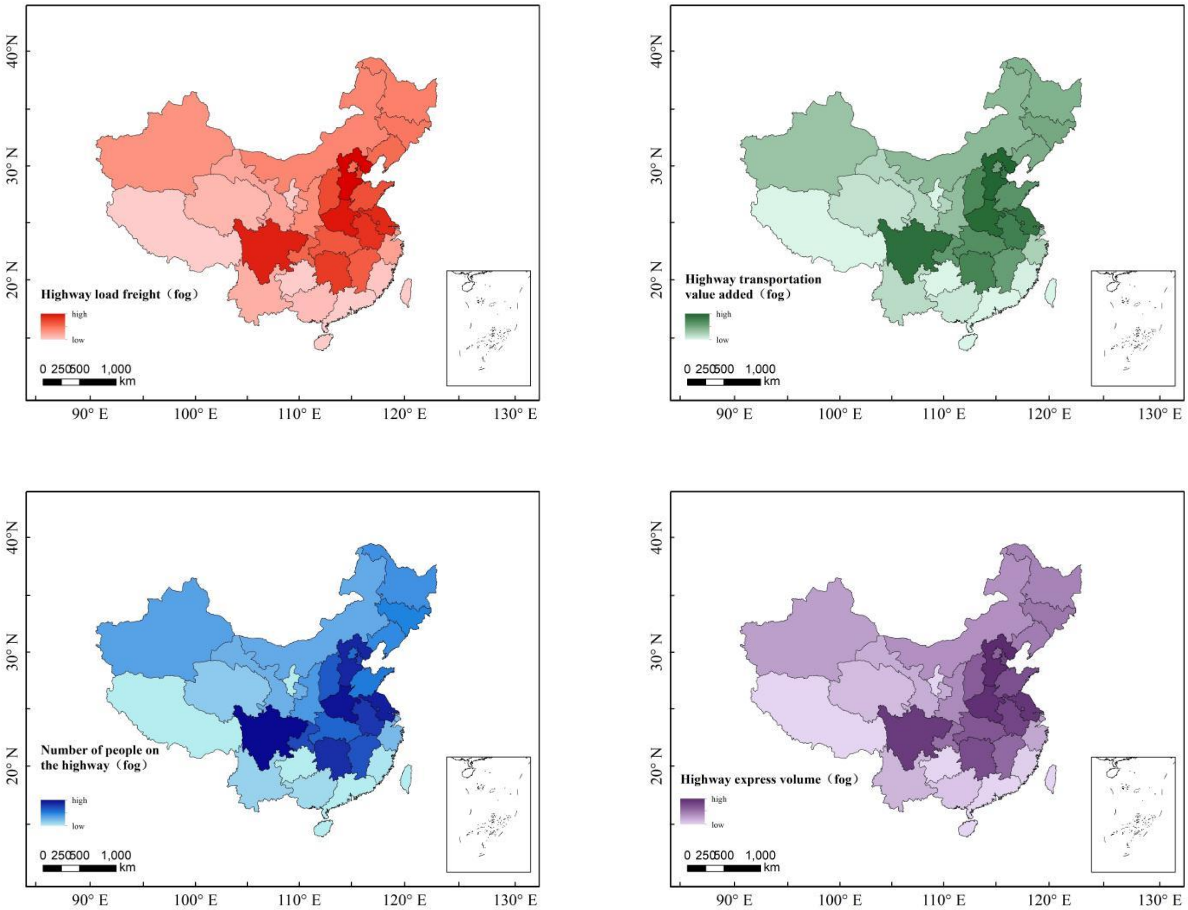

Figure 8. Damage caused by highway blocking due to fog (a: Delay or cancellation of freight transport; b: Transportation related GDP loss; c: Delay or impact on travel people; d: Delay or delay related express package)

5. Conclusions

Based on the K-means cluster analysis and the CRITIC weight assignment method, we analyzed the highway blocking and the highway load features for each province based on economic losses. The high impact weather events considered as fog, rainfall, snowfall (snow cover), icing, hail, gale, snowdrift (Wind blowing snow), typhoon, high temperature, dust etc.

The overall seasonal distribution of highway-blocking events in China displays a pattern of more in winter and summer and less in spring and autumn. The highway-blocking events are characterized by diurnal variation, i.e., most of the blocking events appears from 17:00 BJT to 08:00 BJT in the following day, and fewer occur at the other time.

Through cluster analysis, a classification method of severity levels of highway blocking is developed to classify the severity into five levels. The severity levels of highway blocking due to high-impact weather are evaluated for different types in different seasons. By using the CRITIC weigh method and combining economic indicators and transportation data in China, a

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method for calculating the degree of highway load in China is proposed, and the highway load in each province of China is evaluated. When a highway-blocking event occurs, the higher the load is, the greater the losses and impacts are. The highway load shows a decreasing trend from the eastern coast to the inland. Specifically, the high load is mainly concentrated in three provinces of Jiangsu, Shandong and Guangdong, with the highest in Jiangsu Province.

In this research, the economic losses resulting from highway-blocking events caused by dense fog is also considered. The results indicate that the highway losses caused by dense fog are mainly concentrated in Northern China, Eastern China and Southwestern China. Hebei, Henan, Jiangsu, Sichuan, and Tianjin suffer the most GDP_{trans} losses at 4.43 billion (due to fog), 3.93 billion (due to fog), 3.14 billion (due to fog), 1.52 billion (due to fog) and 1.37 billion (due to fog) yuan, respectively.

The highway-blocking data used in this study is only for the year 2020 as a test year, and additional time series of observations are needed to validate the results. The assessment of losses is only judged by the degree of highway load. However, natural disasters bring not only direct losses, but also indirect losses that may be even more serious. In the subsequent work, economic models can be employed to judge the indirect economic losses to continue refining the research.

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Tables

Table 1 the main weather factors affecting highway blocking in different provinces, China

***,**, no data.**

area	province	High impact weather types				
		Fog	**Rainfall**	**Snow**	**Ice**	total
North China	Beijing	90	6	46	2	144
	Hebei	2376	1184	479	43	4082
	Shanxi	534	1313	957	125	2929
	Inner Mongolia	45	7	147	27	226
	Shandong	228	23	79	4	334
	Tianjin	487	3	125	1	616
Northeast China	Heilongjiang	103	46	571	244	964
	Jilin	126	10	321	214	671
	Liaoning	59	1	36	2	98
Northwest China	Shaanxi	35	28	105	37	205
	Gasnsu	12	25	104	53	194
	Ningxia	0	1	5	3	9
	Xinjiang	51	14	245	149	459
Qinghai-Tibet Region of China	Qinghai	2	7	65	9	83
	Tibet*	0	0	0	0	0
East China	Shanghai	5	0	0	0	5
	Jiangsu	1238	19	64	10	1331
	Anhui	703	119	98	19	939
	Zhejiang	6	2	0	0	8
Central China	Hubei	409	34	25	11	479
	Jiangxi	352	166	6	5	529
	Hunan	905	464	144	212	1725
	Henan	2091	1702	738	83	4614
South China	Guangdong	0	45	0	1	46
	Guangxi	1	5	0	0	6
	Fujian	1	0	0	0	1
	Taiwan**	0	0	0	0	0
	Hainan	0	1	0	0	1
Southwest China	Chongqing	296	834	2	36	1168
	Sichuan	3393	3450	404	35	7282
	Guizhou	0	22	5	75	102
	Yunnan	4	38	48	50	140

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Table 2 clustering center of the highway blocking in China

	Level	type	clustering center(km*h)
1	slight	A	143.37
2	general	C	870.41
3	moderate	B	2019.75
4	serious	E	3933.28
5	emerge	D	6610.59

Table 3 The main weather factors affecting highway blocking and the levels in Spring and Summer in China

	area	level1	level2	level3	level4	level5
Spring	Northeast China	snow, icing, fog	snow, icing	snow, icing, fog	snow, fog	snow, icing
	North China	fog, rainfall, snow	rainfall, fog, snow	rainfall, fog, snow	snow	rainfall, snow
	Central China	fog, rainfall	rainfall	rainfall, fog	/	rainfall
	South China	rainfall	/	rainfall	/	/
	East China	fog	/	fog	/	/
	Southwest China	rainfall, fog	snow	snow, fog	/	/
	Northwest China	dust, snow	dust, snow	dust, snowdrift, snow	/	/
	Qinghai-Tibet Region of China	snow	/	snow	/	/
Summer	Northeast China	rainfall, fog	/	fog, rainfall	/	/
	North China	rainfall, fog	rainfall, fog	rainfall, fog	rainfall	rainfall, fog
	Central China	rainfall, fog	rainfall	rainfall, fog	rainfall	rainfall
	South China	rainfall	rainfall	rainfall	rainfall	rainfall
	East China	fog, rainfall	rainfall	rainfall, fog	rainfall	rainfall
	Southwest China	rainfall, fog	rainfall	rainfall	rainfall	rainfall
	Northwest China	dust, rainfall	dust	dust, rainfall	rainfall	rainfall
	Qinghai-Tibet Region of China	rainfall	/	rainfall	/	/

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Table 4 The main weather factors affecting highway blocking and the levels in Autumn and Winter in China

	area	level1	level2	level3	level4	level5
Autumn	Northeast China	snow, icing, fog	icing, snow	icing, snow, fog	/	snow, icing
	North China	fog, rainfall, snow	snow, rainfall, fog	fog, rainfall, snow	snow	snow, fog, rainfall
	Central China	fog, rainfall, snow	rainfall	rainfall, fog, snow	rainfall	rainfall
	South China	typhoon, rainfall	/	/	/	/
	East China	fog	/	fog	/	/
	Southwest China	fog, rainfall	/	rainfall, fog	/	/
	Northwest China	icing, snow, fog	snow	snow, fog	/	snow
	Qinghai-Tibet Region of China	snow	snow	/	/	/
Winter	Northeast China	snow, fog, icing	snow, icing	snow, icing, fog	/	snow
	North China	fog, snow	snow, fog	fog, snow	snow	snow, fog
	Central China	fog, snow, icing	snow, fog, icing	fog, snow, icing	/	snow
	South China	/	/	/	/	/
	East China	fog, snow	snow, fog	fog, snow	/	/
	Southwest China	fog, snow	snow, icing	fog, snow	/	/
	Northwest China	snow, icing, fog	snow, snowdrift, icing	snow, icing, snowdrift	/	snow, icing
	Qinghai-Tibet Region of China	snow	/	snow, icing	/	snow, icing

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Table 5 Highway length, freight transport for per km, GDP generated by transportation, people for per Km, express package for per Km.

	Length	ΔTF_{load}	GDP_{trans}	ΔP_{load}	EP
	km	10,000-ton/km	100 million yuan/km	10thousand/km	10,000 pieces/km
Beijing	1200	18.16	0.70	20.46	198.52
Tianjin	1300	24.82	0.62	6.10	71.36
Hebei	7800	27.17	0.36	1.36	47.47
Shanxi	5700	17.23	0.18	1.31	9.40
Inner Mongolia	7000	15.57	0.16	0.46	2.79
Liaoning	4300	32.23	0.28	6.10	26.04
jilin	4300	8.90	0.14	2.66	10.39
Heilongjiang	4500	7.89	0.11	1.69	10.12
Shanghai	800	57.56	1.94	1.67	420.41
Jiangsu	4900	35.64	0.65	13.81	142.38
Zhejiang	5100	37.17	0.38	7.62	351.89
Anhui	4900	49.70	0.38	4.65	44.94
Fujian	5600	16.27	0.27	2.66	61.28
Jiangxi	6200	22.89	0.17	5.43	18.07
Shandong	7500	35.63	0.46	2.60	55.36
Henan	7100	27.27	0.40	6.52	43.66
Hubei	7200	15.88	0.24	3.02	24.79
Hunan	7000	25.21	0.21	6.31	21.02
Guangdong	10500	22.02	0.32	5.23	210.30
Guangxi	6800	21.37	0.13	3.94	11.45
Hainan	1300	5.27	0.20	3.51	8.47
Taiwan*	0	0	0	0	0
Chongqing	3400	29.32	0.28	9.25	21.50
Sichuan	8100	19.46	0.17	5.59	26.56
Guizhou	7600	10.45	0.09	4.42	3.70
Yunnan	8400	13.76	0.12	2.29	7.50
Tibet**	100	40.39	0.44	5.76	11.39
Shaanxi	6200	18.72	0.18	4.77	14.80
Gansu	5100	12.01	0.08	4.41	2.71
Qinghai	3500	3.10	0.03	0.95	0.67
Ningxia	1900	18.01	0.10	1.53	3.85
Xinjiang	5600	7.20	0.11	0.88	2.05

*,**, no data.

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Table 6 Weight analysis of different economic indicators

items	Indicators variability	Indicators conflict	Information content	average	Standard deviation	weight
MMS_highway density (km/km2)	0.22	5.403	1.19	0.295	0.220	11.50%
MMS_the volume of freight transport per km (10,000-ton/km)	0.235	4.948	1.162	0.356	0.235	11.23%
MMS_GDP_{trans} (100 million yuan/)	0.278	3.734	1.037	0.368	0.278	10.02%
MMS_P_{load} per km (10thousand /km)	0.203	5.984	1.215	0.214	0.203	11.74%
MMS_vehicle density(10thousand /km)	0.201	5.56	1.117	0.134	0.201	10.79%
MMS_package volume (100 million)	0.223	4.57	1.018	0.121	0.223	9.84%
MMS_ the volume of freight transport (10,000-ton)	0.286	4.587	1.311	0.405	0.286	12.67%
MMS_thevolumeof road passenger (10thousand)	0.258	4.765	1.231	0.323	0.258	11.90%
MMS_civilian car ownership (10thousand)	0.268	3.993	1.069	0.331	0.268	10.33%

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465 **Table 7 Personnel travel delay, freight delay, GDP generated by transportation, express delivery volume in fog weather**

Province	P_{load}	TF_{load}	GDP_{trans}	EP
	person	tonne	Ten thousand	piece
Beijing	8.76×10^5	7.78×10^5	3.01×10^4	8.50×10^6
Tianjin	1.49×10^6	6.07×10^6	1.52×10^5	1.75×10^7
Hebei	1.68×10^6	3.38×10^7	4.43×10^5	5.90×10^7
Shanxi	3.14×10^5	4.14×10^6	4.42×10^4	2.26×10^6
Inner Mongolia	1.52×10^4	5.15×10^5	5.40×10^3	9.25×10^4
Liaoning	2.38×10^5	1.26×10^6	1.10×10^4	1.02×10^6
jilin	1.56×10^5	5.21×10^5	7.93×10^3	6.09×10^5
Heilongjiang	1.03×10^5	4.82×10^5	6.75×10^3	6.18×10^5
Shanghai	2.41×10^3	8.33×10^4	2.80×10^3	6.08×10^5
Jiangsu	6.67×10^6	1.72×10^7	3.14×10^5	6.88×10^7
Zhejiang	5.11×10^3	2.49×10^4	2.52×10^2	2.36×10^5
Anhui	1.16×10^6	1.24×10^7	9.39×10^4	1.12×10^7
Fujian	7.67×10^0	4.70×10^1	7.74×10^{-1}	1.77×10^2
Jiangxi	4.71×10^5	1.99×10^6	1.45×10^4	1.57×10^6
Shandong	2.82×10^5	3.88×10^6	5.05×10^4	6.02×10^6
Henan	6.39×10^6	2.67×10^7	3.93×10^5	4.28×10^7
Hubei	3.70×10^5	1.94×10^6	2.95×10^4	3.04×10^6
Hunan	1.75×10^6	7.00×10^6	5.90×10^4	5.84×10^6
Guangdong	0	0	0	0
Guangxi	8.05×10^2	4.37×10^3	2.67×10^1	2.34×10^3
Hainan	0	0	0	0
Taiwan*	0	0	0	0
Chongqing	6.46×10^5	2.05×10^6	1.94×10^4	1.50×10^6
Sichuan	4.55×10^6	1.59×10^7	1.37×10^5	2.16×10^7
Guizhou	0	0	0	0
Yunnan	1.13×10^3	6.78×10^3	6.16×10^1	3.69×10^3
Tibet**	0	0	0	0
Shaanxi	1.18×10^5	4.62×10^5	4.49×10^3	3.65×10^5
Gansu	6.71×10^3	1.83×10^4	1.22×10^2	4.12×10^3
Qinghai	5.56×10^3	1.82×10^4	1.96×10^2	3.96×10^3
Ningxia	0	0	0	0
Xinjiang	1.98×10^4	1.61×10^5	2.39×10^3	4.60×10^4

*,**, no data.