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Analysis of the Impacts of Students Back to School on the Volatility and Reliability of Travel Speed on Urban Road

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Abstract: How to effectively and accurately evaluate and analyze the volatility and reliability of travel speed on urban road before and after students back to school is a hot and key problem in urban road traffic congestion governance research. The Beijing 3rd Ring Road was taken as the research object and the impacts of the students back to school on the volatility and reliability of the travel speed of road sections were qualitatively and quantitatively analyzed based on the road section travel speed data during the weekday morning peak (7:00–8:59). The results showed that the travel speed of the Beijing 3rd Ring Road had cyclicity, time variability, large-scale volatility, and light congestion during the weekday morning peak, and the volatility and reliability indexes of the travel speed of road sections significantly decreased under the impact of the students back to school. The data showed that after the students back to school, the maximum reduction ratio of average travel speed was larger than 55%, and the maximum travel speed reliability reduction value was larger than 0.85 based on the evaluation model of travel speed reliability of car commuters. The research results provide data and theoretical support for urban road traffic congestion mitigation and governance.

Keywords: urban road traffic; travel speed volatility; travel speed reliability; commuting traffic; traffic congestion

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1. Introduction

Students back to school in September exacerbates the severity of traffic congestion on urban road during the weekday morning peak [1,2]. Urban road traffic congestion typically occurs on urban commuter traffic arterials in the morning and evening peaks on the weekdays [2], and urban road traffic congestion is deterministic in the weekday morning peak [3] due to the need for commuters' on-time arrival. Urban road traffic congestion has become a worldwide problem [4,5], and China's "*Outline for the Country with Strong Transportation Network*" proposed that "urban traffic congestion will be basically relieved" by 2035 [6]. Thus, how to analyze and improve urban road traffic congestion has become a hot topic of social concern [4]. Travel speed is one of the important indicators for evaluating the degree of traffic congestion on urban road. Effectively and accurately evaluating and analyzing the volatility and reliability of travel speed on urban road before and after students back to school has important application value for the evaluation, analysis, mitigation, and governance of urban road traffic congestion.

The rigid commuter travel demands of students getting to school on time and teachers and other school staff getting to work on time increase during the weekday morning peak (see Figure 1), resulting in a greater impact on the volatility and reliability of travel speed on urban road. Survey data showed that the proportion of car commuter travel for primary school students, middle school students, and high school students was larger than 28%, larger than 25%, and larger than 19%, respectively, during the weekday morning peak in Beijing, and the proportion of car commuter travel during school hours was larger than that after school hours [7–13]. As the proportion of parents driving children to primary and secondary schools continues to increase [14–16], the travel and parking demands of car commuter travel on roads around schools have dramatically increased, causing traffic congestion and disorder in roads in front of schools during the weekday morning peak [1,7]. When a road section's travel speed is lower than a certain threshold, it can be considered that the road section is in a congested state [17–22]. Related studies constructed a speed performance index to evaluate and analyze the traffic status of the Beijing urban expressway roads based on actual data [20,21]. It is necessary to evaluate and analyze the volatility and reliability of the travel speed on urban road after students back to school in September to provide data support for urban road traffic congestion governance.

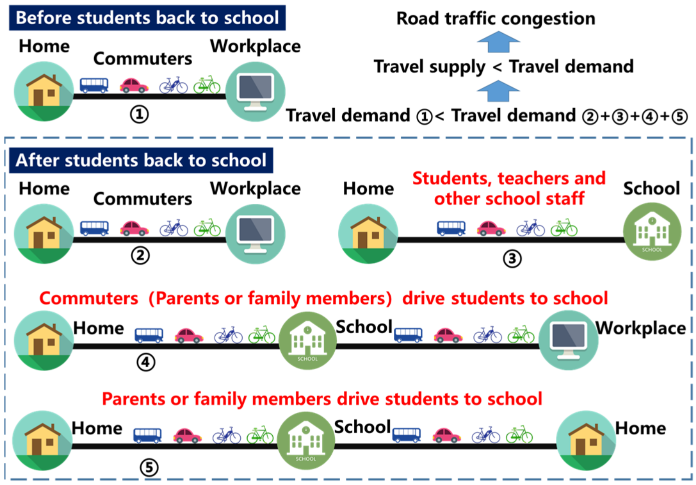


Figure 1. Travel demands before and after students back to school.

On-time arrival is one of the most basic needs of commuters and students [23]. Can the travel speed of road sections guarantee on-time arrival rates for commuters and students? Li et al. constructed a travel speed reliability model based on the traffic congestion tolerance of car commuters from the perspective of on-time arrival of car commuters and analyzed the travel speed volatility and reliability of car commuters based on the actual road section travel speed data in Beijing [23]. Different studies have taken different values for travel speed reliability evaluation model thresholds. Relevant studies constructed a travel speed reliability model (road service level reliability [24]) and analyzed the travel speed reliability of the expressway based on the actual data in Beijing [24,25]. Indicators such as volatility (average, standard deviation, etc.) and reliability (arrival punctuality and road service level reliability) of travel speed on urban road are important evaluation indicators of traffic congestion, service level, and service quality on urban road. Research results on the volatility and reliability of travel speed on urban road are important references for urban road traffic congestion governance.

Existing studies have mainly analyzed the volatility and reliability of travel speed on urban road and urban road traffic congestion, and studies on back-to-school traffic have mainly focused on the proportion of car commuter travel and the current situation of traffic congestion on roads in front of schools, whereas relatively few studies have been conducted on the volatility and reliability of travel speed on urban road before and after students back to school. How to quantitatively evaluate and analyze the impact of students back to school on the volatility and reliability of travel speed on urban road is the focus of this study. The paper analyzes the volatility and reliability of travel speed on urban road before and after students back to school from a "problem-oriented, demand-driven" perspective. The paper constructs evaluation models of the volatility and reliability of travel speed and qualitatively and quantitatively analyzes the volatility and reliability of travel speed of road sections of the Beijing 3rd Ring Road main road (a typical commuting traffic ring expressway) before and after students back to school based on road section speed data from 7:00 to 8:59 on weekdays in August–September 2016.

2. Data Processing

2.1. Data Introduction

The Beijing 3rd Ring Road is a main commuting traffic ring expressway in the urban area of Beijing that crosses the Haidian District, Xicheng District, Chaoyang District, and Fengtai District, the road length is 48 km, the main road has three lanes, the design speed is 80 km/h, and the main road speed limit is 80 km/h. The Beijing 3rd Ring Road main road includes the Inner Ring (14 sections) and the Outer Ring (14 sections), as shown in Figure 2 and Appendix A. There are about 50 overpasses, more than 130 entrances and exits, and a very large number of schools (around the roads) in the Beijing 3rd Ring Road. There is a major impact on road traffic on the Beijing 3rd Ring Road after students back to school in September.

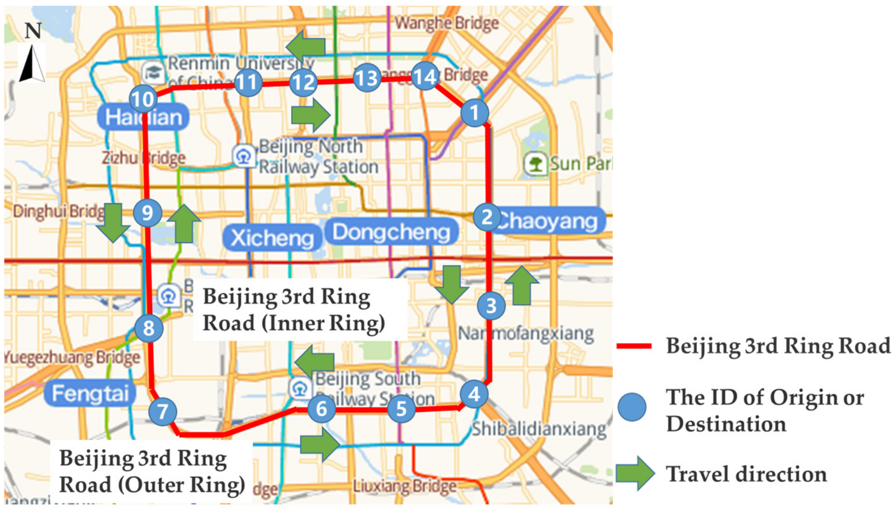


Figure 2. Beijing 3rd Ring Road location information.

The data for the paper are the already-processed road section travel speed data provided by the Beijing Municipal Commission of Transportation. The road section travel speed data of the Beijing 3rd Ring Road main road are from August to September 2016, including information on the road name, origin and destination of the road section, collection time, travel speed, road section length, etc. This paper mainly analyzed the volatility and reliability of travel speed of the road sections of the Beijing 3rd Ring Road main road for the morning peak (7:00–8:59) on 33 sunny weekdays (17 days in August, 16 days in September) based on 105,902 records (53,125 records from the Inner Ring, 52,777 records from the Outer Ring) of the road section travel speed data.

2.2. Data Filtering and Processing

There are duplicate values, missing values, and error values in the road section travel speed data, so we needed to filter and process the road section travel speed data according to the actual situation of the road section travel speed and data processing methods. The cumulative distribution curve of the road section travel speed showed that the travel speed cumulative frequency was larger in September than in August (see Figure 3). The data showed that a very small proportion of the travel speed data exceeded 80 km/h (speed limit) and, therefore, each month's data needed to be filtered and processed for outliers based on the threshold method and Pauta criterion [23–25]. The road section travel speed data for each month were filtered and processed at 10 min intervals, the filtering and processing process of the road section travel speed data is illustrated in Figure 4, and there were 99,023 records of valid data (94% data share).

$$\bar{v}_{T,m} = \frac{\sum_{i=1}^{n} v_{T,m,i}}{n} \tag{1}$$

$$v_{T,m,\sigma} = \sqrt{\frac{\sum_{i=1}^{n} \left(v_{T,m,i} - \bar{v}_{T,m}\right)}{n}} \tag{2}$$

where $\bar{v}_{T,m}$ denotes the average travel speed of road section m in time interval T (km/h), $v_{T,m,i}$ denotes the travel speed of road section m in time interval T (km/h), n denotes the number of sample records of the travel speed of road section m in time interval T, and $v_{T,m,\sigma}$ denotes the standard deviation of the travel speed of road section m in time interval T (km/h).

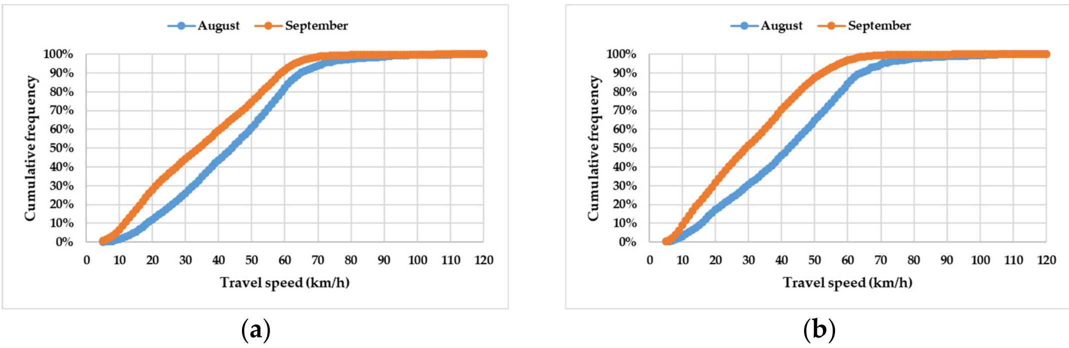


Figure 3. Travel speed cumulative frequency of the Beijing 3rd Ring Road: (**a**) Inner Ring; (**b**) Outer Ring.

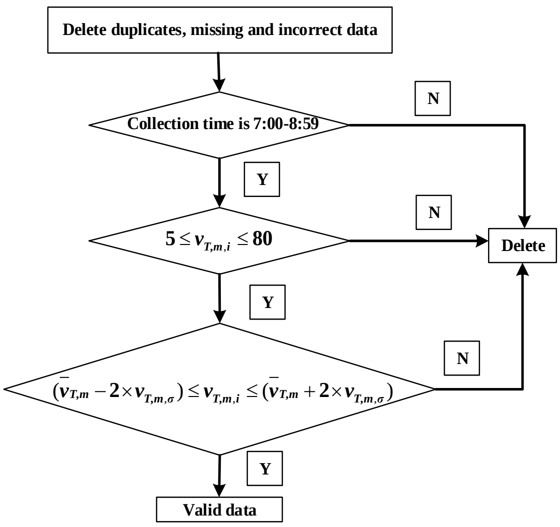


Figure 4. The filtering and processing process of the road section travel speed data.

3. Travel Speed Volatility

3.1. Travel Speed Volatility Evaluation Model

In order to better analyze the travel speed volatility, it was necessary to calculate the average, standard deviation, maximum, minimum, and range of the travel speed of the road section in a certain time interval, as shown in Equations (1)–(5). The lower the average, maximum, and minimum values of the travel speed, the more congested is the road traffic.

The larger the standard deviation and range of the travel speed, the larger the travel speed volatility and the more unstable the road operation status.

$$v_{T,m,\max} = \max\{ v_{T,m,1}, v_{T,m,2}, \cdots, v_{T,m,i}, \cdots, v_{T,m,n} \} \tag{3}$$

$$v_{T,m,\min} = \min\{ v_{T,m,1}, v_{T,m,2}, \cdots, v_{T,m,i}, \cdots, v_{T,m,n} \} \tag{4}$$

$$v_{T,m,R} = v_{T,m,\max} - v_{T,m,\min} \tag{5}$$

where $v_{T,m,\max}$ denotes the maximum travel speed of road section m in time interval T (km/h), $v_{T,m,\min}$ denotes the minimum travel speed of road section m in time interval T (km/h), and $v_{T,m,R}$ denotes the travel speed range of road section m in time interval T (km/h).

In order to better compare the changes in travel speed in the month before and after the students back to school, it was necessary to calculate the reduction ratio of the average travel speed, travel delay per unit of distance based on the average travel speed, reduction in the standard deviation, and reduction in the range of the travel speed of the road section, as shown in Equations (6)–(9). The larger the reduction ratio of the average travel speed, travel delay per unit of distance based on average travel speed, reduction in the standard deviation, and reduction in the range of the travel speed of the road section, the greater the impact of students back to school on the urban road traffic.

$$P_{\overline{v}_{T,m}} = \frac{\overline{v}_{T,m,A} - \overline{v}_{T,m,S}}{\overline{v}_{T,m,A}} \tag{6}$$

$$T_{\overline{v}T,m} = \frac{(\overline{v}_{T,m,A} - \overline{v}_{T,m,S}) \times 3600}{\overline{v}_{T,m,A} \times \overline{v}_{T,m,S}} \tag{7}$$

$$\Delta v_{T,m,\sigma} = v_{T,m,\sigma,A} - v_{T,m,\sigma,S} \tag{8}$$

$$\Delta v_{T,m,R} = v_{T,m,R,A} - v_{T,m,R,S} \tag{9}$$

where $P_{\overline{v}T,m}$ denotes the reduction ratio of the average travel speed of road section m in time interval T, $\overline{v}_{T,m,A}$ denotes the average travel speed of road section m in time interval T for month A (km/h), $\overline{v}_{T,m,S}$ denotes the average travel speed of road section m in time interval T for month S (km/h), $T_{\overline{v}_{T,m}}$ denotes the travel delay per unit of distance based on the average travel speed of road section m in time interval T (s/km), $\Delta v_{T,m,\sigma}$ denotes the reduction in the standard deviation of the travel speed of road section m in time interval T (km/h), $v_{T,m,\sigma,A}$ denotes the standard deviation of the travel speed of road section m in time interval T for month A (km/h), $\Delta v_{T,m,\sigma,S}$ denotes the standard deviation of the travel speed of road section m in time interval T for month S (km/h), $\Delta v_{T,m,R}$ denotes the reduction in the travel speed range of road section m in time interval T (km/h), $v_{T,m,R,A}$ denotes the travel speed range of road section m in time interval T for month A (km/h), $v_{T,m,R,S}$ denotes the travel speed range of road section m in time interval T for month S (km/h), A denotes August, and S denotes September.

3.2. Analysis of Travel Speed Volatility

The data showed that the travel speed of the Beijing 3rd Ring Road had cyclicity, time variability, large-scale volatility, and light congestion during the weekday morning peak. Meanwhile, the travel speed fluctuations in each road section had the fluctuation characteristics of similarity (cyclical, time variability, large-scale volatility, and light congestion) and specificity (different, counter-cyclicity, and non-transmissive), as shown in Table 1.

Table 1. The travel speed volatility characteristics of Beijing 3rd Ring Road sections.

Characteristics	Characterization of Travel Speed Fluctuations
Similarity	• Cyclicity: The average travel speed of the road sections was different during the weekday morning peak from month to month, the average travel speed of the road sections significantly decreased during the weekday morning peak after students back to school in September. • Time variability: During the weekday morning peak, as the departure time was delayed, the average travel speed fluctuation basically showed that it first decreased and then increased, and the fluctuation trend of the average travel speed on different road sections stayed the same. • Large-scale volatility: The travel speed range at 10 min intervals of more than 85% of the road sections was larger than 20 km/h in more than 90% of periods, and the travel speed range was large. • Light congestion: The average travel speed of more than 75% of the road sections was lower than 50 km/h during the weekday morning peak, and the travel speed showed that the traffic status was that of light congestion.
Specificity	• Different: Different road sections had different traffic statuses and different magnitudes of travel speed cyclicity reductions during the same periods. • Counter-cyclicity: Very few road sections showed counter-cyclicity of travel speed in some periods. The average travel speed of a few of the road sections showed an increase rather than a decrease in some periods after the students back to school. • Non-transmissive: Due to the high density of entrances and exits on the Beijing 3rd Ring Road, there was no significant transitivity and lag in travel speed between adjacent road sections.

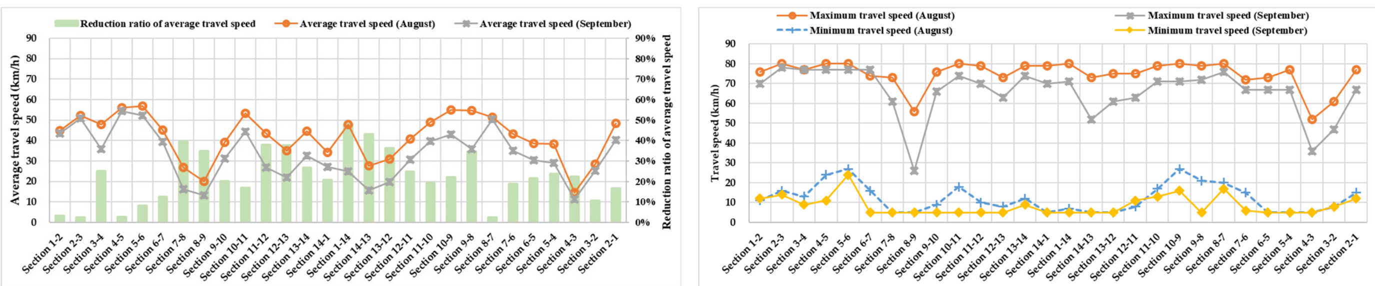
3.2.1. Travel Speed Volatility at Morning Peak

According to the current Chinese code "Urban road traffic performance index (DB11/T 785—2011)" [17] and "Evaluation methods for road traffic congestion levels (GA/T 115—2020)" [18], urban expressway traffic status is defined as four categories based on average travel speed, as shown in Table 2. The data showed that the traffic status of most road sections of the Beijing 3rd Ring Road was that of light congestion during the weekday morning peak and the road sections had a wide travel speed fluctuation range. The average travel speed of more than 75% of the road sections was lower than 50 km/h, as shown in Figure 5a. The maximum travel speed of more than 92% of the road sections was more than 50 km/h, the minimum travel speed of the road sections was 30 km/h, and the travel speed range of more than 92% of the road sections was larger than 50 km/h during the weekday morning peak, as shown in Figure 5b.

Table 2. Urban expressway section traffic status definition.

Traffic Status	Smooth	Light Congestion	Medium Congestion	Severe Congestion
Average travel speed $\overline{v}$ * (km/h)	$\overline{v} \geq 50$	$35 \leq \overline{v} < 50$	$20 \leq \overline{v} < 35$	$0 \leq \overline{v} < 20$

* $\overline{v}$ denotes the average travel speed of the road.



(**a**) (**b**)

Figure 5. Average, maximum, and minimum of the travel speed of the Beijing 3rd Ring Road: (**a**) average travel speed and reduction ratio; (**b**) maximum and minimum of travel speed.

After the students back to school, there were significant reductions in the average, maximum, and minimum of the travel speed of the Beijing 3rd Ring Road during the weekday morning peak, as shown in Figure 5. The data showed that the average travel speed of eight road sections (more than 28% share) was lower than 35 km/h in August, the average travel speed of 15 road sections (more than 53% share) was lower than 35 km/h in September, and the reduction ratio of the average travel speed of 17 road sections (more than 60% share) was larger than 20% in September during the weekday morning peak. The maximum travel speed of about 93% of road sections and the minimum travel speed of more than 60% of road sections were larger in August than in September. Traffic congestion on Section 8-9 of the Beijing 3rd Ring Road was severe after students back to school in September, with an average travel speed of 13 km/h and maximum travel speed of 26 km/h.

3.2.2. Travel Speed Volatility at 10 min Intervals of Morning Peak

The travel speed volatility indexes (average, standard deviation, maximum, minimum, and range) and travel speed volatility change indexes (the reduction ratio of average travel speed, travel delay per unit of distance based on average travel speed, the reduction in standard deviation, and reduction in travel speed range) of 336 periods of 28 road sections of the Beijing 3rd Ring Road were analyzed at 10 min intervals during the weekday morning peak.

The data showed that the average travel speed of 28 road sections of the Beijing 3rd Ring Road significantly decreased in most periods (more than 90% share) after the students back to school, with 73%, 54%, 33%, and 18% of 336 periods showing reduction ratios of the average travel speed of 10%, 20%, 30%, and 40%, respectively, and there were three road sections with a reduction ratio of the average travel speed of more than 55% at 10 min intervals. After the students back to school, the average travel speed of nine sections was lower than 20 km/h in 73 periods (about 22% share), the average travel speed of 20 sections was lower than 35 km/h in 186 periods (more than 55% share), and the average travel speed of 28 sections was lower than 50 km/h in 291 periods (about 87% share), as shown in Figure 6. Eight road sections showed a decrease in the average travel speed larger than 20 km/h in 24 periods (more than 7% share), and 22 road sections had a decrease in the average travel speed larger than 10 km/h in 138 periods (more than 41% share) after the students back to school.

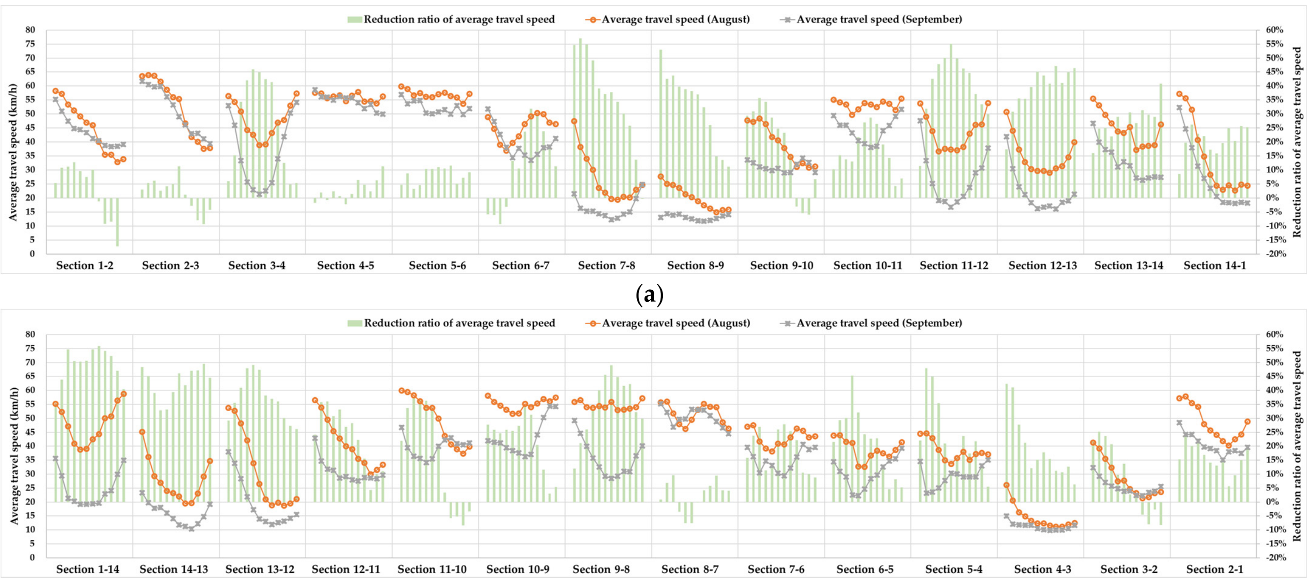
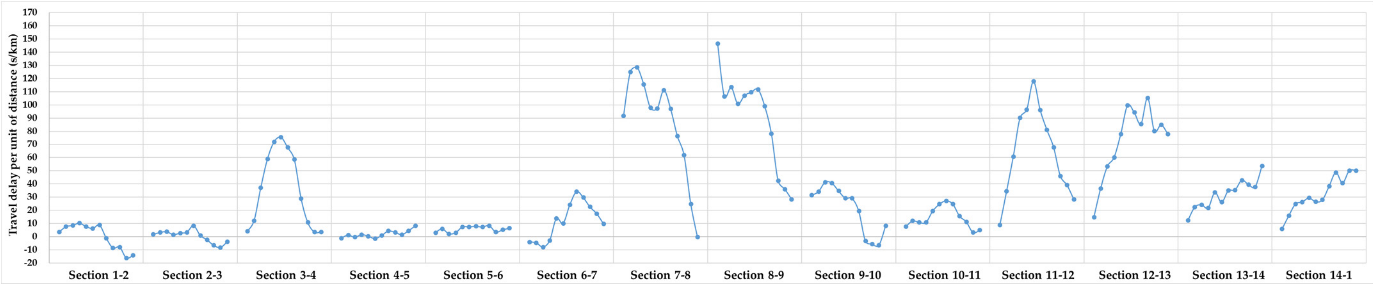
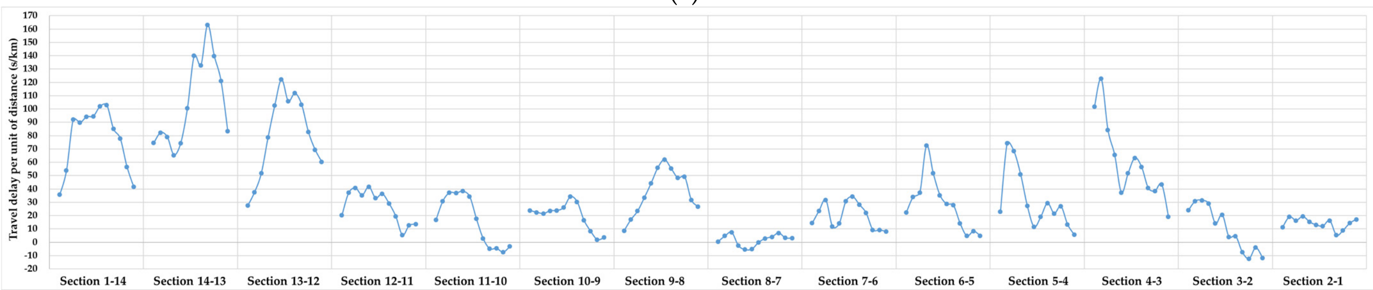


Figure 6. Average travel speed and reduction ratio of the Beijing 3rd Ring Road: (**a**) Inner Ring; (**b**) Outer Ring.

The greater the travel delay per unit distance based on the average travel speed, the greater the impact of the students back to school on road traffic. After the students back to school, the maximum travel delay per unit distance was larger than 160 s/km, and a large traffic congestion impact was generated, as shown in Figure 7. The data showed that the travel delay per unit distance of 24 road sections was larger than 10 s/km in 234 periods (about 70% share), the travel delay per unit distance of 22 road sections was larger than 20 s/km in 192 periods (more than 57% share), and the travel delay per unit distance of 21 road sections was larger than 30 s/km in 146 periods (more than 43% share).



(**a**)

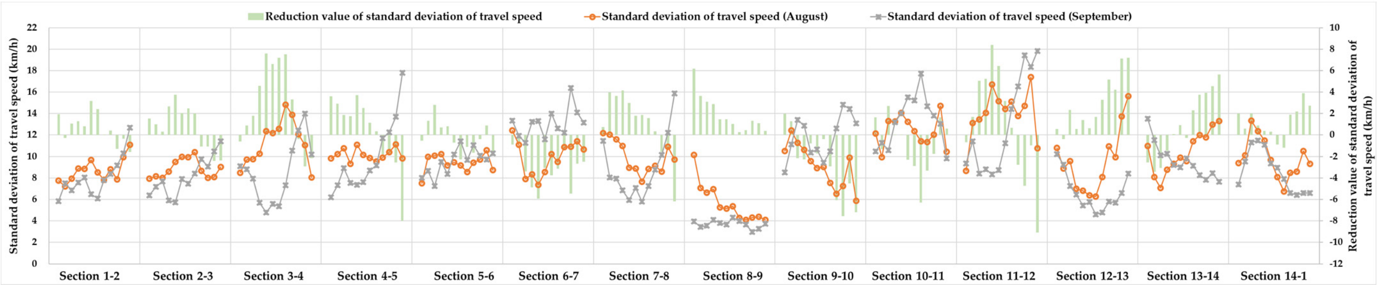


(**b**)

Figure 7. Travel delay per unit of distance based on the average travel speed of the Beijing 3rd Ring Road: (**a**) Inner Ring; (**b**) Outer Ring.

The lower the standard deviation of the travel speed, the smaller the difference between the travel speed and the average travel speed and the more stable the travel speed. The standard deviation of the travel speed of 28 road sections was lower than 20 km/h in 335 periods, the standard deviation of the travel speed of 26 road sections was lower than 10 km/h in more than 193 periods (about 57% share), and the standard deviation of the travel speed of two road sections was lower than 5 km/h in 14 periods (more than 4% share), as shown in Figure 8. After the students back to school, the reduction in the standard deviation of the travel speed of 27 road sections was larger than 0 km/h in 202 periods (more than 60% share), and the reduction in the standard deviation of the travel speed of 25 road sections was larger than 2 km/h in 105 periods (more than 31% share).

The maximum and minimum of the travel speed of most road sections were lower than 75 km/h and lower than 35 km/h, respectively, during most periods, as shown in Figure 9. The travel speed range of 24 road sections was larger than 20 km/h in more than 305 periods (more than 90% share), as shown in Figure 10. After the students back to school, the maximum, minimum, and range of the travel speed of most road sections decreased in most periods. The data showed that the reduction in the travel speed range of 26 road sections was larger than 10 km/h in 126 periods (about 38% share) and the reduction in the travel speed range of 27 road sections was larger than 5 km/h in 189 periods (more than 56% share). The lower the travel speed range, the more stable the travel speed.



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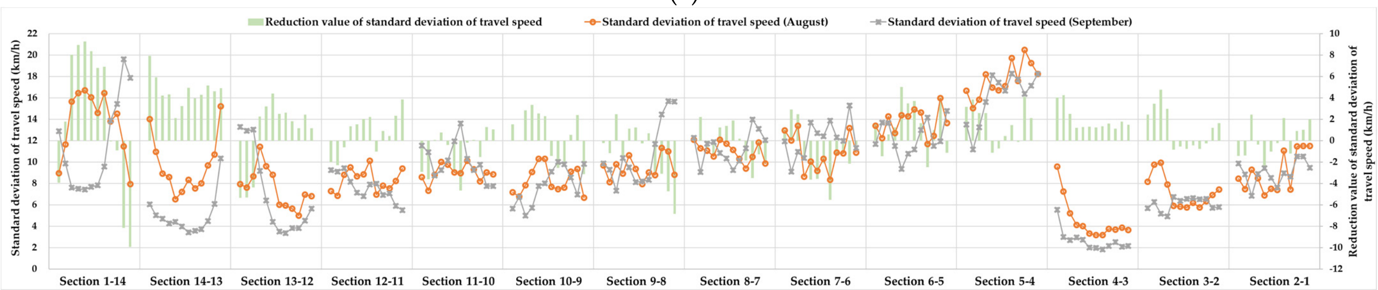
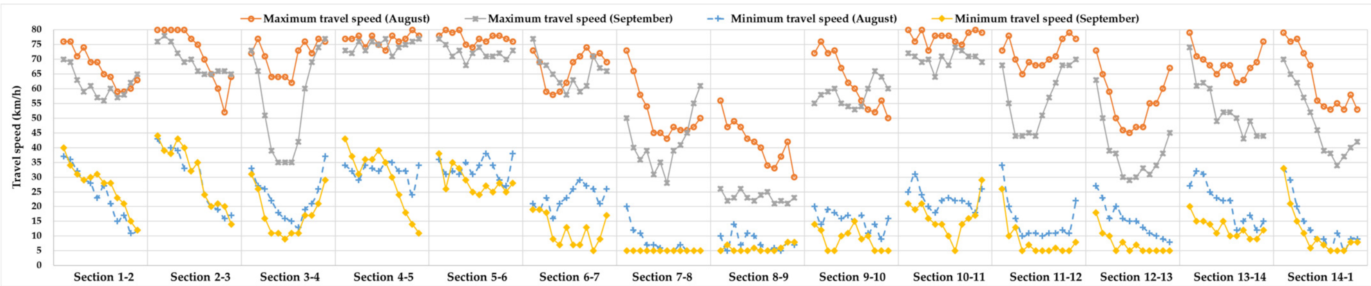


(**b**)

Figure 8. The standard deviation of travel speed of the Beijing 3rd Ring Road: (**a**) Inner Ring; (**b**) Outer Ring.



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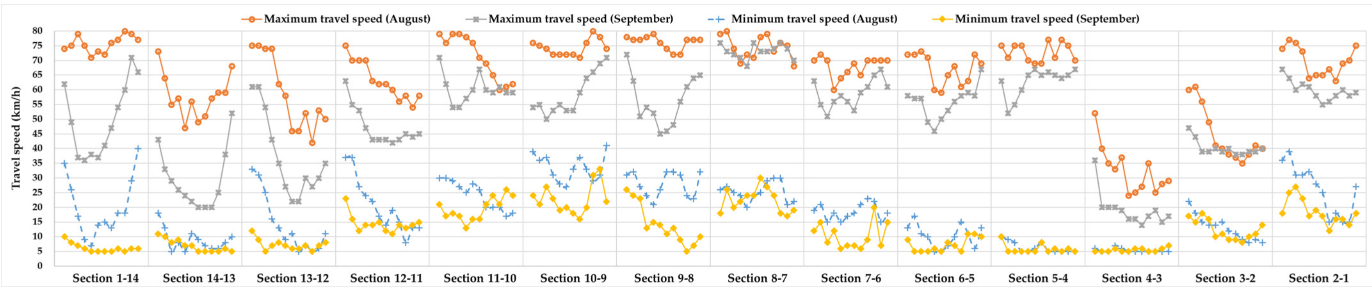

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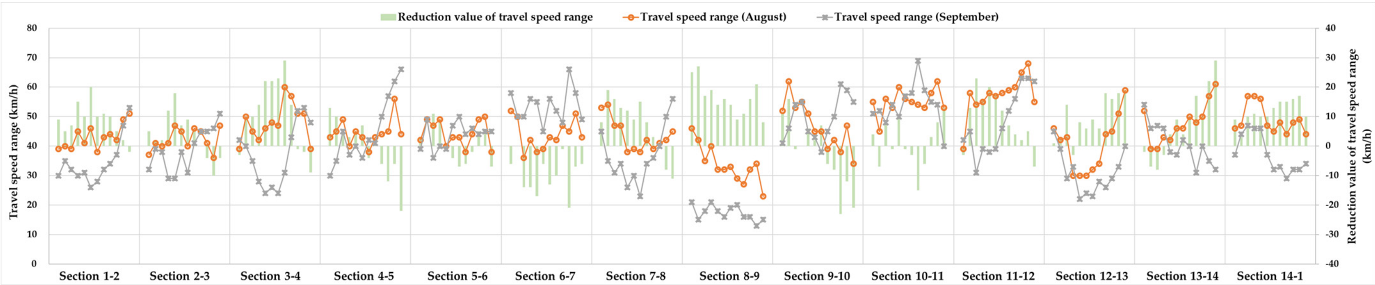
Figure 9. Maximum and minimum of travel speed of the Beijing 3rd Ring Road: (**a**) Inner Ring; (**b**) Outer Ring.



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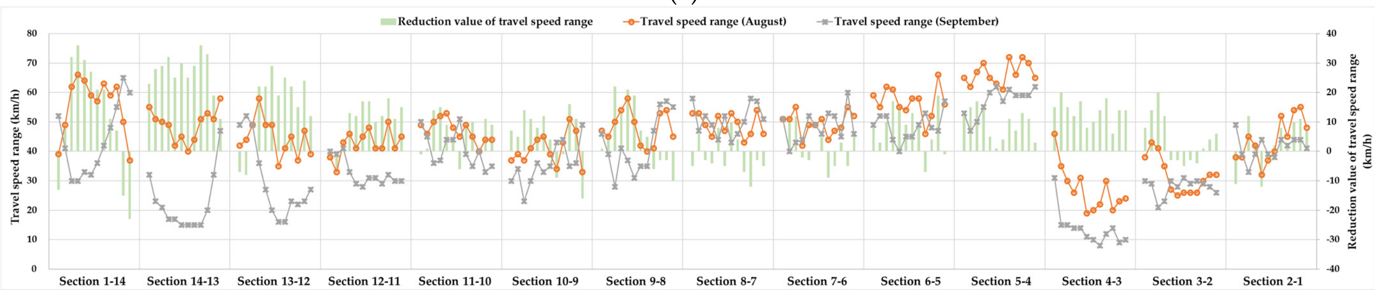


(**b**)

Figure 10. Travel speed range of the Beijing 3rd Ring Road: (**a**) Inner Ring; (**b**) Outer Ring.

4. Travel Speed Reliability

4.1. Travel Speed Reliability Evaluation Model

Travel speed reliability of the road section refers to the probability that the travel speed of the road section is larger or equal to the travel speed reliability evaluation threshold v_* in time interval T under certain road traffic conditions [23–25], as shown in Equation (10). There are two main types of travel speed reliability evaluation threshold values taken, one is a fixed speed value [23–25] and the other is a variable speed value [23].

$$R_{T,m,v_*} = P\{v_{T,m,i} \geq v_*\} = \frac{N}{n} \tag{10}$$

where R_{T,m,v_*} denotes the travel speed reliability of road section m in time interval T, v_* denotes the travel speed reliability evaluation threshold (km/h), and N denotes the number of sample records of the travel speed of road section m larger or equal to the travel speed reliability evaluation threshold v_* in time interval T.

(1) Fixed speed value as the travel speed reliability evaluation threshold

Some studies (road service level reliability) have suggested that the travel speed reliability evaluation threshold can be taken as the minimum average travel speed of the road corresponding to different road service levels [23,24], as shown in Equation (11).

$$v_* = v_s \tag{11}$$

where v_s denotes the minimum average travel speed of the road corresponding to road service level s (km/h).

(2) Variable speed value (a multiple of the average travel speed of the road segment) as the travel speed reliability evaluation threshold

A previous study (travel speed reliability of car commuters) suggested that the travel speed reliability evaluation threshold can be taken as the expected acceptable travel speed of the car commuter, which is equal to 0.71 times the average travel speed of the car commuter, and the average travel speed of the car commuter can be taken as the average travel speed of the road [23], as shown in Equations (12) and (13).

$$v_* = \overline{v}_{EATS} = 0.71 \times \overline{v}_{cc} \tag{12}$$

$$\overline{v}_{cc} = \overline{v}_{T,m} \tag{13}$$

where $\overline{v}_{EATS}$ denotes the expected acceptable travel speed of the car commuter (km/h), and $\overline{v}_{cc}$ denotes the average travel speed of the car commuter (km/h).

The evaluation thresholds of the road service level reliability and the travel speed reliability of car commuters were selected to analyze the travel speed reliability of the Beijing 3rd Ring Road, as shown in Table 3. The minimum average travel speed of the road corresponding to medium traffic congestion, light traffic congestion, and smooth conditions were selected (see Table 2) as the evaluation thresholds of road service level reliability based on the current Chinese code "Urban road traffic performance index (DB11/T 785—2011)" [17] and "Evaluation methods for road traffic congestion levels (GA/T 115—2020)" [18].

Table 3. Travel speed reliability evaluation thresholds.

Threshold	Threshold-1	Threshold-2	Threshold-3	Threshold-4
The values of v_* (km/h)	20	35	50	$v_* = 0.71 \times \overline{v}_{T,m,A}$

4.2. Analysis of Travel Speed Reliability

The data showed that the travel speed reliability of most road sections of the Beijing 3rd Ring Road significantly decreased after the students back to school, and there were differences in the magnitude of the travel speed reliability reduction with the fluctuation of time. Some road sections showed negative decreases in travel speed reliability during very few periods, indicating that the students back to school had a small impact on the travel speed reliability of these road sections during these periods.

4.2.1. Travel Speed Reliability at Morning Peak

Based on different travel speed reliability evaluation thresholds, the 28 road sections of the Beijing 3rd Ring Road were analyzed during the weekday morning peak, as shown in Figure 11. As the travel speed reliability evaluation threshold increased, the travel speed reliability calculation results became lower.

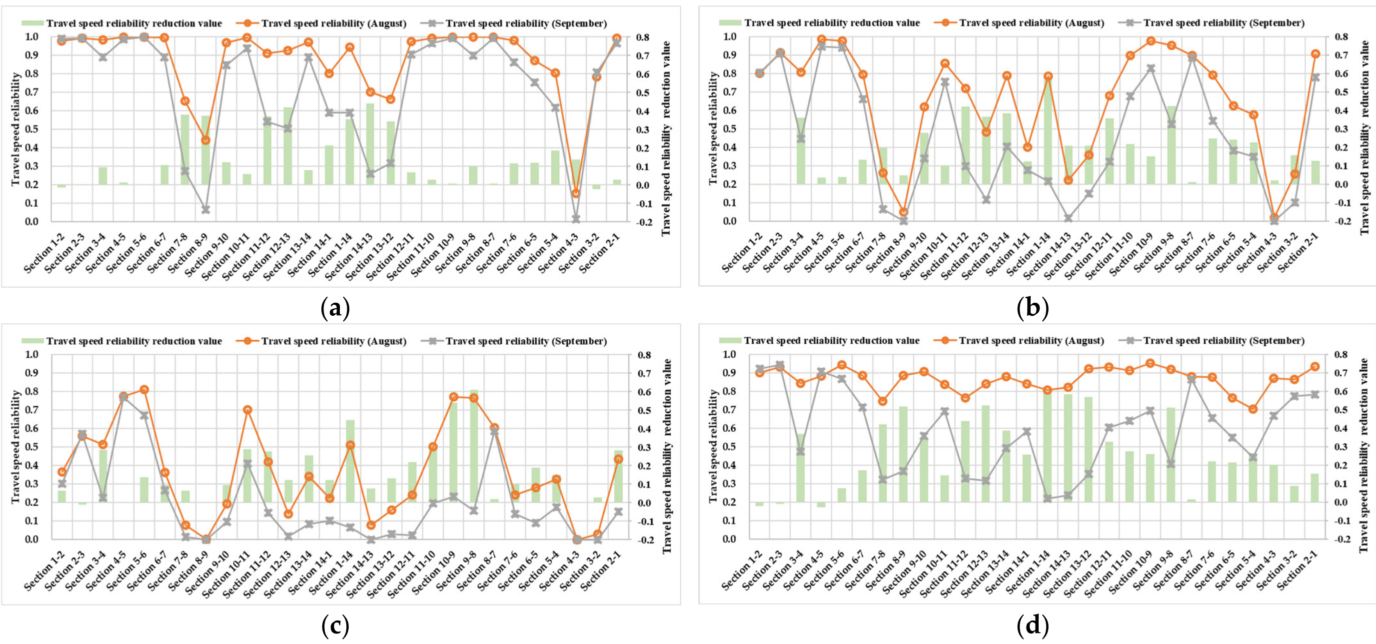


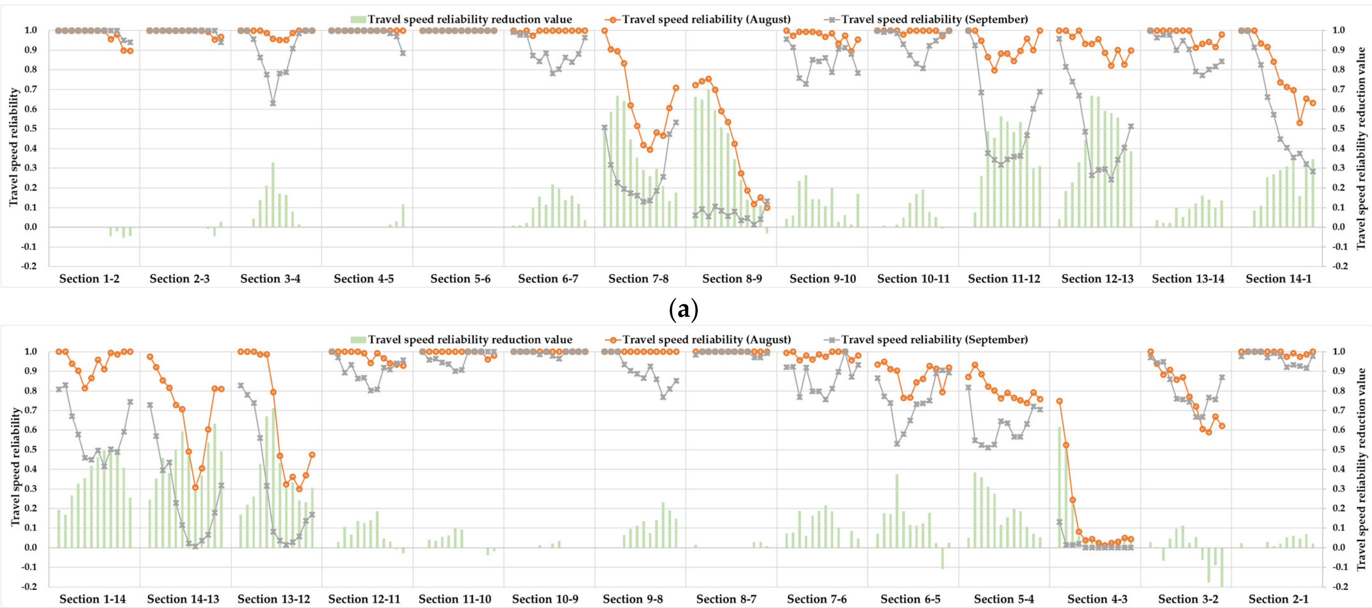
Figure 11. Travel speed reliability of the Beijing 3rd Ring Road based on different travel speed reliability thresholds: (**a**) Threshold-1; (**b**) Threshold-2; (**c**) Threshold-3; (**d**) Threshold-4.

The data showed that the travel speed reliability of 96% of the above road sections of the Beijing 3rd Ring Road was lower than 0.8 based on the Threshold-3 in the morning peak. The travel speed reliability of the Beijing 3rd Ring Road was larger than 0.7 based on the Threshold-4 in the morning peak in August. However, the road service level reliability for the road sections with smooth traffic status was less than 0.8 if the road sections were in a steady state of congestion for long periods and the travel speed reliability of car commuters for these road sections was larger than 0.7 in the morning peak in August, indicating that these road sections were congested and a reliable type of road section in August.

After the students back to school, the travel speed reliability of more than 82% of the road sections of the Beijing 3rd Ring Road significantly decreased. The travel speed reliability of Section 8-9 and Section 4-3 was lower than 0.1 based on the Threshold-1, Threshold-2, and Threshold-3 in the morning peak after students back to school. The maximum travel speed reliability reduction values of the Beijing 3rd Ring Road sections calculated based on the Threshold-1, Threshold-2, Threshold-3, and Threshold-4 were 0.44 (Section 14-13), 0.57 (Section 1-14), 0.61 (Section 9-8), and 0.59 (Section 1-14) during the weekday morning peak, respectively.

4.2.2. Travel Speed Reliability at 10 min Intervals of Morning Peak

The travel speed reliability and travel speed reliability reduction values of 336 periods of 28 road sections of the Beijing 3rd Ring Road were analyzed at 10 min intervals during the weekday morning peak based on different travel speed reliability evaluation thresholds, as shown in Figures 12–15. The data showed that the travel speed reliability fluctuated with the delay of departure time, the travel speed reliability of most road sections significantly decreased after the students back to school, and the travel speed reliability reduction value of very few road sections was more than 0.7 in some periods based on different travel speed reliability evaluation thresholds.



(**a**)

(**b**)

Figure 12. Travel speed reliability of the Beijing 3rd Ring Road based on the travel speed reliability evaluation Threshold-1: (**a**) Inner Ring; (**b**) Outer Ring.

The travel speed reliability of 24 road sections was larger than 0.8 in 195 periods (about 58% share) and the travel speed reliability reduction value of 21 road sections was larger than 0.1 in 155 periods (more than 46% share) based on the Threshold-1, as shown in Figure 12. The travel speed reliability reduction value of 23 road sections was larger than 0.2 in 138 periods (more than 58% share) based on the Threshold-2, as shown in Figure 13.

The travel speed reliability reduction value of 22 road sections was larger than 0.3 in 161 periods (about 48% share), and the maximum travel speed reliability reduction value was larger than 0.85 (Section 11-10) based on the Threshold-3, as shown in Figure 14.

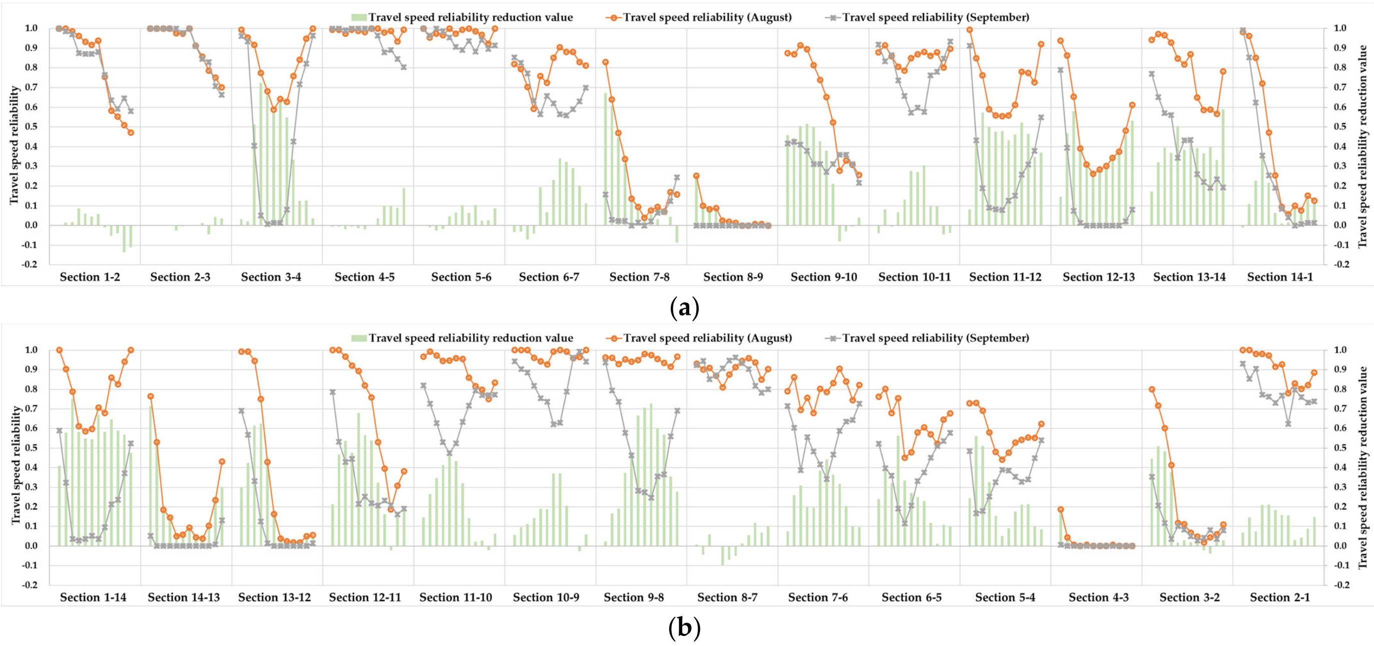


Figure 13. Travel speed reliability of the Beijing 3rd Ring Road based on the travel speed reliability evaluation Threshold-2: (**a**) Inner Ring; (**b**) Outer Ring.

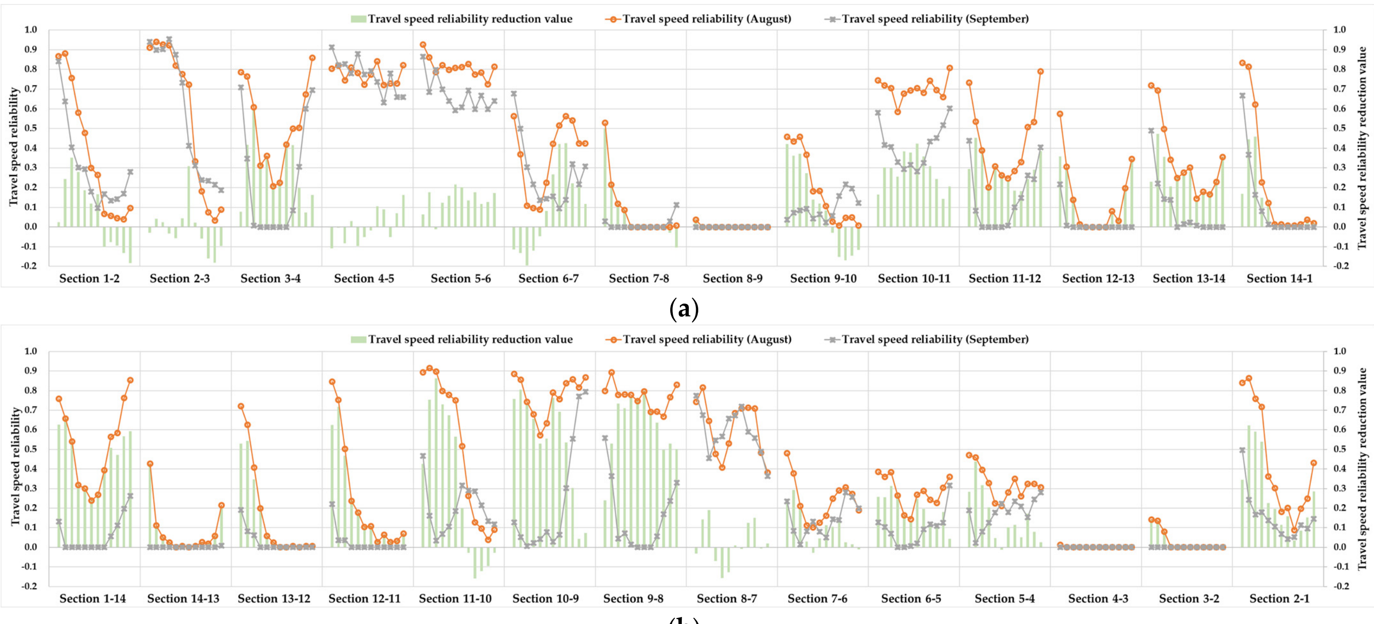


Figure 14. Travel speed reliability of the Beijing 3rd Ring Road based on the travel speed reliability evaluation Threshold-3: (**a**) Inner Ring; (**b**) Outer Ring.

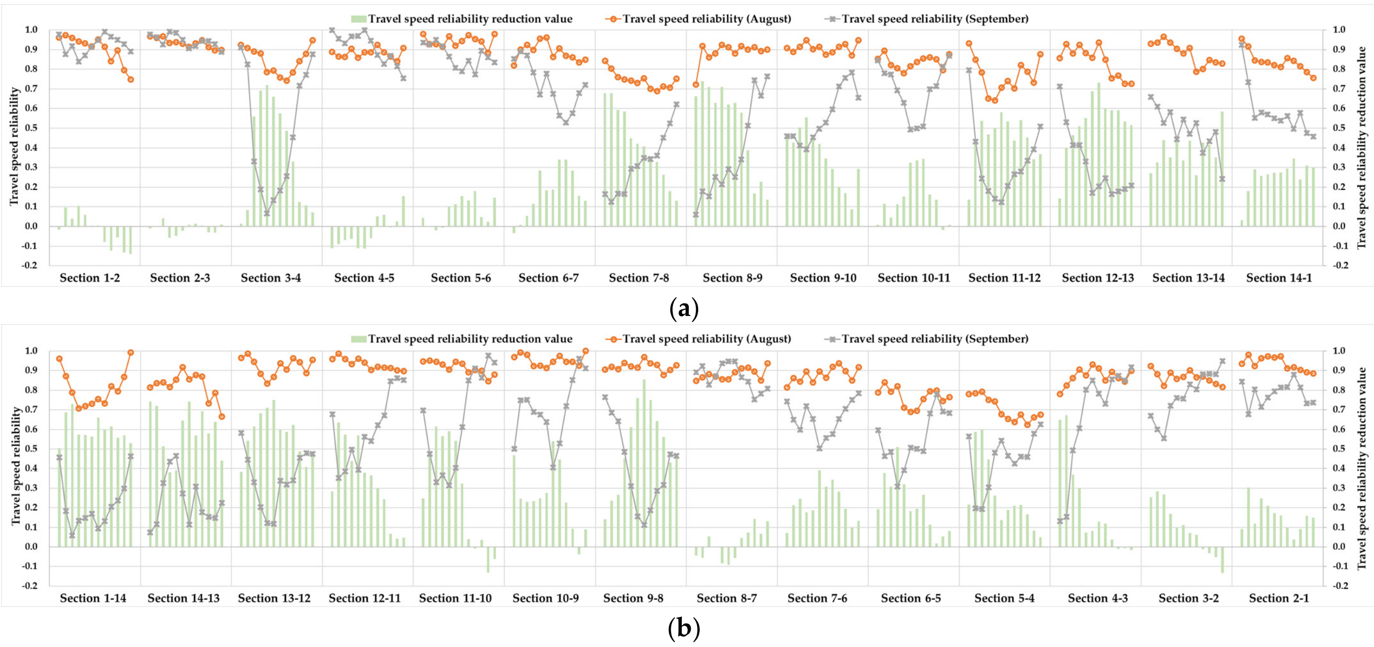


Figure 15. Travel speed reliability of the Beijing 3rd Ring Road based on the travel speed reliability evaluation Threshold-4: (**a**) Inner Ring; (**b**) Outer Ring.

Before students back to school in August, the travel speed reliability of the road sections was larger than 0.6 based on the Threshold-4, as shown in Figure 15. After students back to school in September, the travel speed reliability of the road sections significantly decreased, the travel speed reliability reduction value of 27 road sections was larger than 0.1 in 240 periods (more than 71% share), the travel speed reliability reduction value of 17 road sections was larger than 0.5 in 81 periods (more than 14% share), and the maximum travel speed reliability reduction value was larger than 0.85 (Section 9-8) based on the Threshold-4, as shown in Figure 15. The data showed that the travel speed reliability reduction value of 11 road sections was lower than 0 in 42 periods (12.5% share) based on the Threshold-4.

5. Conclusions

Students back to school in September exacerbates the severity of traffic congestion on urban road during the weekday morning peak, resulting in greater impact on the volatility and reliability of travel speed on urban road during the weekday morning peak. The Beijing 3rd Ring Road (a typical commuting traffic ring expressway) was taken as the research object, evaluation models of the volatility and reliability of travel speed were constructed, and the impact of the students back to school on the volatility indexes (average, standard deviation, maximum, minimum, and range) and reliability indexes (road service level reliability and travel speed reliability of car commuters) of the travel speed of road sections were qualitatively and quantitatively analyzed based on the road section travel speed data from the weekday morning peak (7:00–8:59). The results showed that:

(1) The travel speed of the Beijing 3rd Ring Road had cyclicity (average travel speed of road sections significantly decreased after the students back to school), time variability (average travel speed first decreased and then increased with time), large-scale volatility (the travel speed range of more than 92% of road sections was larger than 50 km/h), and light congestion (average travel speed of more than 75% of road sections was lower than 50 km/h) during the weekday morning peak.

(2) The travel speed reliability of more than 82% of the road sections of the Beijing 3rd Ring Road significantly decreased after the students back to school. The travel speed reliability of 96% of the road sections was lower than 0.8 based on the Threshold-3 during the weekday morning peak. The travel speed reliability of the Beijing 3rd Ring

Road was larger than 0.7 based on the Threshold-4 in the morning peak in August. However, the road service level reliability of road sections with smooth conditions was less than 0.8 if the road sections were in a steady state of congestion for long periods and the travel speed reliability of car commuters for these road sections was larger than 0.7 in the morning peak in August, indicating that these road sections were congested and a reliable type of road section.

The volatility indexes (average, standard deviation, maximum, minimum, and range) and reliability indexes (road service level reliability and travel speed reliability of car commuters) of the travel speed of the road sections significantly decreased under the influence of students back to school. The data (which were analyzed in 10 min intervals during the weekday morning peak) showed that, after the students back to school, the maximum reduction ratio of the average travel speed was larger than 55%, the maximum travel delay per unit distance was larger than 160 s/km, and the maximum reduction in travel speed reliability was larger than 0.85 based on the evaluation model of travel speed reliability of car commuters.

The research results can provide a reference for evaluating and analyzing the volatility and reliability of travel speed on urban road and provide data and theoretical support for the traffic congestion evaluation, analysis, mitigation, and governance of the Beijing 3rd Ring Road and other urban road. Encouraging students and commuters to travel using green transportation and effectively reducing the number of car commuter trips made after the students back to school are some of the most effective means of mitigating the decrease in the travel speed of road sections during the weekday morning peak after the students back to school. Future work could focus on the governance and improvement of the operation status, service level, and service quality of urban road based on the volatility and reliability of travel speed.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Beijing 3rd Ring Road Section Information

Section ID	Road Name	Road Trend	Origin ID	Origin Name	Destination ID	Destination Name	Section Length
1-2	Eastern 3rd Ring Road (Inner Ring)	N-S	1	Sanyuan Bridge	2	Jingguang Bridge	3625 m
2-3	Eastern 3rd Ring Road (Inner Ring)	N-S	2	Jingguang Bridge	3	Shuangjing Bridge	4077 m
3-4	Eastern 3rd Ring Road (Inner Ring)	N-S	3	Shuangjing Bridge	4	Minminji Bridge	3323 m
4-5	Southern 3rd Ring Road (Inner Ring)	E-W	4	Minminji Bridge	5	Liujiayao Bridge	3136 m
5-6	Southern 3rd Ring Road (Inner Ring)	E-W	5	Liujiayao Bridge	6	Yangqiao Bridge	2936 m
6-7	Southern 3rd Ring Road (Inner Ring)	E-W	6	Yangqiao Bridge	7	Fengyi Bridge	5443 m
7-8	Western 3rd Ring Road (Inner Ring)	S-N	7	Fengyi Bridge	8	Liuli Bridge	3730 m
8-9	Western 3rd Ring Road (Inner Ring)	S-N	8	Liuli Bridge	9	Aerospace Bridge	4744 m
9-10	Western 3rd Ring Road (Inner Ring)	S-N	9	Aerospace Bridge	10	Suzhou Bridge	3534 m
10-11	Northern 3rd Ring Road (Inner Ring)	W-E	10	Suzhou Bridge	11	Jimen Bridge	4047 m
11-12	Northern 3rd Ring Road (Inner Ring)	W-E	11	Jimen Bridge	12	Madian Bridge	2502 m
12-13	Northern 3rd Ring Road (Inner Ring)	W-E	12	Madian Bridge	13	Anzhen Bridge	2606 m
13-14	Northern 3rd Ring Road (Inner Ring)	W-E	13	Anzhen Bridge	14	Sun Palace Bridge	1672 m
14-1	Northern 3rd Ring Road (Inner Ring)	W-E	14	Sun Palace Bridge	1	Sanyuan Bridge	2673 m
1-14	Northern 3rd Ring Road (Outer Ring)	E-W	1	Sanyuan Bridge	14	Sun Palace Bridge	2530 m
14-13	Northern 3rd Ring Road (Outer Ring)	E-W	14	Sun Palace Bridge	13	Anzhen Bridge	1529 m
13-12	Northern 3rd Ring Road (Outer Ring)	E-W	13	Anzhen Bridge	12	Madian Bridge	2684 m
12-11	Northern 3rd Ring Road (Outer Ring)	E-W	12	Madian Bridge	11	Jimen Bridge	1607 m
11-10	Northern 3rd Ring Road (Outer Ring)	E-W	11	Jimen Bridge	10	Suzhou Bridge	4070 m
10-9	Western 3rd Ring Road (Outer Ring)	N-S	10	Suzhou Bridge	9	Aerospace Bridge	4359 m
9-8	Western 3rd Ring Road (Outer Ring)	N-S	9	Aerospace Bridge	8	Liuli Bridge	4829 m
8-7	Western 3rd Ring Road (Outer Ring)	N-S	8	Liuli Bridge	7	Fengyi Bridge	3909 m
7-6	Southern 3rd Ring Road (Outer Ring)	W-E	7	Fengyi Bridge	6	Yangqiao Bridge	6026 m
6-5	Southern 3rd Ring Road (Outer Ring)	W-E	6	Yangqiao Bridge	5	Liujiayao Bridge	2918 m
5-4	Southern 3rd Ring Road (Outer Ring)	W-E	5	Liujiayao Bridge	4	Minminji Bridge	2402 m
4-3	Eastern 3rd Ring Road (Outer Ring)	S-N	4	Minminji Bridge	3	Shuangjing Bridge	3513 m
3-2	Eastern 3rd Ring Road (Outer Ring)	S-N	3	Shuangjing Bridge	2	Jingguang Bridge	3988 m
2-1	Eastern 3rd Ring Road (Outer Ring)	S-N	2	Jingguang Bridge	1	Sanyuan Bridge	3916 m

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