A Highway Monitoring Necessity Grading Method Considering Traffic State Stability

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Abstract. In order to meet the basic requirements of expressway operation and maintenance management in the new era,refine the monitoring requirements of different expressway sections,and maximize the operation benefit of expressway monitoring system,this paper puts forward the stability of traffic state related to overtaking frequency,speed difference and traffic fluctuation at the entrance and exit,and obtains the grading detection method of expressway through entropy method and global Moran index,which provides a basis for optimizing monitoring and improving road safety.

Keywords: Traffic Flow Stability;Hierarchical Detection.Entropy Method;Moran's Index

1. Introduction

The construction goal of China's expressway monitoring system is to achieve comprehensive and seamless monitoring coverage to ensure road safety.improve traffic efficiency.and rapidly respond to various emergencies.However.given China's vast territory.with an intricate network of expressways spanning immense distances and ranking among the world's longest.this ambitious objective faces numerous challenges in practical implementation.Due to the excessive length of expressways.complex and varied terrain.diverse climatic conditions.as well as considerations of construction costs and maintenance difficulties.achieving truly comprehensive monitoring coverage in the short term is challenging.

Therefore.to balance monitoring needs with practical feasibility.a hierarchical monitoring strategy should be adopted for expressway monitoring systems.This strategy involves dividing the expressway network into different monitoring levels.with the allocation of monitoring resources based on factors such as road importance.traffic volume.accident proneness.and terrain conditions[1].

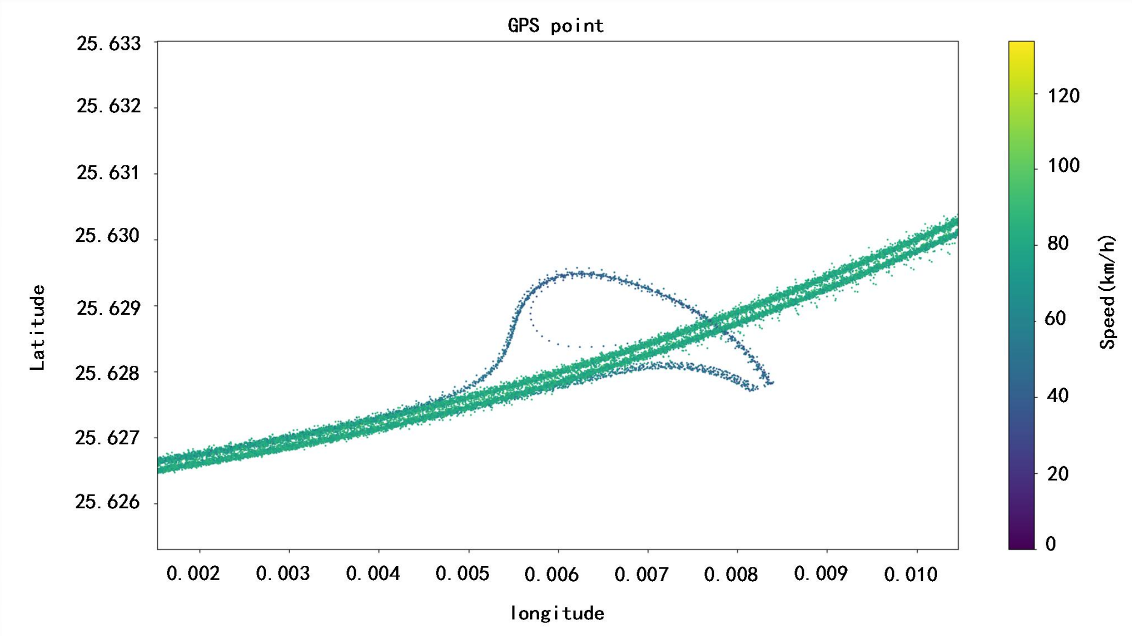

Figure 1 Vehicle Trajectory Points in Traffic Flow

2. .Methodology

2.1 Conceptual Framework

Traffic state stability is a multidimensional concept encompassing vehicle driving stability.the transportation system's resistance to interference.and real-time assessments of traffic conditions.In practical applications.it is necessary to select appropriate indicators and methods to evaluate traffic state stability based on specific circumstances and implement corresponding measures to enhance the overall stability and operational efficiency of the transportation system.

Entropy method:

The entropy method can accurately reflect the utility value of index information entropy.and compared with the analytic hierarchy process and expert experience evaluation method.it provides higher credibility.avoiding subjective biases.Therefore.it is widely used in the calculation of various comprehensive indices.As a comprehensive evaluation tool.the entropy method can reflect the stability of traffic flow in a region from multiple dimensions (such as road geometry indicators.vehicle characteristics.natural conditions.etc.).making it an effective tool for comparing traffic flow in different regions or monitoring areas.

Moran index:

This paper employs the Global Moran's I to analyze the spatial correlation of traffic stability across different highway sections.Moran's I measures the degree of correlation between observations at a given location and those at other locations.though it may not fully capture complex spatial heterogeneity.The index value ranges from [-1.1].A Moran's I closer to 1 indicates a pronounced spatial clustering of traffic stability across highway sections.with minimal differences between sections and their neighbors.Conversely.a value closer to -1 signifies significant spatial disparities between sections and their adjacent ones[9-10].When Moran's I equals zero.the spatial distribution is random.let X_i represent the observation value for region i.and the Global Moran's I (I) for this variable is calculated using Equation (1).

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}\left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij}\sum_{i=1}^{j}\left(x_i - \bar{x}\right)} \qquad (1)$$

Where n represents the number of regional units.and ωij represents the adjacent relationship between regions i and j.If i is adjacent to j.take 1; if i is not adjacent.take 0.

2.2 Development of the Stability Index

Traffic flow theory is an interdisciplinary field that utilizes physics and mathematics methods to describe traffic characteristics from both macro and micro perspectives by examining the movement patterns of vehicles and pedestrians.Through analytical methods.it elucidates traffic phenomena and their underlying mechanisms.Originating in the 1930s.traffic flow theory has evolved over nearly a century.emerging concurrently with the invention of automobiles.Extensive research by experts from various fields has laid a solid foundation for subsequent studies.

Regarding traffic flow states.scholars both domestically and internationally have conducted numerous studies from the perspectives of variation principles and control.Zhao[4]and others considered the influence of communication topology switching and delay on traffic flow in intelligent networking environment.and established a model for analysis..Zheng et al.[5] discovered that autonomous vehicles significantly impact the uncertainty and stability of mixed traffic flow systems.Zeng et al.[6] proposed a novel one-dimensional lattice traffic flow model to investigate the impact of heterogeneity in drivers' risk preferences for perturbations on traffic flow instability.Further.Zeng et al.[7] analyzed the combined influence of driver heterogeneity in risk preferences for perturbations and the closest headway on traffic flow instability in specific traffic scenarios.Meanwhile.scholars have sought to explain the causes of changes in traffic flow stability from various angles[8]-[11].Phase plane analysis has proven to be a suitable tool for analyzing complex traffic flow phenomena[12]-[13].At present.people have put forward many models to study traffic flow by using fluid mechanics and mechanical systems[14]-[16].These physics-based models.grounded in fluid mechanics.can describe traffic flow states effectively.

3. Case Study and Analysis

3.1 Data Collection

The vehicle movement trajectory data used in this study is sourced from a highway in Sichuan province.which comprises comprehensive information such as the location.time.speed.and fuel consumption of sample vehicles traveling on the road.The original trajectory data selected for this paper comprises a sample size of 283,825.with data collection spanning from June to July 2024.

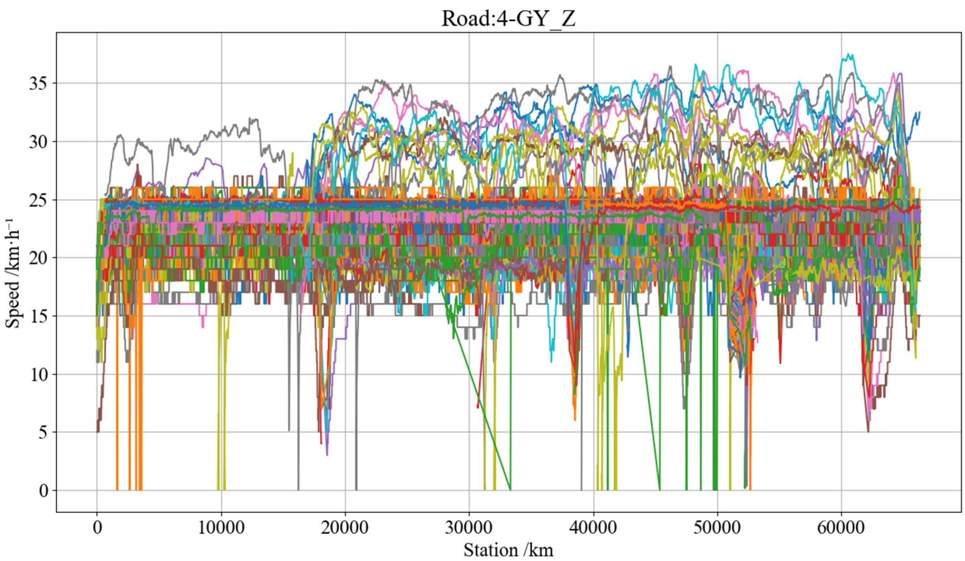

Figure 2 Data denoising processing

3.2 Correlation Analysis

This study utilized floating car technology to collect data from a highway in Sichuan Province.resulting in over four million pieces of relevant information spanning three months.including the number of traffic accidents.severity.accident locations.occurrence times.causes.vehicle speeds.and weather conditions on the highway.Based on relevant research findings.four indicators were selected: abnormal traffic flow fluctuation rate (ai).average accident severity (bi).the average speed difference between accident vehicles and surrounding vehicles (ci).and the number of lane changes on the accident-prone road segments (di).The entropy method was employed to calculate the weight values of these four indicators.and the comprehensive traffic stability index (I) for different highway segments was further determined according to Equation (2).

$$E_i = \omega_1 a_i + \omega_2 b_i + \omega_3 c_i + \omega_4 d_i \tag{2}$$

In the equation,I represents the comprehensive traffic stability index for different highway segments.ai represents the abnormal traffic flow fluctuation rate for a segment.calculated as the change in traffic flow divided by the original traffic flow; bi represents the severity of accidents.which is classified into three levels: 1.2.and 3; ci represents the difference in average travel speed between accident vehicles and surrounding vehicles; di represents the number of lane changes on the accident-prone road segment.measured in times per 100 kilometers per hour; and ω_ij represents the weight of each influencing factor.

Table 1 Weight of each influencing factor

influencing factor	ai	bi	ci	di
weight	0.38	0.3	0.20	0.12

3.3 Monitoring Necessity Grading

Table 2 shows the comprehensive traffic stability index and the global Moran index of the data section obtained according to Formula (1) and Formula (2).and compares them with the accident frequency data of this section.

Table 2 Comprehensive traffic stability index.global Moran index and accident frequency data of each road section

Section number	Ei	Global Moran indexI	accident frequency
1	26.5006	1.0000	45.38
2	20.5648	0.7760	38.12
3	20.0152	0.7553	37.83
4	16.7414	0.6317	35.05
5	12.9272	0.4878	23.89
6	7.6994	0.2905	9.06
7	5.9516	0.2246	6.06
8	4.9618	0.1872	4.94
9	4.0060	0.1512	4.04
10	2.3556	0.0889	3.41
average number	12.1724	0.4593	20.778

Based on the global Moran's I index of the data segment and accident frequency data.the necessity of highway monitoring is divided into three levels: when the global Moran's I index I $\in$ [0.0.2).the necessity of highway monitoring is low; when the global Moran's I index I $\in$ [0.2.0.4).the necessity of highway monitoring is medium; and when the global Moran's I index I $\in$ [0.4,1].the necessity of highway monitoring is high.

4. Conclusion

In summary.the hierarchical detection method for highways proposed in this paper.based on traffic flow stability.entropy method.and global Moran's I index.provides a scientific basis and practical approach for optimizing the setup of highway monitoring systems and enhancing road safety.This research achievement holds significant importance in promoting the construction and development of China's highway monitoring system.

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