

Article

Evaluation of Rural Road Traffic Safety in Loess Plateau Gully Area of China

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Abstract: In order to solve the safety ambiguity problems in the construction and use of rural roads in the gully area of the Loess Plateau, this paper proposes a safety assessment method based on the normal cloud model (NCM). First, a safety assessment index system is constructed by combining the key features of road traffic safety, and the weight coefficients of each index are determined by the entropy weight method (EWM) to set the assessment criteria. Then, the cloud eigenvalue of each indicator is calculated by using the normal cloud model to clarify the degree of its affiliation to different safety levels, which fully reflects the randomness and ambiguity in the assessment process. Finally, this paper selects a typical rural road in the gully area of the Loess Plateau for example analysis. The results show that the assessment method not only reduces the subjective influence of the evaluation criteria, effectively solves the problem of indicator ambiguity, and provides a reliable scientific basis for improving road safety, but also provides lessons and references for the improvement of transportation safety in other similar areas; improves the safety and security capacity and service level of regional roads; meets the needs of the rural masses for safe and comfortable travel; enhances the people's sense of well-being, accessibility, and sense of security; boosts rural development; and better promotes the optimization of regional and even nationwide transportation services and service quality.

Keywords: safety management; gully areas; rural roads; normal cloud model; safety evaluation



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1. Introduction

1.1. Background

The construction of rural roads in China has made remarkable achievements as it develops in depth, but it still faces many challenges, especially the urgent need to solve the problem of safety in complex geographic environments. With the continuous advancement of new rural construction [1] and the “Four Good Rural Roads” [2] construction boom in the country, as of the end of 2022, the total mileage of China's rural roads reached about 4,466,000 km, and the rate of townships and villages [3] equipped with the conditions for access to hardened roads reached 99.64% and 99.47%, respectively. However, for a long time, the construction of rural roads has been characterized by low construction standards, inadequate supervision, and lack of post-maintenance [4], while the special

characteristics of the geographic environment of the Loess Plateau gully area [5] have led to a large number of dangerous factors in the design and construction process, resulting in increasingly significant safety problems in use.

As for the management of rural road traffic safety and the construction of mechanisms [6], the United States, Canada and other countries have more mature policy guidelines for road safety audits [7], in terms of construction management and road maintenance and other governance measures. Since the 1960s, the United States has introduced relevant laws and regulations and standardized management [8] to regulate the whole process of rural road planning, construction, management, and maintenance. Since 2004, the Senate and the House of Representatives have passed bills to promote state traffic safety laws, directly fund the renovation of hazardous road sections for countryside management, establish traffic safety databases, and promote new traffic safety research, among other points, through source management [9]. In recent years, the “USDOT National Roadway Safety Strategy”, “Zero Roadway Fatalities”, “Manual of Uniform Traffic Control Devices” Revision, and so on [10] have been released to promote the construction of national traffic safety. Canada actively adopts engineering measures, safety law enforcement, safety education, and other measures for safety management of rural roads, and Canadian provinces and territories have adopted safety and security measures such as improvement of sight distances, perfecting of traffic signs and marking, installation of additional warning lights, installation of additional turning lanes, increase of illumination, and speed bumps, and so on. In 2022, the World Health Organization (WHO) and the United Nations (UN) jointly formulated and released the “Global Plan for the Decade of Action for Road Safety 2021–2030” [11], which calls for road safety to become a core value, and for rural roads to become a core value. As a branch of road construction in China, the improvement of rural road safety is urgent, and it is necessary to establish a complete planning, construction, and management system. In addition, rural road traffic safety evaluation, as the basis for its safety improvement, is a key link in ensuring the safety of rural road use and improving the quality of the overall transportation environment, so it is necessary to raise the importance of its objectivity and accuracy.

1.2. Literature Review

At present, China has not yet formulated unified and comprehensive rural road traffic safety measures [12] and lacks a comprehensive and targeted safety evaluation index system [13].

Domestic scholars have made significant progress in the field of road traffic safety research, and most of their studies focus on traffic accident prediction [14], traffic safety assessment [15], and traffic route design [16]. Xie and Kong (2021) [17] established a time series combination prediction model based on the Auto Regressive Integrated Moving Average Model (ARIMA) and eXtreme Gradient Boosting Model (XGBoost) to predict the trend of traffic-accident-related indicators. In Dong et al. (2024) [18], based on multi-source traffic big data, a data-driven multi-granularity and multi-view spatio-temporal topology map was constructed, and a traffic accident risk prediction model based on a dynamic spatio-temporal map network was designed to achieve accurate prediction of road-segment-level traffic accident risk. Li et al. (2019) [19] introducing the theory of unconfirmed measure, constructing a vulnerability assessment model of mountain road systems, based on multi-factor coupled entropy weight-uncertainty measure theory, making the results of example analysis more effective. Gao et al. (2023) [20] determined the weights of assessment indexes by hierarchical analysis method, weighted the BPA (bypass air) of each index, and used Dempster–Shafer evidence theory to fuse the weighted BPA to obtain the results of traffic safety assessment. Zhang et al. (2023) [21] proposed the concept of

combining the entropy weight method and cloud model, using the entropy weight method to correct the weights of evaluation indexes, and using the cloud model to assess the risk level of traffic safety, which makes the results of the example analysis more effective. In Zhu et al. (2023) [22], based on a genetic algorithm, an automatic optimization and safety evaluation of highway three-dimensional spatial routing scheme is realized by constructing a highway alignment constraint model, highway automatic routing optimization model, and running speed prediction model. Li (2024) [23] used examples to establish a digital elevation model, to fully grasp and build the terrain, and then a road vectorization method to achieve the three-dimensional model construction of highway routing, so as to judge the advantages and disadvantages of routing schemes for the design of highway routing, to provide the necessary ideas and references. China has introduced advanced technologies and methods for road traffic safety research but lacks comprehensive and targeted research on road traffic safety in rural areas and has not yet formulated unified and comprehensive measures to improve road traffic safety in rural areas.

Foreign scholars have also made significant progress in this direction in recent years, forming a systematic research system. Antonella et al. (2023) [24] analyzed the traffic accident data of Italian rural roads by using the random forest model, found that road geometric characteristics and traffic flow are important factors affecting the occurrence of accidents, and realized a high-precision prediction of the probability of traffic accidents through the construction of a multilayer neural network model that achieves high-precision prediction of the probability of traffic accidents. Mohamed et al. (2023) [25] proposed a framework for traffic safety assessment based on big data analysis, which combines real-time traffic data, historical accident data, and road condition data to achieve a comprehensive assessment of the traffic safety situation, and through data fusion and intelligent analysis, it is able to effectively identify traffic safety hazards. Zhang et al. (2023) [26] investigated the impact of different road design schemes on traffic safety, identified the optimal road design scheme through simulation and field verification methods, and concluded that the use of split-lane design and the addition of traffic signs can significantly reduce the incidence of traffic accidents. Han et al. (2023) [27] proposed a reliable and fast road alignment parameterization method and optimization design framework, quantitatively evaluated road safety and comfort based on vehicle dynamics simulation, quickly estimated construction costs through automatic calculation of earthwork quantities in BIM, automated the optimization process by using data interoperability between the BIM environment and an external vehicle driving simulation software, and established a BIM model of the road in the preliminary design stage, which realized a dual-objective road alignment design that takes into account both driving safety and construction economy. Overseas research on road traffic safety evaluation combines advanced methods such as machine learning [28], big data analysis [29], and the construction of numerical models [30], which provide important references and lessons for the development of this study.

Currently, the commonly used methods for safety evaluation include fuzzy synthesis [31], object-element method [15], BP neural network [32], and unconfirmed theory [33]. Although a variety of methods have been applied to road safety evaluation, it is difficult for most of the evaluation methods to take the uncertain information and stochastic factors of safety risks into account and to enhance the rationality and reliability of the evaluation results through quantitative evaluation. At the same time, the research and application of road traffic safety evaluation are mainly concentrated in urban areas, while the traffic environment in rural areas is significantly different from that in cities, such as poorer road conditions, relatively weak traffic management, and different characteristics of traffic accidents, which make the existing traffic safety evaluation methods for urban roads not fully applicable to rural areas. Therefore, it is necessary to study the road traffic safety

evaluation system specifically for rural areas in order to more accurately identify and solve the safety problems unique to the region, so as to effectively reduce the incidence of traffic accidents and ensure the travel safety of rural residents.

1.3. Research Object and Methods

Road safety in rural areas refers to the comprehensive means of optimizing road infrastructure [34], improving the traffic environment, equipping safety facilities, implementing effective management measures, and carrying out traffic safety education in various aspects of the road traffic system in rural areas. To ensure that motorists, pedestrians, and other traffic participants can minimize the occurrence of accidents and reduce the frequency and severity of traffic accidents [35] when using roads, so as to safeguard their lives and properties. The concern of this study is the safety evaluation of rural roads in the gully area of the Loess Plateau.

Loess Plateau is one of the four major plateaus in China and is also a world-famous plateau covered by a large area of loess. It is covered by thick layers of loess, except for many stony mountains, which have been strongly eroded by flowing water over a long period of time, gradually forming a special natural landscape with thousands of gullies and ravines and a fragmented topography. Loess Plateau is a vast area, with deep soil, complex geomorphology, and serious soil erosion [36]. The complex topographic and geological conditions and fragile ecological environment of the Loess Plateau gully area play an important role in highway construction projects, and the current situation of rural road construction in the Loess Plateau gully area is also problematic, as shown in Table 1.

Table 1. Existing problems of rural roads in gully areas of Loess Plateau.

Serial Number	Problem	Concrete Content
1	Significant geographic features	The gully area accounts for about 40% of the total land area of the region. Most of the rural roads are currently situated in the gully area of the region, which is characterized by a circling type of road, which has a relatively long total mileage despite the short straight-line distance of the road [37].
2	Low standard of road construction	Affected by economic conditions and geography, the linear design of some sections of roads is not smooth, does not meet the requirements of the norms, and has potential safety hazards, such as many sharp curves, poor visibility, and the existence of excessive longitudinal slopes. Many through-village roads are maintained by the villages themselves, with a lack of funds and poor maintenance techniques, resulting in a lack of road maintenance and serious damage at a later stage [38].
3	Roadbed issues	The special topography and geomorphology of loess gully areas lead to roads that are prone to waterlogging, and the loess itself has poor engineering characteristics, so if the reinforcement measures are insufficient and the drainage facilities are imperfect, the foundations will be easily washed away by the rain, which will ultimately lead to the collapse of the road surface and uneven settlement. On the other hand, the phenomenon of overloading of rural transportation vehicles is serious and causes greater damage to the road surface [39].
4	Lack of security facilities	Most areas focus only on the construction of the main project, and the installation of safety facilities is neglected due to insufficient supporting funds or low installation standards. Some sections of the road are narrow and have blind spots, but no signs, markings, guardrails, sight-guiding facilities, etc. have been installed, greatly increasing the risk of traffic safety [40].
5	Complexity of traffic composition	Compared to highways, the situation of the types of vehicles running on rural roads is more complex, including different types of large trucks, tractors, buses, bicycles, and other vehicles [41].

The Loess Plateau gully area has unique natural geographic and climatic conditions, and choosing the Loess Plateau gully area as a case study can not only provide specific and feasible solutions for road traffic safety in the Loess Plateau gully area, but also provide lessons and references for traffic safety improvement in other rural areas. The

complex terrain, large slopes, and poor road surface conditions in the Loess Plateau gully area, coupled with natural disasters such as soil erosion [42] and landslides [43] caused by rainfall, make the road conditions highly susceptible to change, which increases the potential traffic safety hazards. In addition, the region has a relatively low level of economic development, road traffic facilities and management tools are relatively backward, and traffic safety awareness is relatively weak, further exacerbating the frequency and severity of accidents. Establishing an evaluation system based on its characteristics can provide a more comprehensive coverage of the types of risks [44], make the evaluation system more accurate and applicable, reflect the common challenges faced by many rural areas in terms of traffic safety, and be effectively applied to other rural areas with complex terrain, relatively backward infrastructure, and weak traffic safety management.

This study establishes a rural road traffic safety evaluation system based on the normal cloud model (NCM). The normal cloud model (NCM) [45] is a probabilistic reasoning and uncertainty analysis method that transforms qualitative concepts into quantitative representations. This method is based on the probability density function [46] and cloud modeling theory [47] and is implemented by means of forward and inverse cloud generators [48]. The normal cloud model can not only reflect the uncertainty of qualitative concepts, but also reveal the ambiguity of the evaluation object. It has been applied in many fields, such as ecological risk assessment [49], resource assessment [50], and slope stability evaluation [51]. In the process of creating road traffic safety evaluation grades, there are inevitably certain safety ambiguities, so this paper introduces the normal cloud model to establish a road traffic safety evaluation model, and builds a targeted safety evaluation index system based on a full analysis of the safety characteristics of rural road traffic in the gully area of the Loess Plateau [52]. Based on the normal cloud model, the road traffic safety evaluation criteria are set, and through the normal cloud model, the computation is performed. The road traffic safety evaluation level is derived to provide a reliable basis for road reconstruction and expansion as well as safety enhancement.

1.4. Purpose and Significance

The rural road traffic safety evaluation system in the gully area of the Loess Plateau constructed on the basis of the normal cloud model in this paper is of theoretical and practical significance. With the rapid development of China's rural economy and the acceleration of the urbanization [53] process, the construction and management of rural roads are facing more and more challenges. Especially in the gully areas of the Loess Plateau, the road safety problem is particularly prominent due to the complex terrain and variable climate. However, the existing rural road safety evaluation index system has certain deficiencies in theory and practice, which makes it difficult to comprehensively and accurately reflect the actual situation of road safety. In this paper, a multi-level and multi-dimensional safety evaluation system is constructed by quantitatively analyzing the indicators of four aspects, main engineering, traffic environment, safety facilities, and management facilities, through the normal cloud model [54]. The system can not only quantitatively assess the safety status of the road, but also identify the key factors affecting road safety, theoretically improve the accuracy and objectivity of the evaluation system, provide theoretical support for solving the road safety problems in the gully area of the Loess Plateau, and improve the evaluation system [55] of rural road safety problems.

This paper systematically identifies and evaluates road traffic safety risks through scientific methods and finally proposes a series of improvement strategies. The whole paper is divided into six sections, as follows: Part one introduces the background of the study, describing the geographic characteristics of the Loess Plateau gully area and its impact on rural road construction. The second part and the third part describe in

detail the methodology of the normal cloud model adopted in this paper, introduce the theoretical basis of the model and its application advantages in traffic safety evaluation, construct the road traffic safety evaluation index system [56] based on a literature analysis, standard combining, and on-site research, and explain in detail the weights of each index and the evaluation criteria. In the fourth part, an empirical analysis is carried out, and the established evaluation model is applied to assess the safety risk [57] of typical rural roads in the gully area of the Loess Plateau, and the validity and reliability of the model are verified. Based on the results of the empirical analysis, the fifth part puts forward specific improvement suggestions for the main engineering [58], traffic environment, safety facilities, and management facilities, aiming to improve the safety level of rural road transportation in various aspects. Part five also summarizes the research results of the whole paper, points out the limitations of the study as well as future research directions, and provides a reference for further optimizing and improving rural road safety management.

This study proposes a series of innovative methods and ideas in the field of road traffic safety evaluation in the gully area of the Loess Plateau [48]. First, by combining the normal cloud model with the entropy weight method [59], a comprehensive evaluation model that can effectively deal with ambiguity and uncertainty and reduce subjective interference is constructed, which significantly improves the scientificity and reliability of the evaluation results. Secondly, an evaluation system, covering four first-level indicators including main engineering, traffic environment, safety facilities, and management facilities, and its second-level quantitative calculation indicators are constructed, which fully take into account the special geographic and climatic conditions of the region. The safety assessment method based on the normal cloud model significantly improves the accuracy and objectivity of the road safety evaluation through the practical application in the gully area of the Loess Plateau. By comprehensively evaluating all stages of road construction, utilization, and management, it provides targeted and comprehensive construction standards and bases for road projects. The system is not only able to quantitatively assess the safety status of roads, but also to identify the key factors affecting road safety, theoretically improve the accuracy and objectivity of the evaluation system, and provide theoretical support for solving the road safety problems in the gully area of the Loess Plateau. At the same time, through the comprehensive assessment of the road construction [60], use, and management of all stages of the road project, it provides a targeted, comprehensive construction standards and basis. This not only improves the safety and security capacity [61] and service level of regional roads but also meets the needs of the rural masses for safe and comfortable travel; enhances the people's sense of well-being, accessibility, and security; boosts rural development; and even nationwide transport services.

2. Methodology

2.1. Normal Cloud Model

In security assessment, common problems are vagueness, randomness, and uncertainty. Methods for solving these problems include the use of techniques such as fuzzy mathematics [62], probability statistics [63], and uncertainty analysis [64]. In 1995, academician Li proposed cloud modeling theory based on the above methods, which can transform qualitative concepts into quantitative descriptions through cloud computing and reasoning. Cloud modeling is universal and has been successfully applied in the fields of data mining, rock classification, and system evaluation [65].

The normal cloud model is a model that maps qualitative concepts to quantitative representations [66]. It introduces *Ex* (expected value), *En* (entropy), and *He* (hyper entropy) to construct “cloud drops” as random variables. Although there is no regularity in a single cloud droplet, the cloud droplets obtained through multiple operations and analysis

eventually generate a cloud diagram (Figure 1). As the number of cloud drops increases, the overall characteristics of a certain qualitative conceptual indicator will gradually emerge.

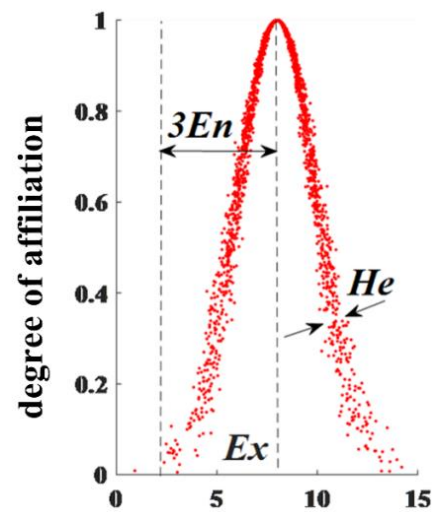


Figure 1. Schematic diagram of cloud model. $Ex = 8$, $En = 2$, $He = 0.1$, $n = 1000$ (image source: created by the author).

Expectation (Ex) is the point that best represents the qualitative concept and is a typical sample in concept quantification [67]. Entropy (En) is the measurable granularity of the qualitative concept, reflecting the degree of discretization of the cloud droplets in the cloud diagram, and when the value of En is larger, it indicates that the cloud droplets are less likely to be accepted. Hyperentropy (He) is used to describe the degree of cohesion of each cloud droplet, and it can also be viewed as an indicator of the thickness of the cloud. Finally, n denotes the number of times the operational analysis is performed, that is, the number of cloud droplets.

In order to be able to describe the fuzzy concepts more clearly and explain the fuzziness and randomness of the things analyzed and the correlation between them, the normal cloud model uses the forward cloud generator (FCM) to map the qualitative concepts into quantitative representations [68]. The steps of vulnerability assessment using the forward cloud generator are shown in Figure 2.

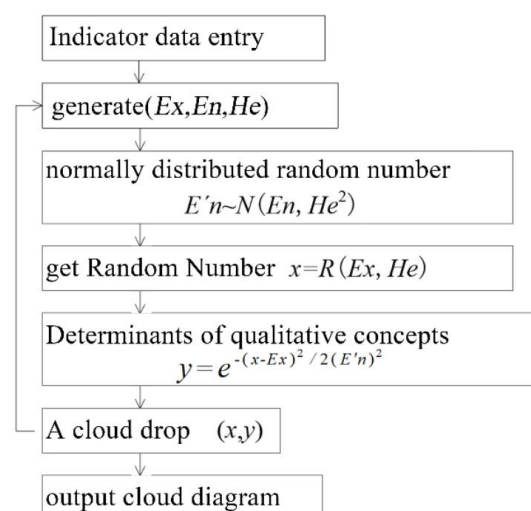


Figure 2. Positive cloud generator operation process (image source: created by the author).

2.2. Build the Normal Cloud Model

- (1) Establish a system of safety evaluation indicators $X = \{x_1, x_2, \dots, x_n\}$ and evaluation level thresholds [69] $V = \{v_1, v_2, v_3, v_4, v_5\}$.
- (2) Determine the evaluation index weight set W .

The entropy weight method (EWM) [21] involves quantifying and synthesizing the information of each unit to be evaluated in the evaluation process. The basic principle is to determine the objective weights based on the degree of variability of the indicators. In order to reduce the influence of subjective factors on the weight of indicators, this paper adopts the EWM to calculate the weight of each evaluation indicator $W = \{w_1, w_2, \dots, w_n\}$. The specific calculation method refers to the literature [70]. A number of researched rural mountainous transportation projects are used as the weight calculation samples. The results are shown in Table 2.

- (3) Construct the affiliation matrix $R = (r_{ij})_{n \times m}$.

The values of the indicators are entered into the forward cloud generator to calculate the affiliation $y(x)$ of the evaluation indicators, and the element r_{ij} in the affiliation matrix [71] represents the affiliation of the indicator x_i corresponding to the j rank v_j . The upper and lower limit boundary values of indicator x_{ij} are x_{ij}^1 and x_{ij}^2 , respectively, and Ex and En are calculated respectively, while He is generally taken by test. According to the number of indicators and the credibility of the results, this study cycles the forward cloud generator 2000 times so that $r_{ij} = \sum_{k=1}^{2000} r_{ij}^k / 2000$ is the degree of affiliation.

$$Ex = (x_{ij}^1 + x_{ij}^2) / 2 \quad (1)$$

$$En = |x_{ij}^1 - x_{ij}^2| / 2.355 \quad (2)$$

- (4) Evaluation results

The fuzzy subset $B = W \cdot R = (b_1, b_2, \dots, b_n)$ on the evaluation level threshold V is derived by fuzzy conversion using the affiliation matrix R and the weight set W . $b_j = \sum_{i=1}^n w_i \times z_{ij}$, $j = 1, 2, \dots, m$ represents the affiliation of the road traffic safety evaluation object to the j level, and the safety level corresponding to the maximum affiliation is selected as the evaluation result according to the calculation results.

The study shows that the use of cloud-model-based evaluation indicators can reflect the connotation of the indicators more accurately, which is more advantageous than the traditional method. In addition, the use of a method that conforms to the calculation rules of the forward cloud generator in calculating the indicator values and determining the evaluation criteria can effectively reduce the impact of indicator ambiguity on the final results.

2.3. Establish a System of Indicators

The road traffic safety evaluation index system is used to comprehensively reflect the comprehensive safety status of a section of the road during a period of use, and it is also the organic embodiment of the evaluation model idea.

For the road traffic in Loess Plateau gully area, its safety risk characteristics have unique complexity and diversity:

- ① The wet subsidence loess area's [72] road surface collapses easily, and foundation damage is significant, which greatly increases the road safety hazards. The wet subsidence of loess makes it settle sharply when it encounters water intrusion, and the roadbed is unstable, thus causing traffic accidents.

- ② The terrain in mountainous areas is variable, the road undulates greatly, and the difficulty of road design and construction increases, making it easy to form accident-prone points [73].
- ③ The road is built on the mountain, and the existence of a large-scale slope reinforcement area [74] becomes a safety hazard that cannot be ignored. Once a landslide or collapse occurs on a slope, it will pose a serious threat to passing vehicles.
- ④ There is an inadequate arrangement of road facilities in rural areas. Compared with cities, road signs, signal lights, and other infrastructure are seriously lacking in rural areas, making it difficult to effectively enforce traffic rules and frequent accidents.
- ⑤ There is a lack of systematic road traffic management. Research has pointed out that scientific traffic management and monitoring systems can significantly reduce the accident rate, but in the gully areas of the Loess Plateau, the investment in this area is obviously insufficient.

There are many influencing factors of road traffic safety in the gully area of Loess Plateau; therefore, this paper firstly summarizes the set of influencing factors of road traffic safety on the basis of a literature analysis, standard combing, and on-site research, following the principles of scientificity, standardization, hierarchy, independence, and sensitivity, and then screens to obtain the system of evaluation indexes of road traffic safety in the gully area of Loess Plateau, which is shown in Table 2.

Table 2. Road traffic safety evaluation index system in gully area of Loess Plateau.

Level 1 Indicators	Level 2 Indicators	Indicator Weights	Security Evaluation Criteria				
			C1	C2	C3	C4	C5
Main engineering	x_{11} Level of foundation damage [75]	0.083	90~100	80~90	70~80	60~70	0~60
	x_{12} Rate of road surface breakage (%) [76]	0.079	90~100	80~90	70~80	60~70	0~60
	x_{13} Skid resistance of road surfaces [77]	0.068	>65	55~65	45~55	35~45	0~35
	x_{14} Road levelness [78]	0.071	90~100	80~90	70~80	60~70	0~60
	x_{15} Visible range (m) [79]	0.058	>75	75~40	40~30	30~20	20~0
	x_{16} Percentage of overrun vertical slopes (%) [80]	0.067	0~10	10~20	20~40	40~70	70~100
	x_{17} Percentage of slope stabilization (%) [81]	0.076	90~100	80~90	70~80	60~70	0~60
Transportation environment	x_{21} Annual average daily traffic (pcu/d) [82]	0.036	0~0.4k	0.4k~0.8k	0.8k~1.2k	1.2k~1.6k	1.6k~2k
	x_{22} Percentage of large- and medium-sized vehicles (%) [83]	0.048	0~20	20~40	40~60	60~80	80~100
	x_{23} Percentage of severe weather in the year (%) [84]	0.026	0~15	15~30	30~45	45~60	60~100
	x_{24} Average speed of representative models (km/h) [85]	0.021	0~15	15~30	30~45	45~60	>60
	x_{25} Percentage of roadside obstacle segments (%) [86]	0.029	0~20	20~40	40~60	60~80	80~100
Safety facilities	x_{31} Ratio of security fence placement (%) [87]	0.099	80~100	60~80	40~60	20~40	0~20
	x_{32} Safety fence performance [88]	0.102	90~100	80~90	70~80	60~70	0~60
	x_{33} Placement rate of sight-guiding facilities (%) [89]	0.046	80~100	60~80	40~60	20~40	0~20
	x_{34} Reduction belt integrity rate (%) [89]	0.033	80~100	60~80	40~60	20~40	0~20
Management facilities	x_{41} Rationality of road safety signs [88]	0.021	80~100	60~80	40~60	20~40	0~20
	x_{42} Intersection signalization coverage (%) [90]	0.019	40~100	30~40	20~30	10~20	0~10
	x_{43} Intersection surveillance coverage (%) [90]	0.031	40~100	30~40	20~30	10~20	0~10

3. Results

This paper is based on the characteristics of road traffic in the gully area of the Loess Plateau, combined with the existing literature on the division of safety evaluation standards, relying on a large number of field studies and testing, identification, and engineering cases. In this study, firstly, on the basis of the literature analysis, standard combing, and on-site research, we summarized the set of road traffic safety influencing factors; then, following

the principles of science, standardization, hierarchy, independence, and sensitivity, we screened and obtained the road traffic safety evaluation index system of the Loess Plateau gully area. According to the risk acceptance criterion [91], the safety level of road traffic in the gully area of the Loess Plateau is classified into five levels: C1 (very high security), C2 (high security), C3 (average security), C4 (low security), and C5 (very low security). With reference to the relevant standards and regulations, the safety evaluation standard is established after comprehensive arithmetic analysis (see Table 3).

Table 3. Normal cloud eigenvalues of rural road traffic safety evaluation indicators in gully areas of the Loess Plateau.

Indicator	Security Level				
	C1	C2	C3	C4	C5
X ₁₁	(95, 4.25, 0.01)	(85, 4.25, 0.01)	(75, 4.25, 0.01)	(65, 4.25, 0.01)	(30, 25.48, 0.01)
X ₁₂	(95, 4.25, 0.01)	(85, 4.25, 0.01)	(75, 4.25, 0.01)	(65, 4.25, 0.01)	(30, 25.48, 0.01)
X ₁₃	(65, 4.25, 0.01)	(60, 4.25, 0.01)	(50, 4.25, 0.01)	(40, 4.25, 0.01)	(17.5, 14.86, 0.01)
X ₁₄	(95, 4.25, 0.01)	(85, 4.25, 0.01)	(75, 4.25, 0.01)	(65, 4.25, 0.01)	(30, 25.48, 0.01)
X ₁₅	(75, 4.25, 0.01)	(57.5, 14.86, 0.01)	(35, 4.25, 0.01)	(25, 4.25, 0.01)	(10, 8.49, 0.01)
X ₁₆	(5, 4.25, 0.01)	(15, 4.25, 0.01)	(30, 8.49, 0.01)	(55, 12.74, 0.01)	(85, 12.74, 0.01)
X ₁₇	(95, 4.25, 0.01)	(85, 4.25, 0.01)	(75, 4.25, 0.01)	(65, 4.25, 0.01)	(30, 25.48, 0.01)
X ₂₁	(0.2k, 169.85, 0.01)	(0.6k, 169.85, 0.01)	(1k, 169.85, 0.01)	(1.4k, 169.85, 0.01)	(1.8k, 169.85, 0.01)
X ₂₂	(10, 8.49, 0.01)	(30, 8.49, 0.01)	(50, 8.49, 0.01)	(70, 8.49, 0.01)	(90, 8.49, 0.01)
X ₂₃	(7.5, 6.37, 0.01)	(22.5, 6.37, 0.01)	(37.5, 6.37, 0.01)	(52.5, 6.37, 0.01)	(80, 16.99, 0.01)
X ₂₄	(7.5, 6.37, 0.01)	(22.5, 6.37, 0.01)	(37.5, 6.37, 0.01)	(52.5, 6.37, 0.01)	(60, 8.49, 0.01)
X ₂₅	(10, 8.49, 0.01)	(30, 8.49, 0.01)	(50, 8.49, 0.01)	(70, 8.49, 0.01)	(90, 8.49, 0.01)
X ₃₁	(90, 8.49, 0.01)	(70, 8.49, 0.01)	(50, 8.49, 0.01)	(30, 8.49, 0.01)	(10, 8.49, 0.01)
X ₃₂	(95, 4.25, 0.01)	(85, 4.25, 0.01)	(75, 4.25, 0.01)	(65, 4.25, 0.01)	(30, 25.48, 0.01)
X ₃₃	(90, 8.49, 0.01)	(70, 8.49, 0.01)	(50, 8.49, 0.01)	(30, 8.49, 0.01)	(10, 8.49, 0.01)
X ₃₄	(90, 8.49, 0.01)	(70, 8.49, 0.01)	(50, 8.49, 0.01)	(30, 8.49, 0.01)	(10, 8.49, 0.01)
X ₄₁	(90, 8.49, 0.01)	(70, 8.49, 0.01)	(50, 8.49, 0.01)	(30, 8.49, 0.01)	(10, 8.49, 0.01)
X ₄₂	(70, 25.48, 0.01)	(35, 4.25, 0.01)	(25, 4.25, 0.01)	(15, 4.25, 0.01)	(5, 4.25, 0.01)
X ₄₃	(70, 25.48, 0.01)	(35, 4.25, 0.01)	(25, 4.25, 0.01)	(15, 4.25, 0.01)	(5, 4.25, 0.01)

Combined with the normal cloud road traffic safety evaluation model, under the premise that the experimental value of hyperentropy (He) is 0.01, the evaluation model established in Section 2.2 of this paper is used to calculate the expectation (Ex) and entropy (En), which in turn leads to the characteristic value of the normal cloud. The specific results are shown in Table 3.

By using MATLAB 2018a software [92] for programming, the normal cloud eigenvalues of each indicator can be obtained, and the normal cloud plots of each evaluation indicator can be further generated, as shown in Figure 3.

Given our limited space, the indicators X₂₂ (large- and medium-sized vehicles) and X₄₃ (intersection monitoring coverage rate) are selected as illustrative examples; see Figure 3 for the X₂₂ and X₄₃ normal cloud diagram.

Indicator X₂₂ (large- and medium-sized vehicles) is a negative indicator: the higher the proportion of large- and medium-sized vehicles, the lower the relative safety of the road. Therefore, the safety grades are ranked in reverse order in the normal cloud diagram. The entropy (En) of each grade of this indicator is 8.49, which means that the probability of various types of vehicles appearing is the same, which is consistent with the reality.

Indicator X₄₃ (intersection monitoring coverage) is a positive indicator: higher intersection monitoring coverage contributes to the improvement of safety. According to the delineation criteria, X₄₃ is low safety at 0–10%, so in the normal cloud diagram, low safety is accepted in a larger range, and the probability of cloud droplets appearing in that segment in the number threshold space is also larger.

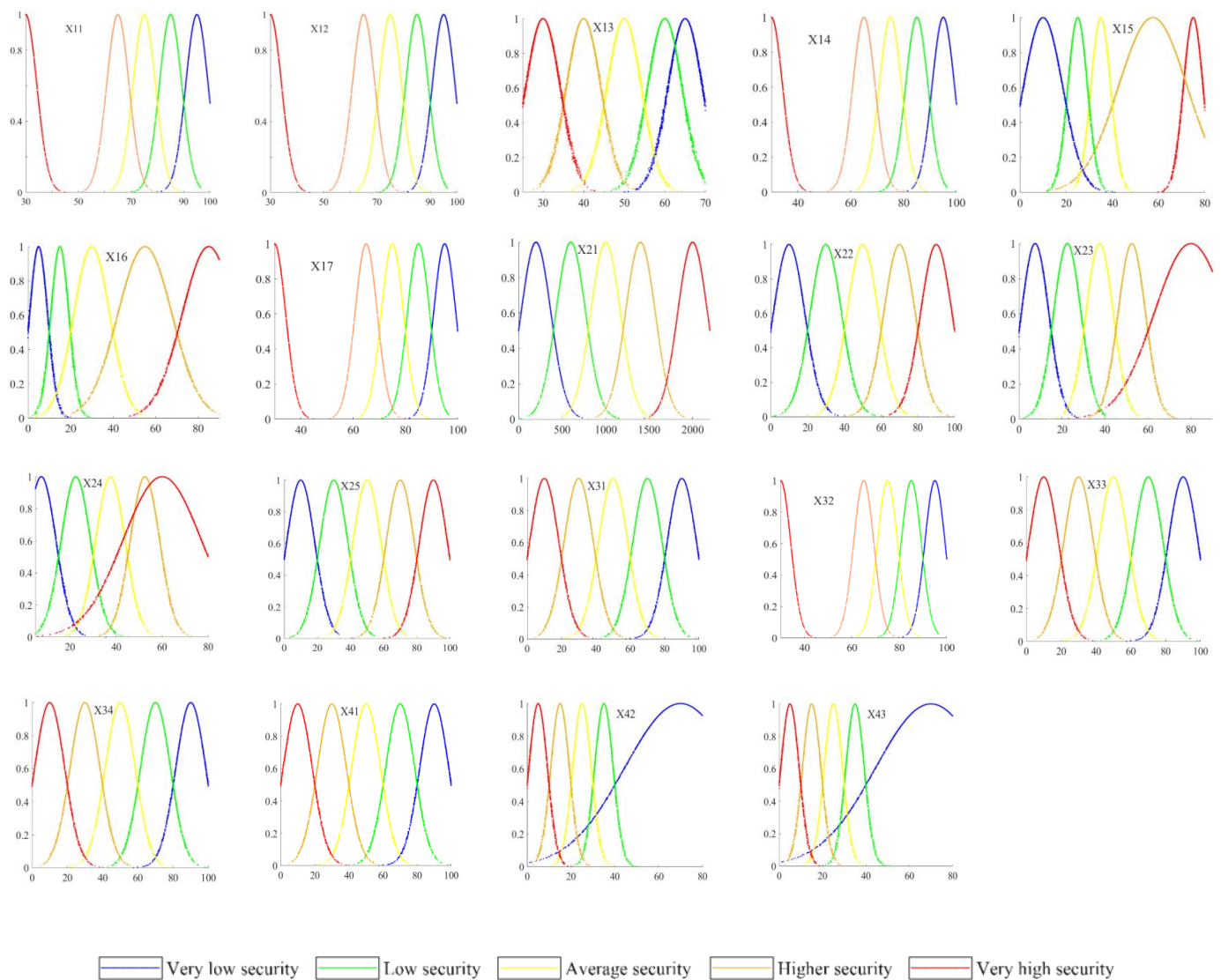


Figure 3. Normal cloud diagram for each evaluation indicator (image source: created by the author).

4. Empirical Analysis

4.1. Overview of the Road Section

Sanshing Village in Hengshan County is located in the southern region of the county, which is a typical Loess Plateau gully area, with Liangwang [93] noting undulating gullies and ravines, an average elevation of 1100 m, and undulating differences of up to more than 200 m. In order to accelerate the construction of new rural areas in the region, the government invested in the construction of a through-village highway from Hanqiao Township to Sanshing Village in 2017, with a total length of 8.4 km, including the main road and the auxiliary road. The route plan is shown in Figure 4. This section of through-village highway is designed as a two-way lane, and part of it as a one-way lane, with a traveling width of 3–6 m and designated speed of 40 km/h.

The main road of the line is cement pavement, and part of the auxiliary road is gravel and brick. The whole line is set up with a 250 cm brick roadside guardrail, no central divider, traffic marking, and only a small number of traffic signs and safety designs set up on important sections.



Figure 4. Line overview (image source: created by the author).

4.2. Cloud Modeling Computing

Road traffic safety evaluation data are from field measurements of the Planning Bureau, the Transportation Bureau, and a meteorological website. The data collected in the research process will be brought into the forward cloud generator to obtain the evaluation index affiliation matrix, the index weight vector, and affiliation matrix fuzzy conversion to obtain the index comprehensive affiliation, according to the principle of maximum affiliation, through the safety evaluation model, to derive the affiliation of each evaluation index corresponding to each level (see Table 4).

Table 4. Results of road traffic safety evaluation.

Indicator	C1	C2	C3	C4	C5	Security Level
Main engineering	0.103	0.165	0.517	0.128	0.085	Average security
Transportation environment	0.245	0.352	0.171	0.124	0.114	Higher security
Safety facilities	0.087	0.166	0.156	0.337	0.254	Low security
Management facilities	0.125	0.163	0.331	0.156	0.221	Average security

Due to limited space, normal cloud plots are only plotted for the indicators X_{14} (pavement smoothness) and X_{23} (share of severe weather), as shown in Figure 5.

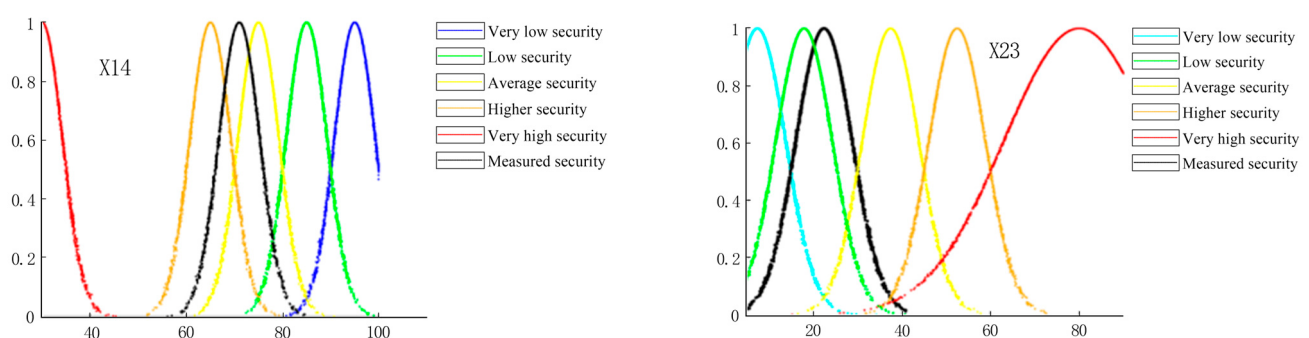


Figure 5. Indicator normality cloud (image source: created by the author).

The indicator X_{14} (pavement leveling) is positive: the higher the pavement leveling, the greater the increase in safety. According to the division standard, X_{14} is low safety at 0–60, so in the normal cloud map, low safety is accepted in a larger range, and the probability of cloud droplets appearing in that section in the number threshold space is also larger.

Indicator X_{23} (severe weather percentage) is a negative indicator: the higher the percentage of severe weather, the lower the relative road safety. Therefore, safety ratings are reverse-ordered in the normal cloud diagram.

4.3. Roadway Safety Analysis

(1) Main engineering

This section of the road is in the area of wet subsidence loess, and the foundation is subject to rainwater erosion. Due to the low construction standard, the foundation wet subsidence [94] treatment is insufficient, resulting in foundation damage in some sections of the road. In addition, there are more large vehicles on the road connected with the county road, and pavement damage occurs on part of the road. Most of the road sections are built on the mountains. The terrain factors lead to 23% of the exceeding longitudinal slopes [71] within the road sections, and the roads are constantly undulating and have more sharp turns, while the sight-inducing facilities [95] are insufficiently arranged, resulting in the sight distance not being sufficient to meet the driving needs. Therefore, the safety of the main engineering is average, which is consistent with the evaluation results.

(2) Transportation environment

Given the remote and undeveloped location of the road section, the daily traffic volume is low. According to the local meteorological information, the annual percentage of severe weather is 23%, and the safety level is C2. Indicator X_2 (traffic environment evaluation safety level) is C2, which is in line with the actual situation.

(3) Safety facilities

The scale of the investment did not allow for full coverage of safety features on the route, particularly the lack of sight-inducing features. The overall safety is enhanced by the presence of 250 millimeter brick guardrails on the main road. The indicator X_3 (safety facilities evaluation result) is C4, biased towards C5, which is poor and does not provide safety.

(4) Management facilities

Considering the low grade of the highway, the design and construction of the road was not equipped with signals or monitoring facilities, which reduces the regulation of unsafe driver behavior, but the weights of indicators X_{41} , X_{42} , and X_{43} are low, so the evaluation grade is C3.

5. Discussion

This article constructs a safety evaluation system for rural roads in the gully area of the Loess Plateau based on the normal cloud model and systematically identifies and evaluates road traffic safety risks. Through the above empirical analysis, the road traffic problems in rural areas of the Loess Plateau gully region are concluded, and the following road traffic safety improvement strategies are proposed in order to improve the overall safety level of rural roads in this region:

5.1. Main Engineering

The special geological structure and climatic conditions of the Loess Plateau gully area lead to serious road foundation issues and pavement damage; the foundation treatment should be strengthened during the road construction process, and advanced geosynthetics [96] such as geotextiles and geogrids should be used to reinforce the foundation, so as to enhance the stability of the foundation and its scouring-resistance ability. In addition, the drainage system should be improved, and reasonable interceptor ditches and drainage

ditches should be constructed to ensure that the water in the roadbed and pavement can be discharged in time when the rainfall is concentrated, so as to avoid the settlement [97] of the roadbed and the destruction of the pavement due to the accumulation of water. Starting with construction and design standards, road design standards should be improved and road alignment design optimized, especially in sharp turns and over-limit longitudinal slope sections, and warning signs and speed limit facilities should be reasonably set up to ensure driving safety.

5.2. Transportation Environment

It is recommended to optimize traffic flow [98] management, rationalize traffic control measures, and implement diversion measures to avoid traffic accidents caused by sudden increases in traffic. In areas where inclement weather is frequent, it is necessary to establish comprehensive emergency plans and emergency facilities and increase anti-skid facilities and snow- and ice-removing equipment on roads. At the same time, the introduction of intelligent traffic management systems, real-time monitoring, and early warning of road traffic conditions would enhance the road traffic contingency and management capacity.

5.3. Safety Facilities

It is recommended to increase safety guardrails and anti-collision facilities, especially on high-risk roads such as slopes, sharp curves, and steep slopes; choose durable materials for guardrail construction; and conduct regular inspections and maintenance to ensure their effectiveness. It is also recommended to improve road signs and markings; set up clear and easy to recognize traffic signs and markings, especially in the blind spots and accident-prone sections; install warning signs and speed limit signs; and regularly update and maintain the signs and markings to ensure that they are clearly visible. In addition, sight-inducing facilities, such as reflective signs and reflective paints, should be installed to improve the reaction time of drivers in poor-sight-distance sections and reduce the occurrence of traffic accidents.

5.4. Management Facilities

Strengthening road monitoring and management, installing traffic monitoring equipment on major road sections and accident-prone areas, and combining it with artificial intelligence technology to realize intelligent analysis of traffic flow and accident early warning, so as to detect and deal with traffic violations in a timely manner, are recommended. It is also recommended to establish a road inspection system, increase the frequency and coverage of inspections, ensure the timely detection and resolution of damage to road facilities, and ensure that road facilities are in good operating condition. In addition, it is necessary to strengthen traffic safety education for rural residents and drivers, to raise their awareness of traffic safety and reduce traffic accidents caused by human factors by means of traffic safety campaigns, the distribution of safety brochures, and the conduct of training.

6. Conclusions

This study clarifies the road safety risk level through road traffic safety evaluation and then develops proactive control measures to reduce the safety risk. The study firstly analyzes the safety status of rural road traffic in the gully area of the Loess Plateau and derives its safety characteristics such as significant geographic features, low road construction standards, many roadbed issues, lack of safety facilities, and complex traffic composition, which provides the basis for model establishment and indicator selection. In order to obtain comprehensive, reasonable, and reliable evaluation results for the complexity and uncertainty of rural road traffic safety risk, this study chooses normal cloud theory to establish the evaluation model, adopts the entropy weighting method to obtain the weights

of indicators in order to reduce the influence of subjective factors, constructs the affiliation matrix $R = (r_{ij})_{n \times m}$ cyclic calculations to obtain the normal cloud diagram, and through fuzzy conversion, obtains the maximum affiliation degree of each indicator to determine the results of the evaluation of the safety level. Considering the specificity of the normal cloud model, this study fully analyzes the safety risk characteristics of rural road traffic in the gully area of the Loess Plateau, and establishes a road traffic safety evaluation index system that includes four first-level indexes, namely main engineering, traffic environment, safety facilities, and management facilities, with quantitatively calculated second-level evaluation indexes underneath. By applying the established evaluation model and evaluation index system in empirical analysis, an accurate and reliable safety risk level of the road section is obtained, which is in line with the actual situation, indicating the practicality and reliability of this method in the process of rural road traffic safety evaluation, and providing effective support for the reconstruction and expansion of the road as well as its safety improvement.

This study uses the normal cloud model combined with the entropy weight method to establish a set of indicators and a system that are more suitable for dealing with the ambiguity and uncertainty in road traffic safety evaluation. The method can more accurately reflect the intrinsic characteristics of road safety conditions and effectively reduce the influence of human subjective factors on the evaluation results compared with traditional evaluation means. Through empirical analysis, the reliability and practicality of the model are verified, providing a solid scientific basis for road reconstruction and safety improvement.

However, this study also has some limitations. This study focuses on the traffic safety of rural roads in the gully area of the Loess Plateau and constructs an evaluation index system based on the normal cloud model and entropy weight method. The research results show that the model has high practicality and reliability in dealing with the ambiguity and uncertainty in road traffic safety evaluation. However, due to the specificity of the research object, the applicability of the research results in other geographical regions may be limited. Therefore, if the model is applied to other scenarios, it is recommended that it be adjusted and optimized according to the specific characteristics of different regions, especially in terms of indicator weights and evaluation criteria. The accuracy and reliability of the model in the evaluation of road traffic safety in different regions can be improved through locally adapted improvements.

This study contributes to society, government, and people in many ways. For the government, the results of the study provide a scientific basis for the formulation and implementation of more effective road safety policies and management measures, optimize the efficient use of transport infrastructure and resources, and enhance the science and accuracy of traffic management through big data analysis and risk assessment techniques. On the social level, the systematic road safety improvement program proposed by this study can help reduce traffic accidents in rural areas, safeguard public life and property, and promote the economic development of rural areas and the sustainability of the regional economy. In addition, the scientific methodology and technical tools of the study provide new research ideas for academics and promote technological innovation in the field of road traffic safety. In the future, this research will further promote the model's application, enhance the integration of intelligent traffic management systems, and develop a dynamic traffic safety management model adapted to climate change, so as to promote the intelligent and scientific management of rural road traffic safety.

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