A Cask Evaluation Model to Assess Safety in Chinese Rural Roads

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Abstract: Suburban roads are an important part of China’s road network and essential infrastructure for rural development. Poorly designed road curves and scarcity of traffic signs have caused an excessively high traffic accident rate in plain topographical areas. In this study, an approach to evaluate and improve rural road traffic safety is introduced. Based on fuzzy and cask theory and weighted analysis, a cask evaluation model is built. It provides a quantitative instant method for analyzing road safety in the absence of traffic accident information or rigorous road space data, by identifying dangerous sections and key impact factors, and ultimately help to put forward traffic safety improvements. Based on the application to a specific section of Xiaodang Central Road in the Fengxian District of Shanghai, the result shows that the pavement conditions of cement-hardened dual-lane rural roads was good, but traffic safety was poor. Missing traffic signs, unreasonable road alignment, and poor roadside conditions were the main problems. Finally, improvements of the short-stave subsystem were proposed: the location of guide signs and roadside conditions should be improved, and the number and efficacy of the rural road traffic signs need to be increased, and markings should be and receive regular maintenance.

Keywords: rural road; traffic safety; fuzzy theory; cask evaluation model; road improvement measures

1. Introduction

In China, traffic accidents cause an enormous number of casualties and extremely high property losses every year. Although a single factor, such as negligence of drivers may be confirmed as the main cause of accident, most of the traffic accidents are due to a number of factors, and other important factors such as the road design and/or difficult driving conditions related to road conditions are often ignored. Road traffic is a large system composed of people, vehicles, roads, and traffic safety is closely related to all of these factors. As the foundation and carrier of road traffic, the influence of roads on traffic safety cannot be ignored [1]. Factors concerning road design and condition play an extremely important role in initiating traffic accidents. Scholars from the Soviet Union have reported that the impact of poor road conditions is a direct or indirect cause of 70% of traffic accidents, and this has been confirmed by similar research results from the European Union [2]. Therefore, assessment of the safety of road conditions is an important measure for reducing traffic accidents [3].

Rural roads, which are crucial for rural economic development, agricultural production, and rural living conditions, are an important part of the overall road network [4]. Construction of rural roads has greatly facilitated travel for rural residents and promoted the local economic development [5]. During the process of urbanization, the construction of rural traffic environments is frequently ignored, and the safety of urban traffic environments is often emphasized at the expense of that of suburban
traffic environments. It is unfortunate that rural roads act as auxiliary collector/distributor roads for urban roads and are used with the same intensity as urban roads. The unsafe driving conditions on rural roads harm not only the lives and vehicles of drivers, but also the lives and property of residents living nearby.

At present, many scholars are studying traffic accidents and their causes on the high-grade highway and urban roads, for which safety assessment technology is more advanced. Compared with highway and urban roads, research on rural road safety has received limited attention. Research on rural road safety is of great significance to safeguarding the fundamental interests of farmers and promoting sustainable development of rural economies [3].

Road traffic safety assessment is a new technology for preventing traffic accidents and improving traffic safety [6]. Factors impacting traffic safety can be determined through the evaluation of hidden risks that may cause traffic accidents, objective descriptions of road safety performance, and trends in road safety. Such information can help prevent and reduce traffic accidents, thereby improving road safety, as well as greatly reduce the cost of road operation and management [7,8]. Therefore, evaluation of road traffic safety is a primary focus for transportation system development.

This research aims at introducing a cask evaluation model to evaluate and improve rural road traffic safety based on fuzzy theory, weighted analysis, and cask theory, and then this rural road traffic safety model is practically applied to evaluate and improve the safety performance of Xiaodang Central Road in the Fengxian District of Shanghai. Through identifying dangerous sections and key impact factors, it provides a quantitative method for analyzing road safety in the absence of traffic accident information or rigorous road space data, and ultimately help to put forward improvements. The paper first conducted a comprehensive review of the road traffic safety and specifically rural road traffic safety assessments in China and abroad, then shows a cask evaluation model based on analyzed methods and main factors influencing road traffic safety. Then, in the case study, rural road traffic safety model is practically applied to evaluate and improve the safety performance of a specific road in Shanghai. Based on the assessment result, a number of recommendations were offered to improve strategies for rural road safety. This approach can provide a quantitative method for analyzing road safety in the absence of traffic accident information or rigorous road space data, and ultimately help to put forward improvements to the current status of rural road traffic safety in China.

2. Reviews of Methods

Government transportation sectors, and experts in the field have developed a series of road traffic assessment models, which have promoted the progress of traffic safety research by providing theoretical support and technical guidance for road planners and builders, road administration departments, and other relative stakeholders.

2.1. Traffic Safety Evaluation

Nations that have advanced in traffic research have taken the lead in the government transportation sector involvement by initiating traffic safety assessments, promulgating a series of relevant government documents and legal provisions. In 1991, the United Kingdom Ministry of Transportation (MOT) developed the first National Road Safety Assessment Directive, the Road Safety Audit Guidelines, which first time clearly defined the concept of road safety assessment and carried out extensive assessments throughout the UK [9]. The National Highway Traffic Association of Australia established a specialized road safety organization, and in 1994 developed and published a national road safety audit [10]. In 1997, the Federal Highway Administration issued the Road Safety Design and Operation Guide, which developed technical standards and safety regulations for road design and operation managers and proposed the establishment of a road safety evaluation system. The Road Traffic Safety Law of the People’s Republic of China was formally implemented in 2003, it provides a legal basis and plan for traffic safety assessment and management. In 2004, the Ministry of Communications published the Guidelines for Safety Evaluation of Highway Projects, which mainly
addresses methods and standards for assessing the safety of expressways and first-class highways in China. These guidelines have played a positive role in promoting the development of highway safety evaluation and corresponding scientific research in China.

To improve road traffic safety and theoretical research on traffic safety, several domestic and foreign scholars have developed a series of assessment methods to help the government transportation departments and other related organizations evaluate traffic safety conditions. The traffic conflict technique has been developed by Chin and Quer [11], to evaluate road safety levels based on observations of accident locations in the absence of a complete, reliable traffic accident record on the road. Karine and Nadjim advanced traffic safety assessments with a decision tree technique that searches for risk sources in spatial distributions of road traffic and evaluates road traffic safety through spatial dimensional traffic data mining [12]. The benefits of traffic safety measures using safety-related risk analysis and urban traffic risks based on the type of traffic participants (drivers, passengers, pedestrians, and cyclists etc.) and accident severity were evaluated by Mangones et al. [13]. The cost–benefit analysis was used by Cafiso et al. to support decision-making processes related to road development by selecting the best alternative measures in terms of the expected benefit and cost–benefit ratio of a road project’s safety performance [14]. Luo and He adopted a contingent assessment method that reflects road traffic safety through the price that people are willing to pay to improve the traffic safety; the higher the road exposure degree, the higher the willingness to pay for road traffic safety [15]. To address the ambiguity problem in traffic systems, Wang et al. applied fuzzy theory to the qualitative and quantitative analysis of the causes of traffic accidents, and a macro fuzzy event tree was set up for traffic accidents caused by roadway departure crashes [16]. A new theory of road alignment design was put forward by Ren et al., suggesting that the traffic requirements of traffic participants and their physiological and psychological response characteristics should be the theoretical basis for the design of road alignment [2].

In general, analysis of road traffic safety is based on traffic information, vehicle safety analysis, traffic participants, and road conditions. The previous research on urban roads provides sufficient theoretical basis for rural road safety assessment.

2.2. Traffic Safety Assessment of Rural Roads

Economic development in the suburban countryside has caused traffic to surge in this area. Compared with urban roads and highways, the geographical environment of suburban and rural roads is poor and the layout of road infrastructure in suburban areas is greatly affected by agricultural housing, farmland, and highways. Rural roads are characterized by low traffic volume, large single-use intensity, and low management and maintenance costs. In addition, high rates of traffic accidents have a large impact on food production and local living standards [7]. Nearly 60% of road deaths in Europe and more than half of road deaths in America occur on rural roads. During 2006 to 2012, there were more than 200 major traffic accidents involving more than 10 deaths in China, with more than 60 cases occurring on rural roads [17–19]. Though current rural road safety is not satisfactory, rural roads are expected to play an increasingly important role in regional economic development. Therefore, evaluating and improving rural road safety is urgent.

2.3. Research Status of Rural Road Traffic Safety Assessment Abroad

International funding is relatively advanced with respect to rural traffic safety assessment research, common research methods rely on statistical method, function model, linear-regression analysis and other methods. Among them, (1) statistical method such as empirical Bayesian before–after analysis, reliability analysis and Latent Class Cluster. (2) Function model such as safety performance functions and adjustment function. (3) Linear-regression analysis such as logistic regression models, latent class logit model, hierarchical ordered logit model and separate ordered-probit models.
2.3.1. Statistical Estimation Methods

Experiential Bayesian before–after analysis has been widely used in rural road traffic safety assessments. For example, Park et al. used this method to analyze safety effects of wider edge lines and assess traffic safety [20]. Khan et al. used Bayesian before-after analysis to study the effectiveness of shoulder rumble strips in reducing run-off-the-road crashes on two-lane rural highways and analyzed their safety benefits for decreasing traffic accidents [21]. de Oña et al. combined Bayesian statistics with latent class cluster analysis to identify the primary factors impacting road traffic, reveal underlying traffic safety problems and analyze the safety of rural roads [22]. Jalayer and Zhou adopted a reliability analysis method to analyze the influence of roadside clearance width, side slope, and other roadside features on the severity of traffic accidents caused by lane deviation; a reliability index was used to measure road safety grade [23].

2.3.2. Function Models

Safety performance functions are often used to predict traffic safety accidents. By exploring the impact of the road characteristics of two-lane rural road networks (hazard exposure, geometry, design consistency, roadside features, traffic volume, road width, curvature change speed, flat curve length, longitudinal gradient, etc.) on the severity of traffic accidents, road safety performance functions have been established to predict the number of traffic accidents on unique roads in rural areas [24,25].

Combined with existing methods, Park and Abdel-Aty estimated the effectiveness of traffic safety reduction factors for a variety of safety measures, and also established adjustment functions to assess the effects of multiple combinations of safety measures and evaluated the effects of multiple safety measures in rural road safety [26].

Cafiso et al. have established a tool RIS (road safety inspections) to inspect road safety by presenting different phases of site inspections, which help to analyze the road conditions thoroughly and access reliable and effectively assessment for low-volume rural roads. For daytime, it introduces preliminary inspections to understand the basic conditions of road traffic safety, general inspections to focus on observe the general safety issues on the road segments, and detailed inspections to observe safety concerns of specific sites of the road segments. And for nighttime, it introduces inspections to examine road conditions without natural lighting [27].

2.3.3. Linear Regression Analysis

Regression models are also used to analyze rural traffic safety. Shinstine et al. established logistic regression models to identify risk factors for rural intersections [28]. Farah et al. used road alignment, traffic condition, and driver characterization datasets to establish Tobit regression models for assessing the risk of passing maneuver in rural two-lane highways [29].

Xie et al. used a latent class logit model to analyze the severity of single-vehicle traffic accidents on rural roads [18]. Chen et al. adopted a hierarchical ordered logit model to predict the severity of driver injuries in rural road traffic accidents based on driver and vehicle characteristics, environmental conditions, and rural road traffic accident characteristics [30].

Ackaah and Salifu used a generalized linear model (GLM) with a negative binomial (NB) error structure to establish a ‘core’ model consisting of key risk variables and a ‘full’ model consisting of more variables for predicting traffic accidents in rural areas of the Alcanti region in Ghana [31].

Anarkooli and Hosseinlou analyzed the influential factors in injury severity under different lighting conditions (day, night and night with lights), developed a separate ordered-probit model to assess the safety level of rural roads under different lighting conditions [32].
2.4. Research Status of Rural Traffic Safety Assessment in China

Scholars mainly use weighted analysis, principal component analysis, analytic hierarchy process methods, and traffic simulations to evaluate rural road traffic safety. Bi analyzed the influence of people, vehicles, roads, and environment on rural road traffic safety, discussed traffic characteristics and types of rural roads accident, and established methods for identifying accident-prone areas based on the principal component-cluster analysis [3]. Liu and Peng used a fuzzy comprehensive evaluation method to analyze road and traffic features, safety facilities, intersection safety facilities, traffic management strategies, and vehicle features and established a hierarchy index system to evaluate road traffic safety [33].

Su used a weighted analysis method to analyze factors of rural roads in mountainous areas such as embankment height, curve radius, intersection branches, and vertical slope; they established a safety assessment method based on these factors and proposed a standard for evaluating the safety of rural mountain roads [7]. According to the personal security, vehicle safety, environmental safety, road safety, safety management, and accidents, Wu combined the analytic hierarchy process and the unascertained measurement method to construct a comprehensive evaluation system for rural road traffic safety [8]. Lu conducted a comprehensive evaluation of rural road traffic accidents in mountainous areas including factors such an accident time, causes, road alignment, and weather conditions [34].

International scientists usually use statistical methods, functional models, and linear-regression analysis to analyze rural road traffic safety, whereas domestic scholars typically employ analytic hierarchy process and fuzzy evaluation methods. This study builds upon domestic traffic safety research and rural traffic safety evaluation methods to identify the main factors influencing rural road traffic safety, analyze the impact of roads on rural road traffic safety, and evaluate the safety of selected representative road sections. We then constructed a road safety evaluation index system and a grading standard based on road alignment, pavement and lateral conditions, and marking lines. Finally, the safety of typical suburban highways was analyzed using the established evaluation method and concrete road safety improvement methods and measures were proposed.

3. Development of Traffic Safety Evaluation Model

3.1. Development of Rural Road System–Bucket Evaluation Model

The principle of the barrel refers to the fact that the amount of water in a bucket is limited by the shortest stave, rather than the longest [35]. Based on this principle, if a road is regarded as a system composed of multisection unit subsystems, the safety of the entire road is determined by the unit subsystem with the lowest safety. The Road System Safety Coefficient (RSSC) can be calculated as follows:

\[ \text{RSSC} = \min\{\text{SCUS}_1, \text{SCUS}_2, \text{SCUS}_3, \ldots, \text{SCUS}_n\} \]  

\( n \) is the number of unit sections, \( \text{SCUS}_i \) is the Safety Coefficient of Unit Section. The calculation for the safety coefficient of unit sections is described in Section 4.2.

3.2. Safety Coefficient of Unit Sections

Previous studies of rural road traffic safety have suggested that the main factors influencing road traffic safety include people, vehicles, roads, management, and environment. Through the investigation of observation videos and field surveys, as well as the comprehensive consideration of various factors triggering traffic accidents, road factors were chosen as the primary index, and road alignment, road surface conditions, lateral conditions, and traffic signs/marking lines were chosen as secondary indices to evaluate road subsystem safety. The evaluation system is shown in Figure 1.
As the impacts of various indicators on traffic safety differ, a weighted analysis method was used to evaluate the road unit comprehensively. The safety coefficient of unit section $j$ is given below.

$$\text{SCUS}_j = \sum_{i=1}^{4} (W_{ji} \cdot V_{ji})$$ (2)

where $W_{ji}$ and $V_{ji}$ are the weights and scores of the $i$th index in road unit $j$ section, respectively. The weight $W_{ji}$ is obtained by consulting the weights of relevant road traffic safety assessment documents, and $V_{ji}$ is evaluated with fuzzy analysis of each factor.

### 3.2.1. Impact Factor Weight

Weight is a measure of the size and relative importance of a single indicator in an overall evaluation index system. This study draws on the weights of factors determined by Ren Xiaojia and Liu Feiyan [4,36]. We compared weights from the same study with corresponding weights from similar studies to obtain a weight ratio for all factors, from which the weights of all factors can be calculated. The weight ratios from two previous studies related to the current study are shown in Table 1.

| Factors                      | Weights | $w_1$ | $w_2$ | $w_3$ | $w_4$ | Literature |
|------------------------------|---------|-------|-------|-------|-------|------------|
| Road alignment $W_1$         | 0.1750  | 0.778 |       |       |       | [4]        |
| Pavement condition $W_2$    | 0.2250  |       |       |       |       |            |
| Road alignment $W_1$         | 0.0228  |       |       |       |       | [37]       |
| Pavement condition $W_2$    | 0.0217  | 1.051 | 0.74  | 0.70  |       |            |
| Traffic signs and markings $W_4$ | 0.0308 |       |       |       |       | [38]       |
| Roadside condition $W_3$    | 0.0270  |       |       |       | 1.35  |            |
| Traffic signs and markings $W_4$ | 0.0200 |       |       |       |       |            |
| Mean weight ratios           | 0.91    | 0.74  | 0.70  | 1.35  |       |            |

The average ratio between weights was calculated as:

$$W_1 : W_2 : W_3 : W_4 = W_1 : \frac{w_1}{0.91} : \frac{w_1}{0.74} : \frac{w_1}{0.74 \times 1.35} = 1 : 1.1 : 1 : 1.4.$$ (2)

Factor weight was obtained according to the weight ratio among different factors:

$$W = \{W_1, W_2, W_3, W_4\} = \{0.22, 0.24, 0.22, 0.31\}. \quad (3)$$

### 3.2.2. Impact Factor Score

According to traffic safety evaluation model developed above, a scoring criteria for the road factors indicators is established, it includes road alignment ($V_1$), road conditions ($V_2$), roadside condition ($V_3$) and traffic standard line ($V_4$). Based on fuzzy theory, the unit is divided into four grades according
to the second-level factor indices (i.e., road characterization factors, where \( V = \{ \text{excellent: 4, good: 3, medium: 2, poor: 1} \} \)). Fuzzy logic facilitates the quantification of factors that are unclear and otherwise difficult to quantify or comprehensively evaluate [39]. Based on the “Highway engineering technical standard JTGB01-2014”, the standard driving speed is 40 (km/h) and the required minimum length of a straight line between road curves is 40 m [40]. Therefore, the length of road section units in this study is defined as 40 m. For the evaluation of road alignment (V1), a score for linear combinations, by the reference to the analysis of linear combination situations, is employed in this study.

The evaluated road section is comprised of fourth-grade cement hardened pavement. The pavement condition (V2) was evaluated according to factors such as pavement damage, road collapse, pits, and ruts, which are common in rural roads. Roadside conditions (V3) consider railing layout, roadside structure, and lateral clearance. The lateral clearance score is determined from the road shoulder and its lateral width. The evaluation standard for road shoulder width was 1.5 m, which is the required width in the “Highway engineering technique standard JTGB01-2014” [40]. Traffic signs and markings (V4) mainly were scored based on integrity, ability to be recognized, and their effectiveness in guiding vehicles. The overall scoring criteria are shown in Table 2.

**Table 2. Standards for indices.**

| Evaluation Indexes     | Evaluation Standards                                                                 | Scoring |
|------------------------|--------------------------------------------------------------------------------------|---------|
| Pavement condition: V2 | Pavement is smooth, without breakage, obstacles, road collapse, potholes, and/or ruts. | 4       |
|                        | Pavement is relatively smooth, with slight breakage and ruts, but without obstacles, road collapse, and/or pot holes. | 3       |
|                        | Pavement is relatively rough, with b breakage and ruts, and vehicles must slow down due to obstacles, road collapse, and/or pot holes. | 2       |
|                        | Pavement is rough, with severe breakage and ruts, and vehicles obviously suffer from vibration due to obstacles, road collapse, and/or pot holes. | 1       |
| Road alignment: V1     | Vertical curve                                                                      | 3       |
|                        | Straight length greater than 1000 m or within 40 m                                  | 2       |
|                        | Horizontal curve                                                                   | 1       |
| Non sharp turns        | Straight length 40 m and 1000 m                                                    |         |
According to the safety assessment of the road system, the road system barrel capacity value was set as Road System Safety Coefficient (RSSC) = [1, 4], and the traffic risk grade classification was set based on this value (Table 3). Roads receiving hazard and high hazard grades have a low level of road safety and should be prioritized in safety improvement programs.

### Table 2. Cont.

| Content of Evaluation                                           | Evaluation Standards                                           | Scoring |
|-----------------------------------------------------------------|----------------------------------------------------------------|---------|
| Roadside condition: V3                                          | Set roadside barriers and lateral clearance L ≥ 1.5 m           | 4       |
|                                                                 | No roadside barriers and lateral clearance L: 1.5 m > L ≥ 1 m   | 3       |
|                                                                 | No roadside barriers and lateral clearance L ≥ 1.5 m            | 2       |
|                                                                 | No roadside barriers, obstacles, lateral clearance L: 1 m > L ≥ 0.5 m | 1       |
| Traffic signs and markings: V4                                  | Traffic signs and markings are present, in good condition, and can be recognized clearly. | 4       |
|                                                                 | Traffic signs and markings are present and can still be recognized despite being severely damaged. | 3       |
|                                                                 | Traffic signs and markings may or may not be present, but due to their severely degraded condition cannot be recognized. | 2       |
|                                                                 | Traffic signs and markings are missing or traffic signs and markings are severely damaged and cannot be recognized. | 1       |

### Descriptions:

1. **Non sharp turns**

   ![Non sharp turns](image)

   Don’t set the clothoid as a dotted line

2. **Straight length between 40 m and 1000 m**

   ![Straight length between 40 m and 1000 m](image)

   Vertical curve (straight line)

3. **Vertical curve**

   ![Vertical curve](image)

   Don’t set the clothoid as a dotted line

4. **Straight length greater than 1000 m or within 40 m**

   ![Straight length greater than 1000 m or within 40 m](image)

   Vertical curve (straight line)

5. **Horizontal curve**

   ![Horizontal curve](image)

   Don’t set the clothoid as a dotted line
Table 3. Road safety evaluation grades.

| Road System Safety Coefficient (RSSC) | Safety grade | Evaluation result |
|--------------------------------------|--------------|-------------------|
| 4 ≥ RSSC ≥ 3.5                       | I            | Safe              |
| 3.5 > RSSC ≥ 3                       | II           |                   |
| 3 > RSSC ≥ 2                         | III          | Not safe          |
| 2 > RSSC ≥ 1                         | IV           |                   |

4. Case Analysis

4.1. Case Introduction

A specific section of Xiaodang Central Road in the Fengxian District of Shanghai in Figure 2 (left) was investigated as a case study. The length of this north–south road section is about 4560 m. It connects to Tuanqing Road in the south and Liutuan Road in the north, and passes through a residential area. The road location is shown in Figure 2 (right). The road principally serves nearby rural residents and meets their transportation need. It also provides convenient transportation system to the surrounding region. This is to help develop the agricultural and industrial sector as well as increase the local income of its populace.

![Figure 2](image)

Figure 2. Map of Xiaodang Central Road in Fengxian District of Shanghai (left); sampling points selected for evaluation (right).

The road is a dual lane, with an administrative designation of a country road and a technical designation of a level IV road. It exhibits a complex traffic composition, consisting of pedestrians, livestock, private cars, trucks, and bicycle that always lead to heavy traffic. Some sections of the road are constrained by residential buildings, roadside vegetation, telegraph poles, and vehicles parked along the roadside—all of which lead to decreased lateral clearance and stopping-sight distance, for these reasons, traffic accidents are likely to occur, there is also probability of increase road accidents.

Cross roads intersect the trunk road at poorly designed junctions. Some residential buildings have main passages that are set at the shoulder of the road, and some residents even occupy the shoulder as private areas for daily activities. The phenomena of occupied shoulders and unrestricted pedestrian crossings are particularly serious issues. The lack of professional planning and management for this rural road has resulted in a chaotic proliferation of vegetation, houses, shops, and links to secondary roads, all of which severely compromise road safety.

According to the road shape, pavement conditions, roadside conditions, and traffic signs and markings, three sections (~40 m in length) that pose the greatest threat to traffic safety were selected to assess the safety of the entire road based on the barrel principle (Figure 2 right; A, B, C).
The Wujiaqiao section (Figure 2 right, A) is located on the main part of Xiaodang Central Road and connects the Xiaodang Central Road to Tuanqing Road. The horizontal alignment and longitudinal section linear of road alignment is straight and is typical of straight sections of Xiaodang Central Road. The Wujiaqiao section was therefore chosen to represent straight and level road sections. The high embankment section in joint of road and bridge was identified as an important factor for the evaluation of road traffic safety. The factors influencing road safety on this section were analyzed using the method described above.

Changlian Road intersects Xiaodang Central Road with a T-junction at the Wanjiafu Supermarket (Figure 2 right, B) largely impacts traffic safety on Xiaodang Central Road and was therefore chosen for evaluation object.

The road surface conditions of the intersection are shown in Figure 3. The intersection has a small turning radius, and the stopping-sight distance is obviously insufficient. Insufficient stopping-sight distance is a phenomenon common to rural roads, so this section may be considered as representative of roads in rural residential areas in that regard. The conditions of this section were analyzed using the proposed evaluation indices. Traffic is heavier at this intersection compared with the other evaluated road sections. Traffic delays at this intersection typically are caused by vehicles turning left and by conflicts between pedestrians and vehicles.

The traffic flow at the exit of the Situan Electric Appliance Factory (Figure 2 right, C) is more complex, characterized by a weaving section of road that connects Xiaodang Central Road, Liutuan Highway, and Caijian Road. In this area, the main road traffic from the northern section of the bridge occurs in the downhill section of the vertical curve, which flows into a horizontal curve with a small radius at the bottom. This type of road structure (i.e., a flat curve at the bottom of vertical curve) causes vehicles to turn sharply while gaining speed and usually produces a sense of distortion to drivers, weakens the stability of vehicles, and reduces the comfort of passengers and drivers. Therefore, this road section was chosen as a case study to analyze Y-shaped rural roads and unsafe conditions caused by horizontal and vertical curves, which is are common phenomena in rural roads.

4.2. Road Safety Assessment

Based on the evaluation indices for selected factors and the evaluation model, the traffic safety of the road system was assessed (Table 4).

![Figure 3. Diagram of road intersection after improvements.](image-url)
Table 4. Road safety assessment.

| Road Sections (Short Staves) | Description of Assessment Standard | Scores v |
|-----------------------------|------------------------------------|----------|
| Wujiaqiao                   |                                     |          |
| Road alignment $W_{A1}$     | Combination of inclines, level areas, curves, and straight areas | 2        |
| Pavement condition $W_{A2}$| Pavement is relatively smooth, with breakage, but without obstacles, road collapse, or potholes | 3        |
| Roadside condition $W_{A3}$ | Roadside bridge barriers, varying lateral clearance: 1~1.5 m | 3        |
| Signs and markings $W_{A4}$ | Traffic signs and markings are missing | 1        |
| Sight distance $W_{A2}$     | Relatively good with range L $\geq$ 40 m | 4        |
| Safety Coefficient of Unit A Section Coefficient | $SCUS = \sum_{i=1}^{4} W_{Ai} V_{Ai} = 2.2$ | safety grade III, not safe |
| Wanjiafu supermarket        |                                     |          |
| Road alignment $W_{B1}$     | Combination of inclines, level areas, curves, and straight areas | 4        |
| Pavement condition $W_{B2}$| Pavement is relatively rough with breakage, slight road collapse, and potholes, but without obstacles. | 3        |
| Lateral clearance $W_{B3}$  | No roadside barriers, but with roadside buildings; varying lateral clearance ($L < 0.5$ m) | 1        |
| Signs and markings $W_{B4}$ | Traffic signs and markings are relatively intact and can be recognized. | 3        |
| Sight distance $W_{B5}$     | Relatively good with range L $\geq$ 1.5 m | 4        |
| Safety Coefficient of Unit B Section Coefficient | $SCUS = \sum_{i=1}^{4} W_{Bi} V_{Bi} = 2.9$ | safety grade III, not safe |
| Exit of Situan Electric Appliance Factory |                                     |          |
| Road alignment $W_{C1}$     | Combination of small-radius curves adjoining the lower end of an incline | 1        |
| Pavement condition $W_{C2}$| Pavement is relatively smooth with breakage, but without obstacles, road collapse, or potholes. | 4        |
| Lateral clearance $W_{C3}$  | Roadside poles; varying lateral clearance (0.5~1 m) | 2        |
| Signs and markings $W_{C4}$ | Traffic signs and markings are missing. | 1        |
| Safety Coefficient of Unit C Section Coefficient | $SCUS = \sum_{i=1}^{4} W_{Ci} V_{Ci} = 2.0$ | safety grade IV, not safe |

Road System Safety Coefficient $RSSC = \min\{2.2, 2.9, 2.0\} = 2.0$ safety grade IV, not safe

According to the evaluation results, the Wanjiafu Supermarket intersection is safer than the Wujiaqiao road section and the exit of the Situan Electric Appliance Factory section. For the road sections conditions, the road conditions are better, but the road alignment, traffic signs and markings, and roadside environment are unsatisfactory, resulting in poor road safety. Therefore, to improve the safety of the entire road system, safety measures should focus on improving the road alignment, roadside conditions, and traffic signs and markings of these unsafe sections.

4.3. Improvement Measures for Road Safety Performance

Based on the safety issues present on evaluated road section, factors affecting traffic safety on unsafe sections were studied so that the traffic safety of the entire road can be improved. Improvement of traffic safety on the Panzao Wujiaqiao road section should focus on improving road alignment and installing new traffic signs and markings. To make the road alignment more reasonable, the line of this road section and neighboring long straight section with the line of neighboring steering road should
be considered, and the curve radius of horizontal curve should be increased. Unambiguous traffic markings should separate opposing traffic flows, and drivers should be able to see the road orientation clearly at night with the addition of edge lines. Anti-collision barrels with reflecting film should be installed to buffer the shock when vehicles hit the sidewalks on the bridge and help guide vehicles. As there is a high embankment at the intersection of the road and bridge, severe overturn accidents are likely to occur when vehicles deviate from their lanes. Wave-shaped guard rails should be installed to prevent such deviations. These improvement schemes are shown in Figure 3.

Based on the safety evaluation results for the Wanjiafu Supermarket intersection, it is necessary to improve roadside conditions and traffic signs/markings in this area. The sight lines at the intersection with the secondary trunk road should be expanded in order to increase the sight distance of drivers trying to turn right to the secondary main road, and thus prevent vehicles from colliding with fixed objects, pedestrians, and vehicles parked in blind zones created by residential buildings. Improvement of traffic signs and markings, as well as installation of a median, would help canalize traffic and reduce the possibility of traffic collisions. In addition, crosswalk traffic markings and road edge lines should be clearly defined to improve pedestrian safety and guide vehicles. The post-improvement iconography is shown in Figure 4.

![Figure 4. Improvement scheme for horizontal curve of the Wujiaqiao road section (above), improvement scheme for traffic signs and markings (below).](image)

To improve road traffic safety, measures should take into account the rural economic situation and specific road conditions. According to the evaluation results, the road of the Situan Electric Appliance Factory exit alignment is unreasonable, traffic signs are missing, and lateral conditions are poor. Road alignment can be improved by changing the horizontal curve of the trunk highway to a straight line and connecting the trunk and secondary roads with a bend, making the linear combination of trunk roads more reasonable (Figure 5) and avoiding unsafe roadside factors such as poles. In addition, traffic signs should be installed to canalize traffic flow, thereby avoiding traffic jams and improving road safety.
5. Conclusions and Recommendations

5.1. Conclusions

The traffic safety system–barrel evaluation model established in this study provides a quantitative method for analyzing road safety in suburban and rural areas. It innovatively applies the wooden barrel principle to evaluate traffic safety, the model overcomes the difficulties of data acquisition, assess rural road safety in the absence of traffic accident information or rigorous road space data. The suggested model uses a method of preliminary inspection of rural roads, general inspections and detailed inspections based on the wooden barrel principle, to find out the short-slab section of the road traffic safety, and then carry out detailed inspection to achieve a safety level assessment of the short-slab section, ultimately to find out the safety of the specific site, additionally it can be used to identify dangerous road sections and the main factors which limits the safety of the entire road system. The model could be useful for a rapid survey on a large road network of which limited data exist. It facilitates rural road managers to manage and keep maintenance of rural road infrastructure in the absence of sufficient management human resources and historical data on road traffic safety accidents. According to the model results, the pavement conditions of cement-hardened two-lane rural roads were good, but traffic safety was poor. The main problems were as follows: missing traffic signs, unreasonable road alignment, and poor roadside conditions. According to the short-stave subsystems in the road system, targeted improvement programs, and measures should be proposed.

Rural road safety assessments help improve the security of rural roads, which in turn impacts social and economic development, life and property safety, and living quality. Due to the strong heterogeneity of rural roads, traffic safety research should be based on specific situations and safety evaluations should focus on key road sections and the factors that limit rural road safety. There are many other technologies that have developed road safety auditing and safety inspection guidelines [27,41], which require abundant data for assessment. But for the huge rural roads system in China, they are usually restricted by natural conditions, poor road infrastructure investment, low-level of rural economy, and insufficient of management human resources, etc. Therefore, the rural road traffic safety assessment usually does not meet the high requirements of urban road or highway traffic safety assessment. The rural road traffic system barrel evaluation model is an assessment method for low-level rural road traffic safety assessment under the circumstances of lack of data, which could be used with caution in a preliminary phase of road safety assessment. However, the model established in this study exists some limitations. The model only focuses on the safety level of the most important infrastructure that affects rural road traffic safety, and does not consider the impact of time, traffic flow, traffic management system, road users, and transportation on road traffic. In addition, the results are influenced by subjectivity inherent in the scoring of road factors and the selection of short-stave road
sections. Therefore, it is necessary for evaluators to have strong professional knowledge of road safety, as well as familiarity with the roads being studied.

5.2. Recommendations for Future Work

Rural road safety is a universal concerned issue. As safe and reliable rural roads and facilities are necessary for guaranteeing traffic safety. Thus, it is important to conduct traffic assessments in rural areas. Rural roads are different from urban and other high-grade roads, problems often exist such as poorly designed road curves, and scarcity of traffic signs, and also its management in lack of data. So, it is necessary to develop a suitable evaluation method for rural road traffic safety. The design and implementation of rural road traffic safety assessment methods involve many theories, methods and techniques. There are still problems to be solved in the evaluation methods proposed in this study, such as compared with “Road safety inspections” (RSI) approach [27], which need to be improved and further studied in the future. At the same time, the traffic safety level of nighttime transportation infrastructure should be considered in future research. With the continuous development of China’s rural economy, the standard for roads is getting higher, so it is necessary to select a more applicable and broader coverage index system. In this study, the factors affecting road safety are scored by fuzzy evaluation method. In the process of implementation, the subjectivity is strong in the selection of short section units. Because of the lack of traffic safety accident data in rural road management, the model proposed in this study was not combined with the actual traffic accident statistics. In future research, it should be included in the scope of research. At the same time, the traffic safety level of nighttime transportation infrastructure should also be considered in future research to improve the coverage of the system [41]. Based on our results, the following suggestions for improving traffic safety in rural areas are proposed:

(1) Sound rural traffic management system should be established on the shoulders of long straight road sections, and warning/deceleration signs and vibration belts should be installed, additionally rural road traffic signs and markings should receive regular maintenance.

(2) Traffic safety investments should be a priority in rural residential areas, as well as installation of shoulder rumble strips in long straight sections and renovation of crash barrier in high subgrade sections. Vegetation should be used reasonably to the guideline of sight of driving and to reduce the severity of roadway departure crashes.

(3) Road safety in rural areas should be regularly publicized to increase awareness among local residents and farmers.

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