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Modeling Impacts of Speed Reduction on Traffic Efficiency on Expressway Uphill Sections

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Abstract: Road geometric design is a key factor impacting driving safety and efficiency. In highway profile design, speed reduction is used to determine critical length of grade. Previous research generally concentrated on the relationship between speed reduction and crash involvement rate to establish the recommended value. Limited research results have been reported at this point concerning speed reduction and traffic efficiency. This study aims to fill the gap by investigating tolerable speed reduction with different vertical slopes considering traffic efficiency. Firstly, appropriate experimental sections were determined after field survey. Traffic data including vehicle count, timely speed, vehicle type, and headway time were then collected on an expressway in Shaanxi Province. The associated traffic efficiency was derived from traffic volume and average speed. After this, the modeling between speed reduction and traffic efficiency was processed with different slopes. The correlation between speed reduction and traffic efficiency was therefore verified. Finally, the prediction model of optimum speed reduction concerning traffic efficiency under different vertical slopes was introduced. It was found that the critical length of grade can be longer with traffic efficiency as the major design control incorporated with slopes of 3–3.5%. The existing regulation in critical length of grade at 3.5–5% can benefit both safety and efficiency. The findings can provide a reference for vertical alignment design, leading to high-efficiency road systems.

Keywords: mountainous freeway; speed reduction; traffic efficiency; critical length of grade

1. Introduction

Recently, the rapid increase in traffic volume has led to traffic jams on expressways, affecting driving safety and efficiency [1]. China is a mountainous country, and the profile designs of its roads need to overcome the country's severe terrain, thus complicating vertical alignment [2]. Road geometry has great influence on road safety and traffic efficiency [3]. On uphill sections of mountainous expressways, heavy vehicles need to decrease their speed to overcome greater slope resistance. The mixed traffic of passenger and freight vehicles with large speed differences can reduce the driving freedom of overtaking, further resulting in lower traffic efficiency, especially on four-lane freeways [4]. Evacuation and rescue are more difficult once congestion or an accident happens on mountainous freeways [5]. Therefore, it is of great importance to study the vehicle driving performance on uphill sections of mountainous freeways for relieving traffic pressure and safe driving. In this paper, speed reduction refers to the reduction in speed of trucks below the average running speed of traffic, revealing the mutual influence between large and small vehicles. In vertical alignment design, speed reduction is used to determine the critical length of grade. Climbing lanes are advantageous when excessive speed reductions are anticipated [6]. Hence, it makes sense to study the effect of speed reduction on traffic efficiency in order to improve the traffic conditions. Overall, the study of speed reduction in relation to traffic efficiency has important practical significance on uphill sections of mountainous freeways.

The American Association of State Highway and Transportation Officials (AASHTO) Policy on Geometric Design of Highways and Streets currently employs a 15-km/h speed reduction criterion [7]. The 15-km/h regulation was chosen from the Texas Highway Department's 1968 speed survey [8]. The crash involvement rate increased rapidly for increases in speed reduction beyond 15 km/h, which was applied to establish an objective basis for the speed-reduction criterion [8]. In this survey, only safety factor was considered. Traffic efficiency is affected greatly by speed reduction, especially on the uphill sections of mountainous freeways [2]. Traffic efficiency refers to the measurement of kilometers of vehicle transportation completed by the expressway facilities per unit of time [9]. However, the existing knowledge about speed reduction and traffic efficiency is very limited [7,8], as the researchers currently pay more attention to speed dispersion [10–20]. Numerous studies have reported positive correlations between estimated traffic crash rate and speed dispersion [10–18]. Speed dispersion has two definitions: the average range of speed difference between two neighboring vehicles and the standard deviation of individual speed [14,15]. It can reveal interactions between adjacent vehicles. Research related to speed dispersion has been conducted regarding road design, traffic flow characteristics, and crash rate. Speed dispersion with the first definition was found to be exponential with density, exponentially negative with mean speed, and two-phase linear to flow [15]. In a specified congested state, flow rate will decrease with an increase in speed dispersion [14]. The first definition of speed dispersion is better in describing traffic flow status. Speed dispersion can influence traffic efficiency with larger average speed [16]. The research scope of speed dispersion has been determined, but the specific value hasn't been given. The positive association between the standard deviation of speed and crash rate has been verified [17] and the findings are basically consistent with the Green Book [18]. However, the positive correlations between traffic crash rate and speed dispersion have been questioned by some scholars [19,20]. They have claimed that the observation of these correlations provides no support for the hypothesis that increases in speed variance increase individual risk. Overall, the relationship between traffic crash rate and speed dispersion has been extensively studied. By contrast, it is difficult to obtain satisfactory reports about speed reduction and traffic efficiency from the relevant research at present. Speed dispersion focuses on speed distribution but it cannot directly reflect the interaction between a truck and passenger car; examining speed reduction can achieve this goal. This paper aims to find reasonable speed reduction concerning traffic efficiency to determine the critical length of grade, thus improving the profile design of roads. After comprehensive consideration, speed reduction was chosen as the research variable in this paper.

To the best of our knowledge, there is still no specific research at present which investigates the effect of speed reduction on traffic efficiency, especially in mountainous areas. The existing studies have mainly concentrated on the relationship between speed reduction and crash involvement ratio [7,8]. To understand the impact of speed reduction on traffic efficiency with different vertical slopes, a field experiment was firstly carried out. Platoons were then selected based on the car-following theory. By applying the data analysis software Origin, the relationship between speed reduction and traffic efficiency was fitted. By comparative analysis, the variation law of traffic efficiency with speed difference was obtained. The advantages of this research are two-fold. Firstly, the optimum speed reductions for different vertical slopes were proposed, which can help determine the critical length of grade. Secondly, this study fills the research gap in speed reduction from the traffic efficiency perspective.

The rest of the paper is organized as follows. The field experiment and the data processing procedures are presented in Section 2. Section 3 describes the relationship between speed reduction and traffic efficiency and the fitting process is also outlined. The whole research is discussed in Section 4 and summarized in Section 5.

2. Methods

2.1. Variable Definition

(1) Traffic Efficiency

Traffic efficiency is defined as the measurement of kilometers of vehicle transportation completed by the expressway facilities per unit of time [9]. It can be calculated by the product of traffic volume and average travel speed of traffic flow within the unit of time. It should be noted that the speed in the calculation of traffic efficiency is average speed on a segment, which is difficult to observe in reality. The observation of speed is the instantaneous speed at a certain section. Besides, the observation of traffic volume is generally the number of passing vehicles at a certain section in a certain period of time. Overall, it only represents the traffic efficiency of the specified section. To solve this problem, raw multi-section traffic data was continuously obtained for long-term observation in this research, and the average of the multiple sections can represent the segment traffic characteristics.

(2) Speed Reduction

The definition of speed reduction is the reduction in speed of vehicles, namely trucks, below the average running speed of traffic. The crash involvement rate increases significantly when truck speed reduction exceeds 15 km/h with the involvement rate being 2.4 times greater for a 25-km/h reduction than for a 15-km/h [10-mph] reduction [7]. On this basis, the general practice has been to use the speed reduction of 15 km/h to identify the critical length of grade. In this paper, we tried to find the tolerable speed reduction to achieve better traffic efficiency. To maximumly reveal the mutual influence between large and small vehicles, the speed reduction was calculated within the platoon.

2.2. Field Experiment

Considering the fact that a field experiment has the potential to directly reflect actual traffic flow characteristics, field research was applied in the study. When the appropriate experimental sections were selected, slope and curve radius were the major considerations. Chinese expressway regulations require a minimum slope of 0.3% considering drainage; the maximum slope is 5% with the design speed of 80 km/h, and 4% with the design speed of 100 km/h [21]. To maximumly reveal the effect of speed reduction on traffic efficiency in vertical sections, vertical slopes were chosen in the range of 1%–5%. Hence, expressways with design speeds of 80 km/h were considered. Previous studies have shown that the influence of curve radius on running speed is not obvious when the radius is larger than 1000 m [22]. The traffic efficiency of four-lane highways is influenced greatly as mentioned earlier. Therefore, the experimental section on a four-lane freeway was selected on the basis of the slope of 1–5% and the curve radius greater than 1000 m. After field surveys, a typical four-lane divided mountainous freeway in Shaanxi Province was chosen for its large traffic volume and topographical conditions (Figure 1). The design speed of the freeway was 80 km/h and the standard cross-section was 24.5 m with 3.75-m wide lanes and a 2.5-m wide hard shoulder. Six experimental segments were finally selected and their geometric indices are listed in Table 1. For multi-section observation, three sections were set for each experimental segment and the spacing was 0.5 m. Due to the small spacing, it is possible that the traffic compositions measured in the three sections were the same. For the experimental segments, the alignments were consistent and the tested locations were at least 1000 m away from ramps, bridges, and tunnels. Therefore, the collected traffic data of these sections is objective and reliable.

Table 1. Geometric element of experimental segments.

Section	Station	Slope (%)	Slope Length (m)	Radius (m)
1	K33 + 100–K33 + 648	1.34	548	2600
2	K39 + 217–K39 + 633	2.00	416	2460
3	K40 + 600–K41 + 220	3.10	620	1175
4	K43 + 250–K43 + 750	3.90	500	∞
5	K51 + 620–K52 + 740	2.582	1120	1000
6	K53 + 691–K54 + 341	4.50	650	∞

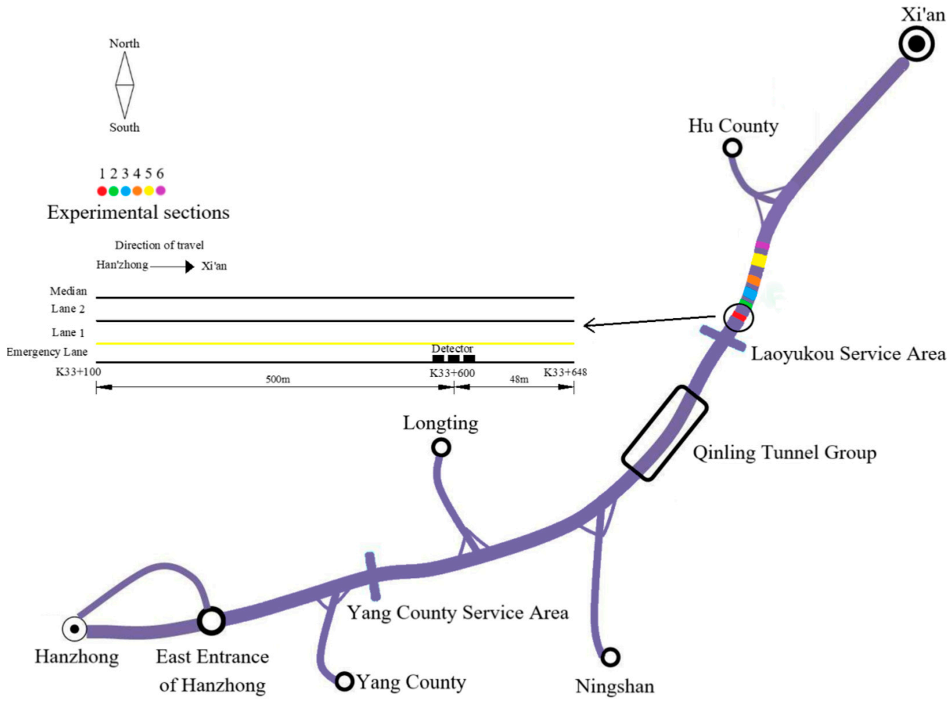

Figure 1. Experimental segments.

To eliminate the influence of the experiment detector and tester on the driving behavior, a real-time traffic-information acquisition instrument (AxleLight RLU11, Figure 2) was selected for the field experiment. The advantages of this instrument are two-fold. Firstly, it has a small size and can be placed on the outermost edge of the hard shoulder (Figure 1). Therefore, the driver cannot be disturbed when collecting the experimental data. Secondly, the instrument can automatically collect and record the vehicle performance data, consisting of vehicle count, timely speed, vehicle type, and headway time with high accuracy.

Figure 2. AxleLight RLU11.

The experimental condition was strictly controlled to eliminate the impact of environment on the drivers' operation. A traffic survey was conducted before the experiment. The experimental segments were located on a provincial expressway that provides long-distance transport with no obvious rush or normal hours except the lunchtime from about 12:00 pm to 2:30 pm. The experiment was carried out from 20 to 30 August between 8 am and 6 pm for ten days. The data filtering was performed during the data collection period other than lunchtime. During the observation period, the weather was fine, with no gale and no fog. The test instruments were checked before the test. They were placed and set at the designated places and then the tester went to the next experimental sections and repeated the operations. The instruments were all set to collect the data at 8 am. A total of 4,951,692 passenger car units (pcu) with 861,303 trucks were collected. The mix rate of trucks was approximately 17%.

2.3. Data Processing

The following procedures populated the complete data processing in this study:

(1) Raw data was acquired through the field experiment.

(2) Platoons were selected with the headway time less than 5 s [23–25]. During the experiment, it was found that the overtaking frequency was low, and the platoons were selected within one lane, so the impact between lanes could be neglected. For the experimental segment, data sieving was further carried out with the principle that the platoon compositions were the same in the three sections.

(3) Equations (1)–(3) were applied to calculate the average speed and speed reduction of the platoons. For each experimental segment, there were three observation sections. The average of the three sections represented the segment average speed and speed reduction for each platoon.

$$\overline{v}_i = \frac{\sum_{i=1}^{n} v_i}{n} \tag{1}$$

$$\overline{v} = \frac{\sum_{i=1}^{3} \overline{v}_i}{3} \tag{2}$$

$$\Delta v = \left| v_t - \overline{v} \right| \tag{3}$$

where $\overline{v}_i$ is the average speed of the platoon in the i-th section, v_i is the speed of i-th passing vehicle (km/h), n is the number of vehicles in the platoon, $\overline{v}$ is the segment average speed (km/h), Δv is the speed reduction (km/h), and v_t is the average speed of the same truck in the three sections (km/h).

(4) Traffic efficiency can be calculated by Equation (4), as suggested by the Highway Capacity Manual 2010 [26]. The segment average speed and traffic volume is

$$E = q \times \overline{V} \times t \tag{4}$$

where E is traffic efficiency (veh·km/h), q is the segment traffic volume in the unit time (veh/h), $\overline{V}$ is the segment average speed, and t is the unit of time (1 h).

Through the procedures described above, a full dataset with speed reduction and traffic efficiency could be accomplished. The interrelationships among the two variables were then acquired via regression analyses.

3. Results

By using the data processing method described in Section 2.3, 2779 platoons with trucks were selected. The operation of a platoon of light trucks may be different from one with heavy trucks. According to the Safety Specifications for Power-Driven Vehicles Operating on Roads (GB 7258-2012), trucks with total weight less than 1.8 tons are considered light trucks and those weighing more than 14 tons are heavy trucks [27]. By analyzing the composition of the platoons, it was found that most of the trucks were heavy trucks in this research. By contrast, only 85 platoons contained light trucks among the 2799 platoons. Partial average speed and speed reduction of platoons with heavy and light trucks are given in Tables 2 and 3 separately. It was obvious that the speeds were relatively consistent with minor speed reduction for the platoons with light trucks. It is possible that the operation of light trucks is not very different from the operation of passenger cars, so there is little effect between light trucks and passenger cars. Therefore, heavy trucks were selected as the research objects in this study.

Table 2. Average speed and speed reduction of platoons with heavy trucks.

Number	Speed Reduction (km/h)	Average Speed (km/h)	Number of Vehicles (veh)	Number of Heavy Trucks (veh)
1	1.41	65.16	18	3
2	6.82	75.12	16	4
3	13.67	72.86	17	2
4	19.20	73.23	19	3
5	24.93	67.19	16	2
6	2.31	66.42	16	3
7	8.23	69.17	19	4
8	14.47	77.18	18	3
9	20.84	73.28	20	2
10	26.48	69.89	19	3

Table 3. Average speed and speed reduction of platoons with light trucks.

Number	Speed Reduction (km/h)	Average Speed (km/h)	Number of Vehicles (veh)	Number of Light Trucks (veh)
1	3.54	88.73	17	3
2	3.58	74.94	18	4
3	4.01	84.28	17	2
4	4.08	82.21	19	3
5	5.93	78.06	16	2
6	5.97	83.67	20	3
7	6.38	83.04	17	4
8	6.46	82.00	18	3
9	7.92	81.59	19	2
10	3.65	86.69	20	3

Correlation analysis was used to examine the relationship between the speed reduction and traffic efficiency. The results indicated that the speed reduction and traffic efficiency were positively correlated. The correlation coefficient of $r = 0.708$ was found to be statistically significant at $p < 0.01$ (two-tailed). Regression analyses were conducted respectively by vertical slope. The relationships between speed reduction and traffic efficiency were depicted for initial screening, and statistically approximated by certain forms like linear, quadratic, and cubic functions. The regression process was demonstrated by taking 2.582% as an example. Distribution of average speeds and speed reduction at a slope of 2.582% are displayed in Figures 3 and 4. The speed of passenger cars was restricted by the mixed driving with trucks, so the average speeds were mainly concentrated in the range of 70–76 km/h. The distribution was relatively uniform when the speed reduction was less than 32 km/h. The majority of speed reductions were less than 40 km/h. The 85th percentile is widely used as the characteristic value describing the features of most individuals, and operating speed is a representative example [28]. The 85th percentile of average speed was 75.13 km/h and that of speed reduction was 32.71 km/h, indicating that the speed difference between trucks and passenger cars is generally greater.

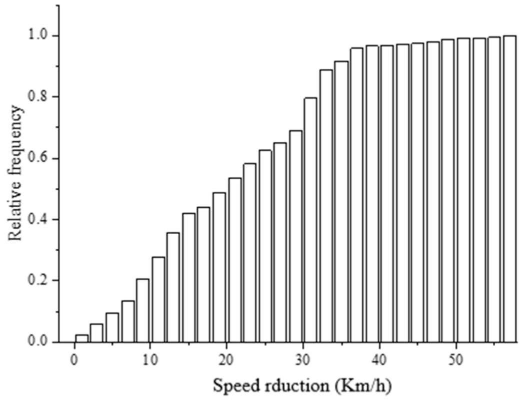

Figure 3. Distribution of speed reduction.

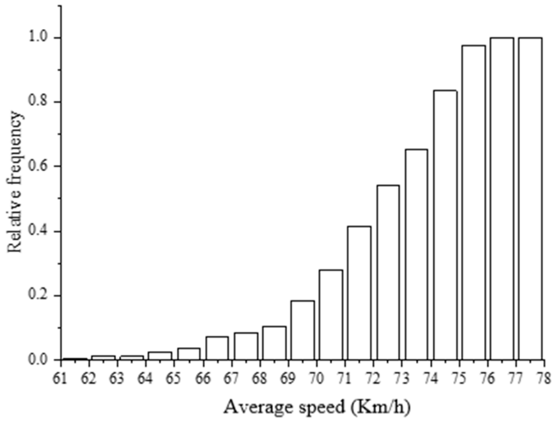

Figure 4. Distribution of average speed.

The scattergram of the speed reduction and traffic efficiency is shown in Figure 5. It is obvious that the speed reduction has a non-linear correlation with the standard deviation of average speed. Quadratic and cubic regressions were chosen for curve analysis after general observation. The calibration of their models and parameters is displayed in Table 4.

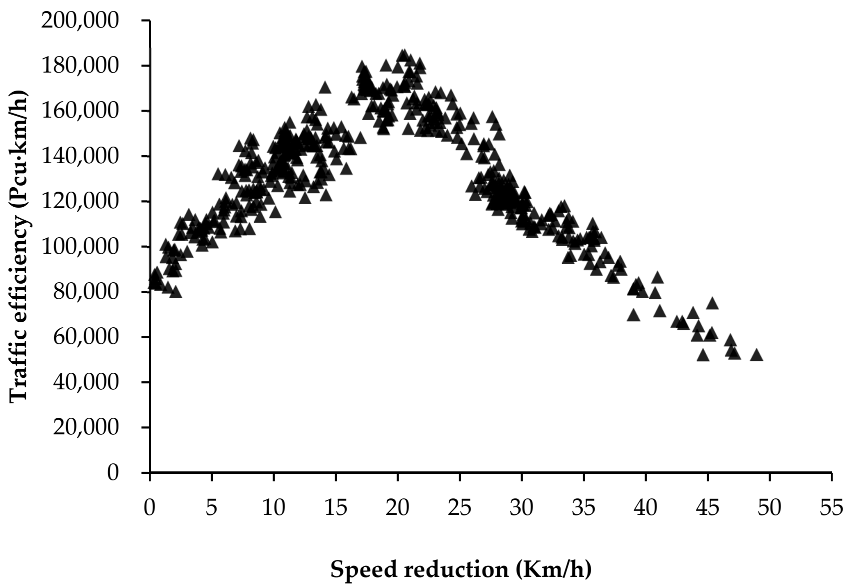

Figure 5. Distribution of speed reduction and traffic efficiency (2.582%).

Table 4. Parameters.

Model	Type	R2	Sig. F	Constant	a	b	c
1	Quadratic	0.754	0.000	90036.718	6726.495	−160.016	—
2	Cubic	0.803	0.000	71297.478	10759.106	−364.327	2.852

For model 1:

$$E = 90036.718 + 6726.495\,\Delta v - 160.016\Delta v^2 \tag{5}$$

For model 2:

$$E = 71297.478 + 10759.106\Delta v - 364.327\Delta v^2 + 2.852\Delta v^3 \tag{6}$$

As presented in Table 4 and Figure 5, the correlation coefficients of the two models were 0.754 and 0.803 separately. The significance level of independent variable F was 0.00, revealing that the relationship between speed reduction and traffic efficiency for the two models showed a significance level. Combing the results of Table 4 and Figure 5, the goodness of fit of the cubic regression line was the best. Although it is a cubic curve, it was similar to the quadratic form because most of the speed reductions were less than 50 km/h and there was no second inflection point. Limited by the test conditions, it was impossible to measure speed reductions greater than 50 km/h, and the speed reductions of 40–50 km/h were also marginal. Overall, the quadratic regression line showed the best fit. As shown in Figure 5, the traffic efficiency showed a trend of first increasing and then decreasing, with rising speed reduction. The interactions between the passenger cars and trucks were minor when their speeds were relatively consistent. As the speed reduction increased, the traffic efficiency also gradually grew. The traffic efficiency peaks at approximately 0.18 million pcu per km/h with a speed reduction of about 22 km/h. Thereafter, the speed reduction was too large to influence the traffic efficiency and the traffic efficiency decreased.

The same process was carried out for the other vertical slopes and the regression results are summarized in Table 5. The relationship between the two variables is shown in Figure 6. Despite the vertical slope, the traffic efficiencies all showed the trend of first increasing and then decreasing with rising speed reduction. For different slopes (from large to small), the optimum speed reduction corresponding to the maximum traffic efficiency was about 12 km/h, 13 km/h, 18 km/h, 22 km/h, 25 km/h, and 26 km/h, respectively. The maximum traffic efficiency decreases by about 20% for the slopes of 3% and 4% compared with 1% and 3%. It is important to note that traffic efficiency tended to be stable and the stability value was relatively close for different slopes.

Table 5. Regression results.

Vertical Slope	Type	R^2	Regression Model
1.34%	Quadratic	0.784	$E = 90653.756 + 6330.856\Delta v - 131.98\Delta v^2$
	Cubic	0.816	$E = 75339.487 + 9257.203\Delta v - 263.637\Delta v^2 + 1.626\Delta v^3$
2.00%	Quadratic	0.775	$E = 93566.028 + 6040.980\Delta v - 133.828\Delta v^2$
	Cubic	0.831	$E = 72926.802 + 10056.760\Delta v - 316.654\Delta v^2 + 2.295\Delta v^3$
2.582%	Quadratic	0.754	$E = 90036.718 + 6726.495\Delta v - 160.016\Delta v^2$
	Cubic	0.803	$E = 71297.478 + 10759.106\Delta v - 364.327\Delta v^2 + 2.852\Delta v^3$
3.10%	Quadratic	0.744	$E = 92869 + 5383\Delta v - 150\Delta v^2$
	Cubic	0.825	$E = 69325 + 10738\Delta v - 435.18\Delta v^2 + 4.1731\Delta v^3$
3.90%	Quadratic	0.753	$E = 81717.693 + 8911.328\Delta v - 358.872\Delta v^2$
	Cubic	0.840	$E = 60169.267 + 16389.945\Delta v - 963.459\Delta v^2 + 13.311\Delta v^3$
4.50%	Quadratic	0.758	$E = 76791.458 + 11174.221\Delta v - 558.224\Delta v^2$
	Cubic	0.824	$E = 57999.642 + 19379.605\Delta v - 1395.587\Delta v^2 + 23.263\Delta v^3$

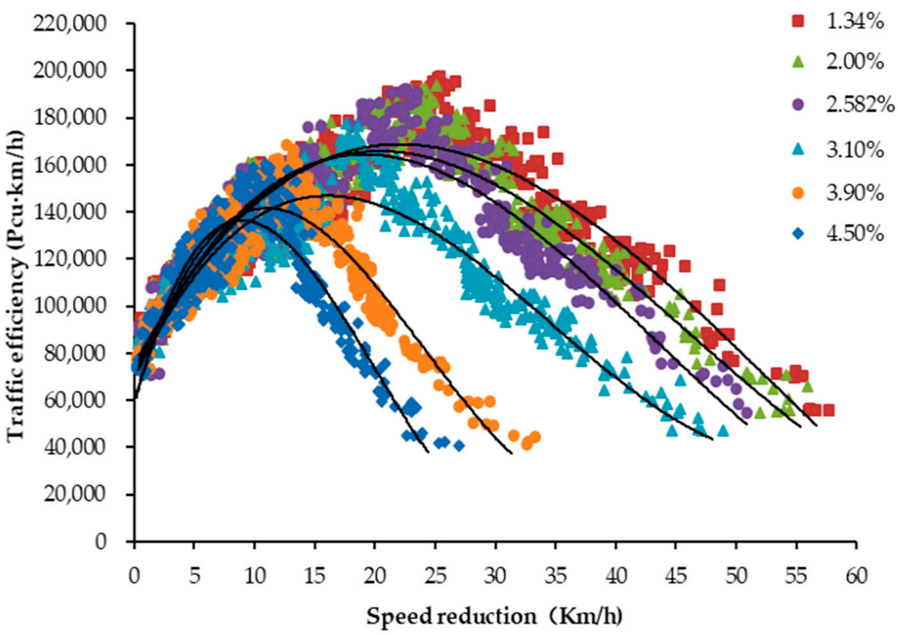

Figure 6. Relationship between traffic efficiency and speed reduction with different slopes.

From the above analysis, it can be summarized that the optimum speed reduction tended to be higher with smaller vertical slopes. Further research was carried out between vertical slope and optimum speed reduction. The fitting result between the two variables is illustrated in Figure 7. The regression equation is

$$\Delta v = 1.215i^3 - 10.806i^2 + 24.567i + 9.5189,\ R^2 = 0.997,\ I \in [1\%, 5\%] \quad (7)$$

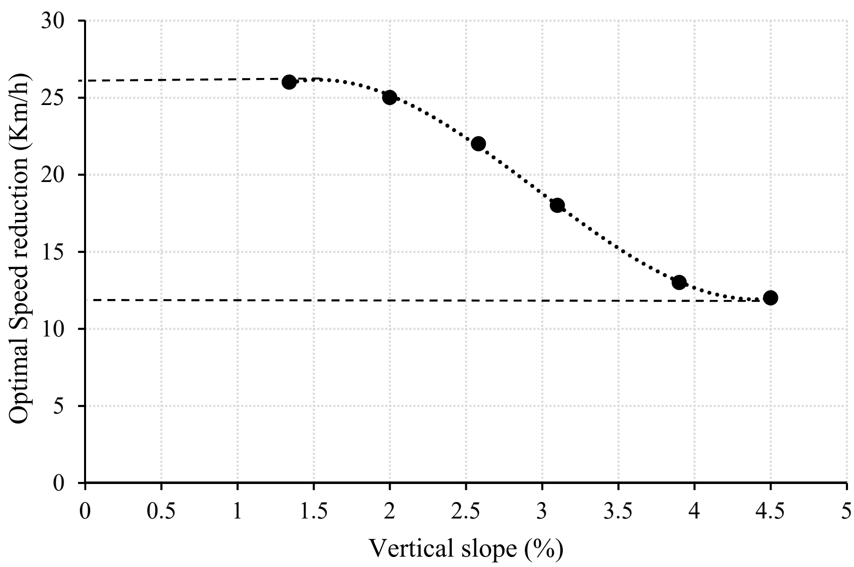

Figure 7. Relationship between vertical slope and optimum speed reduction.

Estimated by the regression equation, the inflection points roughly appeared in 1.53% and 4.40%. For a given slope, the optimum speed reduction could be calculated by the regression equation. Speed reduction was distributed in [12,26]. However, the slopes below 1% and above 5% were not explored in this study. Therefore, the equation applies to vertical slopes within 1–5% for four-lane freeways.

4. Discussion

In this study, the effect of speed reduction on traffic efficiency was investigated. The research reflected the actual traffic conditions of a mountain freeway in Shaanxi Province by field experiment. The speed reduction and traffic efficiency were then derived from speed and traffic volume data. By analyzing the relationship between the two variables, the optimum speed reduction value was determined by regression analysis. Finally, an optimum speed reduction prediction equation was proposed incorporated with vertical slope.

The recommended speed reduction value proposed by AASHTO is 15 km/h [7,8]. Our study has revealed that it can be smaller than 15 km/h when the slope is greater than 3.5% concerning traffic efficiency. In Chinese design specification for highway alignment, the critical length of grade is a strict design control with slope greater than 3% (Table 6). The maximum length of grades in Table 6 was specified by the Ministry of Transport of the People's Republic of China referring to climbing performance of Chinese-typical trucks, the national condition of China (e.g., automobile industry development, economic, environmental, and safety factors), and relevant research achievements. In AASHTO, sufficient flexibility is permitted to encourage desirable vehicle operation. From our research, the critical length of grade can meet the requirements of both safety and traffic efficiency with slopes of 3.5–5%. For the slopes of 3–3.5%, the maximum slope length is not very conducive to traffic efficiency. It means that for the areas where traffic efficiency is the first consideration in highway construction, the critical length of grade can be longer. The main function of roads is to provide the users with a safe, efficient, and practical mass traffic environment. Therefore, safety and traffic efficiency should be taken into consideration in the design process of any road. It could be rigorous to determine the recommended speed reduction considering both safety and traffic efficiency before selecting maximum length of grade. For example, safety could be the first consideration when designing for complex terrain. Therefore, weight of safety and efficiency could depend on the terrain, landform, climate, and other factors. In summary, the maximum length of grade can be flexibly designed instead of being a fixed value.

Table 6. Maximum length of grade.

Design Speed (km/h)		120	100	80	60	40	30	20
Vertical slope (%)	3	900	1000	1100	1200	—	—	—
	4	700	800	900	1000	1100	1100	1200
	5	—	600	700	800	900	900	1000
	6	—	—	500	600	700	700	800
	7	—	—	—	—	500	500	600
	8	—	—	—	—	300	300	400
	9	—	—	—	—	—	200	300
	10	—	—	—	—	—	—	200

In this research, the slopes were restricted to 1–5% and the design speed was 80 km/h. Meanwhile, six discrete slopes were studied and the speed reduction calculation equation was derived from the limited vertical slope. Moreover, the experimental freeway was four-lane, so the findings are not applicable for other road types which may yield different results. However, for the uphill sections of mountainous freeways, the speeds of trucks are mainly influenced by the vertical alignment of road geometry [29]. Furthermore, the dynamic performance of trucks is restricted thus they have a lower potential to change lanes [30]. Meanwhile, the impact between lanes could be neglected as aforementioned in this research. In summary, the influence of lane number was not included in our research and the findings can potentially provide reference for other road types. In the future, the relationship between traffic efficiency and speed reduction with slopes can be investigated for more road types. Then a universal approach can be proposed covering all types of road segments. Moreover, the prospective study of speed reduction can take other factors (e.g., driver performance, weather, speed limit) into consideration. A multi-objective study can be carried out by taking safety, efficiency, human factors, and environment into consideration to further study optimum speed reduction.

5. Conclusions

This study was conducted to determine the optimum speed reduction concerning traffic efficiency. On this basis, a more reasonable critical length of grade was determined which may guide the profile design of high-efficiency highway construction. Varying vertical slopes for the vertical alignment of road geometry were included in this research. The results demonstrated the optimum speed reduction for the investigated vertical slopes and provided a speed reduction prediction equation with the slopes of 1–5%. This study found that the speed reduction value exceeds 15 km/h when the slope is smaller than 3.5% concerning traffic efficiency. The statistical evidences revealed that the critical length of grade can be longer for the regions where traffic efficiency is the major design control with slopes of 3–3.5%. The existing regulation in critical length of grade for slopes of 3.5–5% can benefit users in terms of both safety and efficiency. The length of grade for slopes of 3.5–5% can be shorter than the current standard critical length of grade when the traffic efficiency is taken into consideration, to meet the safety and efficiency of road sections at the same time. Overall, the maximum slope length can be flexibly designed according to the design control, instead of being a fixed value. This research provides a novel method determining the maximum length of grade in the design process and the findings have the potential to offer a reference for Chinese specification revision.

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