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Effects on Deceleration and Acceleration of Combined Horizontal and Vertical Alignments on Mountainous Freeways: A Driving Simulator Study

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ABSTRACT

Combined horizontal and vertical alignments are frequently present in mountainous freeways. These complex geometric alignments prompt drivers to adjust their speeds frequently. Speed changing at considerable rates, particularly deceleration, may indicate reduced driving comfort and even cause potential safety risks. The primary objectives of the presented study were: 1) to investigate which geometric design characteristics have significant influence on deceleration and acceleration, and 2) to help engineers design alignments that promote smooth operating speed profiles and, thus, safer driving. The Tongji driving simulator was used to expose subjects to roadway conditions typical for a freeway designed for a mountainous terrain. The speed changes of drivers were measured every five meters and then classified as deceleration, near-cruising, and acceleration. Since an individual driver's deceleration and acceleration are correlated, a random effects multinomial logistic regression model was used to reflect the relationship between road alignment and acceleration and deceleration. The model showed that the grade of combined alignment segment, tangent-proportion of the following 400-meter segment, and maximum slope change of the preceding 400-meter segment had significant effects on deceleration and acceleration. Various graphs were developed to show the effect of combined alignments on the deceleration and acceleration probabilities.

Keywords: Mountainous Freeway, Combined Alignments, Deceleration and Acceleration, Random Effects Multinomial Logistic Regression Model, Driving Simulator Study

INTRODUCTION

The system of freeways in China has developed rapidly in the last ten years, from 41,000 km (2005) to 125,373 km (2015), increasing by about three times (*1*). Due to the large extent of mountainous terrain in China, many of the new freeways must be located in the mountainous areas of China's western region (*2*). Restricted by the terrain, road designers frequently use combined horizontal and vertical alignments on mountainous freeways. But in China there is still a lack of thorough quantitative guidelines for combined alignments in current design regulations and standards (*3*). The current design regulations and standards apply to individual design features, e.g., horizontal and vertical curves, considered separately and not jointly. Such an approach may ignore important design aspects of combining horizontal and vertical alignments. For example, a horizontal curve with a 400-m radius considered alone may be acceptable on a level road section, but in combination with a convex curve, a larger radius might be needed. Although the Interactive Highway Safety Design Model (IHSDM) and Highway Safety Manual (HSM) provide recommendations for the safety and operational effects of geometric design decisions on highways, there is still limited understanding of the effect of combined horizontal and vertical alignments on driving (*4*, *5*). In mountainous areas of China, poor design of roads with complex alignments and challenging driving conditions may cause both driving discomfort and increased risk even if each curve, considered in separation from other road features, meets the current design standards.

Speed change, particularly deceleration, if executed at a considerable rate, indicates a correction maneuver to adjust to a safer speed when the distance and time for this maneuver is limited. Although the associated risk may be low, the sheer necessity of such adjustments brings discomfort. If this situation is repeated frequently, it may eventually lead to frustration and fatigue, which increases the risk of crash. In a previous study, strong deceleration was used to detect an evasive maneuver to avoid a crash with another vehicle (*6*). This paper discusses a different situation where the deceleration maneuver is executed by a driver separated from other vehicles. The maneuver is a response to road design, and as such, it most likely indicates a certain road design imperfection that if eliminated would increase the driving comfort. Thus, the relationship between the deceleration behavior and the road alignments may shed additional light on the way road design affects driving comfort and safety. Although the primary focus of this paper is on deceleration, its counterpart--acceleration--is also studied as the indication of a driver's recovery of the road, and can help engineers achieve a higher design standard.

A driving simulator is a research tool, aimed at simulating a driving environment in a certain vehicle on a road with assumed design parameters, in order to study driver behavior. In this study, the Tongji driving simulator was used for rendering a virtual model of Yongji Freeway in Hunan Province, China, a typical mountainous freeway. The model exactly replicated the road design parameters and roadside elements from the design blueprint. The vehicle operation data collected during experiments included deceleration and acceleration rates calculated in regular intervals. The obtained values were classified into three levels: deceleration, near-cruising, and acceleration as the indicators of speed change rate. The characteristics of geometric alignment were taken into account as the factors influencing the deceleration and acceleration behaviors.

This paper is divided into five sections.. First, previous studies related to combined alignments and deceleration and acceleration are discussed. The second section describes the data collection procedures; then, the data preparation and modeling techniques are introduced. The fourth section presents the model and results analysis. Finally, conclusions and discussion of this work are provided.

LITERATURE REVIEW

The geometric road design of combined horizontal and vertical alignments have great influence on vehicle operating characteristics. We shall briefly review in the following subsections, 1) works on combined alignments and their effects on driving operation, and, 2) studies of deceleration and acceleration.

Combined Alignments and Their Effects on Driving Operation

In road design process, drivers' behavior characteristics, driving operation ability and driving workload should be adequately considered to reduce the possibility of driving operation errors. An inconsistent design violates most drivers' expectations, increases their workloads and consequently leads to potentially unsafe reactions (*7*). Researchers have found that the vehicle operating characteristics on combined horizontal and vertical alignments are significantly different from characteristics on single configurations. Behaviors are more complex on combined alignments, suggesting that they should be studied specifically (*8, 9, 10*). Previous studies have shown that the driving risk on combined horizontal and vertical alignments is higher than on simple horizontal curves because combined horizontal curve and slope may lead drivers to perceptual errors in vision and to performing sudden driving operations (*11, 12, 13*).

Hanno has investigated the effect of combined horizontal and vertical alignments on collision occurrences. Using the Generalized Linear Regression Model (GLIM) to find the significance of various variables, and developing collision prediction models for different combined horizontal and vertical alignment cases, he concluded that horizontal curves overlapping with crest curves are more prone to collisions than those overlapping with sag curves (*12*). Gibreel et al. (*9, 14*) have researched the influence of convex and sag curves on operating speed, and found that the length of horizontal curve, grade, and turn angle are significant variables for operating speed. To explore the relationship between geometric characteristics and lateral acceleration, Wang et al. (*15*) have classified combined alignments into four segment types: upslope-curve, downslope-curve, sag vertical curve-curve and crest vertical curve-curve.

Deceleration and Acceleration

Speed behavior has been widely studied in previous research; because operating speed alteration is synchronized with the change of road alignment, random changes in vehicle operating speeds are noticeable indicators of inconsistency in geometric design (*16*). Deceleration and acceleration reflect speed change rate. Most of the models calculate operating speeds assuming constant speed on curves, suggesting that deceleration and acceleration occur entirely on the approach tangent and the departure tangent (*17, 18, 19*). But many researchers have found that drivers' speed is not constant along curves (*20, 21, 22*). Montella et al. found that in 28.3% of the cases studied, deceleration ended in a circular curve, and in 41.5% of the cases, acceleration started in a circular curve (*23*). Pérez Zuriaga et al. found that, in most cases, deceleration continues within the curve (*24*). Some studies have found that deceleration and acceleration increased with curvature on two-lane rural roads (*25, 26*). Determination of the deceleration rate based on operating speed has led to an underestimation of the deceleration and acceleration rates effectively experienced by the drivers (*27*). Wen Hua et al. found that several geometric design variables, such as curve direction, curve radius, horizontal curve length, and a vertical curve index are associated with deceleration or acceleration rates when approaching or departing horizontal curves included(*28*).

Because driving behavior is not only influenced by the environment but also influenced by drivers' characteristics, a random effect can provide a promising way to understand the hierarchical variance structure. Random effect models have been used previously in the transportation field to resolve some of these problems (*29, 30, 31*).

Knowledge Gap

Previous studies of combined horizontal and vertical alignments have focused on horizontal curves combined with different vertical alignments. They have excluded, however, other sections of the road with the assumption that drivers' behavior on the studied curves would not be affected. Also excluded were other cases of combined alignments such as tangents combined with vertical alignments. It should be noted that the adjacent segments (preceding or following) may also influence deceleration and acceleration. For a curve with a large slope change on adjacent horizontal alignments, the scale of deceleration and acceleration may be severe. Therefore, a comprehensive study of roads with complex alignments is needed. Such a study that considers an entire road is presented in this paper.

DATA COLLECTION

The section describes the data collection procedures, including the driving simulator, experimental roadway configuration, participants, and experiment procedure.

Tongji Driving Simulator

The Tongji Driving Simulator is a high-fidelity driving simulator (FIGURE 1). It incorporates a fully instrumented Renault Megane III vehicle cab in a dome mounted on an eight degree-of-freedom motion system with an X-Y range of 20 × 5 meters. An immersive five-projector system provides a front image view of 250°×40° at 1000×1050 resolution refreshed at 60 Hz. LCD monitors provide rear views at the central and side mirror positions. In this study, SCANeRTM studio software presented the simulated roadway and controlled a force feedback system that acquired data from the steering wheel, pedals and gear shift lever. A regular privately-owned car was simulated as the study vehicle during the experiment. Vehicle operation data were measured and recorded at a frequency of 20 Hz, and were related to the roadway markers.

In 2011, after construction of the Tongji driving simulator, a series of tests were conducted to validate its capabilities. It was evaluated through three main tests: sickness, braking, and signal size. The Tongji driving simulator passed all three tests.

FIGURE 1 Tongji driving simulator

Experimental Roadway Configuration

Yongji Freeway, a typical mountainous freeway in the western Hunan Province of China, was modeled in the simulator. Yongji is a 24-km four-lane (two-way) mountainous freeway, with a longitudinal grade ranging from – 6.0% to +4.0%; the cross-section is 10.50 m (lane width 3.75 m and shoulder width 1.50 m). The driving scene was reproduced in virtual reality by the exact road design parameters and roadside elements from the design blueprint. Illustrations of the combined vertical and horizontal alignments are shown in FIGURE 2.

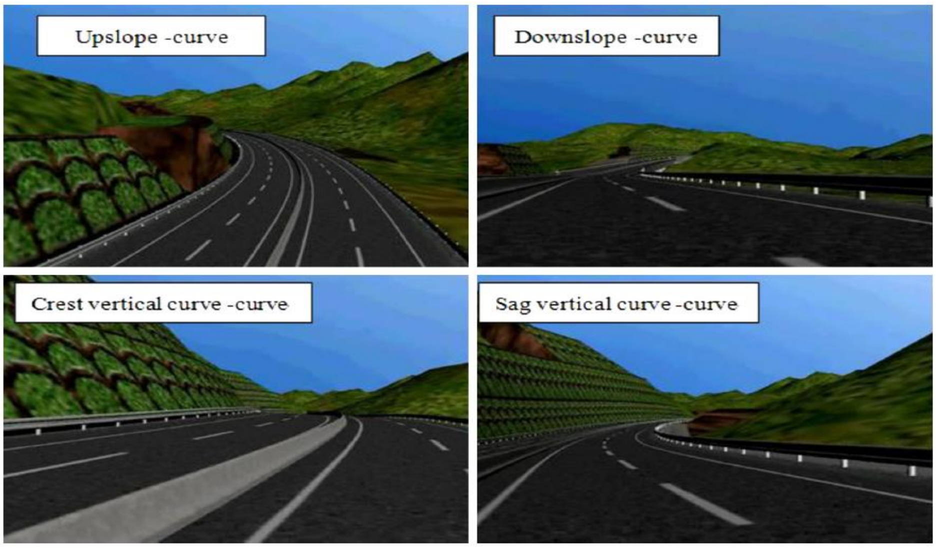

FIGURE 2 Example of combined segments

Participants

More kinds of participants with different occupations and ages were included in the sample as far as possible. Eighteen males and four females, ranging in age from 23 to 59 years, served as participants. Each of them has driven a total mileage of no less than 10,000 kilometers and has driven an average annual distance of at least 3,000 kilometers. One of the participants became sick while driving and was excluded from the study. On the pre-test questionnaire, none of the participants reported using prescribed drugs or drinking alcohol that might affect driving behavior.

Experiment Procedure

The experiment used dry pavement conditions in daylight, with free flow traffic on the two driving lanes and low traffic distributed randomly on the opposing lanes. The drivers encountered no other vehicles as traffic effects were not of interest.

The experimental sessions consisted of three phases: preparation, warm-up, and test. During preparation, participants were asked to complete a questionnaire on their personal information. Then, they were informed of the nature of the simulated driving task, the potential risks, and the purpose of the study, and were familiarized with the vehicle. In the warm-up phase, they were briefed on simulator vehicle operation, and given a 10-minute practice drive. Each participant drove all 24 km of the study road in one simulation and then drive the other direction in the same order in the following test. Vehicle operation data was collected.

DATA AND MODELING

In this section, the calculation and classification of deceleration and acceleration are introduced. The characteristics of the studied geometric combined alignment and adjacent segments were extracted as independent variables, and the data were processed before building the model.

Dependent Variable

A 22-km segment of the road was selected to be studied. Data from the start and end segments were deleted because that deceleration and acceleration is associated with starting and parking the vehicle.

In this research, the entire road section was included in the analysis by dividing it into short five-meter segments. To reduce the measurement error, the acceleration rate at spot *j* was calculated, using the centered method from speed measurements along *k* neighbor segments upstream of spot *j* and *k* neighbor segments downstream of spot *j*. For each series of five-meter speed measurements, the deceleration or acceleration rate at any spot was obtained with Equation 1:

$$a_j = \frac{(\sum_{i=j-k}^{j+k} v_i)(\sum_{i=j-k}^{j+k} \Delta_{ij}) - 2k(\sum_{i=j-k}^{j+k} \Delta_{ij} v_i)}{\left(\sum_{i=j-k}^{j+k} \Delta_{ij}\right)^2 - 2k(\sum_{i=j-k}^{j+k} \Delta_{ij}^2)} \qquad (1)$$

Where $\Delta_{ij} = t_i - t_j$, a_j is the calculated acceleration at spot *j*, v_i is the speed measurement along five-meter segments in the neighborhood of spot *j*, t_i is the recorded time of the *i*th speed measurement, and *k* is the value of the speed measurement upstream and downstream of spot *j* along the five-meter segment.

The degree of deceleration and acceleration varied in different locations on a single combined horizontal and vertical alignment, and it also varied with different drivers. FIGURE 3 shows the deceleration and acceleration of one driver. Most data of deceleration or acceleration are near cruising, but there is a sudden deceleration on the particular location. It is valuable to find out why the drivers have sudden behaviors in those particular locations.

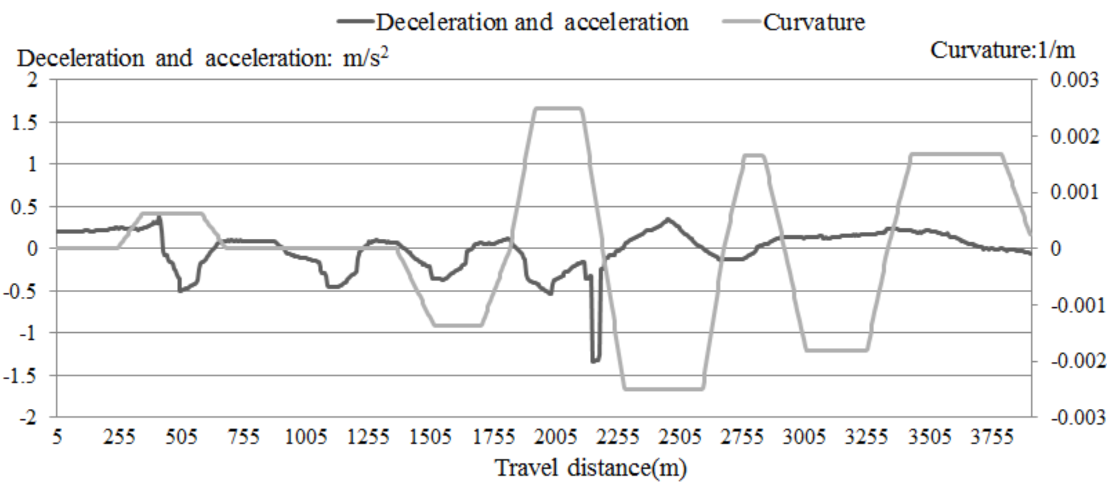

FIGURE 3 Deceleration and acceleration of a sample driver

The drivers encountered no other vehicles. The intent was to keep other environmental influence small and thus keep the data suitable for researching the relationship between the combined alignments and driving operation. Drivers' behavior, that is, will be mostly influenced by the alignments.

FIGURE 4 shows the distribution of deceleration and acceleration rates of all drivers along all studied road sections. Most deceleration and acceleration are concentrated in the middle of the distribution, indicating that the degree of speed change is not large. There are still relatively large decelerations and accelerations on both ends, however, which require analysis.

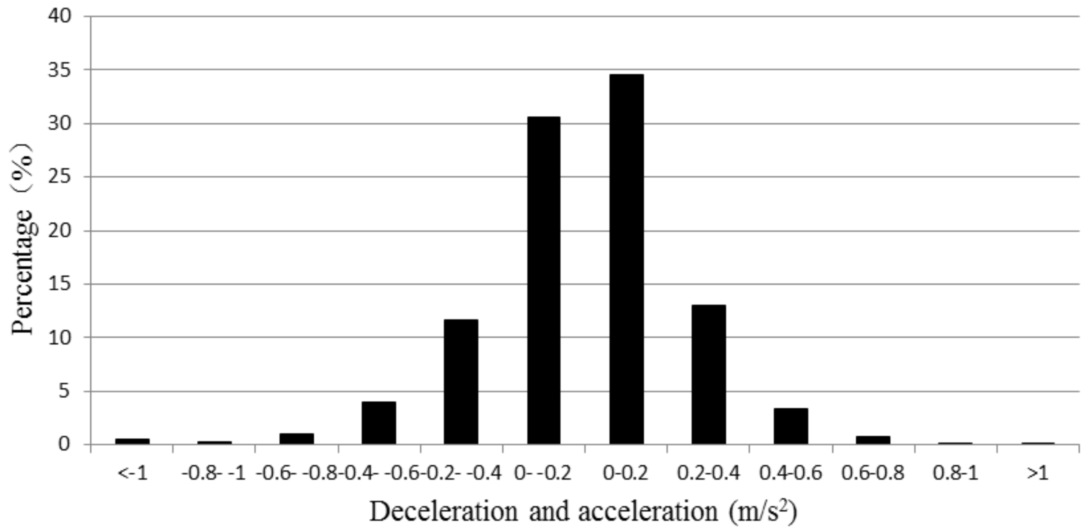

FIGURE 4 Distribution of deceleration and acceleration

The objective of this paper is to explore the road conditions under which drivers change speeds at rates that are considerably larger than typical. Assuming that a typical (or normal) acceleration/deceleration occurs in 90% of observations along the entire road when considering all drivers together, 0.4 m/s^2 and -0.4 m/s^2 were chosen as threshold rates to classify the deceleration and acceleration into 3 levels: considerable deceleration (deceleration), normal behavior (near-cruising), and considerable acceleration (acceleration). Considerable deceleration and acceleration maneuvers typically continue along a number of five-meter segments. To eliminate, or at least to reduce, the independence between observations, one segment was randomly selected to represent the maneuver of considerable decelaration and considerable acceleration. TABLE 1 shows the classification criteria of deceleration and acceleration and the frequency of the three types of driving behavior in the sample used for modeling.

TABLE 1 Deceleration and Acceleration Classification

Conditions	Behavior	Data Size
Acceleration <=-0.4 m/s^2	Deceleration	790
-0.4 m/s^2< Acceleration <0.4m/s^2	Near-cruising	7476
Acceleration >=0.4 m/s^2	Acceleration	476

Geometric Design Data

Driving behavior is influenced not only by the driver's experience at the current spot, but also by the experience along the preceding part of the road and by the view of the following part of the road (*14, 32*). Thus, the characteristics of the alignment at the current spot and of the adjacent segments were taken into account in this research.

To determine the appropriate length of the adjacent segments to consider, the geometric alignment characteristics of 50, 100, 150, 200, 300, and 400 meters of the preceding and following adjacent segments were extracted. The preceding segment is the adjacent segment the driver passes through before entering the combined alignment segment, and the following segment is the adjacent segment the driver sees upon leaving the combined alignment segment (FIGURE 5).

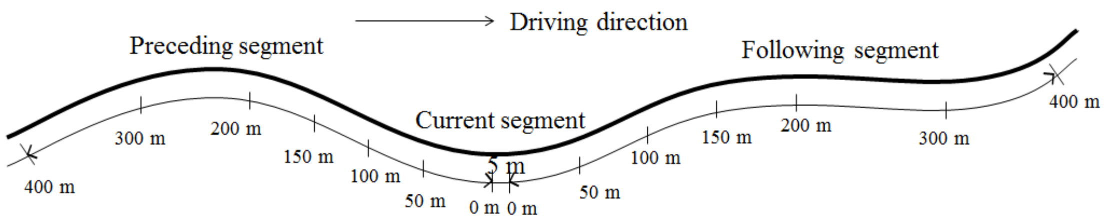

FIGURE 5 Current segment, preceding segment and following segment

Various geometric characteristics were extracted as independent variables, including the grade, direction, and curvature of the current segment (combined alignment), and the average grade, tangent-proportion, and maximum change in slope of the following and preceding segments. Certain continuous geometric characteristics were transformed into classified variables, such as the grade of the current segment and maximum change in slope of the following and preceding segments. Descriptive statistics for the current and adjacent segments are listed in TABLE 2.

TABLE 2 Descriptive Statistics for Geometric Design Characteristics

(a) Continuous Geometric Design Characteristics

Variable	Description	Mean	S.D	Min	Max
Characteristic of combined alignment segment					
Curvature	Curvature of the combined alignment segment	0.0007	0.0007	0	0.0025
Grade	Grade of the combined alignment segment (includes sign)	-0.00584	0.025	-0.06	0.04
Characteristics of 400-m following segments					
AvgGradeF400	Average grade (includes sign)	-0.0064	0.0214	-0.06	0.0351
DifGradeF400	Maximum slope change	0.0233	0.0205	0	0.081
Upslope-proportionF400	Proportion of upslope	0.4734	0.4271	0	1
ChangepointNumF400	Number of grade change points	0.8721	0.7454	0	3
DifGradesumF400	Sum of gradient changes	0.0280	0.0281	0	0.1290
AvgabsCurvature F400	Average curvature	0.0007	0.0006	0	0.0024
MaxCurvatureF400	Maximum curvature	0.0011	0.0008	0	0.0025
Right-proportionF400	Proportion of right turning part	0.3044	0.3361	0	1
Left-proportionF400	Proportion of left turning part	0.3082	0.3476	0	1

Tangent-proportionF400	Proportion of tangent	0.3874	0.3992	0	1

(b) Geometric Design Categorical Data

Variable	Description	Group	Value	Proportion
Characteristic of combined alignment segment				
Slope-type	Slope type	Downslope：grade less than -0.03	-1	15.3%
		Level：grade between -0.03 to 0.03	0	79.2%
		Upslope：grade greater than 0.03	-1	5.5%
Direction	Direction of curve	Tangent	0	38.7%
		Turning left	1	30.2%
		Turning right	2	31.0%
Horizontal-type	Types of horizontal alignment	Tangent	1	38.7%
		Circular curve	2	32.0%
		Approach transition curve	3	14.7%
		Departure transition curve	4	14.6%
Characteristics of 400-m following segments				
DifGrade-typeF400	Maximum change in slope	Equal to 0	0	33.02%
		Between 0 to 0.02	1	12.45%
		Between 0.02 to 0.04	2	28.81%
		Greater than 0.04	3	25.72%
MaxCurvature-typeF400	Maximum curvature	Equal to 0	0	19.11%
		Between 0 to 0.0014(radius is greater than 700 m)	1	41.85%
		Between 0.0014 to 0.0025(radius is less than 700 m)	2	39.04%

Variables for adjacent segments were calculated at 50,100, 150, 200, 300 and 400 meters before and after the combined alignment segment. The addition of P to an adjacent segment variable designates it as a preceding segment; F designates a following segment. The number refers to the length of the segment; for example, avgGradeP400 is the average grade of a preceding 400-meter segment.

Random Effects Multinomial Logistic Regression Model

Deceleration and acceleration are not only influenced by the environment, but are also influenced by driver characteristics. Different drivers may exhibit different driving behaviors under the same road conditions. To account for this additional influence, a random effects multinomial logistic regression model, useful for hierarchical modeling with discrete responses, was used to adapt the data’s hierarchical structures.

Categorical outcomes lead to a generalized linear model with the logic link, which is the logistic regression model. In this paper, the random effects multinomial logistic regression model was used to account for alignment and driver effects.

The dependent variable is the level of acceleration: deceleration, near-cruising and acceleration. The dependent variable classification value for the three levels is as follows: j=1 for deceleration, 2 for near-cruising, and 3 for acceleration. Then, the random effects multinomial logistic regression model is:

$$In\left(\frac{p(y=j)}{p(y=J)}\right) = \beta_0 + u_k + \sum_{i=1}^{m} \beta_{ji} X_i \quad (2)$$

where $i = 1,2,3 \cdots m$ is the alignment level indicator, $k = 1,2,3 \cdots n$ is the driver level indicator, and p(y=j) $j = 1,3$ is the probability of y=j, J=2 means the reference level is near-cruising.

RESULTS AND ANALYSIS

This section presents the obtained random effect models. Based on the model, various graphs of deceleration and acceleration probabilities were developed to show the effect of combined alignments on the deceleration and acceleration probabilities, and the results are discussed.

Model Analysis

TABLE 3 presents the estimated parameters of the fixed effects. Estimates of the fixed effects (Slope-type, difGradeP400, Tangent-proportionF400) all have a low p-value (<0.05), indicating that all three variables are significant predictors for the outcome.

TABLE 3 Estimated Parameters for Fixed Effects

Results for Fixed Effects							
Effect		Deceleration			Acceleration		
		Estimate	Standard error	*pr*>|t|	Estimate	Standard error	*pr*>|t|
Intercept		-2.8635[a]	0.2665	<.0001	-4.2245[b]	0.2602	<.0001
Slope-type	Level	Reference			Reference		
	Downslope	-1.5036	0.2131	<.0001	0.8411	0.1353	<.0001
	Upslope	-0.1772	0.1276	0.1648	-0.8379	0.2189	0.0001
DifgradeP400		14.2205	2.1155	<.0001	29.0924	2.6802	<.0001
Tangent-proportionF400		-0.2832	0.1079	0.0087	0.794	0.2144	0.0002
Random effect							
-2 res log P-like		89001			89012		
Chi sq		0.01			11.26		
P value		0.9342			0.0008		
Note: [a]Corrected intercept -2.46 = -2.8635-ln(0.06/0.09), [b]Corrected intercept -4.04 = -4.2245-ln(0.05/0.06)							

The proportion of deceleration, near-cruising, and acceleration behaviors' frequencies in the sample were different from those of the whole road. The estimated intercepts in the model were adjusted to properly reflect the population conditions (*33*).

The model results indicate that a considerable acceleration maneuver is more likely on downslope and less likely on upslope, while deceleration is less likely on downslope.

Larger maximum slope change along the preceding 400-meter segment (difGradeP400) produces a higher probability of both deceleration and acceleration maneuvers. These larger maximum differences suggest drivers may need to adjust their speed substantially to adapt to the geometric alignment change in the preceding segment, making it difficult to maintain speed on the current segment. Higher tangent-proportion of the following 400-meter segment (Tangent-proportionF400) produces a higher possibility of acceleration and a lower possibility of deceleration. All these results are plausible.

The random effects results indicate that the probability of a considerable deceleration was not affected by individual driver characteristics, while the probability of considerable acceleration does depend on drivers. This result confirms that decelerating at a higher rate is caused by the road conditions that require correction of the speed along a limited distance. On the other hand, an acceleration maneuver is not subject to the external necessity, thus drivers may exercise their individual preferences. This result concurs with the findings by Park (*21*) who also observed different driving behaviors across different drivers. Use of a random effects model has been justified by the results.

Results illustration

In accordance with the model, the ranges of probability of deceleration and acceleration were calculated, based on the maximum slope change for the preceding 400-meter segment,

and tangent-proportion of the following 400-meter segment. Results are shown in FIGURE 6.

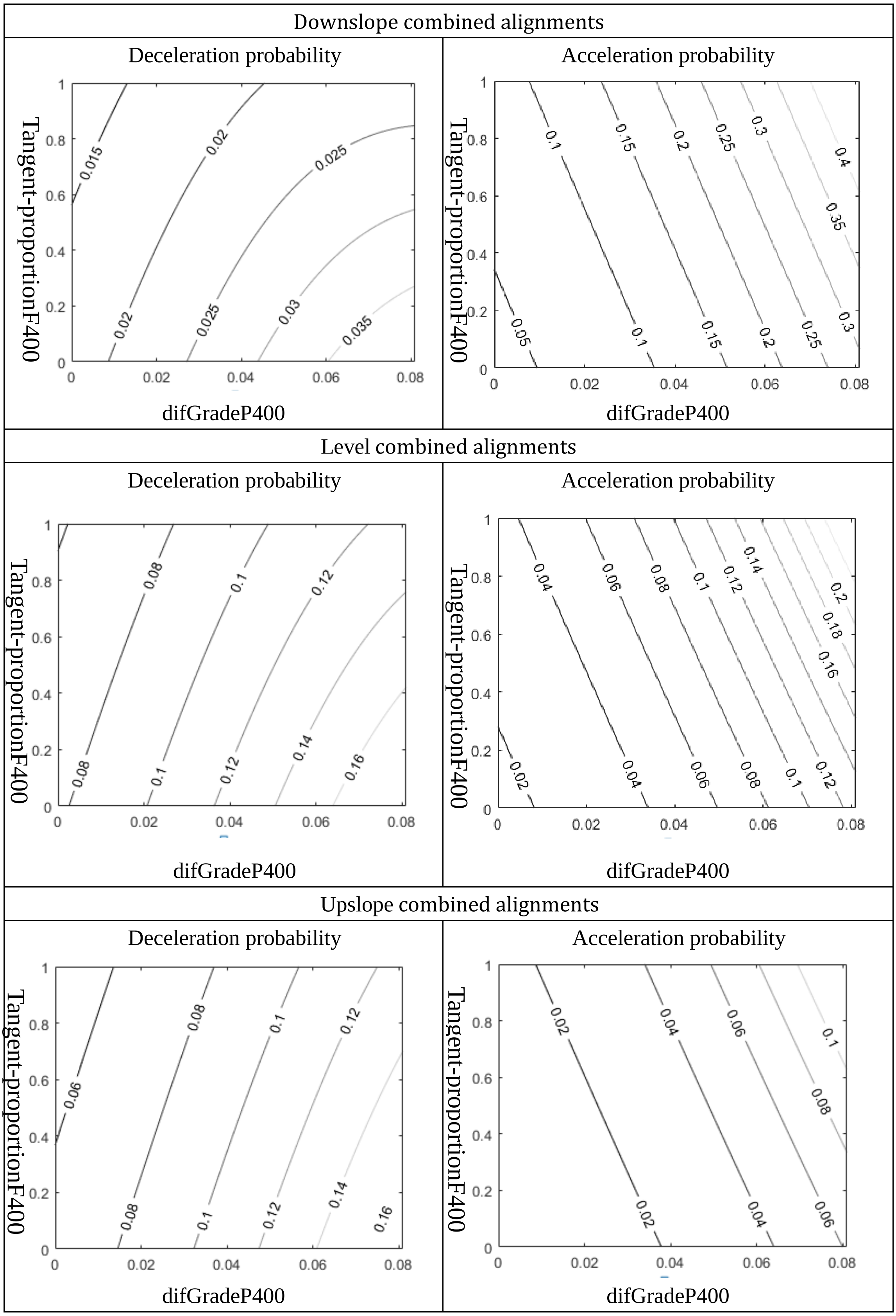

FIGURE 6 Probability of deceleration and acceleration under three alignment scenarios

On a downslope segment, the deceleration probability ranges between 0.01 and 0.04. The probability grows where the preceding segment includes a vertical sag curve and the change of the slope is larger. The presence of a horizontal curve on the following segment increases the probability of deceleration. The acceleration probability is larger than 0.05 and may reach even 0.40 in cases where the driver has just passed a pronounced vertical curve, particularly when facing a straight segment ahead.

On an upslope, the deceleration probability is larger than on downslope and ranges between 0.06 and 0.18. This is consistent with the findings by Montella that at a longitudinal upgrade has a significant speed-reducing effect (*27*). The deceleration is affected by the presence of a vertical sag curve in the preceding segment, and to a smaller extent by the horizontal curve in the following segment.

On a level segment, the deceleration probability is only slightly lower than on an upslope, and ranges between 0.05 and 0.17. The effects of a preceding vertical curve and following horizontal curve are also similar to the scenario with an upslope segment.

It seems that a vertical sag curve along a preceding segment increases the probability of deceleration and acceleration, thus effectively reducing drivers' inclination to maintain speed.

CONCLUSION

The objective of this study was to investigate the effect of complex alignments on drivers' deceleration and acceleration behaviors in order to help design more comfortable and safer freeways in challenging terrains. This study employed a driving simulator to render conditions along a typical four-lane mountainous freeway in Hunan Province. In order to account for the difference between individuals and properly estimate the effect of the road, the random effects multinomial logistic regression model was used.

The research findings show that the different slope types of combined horizontal and vertical alignments examined influence deceleration and acceleration differently. Acceleration is more likely to occur on downslope and less likely to occur on upslope. Deceleration is less likely to occur on downslope. This finding shows vertical grade is an important variable to consider when designing combined alignments. It is consistent with the findings of a previous study by Montella (*27*).

Another finding of potential use to engineers is that in the design stage of freeways, the geometric parameters of different sections of combined alignments should be considered interdependently. That is, not only the combined alignment itself, but also the adjacent segments, should be taken into account. This finding is consistent with Montella (*27*). The optimum length of the adjacent segments, which significantly influences the deceleration and acceleration, is 400 meters. An illustration of the results analysis has been conducted for upslope, downslope and level roads.

One of the interesting findings is uniform deceleration behavior across various drivers, which may indicate that indeed this behavior is caused by external road factors, as deceleration stronger than 0.4 m/s^2 is a corrective maneuver to adjust speed down to changing design along a road. This finding reinforces the assumption that a considerable deceleration in a free-flow condition may be used to evaluate road design and identify spots where an improvement should be considered. Further research is needed to verify this hypothesis with a larger number of drivers.

Several possible developments were considered for the future research. Firstly, a broader sample size from different type highways and a larger number of participants will be helpful to identify more general conclusion; Secondly, it may be valuable to conduct a field experimentation to verify the result.

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