STUDY ON THE INFLUENCE OF MOUNTAIN LANDSCAPE FACTORS ON THE DRIVING STABILITY OF DRIVERS BASED ON VIRTUAL REALITY SIMULATION

H LI, M ZHANG, Q KOU, H JIANG, L YU and J YANG

Hubei University of Technology, Nanli Road, Hongshan District, Wuhan
Tel: 186 7278 7766; Email: 329547758@qq.com;
Tel: 133 8698 0129; Email: 1031793148@qq.com
Tel: 150 6470 0283; Email: 1020081297@qq.com
Tel: 152 7113 0806; Email: 283411533@qq.com
Tel: 195 0388 3857; Email: 2541864619@qq.com
Tel: 155 3826 8315; Email: 2437751639@qq.com

ABSTRACT

This study takes the emerging green highway landscape theory as an entry point and uses simulated driving tests to design different combinations of landscape factors to test driver behavioral characteristics. The study explores the laws of landscape influence on driver driving stability by analyzing and processing four quantitative factors reflecting highway landscape factors, including plant spacing, plant height, plant color, and traffic markings, and then combines them with driving experience. The stability model was used to validate the relationship between the landscape and driver behavior. The study found that a plant height of 6 m, spacing of 8 m, reasonable plant color, and appropriate traffic markings on a mountainous highway landscape in Xianning County are conducive to driving stability and improve road safety. The research results can provide theoretical support for highway landscape design and help to conduct traffic safety theory research.

1. INTRODUCTION

Traffic safety and green traffic in China have grown in importance in recent years. Good highway landscaping can not only beautify the environment but also improve the comfort of drivers and passengers, enhancing vehicle safety. An investigation of road sections on which accidents occurred revealed that the road environment, including the highway landscape setting, accounts for more than 70% of accidents (Guo, Li & Chen, 2019). The highway landscape environment will affect a driver's psychological, physiological, behavioral, and fatigue state through visual stimulation. However, China's existing highway design primarily focuses on engineering design, and most primary highway construction has been completed or nearly completed before the corresponding landscape greening is considered, after landscape greening space has been greatly reduced. Landscape specification (GTAT) (HGDS) also suffers from a predominance of principle-based guidance and a lack of specific data guidance. Therefore, starting from the relationship between the highway landscape and traffic safety, studying the influence of the highway landscape on driver behavior can reduce traffic accidents.

With the continuous development of simulation technology, scholars have explored the relationship between highway landscapes and driving behavior in depth. A scholar (Berlyne & Boundewijns, 1997) and another scholar (Wohlwill, 1976) proposed that changing the complexity of visual stimuli in a road scape can attract driver's attention.

However, continuous complex visual stimuli will be overwhelming, and visual stimulation with too little information or too much simplicity will be boring. Using a virtual simulation system, increasing the density of trees on the roadside can better attract driver attention (Calvi, 2015). The diversity of plants through driving simulation tests and found that plant color had a positive effect on the representation of driving behaviour (Jiang et al., 2020). Establishing highway landscapes at a normatively appropriate critical length threshold can have a positive effect on driving behaviour (Wei & Zhao, 2016). Scholars (Li & Zhang, 2022) quantified landscape factors through a UC-win/Road driving simulator and concluded that appropriate plant height, spacing, and color settings can enhance driver slope perception and speed perception. According to a scholar (Qi, 2013), there are significant differences in the visual characteristics of urban and nonurban road environments as perceived by drivers. Reducing the space between roadside trees and the clear zone made drivers feel more at risk and prompted them to move closer to the center of the road was discovered (Fitzpatrick et al., 2014). These studies all showed that the highway landscape makes a difference in driving stability. Previous studies have mostly focused on a single landscape component analysis, but the landscape setting on an actual road often presents a combination of factors. Based on this, quantitative research on landscape setting combinations can more accurately explore their impact on road safety. Second, previous studies usually analyzed the landscape in terms of plant color, spacing, height, etc. This study integrates traffic facilities and landscape settings to deepen the study of the influence of landscape factors on the stability of the road environment.

This study uses the UC-win/Road software and a driving simulator to quantify different landscape factors, analyze the relationship between different kinds of road landscapes and vehicle handling stability through variable control, build a driving stability model, and rank the stability degree of 14 simulation scenarios. The findings will provide a theoretical foundation for studying the effect of various highway landscapes on the driving environment.

2. DRIVING BEHAVIOR CHARACTERISTICS INDICATORS

Driving behavior is a multidimensional concept, that is, the synthesis of longitudinal and lateral driving parameters (Rosey et al., 2008).

2.1 Longitudinal Motion State Characterization Index

Drivers drive in mountainous sections and safely pass along curved roads by adjusting their speed. Speed variation indicators are quantitative indicators used to characterize the magnitude of changes in vehicle operating speed, of which the average speed is the most commonly used data to measure driving safety. The standard deviations of the longitudinal acceleration and deceleration, which depict the intensity of speed variation, are often employed indicators of driving behavior in addition to the average speed.

2.2 Transverse Movement State Characterization Index

To prevent the car from veering too far from the center of the road while driving, the driver assessed the surrounding traffic circumstances before moving the steering wheel. As a result, the variation in parameters connected to the lateral location indicates the driver's lateral vehicle control. The lateral position, defined as the position of the vehicle's longitudinal axis in the longitudinal road reference system, is the most significant concept in the lateral dimension. Furthermore, the standard deviation of the lateral position (SDLP) is frequently utilized as a measure of lateral trajectory control.

The operating range of the steering wheel and pedals could also be recorded by most driving simulators. The driver adjusted the direction of vehicle travel by turning the steering wheel to adapt to the road alignment. Based on this, the mean and standard deviation of the steering wheel rotation angle can also be used as indicators of driving behavior.

3. MATERIALS AND METHODS

UC-win/Road software was used to model roadside landscapes and roads in this study. The data for driving behavior characterization were obtained through simulated driving simulation experiments, and the data were summarized using Excel software. The driving stability was then analyzed using principal component analysis, and the data were selected and processed using SPSS software. The experimental data were then compared and analyzed.

4. EXPERIMENTAL PREPARATION

Drivers who have been driving for a long time tend to have more driving skills. Therefore, the experiments selected subjects with more than three years of driving experience. In this research, considering the duration of the experiments, the difficulty of recruiting subjects, and the experimental expense, thirty qualified drivers were selected, including twelve women and eighteen men. In addition, all drivers had physical and mental well-being on the day before the experiment to eliminate physical and other causes of interference. The characteristics of the subjects are shown in Table 1.

Table 1: Driver's condition

Gender	Age			Years of Driving		
	Under 24 years of age	24-40 years old	Over 40 years old	3 to 5 years	5 to 10 years	Over 10 years
Male	3	12	3	4	11	3
Female	2	7	3	3	8	1
Total	5	19	6	7	19	4
	30			30		

To fully understand the distribution characteristics and methods of highway landscape element settings, representative secondary highways in and outside Hubei Province (China) were selected for landscape element investigation and statistics. Based on detailed consideration of the geographical location, curve line section, and climatic condition factors, the experimental section selected was a two-way two-lane road with a single-lane width of 3.5 m. The total length of the road was 1.5 km with an uphill gradient of +4% and a horizontal curve radius of 480m in Chongyang County, Xianning City, as shown in Figure 1.

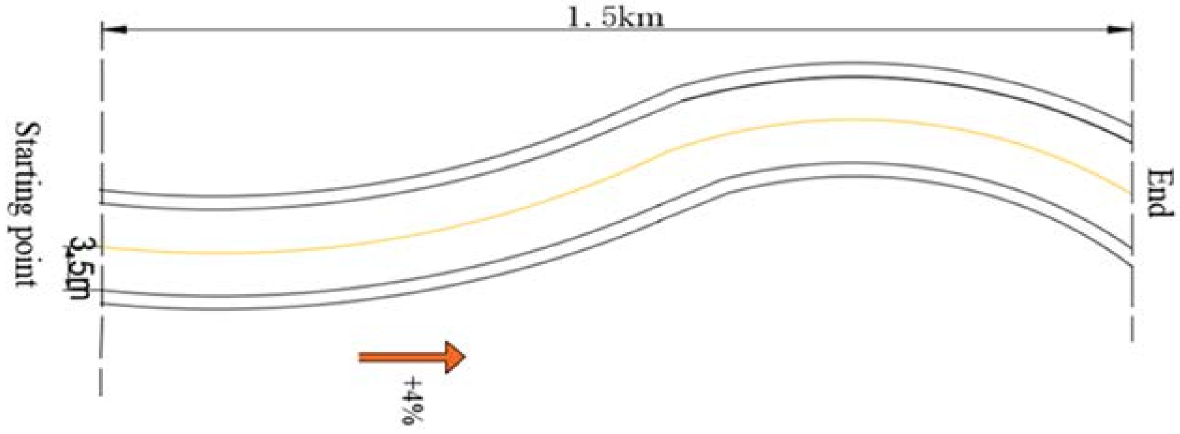

Figure 1: Experimental road alignment and landscape layout

5. RESEARCH ON INFLUENCING FACTORS OF LANDSCAP

5.1 Landscape Color Factors

Grouping the color of street trees into three categories: evergreen and deciduous trees, evergreen trees, and deciduous trees, the speed changes under the three plant color factors were obtained and analyzed as the subject manipulated the vehicle, as shown in Table 2.

Table 2: Index analysis results under different color levels

Driving Behavior Index	Color Level		
	Level 1: Evergreen and deciduous trees	Level 2: Evergreen trees	Level 3: Deciduous trees
Speed average/(km·h^{-1})	52.68	57.57	46.93
Average value of lateral position offset/m	0.95	0.68	1.24

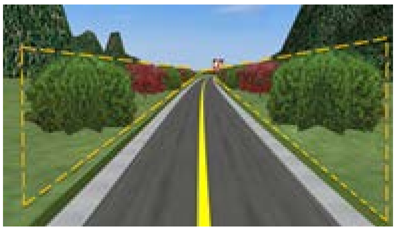

Figure 2: Evergreen and deciduous trees landscape map

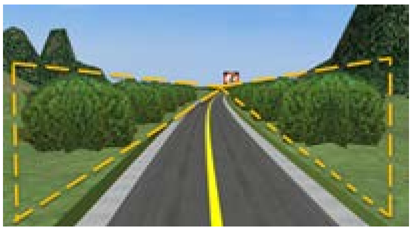

Figure 3: Evergreen trees landscape map

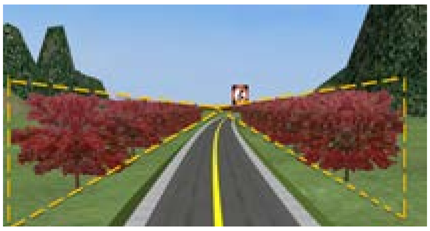

Figure 4: Deciduous trees landscape map

Table 2 shows the results of the analysis of driving behavior characterization indicators under the color factor. The average vehicle speed in the scenario where the road landscape color was only evergreen trees was the highest. Combined with driving experience, drivers thought the evergreen tree landscape was common on mountain roads and could quickly adapt to the environment of such driving scenarios. Therefore, the average value of the lateral position offset of level 2 was relatively small. Figure 4 shows the degree of visual impact that deciduous trees introduce to drivers in real situations, which was one of the reasons why their speed averages were much lower than those of levels 1 and 2. The comprehensive conclusion of the driver feelings about driving was that the colorful tree color causes dazzling, and drivers must turn the steering wheel frequently to keep the vehicle driving smoothly. Therefore, the average speed was much lower than the average speed of levels 1 and 2. In terms of plant maintenance and transportation, deciduous trees have high post maintenance costs and are not suitable for mass planting from the perspective of saving construction costs.

5.2 Plant Spacing Factor

The minimum plant spacing is 2 m (Han, 2005). Spacings of 4 m, 8 m, and 16 m were used, and the speed changes under the three plant spacing factors were obtained and analyzed as the subject manipulated the vehicle, as shown in Table 3.

Table 3: Index analysis results under different spacing levels

Driving Behavior Index	Plant Spacing Level		
	Level 1: 0.004 km	Level 2: 0.008km	Level 3: 0.016 km
Speed average/(km·h^{-1})	47.26	53.34	58.58
Average value of lateral position offset/km	0.0020	0.0014	0.0015

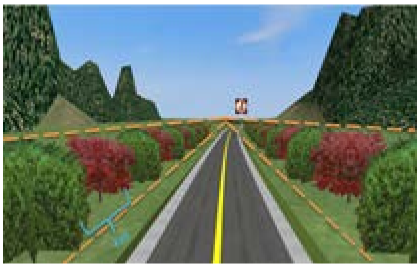

Figure 5: 0.004 km plant spacing landscape map

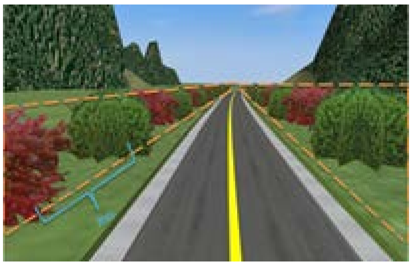

Figure 6: 0.008 km plant spacing landscape map

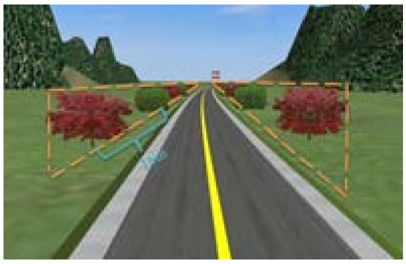

Figure 7: 0.016 km plant spacing landscape map

Table 3 shows the analysis results under the plant spacing factor. Under the three plant spacing levels, the average transverse position of vehicles in the scene with a moderate plant spacing level (8 m) in the road landscape was the smallest among the three scenes. In terms of driver feelings about driving, the average speed under level 3 was the largest, which may be because the scene with large spacing between plants provided drivers with a broader vision, making them feel happy and that they had more driving space. However, the same spacing produced a weaker light and shadow effect, which the driver's visual stimulation was less sensitive to. Moreover, in the opposite situation, drivers chose to slightly reduce their speed and tended to approach the center of the travel lane in that direction.

5.3 Landscape Height Factor

According to the relevant regulations of highway landscape design, the fixed trunk height of street trees is generally not less than 2.8 m, and the crown height is generally in the range of 5 to 8 m. Street tree heights of 3 m, 6 m, and 8 m were used, and the speed changes under the three plant height factors were obtained and analyzed as the subject manipulated the vehicle, as shown in Table 4.

Table 4: Index analysis results under different height levels

Driving Behavior Index	Height Level		
	Level 1: 0.003 km	Level 2: 0.006 km	Level 3: 0.008 km
Speed average/($km \cdot h^{-1}$)	55.77	52.69	48.32
Average value of lateral position offset/km	0.0015	0.0007	0.0013

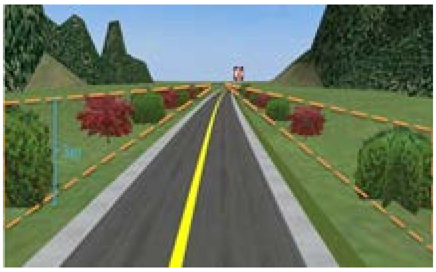

Figure 8: 3 m plant height landscape map

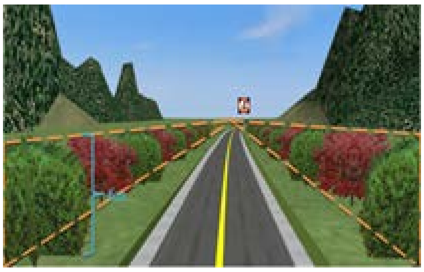

Figure 9: 6 m plant height landscape map

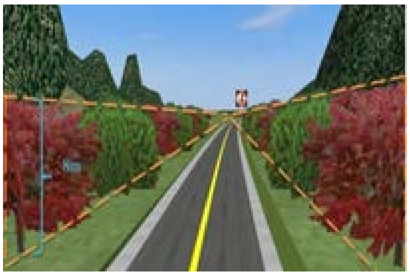

Figure 10: 8 m plant height landscape map

Table 4 shows the analysis results for the plant height factor. The average value of the lateral offset distance in the scenes with moderate plant height (6 m) in the road landscape was the smallest among the three height factor levels. By asking drivers about their driving experience, most drivers thought that the plants in the level 3 scenario were too high, and at the same time, with increasing driving time, being in this scenario for a long time would cause a certain sense of oppression. Therefore, drivers work to avoid sudden accidents by slowing down and other means or being as close as possible to the central dividing zone, which leads to a lateral position shift. The height of the plants in level 2 was suitable, with a wide field of view and the ability to detect all kinds of situations in the road area in time. A lower plant height created a driving environment that was open and relaxing for the driver. This was one of the reasons why the driver's driving speed reached the maximum at level 1, but the plants were small, which may make a driver feel excessively relaxed, thus creating slackness and a potential risk of speeding.

5.4 Road Traffic Marking Factors

The number of traffic markings on the mountain was set to 0, 1, and 2. A setting of 0 refers to there being no traffic signs or road markings. A setting of 1 indicates only a traffic sign with no road markings or only road markings with no traffic sign. When both traffic signs and markings are present, the setup of the traffic signs and markings is specified and clear. Using the three settings of 0, 1, and 2, the speed changes were obtained and analyzed as the subject manipulated the vehicle, as shown in Table 5.

Table 5: Index analysis results under different traffic facility setting levels

Driving Behavior Index	Number of Traffic Markings		
	0	1	2
Speed average/(km·h^{-1})	41.34	49.67	55.49
Average value of lateral position offset/km	0.002	0.0013	0.001

Figure 11: No traffic markings landscape map

Figure 12: One traffic marking landscape map

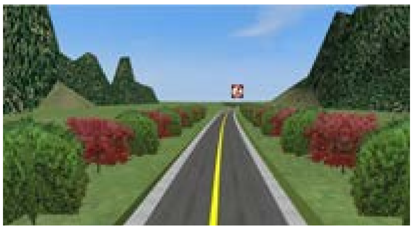

Figure 13: Two traffic markings landscape map

Table 5 displays the analysis results of driving behavior characterization indicators under traffic factors. With no traffic markings, which made it difficult for a driver to accurately assess the state of the road in front of them, the psychological strain of driving is increased, according to the comprehensive driver feeling about driving. Drivers can only maintain smooth vehicle driving by getting as close as possible to the central dividing line because they are unable to accurately evaluate the direction of the road. This explains why there is a much higher lateral distance offset in comparison to the other horizontal cases. With no traffic signs meeting specifications, it is unclear which way the road was going up ahead, forcing drivers to slow down to reserve space for unforeseen accidents. The average speed value when there is one traffic marking is slightly lower than that when there are two markings. With two markings, the linear direction of the road was clear, the sign predicted the road condition ahead, and drivers felt good and restrained.

6. INFLUENCE OF LANDSCAPE FACTORS ON DRIVING STABILITY

Road landscapes affect road users, namely, drivers and passengers, and the impact of the landscape on drivers is the most important, which is related to driving safety. Unreasonable road landscape design will harm driver driving behavior, resulting in vehicle handling instability. Therefore, this research compares driver driving stability to measure the impact of different levels of road landscape factors on driving behavior. Numerical stability is a measure of data volatility and discreteness of an index because its judgment can be taken into account using statistical methods. Therefore, the standard deviation indexes of the following four parameters measured in the experiment to characterize the vehicle state are integrated into the driving stability evaluation index F:

L_{STD}: Standard lateral offset value.
V_{STD}: Standard speed value.
$a_{\bar{v}_t}$: Standard acceleration value.
X: Standard steering wheel offset angle value (a decimal value between [-1,1]).

Since these indicators affect each other interrelatedly and reflect the stability of driving to different degrees, the data were analyzed and processed using principal component analysis to obtain new comprehensive indicators.

6.1 Analysis of Mountain Road Landscape Factors on Driving Stability

The four distinctive roots and their contribution rates were derived using SPSS 22.0 software, and principal component analysis was performed on the driver driving behavior data, as shown in Table 6.

Table 6: Total variance explained

Element	Initial eigenvalue		
	Total	Percentage of variance (%)	Cumulative percentage (%)
X_1	2.338	58.443	58.443
X_2	0.975	24.373	82.815
X_3	0.528	13.199	96.015
X_4	0.159	3.985	100.00

Since the cumulative contribution of the first three eigenvalues reached 96.015% > 85%, the first three principal components were selected to be integrated into a comprehensive evaluation index of driving stability. The following analytical expressions for each principal component were obtained from the SPSS 22.0 software principal component analysis output:

$$F_1=-1.86828ZX_1+1.6064ZX_2-1.6765ZX_3-1.7521ZX_4 \quad (1)$$

$$F_2=-1.5361ZX_1+0.6255ZX_2-1.2201ZX_3-0.7494ZX_4 \quad (2)$$

$$F_3=0.4152ZX_1-0.2738ZX_2-0.8123ZX_3-0.2865ZX_4 \quad (3)$$

F_1, F_2, F_3: major component 1, major component 2, major component 3.
X_1: Standard lateral position offset value.
X_2: Standard velocity value.
X_3: Standard acceleration value.
X_4: Standard steering wheel offset angle value.

ZX_1, ZX_2, ZX_3, and ZX_4 and are the outcomes of a normalized transformation of the original data using the Z score approach. As shown in Table 7, the ratio of eigenvalues corresponding to each principal component to the sum of the eigenvalues of the selected main components is used as the weight to calculate the main component integrated model, and the integrated driver driving stability F can be obtained as:

$$F=\frac{1}{3.616}(2.338F_1+0.975F_2+0.528F_3) \quad (4)$$

The configuration of landscape factors with a plant spacing of 8 m, plant height of 6 m, traffic signs meeting specifications, and evergreen trees properly matched with deciduous trees is a better combination. Whether the result is valid or not, the above factors are taken as the benchmark to make a standard scenario, and the standard scenario is scenario 1. Scenarios 2-9 are eight of the 12 scenarios already available in the driving simulator, excluding duplicate scenarios. All scenarios are introduced in Section 5. The 10th scenario is the one without landscape elements set.

Using the normalized transformed data, the driver driving stability evaluation value was calculated based on the above principal component integrated model for the 14 scenarios, and the stability was ranked according to the principle that the smaller the value, the better the stability. Figure 14 shows a comparison of the values for each factor level. The factor and level numbers in the graph also correspond to Table 8.

Table 7: Standardized processing results

Results of Standardized Processing				
Scene	ZX_1	ZX_2	ZX_3	ZX_4
1	-1.86828	1.60644	-1.67489	-1.7521
2	0	-0.41211	-1.01442	-0.51792
3	0.62276	0.20729	1.39647	0.7934
4	-1.53614	0.62546	-1.22014	-0.74933
5	0.04152	-0.27377	-0.81231	-0.28651
6	-0.49821	-0.3901	0.45449	-1.21215
7	-0.91338	-0.85229	-0.78705	0.09918
8	0.2491	-0.77369	0.95255	0.33059
9	-0.33214	-0.37752	0.08997	0.02204
10	0.2491	-0.8743	-0.28177	0.17631

Table 8: Stability results under various landscape factors

Scene	Corresponding Indicator					
	Plant height/m	Plant spacing/m	Plant color	Traffic markings/pcs	Stability evaluation value	Stability ranking
1	6	8	Color matching	2	-1.044	1
2	6	4	Color matching	2	-0.354	6
3	6	16	Color matching	2	0.378	10
4	3	8	Color matching	2	-0.905	3
5	8	8	Color matching	2	-0.842	4
6	6	8	Evergreen trees	2	-0.456	5
7	6	8	Deciduous trees	2	-0.947	2
8	6	8	Color matching	0	0.234	9
9	6	8	Color matching	1	-0.274	7
10	—	—	—	2	0.160	8

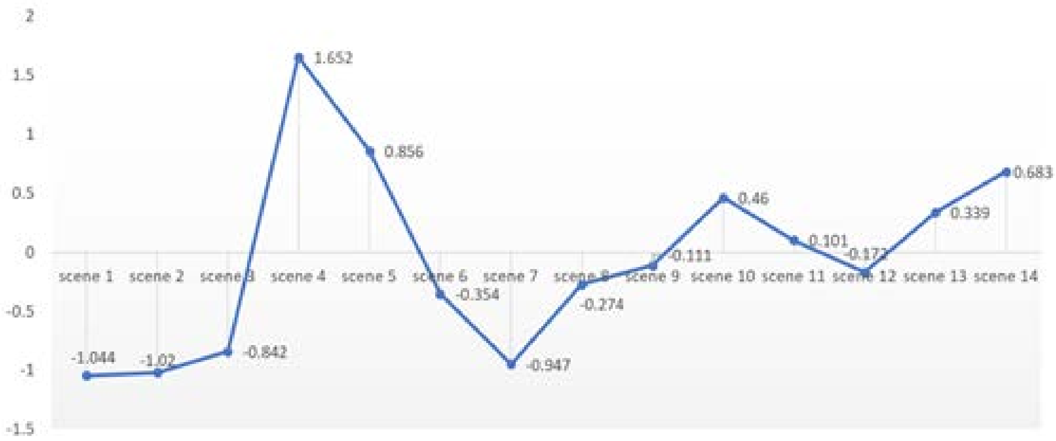

Figure 14: Stability line graph for each factor at each level

Combining Table 8 and Figure 14, it can be seen that scenario 1 has the highest stability, indicating that when the road landscape factors are kept at moderate levels, it improves road safety. Under scenarios 1-3, other variables are treated as fixed values when the plant spacing is altered. It is possible to conclude that the stability is at its lowest when the plant spacing is 16 m and the plant height is 6 m. Under scenarios 1, 4, and 5, the stability gap is small when the plant height and other factors are kept constant. In the case of 8 m spacing, a change in plant height has no significant effect on driving stability. Under scenarios 1, 6, and 7, changing the color of the plants increases the stability value when the appropriate color match is used, indicating that using the color-matching landscape setting facilitates driving stability. By analyzing data on traffic facility placement, it is possible to conclude that compliant traffic markings have a greater impact on driving safety. Scenario 10, ranked eighth, is the case with no landscape settings, and when compared to scenario 3, ranked tenth, it can be concluded that improper landscape settings will harm driver driving.

Combined with a driver questionnaire, the results show that the driving stability influence involves the following aspects:

- High plant height can cause psychological stress to drivers.
- If the plant density is sparse and far from the road, the driver lacks visual stimulation.
- Continuous long times in a monotonous driving environment cause the driver to slack psychology.
- The appropriate application of traffic signs and markings can effectively restrain driver behavior.

7. CONCLUSION

1) Four indicators of height, spacing, color, and traffic markings were selected as highway landscape factors to construct highway landscape scenes at different levels. The driver driving behavior characterization data under different scenes were evaluated using virtual reality simulation technology, and it was found that the selected factors all had different degrees of influence on driving behavior. When landscape factors have moderate settings, they are the most beneficial to a driver's driving stability.

2) This study compares the driving stability of drivers under different landscape factors. The results show that when taking three levels of color, plant spacing, and plant height as moderate selections, along with standardized traffic signs and markings, the driving stability of the driver is better.
3) This study models road scenes using UC-win/Road and uses principal component analysis to filter and compare road landscape influencing factors and evaluate them. It can qualitatively and quantitatively analyze the relationship between overall driver driving stability and the road landscape. The method is simple to use and can be used to design and evaluate road landscapes in various regions.

Data availability:
The [DATA TYPE] data used to support the findings of this study are included within the supplementary information file(s).

Conflicts of Interest:
There is no conflict of interest regarding the publication of this paper.

Funding Statement:
There is no funding for this article.

Supplementary Materials:
Research data are provided and uploaded together with the manuscript.

8. REFERENCES

Berlyne, DE & Boudewijns, WJ. 1977. Hedonic effects of uniformity in variety. Canadian Journal of Psychology, 25(3):195.

Calvi, A. 2015. Does roadside vegetation affect driving performance? Driving simulator study on the effects of trees on drivers' speed and lateral position. Transportation Research Record, 2518(1):1-8.

DB33/T2062-2017, 2017. Highway greening design specification. Ministry of Transportation and Communications (HGDS).

Fitzpatrick, CD, Harrington, CP, Knodler, MA, et al. 2014. The influence of clear zone size and roadside vegetation on driver behavior. Journal of Safety Research, 49: 97:e1-104.

Guo, F, Li, M & Chen, Y, et al. 2019. Effects of highway landscapes on drivers' eye movement behavior and emergency reaction time: A driving simulator study. Journal of Advanced Transportation, 2019: 9897831.

Han Xiangchun Han, 2005. Road Traffic Landscape Design. Harbin: Northeast. Forestry University Press.

Hao Li & Yueyang Zhang. 2022. Influence of Landscape Design on Driving Behavior Based on Slope Illusion, Journal of Advanced Transportation, vol. 2022, Article ID 6407145, 7 pages.

Jiang, B, He, J & Chen, J, et al. 2020. Moderate is optimal: a simulated driving experiment reveals freeway landscape matters for driving performance. Urban Forestry & Urban Greening, 58: 126976.

JTG/T3360-03-2019, 2019. Green Travel Action Plan. Ministry of Transportation and Communication (GTAP).

Qi, B, 2013. A comparison study on the driver's eye movement characteristics on ordinary and urban roads.Changchun: Jilin.

Rosey, F, Auberlet, JM & Bertrand J, et al., 2008. Impact of perceptual treatments on lateral control during driving on crest vertical curves: a driving simulator study. Accident Analysis & Prevention, 40(4):1513-1523.

Wei, ZH, & Zhao X. 2016. Critical Threshold of Highway Length Under Monotonous Landscaping Patterns.Journal of Beijing University of Technology, 42(01):95-106.

Wohlwill JF. 1976. Environmental aesthetics: The environment as a source of affect. Human behavior and environment. New York: Plenum Press, 1976:37-86.