DRIVER'S SENSITIVITY ANALYSIS TO ALIGNMENT CHANGES IN THE THREE DIMENSIONAL VIRTUAL REALITY HIGHWAY

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Abstract: This research modeled 4-lane highway in three dimensional virtual reality in order to overcome difficulties of field experiment, and the research subject was placed in a driving simulator. The driver's sensitivity to the alignment changes in the three dimensional virtual reality highway was analyzed by Multivariate Analysis Method.
The lane change of the three dimensional alignments used for the sensitivity analysis of the driver was designed such that the curvature radius was 460m and grade difference was changed simultaneously by 2% between 0~12%. The vocabulary used in Multivariate Analysis Method was selected by the Korean dictionary and the expert's opinion. The driver's sensitivity analysis and verification was carried out using the Principal Analysis. Also, through the dynamic experiment using the driving simulator, we compensate for the results extracted from the static experiments and analyzed the driver's behavior at the three dimensional alignment by analyzing the drivers behavior characteristic regarding dynamic factors.

Key Words: Three dimensional alignments, Virtual Reality, Driving Simulator

1. PROLOGUE

1.1 Study Background and Purpose

The safe road design is regarded to be formed when the designer's intention is identical with the intention of the driver. The traffic accident is subject to occur and the fatigue, irritation and nervousness that drivers feel when drivers drive the road at the road where such rules aren't established.

The domestic and international road design direction suggests the design standard of the radius and the vertical grade applicable according to the design speed alteration regarding the curve section and the vertical grade section, but fails to suggest the clear design standard at the three dimensional alignment. According to the previous study related with the road geometric, the road designed in accordance with the road design standard, the recognition of the drivers can affect the traffic accident. In such aspect, to enhance the road safety, the importance of the study on the road design device to consider the driver's sensitivity is highlighted domestically and internationally.

This study tries to analyze the safety of alignment of road at the static condition by applying the Kansei Engineering(or Human Sensibility Ergonomics) method after modeling the 4-lane highway, by using the Virtual Reality to overcome the driver’s safety problem and the experiment setting difficulty of the spot experiment. To identify the road image characteristic based upon the researched data, we discerned the safety image factors by the Principal Analysis. Also, through the dynamic experiment using the driving simulator, we compensate for the results extracted from the static experiments and analyzed the driver’s behavior at the three dimensional alignment by analyzing the drivers behavior characteristic regarding dynamic factors.

1.2 Scope and the Method

This study fixed the scope as the 4-lane highway basic section. The driving speed is fixed as the 100km/h, a maximum speed at the general domestic highway (as for the passenger car). The visual factors of the driving simulator are modeled to the extent the vehicles pass the road according to the random distribution.

This study classifies the contents into static experiment and dynamic experiment. The static experiment realizes the Kansei evaluation regarding the alignment change that driver’s sensitivity by providing the road environment database made of the Virtual Reality through the beam projector. Multi Variables Interpretation Kansei Engineering method and Principal Analysis method are applied, in order to analyze the static experiment data.(Soonmook L., et al.) The dynamic experiment analyzes the figure data of the road database (after driving the road database) provided with at the static experiment, using the driving simulator to interpret more concretely and to compensate for the results derived from the static experiment.

2. STUDY TENDENCY

As for the study on the visual information evaluation of the driver when driving at the road, the study on the relationship between the speed through the drive experiment and the visual density and the study on the driver's visual attitude analysis at the curve part of the national road to enhance the traffic safety.(Yasser H., Said M.E.)

As such above, real road drive experiment is followed by various limitations since it cannot guarantee the safety of the driver and has the difficulty to change the design. To overcome such problems at the spot experiment, the road design applying the Virtual Reality and the study on static condition and the human factor analysis utilizing the driving simulator have been prepared.

As for the basic study that is already applied to analyze the driver's mentality amid static condition includes the Kansei Engineering application study on the driver's sensitivity of the movement using the driving simulator and the study that evaluates the driver's recognition according to the alignment change utilizing the animation.(Kwon, S. et al.) Also, the recognition analysis on the speed sensation of the driving environment using the driving simulator, analysis on the characteristic of the drunken driver, realization of the traffic accident due to the abrupt acceleration and the analysis on the driver's reaction have vigorously performed.

3. VIRTUAL ENGINEERING

Virtual Engineering is the technology that combines the Virtual Reality and the Kansei Engineering. The Virtual Reality is the mutual relational system that enables one to react to oneself by building the virtual world like a dream through computer. It generally refers to the technology that enables user to stride freely stride within the virtual environment made by the computer and to experience virtually through the human basic 5 senses.

Classified systematically, the Kansei Engineering is the system that translates the image expressed by the word into the concrete design as the "technology that realizes the human image by interpreting it into a concrete physical design factors." The profound difference between the Kansei Engineering and the conventional technology system is that people are not necessarily satisfied mentally only because they excessively seek for the physical convenience.

The essence of the Kansei Engineering is to measure the human sensitivity function such as the vision, auditory sensitivity, smell, taste and the tactile sensitivity as the basic materials to measure the pleasability of human and measure under which circumstance human can attain the sensitivity as the "luxury", "affection", "novelty" and "differentiation", analyzing and evaluating the extracted qualitative data of human by applying the Multivariate Kansei Engineering method.

4. EXPERIMENT DESIGN

4.1 Collective Details of the Experiment

4.1.1 Subject and the cautions

This test is the basic study that measures the sensitivity change of the drivers driving the three dimensional alignment of various design condition modeled by the Virtual Reality method. It was performed by 20 young drivers (Male:16, Female:4) in their 20's and 30's, considering the test safety and the driving adaptability capacity.

The participants were not aware of the experiment objective before driving and they performed driving exercise sufficiently lest the driving sickness such as dizziness and nausea occur due to the driving simulator, when they drive for the first time. Participants could not take the nicotine, caffeine, drug and alcohol that can affect the autonomic nervous system 24 hours from the test. Also the test environment was built to comfort the participants’ mind during the test.

4.1.2 Three dimensional alignment design using the Virtual Reality

The visual screen of the virtual road used at the static experiment and driving experiment of this study was modeled as Figure 1, using the EVARIST program. To express the test environment more realistically, the visual factor was designed with the consideration of the road surface, central segregation, sign and lane, environmental image and natural color.

1. R=660, A=4%	2. R=660, A=6%	3. R=660, A=8%

Figure 1. The three dimensional alignment realized by the Virtual Reality method

Figure 1 shows the three dimensional alignment(R=660m, A=4,6,8%), confirming that the grade of the road grows with the incline figure proportionately. Here, R is the Radius and A is the Algebraic difference of the grade.

4.2 Kansei Evaluation for Static Test

4.2.1 Kansei Engineering-aspect approach

This study uses the Multivariate Kansei Engineering method to perform the Kansei Engineering-aspect evaluation regarding the road design change. This Kansei Engineering method is the qualitative method that evaluates the driver's sensitivity using the vocabulary, not quantitative method using the vital sign. We conduct the test by suggesting the road environment varying according to the road design that drivers see, through the beam projector and receiving the reaction of the driver.

4.2.2 Extracting the Kansei factors

We choose the Kansei factors as Figure 2 to consider the degree of the Kansei representation and the representative related with certain Kansei factors, not satisfied with mere discovery of the factors related with road image.

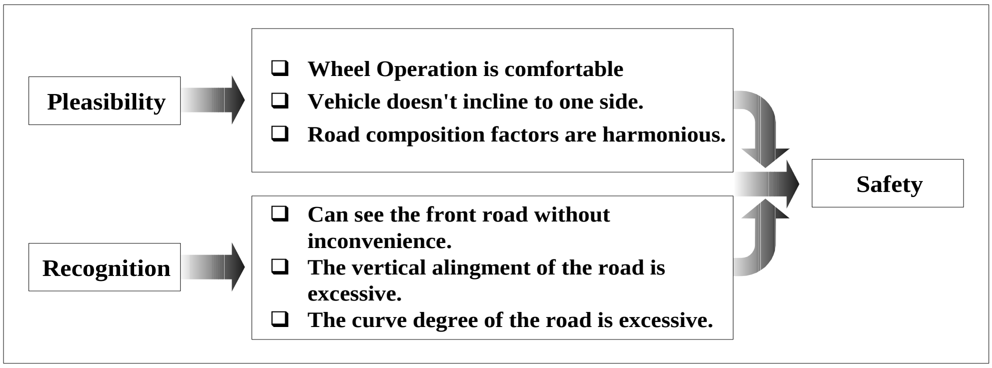

Figure 2. Kansei factors within three dimensional alignment

Especially, we extracted the Kansei factors on main category pleasability related with safety when driving and recognition. We collected the Kansei vocabulary through the Korean-Korean dictionary and refined them based upon the opinion of the experts. We organized the questionnaire to perform the Kansei evaluation using the finally extracted vocabulary.

4.2.3 SD Scale organization and image survey

Based upon the extracted Kansei factors, we organize the questionnaires (scaled to 0-5 points regarding each category) so that participants see the provided Virtual Reality road screen and evaluate the recognition characteristics. In this survey, regarding the scale of the SD (Semantic Differential Method), the higher, the closer to the positive answer.

Table 1. 5-scaled questionnaire category

Category	1	2	3	4	5
1. Wheel operation is comfortable.	□	□	□	□	□
2. Vehicle doesn't incline to one side.	□	□	□	□	□
3. Can see the front road without inconvenience?	□	□	□	□	□
4. Road composition factors are harmonious.	□	□	□	□	□
5. The vertical alignment of the road is excessive.	□	□	□	□	□
6. The curve degree of the road is excessive.	□	□	□	□	□
7. I find the driving this road safe in a road geometric structure aspect.	□	□	□	□	□

The questionnaires provided to the subject are classified into mainly three categories. The first category is composed of personal data such as age, sex and driving experiences and the second one is composed of the questionnaires regarding the adaptation degree toward the driving simulator. The third category is consisted of 5-scaled questionnaires by composing the questionnaires with Kansei vocabularies to evaluate the degree of Kansei that subject feels according to each test. As such, we surveyed the road geometric structure image that drivers feel at the three dimensional alignment through composed questionnaires.

4.3. Simulation for Dynamic Experiment

4.3.1 Driving simulator

Driving simulator used for the driving experiment is equipped with three-channel projection system and electric operation system, and used the KMU DS2 (6 free system) that attains the reality by providing drivers with the wide view scope (150X40 degree).

Figure 3. Driving simulator KMU DS2 and Test Condition

Visual computer creates the highly realistic computer image with high realization rate (30 frames/sec) and realizes the virtual driving condition by projecting the image to screen using the LCD projector. Sound computer realizes various noises and sounds.
Controlling power loading system is composed as to perform the feedback the anti-power and anti-torque of the operation controlling device that drivers feel realistic as well as to extract the driving input by the drivers. Also, to consider the system safety and discern the operation condition of the total system efficiently, we organized the controlling condition supervising system and organized the safety system to confront the malfunctioning of the system and dangerous circumstances.

4.3.2 Composing of driving road database

The road database used at the driving experiment using the driving simulators is as Figure 4. The left of the Figure shows the change condition of the vertical grade difference(A) and the Radius(R) using the matrix while the right of the Figure shows the road shape, curve direction and driving distance that correspond to 6th stage among total 12-stage changes. The road shape, curve direction and the driving distance provided with at each 12 stage are same with those at the 6th stage, but the A figure and R figure are changed as the stage advances.

A(%) / R(m)	0	4	6	8
460	Step 1	Step 2	Step 3	Step 4
660	Step 5	Step 6	Step 7	Step 8
860	Step 9	Step 10	Step 11	Step 12

<table>
<tr><td>Setp 6</td><td colspan="6">R = 660m, A = 4% (+2, -2)</td></tr>
<tr><td>Sahpe</td><td rowspan="2">Tangent</td><td colspan="2">Crest</td><td rowspan="2">Tangent</td><td colspan="2">Sag</td></tr>
<tr><td>Curve Direction</td><td>Left</td><td>Right</td><td>Left</td><td>Right</td></tr>
<tr><td>Distance</td><td colspan="6">2,200 m</td></tr>
</table>

Figure 4. Driving road database made up by the Virtual Reality method

4.3.3 Driving Scenario

Since the driving database that this study built surveys the 4-lane highways, we let the drivers maintain the 100km/h driving speed when driving the driving simulator. The driving experiments are classified into experiment 1 and experiment 2.
At the experiment 1, the A figure is set as 0% beforehand and the vertical curves of the road have no difference only with changed R figures. At the experiment 2, the participants drive the total 24-stage three-dimensional alignment section where both the A figure and R figure are changed.
The data figures acquired from the driving simulator driving experiment are used for interpreting the result of the multivariate Kansei Engineering method experienced under static condition.

5. DATA ANALYSIS

5.1 The Analysis of the Respondent Property

This research surveyed the basic categories such as sex, age, driving experience and highway driving experiences as for the personal data. The sample size and composition ratio of each property of the respondents are as Figure 5. The numbers classified by categories in figure 5 means not a proportion of the experiment respondents but that of driven data according to the scenario.

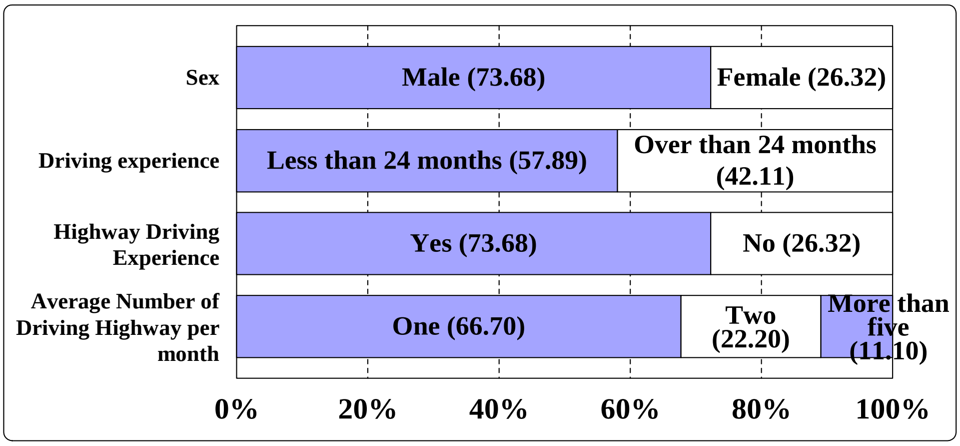

Figure 5. The composition rate according to the respondents' property

5.2 Static Experiment Data Analysis

5.2.1 Kansei data SD figure analysis

Figure 6 shows the average scores regarding the total samples by converting each category into scores after receiving the image of the road geometric structure that drivers feel at the three dimensional alignment. As a result, the average score at the category 'the road vertical grade and the flat curve are excessive' is a little bit lower than other categories.

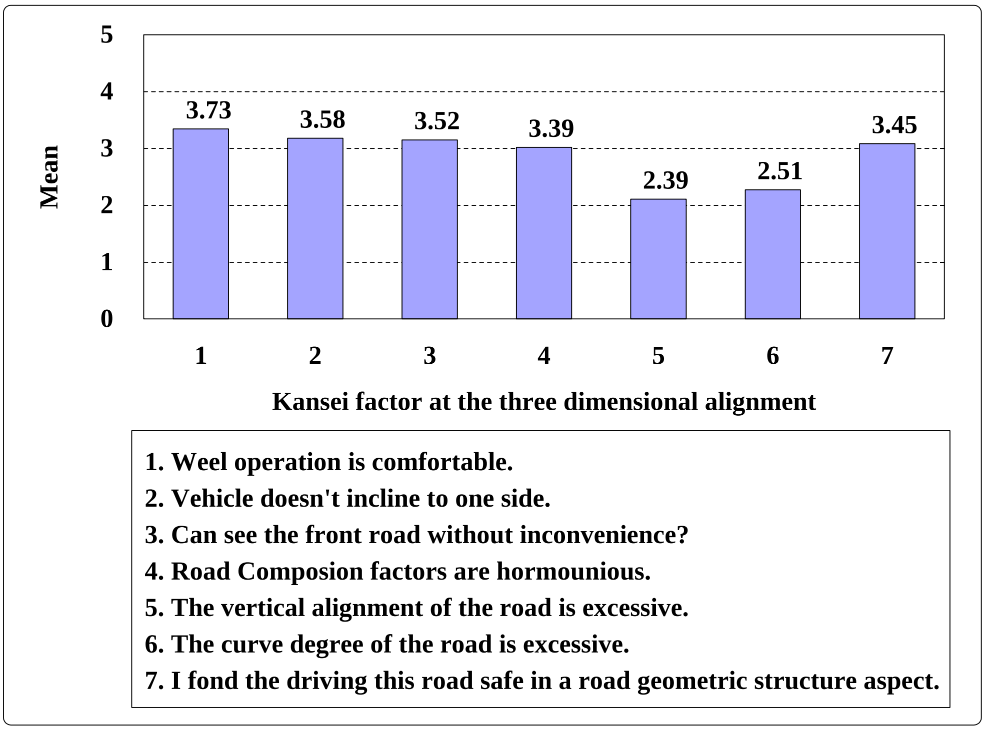

Figure 6. Recognition degree regarding the road image

5.2.2 Principal analysis

This study analyzed the principal factors to analyze the categorized influencing factors regarding the road geometric structure image that drivers feel at the three dimensional alignment. After analyzing the image principal factors regarding the whole road geometric structure condition, the accumulated contribution rate is 65.21% as Table 2, not sufficient enough to explain the meaning of the image explanation variables, but enough to discern the image recognition characteristic factors regarding the road geometric structure at the three dimensional alignment.

Table 2. Results of the Principal analysis of the image variables regarding the whole road geometric structure condition

Main Item	The First Principal Factor (Pleasibility)	The Second Principal Factor (Recognition)
1. Wheel operation is comfortable.	0.471744	0.399304
2. Vehicle doesn't incline to one side.	0.491382	0.351528
3. Can see the front road without inconvenience?	0.428704	-0.198038
4. Road composition factors are harmonious.	0.262561	-0.747346
5. The vertical alignment of the road is excessive.	-0.292233	0.342351
6. The curve degree of the road is excessive.	-0.444833	-0.045109
Eigenvalue	2.94254	0.97021
Cumulative	0.49040	0.65210

At the 1st principal factor, the categories such as "The wheel operation is convenient", "Vehicle is not excessively inclined to one particular direction", "Can see the front road well" and "The road curve is excessive." show high loading figures while the categories such as "the vertical grade of the road is excessive" and "The road curve is excessive" have the negative sign condition, showing the pleasibility.

At the 2nd principal factor, the categories such as "The road composition factors are harmonious", "The road vertical grade is excessive" have the high factor loading while the such categories have the negative sign condition, showing the recognition. Also, Figure 7 classifies the variable characteristic regarding the relationship among principal factors by expressing such variable principal factors loading to the x-y coordinate of the 1st principal factor and 2nd principal factor, in order to identify the relationship among principal factors.

As for the result, two groups exist each closing to the main ingredient axle but not clearly classified since it lacks the independent scope. Therefore, we could decide that the drivers could not feel the image of the road geometric structure at the three dimensional alignment, clearly independently.

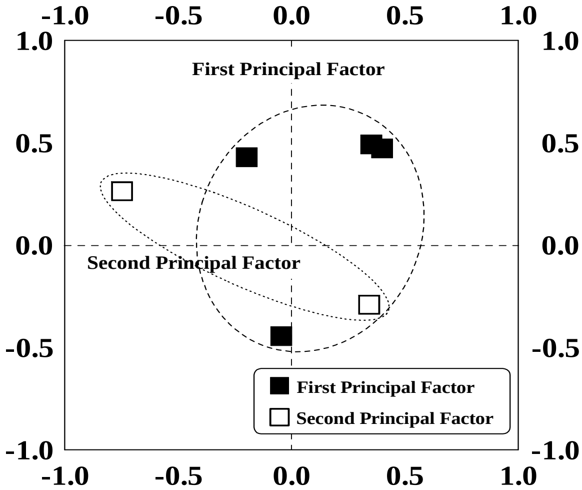

Figure 7. Image variable principal factor loading
for the whole road geometric structure condition

5.3 Dynamic Experiment Data Analysis

5.3.1 Safety factor correlation analysis

We performed the correlation analysis of safety at the static condition and the driving speed, acceleration and deceleration and brake operation, factors most related with the safety among the figure data acquired quantitatively at the dynamic condition, to discern the factors of the safety regarding at the dynamic experiment by driving simulator. As a result, the correlation among each variable was not high as shown at the Figure 8. However, the correlation of the driving speed is fixed as the factor expressing the safety at the dynamic condition in that its figure is 0.14117, a relatively high figure compared with the acceleration and deceleration and brake operation.

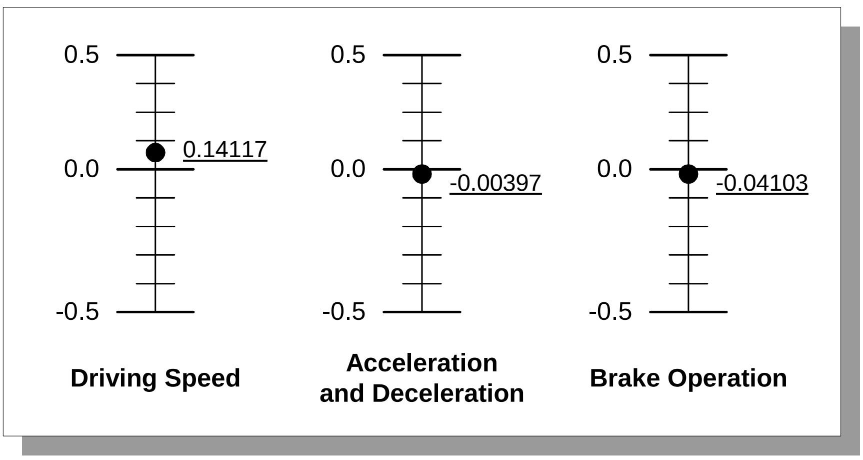

Figure 8. The correlation between dynamic data and static image (safety)

We measured each category average figure to check whether there is difference of individual property at the static and dynamic condition regarding the safety at the road geometric structure. The standard of the safety at the static condition is the image category as "I find the driving safety in a road geometric structure aspect" while the standard of safety at the dynamic condition is the driving speed shown the most correlation with the safety image at the static condition in the correlation analysis. As a result, all the categories express the difference regarding the safety at the dynamic and static conditions as shown at the Table 3.

Table 3. Categorized average figure regarding the static and dynamic safety factors

Item		Category	Number of Sample	Mean	S.D	*t-value*	*p-value*
Static Factor	Sex	Male	115,328	3.477	0.956	55.13	0.0001
		Female	47,534	3.181	0.856		
	Driving experience	Less than 24 months	65,647	3.245	0.895	44.94	0.0001
		Over that 25 months	97,215	3.454	0.953		
	Highway driving Experience	Yes	116,763	3.275	0.915	-64.66	0.0001
		No	46,099	3.608	0.945		
	Average number of Driving Highway per month	Less than 2	73,929	3.513	0.921	78.00	0.0001
		Over than 2	42,971	3.065	0.963		
Dynamic Factor	Sex	Male	159,917	84.452	17.62	114.96	0.0001
		Female	47,534	72.3.6	20.084		
	Driving experience	Less than 24 months	66,062	85.846	17.326	-89.58	0.0001
		Over that 25 months	97,470	77.584	19.652		
	Highway driving Experience	Yes	117,433	83.414	17.156	76.59	0.0001
		No	46,099	74.571	22.34		
	Average number of Driving Highway per month	Less than 2	74,341	85.524	15.879	57.98	0.0001
		Over than 2	43,229	79.527	17.659		

5.3.2 Analyzing the factors that the three dimensional alignment affects the driving speed

We could find how the radius and vertical grade affect the safety at the dynamic condition (under the virtual driving circumstance) by analyzing how these variables affect the driving speed that shows the safety at the road geometric structure at the three dimensional section, according to the vertical line forms. Accordingly, we analyzed whether there is difference according to the alteration of radius and vertical grade regarding the driving speed, according to the alteration of the radius and the vertical grade. The analysis results are as Table 4 and Table 5.

Table 4. Average figures regarding the speed at the crest section

Category	Grade Radius	0%	4%	6%	8%
Left Curve	460m	73.97(15.98)	76.69(15.50)	74.18(12.70)	69.72(16.28)
	660m	82.83(19.46)	79.23(16.38)	80.47(18.25)	74.91(18.34)
	860m	87.34(21.93)	82.47(15.31)	82.22(16.81)	77.34(19.33)
	F	474.90	115.96	248.79	176.60
	p-value	0.0001	0.0001	0.0001	0.0001
	RMSE	18.84	15.74	16.00	17.97
Right Curve	460m	78.72(20.98)	79.85(18.06)	81.52(19.86)	85.38(16.61)
	660m	84.30(19.40)	81.95(18.36)	86.86(19.52)	87.45(15.95)
	860m	86.29(24.13)	86.54(17.16)	85.55(17.75)	85.07(18.29)
	F	115.79	117.86	68.88	18.12
	p-value	0.0001	0.0001	0.0001	0.0001
	RMSE	21.56	17.88	19.08	16.99

( ) Standard Deviation

Table 5. Average figures regarding the speed at the sag section

Category	Grade Radius	0%	4%	6%	8%
Left Curve	460m	81.07(19.40)	78.43(16.88)	83.31(19.38)	83.21(17.15)
	660m	83.16(21.68)	82.21(16.76)	84.53(19.11)	81.97(18.59)
	860m	88.76(22.61)	86.13(17.61)	83.95(19.39)	85.10(19.51)
	F	117.77	169.35	3.28	23.83
	p-value	0.0001	0.0001	0.0378	0.0001
	RMSE	21.23	17.07	19.30	18.43
Right Curve	460m	79.39(21.37)	73.56(18.74)	79.59(19.75)	72.17(16.81)
	660m	81.88(22.37)	79.75(16.56)	78.45(17.87)	75.73(18.48)
	860m	88.18(20.88)	77.87(16.78)	77.89(19.82)	78.17(20.87)
	F	148.42	118.45	6.97	93.62
	p-value	0.0001	0.0001	0.0009	0.0001
	RMSE	21.56	17.42	19.17	18.74

( ) Standard Deviation

After analysis of factors that the three dimensional alignment affects the driving speed, the average driving speed of the right curve is higher compared with the left curve at the crest section while the average driving speed of the left curve is higher at the sag section.

Such result is expressed by the road structural forms of the vertical alignment. If the drivers enter the left curve section at the crest section, the central separation of the road restricted the driver's view. To the contrary, the driving speed seems to increase at the right curve where the central separation affects less.

Also, the average driving speed seems a little bit higher at the sag section rather than crest section with the increase of the vertical grade. It is due to the fact that the view distance reduces totally with the increase of the vertical grade at the crest section while increases at the sag section, guarantying the view regarding the road flat alignment forms. Also, the individual driving speed scope shortens with the increase of the vertical grade at the crest section compared with the sag section at the driving speed distribution according to the geometric condition while it enlarges wit the increase of the radius. Therefore, we could confirm that drivers increase the driving speed at the point where guarantee the view distance, feeling safety.

6. CONCLUSION AND FUTURE STUDY DIRECTION

6.1 Conclusion

This study analyzed the Principal Analysis to discern the main factors that drivers feel at the road and performing the static and dynamic analysis by surveying the three dimensional alignment within the highway basic section induces the results as follows.

1. Based upon the Principal Analysis regarding the road geometric structure image at the three dimensional alignment, the 1st principal factor shows the pleasibility and the 2nd principal factor shows the recognition. However, it is not classified clearly and drivers seem to feel the comprehensive image at the road.

2. Based upon the correlation analysis, the factor most related wit the safety at the static condition is the driving speed. It is analyzed that the driving speed increases with the increase of the radius while it decreases with increase of the vertical grade, showing that the alteration of the radius and the vertical grade affects the safety.

3. The individual driving speed scope narrows with the increase of the vertical grade at the crest section compared with the sag section while it increases with the increase of the radius, confirming that the drivers feel safety at the point where guarantee the view distance.

6.2 Future Study Direction

This study analyzed the drivers behavior regarding driving simulator driving experiment by modeling the three dimensional alignment where R is fixed as 460m using the Virtual Reality method. We need the driver attitude model analysis regarding the three dimensional alignment where possesses the various radius. Also, it is required of applying the driver ecology and physiology experiment to the driver behavior model and of expanding the various traffic condition such as arterial road section, day and night, weather condition and cross section condition using the Virtual Reality method.

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