Evaluation of the Desirable Road Lighting Environment by Coordinating the Various Source of Light at Night

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Abstract: Visual environment of the road at night is established by the sum of various source of light, such as road lighting, headlight of the vehicle and so on. If the visual environment at night is stable, impact to the driving environment will be small. However, if it is not, dangerous situation might occur. In this study, to clarify the influence of illumination from various source of light to the driving environment at night, video image experiment was conducted. And by analyzing the data from this experiment, significant factors for each objective feeling in driving is clarified. By the result of these analyses, it is found that road lighting shares high among the various source of light. However, there is a situation that visual environment only by the road lighting could not satisfy the adequate condition. Therefore, it is important to consider the mixture of light for each case.

Keywords: Visual environment at night, Headlight, Road lighting, Regression analysis

1. INTRODUCTION

Visual environment of the road at night is established by the sum of various source of light, such as road lighting, headlight of the vehicle, illumination of roadside and so on. If the visual environment at night is stable, impact to the driving environment will be small. However, if it is not, dangerous situation might occur due to the obstacles that are hard to detect on the road. Figure 1 shows the Japanese visual environment at night. From this figure, it is easy to understand that super luminosity neon lighting emphasize the dark area as black. Then visual environment changes to unstable. Figure 2 shows the German visual environment at night. Brighter materials are used as the texture of the wall of the buildings. And this makes stable visual environment in cooperating with the reflection by the wall. Furthermore, neon sign from the roadside facilities is less utilized in Germany. Furthermore, lighting instrument is installed at the middle of the road by hanging with the wire. Therefore, visual environment in Germany is quite stable in whole, and this makes easier for drivers to find pedestrians.

Figure 1. Visual environment in Japan


Figure 2. Visual environment in Germany

It is clear that stable visual environment makes better road space. A situation that visual condition changes from/to bright and dark frequently makes drivers difficult to drive at night. Because human eye system has limitations to adapt quick change of darkness/brightness, it is hard for drivers to confirm the crossing pedestrians whether they exists or not in this situation. Many Asian cities, especially in Japan, visual condition changes from place to place. For example, in the bright commercial area, head lights might not be needed to illuminate the road space. It could be useful to turn on the parking lights instead of head lights. Most important thing is to coordinate the various source of light. In this study, the effect of various source of light to the road environment was shown by comparing the user evaluation. Moreover, to consider the desirable brightness of the road, combination of various source of light would be shown by utilizing the result of regression analysis.

To indicate the perspective of this study, related researches were reviewed. Utsugi et al. (2002) evaluated the visual environment for the selected intersection at night. Result of this research shows that the light from the surrounding buildings make significant influence to the driver's evaluation in terms of the visual environment at night. Furthermore, Yaginuma et al. (2009) conducted the study focused on the visibility to the pedestrian from the driver. This study clarified the relationship between the pedestrian visibility and driving behavior by swiveling the headlight angle when driver started to make the right turn at night. In Japan, vehicle runs in the left side of the road. Therefore, the meaning of right turn is equal to the meaning of left turn in United States where vehicle runs in the right side of the road. Hagiwara et al. (2009) clarified the findings that the pedestrian visibility from the right turning driver had influenced by the headlight from the vehicle that had stopped in front of the crosswalk of the crossing direction. Moreover, Hamaoka et al. (2013) analyzes the confirmation point of crossing pedestrian at the intersection. Horii et al. (2012) clarified the difference of distance to find the pedestrian that stands right/left side of the road by comparing the pattern of luminous intensity distribution.

Summarizing these research results, it is easy to understand that there are many researches related to visual environment for drivers at night. However, there is no research that tries to clarify the relationship among headlight, road lighting, illumination of roadside, and so on. Considering this situation, the objective of this study is to clarify the influencing factors for both the comfortability for driving and the pedestrian visibility under the various visual conditions at night. Desirable visual environment at night will be addressed by utilizing these results. Because these results clarify the visual environment for the driver to improve the pedestrian visibility, these findings would contribute to decrease the number of pedestrian accident. In Japan, many pedestrian accidents occur at the middle section of the road that does not have crosswalk due to the less pedestrian visibility to find pedestrian crossing from the right side of road at night. In order to avoid higher glare to the driver of opposing vehicle, headlight has the directionality that have few light to the right side of the road.

2. OUTLINE OF THE EXPERIMENT

To obtain the data about driver's visibility, experiment that subjects watch the video of driving view recorded beforehand was conducted (Table 1). To establish same circumstances, other factors were set to be same because we are trying to clarify the relationship among headlight, road lighting, illumination of roadside, and so on. In this video image, pedestrian that faces to the road stands along the road as if he/she is thinking to cross the road. In acquiring the data, it is considered to conduct the experiment at the actual road space. However, we conducted the laboratory experiment because it was hard to set same conditions for each subjects. If

laboratory environment was not fit with the actual driving environment, it is hard to get reliable data. Therefore, in this laboratory experiment, we adjusted the brightness of video images and the angle of driving view so as to match with the actual condition. Moreover, we set the handle and pedal (accelerator & brake) in front of the screen, and subjects use these as if they drive a vehicle. By introducing these attempts, subjects could feel as if he/she was driving an actual vehicle at night. In this experiment, we set five kinds of factors as the control variables, such as road illumination level, headlight, illumination of roadside, traffic flow, existence of pedestrian (Table 2). Because each factors have more than two levels, 120 runs of experiment is needed for each subjects. This will take longer time for the experiment, and worse reliable data by the fatigue of subjects. Therefore, the number of runs was decreased to 45 by utilizing the concept of orthogonal table. All subjects were university student because we tried to understand the effect of visual environment at first. We thought that differences among the age groups would be the next study to analyze.

Table 1. Outline of the experiment

Place	Seminar room, #6 Buildings, Akita University
# of subjects	35 (Male: 18, Female:17)
Elapsed time of explanation	60 minutes for one subjects (45 runs for each subjects)
Total number of evaluation	1575 (=35*45) for each subjects
Answer for each subjects	5 point scale

Table 2. Pattern of the video image

Road illumination level	5 levels (7.5-14lx, 14-20lx, 20-30lx, 30-40lx, none)
headlight	2 levels (on, off)
Illumination of roadside	2 levels (bright, dark)
Traffic flow	2 levels (heavy, light)
Existence of pedestrian	3 levels (right, left, none)
45 patterns of total (utilized by orthogonal table)	

Figure 3 shows the snapshot of the video image that subjects were seen. At the experiment, subjects answered the question about the feelings in driving, such as the brightness of the road, comfortability for driving, visibility of the pedestrian and so on, by the 5 point scale. Furthermore, if subjects found the pedestrian that stands along the road, he/she ringed the bell. After that, we could calculate the distance by measuring the time interval from the timing that subjects find the pedestrian to the timing that vehicle passes the location of pedestrian in the video image, because vehicle in the video image moves at constant speed (40 km/h).

Figure 3. Snapshot of the video image (Left: without headlight, Right: with headlight)

3. ANALYSIS OF USER EVALUATION IN EACH SITUATION

3.1 Method to Adopt Representative Value

To understand the characteristics of the answer by various kinds of setting related to the visual environment, each answer would be better to be summarized in some representative value. Because questionnaire data was categorized as 5 point scale for the question about the brightness of the road, for example, numerical valuation was conducted, such as, “most bright” was set to “2”, “rather bright” was set to “1”, “even” was set to “0”, “rather dark” was set to “-1”, “most dark” was set to “-1”. This number means the effect of current visual environment. If the number is positive, it is able to understand that subjects could feel bright. And if the number is negative, it is able to understand that subjects could feel dark. By dividing the total scores by the total number of data, average score was obtained. This score is important to analyze the effect of visual environment clearly.

3.2 Result of the Question about the Brightness of the Road

Figure 4 shows the result of the question about the brightness of the road by various kinds of the visual environment. By considering the average score of headlight usage as the representative value, difference of the result of the question about the brightness of the road for each subjects were confirmed by the on/off control of the headlight. It is understood that the score of on-usage of headlight is larger than the score of off-usage of headlight. However, the situation about the off-usage of headlight did not show negative. Therefore, existence of headlight does not seem to affect to the evaluation about the brightness of the road too much. The situation about the bright illumination of roadside shows much larger score compared to the other situation. It is confirmed that the bright illumination of roadside could contribute to increase the evaluation of brightness. Because the score of dark illumination of roadside is negative, subjects feel these situations as comparatively dark. And, of course, score of bright location is positive. This is the different result from the situation about the usage of headlight. In the same way as the result of the question about the illumination of roadside, the situation about light traffic flow shows negative because the light of the headlight from opposing vehicle is small. Therefore subjects evaluate this situation as dark. The situation about without installing road lighting shows negative. Moreover, this score is the minimum among all situations. Therefore, this situation is the worst for subjects to feel bright.

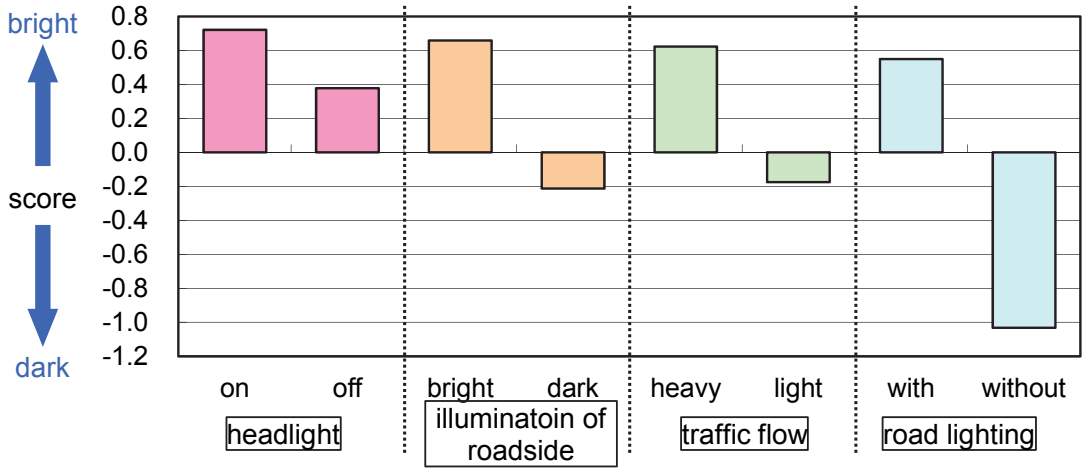

Figure 4. Score for the brightness of the road

3.3 Result of the Question about the Comfortability for driving

Figure 5 shows the result of the question about the comfortability for driving in each situation. The score of the situation for both with and without using headlight does not differ so high compared to the other situations. Therefore, headlight does not show high important factor to improve the comfortability for driving, in the same way as the result of the question about the brightness of the road. Because the situation about the off-control of the headlight shows positive, subjects do not have much difficulty in driving. Highest difference was confirmed in the situation about with or without installing road lighting. It is almost twice compared to the other situations. Moreover, the score of the situation about without installing road lighting shows negative. And this is the only case among all situations. From these results, it is clarified that the role of road lighting indicates most important in driving at night.

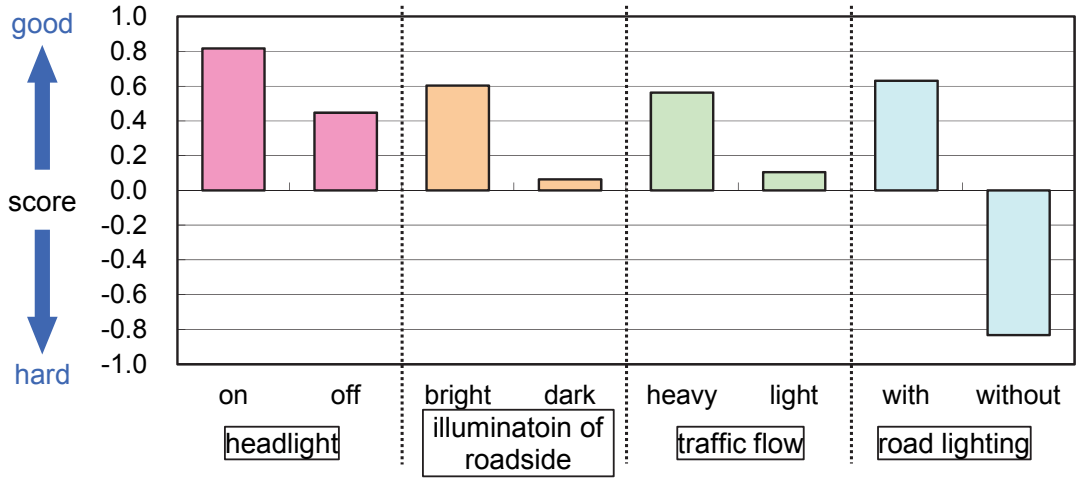

Figure 5. Score for the comfortability for driving

3.4 Result of the Question about the Visibility of the Pedestrian

Figure 6 shows the result of the question about the visibility of pedestrian in each situations. In this figure, "Distance to the pedestrian" shows the distance from the location that subjects could find pedestrian to the location that pedestrian actually stand along the road, as mentioned in Chapter 2. By comparing the "Distance to the pedestrian" by with or without installing headlight, it is confirmed that difference of this is small compared to the other situations. The reason of this could be considered that headlight does not indicate right side of the road more because of avoiding the glare to the driver of opposing vehicle. Therefore, if the pedestrian stands right side of the road, subjects have difficulty in finding the pedestrian because of the headlight performance. By comparing the "Distance to the pedestrian" for the situation about with or without having the illumination of roadside, it is found that the difference between these show high among all situations. Illumination of roadside is formed from the lights of facilities along the road. It is found that existence of the facilities along the road influences to subjects who would like to confirm the pedestrian high.

Moreover, same result is obtained for the level of traffic flow. Because scores for both dark illumination of roadside and light traffic flow shows negative, subjects might feel hard in finding the pedestrian for both situations. By comparing the score between with and without installing road lighting, it is found that the situation with installing the road lighting shows positive and the situation without installing the road lighting shows negative. Difference between these shows largest among all situations. But, positive score of this is not relative high compared to the other better situations. Therefore, effect of the existence of road

lighting tends to be low. The reason of this could be considered that road lighting has an objective to illuminate the road itself better than pedestrian at the walkway.

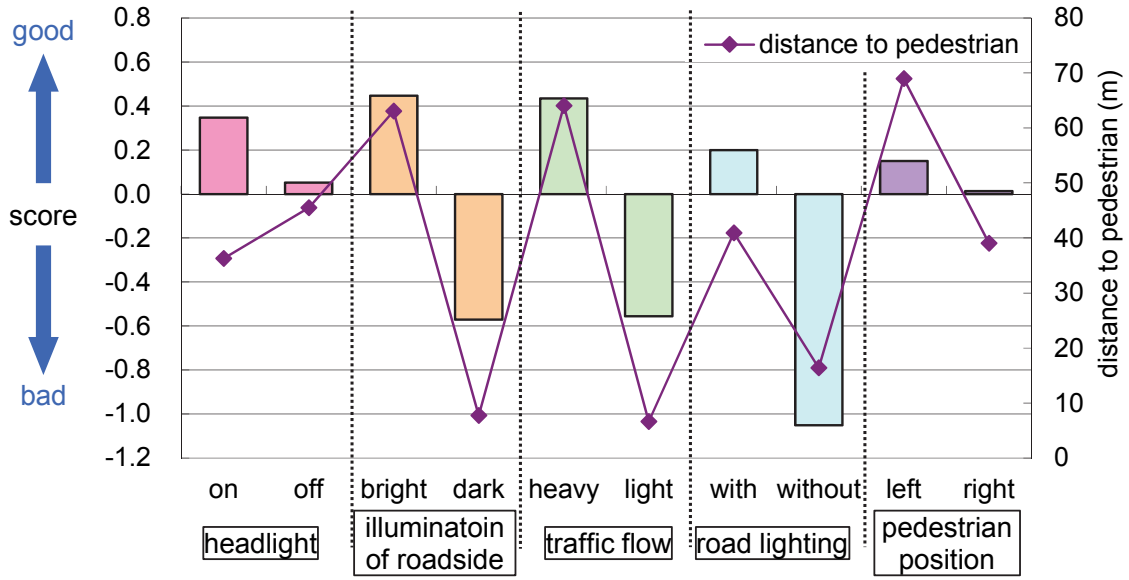

Figure 6. Score and distance to pedestrian for the visibility of the pedestrian

4. REGRESSION ANALYSIS TO EVALUATE THE EFFECT

4.1 Result of Regression Analysis

Based on the result shown above, regression model was established in order to evaluate the effect to each score about the feelings in driving. To make data for regression analysis, data of objective variable was calculated for each combination, such as headlight is on, illumination of roadside is bright, traffic flow is heavy, with road lighting, pedestrian position is left. Table 3 shows the result of regression analysis that objective variables are brightness of the road, comfortability for driving, visibility of the pedestrian, respectively. From this table, it is understood that R-squared values for all models are more than 0.8. Therefore, it could be said that these model is valid in establishing the effect to objective variables. And each parameter for three models have similar trend. Parameters of road lighting indicates highest and parameters of illumination of roadside indicates second highest, excluding the constant. Moreover, it is easy to understand that estimated parameters except constant shows positive. This means that if the any kinds of situation changes better, all evaluation about the feelings in driving changes better. These results could match with the results explained in Chapter 3.

Table 3. Result of regression analysis (t-statistics is shown in parentheses)

	Brightness of the road	Comfortability for driving	Visibility of the pedestrian
Headlight	0.330 (1.70)	0.368 (1.82)	0.129 (0.55)
Traffic flow	0.302 (1.04)	0.123 (0.74)	0.579 (1.66)
Illumination of roadside	0.702 (2.42)	0.594 (3.60)	0.736 (2.11)
Road lighting	1.785 (7.50)	1.710 (9.76)	1.526 (5.34)
Constant	-1.932 (-6.67)	-1.621 (-6.73)	-1.888 (-5.43)
R-squared	0.856	0.979	0.818

T-statistics shows the significance of each explanatory variable. If absolute of t-statistics is larger than 1.96, this variable could be considered as significant in 5% level. Therefore, t-statistics of the parameters of the road lighting shows significant value (t>1.96) and largest among the other parameters for all models. Therefore, effect of the road lighting shows high compared to the other situations. By comparing the t-statistics for each situation within three models, t-statistics of headlight and traffic flow do not show significant (t<1.96). Headlight could be an important factor in driving at night. However, the location of the studied area is urban district. Therefore, visibility condition would never situated as black out. So the role of headlight might be shown as less important in this study. Moreover, by comparing the t-statistics of parameters of illumination of roadside among three models, t-statistics of comfortability for driving shows highest (t=3.60). Therefore, illumination of roadside plays an important role to the comfortability for driving. Moreover, t-statistics of road lighting for the model that objective variable is comfortability for driving shows highest (t=9.76) among three models. This means that the effect of road lighting is highest for the comfortability for driving compared to the other situations such as headlight or illumination of roadside. In the model that objective variable is visibility of the pedestrian, t-statistics of traffic flow shows rather high (t=1.60) compared to the other two models (t=1.04 & t=0.74). This means that high traffic volume plays an important role for drivers to find the pedestrian because of the performance of the headlight from opposing vehicle.

4.2 Analysis by Combining the Parameter of the Result of Regression Analysis

Because variables that are utilized for this regression model are all dummy variables that value of these is 1 or 0, it is easy to conduct sensitivity analysis. In this paper, effect of visual environment was considered by summarizing the value of parameters. If the sum of parameters is larger than absolute of constant, it could be thought that this visual environment is evaluated as acceptable for the driver.

Figure 7 shows the result of the sum of the parameters for the model that dependent variable is brightness of the road. In this figure, red dot-line indicates the absolute of constant parameter that is negative. Therefore, if sum of the parameter is more than red dot-line, it could be thought that this road environment is good.

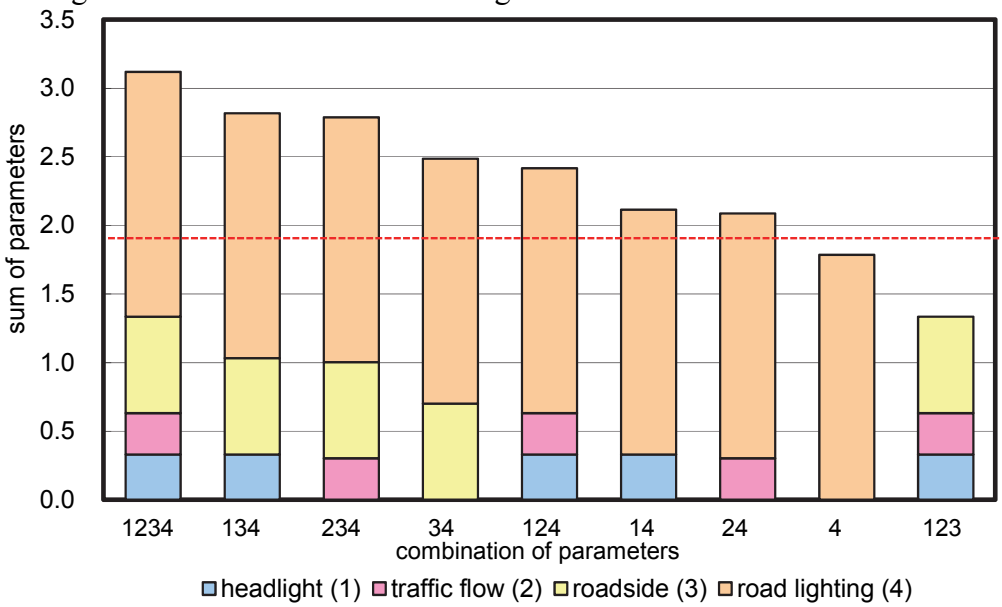

Figure 7. Combination of parameters for the result about brightness of the road

From this figure, it is found that if road lighting and only one of the other variables is added, evaluation for the brightness of the road will be allowable. Therefore, the situation that road lighting and illumination of roadside is added in the road environment, driver could think that this situation is allowable without using headlight. On the other hand, if the road lighting is not added, the sum of parameters does not exceed the red dot-line. Therefore, in the situation without installing road lighting, evaluation for the brightness of the road could not exceed allowable border. It is clarified that road lighting is necessary for driving at night.

Figure 8 shows the result of the sum of parameters that dependent variable is comfortability for driving. From this figure, it is found that the situation will be evaluated as allowable if road lighting is installed at least. Moreover, same as the result mentioned above, if the road lighting is not installed, it will not be allowable whenever all the other variables except road lighting is utilized.

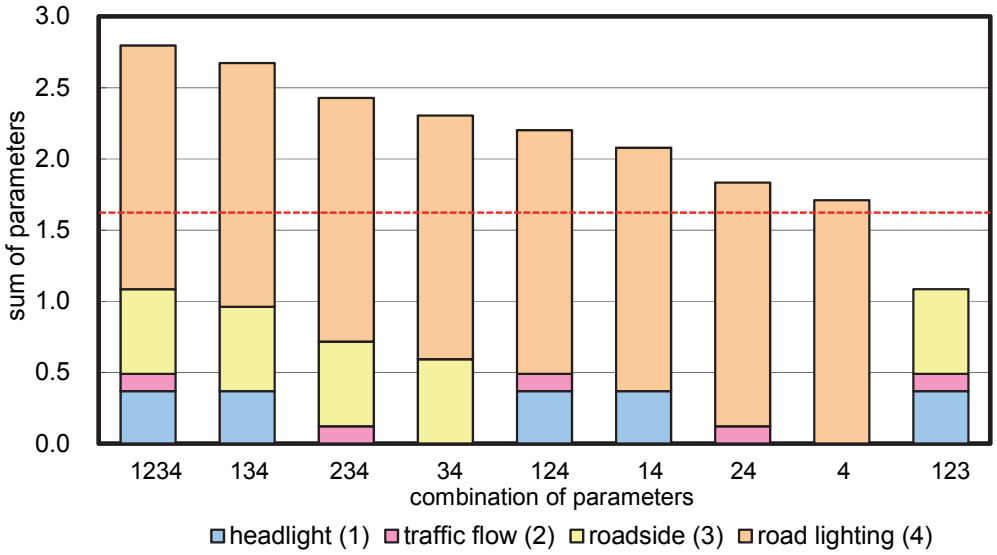

Figure 8. Combination of parameters for the result about illumination of roadside

Figure 9 show the result of the sum of the parameters that dependent variable is visibility of the pedestrian. From this figure, same as the result discussed above, importance of road lighting is confirmed. However, sum of the parameters for both road lighting and headlight do

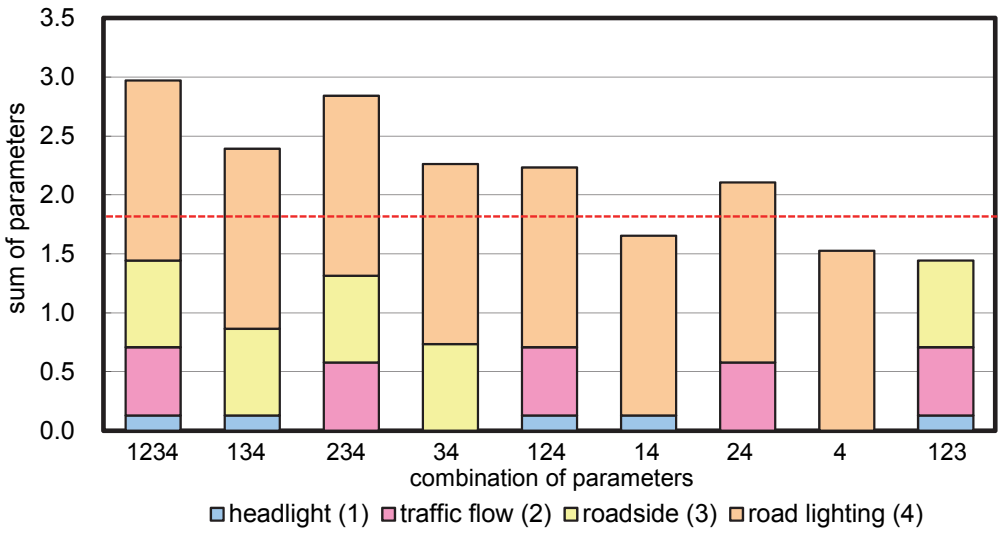

Figure 9. Combination of parameters for the result about visibility of the pedestrian

not exceed the red dot-line. This is different result from the other models. It could be thought that the light from headlight is not effective to illuminate the pedestrian. Headlight is mainly illuminate in front of the road space of a vehicle. Therefore, the reason of increasing pedestrian accident at night could be understood. It is important to give lights to the pedestrian. Besides, same as the result mentioned above, if the road lighting is not installed, it could not be allowable whenever all the other parameters without road lighting is installed.

5. CONCLUSION

In this study, in order to clarify the influence of illumination from various source of light to the driving environment at night, video image experiment was conducted. And by analyzing the data from this experiment, significant factors for each objective feeling in driving is clarified. By the result of these analyses, it is found that road lighting have an important role for the driving at night. By the result of regression analysis, importance to explain the feelings for both brightness of the road and comfortability for driving is shown. The order of importance is road lighting, illumination of roadside, headlight, traffic flow, respectively. On the other hand, setting of visual environment that influences to the farther distance to find pedestrian was not same as the situation as mentioned above. The order of importance is road lighting, illumination of roadside, traffic flow, headlight, respectively. Importance of headlight is smaller compared to the other factors because of its purpose of usage. Moreover, by the result of the analysis that uses the sum of the parameters of the regression model, it is clarified that if road lighting is installed at least, it will be allowable from the viewpoint of comfortability for driving. In the model that dependent variable is visibility of the pedestrian, it is understood that the situation without headlight could be allowable if all the other factors except headlight are utilized. These results show the importance of using the road lighting in the urbanized area.

In the further study, it is important to include the other effects such as the evenness of the road lighting or glare in the rainy days. And also, it is important to include elderly persons as the subjects. Including these, the effect will be shown in detail. In constructing the visual environment at night, it is important to coordinate with various source of light. To realize this, desirable method to utilize these in a proper way should be addressed.

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