Construction of Hazard Map for Traffic Accidents in Hilly and Mountainous Area Using 3D Measurement for Road Alignment

Shota Imai 1) Koki Kamiya 1) Kakeru Manabe 1) Hiroshi Kuniyuki 1)
1) Suwa University of Science, Faculty of Engineering
5000-1 Toyohira, Chino-shi, Nagano, 391-0292, Japan (E-mail: t218016@ed.sus.ac.jp)

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ABSTRACT: In previous paper, evaluation model for four-wheeled vehicle accident risk in hilly and mountainous area was considered using sideslip limitation speed by 3D measurement for road alignment. This paper aimed to improve the risk evaluation model by considering the risk for curve misrecognition, and verified using real accident locations. The distance where driver can recognize the forward curve from its starting point is shorter at the sharp curve compared to the loose curve. The curve misrecognition risk is considered to be the delay of the reducing vehicle speed before the curve. The points of road at the defined accident risk level of 0.75 and more are considered as dangerous location, and a lot of accidents occurred at the point by lane departure. Moreover, hazard map for traffic accident in hilly and mountainous roads was constructed using the accident risk evaluation model.

KEY WORDS: safety, statistical accident analysis, accident investigation and analysis, Hilly and mountainous area (C1)

1. Introduction

Nagano Prefecture has many mountainous areas with high residential altitudes (1), and it is estimated that traffic accidents occur due to the effects of road alignments that differ from those in metropolitan areas. In addition, the number of traffic accident fatalities in Nagano Prefecture in 2019 was 65, a decrease of only 1.5% compared to the previous year, and the reduction is becoming stagnant (2). In order to achieve the goal of reducing the annual number of fatalities due to traffic accidents to 2,000 or less by 2025, as stipulated in the 11th Traffic Safety Basic Plan by the Cabinet Office (3), it is necessary to implement effective measures that take into account the peculiar circumstances of rural areas.

In the previous studies (4)(5)(6), the authors have conducted analysis using traffic accident statistical data and surveys of traffic accident locations that occurred in Nagano Prefecture. Based on these results, the authors have focused on and analyzed accidents on hilly and mountainous roads with longitudinal slope and left or right curves. Common factors in accidents in hilly and mountainous areas include (1) accidents due to lane departure, (2) difficulty in recognizing curves on roads with longitudinal slope and left or right curves, and (3) the existence of a straight section before the accident point where speed can easily increase (5). The factors of accidents caused by these road alignments can be considered as shown in Figure 1. In the previous paper, 3D models were constructed using the SfM (Structure from Motion) method based on photographs taken at the accident locations, and an accident risk evaluation model considering the sideslip limitation speed was examined based on the obtained road alignment (6).

In this study, the authors considered the effect of curve misrecognition due to the difference in curvature on the section before the curve. An accident risk assessment method that took this effect into account was considered and verified at an actual accident location. The results were applied to a wide area of hilly and mountainous roads to construct hazard maps for traffic accidents.

2. Analysis method

2.1. Construction method of 3D model

In this study, the authors improved the method from the conventional method of shooting from the left and right edges of the road at eight angles of view to a method of shooting from a high place with an improved wrap rate. As shown in Figure 3(a), the road was photographed from a height of 3 m with interval shooting from the left and right edges of the road to 10° inside the direction of travel. The camera used was a Sony RX0MII (24mm focal length lens) with an effective pixel count of approximately 15.2 million pixels. The actual shooting situation is shown in Figure 3(b).

Actual road models were reproduced using this method. PhotoScan ver1.4.4 (Agisoft) was used for the analysis same as before. The results are shown in Figure 4. By this method, the...
photos in 150m section could be taken in about 5 minutes, and a 3D model could be constructed with the same quality as previous method.

2.2. Analysis methods for road alignment

Using the method described in the previous section, every 5 m of the curvature, longitudinal slope, and cross-fall were calculated as the road alignment from the obtained 3D model of the road. The curvature and longitudinal slope were calculated from 5 m coordination point before and after at the center of the road. The moving average of the values of the two sections before and after were used to smooth out the variation caused by the condition of the road edge.

2.3. The distance of curve recognition

The authors confirmed in an experiment using a driving simulator (DS) that the distance at which a driver can recognize the curve ahead depends on the curvature of the curve and the left-right direction (10). The distance of curve recognition \( D_{CR} \) was defined as the distance from the starting point of the curve in front of the vehicle that the driver can recognize the curve. The results of the analysis indicated that the smaller radius of curvature, the shorter curve recognition distance, and the curve recognition distance for left curves is shorter than for right curves, indicating that it is more difficult to recognize left curves than right ones. The results are shown in Figure 5. This study considered the evaluation of additional accident risks due to curve misrecognition for each curve characteristic using these results.

2.4. Modeling the risk of traffic accidents

The main cause of accidents involving four-wheeled vehicles that occurred in hilly and mountainous areas was lane departure. The authors think that the main causes for sideslip limitation are overspeeding and misreading of lane for curved road visibility as shown in Figure 1. In this study, a traffic accident risk index \( R_A \) was devised by adding the accident risk due to curve misrecognition in the previous section \( R_{CR} \) to the accident risk due to the sideslip limitation speed \( R_S \) in the previous paper.

\[
R_A = R_S + R_{CR}
\]  

(1)

2.5. Accident risk due to sideslip limitation speed

Lane departure is considered to occur more where the centrifugal force is higher in the curve. The accident risk due to sideslip limitation speed \( R_S \) was considered using the rate of centrifugal force between the ego vehicle speed \( V_1 \) and the sideslip limitation speed \( V_S \) defined as Equation (2).

\[
R_S = \frac{V_1^2}{V_S^2}
\]  

(2)

The sideslip limitation speed \( V_S \) was calculated from Equation (3) using the conditions for not causing sideslip as described in the Road Structure Ordinance (11). Here, \( g \) is the gravitational acceleration, \( \mu_d \) is the friction coefficient of the road surface (here set to 0.5 as the value in the literature for asphalt pavement (11)), \( r_c \) is the curvature of the curve, and \( r_b \) is the cross-fall of road, obtained by substituting the values analyzed for each point from the 3D model of the road.

\[
V_S = \sqrt{g(\mu_d + r_b)/r_c}
\]  

(3)

Vehicle speed tends to increase when the straight section is longer and the descent is steeper. The ego vehicle speed \( V_1 \) was modeled as in Equation (4), assuming an increase in speed \( \Delta V_1 \) due to the gravitational acceleration component in the slope direction according to the longitudinal slope \( r_g \) and an increase in speed \( \Delta V_1 \) according to the length of the straight section, based on the legal speed \( V_R \) of the road in question. Here, the increase in speed with the length of the straight section is assumed to increase by 30% per 100 m (6).
\[ V_1 = V_R + \Delta V_G + \Delta V_L \] (4)

2.6. Accident risk due to misrecognition of a curve

The authors considered that the risk for misreading of lane is consisted of combination of time allowance for decelerating before the curve, tightness of curve, and cognitive delay for left or right curve. Therefore, the accident risk due to curve misrecognition \((R_{CR})\) was defined as in Equation (5).

\[
R_{CR} = \frac{D_{SD} - D_{CP}}{D_{SD}} \times \frac{R_S}{R_{s0}} \times C_{LR}
\] (5)

Here, \(D_{SD}\) is the stopping sight distance defined in the Commentary on the Road Structure Ordinance \((11)\). The stopping sight distance is defined by Equation (6) using the ego vehicle speed \((V_1)\), the perceived reaction time \((t: 2.5\text{sec in this paper from literature})\), the friction coefficient of the road surface \((\mu_G)\) \(0.5\) same as in Section 2.5), and the gravitational acceleration \((g)\) \((13)\).

\[
D_{SD} = \frac{V_1}{3.6} + t + \frac{V_1^2}{2g\mu_G(3.6)^2}
\] (6)

In Equation (5), \(D_{CP}\) is the distance from the vehicle to the start of the curve. In this study, a curve with a radius of 40m was used as the criterion for a sharp curve, and the ratio of the risk due to the sideslip limitation speed of the curve \(R_{s0}\) to the risk of the minimum radius of curvature of the evaluated curve \(R_s\) was considered. Based on the results of Section 2.3, the coefficient \(C_{LR}\) was used to add the risk due to the cognitive difference between left and right curves in order to take into account the fact that the distance of curve recognition is shorter for left curves than for right curves. For the right curve, \(C_{LR} = 1\), and for the left curve, \(C_{LR} = \frac{D_{CR,R}}{D_{CR,L}}\) (the distance of right curve recognition: \(D_{CR,R}\) / the distance of left curve recognition: \(D_{CR,L}\)).

2.7. Objects of analysis

This method was applied to 15 scenes of actual traffic accidents that occurred in hilly and mountainous areas in Nagano Prefecture. Based on the results of the investigations of the accident locations, 3D modeling and analysis of the road alignment were conducted to evaluate the accident risk index. In this paper, the authors showed on typical 3 cases due to space limitations. One case of a downhill right curve (Case A) and two cases of an uphill left curve (Case B) were selected for analysis based on the classification of the previous paper \((6)\). The numbers of the accident locations are shown as sequential numbers from the previous paper so as not to overlap it.

3. Results of analysis

3.1. Summary of accident cases

3.1.1 Downhill with right curve accident: Case A-4

This accident occurred on Route 152 in Chino City, Nagano Prefecture. The circumstances of the accident are shown in Table 1, and photographs of the accident location are shown in Figure 6. The first party, a K car (mini passenger car in Japanese standard), was traveling on a downhill road with a right curve. The driver didn’t pay attention to the road ahead, causing the car to move diagonally across the lane and collide with the second party (regular car), which was traveling in the opposite lane.

| Items            | Contents                        |
|------------------|---------------------------------|
| Day and night, weather | Day, cloudy                     |
| 1st party         | K-car, Male of 33 years old     |
| Road type         | National highway               |
| Road width        | Single lane on each side, 6.5m  |
| Road slope before AP | After AP -7.8% / -6.9%         |
| Road radius of curvature | R=89m                           |
| Length of straight lane before AP | 35m                            |

3.1.2 Uphill with left curve accident: Case B-3

This accident occurred on National Route 142 in Shimosuwa-cho, Nagano Prefecture. The circumstances of the accident are shown in Table 2, and photographs of the accident location are shown in Figure 7. The first party, a regular car, was driving in the lane of an uphill road with a left curve. It moved into the oncoming lane and collided with the second party (medium-sized car) due to misunderstanding of the road alignment.

3.1.3 Uphill with left curve accident: Case B-4

This accident occurred on Prefectural Road 50 in Tatsumo-cho, Nagano Prefecture. The circumstances of the accident are shown in Table 3, and photographs of the accident location are shown in Figure 8. The first party, a regular car, was going up a sharp left curve. The driver failed to operate appropriately to the road conditions and moved into the oncoming lane. It collided with the second party (regular car) which was proceeding in the opposite direction.

3.2. Results of road alignment and traffic accident risk index
3.2.1 Downhill with right curve accident: Case A-4

Figure 9 shows a bird's eye view of the 3D model that analyzed the accident location: Case A-4. The analyzed road alignment and traffic accident risk index are shown in Figure 10. The lane departure point (LP) and the accident point (AP) estimated from the field investigation are shown in the figure. It can be confirmed that the traffic accident risk index increases at the point where the radius of curvature of the right curve is the minimum and the longitudinal slope becomes slightly slower ($R_A = 0.90$). In this accident, lane departure occurred at the point with the maximum of risk index.

3.2.2 Uphill with left curve accident: Case B-3

Figure 11 shows a bird's eye view of the 3D model that analyzed the accident location: Case B-3. The analyzed road alignment and traffic accident risk index are shown in Figure 12. A lane departure occurred at the point where the radius of curvature becomes steep again after the left curve relieves once. The traffic accident risk index exceeded 1.0 at the point. The risk index also increased significantly before the curve. It indicates that there is a high risk of an accident occurring in the section before the accident point.

3.2.3 Uphill with left curve accident: Case B-4

Figure 13 shows a bird's eye view of the 3D model that analyzed the accident location: Case B-4. The analyzed road alignment and traffic accident risk index are shown in Figure 14. As the upward slope increases, the left curve becomes steeper in the section. In particular, lane departure occurred at the point where the radius of curvature suddenly decreases in the middle of the curve (minimum $R=28m$), and led to the accident. The risk index at this point also rises sharply, showing a high value of over 1.5.

3.3. The traffic accident risk index for other investigated accident cases

The other 12 accident cases in hilly and mountainous area were investigated using this method. Table 4 shows the results of road alignment and traffic accident risk index for roads in Nagano prefecture including previous paper cases (6). It shows that approximately 73% cases have the accident risk index 0.75 or higher. The authors consider that 0.75 of accident risk index is threshold for lane departure points. However, some accident cases with gentle curve have lower accident risk index.
4. Construction of hazard map for traffic accidents

4.1. Method of displaying hazard maps

The authors evaluated the road alignment using the traffic accident risk index, and considered that points with accident risk index of more than 0.75 could be estimated as points with high accident risk by evaluating the risk. In order to visualize the accident risk index, a hazard map using the Google My Maps is constructed. The traffic accident risk index was evaluated at 5-meter intervals along the road and displayed as squares in color on the map in 0.25 increments.

4.2. Construction of hazard maps

The hazard maps of the traffic accident risk index for each accident case are shown in Figure 15 to 17. The LP and AP are shown in the figures same as in section 3.2. In each accident case, the accident risk increased from the section before the curve, and it was confirmed that the accident risks are highest near the accident point on the curve section. Furthermore, these maps indicate that there are points where accidents are likely to occur in the future even if no accident have occurred before.

In this study, the evaluation of the road alignment in the section before the curve was taken into account. The traffic accident risk index was calculated from one direction. There are still room for consideration for creating a hazard map that includes evaluations from both directions.

5. Discussion

5.1. Limitation of study

This study indicates the locations where the accident risk index is 0.75 or higher are high risk points for lane departure. However, the certificated accident locations are limited. Some locations have lower accident risk index as shown in section 3.3. The authors also think there are the other causes for lane departure such as incorrect operation, careless driving shown in Figure 1. There is still room for consideration for investigating other accident cases in this study.
5.2. Future study

There are some remaining issues in this study. Firstly, we need to certificate other accident locations as mentioned before. Not all accidents in hilly and mountainous road were caused by overspeeding and misreading of lane. The other factors should be added by additional accident investigations, especially for gentle curve. Secondly, in order to evaluate accident risk index, the walking along roads measurement method needed to be improved efficiently, for example by using car instead of walking. Thirdly, regarding on construction of hazard maps, the accident risk index is calculated from only one direction (uphill or downhill). The index is different from the opposite. We need to point out both risks in a more understandable way.

6. Conclusion

This study investigated that a new evaluation method for constructing 3D roads in a wide area and an evaluation method for traffic accident risks that take into account the risks due to sideslip limitation speed and curve misrecognition. Furthermore, this method was applied to roads in hilly and mountainous areas, and traffic accident hazard maps were constructed. The conclusions obtained are as follows.

(1) The SfM method, which uses photographs taken from high positions, shortened the time required for taking photographs, and enabled 3D modeling of the road. It can extract the road alignment for each point same as the previous paper.

(2) The traffic accident risk index that takes into account accident risk due to sideslip limitation speed and misrecognition of curves was devised.
It was found that traffic accidents occurred at locations where the traffic accident risk index are approximately 0.75 or higher in the investigated accident cases.

The traffic accident hazard maps using Google My Maps were constructed to visualize the traffic accident risk index. They can show the risk at actual accident points. Furthermore, they can indicate the possibility of traffic accident occurrence in the future.

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