Analysis on Speed Reduction at Curve Section on Two-Lane General Road by Sight Distance Estimated by Mobile Mapping System

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Abstract: The advanced surveying technologies have been available to use monitoring of road condition and vehicle running situation. The mobile mapping system can collect 3D spatial road data to estimate road alignment such as sight distance from driver. And more, the precise GPS can detect vehicle trajectory with high accuracy to clarify running position. These new technologies could provide detailed relationship with speed reduction at curve section. Therefore, the objective of this study is to verify influence factor on speed reduction at curve section by using the advanced surveying technologies and evaluation of drivability by questionnaire. It was concluded that the sight distance at short-divided section is critical factor for speed reduction.

Keywords: Speed Reduction, Sight distance, Curve Section, Mobile Mapping System

1. INTRODUCTION

The precise GPS can detect vehicle trajectory with high accuracy to clarify running position at curve section. It may be useful technology to detect lane departure at curve section. On the other hand, the mobile mapping system can estimate sight distance from driver by using 3D spatial road data. However 3D spatial road data originally consist on huge of point cloud data with positioning information. In past research by author (2012) and (2013), the process of 3D point cloud data was developed and can estimate road alignment and the possibility of the precise GPS was verified.

The performance of driving in a curve is generally represented by sight distance. If sight distance is kept far as safety, it will be possible to recognize more distant events more quickly. Therefore, within the section of a curve, as the radius of the curve decreases, the speed would be decreased. In generally, a sight distance can be calculated by road alignment of road design information. However, actual sight distance should be measured under actual condition if there are any obstructs for driver to look forward such as house, wall and telegraph pole. The process of estimating sight distance on short divided road section to identify whether estimated sight distance has obstructs or not, has been not developed.

These new technologies could provide detailed relationship on speed reduction at curve section and driver’s cognition on short divided section by sight distance. The purpose of this study is to clarify the factors that decrease speed in a curve by the experiences and questionnaire survey for drivers. The sight distance is estimated by point cloud data measured by the mobile mapping system. And then actual running position in curve is observed by the precise GPS.
2. LITERATURE REVIEW

Furuichi et al. (2004) focused on driver’s eye movement and vehicle control behavior (i.e., control of speed and steering), which are considered to be relevant to human error that can trigger a traffic accident, and sought the relationship among 3 factors: “driver’s eye movement”, “road alignment” and “driver’s control of vehicle speed and steering”. From the aspect of vehicle control behavior, the study found that there was a wide variety of steering angles between drivers and a tendency of greater centrifugal acceleration on the curve section with a high single-vehicle-crash rate. From the aspect of driver’s eye movement, the study identified the characteristics of driver’s eye movement during driving on the curve section with a high single-vehicle-crash rate.

Hagiwara et al. (2002) attempted to understand a mechanism of driver’s visual cognition of curvature as a study of driver’s information acquisition process when approaching a curve. To understand how a driver recognizes a curvature of road by traffic control devices and road alignment, the authors carried out subjective assessments before and after the drivers passed the curves. Furthermore, they carried out an objective assessment by comparing the vehicle speeds just before and during driving on the curve section and found that drivers tend to rely on their own visual information of road alignment.

Figueroa Medina et al. (2007) show that speed reduction was formulated in the regression models in vicinity of horizontal curves on two lane rural roads. However, the sight distance and cognition of driver about drivability on curve didn’t consider.

This study focuses on extracting information from the three-dimensional point cloud data of the surrounding road acquired by MMS. An MMS with laser measurements can quickly and efficiently acquire road surface data and estimate the road alignment. However, although the data can be measured effectively, the time required to process the large amount of information is prohibitive, and the data do not include attribute information.

Several studies have described methods of extracting road information and estimating road alignment. In this field, the International Society of Photography and Remote Sensing (ISPRS) is an important source of research. For example, Boyko (2011) attempted to extract road surface and road center line information. However, there has been no study in which road information was extracted and the road alignment was estimated using only point cloud data.

Yang (2013) developed the semi-automated extraction method to identify the edge of road objective such as boundary of sidewalk and vehicle lane. Yang (2013) proposed the method to identify road side object by using shaped-based segmentation. And Guan (2015) proposed the automated extraction method for road making and cracks by using reflectivity data. The conclusion of previous studies has described the possibility of identifying the boundary of road and extracting lane marking.

The author (2013) also developed to identify road surface and other road side objective by using reflectively information and RGB information and then developed to extract lane marking and estimate road alignment. And more, The author et al (2012) examined an evaluation method of lane overrun risk which uses vehicle trajectory data from high-accuracy satellite.

In this paper, the methodology to identify any obstructs on sight distance will be developed based on existing study of the authors. And more, the developed method of detecting lane overrun by using precise GPS is applied into actual running test data. Moreover, the advantage of this study can analyze speed reduction by using sight distance on short divided road section.
3. METHODOLOGY

3.1 Outline of Methodology

As shown in table 1, vehicle movement analysis and driving behavior analysis were conducted by three data collection methods: Mobile mapping system, precise GPS, and questionnaire to driver. The vehicle movement analysis shows how far driver overruns outside lane. A part of vehicle movement analysis is the estimation of road alignment which method was developed by author (2013). Therefore, the running test was conducted with the precise GPS by six drivers and five round trips in order to apply this method. The six drivers are students who have held driver license over two years and have usually driven. And these drivers are asked to drive as usual without any instruction not to let them know our objective of experiment. This paper just show the result of vehicle position and lane position estimated by the running test with the precise GPS.

The driving behavior analysis is main part of this paper and shows how driver configures curve by using sight distance and cognition in turning curve with short road section. In this study, the running experiment was conducted in two lane road around rural area as showing Figure 1. The ten students run on this curve five times so that total 50 data is available to analyze. Every running should be free running as first vehicle not to follow other vehicle. The ten driver include beginner driver and well-driving driver half and half. There are six curves on this route and these curves are divided into short segment with 10m distance such as section A and segment 1.

3.2 Running Speed and Trajectory collected by GPS

The Post Processing Kinematic GPS, which is one of advance surveying technologies and can ensure high accuracy under 20 mm, was used in running test for vehicle movement analysis. The time interval of positioning is 20 Hz. The antenna was installed on center of vehicle roof. Therefore, after this section, the position of vehicle means express the center of vehicle.

<table>
<thead>
<tr>
<th>Table 1 Outline of Analysis</th>
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<tr>
<td><strong>Vehicle Movement Analysis</strong></td>
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<tr>
<td>3D point Cloud Data by Mobile Mapping System</td>
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<tr>
<td>The Precise GPS</td>
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<tr>
<td>Questionnaire to driver</td>
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</table>
As shown in Figure 2 and 3, the curve segments and lane departure were defined. The lane departure means moving out of its lane. Because the GPS was installed on center of roof, the gray area which has half width 0.873 m of vehicle from outer lane line is defined as lane departure area and then one tire overrun lane line.

In order to compare lateral acceleration under actual running situation and its limited value under designing road alignment, both value is calculated as

$$\frac{V^2}{R} \leq 127(f + i)$$  \hspace{1cm} (1)

where,  

- $V$ : Design speed at each curve section (km/h)
- $R$ : Radius calculated from design radius (km),
- $f$ : Coefficient of friction for lateral movement and
- $i$ : Superelevation

This equation is defined on the Japanese Road Structure Ordinance Article In experiment, the speed and instantaneous radius calculated from the precise GPS second by second is substituted on Equation (1) instead of its design value. And more, The observed values is compared the limited value of lateral force.
3.3 Road Alignment and Sight distance Estimated by Mobile Mapping System

The sight distance is defined by the Road Structure Ordinance Article 2, 23 and 19 in Japan. Based on the contents, the sight distance is the corresponding distance measured from the center of lane at a height of 1.2m, where the vertex of an object with a height of 10cm in the center lane can be located on the center lane.

This sight distance is measured by applying 3D point cloud data using a MMS. A sight distance on curve can be estimated road design data. However, actual sight distance may be influenced by obstacle such wall, house, telegraph pole which are not drawn on road design data. Therefore it’s useful to measure actual sight distance on curve by using mobile mapping system and provide relationship with speed reduction and actual sight distance.

The mobile mapping system is a system that is equipped with a combination of various measuring devices in the vehicle, which measures the topography and features of the road and roadside while in motion in order to create numerical topographic map data. It is a device capable of rapidly and efficiently acquiring high precision 3D location information related to topography and features of the area around the road while driving the vehicle. Figure 4 shows the devices of MMS which is the Nikon Trimble MX8 for using in this experiments. The accuracy of positioning of point data achieves 0.02 m for horizontality and 0.05 m for altitude. Its accuracy is depending on the accuracy of vehicle position measured by GPS. In the experiment, the condition of signal is very high because there is no tunnel and high buildings along route so that we kept high accuracy. Figure 5 is a gland view of including all sections from A to F. In these point cloud data, segment is divided every 10 m and view point of driver on center of lane is marked on each segment. In figure 6, most foreseeable point which is far point without object blocking view is measured and the sight distance is determined. The analysis is conducted on software “RiScan Pro” which was released by the maker of laser scanner “REIGL”. The software can measured distance between two points. And the process to judge whether any obstructs are on sight line between two points or not is added as function by authors. The RGB color data on each point cloud data and its positioning location outside road are reference value to identify obstructs. Therefore, the accuracy of estimated sight distance has centimeter accuracy if the identification is exactly done.
3.4 Questionnaire to Test Drivers

After the subjects had completed driving, a questionnaire survey is conducted using photos of the short segment separated by 10m interval. The photos were taken to provide driver’s view. As question items for the questionnaire survey about drivability at curve, the following four items were included in conducting the survey. 4. Easy to drive, 3. Somewhat easy to drive, 2. Somewhat difficult to drive, and 1. Very difficult to drive. The purpose of using the four levels was to avoid the medium interpretations and clarify whether they have either a positive or negative impression. The questionnaire survey was conducted after ten driver have driven the route shown in Figure 1.

![Figure 7. GPS antenna and Test Vehicle (TOYOTA PHV Prius)](image)

![Figure 8. Sample of Photos](image)

4. EXPERIMENT RESULT

4.1 Running Position

In Figure 9 and 10, the position is shown by box plot including (minimum value, 25%, median, 75 %, and maximum value). There is no lane departure on curve of 90 m radius but any lane departure on curve segment III and IV of 200m radius. To alleviate curve radius on curve 200m in keeping same speed before curve, some of driver kept their position within road width using shoulder of road. On the other hand, they didn’t over run outer lane on curve 90m because 90m radius is too sharp so speed should be reduced.

As shown in Figure 11, the lateral acceleration under actual running situation and its limited value to design road alignment calculated by formula (1) is compared. The lateral acceleration on 90m radius curve increased as increase of speed after section II. However, the lateral acceleration on 200 m radius is stabile because of constant of speed on each curve segment. Therefore, the lateral deviation over outer white line by driver contributes lateral acceleration to reduce.

As a conclusion of the vehicle movement analysis, it was found that driver tied to mitigate lateral acceleration by running over outer white line in order to keep speed at curve radius 200m. However, the actual lateral acceleration is often over the design lateral acceleration. In the case of 90 m radius, it was concluded that driver tried to reduce speed at beginning of curve section in order to turn sharp curve smoothly.

In comparison with two type of radius, it was found that driver might try to recognize amount of radius and decide driving works during approaching curve. Therefore, the sight distance would be important factor to decide driving works by driver.
Figure 9. Running Position on curve of 90 m radius

Figure 10. Running Position on curve of 200 m radius

Figure 11. % of time in higher than limited value

In examining the results of each segment, it was noted that the section C and D had short sight distances. The section A, E and F indicated long sight distances. The end of section A such as segment 8 to 10 decreased sight distance due to second curve into left. On the section B is straight section in front of third curve ahead so that sight distance is gradually decreasing.

Figure 12. Results of sight distance for each segment
4.3 Speed Reduction

The results of the running speed indicate frequent deceleration on the last segments of section A even if this section had downward sloping roads over section A. Driver couldn’t brake their vehicle down to suitable speed to turn curve smoothly because declivity on section A prevent the speed be reduced. On the section B, the speed was kept constant after section A because this section is straight section.

On the contrary, acceleration is frequent on the section F of the return path which is upward sloping due to recover speed as desired speed of driver. The deceleration rate in the section D is increasing, and is considered to be a result of sudden deceleration subsequent to deceleration and acceleration in the section C.

![Figure 13. Speed on each segment](image)

In examining the running speed results of each of the subjects, the running speed was about 20 km/h and the lowest for the section C, although the speed limit for this section was 40km/h in comparison to actual speed. In addition, the section D had the same curve as the section C, but the section D had a larger curve radius, and although it had a faster running speed, the running speed of the subjects did not meet 40 km/h in relation the speed limit of 40 km/h, and the running speed was in the upper 20s (km/h) or lower 30s (km/h). Then, upon examination of the entire sections, the results indicated that the running speed of the subjects did not reach 40km/h. The existence of a difference in running speed between the section A,B,C and section D,E,F can be due to the difference in curve radius such as on section D and F, but the difference in speed can also be considered due to sections in the section D,E,F where the road is wider.

4.2 Evaluation about Cognition of Drivability at Curve Section

From the running test for driving behavior analysis, there were many results indicating that it was easy to drive in the section A, and the last segment of the section A with a tight curve had low evaluation results about drivability for turning curve. For the section B, as the curve is gentle, this section has high evaluation. In examining the section C, the curve in this section
has a shorter curve radius than any other section, and the curve was tighter. For this reason, there were many evaluation from drivers indicating that it was difficult to drive.

![Figure 14. Drivability by the questionnaire survey](image)

5. RESULT OF MATHEMATICAL QUANTIFICATION THEORY CLASS I

5.1 Method of Analysis

These three data, speed, sight distance and cognition of driver on each segment, are summarized by performing a mathematical quantification theory class I. In these data, sight distance is qualified into qualitative data to convert unit. The objective variable is the difference in speed of which is between the inflow and outflow section of each segment. Then, the three data of questionnaire survey results, speed at first segment, and sight distance are applied as the explanatory variable.

5.2 Results

First of all, the test for independence was conducted to select explanatory variable without high correlative. The following deriving the correlation ratio between the questionnaire and the sight distance, the figure for the square of the correlation ratio with the zero stratification factor was 0.5133 which indicates a somewhat strong correlation between the questionnaire survey and the sight distance.

Therefore, since the results of the questionnaire survey and the results of the sight distance would contain the same description, in this experiment, for the explanatory variable that would explain the difference in speed, mathematical quantification theory class I was conducted with the results of the sight distance and the difference of speed. The results are shown in Table 3. The correlation between sight distance and the running speed, is the square of the multiple correlation coefficient at 0.857, and therefore a strong correlation is noted. Therefore, it was concluded that the difference of speed on short segment can be explained mathematically by the speed entering in segment and sight distance which can be recognized with same trend of cognition of driver for drivability.
Table 2 Results of Correlation Analysis between the Questionnaire and the Sight distance

<table>
<thead>
<tr>
<th>Standard Deviation</th>
<th>1.0607</th>
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<tr>
<td>Correlation Ratio with Stratification Factors</td>
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<tr>
<td>Square of the Correlation Ratio with Stratification Factors</td>
<td>0.5133</td>
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<tr>
<td>F-Value</td>
<td>9.7554</td>
</tr>
</tbody>
</table>

Table 3 Results of Correlation Analysis between the Sight distance and Speed Entering in

<table>
<thead>
<tr>
<th>Item</th>
<th>Range</th>
<th>Single Correlation</th>
<th>Multivariable Correlation</th>
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</thead>
<tbody>
<tr>
<td>Sight distance</td>
<td>6.80</td>
<td>0.658</td>
<td>0.867</td>
</tr>
<tr>
<td>Speed entering in</td>
<td>37.18</td>
<td>0.648</td>
<td>0.860</td>
</tr>
<tr>
<td>Multiple Correlation Coefficients</td>
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<tr>
<td>The Square of the Multiple Correlation Coefficients</td>
<td></td>
<td>0.857</td>
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</table>

6. CONCLUSION

6.1 Result

Based on this study, although sight distance as investigated can be noted as a cause of speed reduction, as per the questionnaire survey and the sight distance, as the sight distance gets shorter, there were instances where the assessment by the driver declines, the difference in speed becomes greater. Then, it was found through the analysis of this study that the result of the sight distance was a causal factor of difference in speed.

Then, when the speed limit was compared to running speed, the speed limit and the running speed did not correspond. It was noted that one of the factors was sight distance. Based on these results, when designing the speed limit, it is preferable to make the determination by placing importance on the sight distance of the driver. Further, the survey revealed that upon designing roads, the most important factor is the sight distance.

6.2 Research in the Future

As this study could only be conducted for students in their 20s, it is considered that a better determination of speed limits could be made if future studies conduct surveys by age levels and understand driving characteristics by age groups. In addition, it is considered that a larger sample size would lead to a determination of a more practical and appropriate speed.

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REFERENCES


