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# The Estimate of Vehicle Speed Active Safety System in Curved Section

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***ABSTRACT:*** *This study deals with the evaluation of the safety system that can improve the running safety in a curved section with a complex configuration of horizontal and vertical alignments. In general, an entry into the curved section after lowering the running speed is effective in increasing the level of traffic safety. Therefore, this paper evaluated the effectiveness of the solution which can stabilize the running speed in the curved section. The field evaluation results showed that the vehicle speed active chevron sign using LED, which contributes to lowering the running speed, was more advantageous than the conventional retro-reflective chevron sign in terms of traffic safety.*

***Keywords:*** *Curved Section, Retro-reflective, Chevron Sign, Running Speed*

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## I. INTRODUCTION

### 1.1 Research background and purpose

Roads are connected by a continuous combination of horizontal and vertical alignments, and the horizontal alignment is composed of a straight line, a circle curve and a transition curve so that a vehicle travelling on the roads can run smoothly according to the design speed. In particular, the section with a combination of horizontal and vertical alignments requires installation of separate safety facilities due to its dangers. The typical safety facility is a chevron sign, which is installed in places with conditions that provide poor sight distance such as a horizontal curved section so that drivers can clearly know the degree of linearity and curvature of the road at day and night as a road appendage specified in Article 3 of the Road Act, and therefore it is also a delineator1 designed to promote safe running.

However, causes for accidents resulting from lane departure in the curved section are thought to be due to the high speed of a vehicle approaching the curved section. In this regard, a curved warning system was developed to inform drivers of the running speed and violation of the speed regulations before the entry into the curved section so that they can enter the curved section within the speed limit and stably pass it through, and it was compared with the conventional retro-reflective chevron sign with respect to the traffic characteristics.

### 1.2 Research contents and methods

Generally, delineators installed on the curved section of a road are important facilities for running safety at night. In the evaluation of effects on the chevron sign among those delineators, the conventional retro-reflective chevron sign and the curved warning system equipped with the functions of the present speed and deceleration on the entire curved section were evaluated in this study.

First, traffic accident characteristics were investigated, and literature review was conducted. The current status of accidents in the curved section were examined, and the running speed characteristics in the curved section as well as the effects of safety sign types and characteristics on driving conditions were investigated through a review of relevant literature.

Second, the effects before and after the installation of the system were evaluated. The evaluation of the effects was conducted before the system installation (retro-reflective chevron system) and after the installation of the system, and the section before the entry into the curved section until the passage through the curved section was selected as a target for analysis.

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[1] Guidelines for the installation and management of road safety facilities, Ministry of Land, Transport and Maritime Affairs, 2008

## II. TRAFFIC ACCIDENT CHARACTERISTICS AND LITERATURE REVIEW

### 2.1 Characteristics of traffic accidents

This study sought to analyze the characteristics of traffic accidents (in 2015) presented by the Korea Transportation Safety Authority in order to investigate the traffic accident characteristics in the curved section. The total number of traffic accidents is 232,035, and the characteristics of traffic accidents by road alignment are summarized in Table 1. The number of accidents in the straight and curved sections was 214,647(92.5%) and 14,082(6.1%) respectively, showing the number of accidents in the straight section was about 15.2 times higher than that of accidents in the curved section. This is because the proportion of the straight section in the entire road alignment is much higher than that of the curved section. The number of deaths in the straight and curved sections was 3,791(82.0%) and 796(17.2%), respectively. The ratio of accidents in the curved section was about 6.1%, but that of deaths was 17.2%. These results indicate that the risk of deaths in the curved section is about 2.8 times higher than that of deaths in the straight section, and therefore there is a need to devise active safety measures against it. Meanwhile, the number of accidents and deaths in the downward curved section was higher than that of accidents and deaths in the upward curved section, and the number of accidents and deaths in the section which is curved to the right was higher, depending on the direction of the curve.

**Table 1 Traffic accident statistics by road alignments (Road Traffic Authority, 2015)**

| Item | 2015(Unit : The number of cases and persons) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | Curve, Corner | | | | | | | | | Straight | | | | Others |
| | | Total | Left | | | | Right | | | | Straight | | | | Others |
| | | | Total | Upward | Downward | Plain | Total | Upward | Downward | Plain | Total | Upward | Downward | Plain | Others |
| Number of accidents | 232,035 | 14,082 | 6,627 | 1,199 | 1,437 | 3,991 | 7,455 | 1,444 | 1,661 | 4,350 | 214,647 | 9,024 | 11,650 | 193,973 | 3,306 |
| Number of deaths | 4,621 | 796 | 403 | 70 | 101 | 232 | 393 | 63 | 101 | 229 | 3,791 | 234 | 288 | 3,269 | 34 |
| Number of injuries | 350,400 | 21,792 | 10,137 | 1,808 | 2,327 | 6,002 | 11,655 | 2,315 | 2,827 | 6,513 | 324,330 | 13,447 | 18,710 | 292,173 | 4,278 |
| Number of serious injuries | 92,522 | 7,190 | 3,491 | 589 | 792 | 2,110 | 3,699 | 685 | 926 | 2,088 | 84,230 | 3,569 | 5,067 | 75,594 | 1,102 |
| Number of minor injuries | 233,646 | 13,121 | 5,973 | 1,112 | 1,372 | 3,489 | 7,148 | 1,488 | 1,683 | 3,977 | 217,728 | 8,967 | 12,353 | 196,408 | 2,797 |

### 2.2 Review of existing literature

Hassan et al (1997) concluded that there is a high risk of accidents when a driver who is travelling on a road encounters an unexpected geometric structure in the section where the convex curve of a vertical alignment and the plane curve of a horizontal alignment come together. Munehiro and Kazunori (2005) claimed that traffic safety facilities bear a great significance on roads in heavy fog, and unfavorable weather conditions such as fog and rain can significantly decrease the performance of most traffic safety facilities at both day and night.

Lee, S. et al (2008) performed an experiment on the visibility and readability of delineators and concluded that an internally illuminated delineator is more advantageous for visibility and readability at night than the conventional retro-reflective delineator.

Hong, S. et al (2012) suggested that factors affecting traffic accidents at night and sunset and sunrise/sunset times include AADT, continuous plane curves, composite alignment of plane curve and convex longitudinal curve, and composite alignment of plane curve and concave longitudinal curve.

Jin, M. and Lee, S.(2016) suggested that there is a difference in the frequency of accidents according to the pedestrians' crossing direction at night, and the improvement effects can be achieved through mutual warning and alarm systems for pedestrians and vehicles.

Lee, S.(2014) conducted a safety evaluation on the plane curved section without night lights and concluded that there is a difference in running safety according to the direction (left/right) of plane curve and due to the lack of sight distance caused by the limitation of vehicle headlamps in unlit section.

## III. VEHICLE SPEED ACTIVE SAFETY SYSTEM IN CURVED SECTION

### 3.1 System components

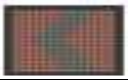
The curved warning system consists of three major components, such as vehicle speed detector and present speed display, over-speed and constant speed display system, and active chevron sign, which monitors the running speed of a vehicle before its entry into the curved section and displays information from the road side so that a driver can travel within speed limits.

**TABLE 2 DISPLAY EXAMPLE OF CURVED WARNING SYSTEM**

| Display type | Running type | Display color | Display example |
|---|---|---|---|
| Display 1 | Constant speed | Black background + 50 in red |  |
| | Over-speed | Black background + 50 in red |  |
| Display 2 | Constant speed | Yellow background + Black arrow |  |
| | Over-speed | Red background + Black arrow |  |

The vehicle speed active safety system in curved section is composed of speed detector, present speed display, speed limit display and active chevron display, and the definitions of terms are shown in Table 3.

**Table 3 The Definitions Of Terms**

| Item | Definition | Remarks |
|---|---|---|
| Speed detector | Speed Detector(SD) | |
| Present speed display | Present Speed Display(PSD) |  |
| Speed limit display | Speed Limit Display(SLD) |  |
| Chevron display | Chevron Display(CD) |   |

### 3.2 System concepts and operating principles

Vehicles that enter the curved section from the straight line of the two-lane local road at a speed higher than the speed limit are highly likely to undergo overturns and rear-end collisions. Therefore, there is a need for a system that dynamically responds to individual vehicles and performs functions of warning before the entry into a dangerous section (curved section) and delineation during the entry into the curved section. The concepts and operating principles of this system are as follows.

1) The vehicle speed is detected in the straight section before the vehicle enters the curved section, and over-speed display warns when the speed is higher than the speed limit.

2) The dynamic delineator on the roadside detects the speed of the vehicle before, during and after entering the curve section and displays it dynamically in colors according to the appropriate speed and speed violation. This facility becomes a group of three facilities and displays the same color while the vehicle is entering the curved section. The first of the three facilities is equipped with an ultrasonic sensor that detects the vehicle speed.

3) The system using solar light can be operated in the case of a local road without basic facilities such as electricity.

4) In the control of the vehicle speed active device, the speed is normally displayed in green when there is no

vehicle and dynamically displayed in colors (yellow, red) appropriate to the vehicle speed when the vehicle entering signal occurs. In addition, it is displayed in yellow when the vehicle leaves the curved section.

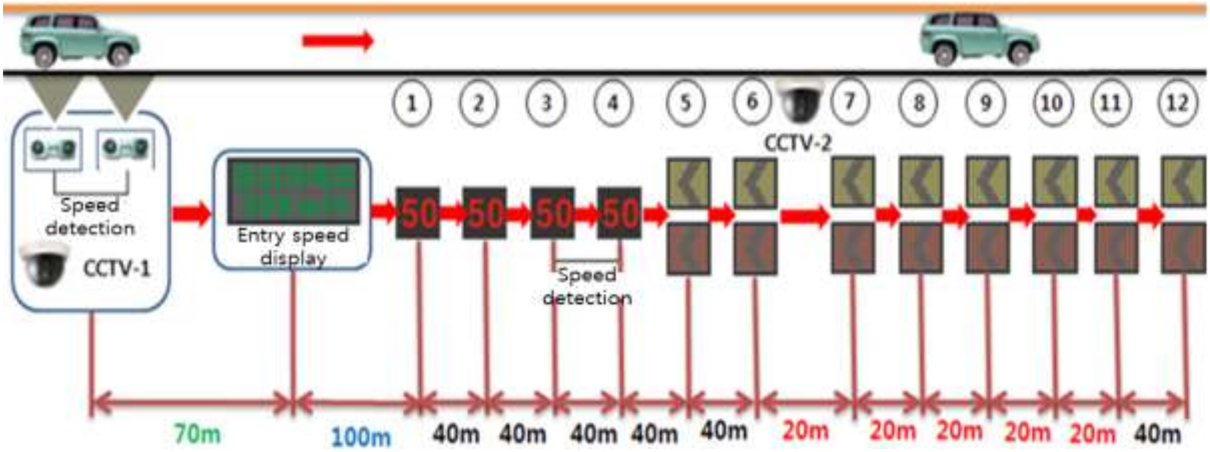



**Figure 1** Components of curved warning system

In traffic engineering, the term “platoon” refers to a group of vehicles travelling together at less than scheduled headways. In general, the US AASHTO (2004) uses 3 to 5 seconds, and the Korea Highway Capacity Manual (2001) specifies 3 seconds. However, since the installation intervals of individual warning lamps is different from the characteristics of a single road, it is necessary to recalculate the headways of the platoon.

The vehicle following the preceding vehicle should be able to acquire its own information only after the preceding vehicle passes the current speed display, and the information of the following vehicle should not be displayed while the preceding vehicle is acquiring its own information from the present speed display. It is therefore required to calculate the appropriate headways and transmit the correct information the preceding and following vehicles.

As shown in Figure 2, the distance at which the current speed display can be seen as close as possible is about 5.2m (5.0m applied), which becomes a lost legibility distance which cannot be seen from a closer location.

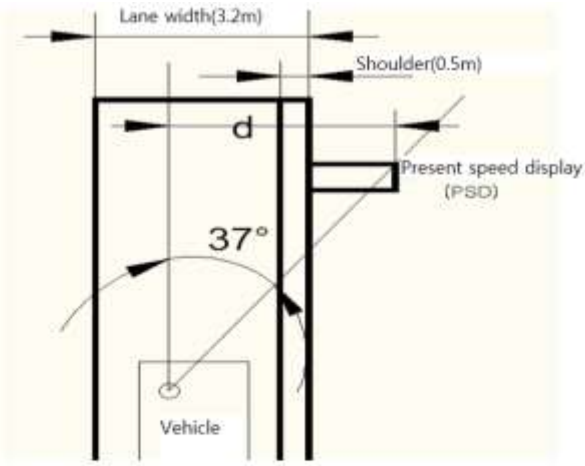



**Figure 2** The closest distance the vehicle can watch PSD

The installation distance between the speed detector (SD) and the present speed display (PSD) is 40m. The approaching vehicle, which is more than 35m away from the preceding vehicle, is recognized as an individual vehicle, and the speed is displayed individually, whereas the following vehicle, which is within 35 m from the lead vehicle, is recognized as a platoon, and therefore the same contents displayed to the lead vehicle are displayed to the following vehicle. This is due to the assumption that the running speed characteristics in the platoon are the same.

When the algorithm is implemented, it is necessary to determine the approach time of the following vehicle in consideration of the running speed from the time when the preceding vehicle is recognized. As a result of the investigation of the running speed before the installation of this system, the approach speed before entry into the curved section was an average of 78.5km/h, and the predicted approach running speed is 80km/h when this system is applied. Therefore, when the following vehicle with headway of more than 1.6 seconds approaches after the lead vehicle enters, it is recognized as an individual vehicle, and the speed is displayed individually in the present speed display (PSD).

**Table 4** Travel distance & travel time by traveling speed

| Running speed (km/h) | Travel distance (m) | Travel time (second) | Remarks |
|---|---|---|---|
| 50 | 14.0 | 2.5 | |
| 60 | 17.0 | 2.0 | |
| 70 | 20.0 | 1.8 | |
| 80 | 22.0 | 1.6 | Applied |
| 90 | 25.0 | 1.4 | |
| 100 | 28.0 | 1.3 | |

The entering vehicle control method considering the lost legibility distance detects the speed of the following vehicle after warning for more than 1.6 seconds after detecting the speed of the lead vehicle. When the vehicles are recognized as individual vehicles, the individual speeds of the preceding and following vehicles are displayed separately in the present speed display. If the speed of the following vehicle is detected within 1.6 seconds after the detection of the speed of the preceding vehicle, the following vehicle is recognized as a platoon, and the speed of the preceding vehicle is displayed in the present speed display.

In the speed detection and control with respect to the active chevron display (CD), the vehicle running speed measured from the speed detector installed in the front of the system is displayed in the present speed display (PSD). In the case of the numbers one to 4 of the speed limit display (SLD) on the rear side, 50 of red (default) is displayed, and the speed is displayed in the first chevron display (CD) after detected from the 3rd to 4th ones(red for more than 50km/h, yellow for less than 50Km/h). The second active chevron display detects the speed from the 4th speed limit display and the 1st active chevron display and then displays the speed. The third active chevron display is configured as a relay system that detects the speed from the 1st and 2nd active chevron displays and then displays the speed, and it uses the average spatial velocity between the two points (Figure 3).

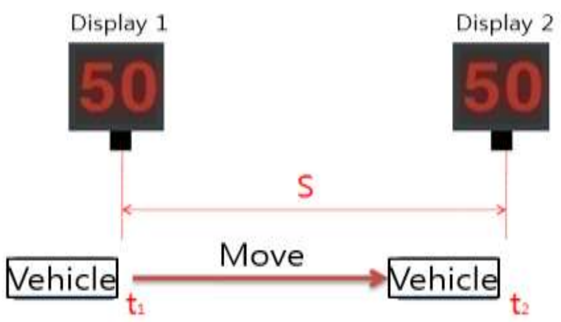



**Figure 3 Average spatial velocity between the two points**

Where, $V(\text{km/h}) = \dfrac{3.6S}{(t_2 - t_1)}$

s : meter

t : second

## IV. FIELD EXPERIMENT

### 4.1 Field characteristics

The running speed of the vehicle was analyzed on the sections where the vehicle runs before, during and after its entry into the curved section before and after the installation of the curved warning system. The analysis target is a mountain road that connects the Local Road No. 86 with the National Highway No. 45 that passes through Namyangju, and it has the characteristics of geometric structure of two-lane two-way highway with a vertical slope of 6% and a curve radius of 200m.

### 4.2 Field characteristics

The target section for field experiment has the geometric characteristics of plane and longitudinal curves. A traffic flow detector (NC97) was used to acquire data for analyzing the running speed of the vehicle passing through the section, and it was designed to acquire the running speed data from the time before the vehicle enters the curved section in the points where the curved warning system is installed.

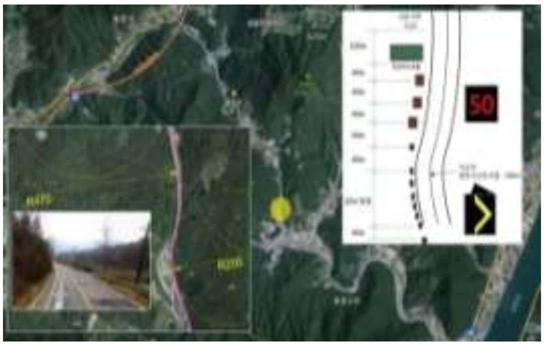



**Figure 4 Field geometry characteristics**

## V. DATA COLLECTION AND ANALYSIS RESULTS

### 5.1 Data Collection

A point-specific speed sensor was used for the field data collection, and Table 5 shows the data depending on the observation point.

**Table 5 Observation point in Curved Section**

| Observation point | Data | Remarks |
|---|---|---|
| 1.Speed Detector(SD) | Entry speed at the beginning point | 1 point : $SD_1 - SD_2$ |
| 2.Speed Limit Display(SLD) | Running speed before entering the curved section | 5 points : $SD_2 - SLD_1$, $SLD_1 - SLD_2$, $SLD_2 - SLD_3$, $SLD_3 \sim SLD_4$ |
| 3.Chevron Display(CD) | Running speed in the curved section | 7 points : $SLD_4 - CD_1$, $CD_1 - CD_2$, $CD_2 - CD_3$, $CD_3 - CD_4$, $CD_4 - CD_5$, $CD_5 - CD_6$, $CD_6 - CD_7$ |
| 4.Chevron Display(CD) | Exit speed in the curved section | 2 points : $CD_7 - CD_8$, $CD_8 - CD_9$ |

### 5.2 Analysis of system installation effects

The average 85%tile speed was reduced from 70.53kph before the installation of the dynamic warning system in the curved section to 65.55kph after the installation of the system, showing a decrease of about 5kph. The average running speed from before the vehicle enters the curved section to the point where the present speed sign is installed showed a deceleration of about 10.50kph, and the average running speed from the entry into the curved section to the speed limit display point was reduced by about 9.0kph. In addition, the running speed in the curved section was reduced by about 2.8kph.

It was found that a driver perceives the current speed through the present speed sign and reduces the running speed in advance(85% tile speed before the installation of the present speed sign: 81.55kph, speed after the installation: 71.10kph). In addition, the speed limit of the curved section was 50kph, and the running speed exceeded the speed limit both before and after the installation of the system. However, the running speed was slightly closer to the speed limit after the installation of the system (85%tile speed before the installation of the speed limit sign: 77.37kph, speed after the installation: 68.37kph)

Even the section where chevron sign is installed exhibited the deceleration effect of about 2.79kph after the installation of the system (85%tile speed before the installation of chevron sign: 66.58kph, speed after the installation: 63.79kph)

The curved warning system was found to have the effects of lowering the vehicle running speed and speed deviation in the curved section.

**Table 6 Results of Vehicle Speed**

| | 85%tile Speed | | Standard Deviation | | Variance | |
|---|---|---|---|---|---|---|
| System | Before | After | Before | After | Before | After |
| Present Speed Sign | 81.55 | 71.10 | 11.11 | 8.16 | 123.50 | 66.66 |
| Speed Limit Sign 1 | 80.10 | 69.00 | 10.90 | 7.64 | 118.76 | 58.35 |
| Speed Limit Sign 2 | 78.00 | 68.00 | 10.07 | 7.76 | 101.33 | 60.22 |
| Speed Limit Sign 3 | 74.00 | 68.10 | 9.44 | 7.81 | 89.17 | 60.94 |
| Chevron Sign 1 | 68.00 | 65.00 | 9.12 | 7.43 | 83.13 | 55.24 |
| Chevron Sign 2 | 67.40 | 63.00 | 8.93 | 7.32 | 79.66 | 53.56 |
| Chevron Sign 3 | 65.00 | 62.10 | 9.02 | 7.41 | 81.42 | 54.85 |
| Chevron Sign 4 | 64.00 | 60.00 | 8.26 | 7.33 | 68.19 | 53.79 |
| Chevron Sign 5 | 66.00 | 63.00 | 8.57 | 7.79 | 73.42 | 60.65 |
| Chevron Sign 6 | 66.00 | 64.00 | 8.58 | 7.53 | 73.62 | 56.69 |
| Chevron Sign 7 | 67.25 | 66.25 | 9.09 | 7.78 | 82.72 | 60.56 |
| Chevron Sign 8 | 69.00 | 67.00 | 8.98 | 8.50 | 80.72 | 72.17 |


**Figure 5 Vehicle Speed in Curved Section**

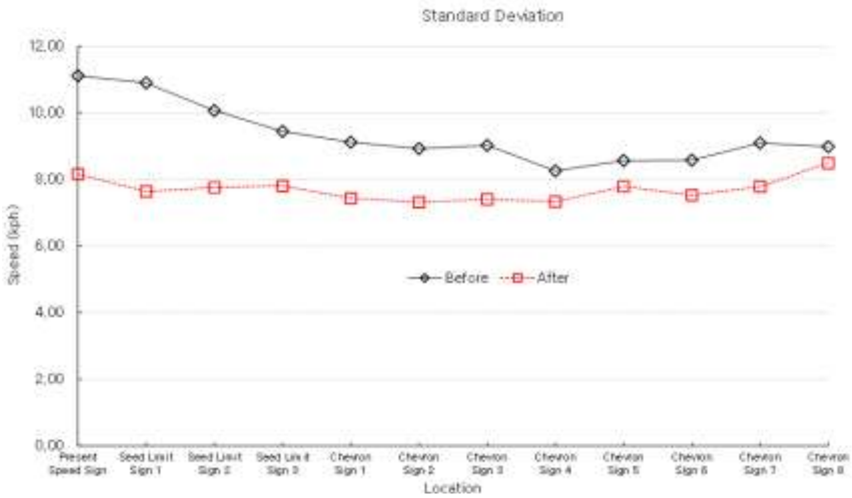



**Figure 6 Standard Deviation in Curved Section**

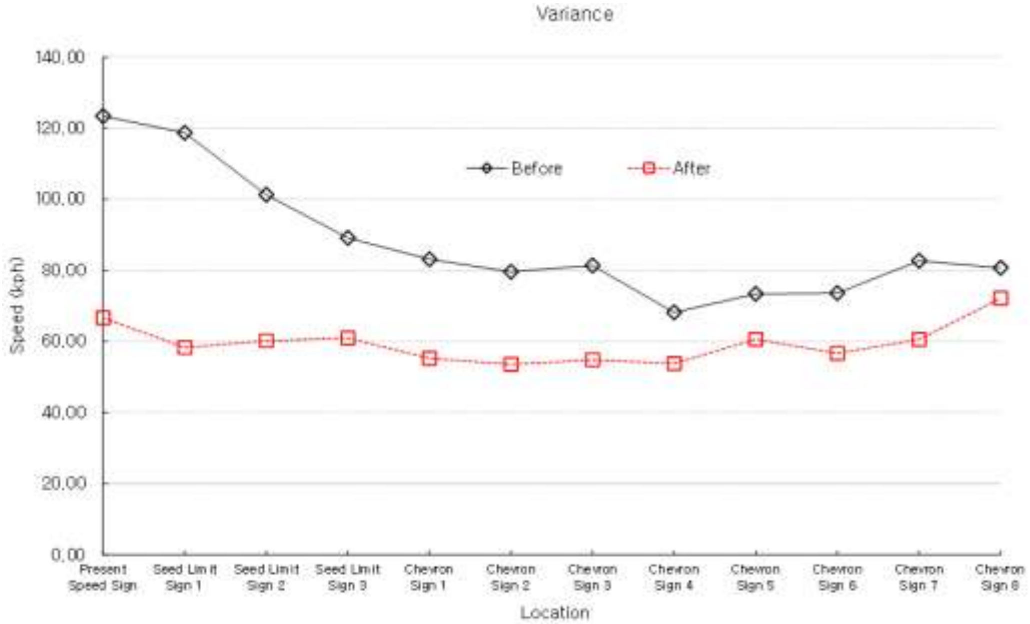



**Figure 7 Variance in Curved Section**

## VI. CONCLUSION AND IMPLICATIONS

This study deals with the evaluation of the safety system that can improve the running safety in a curved section with a complex configuration of horizontal and vertical alignments. In general, an entry into the curved section after lowering the running speed is effective in increasing the level of traffic safety. Therefore, this paper evaluated the effectiveness of the solution which can stabilize the running speed in the curved section.

85%tile speed was an average of 70.53kph before the installation of the dynamic warning system in the curved section, but it was 65.55kph after the installation of the system, showing a decrease of about 5kph. The average running speed from before the vehicle enters the curved section to the point where the present speed sign is installed was reduced by about 10.50kph, and therefore it was confirmed that the driving safety can be improved.

The average running speed from before the entry into the curved section to the point of the speed limit sign was reduced by about 9.0kph, and the running speed in the curved section was reduced by about 2.8kph.

This paper sought to evaluate the effectiveness of solutions to improve the running safety in the curved section, and an additional analysis on the driver’s compliance to the deceleration towards variable speed limits in adverse weather conditions (snow, rain) will be conducted for future work.

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