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EFFECTS OF VARIABLE MESSAGE SIGNS AND GEOMETRY ON MEAN SPEED UNDER ADVERSE FOG CONDITIONS.

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Abstract

To display varying speed restrictions depending on the circumstances, variable message signs (VMS) are now being used. These signs are utilised to convey dynamic information. The current research focuses on the effectiveness of traffic advisory information in assisting drivers to avoid potentially hazardous situations. This is because speed is a significant factor that contributes to accidents that occur on automobile roads. The driving simulator experiment was conducted in a laboratory environment on a simulated Oyamazaki portion that was 8.5 km long. This made it simple to investigate the impact of VMS and geometry on either the mean speed or the speed deviations. A system of two equations will be established in order to develop a model of mean speed and speed deviation. The mean speed and speed deviation will be represented endogenously in the first equation. The three-stage least squares (3SLS) technique is the most effective approach to use when attempting to estimate these two structural equations concurrently. Detailed interpretations of 3SLS estimates of mean speed and speed deviation with regard to VMS and geometry are provided by the analytical findings, which also include a commentary on the speeds that were chosen by each subject according to the model.

Keywords: Variable message signs, Geometry, Speed, Driving simulation, Adverse conditions

1. Introduction

Overspeeding is a major contributor to accidents on the roads across the globe, accounting for between 5 and 15 percent of all accidents. It has been reported by TRL (1997) and Andersson and Nilsson (1997) that a decrease in speed of one mile per hour results in a reduction in casualties by five percent, and a drop in mean speed of ten percent leads in a reduction of deaths by forty percent. According to the findings of Finch et al. (1994), an increase in mean speed of two to four miles per hour leads to a 19-34% increase in the number of deaths. Even little decreases in the average travel speed have a significant influence on the number of injuries and deaths that occur. In addition, the environmental (weather) conditions, such as fog and rain, which have an effect on visibility, are a consideration in both speed and accidents. The driver's senses are diminished and their perceptual judgement of speed and distance is impacted when adverse environmental circumstances are present. When poor circumstances are present, a drop in speed that is adequate may lead to a reduction in the number of accidents and deaths. In the majority of nations, drivers are not provided with any information on the speed that they are required to adhere to, other than the speed limit signs that are placed. This is because visibility is limited, which makes the degree of hazard high in unfavourable circumstances. If the authorities in charge of the roads offer the essential information, drivers will be able to adjust their behaviour and slow down, which would result in fewer accidents and an increase in the overall safety of the roads. The provision of traffic advisory information to drivers is facilitated by variable message signs, which are among the most effective technologies currently available. Using a driving simulator in a laboratory environment, the purpose of this research is to investigate the impact of vehicle management systems (VMS) and geometry on the mean speed and speed deviation of a simulated Oyamazaki portion that is 8.5 km long and is driven by ten individuals. The mean speed and speed deviation are modelled as a function of velocity-mean-square (VMS) and geometry in this research. The investigation is conducted under bad fog conditions, where the amount of fog and visibility are both fixed variables. A model of the mean speed and the speed deviation is going to be created. In order to demonstrate that mean speed and speed deviation are endogenous, a system consisting of two equations will be established. The three-stage least squares approach, which is asymptotically more efficient than other regression procedures, is the method that should be used if you want to estimate these two equations concurrently. When compared to the previous research, which was performed by Shankar et al. (2001), this study has an advantage. Shankar et al. (2001) carried out a simulator experiment under free flow circumstances. On the other hand, the current study will put a maintenance truck and a few passing cars, which will bring the simulated section almost identical to the actual section.

2. Literature Review - Speed, Geometry and VMS

In the field of transportation engineering, speed is a crucial metric, and several studies have been conducted to investigate the elements that influence speed. These aspects include geometry, vehicle features, driver behaviour, surroundings, and many more. Kanellaidis et al. (1990) conducted an investigation on the behaviour of speed in horizontal curves, while Milosevic and Milic (1990) disclosed their findings about the perception of speed in curves. According to the findings of Kanellaidis et al. (1995), the largest group of high-speed drivers who had extremely strong intents to speed was comprised of young men with more education. Multiple regressions were used by Galin (1981) in order to estimate the rate of average speed as a function of the characteristics of the driver population, the circumstances of the traffic, the features of the vehicle and the road, and environmental variables. When it came to small cars, he discovered that older drivers drove at slower speeds, but when it came to heavier trucks, age was not a major factor. The researchers also discovered that female drivers drove at much slower speeds than male drivers. Within the context of an ITS field operational test, Yang G, Ahmed MM, Gaweesh S. (2019) investigated the impact of visibility and environmental elements on driver speed. The purpose of this research was to decrease the number of accidents that were brought on by unexpected shifts in visibility levels.

Luoma and Rama (2001) did a study on the understanding of pictograms for varied message signs. The study was done on European drivers, and the results highlighted how difficult it is to find pictures that are easily comprehended. It has been reported by Khan MN, Ghasemzadeh A, Ahmed MM. (2018) that vehicle monitoring systems (VMS) that collect information from loop detectors that compute vehicle speed and length have been used to increase safety in an area that is prone to accidents. Swann et al. (1995) discovered that vertical management systems (VMSs) were able to lessen the amount of accidents that resulted in injuries at an interchange that connected two motorways. In a study that was done in two major cities in Canada and the United Kingdom, Cheng (2002) compared the attitudes of motorists towards the prospective usage and assessment of vehicle monitoring systems (VMS). The study focused on the driver's opinions of the usefulness of VMS. When compared to drivers in the United Kingdom, Cheng writes that Canadian drivers are more likely to encounter vehicle monitoring systems (VMSs), that they believe information to be more current and trustworthy, and that they also regard safety slogans to be more successful in creating a safer driving environment. According to Miller et al. (1995), a vehicle management system (VMS) should not employ more than two message displays. This recommendation is based on theoretical calculations as well as the experiences of motorists. It is also suggested that a single message screen is ideal, and that the presence of inaccurate information might have severe effects on the performance of the VMS. In his study on motorists' views towards the content of vehicle monitoring systems (VMS), Benson (1996) found that the responses were favourable to VMS messages that were straightforward, dependable, and helpful. High levels of support were expressed for the precise location of incidents, the time tagging of traffic information, and other related topics. It has been reported by Wu Y, Abdel-Aty M, Park J, Selby RM. (2018) that the modelling of traffic systems often makes use of modern programming methods such as object-oriented programming and virtual reality tools. According to the findings of a study conducted by Kaptein et al. (1996) on the validity of driving simulators, mid-level simulators demonstrate absolute validity of route choice behaviour and relative validity of speed and lateral control behaviour. Additionally, it is suggested that the validity of the driving simulator might be improved by including a moving base and potentially a greater picture quality.

3. Driving Simulator - VERS III

The current investigation made use of the Virtual Evaluation for Road Space III (VERS III) driving simulator, which was created by Osaka University and ODEX. One graphic workstation is used for the front screen, and four personal computers are used for the side screens and side mirrors. Additionally, there are three wide 120-inch screens and two side mirror size displays, a driver cabin, a sound generator that simulates the noise of running vehicles, and other measurement equipment such as a gaze point recorder and a heartbeat recorder. The structure of the VERS III driving simulator is depicted in Figure 1. The projectors are used to show the computer graphics picture that was created by the workstation for the driver's perspective. In order to manage the car while simultaneously seeing the graphical representations, the driver makes use of the accelerator pedal, the brake pedal, and the steering wheel of the driving simulator. Changes in the way the accelerator and brake pedals are used, as well as movements of the steering wheel, are sent to the workstation. The information that is provided about driving is used by the workstation in order to build the subsequent frame of the graphic picture that will be shown. The workstation is responsible for calculating the speed of the vehicle, which is then shown on the speedometer that is located in the driver's cabin.

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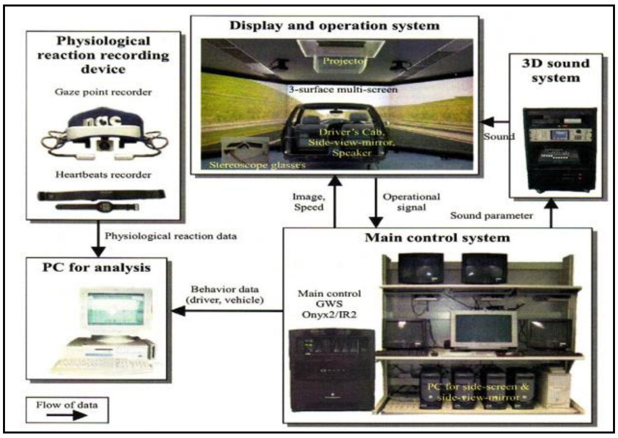

Figure 1 Configuration of VERS III Driving Simulator

In order to investigate the dependability of VERS III, Mori et al. (2003) estimated the speed, the amount of accelerator that was used, and the heartbeat on both an experimental road segment and a simulated road section that was included in VERS III. In order to explain the dependability and validity of VERS III, the statistical values that were obtained for a few independent variables on the experimental road and VERS III are shown in Table 1.

Table 1 Statistical Values for Each Item of Evaluation on Experimental Road and VERS III

Parameter	Experiment on Road	Experiment on VERS III
Speed (km/h)	103.8	104.2
Use of accelerator (%)	20.1	45.6
Heartbeat (beats/min.)	74.5	68.8

In the experimental road part, they discovered a running speed of 103.8 kilometres per hour, whereas in VERS III, they discovered a speed of 104.2 kilometres per hour. It has been shown that VERS III is dependable and valid due to the fact that these speeds are quite near to one another and speed is an essential result of driver conduct.

4. Experimental Set Upon Oyamazaki Section

4.1 Oyamazaki Section

Because it links the Kansai area to Nagoya and because it travels through typical geographical circumstances, the Oyamazaki stretch of the motorway is considered to be one of the most significant parts in Japan. For the sake of this simulation, the Oyamazaki segment begins at km 510.000 and continues until km 501.500.

4.2 Experimental Setup

Condensed water vapour that is arranged in cloud-like masses and lies near to the ground, fog is a phenomenon that reduces visibility. According to observations made by the National Oceanic and Atmospheric Administration in 1997, fog is considered to be present when visibility is less than one km. It is possible for a driver to misjudge his own speed owing to fog, which often results in accidents. Under typical circumstances, Ritzel (2001) states that it takes a car travelling at 90 km per hour six seconds to come to a full stop. Additionally, Ritzel said that vision is significantly diminished as a result of fog, and it will be difficult to bring the vehicle to a stop within the prescribed stopping sight distance. Therefore, while driving in poor circumstances, it is necessary to increase the stopping sight distance by a factor of two and to decrease the speed by a factor of one-third or one-half. In this experiment, the amount of fog is a constant variable, and a speed scenario of sixty kilometres per hour is suggested in conjunction with VMS. In order for the subject to be able to operate the driving simulator in foggy circumstances, the level of fog should be adjusted in such a manner that a visibility range of one hundred metres is accessible as the stopping sight distance (AASHTO, 1984). Figure 2 depicts a schematic design of the situation that has been provided, and it is desired that the subjects drive in the centre lane. In the centre lane, following P2 (km 507.426), there is a single repair truck that has been arbitrarily placed. The explanation is because the subject views the VMS first, and then the maintenance truck comes in from behind. Following the completion of the overtaking attempt, the subject will request that the repair vehicle relocate to the centre lane. The subject will attempt to pass the maintenance vehicle by driving in the side lane. The section will be brought closer to the actual part with the placement of passing cars as well as a maintenance truck.

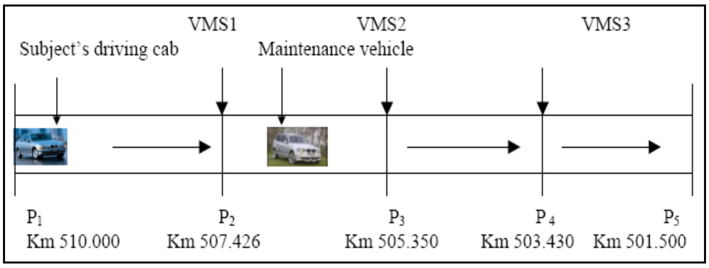

Figure 2 Proposed Scenario for Experiment

A technique that is suggested for the deployment of the maintenance vehicle will be to go at a pace of thirty kilometres per hour and to position it at random after the subject reaches P2 (km 507.426). A distance of between 300 and 500 metres will separate the position of the repair truck from P2. The reason for this is that the maintenance vehicle will drive around 300-500 metres at a speed of 30 kilometres per hour, and if the subject adopts the indicated speed or more than the suggested speed, it will provide them the opportunity to overtake at a distance of 600-1000 metres relative to P2. After considering the geometric circumstances, it has been suggested that three VMS message boards of the gantry type should be installed at the following locations: kilometre 503.430, km 505.350, and km 507.426. All three of these VMS boards display the same message. In the first place, the VMS will serve as a cautionary or warning message to the subject by emphasising the importance of fog and the speed that should be observed. Once again, the second and third VMS will have an emphasis on safety by recommending the speed that should be used when fog circumstances are unfavourable. Under situations of fog, the proposed vehicle management system (VMS) would show the phrase "Careful for Fog" along with the recommended speed. This will be done in accordance with the recommendations established by the Japan Public Highway Corporation. Figure 3 depicts the proposed statement, which is written in Japanese and translates as "Fog, 60 kilometres per hour speed limit."

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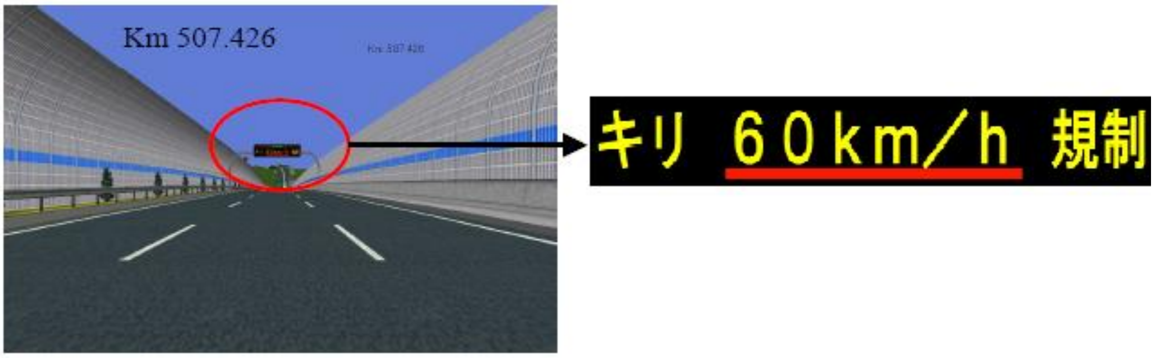

Figure 3 Proposed Content of VMS Message

4.3 Subject Characteristics

Students from Kobe University in Kobe, Japan, were asked to operate the simulator, and ten volunteers were chosen for the experiment based on their holding of a valid driver's licence and their prior experience operating a vehicle on roads. The experiment was carried out on June 21, 2004, and the two groups of ten people who were chosen were labelled as S1 and S10. Every topic is comprised of male students between the ages of 21 and 30.

5. Data Processing And Variables To Design The Model

5.1. Data Processing

The information that was gathered via the use of a driving simulator must first be processed before it can be used for the analysis of this research. A precision of one sixtyth of a second will be used to record the observations, and this information will be saved in the appropriate data files. The data that was collected from the experiment using the driving simulator comprises

- Time (sec)
- Line number
- Position (Km)
- Speed (kmph)
- Gradient (up/down, %)
- Accelerator (degree of relaxing accelerator, %)
- Brake (degree of relaxing brake, %)
- Handle (angle)
- X, Y and Z (geometric parameters of simulated section, m)

Line number is a piece of information that indicates whether or not the individual is driving in the lane that was requested. For the purpose of determining the influence of VMS on mean speed and speed deviation, speed is used. The location of the vehicle in relation to distance and other factors may be determined by the trajectory of the vehicle. Calculating geometric parameters takes into account the X, Y, and Z values of the simulated section. These parameters include the kind of curve, the length of the curve, the radius of the horizontal and vertical curves, and so on.

It is more probable that sections of even lengths will contain a comparable number of observations, and as a result, error terms will be more equally distributed. This is because even lengths are more likely to be tabulated for analysis. It is because of this that heteroskedasticity is reduced. This research divides the whole stretch into four subsections, each of which is two kilometres in length, based on the geometric circumstances that were present. While the simulator is speeding from a nearly stationary position, the first half kilometre is lost while the data for analysis is being considered. It is possible to get 80 observations from ten participants, which is a sample size that is statistically significant. It is important to note that each person will contribute 8 observations both without and with VMS. The findings of Mannering and Chu Te (1986) indicate that a considerable number of observations may be obtained from a single subject, and hence, a comparatively smaller number of subjects are required to provide a sample size that is statistically valid.

5.2 Variables to Design the Model

In this research, the degree of fog and visibility are both considered to be fixed variables when bad circumstances are present. The variables that are used for data processing are chosen on the premise that they have the potential to provide explanations. Out of all the variables that are accessible, the mean speed and the speed deviation are regarded to be two endogenous variables. These variables are chosen in such a manner that they should be reliant on other factors. As part of the model's design, the variables include

Endogenous variables

- Mean speed in a section
- Speed deviation in a section

For the purposes of this investigation, the term "mean speed" refers to the average speed of each individual subject, while the term "speed deviation" refers to the change in the observed speed that is calculated for each subsection. Additionally, the mean speed and the variance from the mean speed.

6. Model

The creation of a model of mean speed and speed deviation requires the establishment of a system of two equations in which the mean speed and speed deviations are formulated in an endogenous manner. Calculating the t-statistic and standard errors from the covariance matrix is a method that may be used to test the hypothesis. For the purpose of determining the mean speed and speed deviation, the estimator $\approx\delta$ is often known as the three stage least squares estimator. According to Judge et al. (1988) and Griffiths et al. (1992), the comprehensive discussions on 3SLS estimate may be found in those two publications. It is possible to examine the influence of VMS and geometry on mean speed and speed deviation using the 3SLS coefficients that have been calculated using the information.

7. Results and Discussion

7.1 Speeds Adopted by Each Subject

Table 2 Speeds (kmph) Adopted by Each Subject

Subject	Mean speed		Entire section mean speed		Entire section speed deviation	
	before VMS	after VMS	without VMS	with VMS	without VMS	with VMS
Effective						
S1	102	65	81.72	72.93	1.99	2.52
S3	109	99	114.45	103.15	7.15	6.70
S6	116	92	104.55	98.68	5.45	11.56
S8	112	82	107.14	91.34	9.81	15.94
Marginal effect						
S2	117	108	123.44	109.2	3.03	3.23
S4	84	77	90.38	79.81	8.23	6.23
S5	136	131	136.34	131.38	7.38	5.27
S10	110	104	116.00	107.46	5.34	4.50
No effect						
S7	111	110	108.28	109.67	4.91	5.84
S9	100	98	89.73	92.14	7.98	7.15

The speeds that were used by each individual participant were evaluated, and the findings were classified as VMS having an effective impact, a minor effect, or no effect at all. The classification was carried out on the basis of mean speeds calculated both before and after messages were sent in using VMS, despite the fact that the subjects' speeds were greater in the absence of VMS compared to when they were using VMS. The subject was considered to have received VMS effectively if the difference in mean speeds was more than 10 kilometres per hour; if the difference was between 5 and 10 kilometres per hour, then there was a marginal influence on the subject; and if the difference was less than 5 kilometres per hour, then there was no effect of VMS on the subject. Table 2 displays the mean speed of each topic both before and after the implementation of VMS, as well as the mean speed and speed deviation of the whole section both before and after the implementation of VMS. All of the subjects' mean speeds and variances from those speeds are shown in Figures 4 and 5, respectively, under and with VMS conditions.

7.2 Discussion

In all, forty percent of the participants were able to successfully receive VMS, whereas twenty percent of the subjects had no impact at all. Subjects were taken aback by the abrupt appearance of a maintenance vehicle in the centre lane, despite the fact that they were travelling on a part of the road where there was only one maintenance vehicle and a small number of passing cars. After that moment, a shift in the behaviour of the subject's speed was detected. Nevertheless, prior to the trial, information about the positioning of passing cars and maintenance trucks was not given under any circumstances.

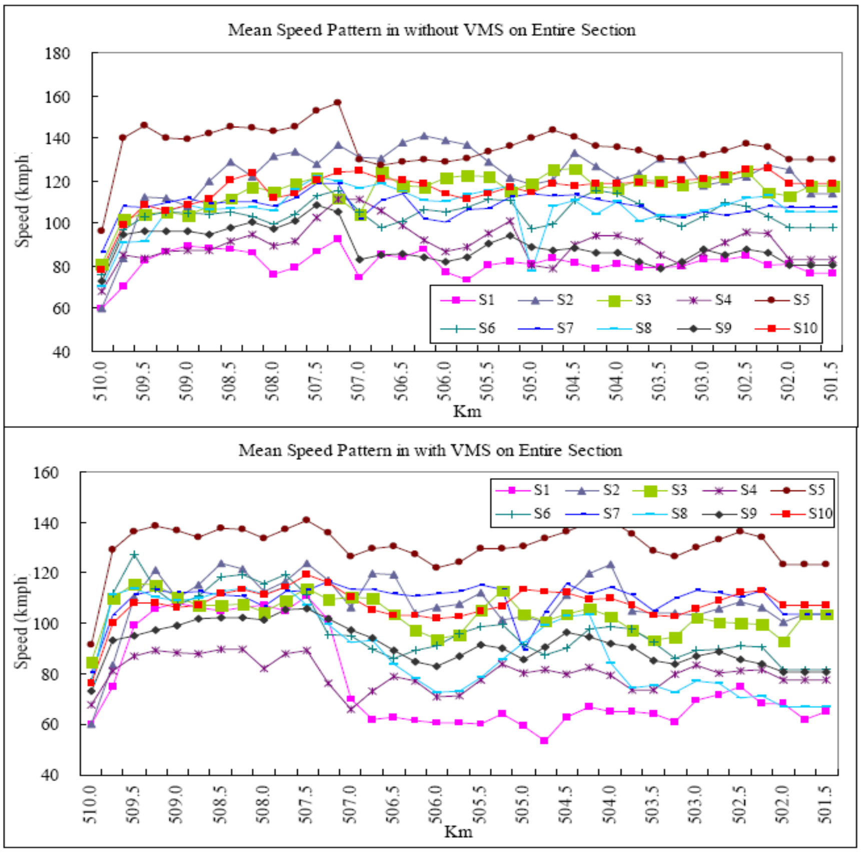

Figure 4 All Subjects Mean Speed Pattern under Without VMS and With VMS

7.3 Discussion on mean speed equation

- The speed deviation has a negative impact to the mean speed, and the greater the speed deviation, the lower the mean speed. In light of the fact that subjects vary their speed from their desired speed when they slow down, it is reasonable to assume that they are driving as fast as they want when fog conditions are present that this conclusion is plausible. There are occasions when people seek to restore the speed that they want, and this causes a larger speed deviation to be associated with lower speeds.
- The scenario has a negative influence to the mean speed, and this conclusion is plausible since the mean speeds were lower when VMS was there as opposed to when VMS was not present. It was noticed that the subjects slowed down their speeds when driving with VMS, and the mean speed difference between driving with VMS and driving without VMS was roughly 8 kilometres per hour.
- The curve indication is directly related to the mean speed of the simulated vehicle, which leads to the conclusion that a section that has a greater number of horizontal curves than vertical curves would have higher mean speeds.
- A positive contribution is made by the grade indicator to the mean speed, which is a finding that makes sense. Furthermore, if the maximum gradient for a section is less than 2%, the mean speed is likely to be greater than the mean speed for other sections. As the number of upgrades increases, the performance of the simulated vehicle

decreases, which in turn causes the vehicle to slow down and ultimately results in lower mean speeds on the section.

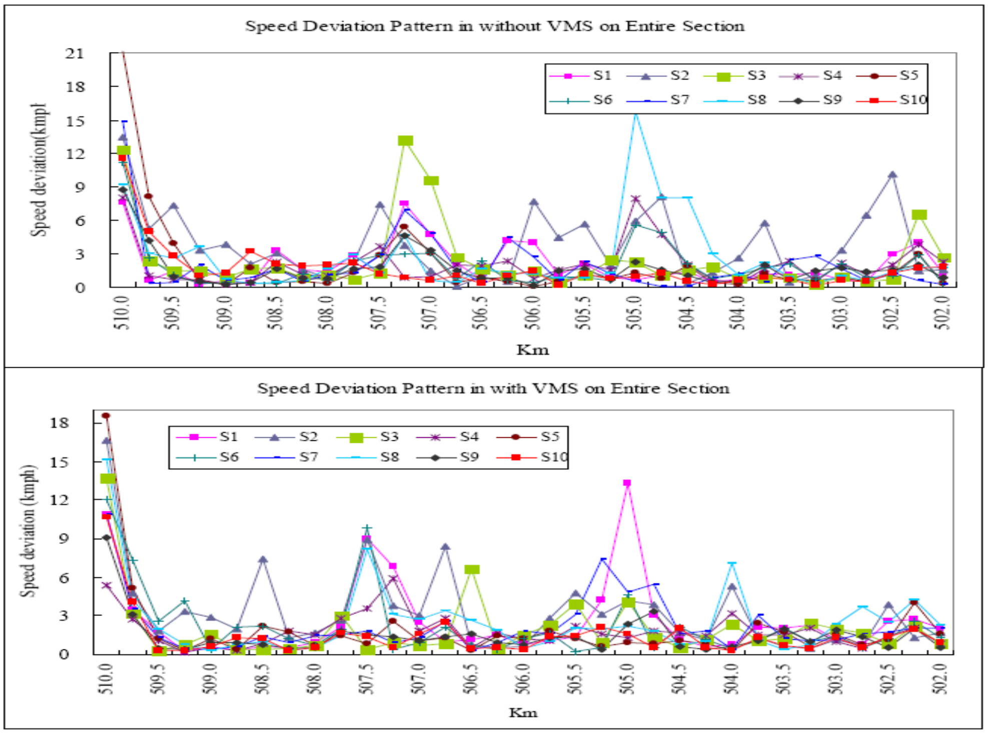

Figure 5 All Subjects Speed Deviation Pattern under Without VMS and With VMS

a. Discussion on speed deviation equation

- A negative contribution to speed deviation is made by the mean speed, and this conclusion is consistent with the one that was calculated for the speed deviation in the section before this one. This is because higher mean speeds are connected with smaller speed deviations.
- The presence of VMS in the segment will have a positive impact to the speed deviation, and this conclusion is consistent with logic. Considering that the scenario has a negative influence on mean speeds, this finding is consistent with the hypothesis that the existence of VMS in a segment will correspond to a positive impact on speed deviation.
- The maximum distance measured in the horizontal curve in the section makes a negative contribution to the divergence in speed. There is no error in this output. In the event that the horizontal curve is lengthy, the subject will keep the simulated vehicle speed constant in order to traverse the curve for a longer period of time. This will result in a lower speed deviation for the greatest distance in the horizontal curve in section.
- A positive contribution to speed deviation is made by the maximum distance in the vertical curve shown in the section diagram. This conclusion does make sense. For the purpose of travelling a greater distance over vertical bends, participants tend to adopt lower mean speeds, which ultimately leads to greater speed deviations.

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8. Conclusion

The mean speed and speed deviation model that was developed is used in order to investigate the impact that VMS and geometry have on endogenous variables like mean speed and speed deviation. The 3SLS estimates demonstrated that the mean speed and speed deviations are endogenous and statistically significant in each other equation. This means that greater mean speeds are associated with lower speed deviations, while higher speed deviations are associated with lower mean speeds. The conclusion that can be drawn from the 3SLS calculation of the mean speed equation is that the scenario has a reduction in the mean speed. While the subjects were driving in with VMS, they slowed down, and the mean speed difference that was recorded was roughly 8 kilometres per hour. The curve indication is directly related to the mean speed of the simulated vehicle, which shows that a section that has a greater number of horizontal curves than vertical curves would have higher mean speeds. When the maximum slope for a segment is less than 2%, the mean speed of that section is often greater than the mean speed of other sections. As the number of upgrades increases, the performance of the simulated vehicle decreases, which in turn causes the vehicle to slow down and ultimately results in lower mean speeds on the section.

- The results of the 3SLS estimate of the speed deviation equation indicate that the subjects reacted well to the presence of VMS in the section, and a rise in speed deviations was noted. Given that the scenario has a negative influence on mean speeds, there will be a positive impact on speed deviation as a result of the existence of VMS in a segment.
- In the case of lengthy horizontal curves, the subject keeps the simulated vehicle speed constant so that it may travel the curve for a longer period of time, which ultimately results in a lower speed deviation. For the purpose of travelling a greater distance over vertical bends, participants tend to adopt lower mean speeds, which ultimately leads to greater speed deviations.
- In all, forty percent of the participants were able to successfully receive VMS, whereas twenty percent of the subjects had no impact at all. The endogenous link between mean speed and speed deviation was shown to be substantial and valid under the Intelligent Transport System, as demonstrated by the evaluation of VMS on mean speeds and speed deviations.
- Because to the influence of VMS and geometry, the mean speeds were decreased but the speed variances were increased. Increases in speed deviation have the potential to contribute to an increase in accident frequency, particularly in close proximity to or at VMS sites. This may have the effect of mitigating the impact of lower mean speeds, which operate to decrease the severity of accidents and the number of accidents that occur.
- The findings of this experiment are restricted to the VMS message that was taken into consideration, and they demonstrate that the supply of traffic advisory information by VMS and geometry had an impact on the mean speed and speed deviation when severe fog conditions were present or present.
- Additional variation in mean speed and speed deviation may offer an indication of whether there is a likelihood of an increase or reduction in the frequency of accidents and the severity of accidents.

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