Suppressive Effect on Speed Reduction at Sag Sections by Utilizing Visual Illusions

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Abstract: Currently about 60% of traffic jams on express highways nationwide are said to occur at sag sections, as traffic congestion at tollgates decreased significantly with the introduction of electronic ETC (toll collection system). Therefore, in order to further decrease traffic jams on express highways, there is an urgent need to consider measures to reduce traffic congestion at sag sections. A wide variety of hardware and software has been suggested to deal with traffic jams. In this study, a measure for suppressing traffic congestion at sag sections has been proposed, expected to be low in cost and readily installed, which utilizes optical illusions for drivers. An experiment which used a driving simulator resulted in a suggestion that setting gates at incremental intervals at uphill sag sections resulted in suppression of speed reduction in those sections.

Key words: Traffic flow, sag sections, illusion, driving simulator.

1. Introduction

As traffic congestion at tollgates has been nearly eliminated, 59% of traffic jams on the express highways nationwide now occur at sag sections in Japan [1]. Therefore, in order to further decrease traffic jams on express highways, it can be said that there is an urgent need to consider measures for solving traffic congestion at sag sections.

As a countermeasure against these traffic jams, provision of traffic jam position information on an LED (light-emitting diode) display board, a sign to help avoid and alleviate traffic congestions, and utilization of advanced ACC (adaptive cruise control) [2] etc., are proposed. Okada et al. [3] proposed measures to set light-emitting devices at uniform intervals along the shoulder, and to alter the light patterns to give drivers the sense that they are decelerating, in order to encourage drivers to recover the lost speed. The result of the verification experiment conducted on an actual road suggested that there was an effect on the countermeasures for speed suppression and speed reduction.

Further, Iwasaki et al. [4] proposed that optical illusion gates should be set at decreasing intervals as a measure to reduce speeding. This is based on a phenomenon where by the visual stimulation of drivers passing through a group of optical illusion gates at a constant speed, and that of drivers passing through whilst accelerating, are the same. An experiment using a driving simulator (hereafter “DS”) resulted in the following findings: (1) when passing through a group of optical illusion gates at a constant speed, drivers felt as though they were accelerating; (2) that as the result, drivers reduced their speed when instructed to keep at a constant speed.

Han et al. [5] proposed the introduction of optical dots that use the concept of sequence design to control driving speed, and suggested that the method is useful for downhill gradients on express highways. In their study, using a DS, they had drivers drive at about 100 km/h under conditions where optical dots were set to give drivers the feeling they were accelerating or decelerating. As a result, use of optical dots set to give drivers the feeling of acceleration resulted in a decrease in speed that was statistically significant. In addition,
they anticipated that when aiming to give drivers the feeling of deceleration, having drivers drive at about 80 km/h will demonstrate a statistically significant difference.

In the present study, referring to the method of Iwasaki et al. [4], introduction of a group of optical illusion gates set at incremental intervals has been proposed, which aims to alleviate traffic congestions by: (1) prompting drivers passing sag sections to feel as if they are decelerating; (2) resulting in drivers accelerating in response to (1). In addition, its effect has been verified using a DS experiment.

2. Overview of experiment

2.1 Experimental Equipment

In this experiment, as it was necessary to have more than one participant drive under identical driving conditions, a DS experiment was conducted on a straight road with no buildings at all in the vicinity, created utilizing the software UC-win/Road (made by FORUM8 Co., Ltd.). Data was recorded including speed, acceleration, accelerator pedal input, and the position of the vehicle, etc.

Fig. 1 shows the DS’s system configuration. Three 32-inch displays, one main computer, two computers for video generation, and computers for the console behind the seat are arranged as shown. On the three displays, scenes from the driver’s viewpoint are displayed. Fig. 2 shows an example of a front view. With regard to the optical illusion gates, a pole type and a gate type were created in reference to the CG (computer graphics) [6] made by Adachi et al. in the image of a torii, a large gate used to mark the entrance to a Shinto shrine. In the preliminary study, the gate type seemed to have a better effect, and thus the gate type was used to conduct this experiment.

2.2 Study Scenario

Based on a previous study [4], gates were set from the bottom of sag sections at the intervals shown in Eq. (1):

\[ I(n) = d_0 (1 + x)^n \quad (0 < x < 1) \]  

where, \( I(n) \) is the interval of the \( n \)th gate, \( d_0 \) is the initial interval, and \( x \) is the rate of increments for the distance between gates. From Eq. (1), it can be seen that the distances between gates gradually increased. Drivers passing a group of gates are expected to accelerate at uphill sag sections due to the feeling of deceleration from the optical illusions, and as a result, easing of traffic congestions at sag sections on express highways is attained.

With regard to longitudinal gradient, in reference to the research of Fushiya et al. [7], a gentle sag (climbing an upward slope of +1.5% after descending a downward slope of -0.5%) and a steep sag (climbing an upward slope of +3.0% after descending a downward slope of -0.5%) are created as shown in Fig. 3.

During the experiment, the speedometer was disabled so that participants could not adjust their speed by looking at the speedometer. Therefore, a speed regulation vehicle, which is to disappear from
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the experiment environment at the junction set 300 m short of the sag bottom after accelerating from 0 km/h to 80 km/h in the left driving lane, was made to run. For the speed pattern of the speed regulation vehicle, data which was obtained when an average man in his twenties (having held his driver’s license for 2 years and 5 months, and who drives once a month) drove at the DS was used (see Fig. 4). The experiment participants were instructed to drive in the right-hand lane.

3. Experimental Conditions and Participants

3.1 Experimental Conditions

As a practice run prior to the experiment, participants were asked to get used to the DS environment as well as driving operation by driving in the following scenarios once each: (1) scenario in which the driver follows a vehicle running in JC-08 mode; (2) scenario in which a speed regulation vehicle, that is to be made to run on the left lane when in the experiment, is going out through a junction.

In the experiment, each participant drove over both a gentle sag and a steep sag once “with gates” and once “without gates”, totaling four runs. Driving experiments were performed randomly to minimize the influence of the order. In addition, to measure mental load, participants took questionnaire using NASA-TLX [8] after each driving.

3.2 Participants

Participants in the experiment consisted of 16 average drivers (12 men and 4 women) ranging in age from their late teens to early 40’s. Table 1 shows the

<table>
<thead>
<tr>
<th>ID</th>
<th>Age</th>
<th>Gender</th>
<th>Driving experience</th>
<th>Driving frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>19</td>
<td>Male</td>
<td>6 months</td>
<td>Once every 2-3 months</td>
</tr>
<tr>
<td>B</td>
<td>20</td>
<td>Male</td>
<td>2 years 2 months</td>
<td>Almost everyday</td>
</tr>
<tr>
<td>C</td>
<td>22</td>
<td>Male</td>
<td>2 years 1 month</td>
<td>Once every 2-3 months</td>
</tr>
<tr>
<td>D</td>
<td>23</td>
<td>Male</td>
<td>4 years 7 months</td>
<td>1-2 times per week</td>
</tr>
<tr>
<td>E</td>
<td>21</td>
<td>Female</td>
<td>3 years 2 months</td>
<td>Once a month</td>
</tr>
<tr>
<td>F</td>
<td>23</td>
<td>Male</td>
<td>3 years 8 months</td>
<td>1-2 times per week</td>
</tr>
<tr>
<td>G</td>
<td>19</td>
<td>Male</td>
<td>4 months</td>
<td>Almost everyday</td>
</tr>
<tr>
<td>H</td>
<td>22</td>
<td>Male</td>
<td>3 years 4 months</td>
<td>Almost everyday</td>
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<tr>
<td>I</td>
<td>20</td>
<td>Female</td>
<td>2 years 1 month</td>
<td>Once a month</td>
</tr>
<tr>
<td>J</td>
<td>20</td>
<td>Female</td>
<td>1 year 7 months</td>
<td>Once a month</td>
</tr>
<tr>
<td>K</td>
<td>22</td>
<td>Male</td>
<td>1 year 4 months</td>
<td>3-4 times per week</td>
</tr>
<tr>
<td>L</td>
<td>22</td>
<td>Male</td>
<td>3 years 10 months</td>
<td>Once a month</td>
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<tr>
<td>N</td>
<td>21</td>
<td>Male</td>
<td>3 years 2 months</td>
<td>Once a month</td>
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<td>O</td>
<td>22</td>
<td>Male</td>
<td>4 years 9 months</td>
<td>Almost everyday</td>
</tr>
<tr>
<td>P</td>
<td>42</td>
<td>Female</td>
<td>23 years 10 months</td>
<td>Almost everyday</td>
</tr>
</tbody>
</table>
Life (HQL). The results showed that there are some subjects whose driving characteristics partly deviated from the average, however, there were no subjects for whom too much anxiety or a mental burden would affect their driving operation.

3.3 Instructions

Fully informed consent on the participation in the experiments was obtained from all the participants in advance, after explanations were given regarding the following matters: (1) disadvantages caused by the experiments; (2) consideration of privacy; and (3) guarantee of their right to not participate in the experiment.

They were then given instructions for each run as described below.

- To drive as they would on an actual road, not as though they were in a game;
- To keep right without making a lane change;
- To drive carefully while obeying road rules;
- To notify staff immediately if they become sick, even while driving;
- The speed of the vehicle running in the adjacent lane is about 80km/h;
- To drive at about 80km/h;
- To start driving simultaneously with the vehicle in the adjacent lane.

4. Results/Discussions

4.1 Changes in Speed Provided by Installation of Gates

Targeted analytical sections in this chapter were the sections installed with groups of optical illusion gates (hereafter called “gate sections”).

Figs. 8 and 9 show the X axis plotted with the average speed in gate sections without gates, and the Y axis plotted with the average speed with gates, for gentle and steep sags, respectively.

In gentle sags, the participants who drove at 60-80 km/h without gates increased their average speed in the presence of gates. In addition, some of the...
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participants who drove at more than 80 km/h without gates showed a decrease in speed with gates, which infers that they operated to get their speeds closer to 80 km/h following the above instructions. On the other hand, in steep sags, there is no substantial difference between runs with and without optical illusion gates.

Shown in Fig. 10a and 10b are the box plots of data from Figs. 8 and 9. The average speed with gates at gentle sags increased by 5.2% (p = 0.021) compared with that of without gates. On the other hand, in steep sags, the average speed with gates increased by 2.9%, however, there was no statistically significant difference seen. In addition, for gentle sags, it can be seen that the variability in speed was suppressed slightly at uphill sag sections.

4.2 Changes in Minimum Speed and Its Position with/without Gates

Table 2 shows the mean minimum speed and its position with/without gates. The mean position at minimum speed in gate sections was shortened by 87.9 m at gentle sags, and by 157.4 m at steep sags. In addition, the minimum speed increased by 3.3 km/h (p = 0.093) at gentle sags, and 2.2 km/h (p = 0.251) at steep sags.

From the above results, it is suggested that early speed recovery effects can be expected at uphill sag sections with the installation of optical illusion gates.
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### Table 2  Mean minimum speed and its position.

<table>
<thead>
<tr>
<th>Conditions of the course</th>
<th>Mean minimum speed (km/h)</th>
<th>Mean position where minimum speed was recorded (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gentle sags</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without gates</td>
<td>75.1</td>
<td>1,961.4</td>
</tr>
<tr>
<td>With gates</td>
<td>78.3</td>
<td>1,873.6</td>
</tr>
<tr>
<td>Steep sags</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Without gates</td>
<td>69.3</td>
<td>1,910.2</td>
</tr>
<tr>
<td>With gates</td>
<td>71.4</td>
<td>1,752.8</td>
</tr>
</tbody>
</table>

Presented next is a consideration of a concrete example for improvement. Fig. 11 shows participant A’s speed and accelerator pedal input in gate sections at steep sags.

From this figure, it can be seen that in the presence of gates, recovery of speed was made earlier than without gates, and that installation of gates led to less speed reduction at sags.

### 4.3 Changes in Accelerator Pedal Input

Fig. 12 shows accelerator pedal input on a scatter diagram with the horizontal axis showing input without gates, and the vertical axis showing input with gates.

With optical illusion gates installed, accelerator pedal input at gate sections increased. On average, a 9.8% ($p = 0.0216$) increase was seen at gentle sags, and a 11.3% ($p = 0.0036$) increase seen at steep sags.

From the above, it can be seen that the introduction of gates prompts an increase in accelerator pedal input at both gentle and steep sags.

### 4.4 Discussion of Speed at Steep Sags

Table 3 shows the list of participants whose mean speed in gate sections decreased with optical illusion gates installed at steep sags.

Here, participants who reduced their speed by 2 km/h or more (E, H, I, and K) are discussed. Figs. 13 and 14 show the speed patterns of these 4 participants with/without gates. Shaded areas indicate the gate sections.

With reference to the speed pattern in the presence of gates, it can be seen that the participants whose speed reduced decelerated before entering the gate sections. In addition, 3 out of 4 participants (E, H, and K) answered...
that they felt pressure with the addition of gates on the questionnaire conducted after the experiment. However, no participants whose speed increased answered that they felt such pressure. Therefore, it can be inferred that those 4 participants, whose speed decreased with gates, felt strong pressure when entering gate sections, and therefore reduced pressure on the accelerator to decelerate.

5. Conclusions

In this study, as part of the measures to alleviate traffic congestion at sag sections on expressways where jams occur frequently, introduction of visual illusion gates set at incremental intervals so as to give drivers the feeling of deceleration was proposed. This measure is based on using illusions to alter the distance perception of drivers, giving them the feeling of deceleration, which then prompts acceleration, resulting in less speed reduction at sag uphill sections.

Based on the results from the driving simulator experiment, installing a group of optical illusion gates at uphill sag sections resulted in: (1) prompting early pedal input to recover speed; (2) the position of the minimum speed coming earlier; and (3) suppressing speed reduction at sag sections.

Issues in the future include experiments on actual roads, and more detailed data analyses and discussions. Specifically, this includes optimizing gate sizes and intervals for providing optical illusions, as well as verifying the effect of optical illusions when multiple vehicles are running.

Acknowledgments

We are deeply grateful to Prof. Hironao Kawashima, professor emeritus from Keio University, Prof. Tatsuru Daimon from Keio University, Mr. Hisafumi Kokubugata from Keio Girls Senior High School, Assistant Professor Makoto Kasai from Tokyo University of Science, Dr. Toshihiro Hiraoka from Kyoto University, and Mr. Katsumi Matsuda from FORUM 8 Co., Ltd. for their significant advice on this study.

Reference


