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Investigating the Effectiveness of Intelligent Lane Control Signals on Driver Behavior

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16. Abstract (Limit: 250 words)

A fully interactive PC-based STISIM driving simulator was used to test the effectiveness of Intelligent Lane Control Signals (ILCS). The participants were 160 licensed drivers from four age groups: 18-24, 32-47, 55-65, and 70+ years of age. Each participant drove three times in a counterbalanced order. In each trial, after driving five miles in the center lane of a six-lane highway where the speed limit was 65 mph, they encountered five sets of ILCSs that occurred at half-mile intervals. These ILCSs presented (1) 45-mph speed limit messages; (2) 35-mph speed limit messages; (3) a yellow lane closure warning; (4) one of three merge messages that used a diagonal arrow, or words, or dynamic chevrons to indicate that drivers should move from the center lane; (5) a red lane closure warning.

Analysis of lane position data showed that the diagonal arrow merge sign was the most effective; participants moved from the center lane 266 feet before reaching the diagonal arrow merge sign, 123 feet before reaching the dynamic arrow merge sign, and 54 feet before the merge sign with words.

Analysis of driving speed data indicated that the speed limit signs were effective. Before the 45-mile speed limit was visible, participants drove at 63 mph. When the 45-mph speed limit was visible, they reduced speed by approximately 10 mph. Then on the approach to the 35-mph speed limit, they reduced speed by a further 14 mph—on average, they were driving at 38.7 mph shortly after passing the 35-mph speed limit.

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Final Report

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Table of Contents

Chapter 1. Introduction **1**
1.1 Objective 1
1.2 Introduction 1
1.2.1 Participants 1
1.2.2 Driving Simulator 2
1.2.3 Driving Scenario 2
1.2.4 Simulator Data 2
1.3 Organization of this Report 3
Chapter 2. Method **4**
2.1 .Participants 4
2.2 Driving Simulator 4
2.2.1 Visuals 5
2.2.2 Sound 5
2.2.3 Controls 5
2.3 Experimental Design 6
2.3.1 ILCS Conditions 6
2.3.1.1 First set of ILCSs. 6
2.3.1.2 Second set of ILCSs. 7
2.3.1.3 Third set of ILCSs. 7
2.3.1.4 Fourth set of ILCSs. 8
2.3.1.5 Fifth set of ILCSs. 12
2.3.2 Order of Presentation of the Merge Signs 12
2.3.3 Simulator Data 13
2.3.4 Survey 13
2.4 Procedure 13
Chapter 3. Results and Discussion **15**
3.1 Simulator Results 15
3.2 Lane Position Data 15
3.2.1 Lane Changing Behavior Related to “X/1 Mile” Lane Closure Warning 15
3.2.1.1 Effect of age. 16
3.2.1.2 Effect of gender 16
3.2.2 Lane Changing Behavior Related to the Merge Messages 17

3.2.2.1 Effect of age. 19
3.2.2.2 Effect of type of merge sign. 20
3.3 Driving Speed Data 21
3.3.1 Analysis of Speed Data 21
3.3.2 Effect of Highway Segment 25
3.3.3 Effect of Age 27
3.3.4 Interaction between Age and Highway Segment 28
3.2.5 Effect of Gender 31
3.2.6 Effect of Trials 32
3.2.7 Interaction between Trials and Highway Segments 33
3.4 Survey Data 35
Chapter 4. Summary and Conclusion 36
4.1 Objective 36
4.2 The Experiment 36
4.3 Summary Results 37
4.3.1 Lane Changing Behavior 37
4.3.1.1 Effect of age. 37
4.3.1.2 Effect of merge sign type. 37
4.3.2 Driving Speed Data 38
4.3.2.1 Effect of highway segment. 38
4.3.2.2 Interaction between age and highway segment. 38
4.3.2.3 Effect of gender. 39
4.3.2.4 Interaction between trials and highway segments. 39
4.4 Conclusion 39
References 41
Appendix A - Counterbalanced Order
Appendix B - Survey Questions
Appendix C - Survey Data

List of Tables

Table 2.1 Breakdown of participants by age and gender 4

Table 2.2 The twelve different combinations of merge sign and direction 12

Table 3.1 Number of trials in which participants moved from the center lane on the approach to the "X/1 mile" lane closure warning 16

Table 3.2 Number of trials in which participants moved from the center lane on the approach to the "X/1 mile" lane closure warning as a function of age 16

Table 3.3 Summary of the ANOVA conducted on average distance from the merge signs 18

Table 3.4 Average distance at which lane change occurred on the approach to the merge signs as a function of the age of the participants 19

Table 3.5 Average distance at which lane change occurred on the approach to the merge signs as a function of the type of merge sign 20

Table 3.6 Segments over which driving speed was averaged for each set of ILCSs 22

Table 3.7 P-values obtained in the five ANOVAs performed on average driving speed on the approaches to the five sets of ILCSs 23

Table 3.8 Average speed (mph) in each of the four segments on the approaches to the 45-mph and 35-mile speed limits, the "X/1mile" closure warning, and the merge signs 25

Table 3.9 Average speed on the approach to the 45-mph speed limit as a function of the age of the participants 27

Table 3.10 Effect of the interaction between the age of the participants and highway segments on average speed (mph) on the approach to the 45-mph speed limit 28

Table 3.11 Interaction between average speed and age of the participants on the approach to the 35-mile speed limit 29

Table 3.12 Interaction between average speed and age of the participants on the approach to the "X/1 mile" closure warning 30

Table 3.13 Interaction between average speed and age of the participants on the approach to the merge signs 31

Table 3.14 Average speed on the approaches to the 45-mph and 35-mph speed limits as a function of the gender of the participants 31

Table 3.15 Average speed (mph) on the approaches to the 45-mph and 35-mph speed limits and the "X/1 mile" and "X" lane closure warnings as a function of trials 32

Table 3.16 Interaction between trials and highway segments for average speed (mph) on the approach to the 45-mph speed limit 33

Table 3.17 Interaction between trials and highway segments for average speed (mph) on the approach to the 35-mph speed limit 34

Table 3.18 Interaction between trials and highway segments for average speed (mph) on the approach to the "X/1 mile" lane closure warning 35

List of Figures

Figure 2.1 The STISIM simulator (shown from the left of the driver's seat) 5
Figure 2.2 The first set of ILCSs displaying the 45-mph speed limit 6
Figure 2.3 The second set of ILCSs displaying the 35-mph speed limit 7
Figure 2.4 The third set of ILCSs with the "X/1 mile" lane closure warning on the center display 8
Figure 2.5 The fourth set of ILCSs with a diagonal arrow indicating merge right 9
Figure 2.6 The fourth set of ILCSs with words indicating merge left 9
Figure 2.7 The fourth set of ILCSs with the first in the sequence of dynamic chevrons indicating merge right 10
Figure 2.8 The fourth set of ILCSs with the second in the sequence of dynamic chevrons indicating merge right 10
Figure 2.9 The fourth set of ILCSs with the third in the sequence of dynamic chevrons indicating merge right 11
Figure 2.10 The fifth set of ILCSs with the "X/1 mile" lane closure warning on the center display and green arrows on the left and right ILCSs 11
Figure 3.1 Average distance (in feet) from the merge signs at which lane changes occurred as a function of age 20
Figure 3.2 Average distance (in feet) at which lane changes occurred as a function of the type of merge sign 21
Figure 3.3 Average speed on the approach to the 45-mph speed limit 26
Figure 3.4 Average speed on the approach to the 35-mph speed limit 26
Figure 3.5 Average speed for four age groups on the approach to the 45-mph speed limit 29
Figure 3.6 Average speed for four age groups on the approach to the 35-mph speed limit 30
Figure 3.7 Average speed on the approaches to the 45-mph and 35-mph speed limits as a function of the gender of the participants 32
Figure 3.8 Interaction between trials and highway segments for average speed on the approach to the 45-mph speed limit 33
Figure 3.9 Interaction between trials and highway segments for average speed on the approach to the 35-mph speed limit 34

Executive Summary

1. Introduction

The objective of this driving simulation study was to test the effectiveness of Intelligent Lane Control Signals (ILCSs) presented overhead in freeway lanes. This was the fourth study in a series exploring the effectiveness of roadway signage. In the previous studies, we investigated the effectiveness of various Changeable Message Signs (CMSs). The current study extended the previous work by investigating another type of changeable message sign: Intelligent Lane Control Signals. The ILCSs tested included merge signs, speed limit signs and lane closure warnings. We were particularly interested in determining which of three types of merge signs—(1) a diagonal arrow, (2) words, or (3) dynamic chevrons—was most effective, and the extent to which participants reduced speed on encountering the speed limit signs. The specific situation that we investigated involved the use of ILCSs to control driving behavior when drivers were confronted with a lane closure on a six-lane divided highway. This study is one of the first to investigate the effectiveness of ILCSs in directing driver behavior.

2. The Experiment

The experiment used 160 participants who were drawn from four age groups: a younger age group with participants between 18 and 24 years old; a middle age group with participants between 32 and 47 years old; an older age group with participants between 55 and 65 years old; and a senior age group with participants who were 70 years old or more. There were 40 participants in each age group, and within each age group there were 20 females and 20 males. All 160 participants were licensed drivers.

We used a fully interactive PC-based STISIM driving simulator to present a driving scenario in which participants drove on a six-lane divided highway with a posted speed limit of 65 mph. After driving in the center lane for approximately five miles, participants encountered a sequence of five sets of ILCSs. The sets of ILCSs, which occurred at half-mile intervals, were used to direct driving behavior when participants were confronted with a lane closure situation. Each set consisted of three ILCSs located over the right lane, center lane, and left lane. In the first set, the three ILCSs presented identical yellow speed reduction messages, indicating that the speed limit was 45 mph. In the second set, the three ILCSs presented identical yellow speed reduction messages, indicating that the speed limit was 35 mph. In the third set, the ILCSs over the right and left lanes were both blank, while the ILCS over the center lane presented a yellow lane closure warning, with an “X” on the first line and “1 mile” on the second line. In the fourth set, the ILCSs over the right and left lanes were also both blank, while the ILCS over the center lane presented one of three merge messages—(1) a diagonal arrow, (2) words, or (3) dynamic chevrons—to indicate that drivers should move from the center to the right or left lane. In the fifth set, the ILCSs over the right and left lanes presented downward green arrows, while the ILCS over the center lane presented a red “X” lane closure warning.

In the three trials driven by the participants in this experiment, they encountered each of the three types of merge sign (the diagonal arrow, words, or dynamic chevrons). The direction (to the left or to the right) in which the participants were asked to merge changed from trial 1 to trial 2, and trial 2 to trial 3. To control for possible effects of stimuli presentation order, twelve different

combinations of type of merge message and direction were assigned in a counterbalanced fashion to the 160 participants.

3. Results and Discussion

There were three experimental trials for each participant, with merge information conveyed by a different type of merge sign in each trial. We collected lane position data and driving speed data in each trial. We analyzed the lane position and driving speed data to determine how effectively the ILCSs conveyed the intended messages to the participants.

3.1 Lane Changing Behavior in Response to the Merge Signs

There were two sections of the highway in which many participants moved out of the center lane. On the approach to the third set of ILCSs, with the "X/1 mile" lane closure warning, participants moved from the center lane in 189 trials. Fewer participants from the younger and middle age groups changed lanes on encountering the "X/1 mile" lane closure warning than participants from the older and senior groups. Then on the approach the merge signs, participants moved from the center lane in 267 trials. In order to determine which of the three types of merge signs was most effective, we determined the distance from the merge signs at which participants changed lanes in these 267 trials. We found that participants responded to the diagonal arrow merge sign much earlier than they did to the other two types of merge sign. On average, they moved from the center lane 266 feet before reaching the diagonal arrow—in contrast, they moved from the center 123 feet before reaching the dynamic chevron merge sign, and 54 feet before reaching the merge sign using words.

In addition, we found that the age of the participants had an effect on the distance at which they changed lanes. On average participants in the middle age group moved from the center lane 312 feet before reaching the merge signs. The younger and senior groups also changed lanes before reaching the merge signs—at 162 feet and 147 feet, respectively; while participants in the older group changed lanes much later—25 feet after they had passed the merge signs.

3.2 Driving Speed Data

In each trial, the driving speed of the participants was recorded on the approach to each set of ILCSs. For analysis purposes, we divided the half-mile distance between the sets into three segments of 880 feet, and then determined average driving speed in the three segments before the location of the ILCSs and in the first segment after that location. Our analysis of driving speed data revealed several significant effects.

3.2.1 Driving speed on the approaches to the speed limit signs.

There were dramatic changes in driving speed on the approaches to the first two sets of ILCSs (with the 45-mph and 35-mph speed limits). At the beginning of the approach to the 45-mph speed limit, average driving speed was initially 63 mph; then, between the third and fourth segments, participants reduced speed by approximately 10 mph. On the approach to the 35-mph speed limit, participants reduced speed by a further 14 mph, so that in the fourth segment of that approach they were driving at 38.7 mph—3.7 mph above the 35-mph speed limit.

3.2.2 Age and gender of the participants.

Both the age and gender of the participants affected driving speed. With regards to age, on the approach to the first set of ILCS, in first segment (i.e., 2,640 feet to 1,760 feet before reaching the ILCSs, when it was not yet possible for the participants to decipher the 45-mph speed limit message) the average driving speed was 0.67 mph faster for the younger participants than for the middle age participants; 2.62 mph faster for the middle age participants than for the older participants; and 1.72 mph faster for the older participants than for the senior participants.

Also, there were differences in average driving speed between the age groups for the first three segments on the approach to the 45-mph speed limit. However in the fourth segment, after they had responded to the 45-mph speed limit sign, differences between age groups essentially disappeared.

With regards to gender, on the approaches to the 45-mph speed limit and the 35-mph limit there were relatively small, but statistically significant, gender differences in driving speed—male participants drove 1.4 mph faster than the female participants on both approaches.

3.3 Conclusion

In this study we were particularly interested in determining which of three types of merge sign was most effective in directing driver behavior and the extent to which participants reduced speed on encountering the speed limit signs. We found that participants responded to the diagonal arrow merge sign much earlier than they did to the merge signs using words or dynamic chevrons; they moved from the center lane 266 feet before reaching the diagonal arrow merge sign, 123 feet before reaching the dynamic arrow merge sign, and 54 feet before the merge sign with words. The merge signs with words and dynamic chevrons both had two lines—the first line presented the word “merge” on both signs, while the second line either gave a direction (“right” or “left”), or displayed the chevrons. In contrast, the diagonal arrow merge sign was simpler, and as a result likely required less time to process cognitively; the arrow itself was larger than the elements used on the other two merge signs, making it visible when the participants were further away.

Also, we found that the speed limit signs proved to be effective. Initially on the approach to the first speed limit sign participants drove at 63 mph. Then when the 45-mph speed limit was visible, they reduced speed by approximately 10 mph—to 53 mph. On the approach to the 35-mph speed limit, they reduced speed by a further 14 mph—so that on average, they were driving at 38.7 mph shortly after passing the 35-mph speed limit sign.

Chapter 1. Introduction

1.1 Objective

The objective of this driving simulation study was to test the effectiveness of Intelligent Lane Control Signal (ILCS) messages that are presented overhead in freeway lanes. The ILCS messages that were tested included merge signs, speed limit signs and lane closure warnings. We were particularly interested in determining which of three merge signs—(1) a diagonal arrow, (2) words, or (3) dynamic chevrons—was most effective in directing driver behavior and the extent to which participants reduced speed on encountering the speed limit signs. To achieve this objective, we used a fully interactive PC-based STISIM driving simulator to determine the responses of 160 participants to the ILCS messages. We recorded whether or not the participants changed lanes and determined the extent to which they modified their speed when they encountered the ILCSs. By analyzing the lane changing behavior and driving speed of the participants, we were able to determine how effectively the ILCSs conveyed the intended messages.

1.2 Introduction

This is the fourth in a series of studies we have conducted to explore the effectiveness of roadway signage. In the previous studies in the series, we investigated the effectiveness of static Changeable Message Signs (CMSs) that displayed traffic-related messages advising drivers to take a specific exit and static CMSs that displayed "Abducted Child" messages (Harder, Bloomfield, & Chihak, 2003; Harder & Bloomfield, 2008), and the effectiveness of static and dual-phase CMSs that provided airline information on the approach to an airport (Harder & Bloomfield, 2010).

The current study extends our previous work by investigating another type of changeable message sign: Intelligent Lane Control Signals (ILCSs). The particular situation that we investigated involved the use of ILCSs to direct driving behavior when drivers were confronted with a lane closure on a six-lane divided highway. We determined the effectiveness of a sequence of five sets of ILCSs that were employed at half-mile intervals on the highway. The sets of ILCSs included speed limit signs, lane closure warnings, and merge signs. This is one of the first studies in the US investigating the effectiveness of ILCSs in directing driver behavior.

1.2.1 Participants

In the first three studies in this series, we used 120 participants drawn from three age groups (younger, middle age, and older). In the current study we increased the number of participants to 160—adding a fourth age group (senior drivers). The specific ages of the groups were as follows:

- Younger age group: 18 - 24 years old.
- Middle age group: 32 - 47 years old.
- Older age group: 55 - 65 years old.
- Senior age group: 70 years old or more.

There were 40 participants in each age group, and within each age group there were 20 females and 20 males. All 160 participants were licensed drivers.

1.2.2 Driving Simulator

In this study, we used the same fully interactive PC-based STISIM driving simulator that was used in the three previous studies. Each participant sat in an automotive-style seat facing a bank of three 17" CRT displays and controlled the simulator with a steering wheel, an accelerator pedal, and a brake pedal. Three PCs generated the virtual environment presented on the CRT displays.

1.2.3 Driving Scenario

There were three experimental trials for each participant. In each trial the participant started driving in the center lane on a six-lane divided freeway; the posted speed limit was 65 mph. The participant was asked to drive "as you normally would drive in the center lane". After driving approximately five miles the participant encountered the following five sets of ILCSs that occurred at half-mile intervals.

- The messages on the first set of ILCSs—which were located over the right lane, center lane, and left lane—were identical yellow speed reduction messages, indicating that the speed limit was now 45 mph.
- The messages on the second set of ILCSs were identical yellow speed reduction messages, indicating that the speed limit was now 35 mph.
- The ILCSs over the right and left lanes for the third set were both blank; while the message on the ILCS over the center lane presented a yellow lane closure warning with an "X" on the sign's first line and "1 mile" on the sign's second line.
- The ILCS displays over the right and left lanes for the fourth set were left blank; and the ILCS over the center lane presented one of three types of merge message—(1) a diagonal arrow, (2) words, or (3) dynamic chevrons were used to indicate that the participant should move from the center lane to the right or left lane.
- The ILCSs over the right and left lanes for the fifth set displayed downward green arrows, and the ILCS over the center lane displayed a red "X" lane closure warning.

1.2.4 Simulator Data

In each of the three trials driven by the participants, the merge information was presented by means of a different type of merge sign—a diagonal arrow, words, or dynamic chevrons. We collected lane position data and driving speed data in each trial. We used the lane position data to determine (1) whether participants moved from the center lane to the right or left lane as they approached the ILCSs displaying the merge signs, and (2) the distance from the merge signs at which any such lane changes occurred. We used the driving speed data to determine whether the participants modified their speed on the approach to the merge signs, the lane closure warnings, and the speed limit signs. By examining the changes in lane position and driving speed made by the participants in response to the ILCSs, we were able to determine how effectively the ILCSs had conveyed the intended messages.

1.3 Organization of this Report

The remainder of this report describes the driving simulation experiment conducted in order to investigate the effectiveness of ILSCs in directing driving behavior when participants were confronted with a lane closure situation on a six-lane divided highway. The chapters are organized as follows:

- Chapter 2 describes the method used to conduct the simulation experiment
- Chapter 3 presents the results of the simulation experiment. It includes with an analysis of lane changing behavior and driving speed as the participants approached the speed limit signs, lane closure warnings, and merge signs.
- Chapter 4 summarizes the findings and conclusions.

Chapter 2. Method

2.1 .Participants

One hundred sixty licensed drivers participated in this study. The breakdown of these participants in terms of age and gender is shown in Table 2.1.

Table 2.1 Breakdown of participants by age and gender

Age	Male	Female	Total
Younger (18 to 24 year olds)	20	20	40
Middle (32 to 47 year olds)	20	20	40
Older (55 to 65 year olds)	20	20	40
Senior (70 year olds or more)	20	20	40
Total	**80**	**80**	**160**

As Table 2.1 shows, there were 40 participants in each of four age groups—younger (18 to 24 year olds), middle age (32 to 47 year olds), older (55 to 65 year olds), and seniors (70 years old or more). There were 20 males and 20 females within each age group. The participants were recruited from the Twin Cities metropolitan area, and each was paid $50 for his or her participation.

2.2 Driving Simulator

We used a fully interactive, PC-based, STISIM driving simulator, with an automotive-style seat that faced a bank of three 17” CRT displays. Three PCs generated the virtual environment presented on the CRT displays—which are shown below in Figure 2.1.

Figure 2.1 The STISIM simulator (shown from the left of the driver's seat)

2.2.1 Visuals

In this study, the virtual environment shown on the three CRT displays was a six-lane freeway. The center display showed the freeway ahead. A small section in the upper right corner of this display provided a rear view of the participant's route. Also, the lower part of the center display showed the front of the simulated vehicle. Two dials were also shown—one to the left showing driving speed, the other to the right showing the RPM rate. On the CRT displays to the left and right, two small sections simulated side-view mirrors that also provided rear views of the route.

2.2.2 Sound

Two small speakers located behind the three CRT displays generated the simulator's engine noise. The speakers were approximately at the shoulder height of the participants. A subwoofer positioned on the floor beneath the driver's seat provided low-frequency sound.

2.2.3 Controls

Each participant controlled the simulator with a steering wheel, an accelerator pedal, and a brake pedal. The simulator PCs registered inputs to these controls and adjusted speed and direction accordingly. The steering wheel was linked to a torque motor, which provided forced-feedback, in order to add realism to the "feel" of the steering.

2.2.4 Scenario Development

The driving scenario used in this study was developed using STISIM's Scenario Definition Language (SDL). Additional modifications were made to the experimental scenario so that the lettering on the ILCS displays could be seen when the participants were at a simulated distance of approximately 860 feet (262 meters) from them.

2.3 Experimental Design

2.3.1 ILCS Conditions

There were three experimental trials for each participant. In each trial the participant began driving in the center lane on a six-lane divided freeway on which the speed limit was 65 mph. The participant was asked to drive "as you normally would drive in the center lane". After driving approximately five miles the participant encountered five sets of ILCSs that occurred at half-mile intervals. A description of the five sets of ILCSs follows.

2.3.1.1 First set of ILCSs.

The messages on the first set of ILCSs— located over the right lane, center lane, and left lane— were identical yellow speed reduction messages, indicating that the speed limit was 45 mph. The first set of ILCSs is shown in Figure 2.2 on the next page of this report.

Figure 2.2 The first set of ILCSs displaying the 45-mph speed limit

Figure 2.3 The second set of ILCSs displaying the 35-mph speed limit

2.3.1.2 Second set of ILCSs.

The messages on the second set of ILCSs were also identical yellow speed reduction messages. They indicated that the speed limit was 35 mph. The second set of ILCSs is shown in Figure 2.3 on the previous page.

2.3.1.3 Third set of ILCSs.

The ILCSs over the right and left lanes for the third set of ILCSs were both left blank, while the message on the ILCS over the center lane presented a yellow lane closure warning with an “X” on the sign’s first line and “1 mile” on the sign’s second line. The third set of ILCSs is shown in Figure 2.4 on the following page.

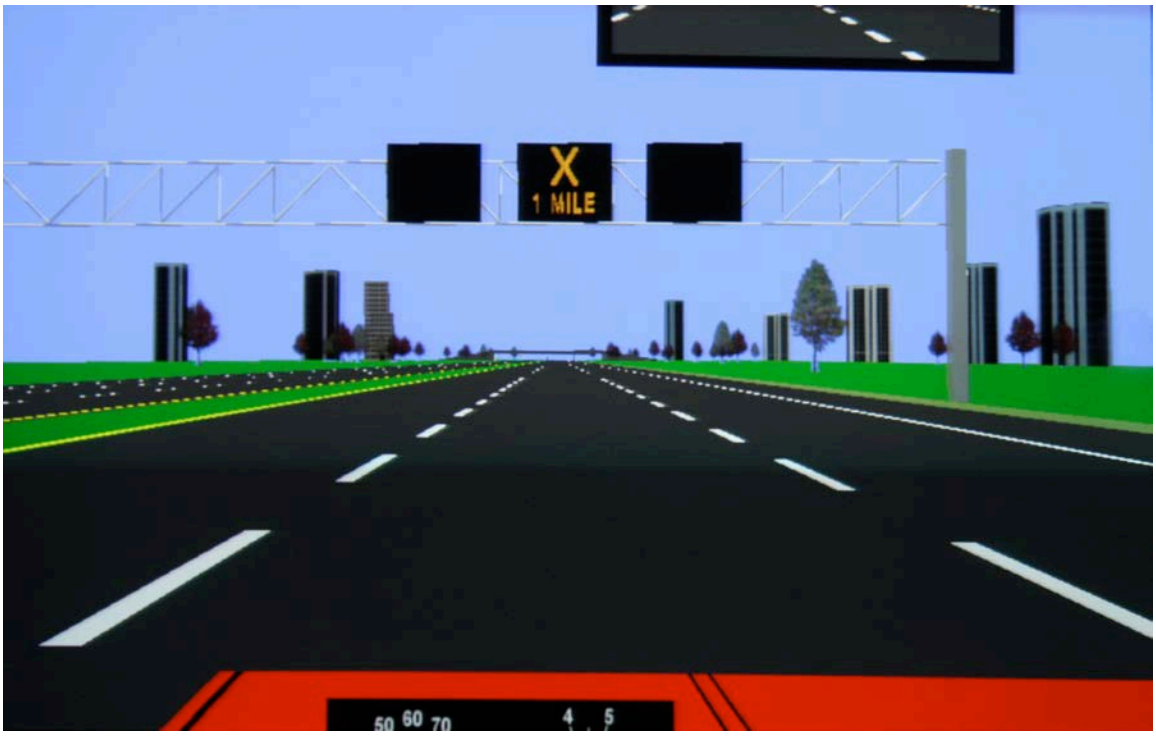

Figure 2.4 The third set of ILCSs with the "X/1 mile" lane closure warning on the center display

2.3.1.4 Fourth set of ILCSs.

The ILCS displays over the right and left lanes for the fourth set of ILCSs were also left blank. On the ILCS over the center lane one of three types of merge sign indicated whether the participant should move to the right or left lane. The following three different types of merge message were used—(1) a diagonal arrow, (2) words, or (c) dynamic chevrons, with one, then two, and then three chevrons shown one after another. Examples of these different merge messages are shown in the following series of Figures. Figure 2.5 has a diagonal arrow indicating participants should move to the right. Figure 2.6 has words indicating that they should merge left. And Figures 2.7, 2.8, and 2.9 show the three stages of the dynamic chevron merge sign—with one, then two, and then three chevrons, indicating they should move to the right lane.

Figure 2.5 The fourth set of ILCSs with a diagonal arrow indicating merge right

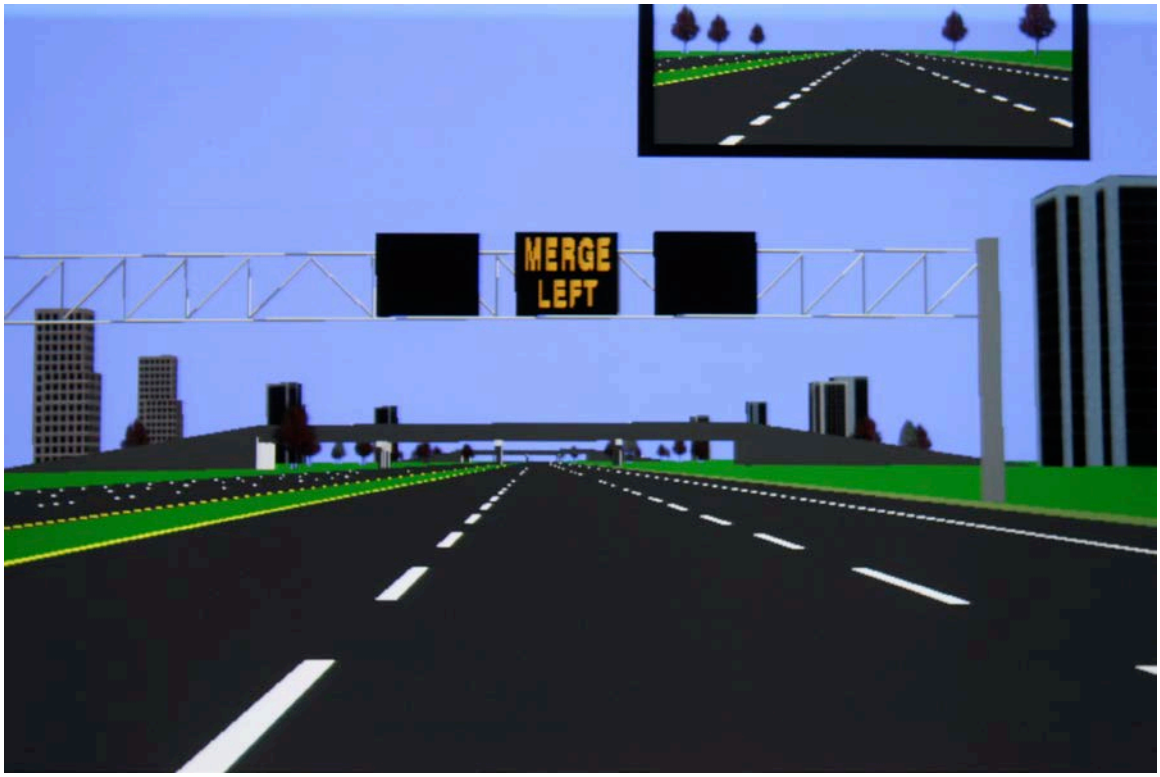

Figure 2.6 The fourth set of ILCSs with words indicating merge left

Figure 2.7 The fourth set of ILCSs with the first in the sequence of dynamic chevrons indicating merge right

Figure 2.8 The fourth set of ILCSs with the second in the sequence of dynamic chevrons indicating merge right

Figure 2.9 The fourth set of ILCSs with the third in the sequence of dynamic chevrons indicating merge right

Figure 2.10 The fifth set of ILCSs with the "X/1 mile" lane closure warning on the center display and green arrows on the left and right ILCSs

2.3.1.5 Fifth set of ILCSs.

With the fifth set of ILCSs, the ILCS over the center lane displayed a red lane "X" lane closure warning—while the ILCSs over both the right and left lanes presented downward green arrows. The fifth set of ILSCs is shown in Figure 5.10, which appears on the previous page of this report.

2.3.2 Order of Presentation of the Merge Signs

In the three trials driven by the participants in this experiment, they encountered each of the three types of merge sign (the diagonal arrow, words, or dynamic chevrons). The direction (to the left or to the right) in which the participants were asked to merge changed from trial 1 to trial 2, and trial 2 to trial 3. There are twelve different combinations of the three types of merge messages and two alternating directions; these twelve different combinations are shown in Table 2.2.

Table 2.2 The twelve different combinations of merge sign and direction

Trial One	Trial Two	Trial Three
Diagonal Arrow Left	Words Right	Dynamic Chevrons Left
Diagonal Arrow Left	Dynamic Chevrons Right	Words Left
Diagonal Arrow Right	Words Left	Dynamic Chevrons Right
Diagonal Arrow Right	Dynamic Chevrons Left	Words Right
Words Left	Diagonal Arrow Right	Dynamic Chevrons Left
Words Left	Dynamic Chevrons Right	Diagonal Arrow Left
Words Right	Diagonal Arrow Left	Dynamic Chevrons Right
Words Right	Dynamic Chevrons Left	Diagonal Arrow Right
Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
Dynamic Chevrons Left	Words Right	Diagonal Arrow Left
Dynamic Chevrons Right	Diagonal Arrow Left	Words Right
Dynamic Chevrons Right	Words Left	Diagonal Arrow Right

To control for possible effects of stimuli presentation order, twelve different combinations of type of merge message and direction were assigned in a counterbalanced fashion to the 160 participants. [Please note: The order in which the twelve different combinations were presented to the participants is shown in Appendix A.]

2.3.3 Simulator Data

We recorded the lane position and driving speed of the participants throughout each trial. To determine the effectiveness of the merge messages, for each trial we determined changes in lane position made by the participant as he or she approached the three different merge messages. In addition, we determined changes in driving speed that occurred as each participant approached the five sets of ILCSs—with (1) the 45-mph speed limit message, (2) the 35-mph speed limit message, (3) the "X/1-mile" lane closure warning, (4) the three different merge signs, and (5) the "X" lane closure warning.

2.3.4 Survey

After the participants finished driving three trials in the simulator, they were asked to complete a brief survey. This survey included questions regarding their attitude to various CMS messages they may have encountered on roadways in the Twin Cities. [Please note: The questions asked in this survey are presented in Appendix B and details of the analysis of the participant's responses to the survey questions are reported in Appendix C.]

2.4 Procedure

In this experiment, we tested the effectiveness of several ILCS messages displayed above freeway lanes. The tested ILCS messages included two speed limit signs, which instructed the participants to reduce their driving speed to 45 mph and then 35 mph, and three different signs conveying merge information using (1) a diagonal arrow, (2) words, or (3) dynamic chevrons.

We used a STISIM driving simulator to conduct the experiment. The experimental design called for 160 participants, from four age groups—a younger group, with participants who were18 to 24 years old; a middle age group 32 to 47 years old; an older group 55 to 65 years old; and a senior group 70 years old or more. A counterbalanced design was used to assign the twelve combinations of three types of merge message and two directions (left or right) in which the participants were asked to merge. The participants drove the simulated route three times—once with each of the three different merge signs.

Prior to the experiment, potential participants were contacted by phone. They were asked their age and whether or not they drove a car in and around the Twin Cities. They were recruited if they were in one of the four age groups, currently drove a vehicle, and (1) had not experienced motion sickness in automobiles or in airplanes, (2) had not been sick on any amusement park rides, (3) had not felt queasy at IMAX presentations, and (4) had not had migraines or severe tension headaches.

When each participant arrived at the lab housing the driving simulator, the experimenter examined his or her driver's license to ensure it was valid and to verify the participant's age. Then, the participant read and signed the consent form. The participant was told that he or she would drive in the simulator and then would be asked to complete a brief survey. They were told that the session would be approximately one hour long.

A brief training session followed. In the training session, the participant drove on a simulated six-lane divided highway for approximately six or seven minutes. During the session, which

began with the simulator vehicle in the center lane, the participant was asked to accelerate, to reduce speed, and to change lanes. The session continued until the participant felt comfortable driving the simulator vehicle. Then, the experimenter answered any questions that the participant had.

Before each experimental trial the participants were told that they would be driving on a six-lane divided highway, that the speed limit on this highway was 65 mph, and that at the beginning of the trial they would be in the center lane. They were asked to "Please drive as you normally would when you're in the center lane."

After driving in three trials, the participants left the simulator and moved to a table in the lab. There, they were asked to complete a brief survey. After completing the survey, the participant was debriefed. The debriefing was as follows:

> *"In this study, we're interested in driving behavior in various roadway environments. We'd like you to keep the information about this study confidential. Please do not discuss the study with anyone. We don't want anyone who might take part in the study to know anything about it beforehand."*

After the debriefing, the participant was paid. The experimental session lasted approximately one hour.

Chapter 3. Results and Discussion

3.1 Simulator Results

In this experiment, we tested the effectiveness of ILCS messages displayed overhead in freeway lanes. The ILCS messages in the three trials driven by each of the 160 participants were as follows.

- Three different lane merge signs—in which the merge information was conveyd by use of (1) a diagonal arrow, (2) words, or (3) dynamic chevrons.
- Two lane closure warnings, the first warned that the center lane was closed 1 mile ahead; the second that the center lane was closed directly ahead.
- Two speed limit signs, which instructed the participants to reduce their driving speed first to 45 mph, then to 35 mph.

We collected two types of simulator data throughout each trial—(1) lane position data, and (2) driving speed data. The lane position data allowed us to determine whether or not the participants changed lanes as they approached the ILCSs displaying the merge signs, and their distance from those ILCSs if they did. We used the driving speed data to determine whether the participants changed speed on the approach to the merge signs, the lane closure warnings and the speed limit signs. The lane position data are discussed in the following section of this chapter, Section 3.2; then the driving speed data are discussed in Section 3.3.

3.2 Lane Position Data

When we inspected the lane position data, we discovered that there were two sections of the route where many participants moved out of the center lane. The first of these was associated with the third set of ILCSs—where the "X/1 mile" lane closure warning was located. The second was associated with the fourth set of ILCSs—where the merge signs were displayed. This lane changing behavior is discussed below.

3.2.1 Lane Changing Behavior Related to "X/1 Mile" Lane Closure Warning

It was expected that some participants would move from the center lane when they encountered the "X/1 mile" lane closure warning. However, the number of trials in which this occurred was surprising—it occurred in 189 of the 480 trials. The number of trials in which participants moved to the right or left lane when they encountered the "X/1 mile" lane closure warning is shown in Table 3.1.

Table 3.1 Number of trials in which participants moved from the center lane on the approach to the "X/1 mile" lane closure warning

Direction of move	Number of trials (out of 480)
To right lane	160
To left lane	29
Total number of moves	**189**

3.2.1.1 Effect of age.

With regard to age, we found that fewer participants from the younger (18 to 24 year-old) and middle age (32 to 47 year-old) groups changed lanes on encountering the "X/1 mile" sign than participants from the older (55 to 65 year-old) and senior (70 years old or more) groups. Table 3.2 shows the number of trials in which participants moved from the center lane on encountering the "X/1 mile" lane closure warning as a function of age.

Table 3.2 Number of trials in which participants moved from the center lane on the approach to the "X/1 mile" lane closure warning as a function of age

Age group	Number of trials
Younger (18 to 24 year olds)	30
Middle Age (32 to 47 year olds)	36
Older (55 to 65 year olds)	69
Senior (70 years old or more)	54
Total	**189**

A chi-square test was performed on the data shown in Table 3.2. It revealed a statistically significant effect of age; we obtained a χ^2 value of 19.95—this exceeds 16.27, the critical value of χ^2 for 3 *df* and $\alpha = 0.001$. These data suggest that, on encountering the "X/1 mile" lane closure warning, older and senior drivers are more likely to anticipate that subsequently they will be advised to change lanes than drivers in the younger and middle age groups. And as a result, these older and senior drivers change lanes relatively early.

3.2.1.2 Effect of gender.

With regard to gender, there were 86 trials for males and 103 trials for females in which the participants moved from the center lane on encountering the "X/1 mile" closure warning. However, this difference was not statistically significant—when the Chi-Square Test was

conducted on these data, we obtained a χ^2 value of 1.529, which does not exceed 3.84, the critical value of χ^2 for 1 *df* and $\alpha = 0.05$.

3.2.2 Lane Changing Behavior Related to the Merge Messages

As mentioned above, in 189 trials the participants moved from the center lane on encountering the third set of ILCSs. Therefore, there were 291 trials in which participants were still in the center lane when they encountered the fourth set of ILCSs, where the merge signs were displayed. In 24 of these 291 trials, participants ignored the merge message and remained in the center lane—as a result, there were 267 trials in which the participants changed lanes in response to the merge signs.

For each of these 267 trials, we determined the point at which the lane change occurred and the distance between that point and the merge message. An Analysis of Variance (ANOVA) was conducted on the distance data from the 267 trials, in order to determine whether the distances were affected by:

- The type of merge sign with (1) the diagonal arrow, (2) words, or (3) dynamic chevrons.
- The direction indicated by the merge message—left or right.
- The age of the participants.
- The gender of the participants.
- Whether the trial was the first, second, or third driven by the participant.

A summary of this analysis is presented in Table 3.3 on the following page.

Table 3.3 Summary of the ANOVA conducted on average distance from the merge signs

Source of Variation	Degrees of Freedom	F-value	p-value
Age	3	5.08	0.0037
Gender	1	0.93	*ns*
Merge Sign	2	5.79	0.0042
Direction	1	0.05	*ns*
Trial	2	2.36	*ns*
Age x Gender	3	0.36	*ns*
Age x Merge Sign	6	1.54	*ns*
Age x Direction	3	0.17	*ns*
Age x Trial	6	0.46	*ns*
Gender x Merge Sign	2	0.14	*ns*
Gender x Direction	1	0.00	*ns*
Gender x Trial	2	2.46	*ns*
Merge Sign x Direction	2	1.78	*ns*
Merge Sign x Trial	4	0.13	*ns*
Direction x Trial	2	0.05	*ns*
Age x Gender x Merge Sign	6	0.88	*ns*
Age x Gender x Direction	3	0.94	*ns*
Age x Gender x Trial	6	0.67	*ns*
Age x Merge Sign x Direction	6	0.27	*ns*
Gender x Merge Sign x Direction	2	0.02	*ns*
Merge Sign x Direction x Trial	4	0.95	*ns*
Age x Gender x Merge Sign x Direction	6	1.15	*ns*

Table 3.3 indicates that there were two statistically significant main effects—the age of the participants and the type of merge sign—and no significant interactions. The effects of age and type of merge sign are explored in the following subsections.

3.2.2.1 Effect of age.

The main effect of the age of the participants on the average distance from the merge signs at which they changed lanes is shown in Table 3.4.

Table 3.4 Average distance at which lane change occurred on the approach to the merge signs as a function of the age of the participants

Age group	Distance
Younger (18 to 24 year olds)	162 feet before sign
Middle Age (32 to 47 year olds)	312 feet before sign
Older (55 to 65 year olds)	25 feet after sign
Senior (70 years old or more)	147 feet before sign

As Table 3.4 shows, the average distance at which the participants changed lanes was greatest for the middle age group—on average they moved from the center lane 312 feet before they reached the merge signs. The younger and senior groups also changed lanes before they reached the merge signs—at 162 feet and 147 feet, respectively. However, on average the participants in the older group changed lanes 25 feet after they reached the merge signs. A pairwise comparison of the distances shown in Table 3.4 was conducted using the Tukey HSD correction for multiple comparisons. This procedure showed that the difference between the average distance for the participants in the middle age group and those in the senior group was statistically significant ($p = 0.002$), while there were no other significant pairwise comparisons. The distance data presented in Table 3.4 are illustrated in Figure 3.1.

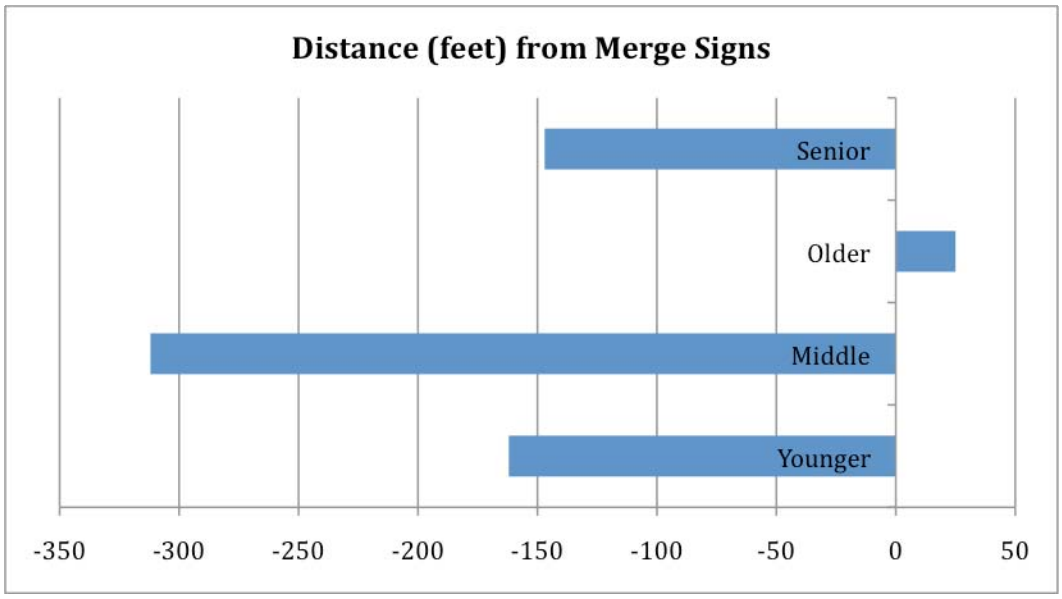

Figure 3.1 Average distance (in feet) from the merge signs at which lane changes occurred as a function of age

3.2.2.2 Effect of type of merge sign.

The main effect of the type of merge sign on the average distance from the merge signs at which participants changed lanes is shown in Table 3.5.

Table 3.5 Average distance at which lane change occurred on the approach to the merge signs as a function of the type of merge sign

Type of merge sign	Distance
Diagonal arrow	266 feet before sign
Words	54 feet before sign
Dynamic chevrons	123 feet before sign

Table 3.5 indicates that the average distance at which participants changed lanes on the approach to the merge signs was greatest for the diagonal arrow merge sign—on average the participants moved from the center lane 266 feet before they reached the diagonal arrow merge sign. For the merge sign using dynamic chevrons, the participants changed lanes 123 feet before they reached the sign; while for the merge sign using words they moved from the center lane when they were 54 feet away from the merge sign. A pairwise comparison of the distances shown in Table 3.5 was conducted using the Tukey HSD correction for multiple comparisons; this procedure indicated that the difference between the merge sign using the diagonal arrow and the merge sign using words was statistically significant ($p = 0.0037$), and that the difference between the merge sign with the diagonal arrow and the merge sign using dynamic chevrons almost achieved significance ($p = 0.0554$). The distance data from Table 3.5 are illustrated in Figure 3.2.

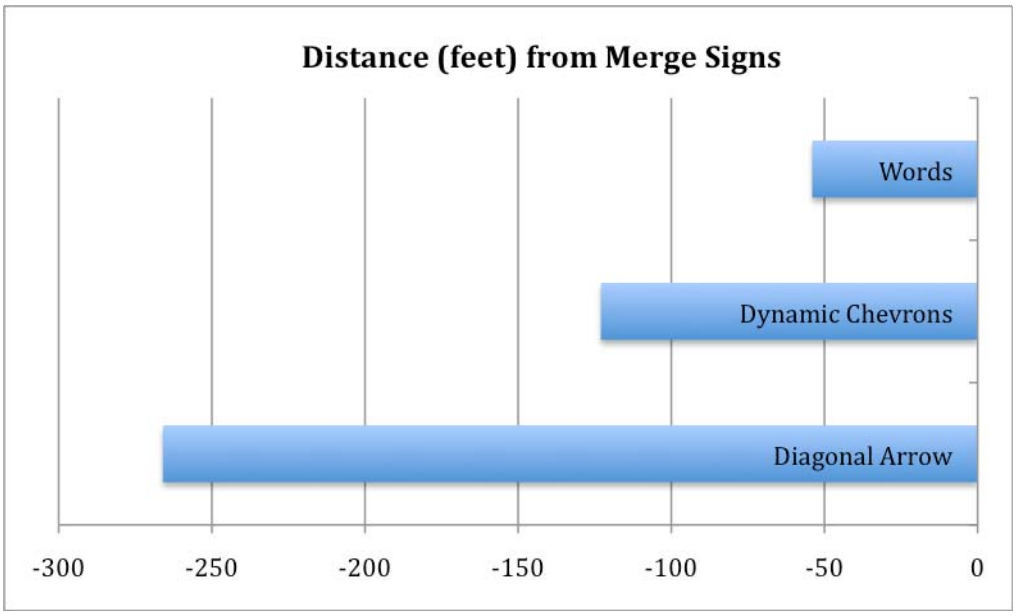

Figure 3.2 Average distance (in feet) at which lane changes occurred as a function of the type of merge sign

The distance data shown in Table 3.5 and illustrated in Figure 3.2 indicate that participants responded to the diagonal arrow much sooner than they did to the other two merge signs. The merge signs using words and dynamic chevrons both used two lines—the first of which used the word "merge". In contrast, the diagonal arrow merge sign was simpler, and as a result likely took less time to process; the arrow itself was larger than the elements used for the other two merge signs making it visible when the participants were further away.

3.3 Driving Speed Data

3.3.1 Analysis of Speed Data

The driving speed of each participant was recorded throughout all three experimental trials. In each trial, the participant encountered five sets of ILCSs, with the (1) 45-mph speed limit, (2) 35-mph speed limit, (3) "X/1 mile" lane closure warning, (4) merge sign, and (5) "X" lane closure warning. We wanted to determine how the participants reacted to the 45-mph and 35-mph speed limits and, in addition, we wanted to discover whether there were any variations in driving speed associated with the two lane closure warnings (i.e., the "X/1 mile" and "X" lane closure warnings) and the three different types of merge sign. The five sets of ILCSs occurred at half-mile intervals. For analysis purposes we divided the distance between the sets into three segments of 880 feet. Then for each set of ILCSs, we determined average driving speed in the three segments before the set and in the first segment after the set. Table 3.6 shows the segments over which driving speed was averaged for each set of ILCSs.

Table 3.6 Segments over which driving speed was averaged for each set of ILCSs

Segment	Distance from ILCS
Segment #1	2,640 feet to 1,760 feet
Segment #2	1,760 feet to 880 feet
Segment #3	880 feet to 0 feet
Location of ILCS	0 feet
Segment #4	0 feet to minus 880 feet

Five ANOVAs were conducted in order to analyze the average speed of the participants in four segments for each set of ILCSs. The ANOVAs were used to determine whether average driving speed was affected by:

- Type of merge sign.
- Direction indicated by the merge sign.
- Age of the participants.
- Gender of the participants.
- Whether the trial was the first, second or third driven by the participants.

A summary of all five ANOVAs is presented in Table 3.7.

Table 3.7 P-values obtained in the five ANOVAs performed on average driving speed on the approaches to the five sets of ILCSs

Source of Variance	45 mph limit	35 mph limit	"X/1-mile" closure	Merge sign	"X" closure
Age	<0.0001	*ns*	*ns*	*ns*	*ns*
Gender	0.0154	0.0355	*ns*	*ns*	*ns*
Trial	0.0101	<0.0001	0.0008	*ns*	0.0426
Segment	<0.0001	<0.0001	<0.0001	<0.0001	*ns*
Merge Sign	*ns*	*ns*	*ns*	*ns*	*ns*
Direction	*ns*	*ns*	*ns*	*ns*	*ns*
Age x Gender	*ns*	*ns*	*ns*	*ns*	*ns*
Age x Trial	*ns*	*ns*	*ns*	*ns*	*ns*
Age x Segment	<0.0001	<0.0001	0.0009	0.0392	*ns*
Age x Merge Sign	*ns*	*ns*	*ns*	*ns*	*ns*
Age x Direction	*ns*	*ns*	*ns*	*ns*	*ns*
Gender x Trial	*ns*	*ns*	*ns*	*ns*	*ns*
Gender x Segment	*ns*	*ns*	*ns*	*ns*	*ns*
Gender x Merge Sign	*ns*	*ns*	*ns*	*ns*	*ns*
Gender x Direction	*ns*	*ns*	*ns*	*ns*	*ns*
Trial x Segment	<0.0001	0.0385	<0.0001	*ns*	*ns*
Trial x Merge Sign	*ns*	*ns*	0.0496	*ns*	*ns*
Trial x Direction	*ns*	*ns*	*ns*	*ns*	*ns*
Segment x Merge Sign	*ns*	*ns*	*ns*	*ns*	*ns*
Segment x Direction	*ns*	*ns*	*ns*	*ns*	*ns*
Merge Sign x Direction	*ns*	*ns*	*ns*	*ns*	*ns*

Age x Gender x Trial	*ns*	*ns*	*ns*	*ns*	*ns*
Age x Gender x Segment	*ns*	*ns*	*ns*	*ns*	*ns*
Age x Gender x Merge Sign	*ns*	*ns*	*ns*	*ns*	*ns*
Age x Gender x Direction	*ns*	*ns*	*ns*	*ns*	*ns*
Age x Merge Sign x Direction	*ns*	*ns*	*ns*	*ns*	*ns*
Gender x Merge Sign x Direction	*ns*	*ns*	*ns*	*ns*	*ns*
Segment x Merge Sign x Direction	0.0027	*ns*	*ns*	*ns*	*ns*
Trial x Merge Sign x Direction	*ns*	*ns*	*ns*	*ns*	*ns*
Age x Gender x Merge Sign x Direction	*ns*	0.0326	*ns*	*ns*	*ns*

Table 3.7 indicates that four of the main variables (Segment, Age, Gender, and Trials) affected driving speed on the approach to at least one set of ILCSs. However, it should be noted that neither the type of Merge Sign, nor Direction had a statistically significant effect on driving speed. The significant main effects were as follows—

- *Segment*: Driving speed differed significantly in the highway segments on the approach to the first four sets of ILCSs—with the 45-mph speed limit, 35-mph speed limit, "X/1 mile" closure warning, and merge signs.
- *Age:* The age of the participants affected driving speed on the approach to the first set of ILCSs, with the 45-mph speed limit.
- *Gender:* The gender of the participants affected driving speed on the approach to the first two sets of ILCSs—with the 45-mph and 35-mph speed limits.
- *Trials:* There was an effect of trials on the approach to the first three sets of ILCSs—with the 45-mph speed limit, 35-mph speed limit, and "X/1 mile" closure warning—as well as the fifth set of ILCSs, with the "X" lane closure warning.

Table 3.7 also shows that two two-way interactions involving segments affected average driving speed on several approaches—specifically:

- *Age x Segment:* There was an effect of the interaction between Age and Segment on the approach to the first four sets of ILCSs, with the 45-mph speed limit, 35-mph speed limit, "X/1 mile" closure warning, and merge sign.

- *Trial x Segment:* There was an effect of the interaction between Trial and Segment on the approach to the first three sets of ILCSs—with the 45-mph speed limit, 35-mph speed limit, and "X/1 mile" closure warning—and the fifth set of ILCSs, with the "X" closure warning.

The four main effects and two interactions listed above are discussed in detail in the following subsections of this report.

[It should be noted that Table 3.7 also shows three other significant interactions. On the approach to: (1) the first set of ILCSs (with the 45-mph speed limit), there was a significant three-way interaction (Segment x Merge Sign x Direction); (2) the second set of ILCSs (with the 35-mph speed limit), there was a significant four-way interaction (Age x Gender x Merge Sign x Direction); and (3) the third set of ILCSs (with the "X/1 mile" lane closure warning), there was a significant two-way interaction (Trial x Merge Sign). All three of these interactions involved Merge Sign and two involved Direction. However, the participants did not experience either of these two variables in the first, second, or third set of ILCSs where these interactions were found—therefore, neither variable could actually have affected driving speed. Further, on the approach to the fourth set of ILCSs (at which the merge signs did indicate direction), neither variable had an effect on driving speed. In addition, these interactions involve average speed differences of relatively small magnitude that do not impinge on the main effects—as a result they are not discussed further in this report.]

3.3.2 Effect of Highway Segment

The ANOVA summary presented in Table 3.6 indicates there were significant differences in average speed between the segments on the approach to the first four sets of ILCSs—i.e., the ILCSs with the 45-mph speed limit, 35-mph speed limit, "X/1 mile" closure warning, and merge sign. However, there were no differences in speed on the approach to the fifth set, with the "X" closure warning. Table 3.8 shows the average speed on the approach to the first four sets of ILCSs.

Table 3.8 Average speed (mph) in each of the four segments on the approaches to the 45-mph and 35-mile speed limits, the "X/1mile" closure warning, and the merge signs

Segment	45-mph limit	35-mph limit	"X/1 mile" warning	Merge signs
Segment #1	63.11	52.88	38.75	38.41
Segment #2	63.77	47.57	37.53	39.02
Segment #3	62.97	45.62	37.70	39.18
Segment #4	52.86	38.71	38.43	39.38

Table 3.8 shows the changes in average speed that occurred on the approach to the first four sets of ILCSs. As might be expected, there were dramatic changes in speed for the first two sets of ILCSs—which included the 45-mph speed limit and the 35-mph speed limit. The changes in average speed that occurred with the first two sets of ILCSs are illustrated in Figures 3.3 and 3.4.

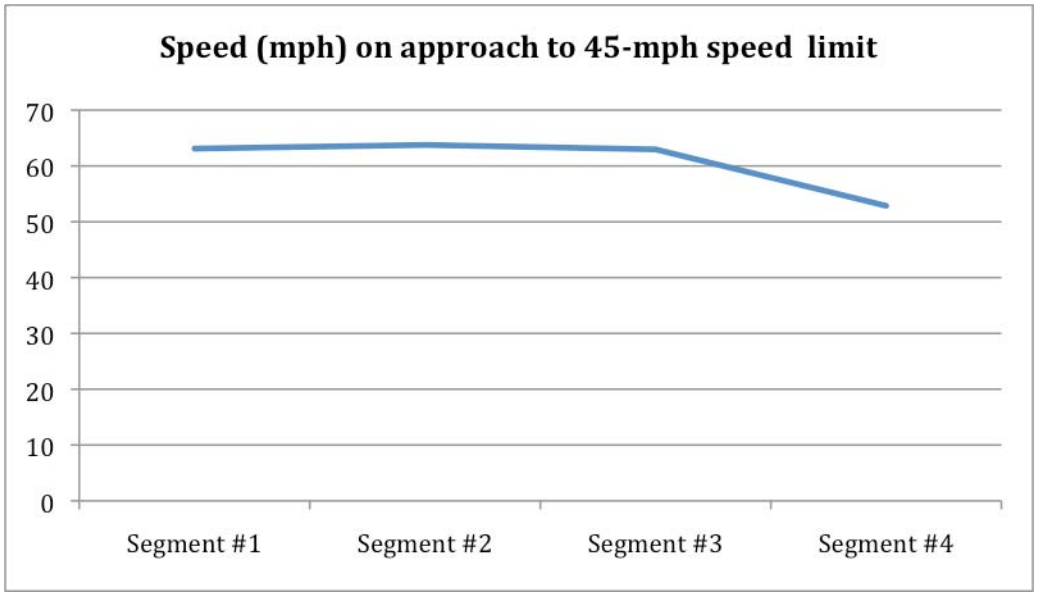

Figure 3.3 Average speed on the approach to the 45-mph speed limit

Figure 3.3 shows that there were no changes in average driving speed in the first three segments of the approach to the 45-mph speed limit. Then, between segment #3 and segment #4, the participants reduced speed by approximately 10 mph—although they were still traveling at approximately 8 mph above the 45-mph limit in segment #4.

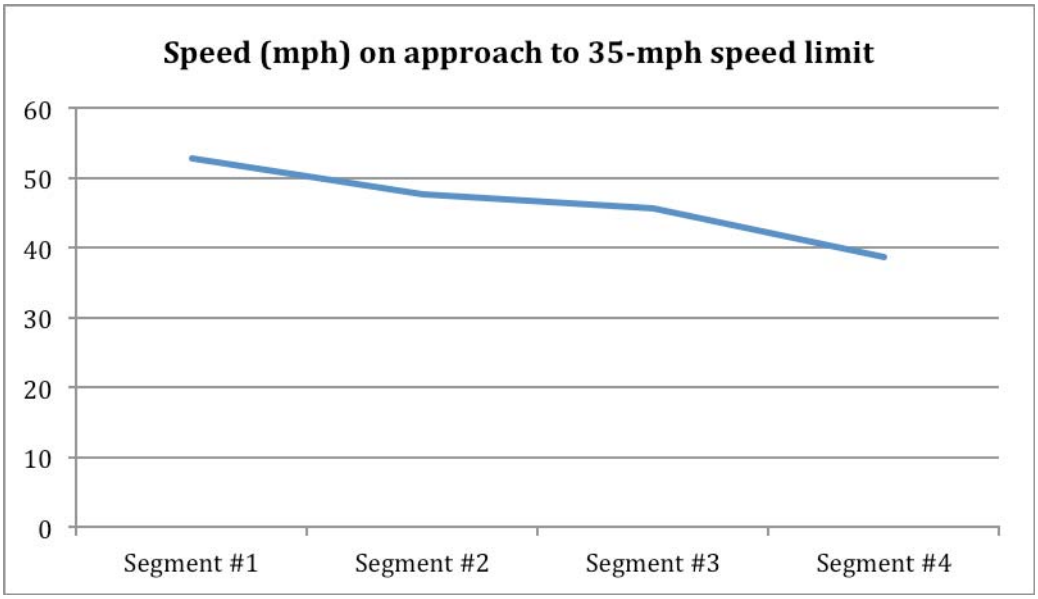

Figure 3.4 Average speed on the approach to the 35-mph speed limit

Figure 3.4 shows that after they passed the 45 mph speed limit, the participants continued to reduce speed. Between segment #1 and segment #4 on the approach to the 35-mph speed limit, they reduced speed by approximately 14 mph. On average, they were driving at 38.7 mph—3.7 mph above the 35-mph speed limit—in segment #4.

In comparison, to the substantial reductions in average driving speed on the approaches to the 45-mph and 35-mph speed limits, Table 3.8 shows that the differences in average speed on the approaches to the next two sets of ILCSs (with the "X/1 mile" warning and the merge sign), while statistically significant, were relatively small. For the "X/1 mile" warning, the speeds ranged between 38.75 mph (segment #1) and 37.53 mph (segment #2). And on the approach to the merge sign, the average speeds increased by approximately 1.00 mph, from 38.41 in segment #1 to 39.38 mph in segment #4. [It should be noted that on the approach to the fifth set of ILCSs, where differences in average speed in the segments were not significant, the participants drove at approximately 39.4 mph.]

3.3.3 Effect of Age

The ANOVA summary presented in Table 3.7 indicates that the age of the participants affected the average driving speed on the approach to the first set of ILCSs, with the 45-mph speed limit—as Table 3.9 shows.

Table 3.9 Average speed on the approach to the 45-mph speed limit as a function of the age of the participants

Age group	Average speed (mph)
Younger (18 to 24 year olds)	62.02
Middle Age (32 to 47 year olds)	62.08
Older (55 to 65 year olds)	59.96
Senior (70 years old or more)	58.64

Table 3.9 shows that overall, on the approach to the 45-mph speed limit, the average speed was fastest for the younger and middle age groups, was approximately 2 mph slower for the older group of participants, and a further 1.3 mph slower for those in the senior group. As there were interactions between age and segments on the approach to the 45-mph speed limit, as well as on three other approaches, further discussion of the effect of the age of the participants on average speed is presented in the following sub-section.

3.3.4 Interaction between Age and Highway Segment

The ANOVA summary presented in Table 3.7 indicates that there were significant interactions between the age of the participants and highway segments on the approaches to the first four sets of ILCSs—with the 45-mph speed limit, 35-mph speed limit, "X/1 mile" closure warning, and merge sign. The driving speed data associated with these interactions are shown in Tables 3.10, 3.11, 3.12, and 3.13.

Table 3.10 Effect of the interaction between the age of the participants and highway segments on average speed (mph) on the approach to the 45-mph speed limit

Age group	Segment #1	Segment #2	Segment #3	Segment #4
Younger (18 to 24 year olds)	65.35	65.82	64.14	52.78
Middle Age (32 to 47 year olds)	64.68	65.39	64.79	53.44
Older (55 to 65 year olds)	62.06	62.62	62.28	52.68
Senior (70 years old or more)	60.34	61.22	60.65	52.34

Inspection of Table 3.1 allows us to compare average speeds in segment #1 for the four age groups: The speed was 0.67 mph faster for the younger participants than for the middle age participants; 2.62 mph faster for the middle age participants than for the older participants, and in turn 1.72 mph faster for the older participants than for the senior participants. While the participants were driving in segment #1, which covers the distance from 2,640 feet to 1,760 feet before the first set of ILCSs, it was not possible to decipher the 45-mph speed limit; in fact Table 3.10 shows, the participants in all four age groups did not respond to the 45-mph speed limit until segment #4.

In three previous studies in this series (Harder, Bloomfield, and Chihak, 2003; Harder and Bloomfield, 2008; Harder and Bloomfield, 2010), we determined driving speeds for three age groups (younger, middle age, and older) and found similar differences in average driving speed for freeway driving to those for segment #1 shown in Table 3.10.

Continued inspection of Table 3.10 indicates that the differences in average driving speed between the four age groups occurred in segment #1, segment #2, and segment #3. However in segment #4, after the participants responded to the 45-mph speed limit sign, the differences between the age groups essentially disappeared.

The differences between driving speeds for the four age groups in the four segments on the approach to the 45-mph speed limit are illustrated in Figure 3.5.

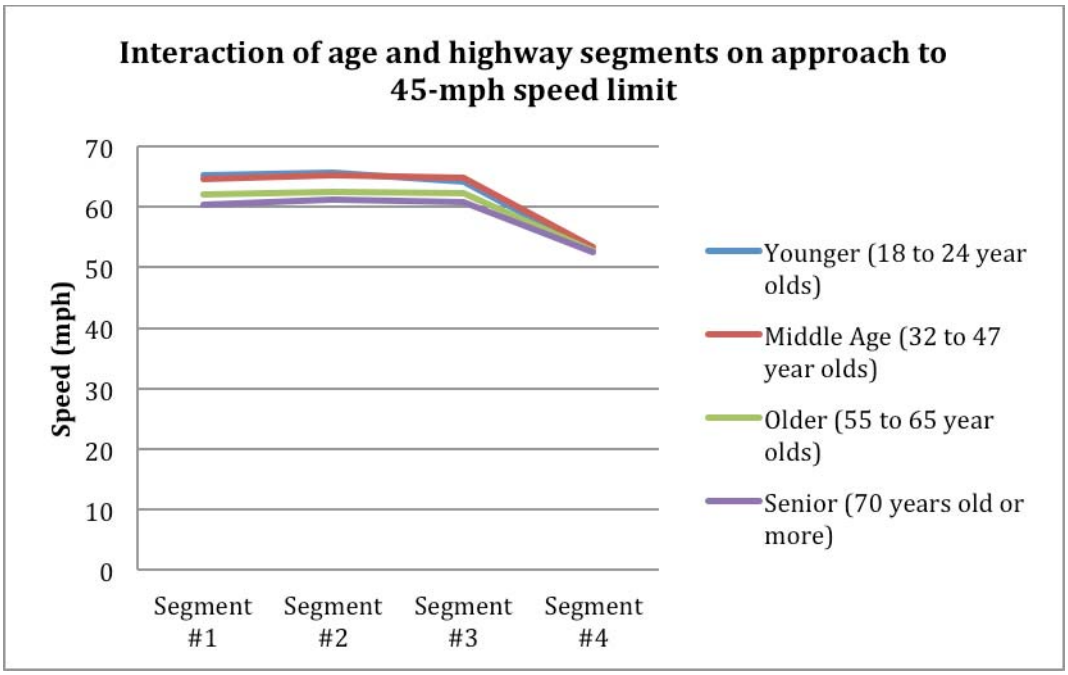

Figure 3.5 Average speed for four age groups on the approach to the 45-mph speed limit

Table 3.11 shows the interaction between the age of the participants and the highway segments on the approach to the second set of ILCSs with the 35-mph speed limit.

Table 3.11 Interaction between average speed and age of the participants on the approach to the 35-mile speed limit

Age group	Segment #1	Segment #2	Segment #3	Segment #4
Younger (18 to 24 year olds)	52.78	48.25	46.58	39.75
Middle Age (32 to 47 year olds)	53.44	47.62	45.07	37.90
Older (55 to 65 year olds)	52.88	46.84	44.91	38.08
Senior (70 years old or more)	52.42	47.59	45.91	39.10

Table 3.11 shows that, even though the changes in average driving speed between the four segments were substantial, the differences between the four age groups were relatively small; this is illustrated in Figure 3.6.

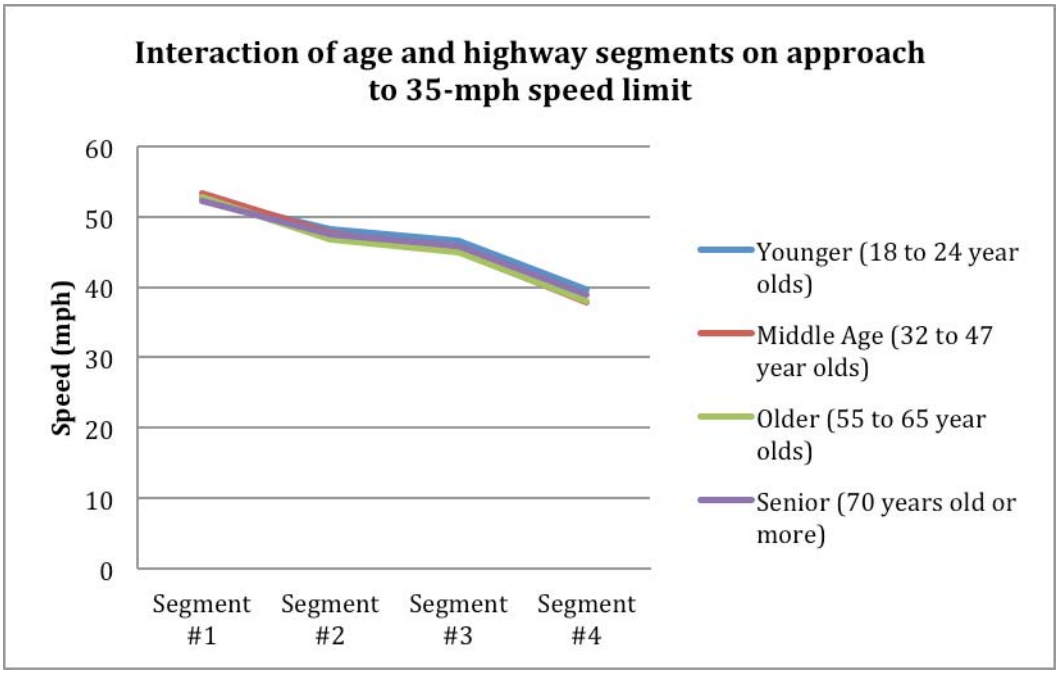

Figure 3.6 Average speed for four age groups on the approach to the 35-mph speed limit

Table 3.12 and Table 3.13 below show the interaction between the age of the participants and the highway segments on the approach to the third set of ILCSs (with the "X/1 mile" closure warning) and the fourth set (with the merge signs).

Table 3.12 Interaction between average speed and age of the participants on the approach to the "X/1 mile" closure warning

Age group	Segment #1	Segment #2	Segment #3	Segment #4
Younger (18 to 24 year olds)	39.76	38.44	38.66	39.92
Middle Age (32 to 47 year olds)	38.02	36.86	37.45	38.35
Older (55 to 65 year olds)	38.09	37.22	37.35	38.02
Senior (70 years old or more)	39.13	37.59	37.34	37.42

Table 3.13 Interaction between average speed and age of the participants on the approach to the merge signs

Age group	Segment #1	Segment #2	Segment #3	Segment #4
Younger (18 to 24 year olds)	39.89	40.81	41.45	41.67
Middle Age (32 to 47 year olds)	38.31	38.77	38.98	39.25
Older (55 to 65 year olds)	38.04	38.39	38.24	38.53
Senior (70 years old or more)	37.40	38.08	38.07	38.07

Although there were statistically significant differences in driving speed for the four age groups in the various highway segments on the approaches to the third and fourth sets of ILCSs with the "X/1 mile" closure warning and the merge signs, both tables show that these differences were of relatively small magnitude.

3.2.5 Effect of Gender

The ANOVA summary presented in Table 3.7 indicates that the gender of the participants influenced average driving speed on the approach to the first set of ILCSs and the second sets of ILCSs, with the 45-mph speed limit and 35-mph speed limit, respectively. The overall average speeds for female and male participants on the two approaches are presented in Table 3.14 and illustrated in Figure 3.14.

Table 3.14 Average speed on the approaches to the 45-mph and 35-mph speed limits as a function of the gender of the participants

Gender	45-mph limit	35-mphzaq limit
Female	59.98	45.46
Male	61.37	46.93

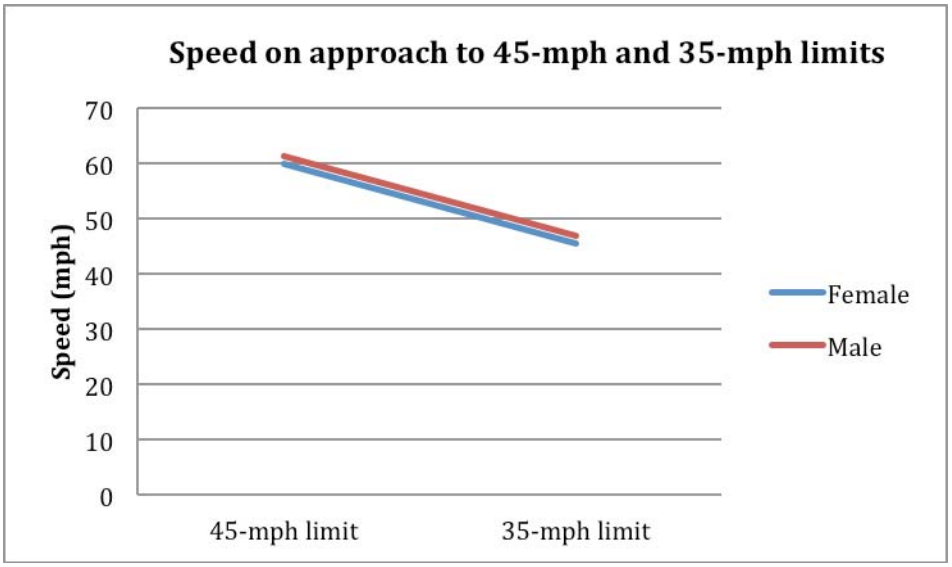

Figure 3.7 Average speed on the approaches to the 45-mph and 35-mph speed limits as a function of the gender of the participants

Both Table 3.14 and Figure 3.7 show that, while average speeds were considerably faster (by approximately 14 mph) on the approach to the 45-mph limit than they were on the approach to the 35-mph limit, the gender differences were similar on both approaches, and relatively small (the male participants drove 1.4 mph faster than the female participants in both cases).

3.2.6 Effect of Trials

The summary of ANOVAs presented in Table 3.7 indicates differences in the average speeds obtained for the first, second, and third trials driven by each participant on the approaches to the first, second, third, and fifth sets of ILCSs. The average speeds for the three drives on these four approaches are shown in Table 3.15.

Table 3.15 Average speed (mph) on the approaches to the 45-mph and 35-mph speed limits and the "X/1 mile" and "X" lane closure warnings as a function of trials

Trial	45-mph limit	35-mph limit	"X/1 mile" lane closure warning	"X" lane closure warning
Trial 1	61.30	48.45	39.48	40.41
Trial 2	60.31	45.30	37.32	39.07
Trial 3	60.41	44.83	37.51	38.82

Table 3.15 shows that, on all four approaches, average speed was faster for the first trial than it was for the second and third trials. As there were interactions between trials and segments on the approach to the first three segments, further discussion of the effect of trials is presented in the following sub-section.

3.2.7 Interaction between Trials and Highway Segments

The ANOVA summary presented in Table 3.7 indicates there were significant interactions between trials and the highway segments on the approaches to the first three sets of ILCSs—with the 45-mph speed limit, 35-mph speed limit, and the "X/1 mile" closure warning. The average speeds associated with these interactions on the approaches to the first set of ILCSs, with the 45-mph speed limit, are shown in Table 3.16 and illustrated in Figure 3.8.

Table 3.16 Interaction between trials and highway segments for average speed (mph) on the approach to the 45-mph speed limit

Trial	Segment #1	Segment #2	Segment #3	Segment #4
Trial 1	62.73	63.37	63.52	55.58
Trial 2	62.98	63.56	62.73	51.99
Trial 3	63.61	64.37	62.65	51.00

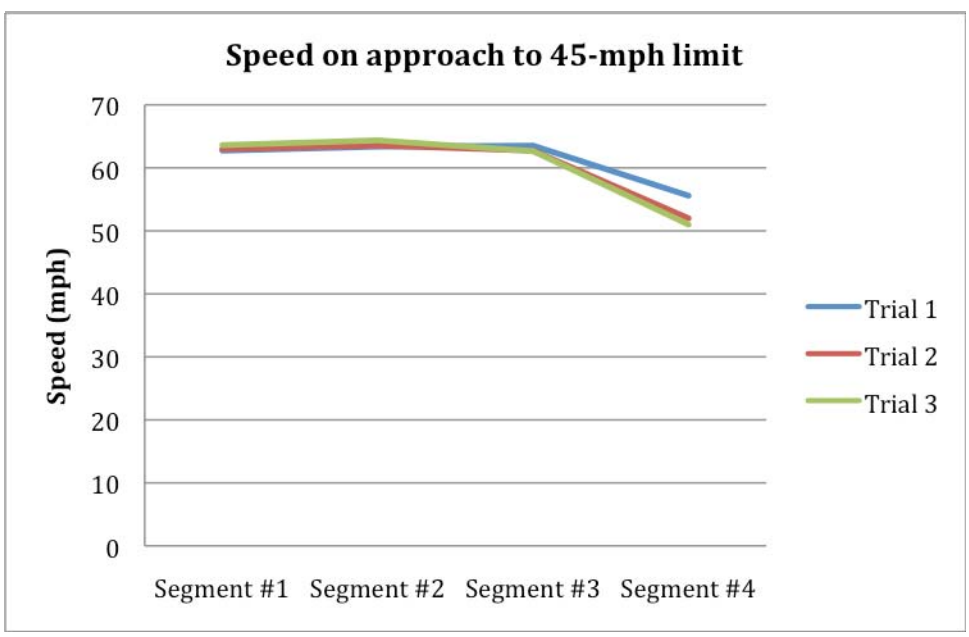

Figure 3.8 Interaction between trials and highway segments for average speed on the approach to the 45-mph speed limit

Table 3.16 and Figure 3.8 show that there was no difference in average speed for the first three segments on the approach to the 45-mph speed limit. However, in segment #4 the participants drove slower in the second and third trials, by 3.59 mph and 4.58 mph, respectively.

The average speeds associated with the interaction between trials and segments on the approach to the second set of ILCSs, with the 35-mph speed limit, are shown in Table 3.17 and illustrated in Figure 3.9.

Table 3.17 Interaction between trials and highway segments for average speed (mph) on the approach to the 35-mph speed limit

Trial	Segment #1	Segment #2	Segment #3	Segment #4
Trial 1	55.62	49.78	47.71	40.72
Trial 2	52.03	46.64	44.91	37.60
Trial 3	50.99	46.29	44.23	37.81

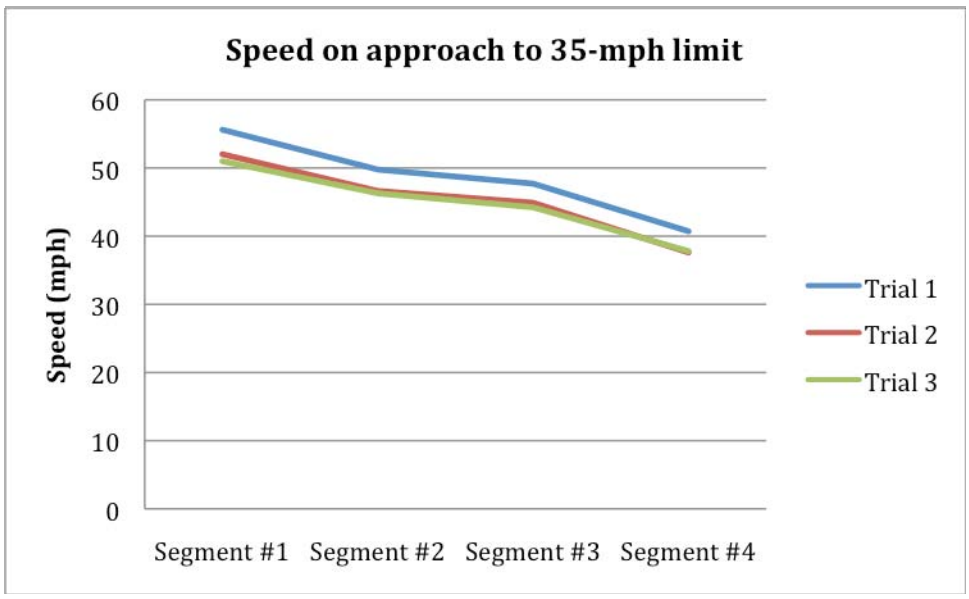

Figure 3.9 Interaction between trials and highway segments for average speed on the approach to the 35-mph speed limit

The differences between the driving speed on the first trial and on the second and third trials that emerged for segment #4 on the approach to the 45-mph limit, continued—as Table 3.17 and Figure 3.9 show—throughout the approach to the 35-mph limit.

The average speeds associated with the interaction between trials and segments on the approach to the third set of ILCSs, with the “X/1 mile” lane closure warning, are shown in Table 3.18.

Table 3.18 Interaction between trials and highway segments for average speed (mph) on the approach to the "X/1 mile" lane closure warning

Trial	Segment #1	Segment #2	Segment #3	Segment #4
Trial 1	40.77	39.15	38.87	39.14
Trial 2	37.65	36.70	36.89	38.03
Trial 3	37.83	36.74	37.35	38.11

The differences between the driving speed on the first trial and the speed on the second and third trials found in segment #4 on the approach to the 45-mph speed limit, and found throughout the approach to the 35-mph speed limit, continued—as Table 3.18 shows—throughout the approach to the "X/1 mile" lane closure warning.

3.4 Survey Data

After they finished driving in three simulator trials, the 160 participants were asked to complete a survey that consisted of ten questions. They were asked questions about the use of CMSs to display: (1) travel time information, (2) information about traffic problems, (3) safety messages, and (4) information about scheduled roadway maintenance. (Responses to these questions are reported in detail Appendix C.)

Chapter 4. Summary and Conclusion

4.1 Objective

The objective of this driving simulation study was to test the effectiveness of ILCS messages presented overhead in freeway lanes. The ILCS messages tested included merge signs, speed limit signs, and lane closure warnings. The particular situation investigated involved the use of ILCSs to direct driving behavior when drivers were confronted with a lane closure on a six-lane divided highway. We were particularly interested in determining which of three merge signs—(1) a diagonal arrow, (2) words, or (3) dynamic chevrons—was most effective, and the extent to which participants reduced speed on encountering the speed limit signs.

4.2 The Experiment

We used a fully interactive PC-based STISIM driving simulator to present a driving scenario in which participants drove on a six-lane divided highway. After driving in the center lane for approximately five miles, participants encountered five sets of ILCSs that occurred at half-mile intervals. Each set consisted of three ILSCs located over the right lane, center lane, and left lane.

- For the first set of ILCSs, the messages were identical yellow speed reduction messages, indicating that the speed limit was 45 mph.
- For the second set of ILCSs, the messages were identical yellow speed reduction messages, indicating that the speed limit was 35 mph.
- For the third set, the ILCSs over the right and left lanes were both blank, while the ILCS over the center lane presented a yellow lane closure warning, with an “X” on the sign’s first line and “1 mile” on the sign’s second line.
- For the fourth set, the ILCSs over the right and left lanes were also both blank, while the ILCS over the center lane presented one of three merge messages—(1) a diagonal arrow, (2) words, or (3) dynamic chevrons—to indicate that drivers should move from the center to the right or left lane.
- For the fifth set, the ILCSs over the right and left lanes presented downward green arrows, while the ILCS over the center lane presented a red “X” lane closure warning.

The experiment used 160 participants who were drawn from four age groups: a younger age group with participants 18 to 24 years old; a middle age group with participants 32 to 47 years old; an older age group with participants 55 to 65 years old; and a senior age group with participants 70 years old or more. There were 40 participants in each age group, and within each age group there were 20 females and 20 males. All 160 participants were licensed drivers.

There were three experimental trials for each participant, with merge information conveyed in a different way in each of the trials. In each trial, the participant started driving in the center lane on a six-lane divided freeway on which the speed limit was 65 mph. We collected lane position data and driving speed data in each trial. We analyzed the lane position and driving speed data to determine how effectively the ILCSs conveyed the intended messages to the participants.

4.3 Summary Results

4.3.1 Lane Changing Behavior

On inspecting the lane position data, we discovered that there were two sections of the highway in which many participants moved out of the center lane—the first of these sections included the third set of ILCSs, with the "X/1 mile" lane closure warning; the second section included the fourth set of ILCSs, with the merge messages.

In 189 trials, participants moved from the center lane when they encountered the "X/1 mile" lane closure warning. Fewer participants from the younger and middle age groups changed lanes on encountering the "X/1 mile" lane closure warning than participants from the older and senior groups. In addition, there were 24 trials in which participants ignored the merge sign and remained in the center lane.

There were 267 trials in which the participants changed lanes in response to the merge signs. For each of these 267 trials, we determined the point at which the lane change occurred and the distance between that point and the merge signs. An ANOVA conducted on the distance data from these 267 trials revealed two statistically significant effects—the age of the participants and the type of merge sign.

4.3.1.1 Effect of age.

The average distance at which the participants changed lanes was greatest for the middle age group—on average they moved from the center lane 312 feet before they reached the merge signs. The younger and senior groups also changed lanes before they reached the merge signs—at 162 feet and 147 feet, respectively. However, on average the participants in the older group changed lanes much later—25 feet after they passed the merge signs.

4.3.1.2 Effect of merge sign type.

The participants responded to the diagonal arrow merge sign much earlier than they did to the other two merge signs—on average, when the diagonal arrow was presented the participants moved from the center lane 266 feet before reaching the merge sign. When the dynamic chevrons were used participants changed lanes 123 feet before reaching the merge sign and when words were used to deliver the merge message participants moved from the center lane when they were 54 feet away from the sign.

The merge signs with words and dynamic chevrons both had two lines. On the first line for both signs there was the word "merge". On the second line for the words merge sign, a word indicated direction ("right" or "left"); while on the second line for the dynamic chevron merge sign, the chevrons appeared on the second line. In contrast, the diagonal arrow merge sign was simpler, and as a result likely took less time to process. In addition, the arrow itself was twice the size of the elements used for the other two merge signs—making it visible when the participants were at a greater distance from it.

4.3.2 Driving Speed Data

In each trial, the participant's driving speed was recorded on the approach to each set of ILCSs. The five sets of ILCSs occurred at half-mile intervals and, for analysis purposes, we divided the distance between the sets into three segments of 880 feet. Then for each set of ILCSs, we determined average driving speed in the three segments before the location of the ILCSs and in the first segment after that location. Five ANOVAs were used to analyze the average speed of the participants in these segments on the approach to each set of ILCSs. There were several significant effects.

4.3.2.1 Effect of highway segment.

There were significant differences in average speed between the segments on the approach to the first four sets of ILCSs. There were dramatic changes in speed for the first two sets of ILCSs—which included the 45-mph speed limit and the 35-mph speed limit.

On the approach to the 45-mph speed limit the average driving speed was 63 mph in the first three segments. However, between segment #3 and segment #4, participants reduced speed by approximately 10 mph—although they were still traveling approximately 8 mph above the 45-mph limit in segment #4.

Between segment #1 and segment #4 on the approach to the 35-mph speed limit, the participants reduced speed by approximately 14 mph. On average, in the fourth segment they were driving at 38.7 mph—3.7 mph above the 35-mph speed limit.

In comparison to the substantial reductions in average driving speed obtained on the approaches to the 45-mph and 35-mph speed limits, the differences in average speed on the approaches to the next two sets of ILCSs (with the "X/1 mile" warning and the merge signs), while statistically significant, were of relatively small magnitude.

4.3.2.2 Interaction between age and highway segment.

There were significant interactions between the age of the participants and highway segments on the approaches to the first four sets of ILCSs.

In segment #1 of the approach to the first set of ILCS—the 2,640 feet to 1,760 feet before the first set of ILCSs when it was not yet possible for the participants to decipher the 45-mph speed limit message—the average driving speed was 0.67 mph faster for the younger participants than for the middle age participants, 2.62 mph faster for the middle age participants than for the older participants, and in turn 1.72 mph faster for the older participants than for the senior participants. In the previous studies in this series, we found similar differences in average driving speed for younger, middle age, and older participants.

In this study, the differences in average driving speed between the four age groups occurred in segment #1, segment #2, and segment #3 of the approach to the 45-mph speed limit. However in segment #4, after the participants responded to the 45-mph speed limit sign, the differences between the age groups essentially disappeared.

On the approach to the 35-mph speed limit, even though there were substantial changes in average driving speed from segment to segment, the differences between the four age groups were relatively small. Similarly, there were statistically significant differences in driving speed for the four age groups in the various highway segments on the approaches to the "X/1 mile" closure warning and the merge signs, but these differences were also of relatively small magnitude.

4.3.2.3 Effect of gender.

Overall average speeds were considerably faster (by approximately 14 mph) on the approach to the 45-mph limit than on the approach to the 35-mph limit. However, while the gender differences on the two approaches were statistically significant, they were of relatively small magnitude (the male participants drove 1.4 mph faster than the female participants in both cases).

4.3.2.4 Interaction between trials and highway segments.

There were significant interactions between trials and the highway segments on the approaches with the 45-mph speed limit, the 35-mph speed limit, and the "X/1 mile" closure warning. On the first three segments of the approach to the first of set of ILCSs there was virtually no difference in average speed between the three trials. However in segment #4, when the participants began to respond to the 45-mph speed limit by reducing speed, differences between the trials emerged—the participants drove 3.59 mph slower in the second trial and 4.58 mph slower in the third trial than they did in the first. Differences between the driving speed on the first trial and the speed on the second and third trials continued throughout the approaches to the next two sets of ILCSs, with the 35-mph speed limit and the "X/1 mile" lane closure warning.

4.4 Conclusion

In this study, we used a driving simulator to investigate the effectiveness of ILCS messages that are presented overhead in freeway lanes. The messages investigated included merge signs, speed limit signs and lane closure warnings. We were particularly interested in determining which of three merge signs—(1) a diagonal arrow, (2) words, or (3) dynamic chevrons—was most effective, and the extent to which participants reduced speed on encountering the speed limit signs. We obtained lane position data and driving speed data from 160 participants who each drove the simulated road three times.

Our main findings were as follows:

- *Effectiveness of the speed limit signs.* The speed limit signs proved to be effective. Initially, as the participants began the approach to the first speed limit sign they drove 63 mph, on average. Then when the 45-mph speed limit was visible they reduced speed by approximately 10 mph to 53 mph. In the next half-mile on the approach to the 35-mph speed limit, they reduced speed by a further 14 mph—so that on average, they were driving at 38.7 mph shortly after they passed the 35-mph speed limit.

- *Effectiveness of merge signs.* We found that one type of merge sign was more effective than the others. The participants responded to the merge sign that used the diagonal arrow much earlier than they did to the merge signs using words or dynamic chevrons. On average, when the diagonal arrow was displayed, they moved from the center lane 266 feet before they reached the merge sign; while for the merge sign using dynamic chevrons, they changed lanes 123 feet before reaching the sign, and for the merge sign with words they did not move from the center lane until they were 54 feet away from the sign. The merge signs with words and dynamic chevrons both had two lines. The first line presented the word "merge" on both signs, while the second line either used a word to indicate a direction ("right" or "left"), or displayed the dynamic chevrons. In contrast, the diagonal arrow merge sign was simpler, and as a result likely required less time to process. The arrow itself was larger than the elements used on the other two merge signs—making it visible when the participants were further away.

References

Harder, K.A. and Bloomfield, J.R. (2008). *The Effectiveness and Safety of Traffic and Non-Traffic Related Messages Presented on Changeable Message Signs—Phase II*. Mn/DOTReport No.: MN/RC 2008-27. Minnesota Department of Transportation, St. Paul, MN.

Harder, K.A. and Bloomfield, J.R. (2010). *Comparison of Dual-Phase and Static Changeable Message Signs to Convey Airline Information on Interstate Freeways.* Mn/DOT Report No.: MN/RC 2010-02. Minnesota Department of Transportation, St. Paul, MN.

Harder, K.A., Bloomfield, J.R., and Chihak, B.J. (2003). *The Effectiveness and Safety of Traffic and Non-Traffic Related Messages Presented on Changeable Message Signs (CMS)*. Mn/DOT Report No.: MN/RC 2004-27. Minnesota Department of Transportation, St. Paul, MN.

Appendix A - Counterbalanced Order

The eight tables presented in the following four pages of this appendix show the order in which the twelve combinations of three types of merge sign (diagonal arrow, words, or dynamic chevrons) and two directions (to the left or to the right) in which the participants were asked to merge, were assigned to the three drives completed by each participant.

Tables A.1 and A.2 show these combinations for the younger (18 to 24 year-old) female and male participants, respectively. Tables A.3 and A.4 show these combinations for the middle age (32 to 47 year-old) female and male participants, respectively. Tables A.5 and A.6 show these combinations for the older (55 to 65 year-old) female and male participants, respectively. And Tables A.7 and A.8 show these combinations for the senior (70 year-old or more) female and male participants, respectively.

Table A.1 Order for the younger (18 to 24 year-old) females

Number	Trial One	Trial Two	Trial Three
1101	Diagonal Arrow Left	Words Right	Dynamic Chevrons Left
1102	Words Right	Dynamic Chevrons Left	Diagonal Arrow Right
1103	Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
1104	Diagonal Arrow Right	Dynamic Chevrons Left	Words Right
1105	Words Left	Diagonal Arrow Right	Dynamic Chevrons Left
1106	Dynamic Chevrons Right	Words Left	Diagonal Arrow Right
1107	Diagonal Arrow Left	Dynamic Chevrons Right	Words Left
1108	Words Right	Diagonal Arrow Left	Dynamic Chevrons Right
1109	Dynamic Chevrons Left	Words Right	Diagonal Arrow Left
1110	Diagonal Arrow Right	Words Left	Dynamic Chevrons Right
1111	Words Left	Dynamic Chevrons Right	Diagonal Arrow Left
1112	Dynamic Chevrons Right	Diagonal Arrow Left	Words Right
1113	Diagonal Arrow Left	Words Right	Dynamic Chevrons Left
1114	Words Right	Dynamic Chevrons Left	Diagonal Arrow Right
1115	Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
1116	Diagonal Arrow Right	Dynamic Chevrons Left	Words Right
1117	Words Left	Diagonal Arrow Right	Dynamic Chevrons Left
1118	Dynamic Chevrons Right	Words Left	Diagonal Arrow Right
1119	Diagonal Arrow Left	Dynamic Chevrons Right	Words Left
1120	Words Right	Diagonal Arrow Left	Dynamic Chevrons Right

Table A.2 Order for the younger (18 to 24 year-old) males

Number	Trial One	Trial Two	Trial Three
2201	Dynamic Chevrons Left	Words Right	Diagonal Arrow Left
2202	Diagonal Arrow Right	Words Left	Dynamic Chevrons Right
2203	Words Left	Dynamic Chevrons Right	Diagonal Arrow Left
2204	Dynamic Chevrons Right	Diagonal Arrow Left	Words Right
2205	Diagonal Arrow Left	Words Right	Dynamic Chevrons Left
2206	Words Right	Dynamic Chevrons Left	Diagonal Arrow Right
2207	Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
2208	Diagonal Arrow Right	Dynamic Chevrons Left	Words Right
2209	Words Left	Diagonal Arrow Right	Dynamic Chevrons Left
2210	Dynamic Chevrons Right	Words Left	Diagonal Arrow Right
2211	Diagonal Arrow Left	Dynamic Chevrons Right	Words Left
2212	Words Right	Diagonal Arrow Left	Dynamic Chevrons Right
2213	Dynamic Chevrons Left	Words Right	Diagonal Arrow Left
2214	Diagonal Arrow Right	Words Left	Dynamic Chevrons Right
2215	Words Left	Dynamic Chevrons Right	Diagonal Arrow Left
2216	Dynamic Chevrons Right	Diagonal Arrow Left	Words Right
2217	Diagonal Arrow Left	Words Right	Dynamic Chevrons Left
2218	Words Right	Dynamic Chevrons Left	Diagonal Arrow Right
2219	Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
2220	Diagonal Arrow Right	Dynamic Chevrons Left	Words Right

Table A.3 Order for the middle age (32 to 47 year-old) females

Number	Trial One	Trial Two	Trial Three
3301	Words Left	Diagonal Arrow Right	Dynamic Chevrons Left
3302	Dynamic Chevrons Right	Words Left	Diagonal Arrow Right
3303	Diagonal Arrow Left	Dynamic Chevrons Right	Words Left
3304	Words Right	Diagonal Arrow Left	Dynamic Chevrons Right
3305	Dynamic Chevrons Left	Words Right	Diagonal Arrow Left
3306	Diagonal Arrow Right	Words Left	Dynamic Chevrons Right
3307	Words Left	Dynamic Chevrons Right	Diagonal Arrow Left
3308	Dynamic Chevrons Right	Diagonal Arrow Left	Words Right
3309	Diagonal Arrow Left	Words Right	Dynamic Chevrons Left
3310	Words Right	Dynamic Chevrons Left	Diagonal Arrow Right
3311	Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
3312	Diagonal Arrow Right	Dynamic Chevrons Left	Words Right
3313	Words Left	Diagonal Arrow Right	Dynamic Chevrons Left
3314	Dynamic Chevrons Right	Words Left	Diagonal Arrow Right
3315	Diagonal Arrow Left	Dynamic Chevrons Right	Words Left
3316	Words Right	Diagonal Arrow Left	Dynamic Chevrons Right
3317	Dynamic Chevrons Left	Words Right	Diagonal Arrow Left
3318	Diagonal Arrow Right	Words Left	Dynamic Chevrons Right
3319	Dynamic Chevrons Right	Diagonal Arrow Left	Words Right
3320	Diagonal Arrow Right	Words Left	Dynamic Chevrons Right

Table A.4 Order for the middle age (32 to 47 year-old) males

Number	Trial One	Trial Two	Trial Three
4401	Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
4402	Diagonal Arrow Right	Dynamic Chevrons Left	Words Right
4403	Words Left	Diagonal Arrow Right	Dynamic Chevrons Left
4404	Dynamic Chevrons Right	Words Left	Diagonal Arrow Right
4405	Diagonal Arrow Left	Dynamic Chevrons Right	Words Left
4406	Words Right	Diagonal Arrow Left	Dynamic Chevrons Right
4407	Dynamic Chevrons Left	Words Right	Diagonal Arrow Left
4408	Diagonal Arrow Right	Words Left	Dynamic Chevrons Right
4409	Words Left	Dynamic Chevrons Right	Diagonal Arrow Left
4410	Dynamic Chevrons Right	Diagonal Arrow Left	Words Right
4411	Diagonal Arrow Left	Words Right	Dynamic Chevrons Left
4412	Words Right	Dynamic Chevrons Left	Diagonal Arrow Right
4413	Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
4414	Diagonal Arrow Right	Dynamic Chevrons Left	Words Right
4415	Words Left	Diagonal Arrow Right	Dynamic Chevrons Left
4416	Dynamic Chevrons Right	Words Left	Diagonal Arrow Right
4417	Diagonal Arrow Left	Dynamic Chevrons Right	Words Left
4418	Words Right	Diagonal Arrow Left	Dynamic Chevrons Right
4419	Dynamic Chevrons Left	Words Right	Diagonal Arrow Left
4420	Diagonal Arrow Right	Words Left	Dynamic Chevrons Right

Table A.5 Order for the older (55 to 65 year-old) females

Number	Trial One	Trial Two	Trial Three
5501	Words Left	Dynamic Chevrons Right	Diagonal Arrow Left
5502	Dynamic Chevrons Right	Diagonal Arrow Left	Words Right
5503	Diagonal Arrow Left	Words Right	Dynamic Chevrons Left
5504	Words Right	Dynamic Chevrons Left	Diagonal Arrow Right
5505	Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
5506	Diagonal Arrow Right	Dynamic Chevrons Left	Words Right
5507	Words Left	Diagonal Arrow Right	Dynamic Chevrons Left
5508	Dynamic Chevrons Right	Words Left	Diagonal Arrow Right
5509	Diagonal Arrow Left	Dynamic Chevrons Right	Words Left
5510	Words Right	Diagonal Arrow Left	Dynamic Chevrons Right
5511	Dynamic Chevrons Left	Words Right	Diagonal Arrow Left
5512	Diagonal Arrow Right	Words Left	Dynamic Chevrons Right
5513	Words Left	Dynamic Chevrons Right	Diagonal Arrow Left
5514	Dynamic Chevrons Right	Diagonal Arrow Left	Words Right
5515	Diagonal Arrow Left	Words Right	Dynamic Chevrons Left
5516	Words Right	Dynamic Chevrons Left	Diagonal Arrow Right
5517	Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
5518	Diagonal Arrow Right	Dynamic Chevrons Left	Words Right
5519	Words Left	Diagonal Arrow Right	Dynamic Chevrons Left
5520	Dynamic Chevrons Right	Words Left	Diagonal Arrow Right

Table A.6 Order for the older (55 to 65 year-old) males

Number	Trial One	Trial Two	Trial Three
6601	Diagonal Arrow Left	Dynamic Chevrons Right	Words Left
6602	Words Right	Diagonal Arrow Left	Dynamic Chevrons Right
6603	Dynamic Chevrons Left	Words Right	Diagonal Arrow Left
6604	Diagonal Arrow Right	Words Left	Dynamic Chevrons Right
6605	Words Left	Dynamic Chevrons Right	Diagonal Arrow Left
6606	Dynamic Chevrons Right	Diagonal Arrow Left	Words Right
6607	Diagonal Arrow Left	Words Right	Dynamic Chevrons Left
6608	Words Right	Dynamic Chevrons Left	Diagonal Arrow Right
6609	Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
6610	Diagonal Arrow Right	Dynamic Chevrons Left	Words Right
6611	Words Left	Diagonal Arrow Right	Dynamic Chevrons Left
6612	Dynamic Chevrons Right	Words Left	Diagonal Arrow Right
6613	Diagonal Arrow Left	Dynamic Chevrons Right	Words Left
6614	Words Right	Diagonal Arrow Left	Dynamic Chevrons Right
6615	Dynamic Chevrons Left	Words Right	Diagonal Arrow Left
6616	Diagonal Arrow Right	Words Left	Dynamic Chevrons Right
6617	Words Left	Dynamic Chevrons Right	Diagonal Arrow Left
6618	Dynamic Chevrons Right	Diagonal Arrow Left	Words Right
6619	Diagonal Arrow Left	Words Right	Dynamic Chevrons Left
6620	Words Right	Dynamic Chevrons Left	Diagonal Arrow Right

Table A.7 Order for the senior (70 year-old or more) females

Number	Trial One	Trial Two	Trial Three
7701	Dynamic Chevrons Right	Words Left	Diagonal Arrow Right
7702	Diagonal Arrow Left	Dynamic Chevrons Right	Words Left
7703	Words Right	Diagonal Arrow Left	Dynamic Chevrons Right
7704	Dynamic Chevrons Left	Words Right	Diagonal Arrow Left
7705	Diagonal Arrow Right	Words Left	Dynamic Chevrons Right
7706	Words Left	Dynamic Chevrons Right	Diagonal Arrow Left
7707	Dynamic Chevrons Right	Diagonal Arrow Left	Words Right
7708	Diagonal Arrow Left	Words Right	Dynamic Chevrons Left
7709	Words Right	Dynamic Chevrons Left	Diagonal Arrow Right
7710	Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
7711	Diagonal Arrow Right	Dynamic Chevrons Left	Words Right
7712	Words Left	Diagonal Arrow Right	Dynamic Chevrons Left
7713	Dynamic Chevrons Right	Words Left	Diagonal Arrow Right
7714	Diagonal Arrow Left	Dynamic Chevrons Right	Words Left
7715	Words Right	Diagonal Arrow Left	Dynamic Chevrons Right
7716	Dynamic Chevrons Left	Words Right	Diagonal Arrow Left
7717	Diagonal Arrow Right	Words Left	Dynamic Chevrons Right
7718	Words Left	Dynamic Chevrons Right	Diagonal Arrow Left
7719	Dynamic Chevrons Right	Diagonal Arrow Left	Words Right
7720	Diagonal Arrow Left	Words Right	Dynamic Chevrons Left

Table A.8 Order for the senior (70 year-old or more) males

Number	Trial One	Trial Two	Trial Three
8801	Words Right	Dynamic Chevrons Left	Diagonal Arrow Right
8802	Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
8803	Diagonal Arrow Right	Dynamic Chevrons Left	Words Right
8804	Words Left	Diagonal Arrow Right	Dynamic Chevrons Left
8805	Dynamic Chevrons Right	Words Left	Diagonal Arrow Right
8806	Diagonal Arrow Left	Dynamic Chevrons Right	Words Left
8807	Words Right	Diagonal Arrow Left	Dynamic Chevrons Right
8808	Dynamic Chevrons Left	Words Right	Diagonal Arrow Left
8809	Diagonal Arrow Right	Words Left	Dynamic Chevrons Right
8810	Words Left	Dynamic Chevrons Right	Diagonal Arrow Left
8811	Dynamic Chevrons Right	Diagonal Arrow Left	Words Right
8812	Diagonal Arrow Left	Words Right	Dynamic Chevrons Left
8813	Words Right	Dynamic Chevrons Left	Diagonal Arrow Right
8814	Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
8815	Diagonal Arrow Right	Dynamic Chevrons Left	Words Right
8816	Words Right	Dynamic Chevrons Left	Diagonal Arrow Right
8817	Dynamic Chevrons Left	Diagonal Arrow Right	Words Left
8818	Diagonal Arrow Right	Dynamic Chevrons Left	Words Right
8819	Words Left	Diagonal Arrow Right	Dynamic Chevrons Left
8820	Dynamic Chevrons Right	Words Left	Diagonal Arrow Right

Appendix B - Survey Questions

Subject Number_____

Survey Questions

Question #1: When you are driving on Metro Freeways, have you seen message boards that give travel time information—i.e., messages that tell you how much time it will take to get to a particular location or to a freeway?
Yes____ No____

If you answer "Yes" please continue with Question #2.
If you answer " No" please proceed to Question #4.

Question #2: How useful to you is travel time information? Please mark your answer on the scale which goes from 1 to 7—where "1" means "Not at all useful" and "7" means "Very useful."

Not at all Useful 1 2 3 4 5 6 7 Very useful

Question #3: Does travel time information affect your stress level when you are driving? Please mark your answer on the scale which goes from 1 to 7—where "1" means "Greatly increases my stress level" and "7" means "Greatly reduces my stress level"

Greatly Increases My Stress Level 1 2 3 4 5 6 7 Greatly Reduces My Stress Level

Question #4: When you are driving on Metro Freeways have you seen message boards that give information about traffic problems ahead that could affect traffic speed—i.e., messages tell you that there is a "Crash Ahead" or "Congestion Ahead" or "Road Work Ahead" or "Stalled Vehicle Ahead"?
Yes____ No____

If you answer "Yes" please continue with Question #5.
If you answer " No" please proceed to Question #7.

Question #5: How useful to you is information about traffic problems? Please mark your answer on the scale which goes from 1 to 7—where "1" means "Not at all useful" and "7" means "Very useful."

Not at all Useful 1 2 3 4 5 6 7 Very useful

Question #6: Does information about traffic problems affect your stress level when you are driving? Please mark your answer on the scale which goes from 1 to 7—where "1" means "Greatly increases my stress level" and "7" means "Greatly reduces my stress level"

Greatly Increases My Stress Level 1	2	3	4	5	6	7 Greatly Reduces My Stress Level

Question #7: When you are driving on Metro Freeways have you seen message boards that give safety messages—like "Buckle Up" or "Don't Drive Drowsy" or "Don't Drink and Drive"?

Yes____ No____

If you answer "Yes" please continue with Question #8.
If you answer " No" please proceed to Question #9.

Question #8: How useful to you are safety messages? Please mark your answer on the scale which goes from 1 to 7—where "1" means "Not at all useful" and "7" means "Very useful."

Not at all Useful 1	2	3	4	5	6	7 Very useful

Question #9: When you are driving on Metro Freeways have you seen message boards that give information about roadway maintenance schedules—like "Road Closed Thru June 1" or "Road Closed June 19 Thru July 25"?

Yes____ No____

If you answer "Yes" please continue with Question #10.
If you answer " No" you have completed the survey.

Question #10: How useful to you is information about roadway maintenance schedules? Please mark your answer on the scale which goes from 1 to 7—where "1" means "Not at all useful" and "7" means "Very useful."

Not at all Useful 1	2	3	4	5	6	7 Very useful

Appendix C - Survey Data

Survey data

After they finished driving in three simulator trials, the 160 participants were asked to complete a survey that consisted of ten questions. Their responses to these questions are reported below.

Travel Time Information—The first three questions of the survey related to travel time information. The first question asked, "When you are driving on Metro Freeways, have you seen message boards that give travel time information—i.e., messages that tell you how much time it will take to get to a particular location or to a freeway? The responses to this question were as follows:

- 150 (93.75%)—participants had seen message boards presenting travel time information on the Metro Freeways.
- 10 (6.25%)—had not seen these messages.

The second question asked, "How useful to you is travel time information? Please mark your answer on the scale which goes from 1 to 7—where "1" means "Not at all useful" and "7" means "Very useful." The distribution of the responses of the 150 participants who said that they had seen these messages is shown in Figure C1.

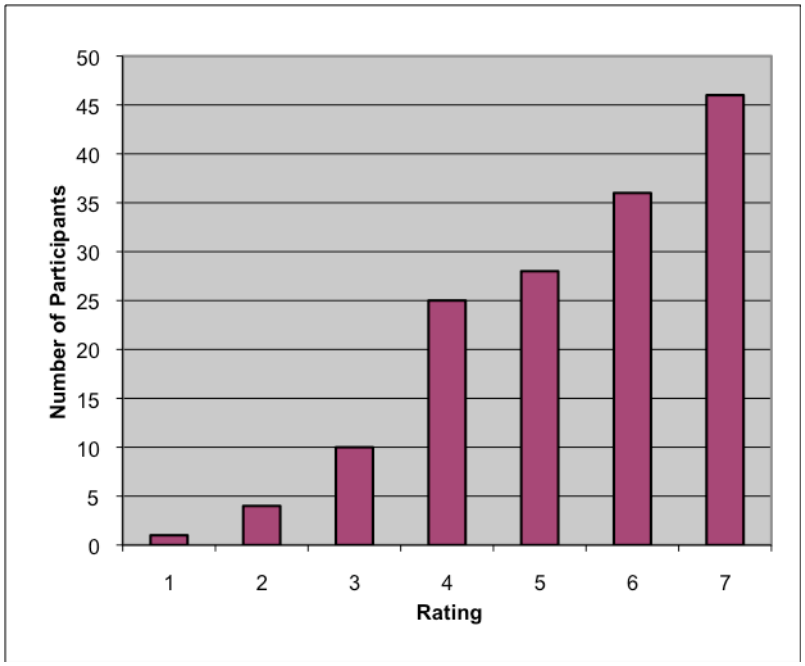

Figure C.1 Distribution of responses rating the usefulness of travel time information to the participants

As the figure shows, the distribution of responses was positively skewed. The mean value of the responses was 5.42, and the standard deviation was 1.41. The majority of the participants who responded to this question indicated that they found travel time information to be useful.

The third question was, "Does travel time information affect your stress level when you are driving? Please mark your answer on the scale which goes from 1 to 7—where "1" means

"Greatly increases my stress level" and "7" means "Greatly reduces my stress level." The distribution of the responses of 150 participants who had seen these messages is shown in Figure C2.

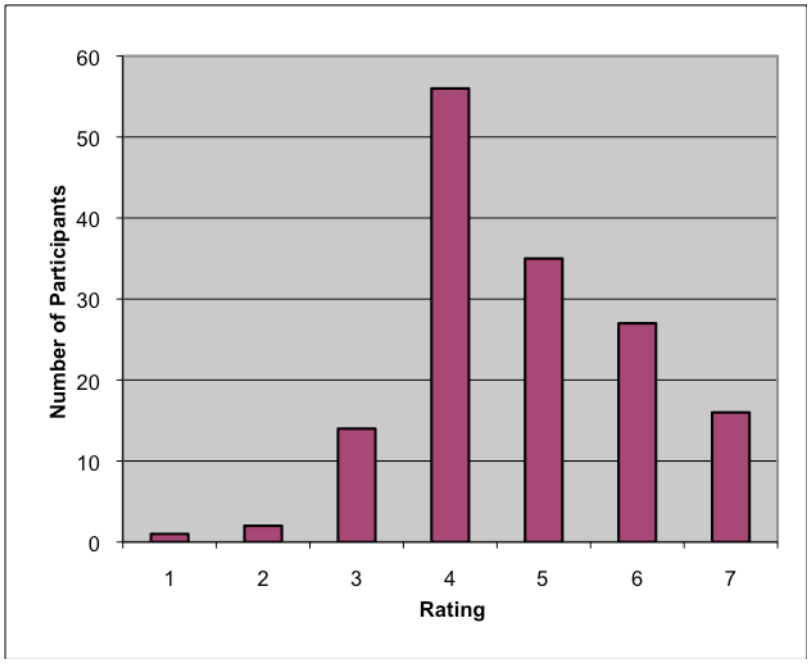

Figure C.2 Distribution of responses rating the effect of travel time information on the stress level of the participants

The mean value of the responses shown in Figure C2 was 4.74, and the standard deviation was 1.22.

Information about Traffic Problems—The fourth, fifth, and sixth questions on the survey dealt with information about traffic problems.

The fourth question was, "When you are driving on Metro Freeways have you seen message boards that give information about traffic problems ahead that could affect traffic speed—i.e., messages that tell you that there is a "Crash Ahead" or "Congestion Ahead" or "Road Work Ahead" or "Stalled Vehicle Ahead"?" The responses to this question were as follows:

- 156 (97.5%)—had seen message boards presenting information about traffic problems ahead.
- 4 (2.5%)—had not seen these messages.

The fifth question was, "How useful to you is information about traffic problems? Please mark your answer on the scale which goes from 1 to 7—where "1" means "Not at all useful" and "7" means "Very useful." The distribution of the responses of the 156 participants who responded to this question is presented in Figure C3.

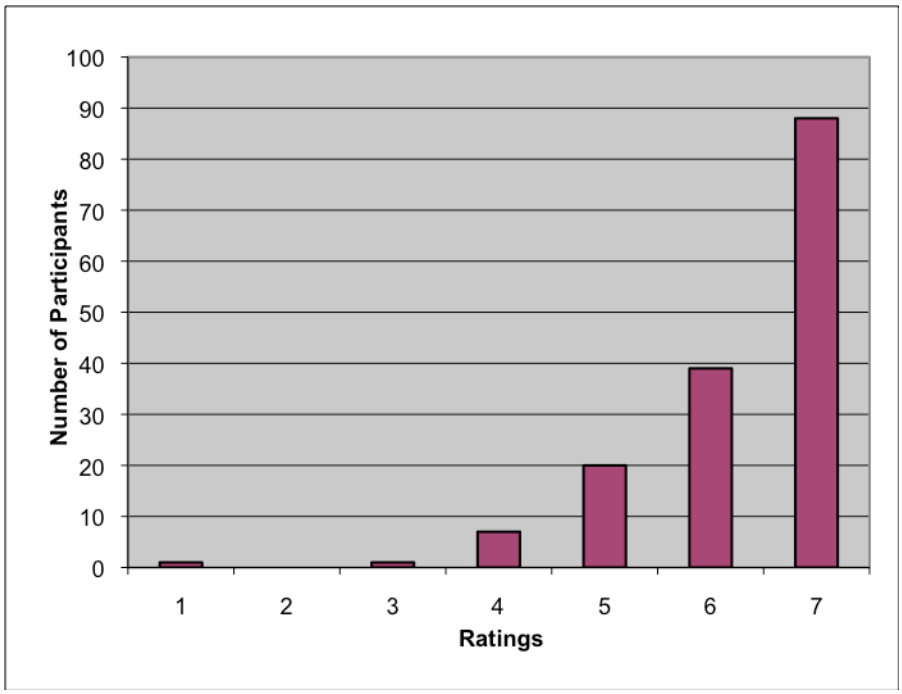

Figure C.3 Distribution of responses rating the usefulness of information about traffic problems to the participants

Figure C3 shows the distribution of responses rating the value of information about traffic problems ahead was highly positively skewed. The mean value of these responses was 6.26, and the standard deviation was 1.00. Most of the participants indicated that they found information about traffic problems to be useful.

The sixth question was, "Does information about traffic problems affect your stress level when you are driving? Please mark your answer on the scale which goes from 1 to 7—where "1" means "Greatly increases my stress level" and "7" means "Greatly reduces my stress level." The distribution of the responses of the 156 participants who responded to this question is presented in Figure C4.

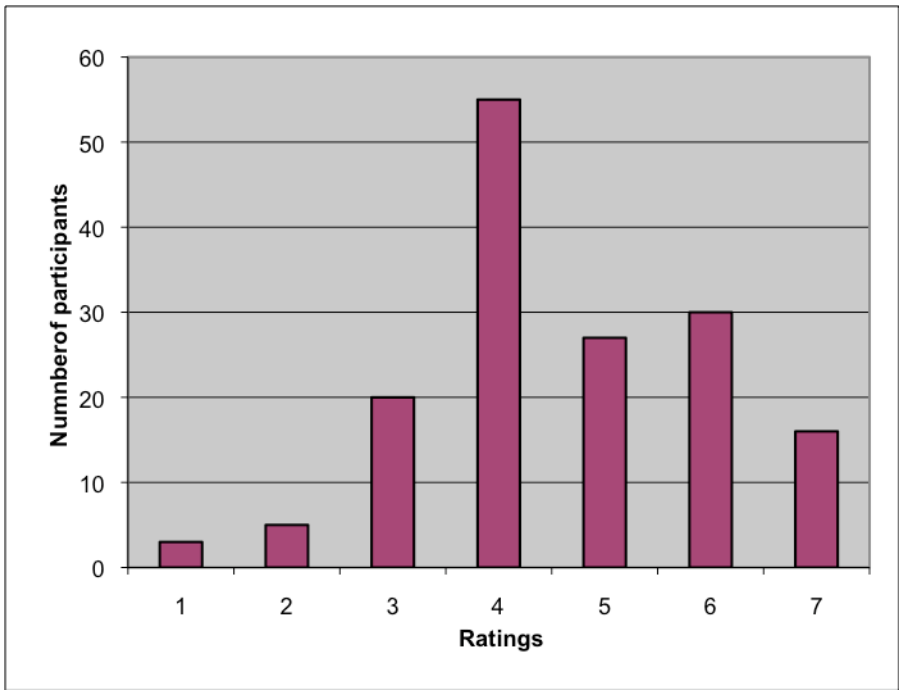

Figure C.4 Distribution of responses rating the effect that information about traffic problems has on the stress level of the participants

The mean value of the ratings in Figure C4 was 4.59, and the standard deviation was 1.37.

Safety Messages—The next two questions dealt with safety messages on CMS displays. The seventh question was, "When you are driving on Metro Freeways have you seen message boards that give safety messages—like 'Buckle Up' or 'Don't Drive Drowsy' or 'Don't Drink and Drive'?" The responses to this question were:

- 145 (90.6%)—had seen message boards presenting safety messages.
- 15 (9.4%)—had not seen these messages.

The eighth question asked, "How useful to you are safety messages? Please mark your answer on the scale which goes from 1 to7—where "1" means "Not at all useful" and "7" means "Very useful." The distribution of response of the 145 participants who reported that they had seen these messages is presented in Figure C5.

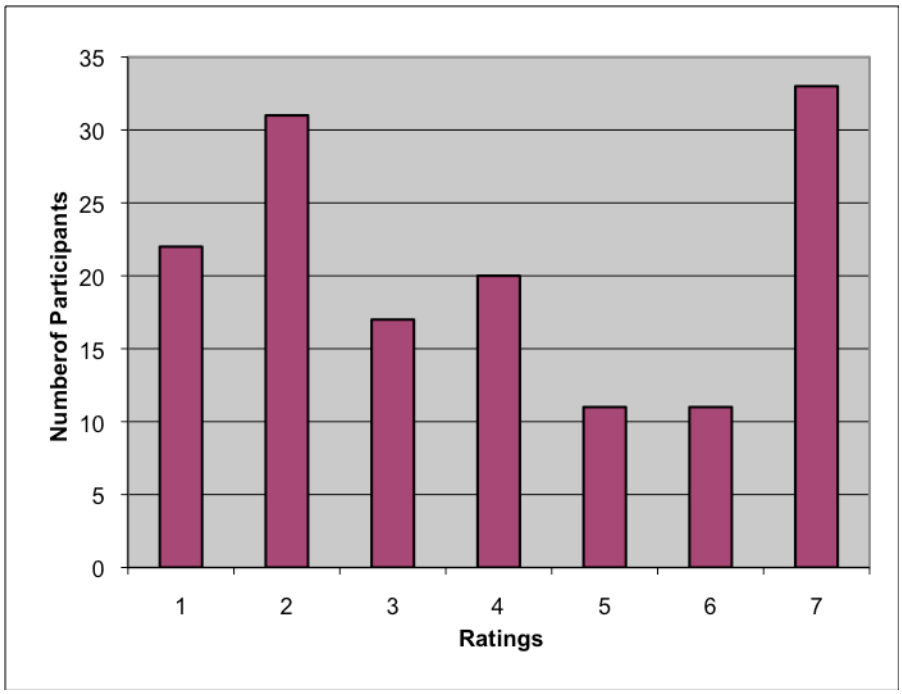

Figure C.5 Distribution of responses rating the usefulness of safety messages to the participants

Figure C5 shows that there was little agreement among the participants when asked about the usefulness of safety messages. The mean of these ratings was 3.88, while the standard deviation was 2.18

Information about Roadway Maintenance Schedules—The next two survey questions dealt with information about roadway maintenance schedules. The ninth question asked, "When you are driving on Metro Freeways have you seen message boards that give information about roadway maintenance schedules—like "Road Closed Thru June 1" or "Road Closed June 19 Thru July 25"? The responses to this question were:

- 156 (97.5%)—had seen message boards that displayed information about roadway maintenance schedules.
- 4 (2.5%)—had not seen these messages.

The tenth question asked the participants, "How useful to you is information about roadway maintenance schedules? Please mark your answer on the scale which goes from 1 to 7—where "1" means "Not at all useful" and "7" means "Very useful." Figure 6 presents the distribution of the ratings given by the 156 participants who responded to this question.

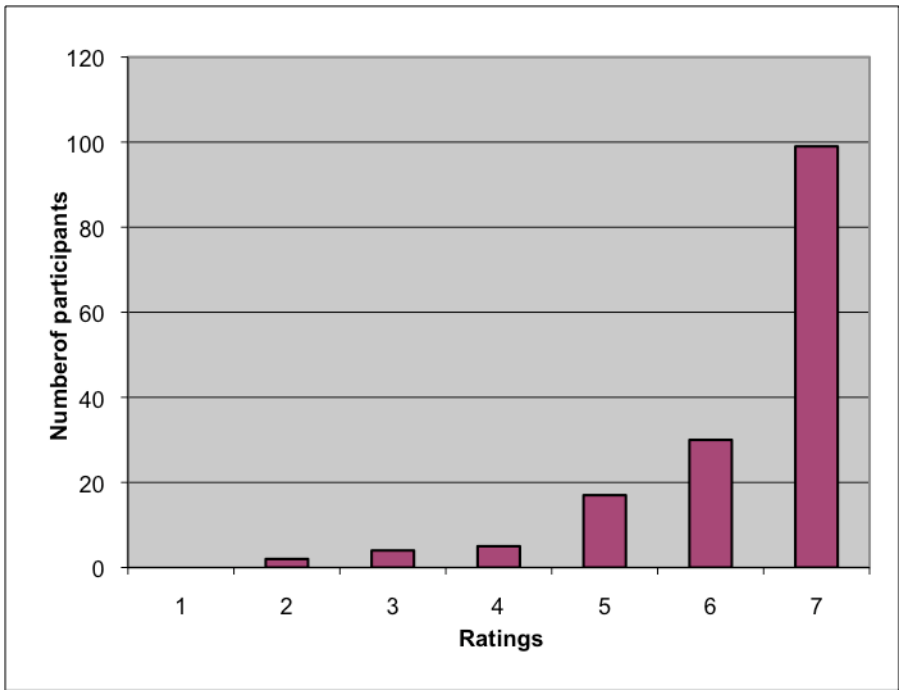

Figure C.6 Distribution of responses rating the usefulness of information about roadway maintenance schedules

The distribution shown in Figure C6 is highly positively skewed. The mean rating value was 6.31, and the standard deviation was 1.09. Most of the participants indicated that they found information about roadway maintenance schedules to be very useful.