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Comparison of Dual-Phase and Static Changeable Message Signs to Convey Airline Information on Interstate Freeways

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16. Abstract (Limit: 200 words)

We used a fully interactive PC-based STISIM driving simulator to compare dual-phase Changeable Message Signs (CMSs) and static CMSs. The participants were 120 licensed drivers from three age groups: 18-24, 32-47, and 55-65 years of age. They drove eleven miles on a simulated six-lane highway towards an airport, knowing which airline to look for. Airline information was provided on two separate CMSs located 500 ft (152.4 m) apart on the highway in one condition, or on a single dual-phase CMS in the other condition. The participants took the correct exit on 89.6% of the drives (215 of 240). There were no statistically significant differences between the number of participants who failed to take the correct exit in the dual-phase and the static CMS conditions. On the approach to the CMSs displaying airline information, there were significant differences in average speed between the three age groups—younger drivers drove faster than middle age and older drivers. However, average speeds were not different in the dual-phase and static CMS conditions. Some individuals reduced speed on approaching the CMSs—suggesting similar reductions could occur in real world driving in free flow conditions. There were no differences in the number or magnitude of the speed reductions for the dual-phase and static CMS conditions. In this experiment, displaying airline information on a single dual-phase CMS was as effective in influencing driving behavior as displaying the same airline information on two static CMSs.

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Executive Summary

1. Introduction

This report describes an investigation conducted to determine whether messages presented on dual-phase Changeable Message Signs (CMSs)—that have been proposed for use on the Trunk Highway approaches to the Minneapolis-St. Paul International (MSP) airport—are as effective in influencing driving behavior as messages displayed on static CMSs. The MSP airport has two terminals, but it does not have a shared roadway system for public use between the two terminals. As a result, passengers who drive to the MSP airport need to select the exit for the terminal they are planning to use while still on the highway. If they arrive at the wrong terminal, they have to go back onto the highway system to reach the correct terminal.

Currently, the signs located on the highway approaches to the airport display only terminal information. They do not display individual airline information; as a result, passengers need prior knowledge of the terminal servicing their airline. This study was conducted to assist the Metropolitan Airports Commission (MAC) and the Minnesota Department of Transportation (Mn/DOT) as they decide how to provide information linking the individual airlines to the two terminals on CMSs that will be installed on the highway approaches. There are many road signs clustered together on the highway approaches to the MSP airport; therefore, it would be preferable if the airline information could be displayed on as few CMSs as possible.

The Humphrey Terminal (which is to be renamed Terminal 2) services five airlines. It is possible to display these names on a single CMS. In contrast, the Lindbergh Terminal (to be renamed Terminal 1) services nine airlines. It is not possible to display the names of nine airlines simultaneously on a single CMS, and still have the names legible at a reasonable distance.

2. The Experiment

Two alternative presentation methods were compared in this study. One method used two separate CMSs located 500 ft (152.4 m) apart on the highway. The other method used a single CMS to display the Terminal 1 airline information in two phases. A fully interactive, PC-based, STISIM driving simulator was used to conduct an experiment exploring these two presentation methods.

The participants were 120 licensed drivers—60 of whom were assigned to the dual-phase CMS condition and 60 to the static CMS condition. For both CMS conditions, there were ten males and ten females from each of three age groups: a younger group with participants between the ages of 18-24, a middle age group with participants between 32-47, and an older group with participants between 55-65.

Each participant drove toward the airport twice, on a simulated 11-mile-long, six-lane, divided highway. Before each drive, the participant was informed that he or she was driving toward an airport, and told which airline to look for—the airlines to which the participants were assigned were presented in a counterbalanced order for both CMS conditions. The participants were told that speed limit was 60 mph, and that they should drive as they normally would. When each drive was completed, the experimenter noted whether or not the participant took the correct exit for the airline to which he or she was assigned. Driving speed data were also collected in five highway segments on the approach to the CMSs displaying airline information

3. Results

The 120 participants drove the experimental route twice—so there were a total of 240 drives. The participants took the correct exit on 89.6% of the drives (215 of 240 drives). They failed to take the correct exit on 10.4% of the drives (25 out of 240). Twenty of the 25 failures occurred on the first drive—only five occurred on the second drive. There were more failures to take the correct exit for older drivers (14) than for middle age drivers (7) and younger drivers (4). The gender of the participants had no effect on the number failures to take the correct exit.

Most importantly, given the objective of this study, there was no statistically significant difference between the number of participants in the dual-phase CMS condition who failed to take the correct exit and the number of participants in the static CMS condition who failed to take the correct exit.

In each drive, the average speed of the participant was determined in five different highway segments of the approach to the CMSs displaying airline information. The first two segments—each of 880 ft (243.8 m)—were directly before the CMSs were visible. The third segment—also of 800 ft (243.8 m)—ended at the location of the first static CMS in the static condition and of the dual-phase CMS in the dual-phase condition. The fourth segment—of 500 ft (152.4 m)—ended at the location of the second static CMS (in the static condition). And the fifth segment—of 800 ft (243.8 m)—ended at the location of the CMS displaying the names of the airlines serviced at Terminal 2 in both the dual-phase and the static CMS condition.

Analysis of the speed data indicated there were statistically significant differences in average speed between the three age groups: the younger drivers drove 2.82 mph faster than the middle age drivers who, in turn, drove 2.17 mph faster than the older drivers. These differences were obtained on a simulated six-lane highway where the speed limit was 60 mph. They were similar in magnitude to the differences in average speed found with younger, middle age, and older drivers in a previous CMS study conducted by Harder and Bloomfield (2008) using the same driving simulator.

The analysis indicated that the average speed of the participants was significantly faster on the second drive than on the first drive, and that average speed was significantly slower in the fifth segment than it was in the first four segments.

However, no statistically significant difference in speed could be related to the CMS conditions; the average speeds for the participants in the dual-phase CMS condition were not different from the average speeds for those in the static CMS condition.

We also focused on the speed of the individual participants, examining reductions in speed from one segment to the next. We considered all reductions that were 2 mph or more; smaller reductions are not likely to impact traffic flow. Twenty-nine participants reduced speed by 2 mph or more between segments: nine participants reduced speed between segments on both the first and second drives, and 13 participants reduced speed by 2 mph or more on two occasions during the same drive. As a result, the 29 participants were responsible for a total of 53 reductions in speed between various segments in the two drives.

There were no statistically significant effects for age or gender of the participants, and no difference in the number of participants who reduced speed in the first drive and the second drive. The only statistically significant difference in the number of speed reductions was related to the segments. The number of reductions gradually increased from segment #1 to segment #5, with the largest number of reductions in speed occurring in the segment that ended with the CMS that displayed airline information related to Terminal 2.

We also compared the magnitude of the speed reductions for the dual-phase and static conditions, but this comparison showed that there was no difference between the dual-phase and static CMS conditions.

4. Conclusions

The driving simulation experiment was conducted to determine whether messages displayed on dual-phase CMSs are as effective in influencing driving behavior as messages displayed on static CMSs. Although we found several significant effects, our analysis did not show any performance differences related to the CMS conditions. There was no significant difference in the number of participants in the dual-phase and static conditions who failed to take the correct exit. The two methods of displaying the information were equally effective and the correct exit was selected on 89.6% of the drives.

There was no statistically significant difference in the average speeds of the participants in the dual-phase condition and the static condition on the approach to the CMSs. An examination of individual driving speeds found no differences between the two CMS conditions in the number of individuals who reduced speed by 2 mph or more on the approach to the CMSs. Also, there were no differences in the magnitude of the individual reductions in speed for the dual and static CMS conditions.

In this driving simulator experiment, a single dual-phase CMS and two static CMSs were equally effective in displaying airline information on the simulated airport approach. With regard to driving behavior, there is no evidence to suggest that one mode of displaying airline and terminal information is better than the other.

Chapter 1. Introduction

1.1 Objective

The objective of this study was to conduct a driving simulation experiment to determine whether messages displayed on dual-phase Changeable Message Signs (CMSs) that the Metropolitan Airports Commission (MAC) has proposed for use on the Trunk Highway approaches to the Minneapolis-St. Paul International (MSP) airport, are as effective in influencing driving behavior as messages displayed on static CMSs. To achieve this objective, we determined the accuracy of driver responses—i.e., whether or not the drivers took the appropriate highway exit—when airline information was displayed on either a dual-phase or two static CMSs. In addition, we also evaluated whether or not the CMSs caused the drivers to reduce their driving speed.

1.2 Changeable Message Signs

Changeable Message Signs (CMSs) are traffic control devices designed to display messages that can be varied. They are also known as Variable Message Signs (VMSs), Dynamic Message Signs (DMSs), and Electronic Message Signs (EMSs). For the sake of consistency, throughout this report they are referred to as Changeable Messages Signs (CMSs)—which is the way that the Federal Highway Administration's "Manual on Uniform Traffic Control Devices" (MUTCD, 2007) refers to them.

The two types of CMS investigated in this study were as follows:

- A static CMS—which displays information on a single CMS. This is the way that CMSs are most commonly used on U.S roads.
- A dual-phase CMS—which displays information in two phases, sequentially, on a single CMS. This type of CMS is used when the information to be displayed does not all fit into the dimensions of a single static CMS.

The study compared the effectiveness of using a single dual-phase CMS to display the same airline information as was displayed on two static CMSs.

1.3 Previous Research with Changeable Message Signs

There are many studies of various issues related to the use of CMSs—for reviews of this research see Dudek (1997, 2004) and Pedic and Ezrakhovich (1999). Several studies which are relevant to the current study are described briefly below.

Ullman, Ullman, Dudek, and Williams (2007) used static and dual-phase CMSs in a complex driving simulation experiment. They included conditions in which there was a static message or a dual-phase message on a full-size CMS. However unfortunately, the message content in the two conditions was different, and the investigators did not compare the responses of the participants to these two conditions (rather they were interested in comparing the responses when there was redundant or non-redundant information on the dual-phase CMSs).

In an earlier study, Guerrier, Wachtel, and Budenz (2002) investigated dual-phase and static CMS messages using a STISIM driving simulator. There were a number of methodological problems with the study. For example, a supplemental screen was used to present the CMS messages—the screen was not integrated into the simulation scenario and the investigators were not able to vary the size of the lettering in the message as the participants drove on the simulated route. Further, at the onset of the messages the participants were given an auditory cue to alert them to the presence of the message. Also, the content of the dual-phase and static CMSs differed—so that the messages were not equivalent. Because of these problems, it is difficult to draw any firm conclusions about the results of this experiment—other than that younger drivers (aged between 24 and 54 years old) drove faster than older drivers (who were at least 55 years old.).

In two other CMS studies, conducted with the STISIM driving simulator utilized in the study reported here, Harder, Bloomfield, and Chihak (2003) and Harder and Bloomfield (2008), also found that average speed decreased with age—younger drivers (aged between 18 and 24) drove faster than middle age drivers (aged between 32 and 47) who in turn drove faster than older drivers (aged between 55 and 65). Also, in both studies, between 16 and 31 individual participants (out of 120) reduced speed by at least 2 mph on the approach to the CMS (which displayed either traffic-related CMS messages or AMBER Alert/Abducted Child messages).

The results of two other studies involving signage are relevant to the current experiment. Forbes, Moskowitz, and Morgan (1950) and, more recently, Garvey, Pietrucha, and Meeker (1997) showed that, when drivers are looking for specific words on a sign—i.e., when they have a recognition task—the use of lower-case lettering produces better performance than upper-case lettering. The task of the participants in the current study was also a recognition task—they had to select a particular airline from the fourteen airlines serviced by the two MSP airport terminals. Because of this, lower-case lettering was used on the CMSs in both the dual-phase and static CMS conditions.

1.4 The Minneapolis-St. Paul Airport

The current study focused on the Minneapolis-St. Paul International (MSP) airport. The MSP airport is the sixteenth largest in the US, in terms of number of passengers—the airport serviced over 34 million passengers in 2008 (MSP Website, 2009). The MSP airport has two terminals. However, unlike other major U.S. airports, there is no shared roadway system between the two terminals. As a result, when passengers drive towards the MSP airport, they need to select the exit for the terminal they are planning to use while they are still on the highway—any passenger who goes to the wrong terminal has to return to the highway in order to drive to the correct terminal.

1.5 Highway Signage on the Approaches to the Minneapolis-St. Paul Airport

At present, only terminal information is displayed on signs on the Trunk Highway approaches to the MSP airport—individual airline information is not presented. However, the MAC and the Minnesota Department of Transportation (Mn/DOT) are working together to change this. They are planning to provide airline information on CMSs that will be located on the Trunk Highway approaches. This information will link individual airlines to the two terminals. It should be noted that, before this study was conducted, a decision had already been made that the two terminal buildings, the Lindbergh Terminal and the Humphrey Terminal, would be renamed Terminal 1 and Terminal 2, respectively. Also, it should be noted that the highway approaches to the MSP airport have a large number of road signs located within a relatively short distance, making it desirable to display the airline information on as few CMSs as possible.

Currently, the Humphrey Terminal (Terminal 2) services five airlines. The Lindbergh Terminal (Terminal 1) services nine airlines: It is not possible to display information about all nine airlines in a legible fashion simultaneously on a single CMS. Two alternative methods of presenting the Terminal 1 airline information were considered. In one case, the Terminal 1 airline information is displayed on two separate static CMSs, with one CMS located a short distance after the other on the highway approach. In the other case, Terminal 1 information is displayed on a single CMS, sequentially, in two phases. These two alternatives were compared in the experiment conducted in this study. For both alternatives, we compared whether or not the drivers took the appropriate highway exit. In addition, we also evaluated whether or not the CMSs caused the drivers to reduce their driving speed.

In this experiment, we were particularly interested in the responses of passengers unfamiliar with the MSP airport. Frequent users of the airport are likely to have a good understanding already of the linkage between the various airlines and the two terminals. In contrast, passengers unfamiliar with the airport are much more likely to benefit from the provision of information linking specific airlines to the terminals while they are still driving on the highway.

The simulated approach to the airport used in the experiment shared some features with the westbound approach to the MSP airport on I-494—the number of overpasses and highway signs were the same on the simulated approach and on the last eleven miles of westbound I-494 approach. However, the simulated approach was not recognizable as the westbound I-494 approach because (1) the specific content of all the highway signs, including all highway names, was changed (for example, I-494 was renamed I-410, Highway 5 was renamed Highway 77, and 34th Avenue was renamed 110th Avenue), and (2) the roadside features (the ground cover, trees and buildings) were distinctly different from the roadside features on the westbound I-494 approach. Because it was not recognizable as the westbound I-494 approach, the study participants (all of whom were Twin Cities motorists) were unfamiliar with the airport approach simulated in this experiment.

1.6 Organization of This Report

The remainder of this report describes the driving simulation experiment in which airline information was displayed on either a dual-phase CMS or on two static CMSs. The objective was to determine the relative effectiveness of the two methods of presentation and assist the MAC and Mn/DOT in making a decision about how to present airline information on the Trunk Highway approaches to the MSP airport. 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 an analysis of the accuracy of driver responses in both the dual-phase and static CMS conditions, and an analysis of driving speeds in both conditions.
- Chapter 4 summarizes the findings and conclusions.

Chapter 2. Method

2.1 Participants

There were 120 participants in this study. They were all licensed drivers from the following three age groups: 18-24, 32-47, and 55-65. There were 40 participants in each age group. Within each age group, there were 20 males and 20 females. The participants were recruited from the Twin Cities metropolitan area. After completing the experiment, each participant was paid $50 for his or her participation.

2.2 Driving Simulator

Each participant drove in a fully interactive, PC-based, STISIM driving simulator. The simulator was comprised of an automotive-style seat for the driver, which faced a bank of three 17" CRT displays. Three PCs generated the virtual environment presented on the CRT displays. Figure 2.1 shows the arrangement of the three PCs used in the STISIM simulator.

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

2.2.1 Visuals

The virtual environment displayed in the study was a six-lane freeway. As well as showing the freeway ahead, in the upper right corner of the center display a small window provided a rear view of the route on which the participant was diving. In the lower part of this display, the front of the simulated vehicle was shown, along with two dials—one to the left showing driving speed, the other to the right showing the RPM rate. In addition, in the left- and right-side displays there were two small windows simulating side-view mirrors that also provided rear views of the route.

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

2.2.3 Controls
The participants controlled the simulator with a steering wheel, an accelerator pedal, and a brake pedal. The simulator PCs registered the participants' 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—i.e., the simulated route driven by the participants—was developed using STISIM's Scenario Definition Language (SDL). In addition, modifications were made so that the lettering on the CMS displays and the Guide signs that were added to the simulated route could be read when the participants were at a simulated distance of approximately 860 feet (262 meters) from them.

2.3 Experimental Design

2.3.1 Airlines serviced by the MSP airport
The MSP airport currently services fourteen airlines—Terminal 1 (the Lindbergh Terminal) services nine airlines, and Terminal 1 (the Humphrey Terminal) services five. A single CMS can display the names of the five Terminal 2 airlines simultaneously. However, it is not possible to display the names of all nine Terminal 1 airlines simultaneously on a single CMS and have them visible from a reasonable distance. Two alternative ways of presenting the Terminal 1 airline information were tested in the experiment—one alternative used a dual-phase CMS, the other used two separate static CMSs.

There were five lines on the dual-phase CMS used to present the Terminal 1 information. One of the first line, the exit number—Exit 1A—was displayed, while on the second line the terminal number—Terminal 1—was displayed. Then, for one phase of the dual-phase CMS, the names of five airlines—Air Canada, Alaska, American, Continental, and Delta—were presented alphabetically in two columns, on the remaining three lines, as shown in the schematic in Figure 2.2.

EXIT 1A	
Terminal 1	
Air Canada	Continental
Alaska	Delta
American	

Figure 2.2. Terminal 1 airline information displayed on one phase of the dual-phase CMS

For the other phase of the dual-phase CMS, the names of four airlines—Frontier, Northwest, United, and US Airways—were presented alphabetically in two columns on the third and fourth lines of the panel, with the fifth line blank, as shown schematically in Figure 2.3.

EXIT 1A	
Terminal 1	
Frontier	United
Northwest	US Airways

Figure 2.3. Terminal 1 airline information displayed on the other phase of the dual-phase CMS

The alternative way of displaying the Terminal 1 airline information involved the use of two static CMSs located 500 ft (152.4 m) apart on the highway. There were also five lines on these two CMS. The information displayed on the first of these static CMSs was the same as the information presented in Figure 2.2, while the information displayed on the second static CMSs was identical to the information presented in Figure 2.3.

The names of the five airlines that utilize Terminal 2 (the Humphrey Terminal) were shown on a single static CMS. Again, there were five lines on this CMS, with the first line displaying the exit number—Exit 1B—the second line displaying the terminal number—Terminal 2—and the remaining three lines displaying the names of five airlines—Air Tran, Icelandair, Midwest, Southwest, and Sun Country—arranged alphabetically in two columns. The information displayed on this static CMS is shown schematically in Figure 2.4.

EXIT 1B	
Terminal 2	
Air Tran	Southwest
Icelandair	Sun Country
Midwest	

Figure 2.4. Terminal 2 airline information displayed on the final CMS

In the dual-phase condition, the CMS displaying Terminal 2 airline information was located on the highway 1,300 ft (396.2 m) beyond the dual-phase CMS displaying Terminal 1 information; while in the static condition, the CMS with Terminal 2 airline information was located 1,300 ft (396.2 m) beyond the first static CMS and a further 800 ft (243.8 m) beyond the second static CMS with Terminal 1 information.

2.3.2 CMS conditions

The 120 participants in the experiment were assigned—at random—to one of two groups. The participants did not know that there were two experimental groups nor did they know that they had been assigned to one of these groups.

There were 60 participants in each group, with an equal numbers of males and females in each group. One group was randomly assigned to the dual-phase condition, and the other to the static condition—the breakdown of participants is shown in Table 2.1

Table 2.1. Breakdown of participants

	Dual–Phase Condition		**Static Condition**	
Age	**Male**	**Female**	**Male**	**Female**
Younger	10	10	10	10
Middle Age	10	10	10	10
Older	10	10	10	10

In both conditions, the participants drove twice on the simulated route, which was a six-lane freeway. Before each drive, the participants were told that they were driving towards an airport—and they were also told which airline to look for (and given a piece of paper with the name of that airline printed on it). The simulated route was approximately eleven miles in length.

2.3.2.1 Static condition—At the beginning on the final section of the route, the participants assigned to the static condition saw an overhead sign warning them that they were approaching the airport. This sign is illustrated in Figure 2.5.

Figure 2.5. Overhead sign informing participants they were approaching the airport

The next sign seen by the participants in the static condition was a static CMS located 800 ft (243.8 m) beyond the sign shown in Figure 2.5. This CMS displayed the names of the five airlines serviced by Terminal 1. The sign, which also informed the participants that passengers for these five airlines should take Exit 1A, is shown in Figure 2.6.

Figure 2.6. First CMS with Terminal 1 airline information seen by participants in the static condition

After the first CMS (shown directly above in Figure 2.6), participants in the static condition saw the second static CMS, which was located 500 ft (154.2 m) further down the highway. This CMS displayed the names of the remaining four airlines serviced by Terminal 1—and also informed the participants that passengers for these four airlines should take Exit 1A. It is shown below in Figure 2.7.

Figure 2.7. Second CMS with Terminal 1 airline information seen by participants in the static condition

The participants in the static condition saw the third CMS—which displayed the names of the airlines serviced at Terminal 2—an additional 800 ft (243.8 m) further down the highway beyond the second static CMS. The third CMS, which is illustrated in Figure 2.8 below, informed the participants that passengers for these five airlines should take Exit 1B.

Figure 2.8. Third CMS with Terminal 1 airline information seen by participants in the static condition

2.3.2.2 Dual-phase condition—As they approached the airport, the participants assigned to the dual-phase condition also saw the overhead sign (shown earlier in Figure 2.5) that informed them that they were nearing the airport.

Eight hundred feet (243.8 m) after this overhead sign, the participants assigned to the dual-phase condition saw the dual-phase CMS. This CMS showed all nine of the names of the airlines serviced at Terminal 1—in two distinct phases. The participants saw the information shown earlier in Figure 2.6 in one phase and the information shown in Figure 2.7 in the other phase. The duration of each phase was two seconds, which is the minimum phase length required by Mn/DOT. The CMS cycled through the two phases continuously. The participants saw each phase at least twice—which is an FHWA requirement (MUTCD, 2007)—as they drove toward the dual-phase CMS. The phase of the CMS that participant saw first was a function of the time it took them to drive the experimental route prior to encountering the dual-phase CMS—it was equally likely that each participant would see either the message with five airline names or the message with four airline names first.

The CMS displaying Terminal 2 airline information (shown in Figure 2.8) was located 1,300 ft (396.2 m) farther down the highway than the dual-phase CMS.

2.3.3 Airline assignment
In the experiment, each participant drove the route towards the airport twice. The airlines to which they were assigned were presented in a counterbalanced order.

The counterbalancing was achieved using the following steps. First, the airlines to which each participant was assigned were different on the two drives. Second, the two airlines were selected from an equal number of times from each of the three CMS messages—as indicated below:

- For 20 participants, the airline was selected from the five possible airlines shown in Figure 2.6 for the first drive, then from the four possible airlines shown in Figure 2.7 for the second drive.
- For 20 participants, the airline was selected from the five airline names shown in Figure 2.6 for the first drive, then from the five airline names shown in Figure 2.8 for the second drive.
- For 20 participants, the airline was selected from the four airlines shown in Figure 2.7 for the first drive, then from the five airlines shown in Figure 2.8 for the second drive.
- For 20 participants, the airline was selected from the four possible airlines shown in Figure 2.7 for the first drive, then from the five possibilities shown in Figure 2.6 for the second drive.
- For 20 participants, the airline was selected from the five possibilities shown in Figure 2.8 for the first drive, then from the five airline names shown in Figure 2.6 for the second drive.
- And for 20 participants, the airline was selected from the five names shown in Figure 2.8 for the first drive, then from the four airline names shown in Figure 2.7 for the second drive.

Third, Figure 2.6 and Figure 2.8 both displayed five airlines, while Figure 2.7 displayed the names of four airlines. Therefore, in order to select airlines an equal number of times from all three CMS messages, for the both the static and the dual-phase CMS conditions, it was necessary to assign each of the five airlines presented on the CMSs shown in Figure 2.6 and Figure 2.8 eight times (four times for the first drive, and four times for the second drive); and it was necessary to assign each of the four airlines on the CMS shown in Figure 2.7 ten times (five times on the first drive, and five on the second drive). Sixty unique combinations of airlines assigned for the first and second drives were generated using these steps.

Fourth, the 60 combinations of airlines were assigned to the 60 participants in the dual-phase and static conditions. The 60 combinations were assigned in such a way that direct comparisons could be made between the two conditions. For example for the younger participants, the ten young male participants in the dual-phase condition were assigned the same ten combinations of airlines that were assigned to the ten young female participants in the static condition, and the ten combinations of airlines assigned to the ten male participants in the static condition were also assigned to the ten female participants in the dual-phase condition. A similar procedure was used to assign the combinations to the participants in both the middle age group and the older group of participants.

[It should be noted that, in Appendix A, the full details of the assignment of the 60 combinations of airlines to the younger, middle age, and older participants in both the dual-phase condition and the static condition are presented.]

2.3.4 Data

Data were collected from the 120 experimental participants both during and after the drives.

2.3.4.1 Experimental data—Two types of data were collected during the experimental drives. First, in order to determine the effectiveness of the CMS messages, we recorded the response of the participants at the end of both of their drive—i.e., whether or not they selected the correct exit for the assigned airlines. Second, we also determined whether or not their driving speed differed during the time that the CMS messages were visible, from their driving speed when these CMSs were not visible. The results of analyzing these two types of data are reported in Chapter 3.

2.3.4.2 Survey data—After each participant completed the second drive, he or she was asked to complete a survey. The survey included questions regarding the attitude of the participants to CMS messages they may have encountered on roadways in the Twin Cities—the complete survey is presented in Appendix C. Details of the analysis of the responses of the participants to the survey questions are reported in Appendix D.

2.4 Experimental Procedure

Before arriving at the simulator facility, each participant (without his or her knowledge) was pre-assigned to either the dual-phase or static condition. When the participant arrived at the simulator facility, 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 the experimental session would last approximately one hour, and that during that time he or she would be asked to drive twice in the driving simulator and, following that, to complete a survey.

Next, the participant sat in the simulator and was told that to drive on the simulated road, he or she would need to use the steering wheel, the accelerator, and brake pedals. The participant was informed that the turn signal was functional, and shown the rear-view mirror and two side mirrors.

Each participant was told that he or she would be driving on a six-lane divided highway and that the speed limit on this highway was 60 mph. Then, he or she had a brief practice drive (of approximately six or seven minutes). During the practice drive, the experimenter asked the participant to drive at 60 mph, to change lanes, to slow down to 35 mph, and to accelerate back to 60 mph. After the practice drive, if the participant had any questions, the experimenter answered them.

Before the first drive the following information was provided to each participant. The participant was

- Informed that he or she would be driving towards an airport.
- Told which airline he or she was looking for—and was given a piece of paper with the name of that airline.
- Told that the speed limit on the road was 60 mph.
- Asked to "Please drive as you normally would."

It should be noted that the participant was not given any information about highway signage, including CMS displays.

At the end of the first drive, the participant was asked to pull over to the hard shoulder and stop. The experimenter noted whether or not the participant took the correct exit—i.e., the exit that would take them to the terminal for his or her assigned airline. It should be noted that the experimenter did not comment on this to the participant.

Next, the experimenter reset the simulator for the second drive. When it was ready, the experimenter again told the participant that he or she would be driving towards an airport, and which airline he or she was looking for, and also gave him or her a piece of paper with the name of that airline. Once more, the participant was told that the speed limit on the road was 60 mph, and was asked to "Please drive as you normally would."

At the end of this drive, the participant was asked to pull over to the hard shoulder and stop and, again, the experimenter noted whether or not the participant took the correct exit.

If the participant failed to take the correct exit on the second drive, the experimenter said "I noticed that you didn't take the exit for your airline. Can you tell me why you didn't?" The experimenter noted the participant's response. Then, if the participant had failed to take the correct exit on the first drive, the experimenter asked the participant why they had not taken it. [The full text of the questions is presented in Appendix B.]

At this point, the participant was asked moved to a desk at the back of the simulator room. There, he or she was given a brief survey. The survey included questions regarding his or her attitude to CMS messages that he or she may have encountered on roadways in the Twin Cities. [As mentioned above, the text of the survey is presented in Appendix C.]

On completing the survey, the participant was debriefed. The debriefing was as follows:

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

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

Chapter 3. Results and Discussion

3.1 Driving Performance Data

Two types of data were collected during the experimental drives—exit response data and speed data. The exit response data obtained from the participants in the static and dual-phase CMS conditions were analyzed in order to compare the relative effectiveness of the two types of CMSs. Then, the speed data were analyzed to determine whether or not the driving speed of the participants differed during the time that the static and dual-phase CMS messages were visible, from the driving speed of the participants when these CMSs were not visible.

3.2. Exit Data

Each of the 120 participants drove the experimental route twice—giving a total of 240 drives. The exit data showed that the participants took the correct exit for the airline to which they were assigned on 215 of 240 drives (i.e., on 89.6% of the drives). They failed to take the correct exit on the remaining 25 drives (i.e., on 10.4% of the drives). We conducted further analysis to determine whether or not the 25 failures to take the correct exit were associated with the:

- Drive (i.e., whether more participants failed to take the correct exit on the first drive or the second).
- Age of the participants.
- Gender of the participants.
- CMS condition (i.e., whether the participants who failed to take the correct exit were in the dual-phase CMS condition or the static CMS condition).

The results of this further analysis are reported below.

3.2.1 Effect of drive

The number of participants who failed to take the correct exit on the first drive and second drives is shown in Table 3.1.

Table 3.1. Number of failures to take the correct exit on drive 1 and drive 2

Drive	**Number of Failures**
Drive 1	20
Drive 2	5
Total	25

Table 3.1 shows that 20 participants failed to take the correct exit on the first drive, while only five participants failed to take the correct exit on the second drive. The binomial test was performed on these data. The test indicated that the two-tailed probability of having only five failures to take the correct exit out the total of 25 failures is statistically significant (at the 0.004 level)—so, the participants were more likely to fail to take the correct exit on the first drive.

3.2.2 Effect of age

Table 3.2 shows the number of participants in each of the three age groups who failed to take the correct exit.

Table 3.2. Number of failures to take the correct exit for each age group

Age Group	Number of Failures
Younger	4
Middle Age	7
Older	14
Total	25

A chi-square test performed on the data shown in Table 3.2 indicated that there was a statistically significant effect of age—the χ^2 value was 6.35, which exceeds 5.99, the critical value of χ^2 for 2 *df* and $\alpha = 0.05$. For the older drivers there were more failures to take the correct exit than there were for the middle age drivers and, in turn, for the middle age drivers there were more failures than there were for the younger drivers. The effect of age on the number of failures to take the correct exit is illustrated in Figure 3.1.

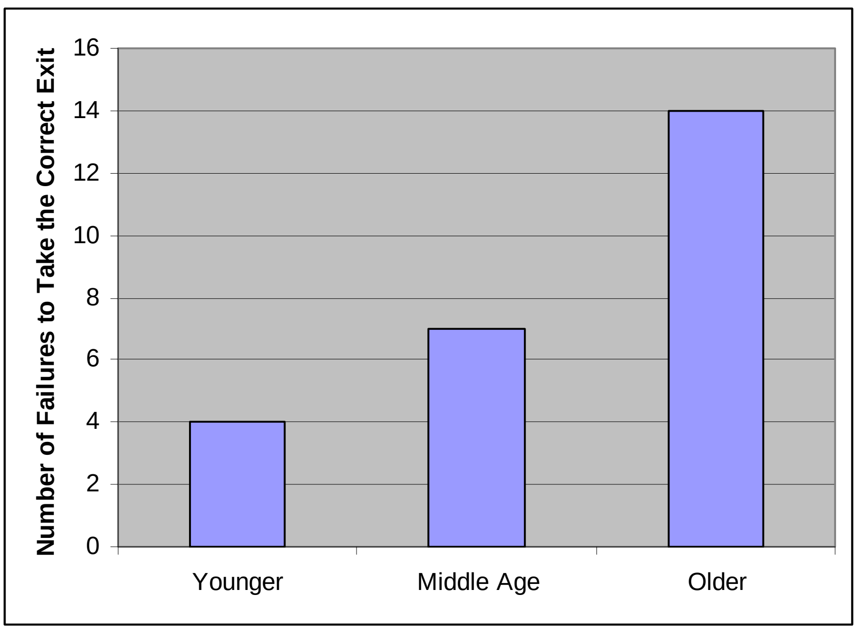

Figure 3.1. Number of participants who failed to take the correct exit in each age group

3.2.3 Effect of gender

The number of male and female participants who failed to take the correct exit is shown in Table 3.3.

Table 3.3. Number of failures to take the correct exit for the male and female participants

Gender	Number of Failures
Males	13
Females	12
Total	25

As Table 3.3 indicates gender had no effect on the number of participants who failed to take the correct exit.

3.2.4 Effect of CMS condition

The number of participants in the dual-phase and static CMS conditions who failed to take the correct exit is presented in Table 3.4.

Table 3.4. Number of failures to take the correct exit for participants in the dual-phase and static CMS conditions

Condition	Number of Failures
Dual-phase	11
Static	14
Total	25

The binomial test was used to compare the data presented in Table 3.4. The test indicated that there was no statistically significant difference between the number of participants in the dual-phase CMS condition who failed to take the correct exit and the number of participants in the static CMS condition who did not take the correct exit.

3.3. Speed Data

3.3.1 Analysis of speed data

For all 120 participants in both of their drives, average speed was determined in five different segments of the approach to the CMSs that displayed airline information. The within-segment distances were measured from the location of the CMS displaying Terminal 2 airline information in both CMS conditions. Table 3.5 shows these segment distances, as well as the location of the CMSs in both the dual-phase CMS condition and the static CMS condition.

Table 3.5. Segments in which speed was collected (and the location of CMSs in the dual-phase and static CMS conditions)

Segment	Distance (from Terminal 2 CMS)	Location of CMSs in Dual-Phase Condition	Location of CMSs in Static Condition
Segment #1	3,700 feet to 2,900 ft	—	—
Segment #2	2,900 feet to 2,100 ft	—	—
Segment #3	2,100 feet to 1,300 ft	—	—
	1,300 ft	Dual-phase CMS	First static CMS
Segment #4	1,300 feet to 800 ft	—	—
	800 ft	—	Second static CMS
Segment #5	800 feet to 0 ft	—	—
	0 ft	Terminal 2 CMS	Terminal 2 CMS

As Table 3.5 shows that, in addition to determining the average speed in the three segments that immediately precede the CMSs containing airline information (i.e., segment #3, segment #4, and segment #5), we also determined average speed in the two 800-ft (243.8-m) segments preceding segment #3. This was done to allow a comparison between the average speed before the participants were able to see the CMSs displaying airline information and the average speed when they were able to see these CMSs.

An Analysis of Variance (ANOVA) was used to analyze the average speed of the participants in the five segments. A summary of this analysis is presented in Table 3.6.

Table 3.6. Summary of ANOVA conducted on average speed in the five highway segments

Source of Variation	Degrees of Freedom	F-value	p-value
Gender (G)	1	2.63	0.1079
Age (A)	2	10.42	**0.0001**
Condition (C)	1	0.18	0.6716
Segment (S)	4	9.59	**0.0001**
Drive (D)	1	14.65	**0.0001**
G x A	2	0.87	0.4226
G x C	1	0.01	0.9394
G x S	4	0.63	0.6381
G x D	1	1.34	0.2469
A x C	2	1.33	0.2679
A x S	2	1.52	0.1449
A x D	8	1.11	0.3311
C x S	4	0.44	0.7830
C x D	1	4.53	**0.0335**
S x D	4	0.20	0.9404
G x A x C	2	0.27	0.7641
G x A x S	8	1.16	0.3173
G x A x D	2	4.18	**0.0155**
G x C x S	4	0.18	0.9487
G x C x D	1	7.19	**0.0075**
G x D x S	4	0.22	0.9254
A x C x S	8	2.27	**0.0211**
A x C x D	2	0.61	0.5413
A x S x D	8	0.67	0.7164
C x S x D	4	0.92	0.4509
G x A x C x S	8	0.34	0.9494
G x A x C x D	2	2.82	0.0604
G x A x S x D	8	1.46	0.1692
G x C x S x D	4	0.08	0.9898
A x C x S x D	8	0.23	0.9849

Table 3.6 indicates that there were three highly significant main effects (all at the 0.0001 probability level). The table also shows there was one two-way interaction and there were three three-way interactions. While statistically significant, these interactions involve average speed differences of relatively small magnitude that do not impinge on the main effects. [These interactions are explored in detail in Appendix E.]

The statistically significant main effects—of the age of the participants, of drive, and of segment—are explored in the following subsections.

3.3.2 Effect of age

The main effect of age of the participants on the average speed through the five highway segments on the approach to the CMSs displaying airline information is shown in Table 3.7 below.

Table 3.7. Average speed as a function of the age of the participants

Age	Average Speed (mph)
Younger	64.35
Middle Age	61.53
Older	59.36

As Table 3.7 indicates, the average speed throughout the five segments was 2.82 mph faster for the younger drivers than it was for the middle age drivers who, in turn, drove 2.17 mph faster the participants in the older driver group. These differences in average speed are illustrated in Figure 3.2 below.

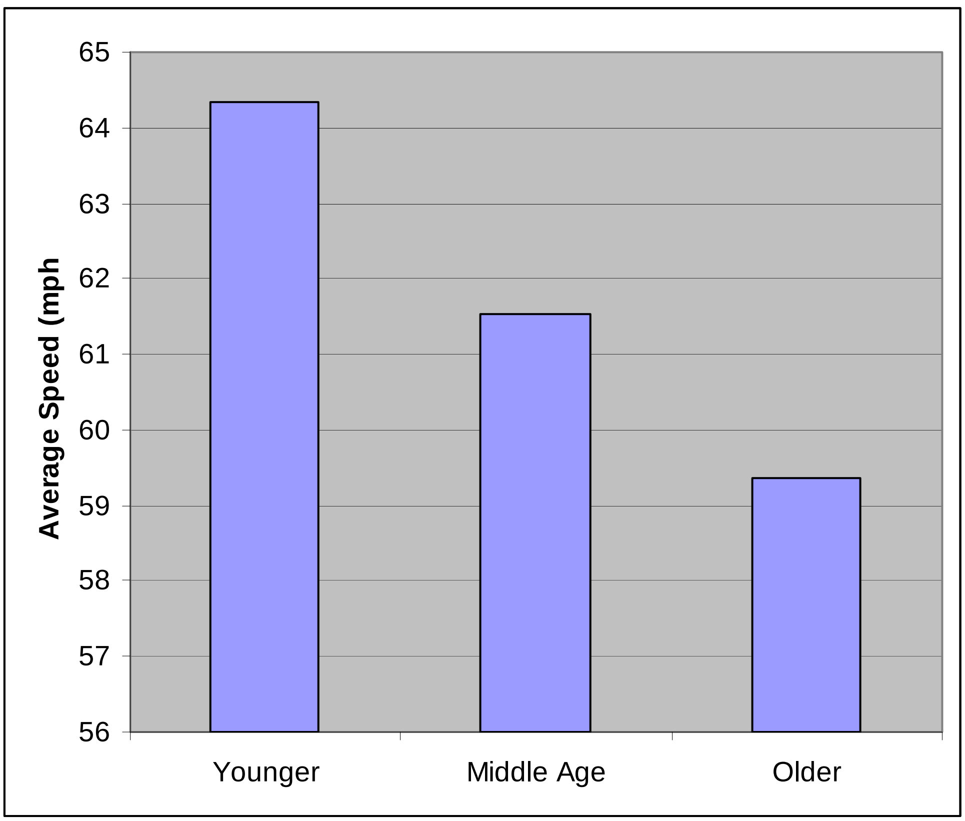

Figure 3.2. Average speed as a function of the age of the participants

The differences in average speed for the participants in the three age groups illustrated in Figure 3.2 were obtained with the participants driving on a simulated six-lane highway with a speed limit of 60 mph. The differences are similar in magnitude to differences in average speed that were obtained in previous studies of CMSs using the same STISIM driving simulator. For example, in an experiment that involved participants from the same three different ages driving on a simulated four-lane highway, where the speed limit was 55 mph, Harder and Bloomfield (2007) also found differences of 2 to 3 mph between younger and middle age drivers, and between middle age and older drivers.

3.3.3 Effect of drive

There was also a statistical significant main effect of the drive on average speed. The average speeds in the first and second drives are presented in Table 3.8 and illustrated in Figure 3.3 below.

Table 3.8. Average speed in the first and second drives

Drive	Average Speed (mph)
Drive 1	61.43
Drive 2	62.06

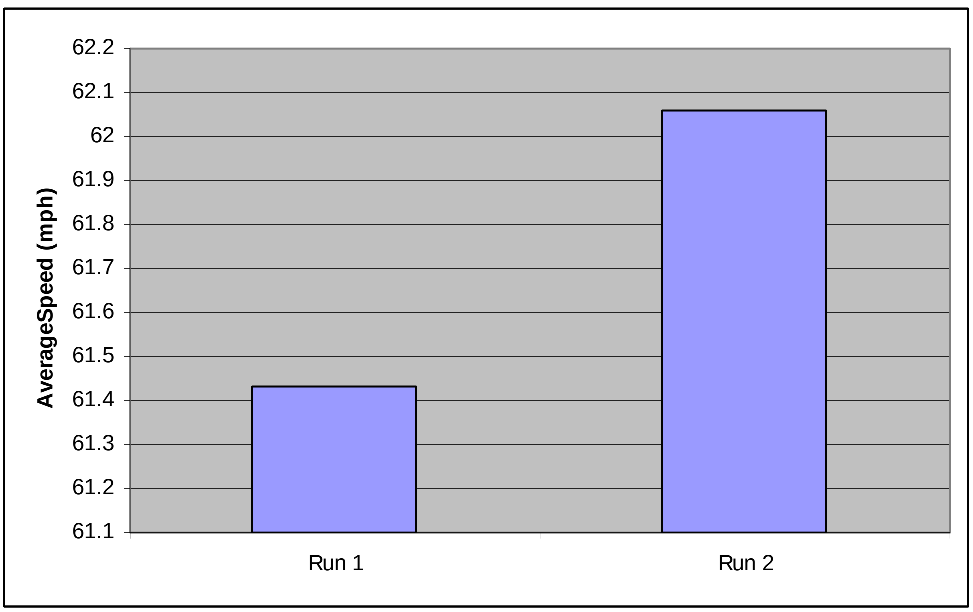

Figure 3.3. Average speed in the first and second drives

As both Table 3.8 and Figure 3.3 show, the average speed of the participants increased from the first to the second drive. Average speed increased by 0.63 mph from the first drive to the second.

3.3.4 Effect of highway segment

The ANOVA summary presented in Table 3.6 indicated that there was a significant difference in the average speed in the five segments on the approach to the CMSs that displayed airline information. The average speed in each of these five segments is reported below in Table 3.9.

Table 3.9. Average speed in each of the five segments

Segment	Average Speed (mph)
Segment #1	62.22
Segment #2	62.04
Segment #3	62.22
Segment #4	62.07
Segment #5	61.59

As Table 3.9 indicates, the differences in average speed were relatively small in magnitude. When Tukey-Kramer tests were administered *post hoc* to further explore the differences, the tests indicated that the average speeds in the first four segments were not significantly different from each other, but that the average speeds in these first four segments were all significantly faster than the average speed in segment #5—i.e., in the final 800-ft (243.8 m) segment before the static CMS displaying the Terminal 2 airline information. The average speeds in the five segments to are illustrated in Figure 3.4 below.

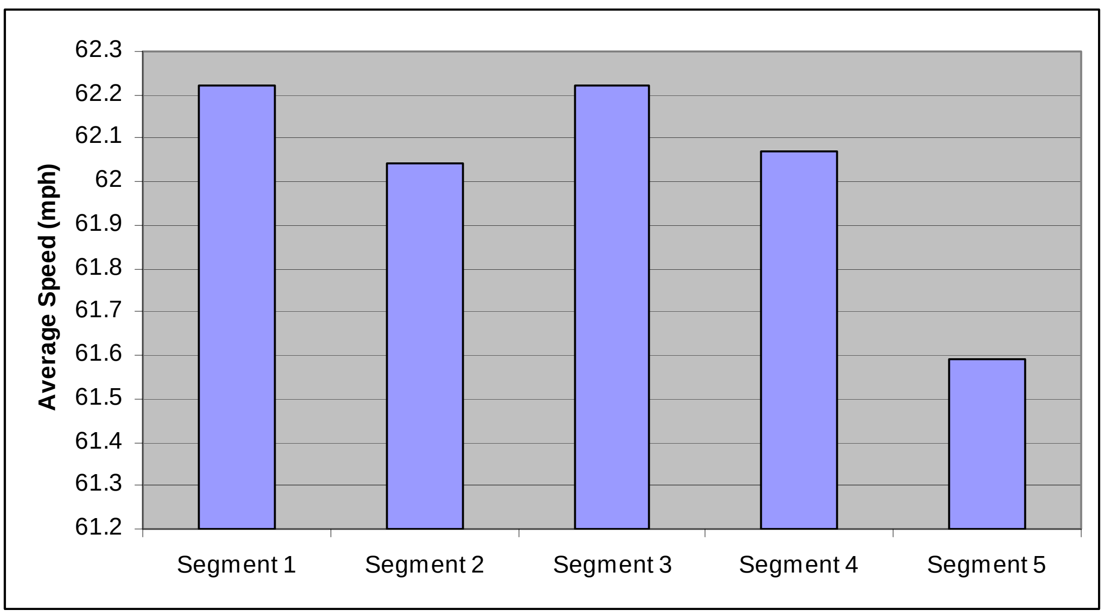

Figure 3.4. Average speed in each of the five segments

While the differences in average speed between the first four segments and segment #5 were statistically significant, they were relatively small in magnitude—the average speeds in the first four segments were between 0.45 mph and 0.63 mph faster than the average speed obtained in segment #5.

3.3.5 Effect of CMS condition

It should be noted that, while the ANOVA presented in Table 3.6 indicated that there were three main effect on driving speed, there was no main effect on the speed in the five segments that could be related to the CMS conditions (*i.e., the average speed was not affected by whether the participants drove in the dual-phase CMS condition or the static CMS condition*).

3.3.6 Effect of gender

The ANOVA presented in Table 3.6 also indicated that there was also no effect of the gender of the participants on driving speed.

3.4 Individual Speed Reductions

Because average speed data do not reveal the extent to which an individual driver might reduce speed from one segment to another, we examined the speed of individual participants in more detail. In particular, we examined all speed reductions, from one segment to the next, that were 2 mph or more—smaller reductions than this are unlikely to have much impact on traffic flow.

We found that a total of 29 of the 120 participants (i.e., 24.2%) reduced speed by 2 mph or more between segments. Nine of these 29 participants reduced speed between segments on *both* the first and second drives. In addition, 13 of the 29 participants reduced speed by 2 mph or more on two or three occasions during the *same* drive. As a result, the 29 participants were responsible for a total of 53 reductions in speed of 2 mph or more between various segments in the two drives.

3.4.1 Speed reductions and age

Table 3.10 shows the number of participants in each of the three age groups who reduced speed by 2 mph or more on at least one occasion

Table 3.10. Number of younger, middle age, and older participants who reduced speed by 2 mph or more

Age	**Number Who Reduced Speed**
Younger	11
Middle Age	8
Older	10
Total	29

A chi-square test performed on the data reported in Table 3.10 indicated that the age of the participants did not have a statistically significant on whether or not they reduced speed by 2 mph or more between the segments.

3.4.2 Speed reductions and gender
The number of male and female participants who reduced speed by 2 mph or more is reported in Table 3.11.

Table 3.11. Number of male and female participants who reduced speed by 2 mph or more

Gender	**Number Who Reduced Speed**
Males	14
Females	15
Total	29

As Table 3.11 shows, gender was not related to whether or not the participant reduced speed by 2 mph between the segments.

3.4.3 Speed reductions and drive
The number of participants who reduced speed by 2 mph or more on the first drive, on the second drive, or on both drives is shown in Table 3.12.

Table 3.12. Number of participants who reduced speed by 2 mph or more in drive 1, drive 2, or both drives

Drive	**Number Who Reduced Speed**
Drive 1	9
Drive 2	9
Both Drive 1 & 2	10
Total	29

Table 3.12 indicates that whether the participants were driving on the simulated route for the first time or the second time did not affect the number of participants who reduced speed by 2 mph or more between segments.

3.4.4 Speed Reductions and CMS condition
The number of participants in the dual-phase and static CMS conditions who had speed reductions of 2 mph or more is presented in Table 3.13.

Table 3.13. Number of participants in the dual-phase and static CMS conditions who reduced speed by 2 mph or more

Condition	Number Who Reduced Speed
Dual-phase	16
Static	13
Total	29

The binomial test was used to compare the data presented in Table 3.13. The test indicated that there was no statistically significant difference in the number of participants who reduced speed by 2 mph or more in the dual-phase CMS condition and those who reduced speed in the static CMS condition.

3.4.5 Speed reductions and highway segment

As mentioned above, the 29 participants who did reduce speed by 2 mph at least once were responsible for a total of 53 reductions in speed in the two drives. The number of speed reductions between consecutive segments is shown in Table 3.14

Table 3.14. Number of speed reductions between segments

	Number of Speed Reductions
Segments 1 & 2	7
Segments 2 & 3	9
Segments 3 & 4	15
Segments 4 & 5	22
Total	53

A chi-square test performed on the data shown in Table 3.14. The test indicated that there was a statistically significant effect of segments on the number of reductions in speed—the χ^2 value was 10.32, which exceeds 9.84, the critical value of χ^2 for 3 *df* and $\alpha = 0.02$. The change in the number of speed reductions is illustrated in 3.5 below.

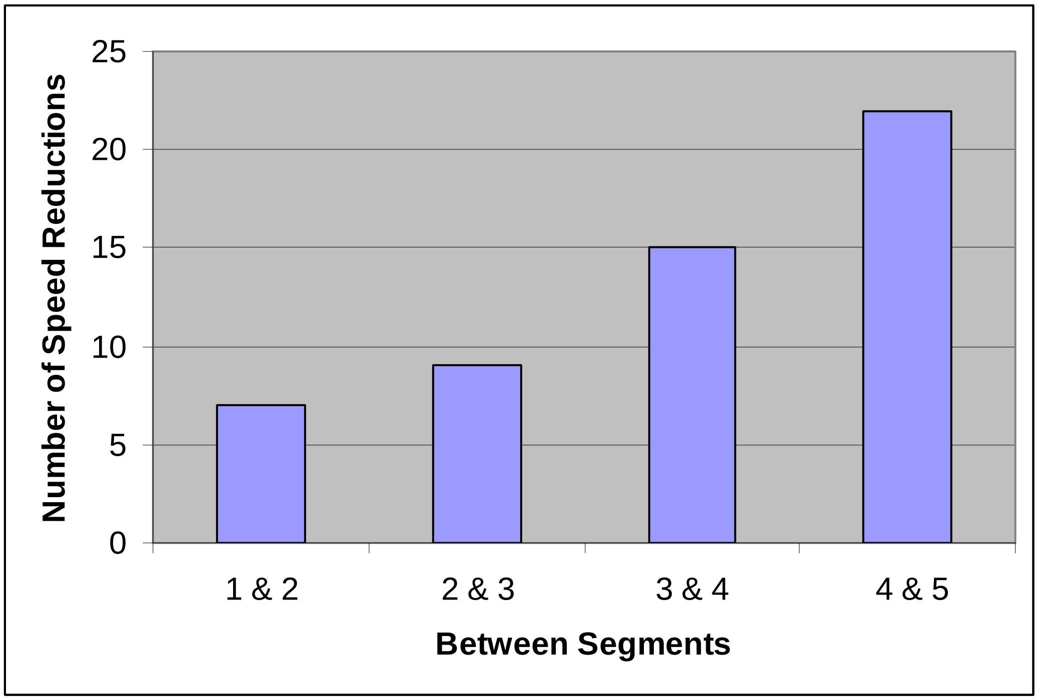

Figure 3.5. Number of speed reductions between segments

As Figure 3.5 shows there were seven speed reductions of 2 mph or more between segment #1 and segment #2—i.e., *before* the participants were able to see the first CMS presenting airline information.

It should also be noted that Figure 3.5 shows that the largest number of reductions in speed occurred between segment #4 and segment #5—i.e., they occurred in the segment that ended with the CMS that displayed airline information related to Terminal 2.

3.4.6 Magnitude of speed reductions

Next, we examined the magnitude of the 53 reductions in speed of 2 mph or more (made by the 29 participants). Twenty-six of these reductions occurred for participants in the dual-phase CMS condition and 27 for participants in the static CMS condition. The magnitude of these reductions in both conditions is shown in Table 3.15 below.

Table 3.15. Magnitude of speed reductions in the dual-phase and static CMS conditions

Speed Range	Number of Participants in Range in Dual-Phase CMS Condition	Cumulative Number of Participants in Dual-Phase CMS Condition	Number of Participants in Range in Static CMS Condition	Cumulative Number of Participants in Static CMS Condition
Reductions greater than -14 mph	1	26	1	27
-13 to -14 mph	0	25	1	26
-12 to -13 mph	1	25	0	25
-11 to -12 mph	0	24	1	25
-10 to -11 mph	0	24	2	24
-9 to -10 mph	1	24	1	22
-8 to -9 mph	1	23	0	21
-7 to -8 mph	1	22	0	21
-6 to -7 mph	2	21	2	21
-5 to -6 mph	3	19	3	19
-4 to -5 mph	2	16	3	16
-3 to -4 mph	6	14	4	13
-2 to -3 mph	8	8	9	9

Table 3.15 shows that there was virtually no difference in the number of reductions between the dual-phase and static CMS conditions at all reduction magnitudes.

[It should be noted that there were two participants who reduced speed by more than -13 mph. An older male in the dual-phase CMS condition reduced speed by -15.94 mph between segments 4 and 5, and an older female in the static CMS condition reduced speed by -26.35 mph between segments 4 and 5. In both cases, these reductions in speed occurred in the second drive.]

3.5 Survey Data

After the 120 participants had finished both drives, they 120 were asked to complete a survey that consisted of fifteen questions. First, 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 Appendix D).

After this, there were three questions on the survey that were related to airports. When they were asked whether or not, when driving on Metro Freeways, they had seen signs that give general directions to the airport, 118 of the 120 participants (98%) indicated that they had seen them.

When asked whether or not they had driven to airports in other cities, 100 participants (88.3%) indicated that they had. The third questions asked the participants to use a seven-point rating scale to compare the current roadway signs giving directions to the MSP airport with the roadway signs giving directions to airports in other cities—the average rating given was 4.6 (standard deviation = 1.2), indicating that respondents think the airport signage in the Twin Cities is slightly better than the signage they have seen in other cities.

The final two questions on the survey related to dual-phase CMS messages. Ninety-one of the 120 participants (76%) indicated that they had seen message boards that switch between two messages. The next question asked these 91 participants to use a seven-point rating scale, from "Very difficult" (a rating of 1) to "Very Easy" (a rating of 7), to rate how easy or difficult is to understand the messages on message boards that switch between two messages. The average rating given was 4.4 (standard deviation = 1.5), indicating these messages were judged to be slightly to the easy side of the mid-point of the seven-point scale.

[Please note, a more detailed account of the analysis of the participants' responses to the questions related to airports and dual-phase messages are also given in Appendix D].

Chapter 4. Summary and Conclusion

4.1 Objective

The objective of this study was to determine whether messages displayed on dual-phase CMSs, which the MAC has proposed for use on the Trunk Highway approaches to the MSP airport, are as effective in influencing driving behavior as messages displayed on static CMSs.

The MSP airport has two terminals but no shared roadway system between the two terminals. As a result, passengers driving towards the MSP airport need to select the exit for the terminal they are planning to use while they are still on the highway—passengers who arrive at the wrong terminal have to go back to the highway in order to reach the correct terminal.

Currently, only terminal information is displayed on signs on the highway approaches to the airport—individual airline information is not presented. However, the MAC and Mn/DOT are planning to provide information that links the individual airlines to the two terminals on CMSs to be installed on the highway approaches. The highway approaches to the MSP airport already contain a large number of road signs in a relatively short distance—therefore, it desirable to display the airline information on as few CMSs as possible.

The Humphrey Terminal (which is to be renamed Terminal 2) services five airlines—this information can be displayed on a single CMS. In contrast, the Lindbergh Terminal (to be renamed Terminal 1) services nine airlines—and it is not possible to display the names of all these airlines simultaneously on a single CMS, and have the names legible to drivers at a reasonable distance.

4.2 The Experiment

Two alternative presentation methods were compared in this study, which utilized a STISIM driving simulator. One method used two separate CMSs that were located 500 ft (152.4 m) apart on the highway. The other method used a single CMS that displayed the Terminal 1 information in two phases.

We conducted an experiment using 120 participants—60 of whom were assigned to the dual-phase CMS condition and 60 to the static CMS condition. The 60 participants assigned to each condition included ten males and ten females from each of three age groups—i.e., younger participants between the ages of 18-24, middle age participants who were between 32-47, and older participants who were between 55-65. Each participant drove towards the airport twice, on an eleven-mile long six-lane divided highway. Both drives for each participant were with the same CMS condition.

The airlines to which the participants were assigned were presented in a counterbalanced order. Before each experimental drive, the participants were told that they would be driving on a six-lane divided highway towards an airport. They were also told which airline they were looking for, that speed limit on the road was 60 mph, and that they should drive as they normally would. When each drive was completed, the experimenter noted whether or not the participant took the correct exit for the airline to which he or she was assigned. We also collected driving speed data in five highway segments on the approach to the CMSs displaying airline information

4.3 Results

4.3.1 Exit data

All 120 participants drove the experimental route twice—giving a total of 240 drives. The results showed that participants took the correct exit on 89.6% of the drives (215 of 240 drives). They failed to take the correct exit on 10.4% of the drives (25 out of 240).
Twenty of the 25 failures occurred on the first drive, and only five occurred on the second. With regard to the age of the participants, there were more failures for the older drivers (14) than the middle age drivers (7) and the younger drivers (4). The gender of the participants had no effect on the number failures to take the correct exit.

Also, and most importantly, given the objective of this study, there was no statistically significant difference between the number of participants in the dual-phase CMS condition who failed to take the correct exit and the number of participants in the static CMS condition who did not take the correct exit.

4.3.2 Speed data

In each drive, the average speed of the participant was determined in five different segments of the approach to the CMSs displaying airline information. The first two highway segments—each of 880 ft (243.8 m)—were directly before the CMSs were visible. The third segment—also of 800 ft (243.8 m)—ended at the location of the first CMS (i.e., at the location of the first static CMS in the static condition, and of the dual-phase CMS in the dual-phase condition). The fourth segment—of 500 ft (152.4 m)—ended at the location of the second static CMS (in the static condition). And the fifth segment—of 800 ft (243.8 m)—ended at the location of the CMS displaying the names of the airlines serviced at Terminal 2.

The analysis of the speed data indicated that there were statistically significant differences in average speed for the three age groups—the younger drivers drove 2.82 mph faster than the middle age drivers, and the middle age drivers drove 2.17 mph faster than the older drivers. These differences in average speed were obtained with the participants driving on a simulated six-lane highway with a speed limit of 60 mph. They were similar in magnitude to differences in average speed obtained for younger, middle age, and older drivers by Harder and Bloomfield (2008) in a previous study of CMSs using the same STISIM driving simulator.

The analysis also indicated that the average speed of the participants was significantly faster on the second drive than it was on the first drive. Also, the average speed was significantly slower in the fifth segment than it was in the first four segments.

However, there was no statistically significant difference in speed that could be related to the CMS conditions—the average speed was not affected by whether the participants drove in the dual-phase CMS condition or the static CMS condition.

4.3.3 Speed reduction data
Since average speed data do not reveal the extent to which individuals might reduce speed from one segment to another, we also examined the speed of the individual participants, focusing on individual reductions in speed from one segment to the next. We considered all reductions that were of 2 mph or more—smaller reductions than this are not likely to have much impact on traffic flow.

Twenty-nine participants reduced speed by 2 mph or more between segments—nine of them reduced speed between segments on both drives. And 13 of them reduced speed by 2 mph or more on two occasions in the same drive. The result was that these 29 participants were responsible for a total of 53 reductions in speed of 2 mph or more between various segments in the two drives.

We found that the CMS conditions had no statistically significant difference on the number of participants who reduced speed by 2 mph or more. Similarly, there were also no statistically significant effects of the age or gender of the participants. And, there was no difference between the number of participants who reduced speed by 2 mph in the first and second drives.

The only statistically significance in the number of speed reductions of at least 2 mph was related to the segments. The number of reductions gradually increased from segment #1 to segment #5, with the largest number of reductions in speed occurring between segment #4 and segment #5—i.e., they occurred in the segment that ended with the CMS that displayed airline information related to Terminal 2.

We also compared the magnitude of the speed reductions for the dual-phase and static conditions. The comparison showed that there was no difference in the magnitude of the speed reductions between the dual-phase and static CMS conditions.

4.4 Conclusion

We conducted a driving simulation experiment in order to determine whether messages displayed on dual-phase CMSs are as effective in influencing driving behavior as messages displayed on static CMSs.

Although we found several statistically significant effects, our analysis did not show any performance differences that were related to the CMS conditions. There was no statistically significant difference between the number of participants in the dual-phase and static conditions who failed to take the correct exit. The two methods of displaying the information were equally effective—with 89.6% of the participants taking the correct exit.

There was also no statistically significant difference in the average speed of the participants in the dual-phase and static CMS conditions on the approach to the CMSs. Further, when the individual driving speeds were examined there were no differences in the number of individual participants in the two groups who reduced speed at least by 2 mph in the five segments on the approach to the CMSs. And finally, there were no differences in the magnitude of the individual reductions in speed between the participants in the dual-phase CMS condition and the participants in the static CMS conditions

Based on the data obtained in this experiment, displaying airline information on a dual-phase CMS is as effective in influencing driving behavior as displaying the same airline information on two static CMSs. There was no evidence to suggest that a dual-phase CMS should not be used instead of two static CMSs. In this driving simulator experiment, a single dual-phase CMS and two static CMSs were equally effective in displaying airline information on the simulated airport approach.

References

Dudek, C.L. (1997). *Changeable Message Signs*. Report No.: NCHRP Synthesis Report 237. Washington, D.C.: Transportation Research Board.

Dudek, C.L. (2004). *Changeable Message Sign Operation and Messaging Handbook*. Report No.: FHWA-OP-03-070. Washington, D.C.: Federal Highway Administration.

Forbes, T.W., Moskowitz, K., and Morgan, G. (1950). "A Comparison of Lower Case and Capital Letters for Highway Signs." *Proceedings, Highway Research Board* 30, 355-73.

Garvey, P.M. and Mace, D.J. (1996). *Changeable Message Sign Visibility*. Report No.: FHWA-RD-94-077. Washington, D.C.: Federal Highway Administration.

Garvey, P.M., Pietrucha, M.T., and Meeker, D. (1997). "Effects of Font and Capitalization on Legibility of Guide Signs." *Transportation Research Record*, 1605, 73-79.

Guerrier, J.H., Wachtel, J.A., and Budenz, D.L. (2002). "Drivers' Responses to Changeable Message Signs of Differing Message Length and Traffic Conditions." In: McCabe, P.T. *Contemporary Ergonomics* (2002). London, U.K.: Taylor & Francis, 223-228.

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/DOT Report No.: MN/RC 2008-27. Minnesota Department of Transportation, August.

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, June.

MUTCD. (2007). *Manual on Uniform Traffic Devices for Streets and Highways* (2003 Edition with Revision Number 1, incorporated in November 2004, and Revision 2 incorporated in December 2007). Accessed online at http://mutcd.fhwa.dot.gov/kno_2003r1r2.htm.

MSP Website. (2009). Accessed on July 23, 2009 at http://www.mspairport.com/about-msp/statistics.aspx.

Pedic, F., and Ezrakhovich, A. (1999). "A Literature Review: The Content Characteristics of Effective VMS." *Road & Transport Research*, 8(2), 3-11.

Ullman, B.R., Ullman, G.L., Dudek, C.L. and Williams, A.A. (2007). "Driver Understanding of Sequential Portable Changeable Message Signs in Work Zones." *Transportation Research Record*, 2015, 28-35.

Appendix A
Counterbalanced Order

The twelve tables presented in this appendix show the order in which the 60 combinations of airlines were assigned to the first and second drives completed by the participants in the experiment. Tables A.1 through A.6 show the combinations of airlines assigned for both drives completed by the 60 participants in the dual-phase condition. Similarly, Tables A.7 through A.12 detail how the same 60 combinations of airlines were assigned in the two drives undertaken by the 60 participants in the static condition.

As mentioned in the main text, the 60 combinations of airlines were assigned so that direct comparisons could be made between the two conditions. For example, the ten combinations of airlines that were presented to ten male participants in the dual-phase condition (shown in Table A.1) were presented to ten female participants in the static condition (shown in Table A.8). And, the ten combinations of airlines that were presented to ten female participants in the dual-phase condition (shown in Table A.2) were presented to ten male participants in the static condition (shown inTable A.7).

Table A.1. Order for Younger Males in the Dual-Phase Condition

Subject	Drive	Airline	CMS Panel	Terminal
YM 01	1	Air Canada	1	1
YM 01	2	Northwest	2	1
YM 03	1	Continental	1	1
YM 03	2	Air Tran	3	2
YM 05	1	Frontier	2	1
YM 05	2	Alaska	1	1
YM 07	1	US Airways	2	1
YM 07	2	Icelander	3	2
YM 09	1	Air Tran	3	2
YM 09	2	Alaska	1	1
YM 11	1	Midwest	3	2
YM 11	2	US Airways	2	1
YM 13	1	Alaska	1	1
YM 13	2	Frontier	2	1
YM 15	1	Delta	1	1
YM 15	2	Icelandair	3	2
YM 17	1	Northwest	2	1
YM 17	2	American	1	1
YM 19	1	United	2	1
YM 19	2	Sun Country	3	2

Table A.2. Order for Younger Females in the Dual-Phase Condition

Subject	Drive	Airline	CMS Panel	Terminal
YF 02	1	Icelandair	3	2
YF 02	2	Air Canada	1	1
YF 04	1	Sun Country	3	2
YF 04	2	Northwest	2	1
YF 06	1	American	1	1
YF 06	2	Northwest	2	1
YF 08	1	Air Canada	1	1
YF 08	2	Icelandair	3	2
YF 10	1	United	2	1
YF 10	2	Alaska	1	1
YF 12	1	Frontier	2	1
YF 12	2	Midwest	3	2
YF 14	1	Midwest	3	2
YF 14	2	Continental	1	1
YF 16	1	Southwest	3	2
YF 16	2	Frontier	2	1
YF 18	1	Continental	1	1
YF 18	2	US Airways	2	1
YF 20	1	Alaska	1	1
YF 20	2	Midwest	3	2

Table A.3. Order for Middle Age Males in the Dual-Phase Condition

Subject Number	Drive	Airline	CMS Panel	Terminal
MM 01	1	US Airways	2	1
MM 01	2	Continental	1	1
MM 03	1	Northwest	2	1
MM 03	2	Sun Country	3	2
MM 05	1	Southwest	3	2
MM 05	2	Air Canada	1	1
MM 07	1	Air Tran	3	2
MM 07	2	Northwest	2	1
MM 09	1	Delta	1	1
MM 09	2	United	2	1
MM 11	1	American	1	1
MM 11	2	Air Tran	3	2
MM 13	1	Frontier	2	1
MM 13	2	Air Canada	1	1
MM 15	1	United	2	1
MM 15	2	Midwest	3	2
MM 17	1	Sun Country	3	2
MM 17	2	American	1	1
MM 19	1	Icelandair	3	2
MM 19	2	United	2	1

Table A.4. Order for Middle Age Females in the Dual-Phase Condition

Subject Number	Drive	Airline	CMS Panel	Terminal
MF 02	1	Air Canada	1	1
MF 02	2	United	2	1
MF 04	1	Continental	1	1
MF 04	2	Sun Country	3	2
MF 06	1	Frontier	2	1
MF 06	2	Delta	1	1
MF 08	1	US Airways	2	1
MF 08	2	Air Tran	3	2
MF 10	1	Air Tran	3	2
MF 10	2	Continental	1	1
MF 12	1	Midwest	3	2
MF 12	2	Frontier	2	1
MF 14	1	Alaska	1	1
MF 14	2	US Airways	2	1
MF 16	1	Delta	1	1
MF 16	2	Southwest	3	2
MF 18	1	Northwest	2	1
MF 18	2	Continental	1	1
MF 20	1	US Airways	2	1
MF 20	2	Icelandair	3	2

Table A.5. Order for Older Males in the Dual-Phase Condition

Subject Number	Drive	Airline	CMS Panel	Terminal
OM 01	1	Icelandair	3	2
OM 01	2	Delta	1	1
OM 03	1	Sun Country	3	2
OM 03	2	Frontier	2	1
OM 05	1	American	1	1
OM 05	2	United	2	1
OM 07	1	Air Canada	1	1
OM 07	2	Midwest	3	2
OM 09	1	United	2	1
OM 09	2	Air Canada	1	1
OM 11	1	Frontier	2	1
OM 11	2	Southwest	3	2
OM 13	1	Midwest	3	2
OM 13	2	Delta	1	1
OM 15	1	Southwest	3	2
OM 15	2	US Airways	2	1
OM 17	1	Continental	1	1
OM 17	2	Frontier	2	1
OM 19	1	Alaska	1	1
OM 19	2	Southwest	3	2

Table A.6. Order for Older Females in the Dual-Phase Condition

Subject Number	Drive	Airline	CMS Panel	Terminal
OF 02	1	US Airways	2	1
OF 02	2	American	1	1
OF 04	1	Northwest	2	1
OF 04	2	Air Tran	3	2
OF 06	1	Southwest	3	2
OF 06	2	American	1	1
OF 08	1	Air Tran	3	2
OF 08	2	United	2	1
OF 10	1	Delta	1	1
OF 10	2	Northwest	2	1
OF 12	1	American	1	1
OF 12	2	Sun Country	3	2
OF 14	1	Northwest	2	1
OF 14	2	Delta	1	1
OF 16	1	United	2	1
OF 16	2	Southwest	3	2
OF 18	1	Sun Country	3	2
OF 18	2	Alaska	1	1
OF 20	1	Icelandair	3	2
OF 20	2	US Airways	2	1

Table A.7. Order for Younger Males in the Static Condition

Subject Number	Drive	Airline	CMS Panel	Terminal
YM 02	1	Icelandair	3	2
YM 02	2	Air Canada	1	1
YM 04	1	Sun Country	3	2
YM 04	2	Northwest	2	1
YM 06	1	American	1	1
YM 06	2	Northwest	2	1
YM 08	1	Air Canada	1	1
YM 08	2	Icelandair	3	2
YM 10	1	United	2	1
YM 10	2	Alaska	1	1
YM 12	1	Frontier	2	1
YM 12	2	Midwest	3	2
YM 14	1	Midwest	3	2
YM 14	2	Continental	1	1
YM 16	1	Southwest	3	2
YM 16	2	Frontier	2	1
YM 18	1	Continental	1	1
YM 18	2	US Airways	2	1
YM 20	1	Alaska	1	1
YM 20	2	Midwest	3	2

Table A.8. Order for Younger Females in the Static Condition

Subject Number	Drive	Airline	CMS Panel	Terminal
YF 01	1	Air Canada	1	1
YF 01	2	Northwest	2	1
YF 03	1	Continental	1	1
YF 03	2	Air Tran	3	2
YF 05	1	Frontier	2	1
YF 05	2	Alaska	1	1
YF 07	1	US Airways	2	1
YF 07	2	Icelander	3	2
YF 09	1	Air Tran	3	2
YF 09	2	Alaska	1	1
YF 11	1	Midwest	3	2
YF 11	2	US Airways	2	1
YF 13	1	Alaska	1	1
YF 13	2	Frontier	2	1
YF 15	1	Delta	1	1
YF 15	2	Icelandair	3	2
YF 17	1	Northwest	2	1
YF 17	2	American	1	1
YF 19	1	United	2	1
YF 19	2	Sun Country	3	2

Table A.9. Order for Middle Age Males in the Static Condition

Subject Number	Drive	Airline	CMS Panel	Terminal
MM 02	1	Air Canada	1	1
MM 02	2	United	2	1
MM 04	1	Continental	1	1
MM 04	2	Sun Country	3	2
MM 06	1	Frontier	2	1
MM 06	2	Delta	1	1
MM 08	1	US Airways	2	1
MM 08	2	Air Tran	3	2
MM 10	1	Air Tran	3	2
MM 10	2	Continental	1	1
MM 12	1	Midwest	3	2
MM 12	2	Frontier	2	1
MM 14	1	Alaska	1	1
MM 14	2	US Airways	2	1
MM 16	1	Delta	1	1
MM 16	2	Southwest	3	2
MM 18	1	Northwest	2	1
MM 18	2	Continental	1	1
MM 20	1	US Airways	2	1
MM 20	2	Icelandair	3	2

Table A.10. Order for Middle Age Females in the Static Condition

Subject Number	Drive	Airline	CMS Panel	Terminal
MF 01	1	US Airways	2	1
MF 01	2	Continental	1	1
MF 03	1	Northwest	2	1
MF 03	2	Sun Country	3	2
MF 05	1	Southwest	3	2
MF 05	2	Air Canada	1	1
MF 07	1	Air Tran	3	2
MF 07	2	Northwest	2	1
MF 09	1	Delta	1	1
MF 09	2	United	2	1
MF 11	1	American	1	1
MF 11	2	Air Tran	3	2
MF 13	1	Frontier	2	1
MF 13	2	Air Canada	1	1
MF 15	1	United	2	1
MF 15	2	Midwest	3	2
MF 17	1	Sun Country	3	2
MF 17	2	American	1	1
MF 19	1	Icelandair	3	2
MF 19	2	United	2	1

Table A.11. Order for Older Males in the Static Condition

Subject Number	Drive	Airline	CMS Panel	Terminal
OM 02	1	US Airways	2	1
OM 02	2	American	1	1
OM 04	1	Northwest	2	1
OM 04	2	Air Tran	3	2
OM 06	1	Southwest	3	2
OM 06	2	American	1	1
OM 08	1	Air Tran	3	2
OM 08	2	United	2	1
OM 10	1	Delta	1	1
OM 10	2	Northwest	2	1
OM 12	1	American	1	1
OM 12	2	Sun Country	3	2
OM 14	1	Northwest	2	1
OM 14	2	Delta	1	1
OM 16	1	United	2	1
OM 16	2	Southwest	3	2
OM 18	1	Sun Country	3	2
OM 18	2	Alaska	1	1
OM 20	1	Icelandair	3	2
OM 20	2	US Airways	2	1

Table A.12. Order for Older Females in the Static Condition

Subject Number	Drive	Airline	CMS Panel	Terminal
OF 01	1	Icelandair	3	2
OF 01	2	Delta	1	1
OF 03	1	Sun Country	3	2
OF 03	2	Frontier	2	1
OF 05	1	American	1	1
OF 05	2	United	2	1
OF 07	1	Air Canada	1	1
OF 07	2	Midwest	3	2
OF 09	1	United	2	1
OF 09	2	Air Canada	1	1
OF 11	1	Frontier	2	1
OF 11	2	Southwest	3	2
OF 13	1	Midwest	3	2
OF 13	2	Delta	1	1
OF 15	1	Southwest	3	2
OF 15	2	US Airways	2	1
OF 17	1	Continental	1	1
OF 17	2	Frontier	2	1
OF 19	1	Alaska	1	1
OF 19	2	Southwest	3	2

Appendix B
Post-Drive Questions

The questions that each participant was asked immediately after he or she completed the second experimental drive are presented on the following pages of this appendix.

Subject Number_____

Questions

Questions to be asked by the experimenter immediately after the subject completes the second drive.

If the subject did not take the correct exit for their airline at the end of the second drive, ask him/her the following question

Question #1: "I noticed that you didn't take the exit for your airline. Can you tell me why you didn't?"

____

____

____

If the subject did not take the correct exit for their airline at the end of the first drive, ask him/her the following question

Question #2: "I noticed that you didn't take the exit for your airline at the end of the first drive. Can you tell me why you didn't?

____

____

____

Appendix C
Post-Drive Survey

The questions asked in the survey completed by the 120 experimental participants after they finished driving the simulator are presented on the following pages of this appendix.

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" please proceed to Question #11.

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

Question #11: When you are driving on Metro Freeways, have you seen signs that give general directions to the airport?

Yes____ No____

Question #12: Have you driven to airports in other cities?

Yes____ No____

If you answered "Yes" to both Question #11 and #12, please continue with Question #13.
If you answered " No" to either Question #11 or #12, please proceed to Question #14.

Question #13: How do the roadway signs that give directions to the Minneapolis/St. Paul International Airport compare with the roadway signs you have seen in other cities that give directions to airports? Please mark your answer on the scale which goes from 1 to 7—where "1" means "Much worse" and "7" means "Much better."

Much Worse 1 2 3 4 5 6 7 Much Better

Question #14: When you drive on Metro Freeways, have you seen message boards that switch between two messages?

Yes____ No____

If you answer "Yes" please continue with Question #15.
If you answer " No" you have completed the survey.

Question #15: How easy or difficult is it for you to understand the messages on message boards that switch between two messages? Please mark your answer on the scale which goes from 1 to 7—where "1" means "Very difficult" and "7" means "Very easy."

Very difficult 1 2 3 4 5 6 7 Very easy

Appendix D
Survey Results

Survey data
After finishing the both drives, the 120 participants were asked to complete a survey that consisted of fifteen questions. Responses to these questions are reported in detail 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:

- 113 (94%)—participants had seen message boards presenting travel time information on the Metro Freeways.
- 8 (6%)—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 113 participants who had seen these messages is shown in Figure D.1.

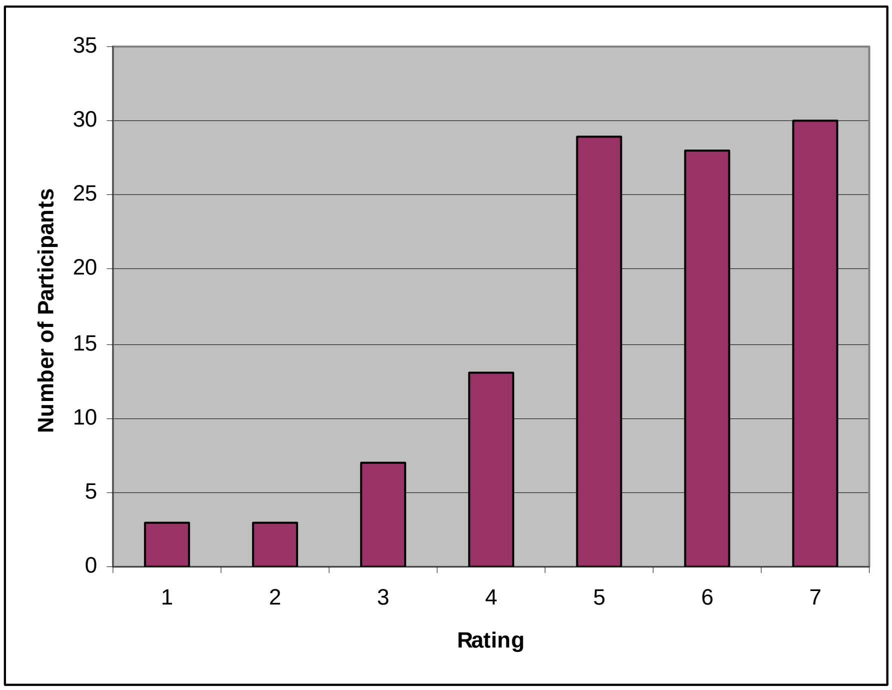

Figure D.1. Distribution of responses rating the usefulness of travel time information to the participants

As the figure shows, the distribution of responses was positively skewed. The mean value of the responses was 5.3, and the standard deviation was 1.5.

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 113 participants who had seen these messages is shown in Figure D.2.

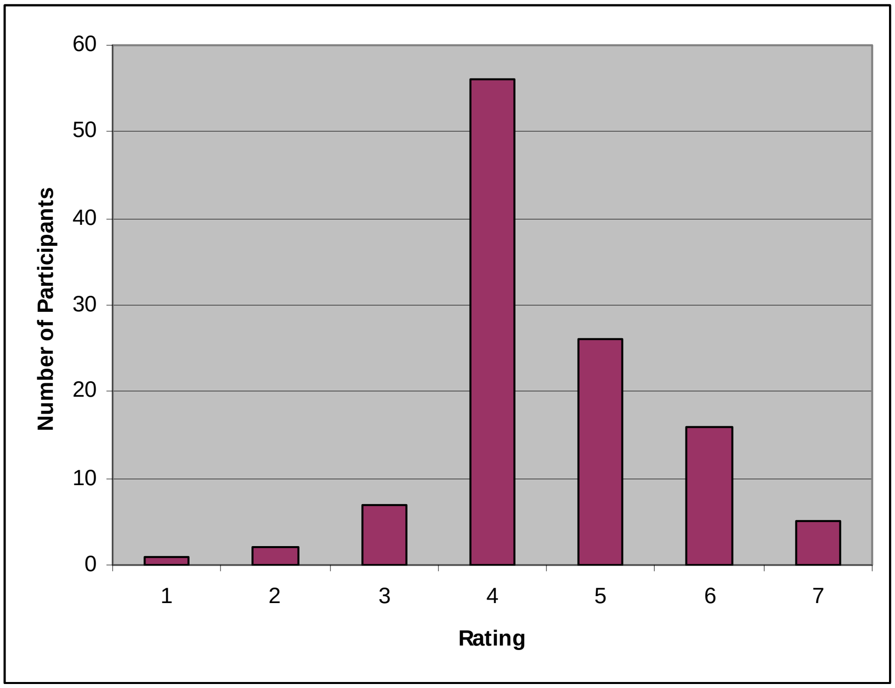

Figure D.2: Distribution of responses rating the effect of travel time information on the stress level of the participants

The mean value of the responses shown in Figure D.2 was 4.5, and the standard deviation was 1.1.

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:

- 116 (97%)—had seen message boards presenting information about traffic problems ahead.
- 4 (3%)—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 116 participants who responded to this question is presented in Figure D.3.

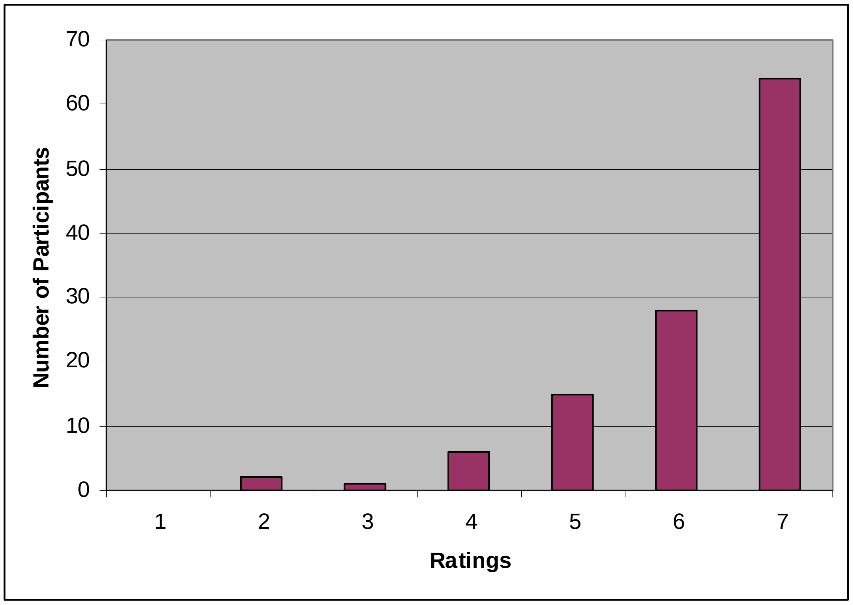

Figure D.3: Distribution of responses rating the usefulness of information about traffic problems to the participants

Figure D.3 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 6.2, and the standard deviation was 1.1.

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 116 participants who responded to this question is presented in Figure D.4.

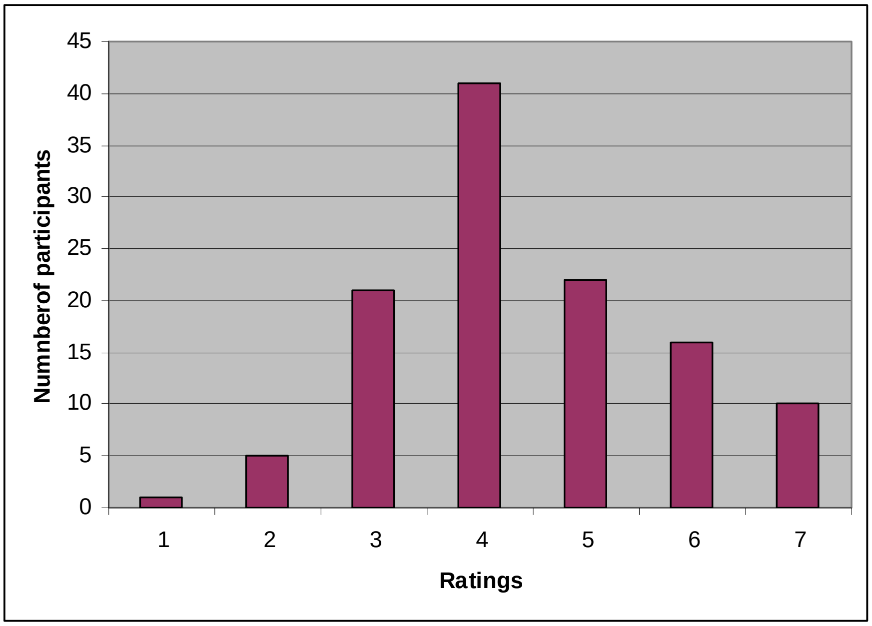

Figure D.4: Distribution of responses rating the effect that information about traffic problems has on the stress level of the participants

The mean value of the ratings in Figure D.4 was 4.4, and the standard deviation was 1.3.

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:

- 114 (95%)—had seen message boards presenting safety messages.
- 6 (5%)—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 114 participants who reported that they had seen these messages is presented in Figure D.5.

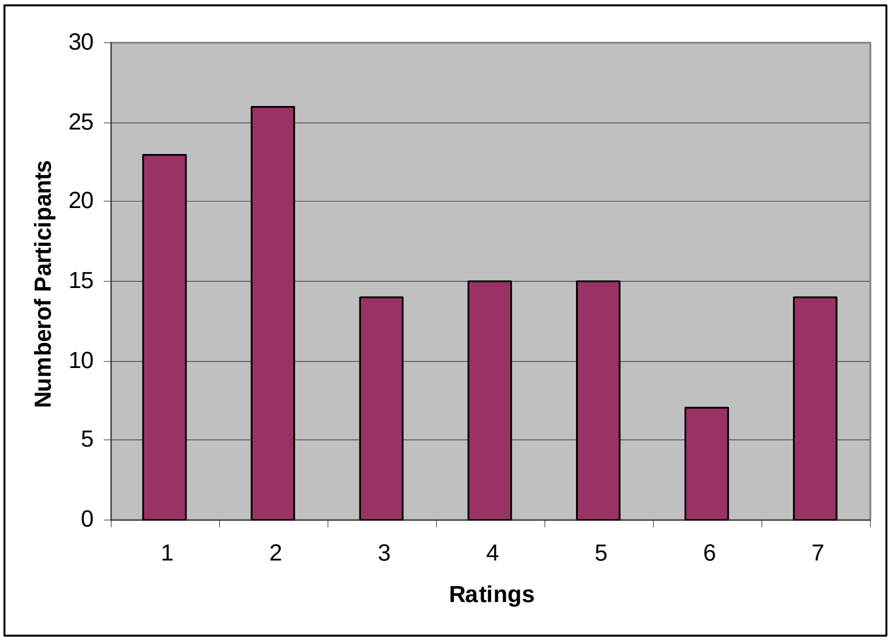

Figure D.5: Distribution of responses rating the usefulness of safety messages to the participants

Figure D.5 shows that there was little agreement among the participants responding to this sixth question. The mean of these ratings was 3.4, while the standard deviation was 2.0

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:

- 119 (99%)—had seen message boards that displayed information about roadway maintenance schedules.
- 1 (1%)—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 D. 6 presents the distribution of the ratings given by the 119 participants who responded to this question.

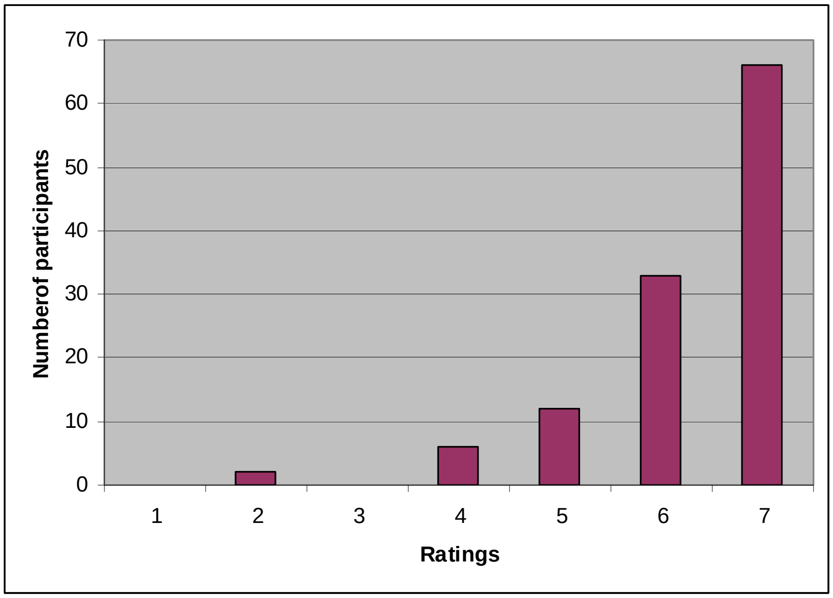

Figure D.6: Distribution of responses rating the usefulness of information about roadway maintenance schedules

The distribution shown in Figure D.6 is highly positively skewed. The mean rating value was 6.3, and the standard deviation was 1.0.

Information about Airports—The next three questions related to airports. Question 11 asked, “When you are driving on Metro Freeways, have you seen signs that give general directions to the airport?” The responses to this question were:

- 118 (98%)—had seen message boards presenting information giving general directions to the airport.
- 2 (2%)—had not seen these messages.

Question #12 asked, “Have you driven to airports in other cities?” The responses to this question were:

- 100 (83%)—had driven to airports in other cities.
- 20 (17%)—had not driven to airports in other cities.

The next question asked “How do the roadway signs that give directions to the Minneapolis/St. Paul International Airport compare with the roadway signs you have seen in other cities that give directions to airports? Please mark your answer on the scale which goes from 1 to 7—where “1” means “Much worse” and “7” means “Much better.” The distribution of responses of the 100 participants who had seen roadway signs giving airport directions in other cities and in the Twin Cities is shown in Figure D.7.

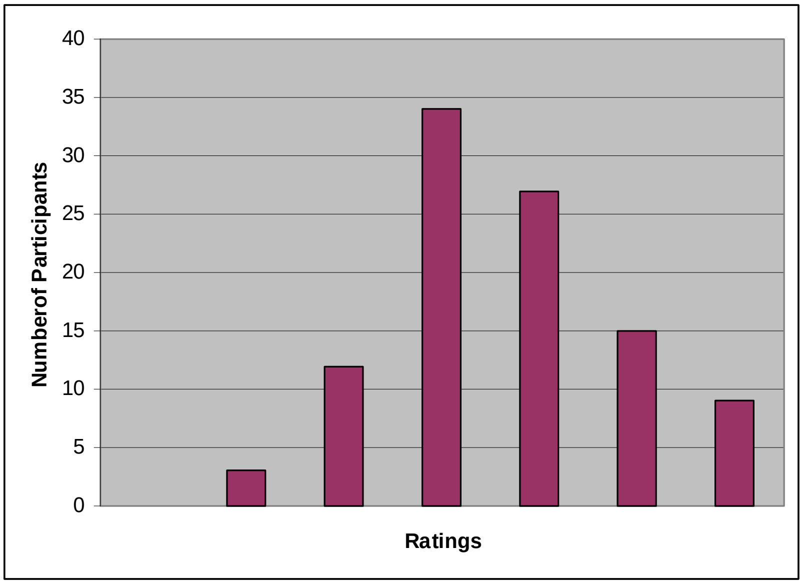

Figure D.7: Distribution of responses comparing the roadway signs giving directions to the airport in the Twin Cities and to airports in other cities.

The mean value of the ratings shown in Figure D.7 was 4.6, and the standard deviation was 1.2.

Information about Dual-Phase CMSs—The final two questions related to dual-phase CMS messages.

Question #14 was, "When you drive on Metro Freeways, have you seen message boards that switch between two messages? The responses to this question were:

- 91 (76%)—had seen message boards that switch between two messages.
- 29 (24%)—had not seen these types of message boards.

Question #15 was, "How easy or difficult is it for you to understand the messages on message boards that switch between two messages? Please mark your answer on the scale which goes from 1 to 7—where "1" means "Very difficult" and "7" means "Very easy." The distribution of the responses of the 91 participants who had seen these messages is shown in Figure D.8.

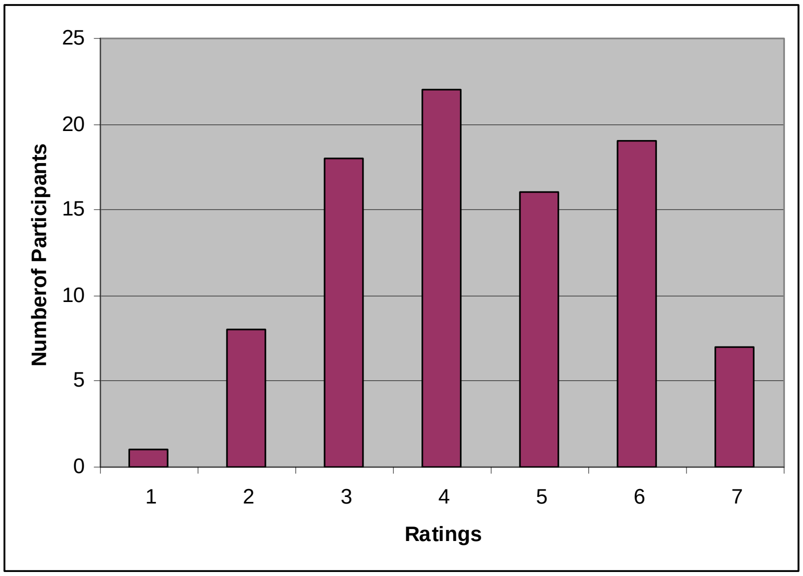

Figure D.8: Distribution of responses rating the ease or difficulty of understanding dual-phase CMS messages.

The mean value of the ratings shown in Figure D.8 was 4.4, and the standard deviation was 1.5.

Appendix E
Interaction Effects

In Chapter 3, the results of the ANOVA on the speed data were summarized in Table 3.2. The table indicated that there were three statistically significant main effects [These main effects were discussed in Chapter 3]. In addition, the table also indicated that there was one statistically significant two-way interaction and that there were three significant three-way interactions. While these interactions were statistically significant, they involve average speed differences of relatively small magnitude—that do not impinge on the main effects. These interactions are discussed in detail in this appendix.

E.1 Interaction between CMS Condition and Drive

The two-way interaction was between condition and drive and was statistically significant (at the 0.0355) level. The data involved in this interaction are shown in Table E.1 below.

Table E.1. Average speed in the first and second drives for the dual-phase and static CMS conditions

Condition	Drive 1	Drive 2
Dual-Phase	61.80	62.08
Static	61.07	62.05

The Tukey-Kramer test was applied *post hoc* to the data in Table E.1. The test did not indicate that there was a significant difference between the dual-phase and the static CMS conditions in the first drive—only the increase in average speed (of 0.98 mph) between drive 1 and drive 2 for participants in the static CMS condition was significant. This effect is illustrated in Figure E.1 below.

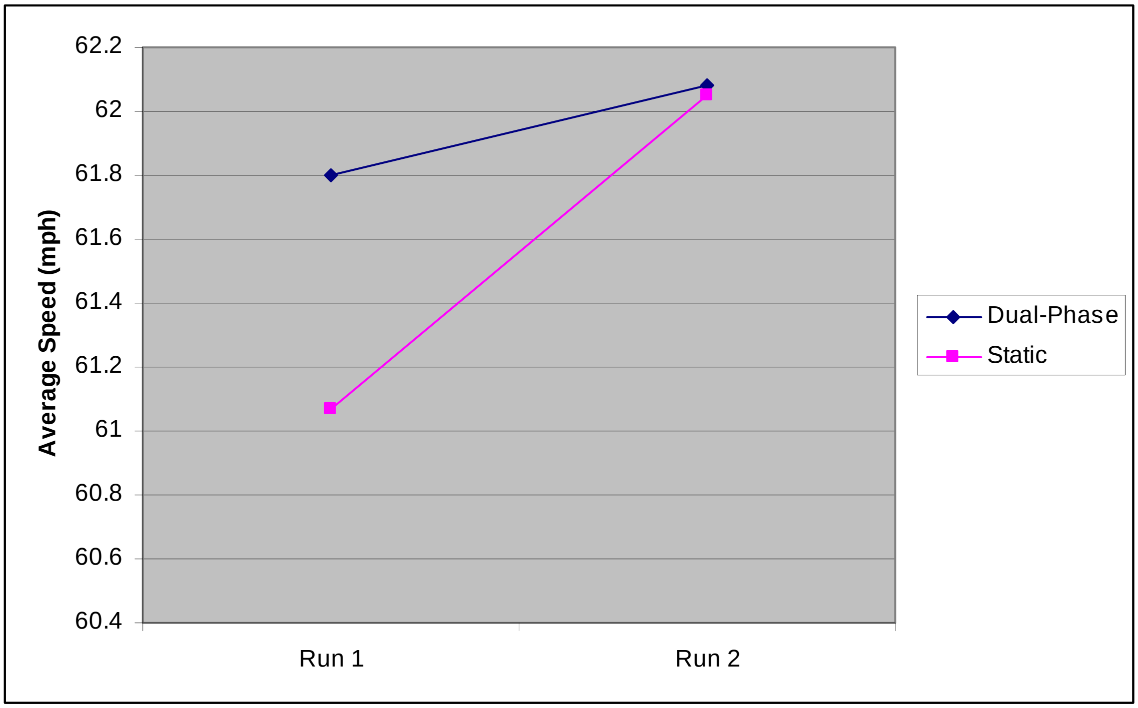

Figure E.1: Average speed in the first and second drives for the dual-phase and static CMS conditions

E.2 Interaction between Gender, CMS Condition, and Drive

There was also a statistically significant interaction between the gender of the participants, the CMS condition, and drive that relates to the differences shown in Figure E.1 above—this interaction is illustrated in Figure E.2 below.

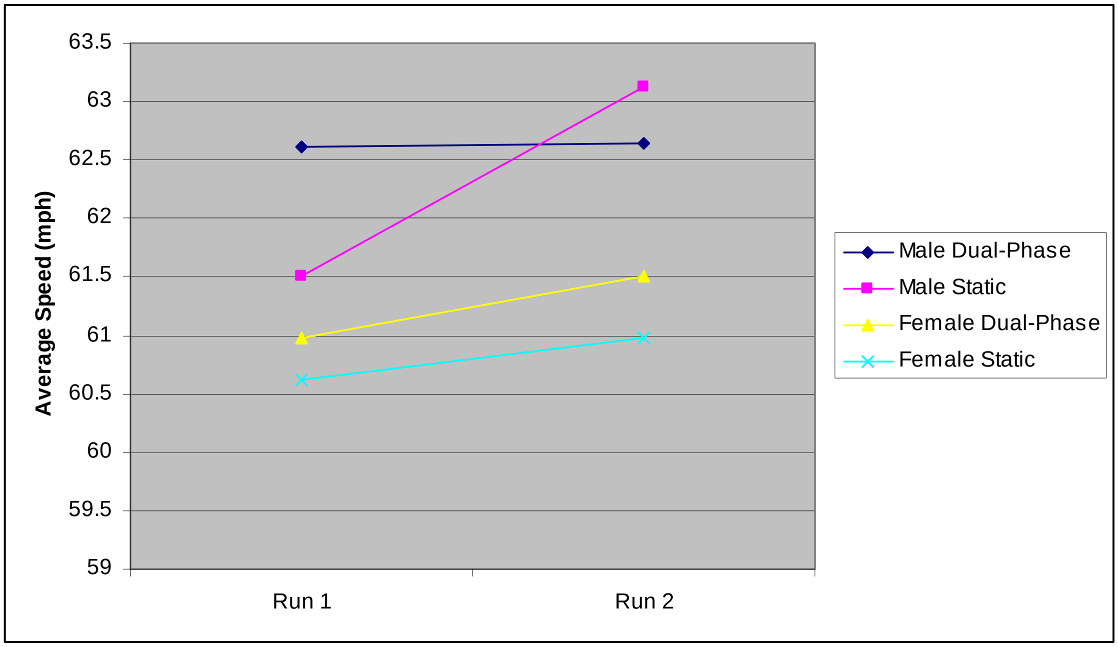

Figure E.2: Average speed in the first and second drives for the male and female participants in the dual-phase and static CMS conditions

Figure E.2 suggests that the increase in average speed exhibited by male participants in the static CMS condition was primarily responsible for the overall increase in average speed from drive 1 to drive 2 in the static CMS condition shown in Figure E.1.

E.3 Interaction between Gender, Age, and Drive

There was also a statistically significant three-way interaction between the gender and age of the participants, and drive. This interaction is reported in Table E.2 and illustrated in Figure E.3 below.

Table E.2. Average speed in the first and second drives as a function of the gender and age of the participants

Gender	**Age**	**Drive 1**	**Drive 2**
Male	**Young**	65.36	66.34
	Middle	62.10	62.19
	Older	58.73	60.13
Female	**Young**	62.39	63.33
	Middle	60.58	61.24
	Older	59.44	59.12

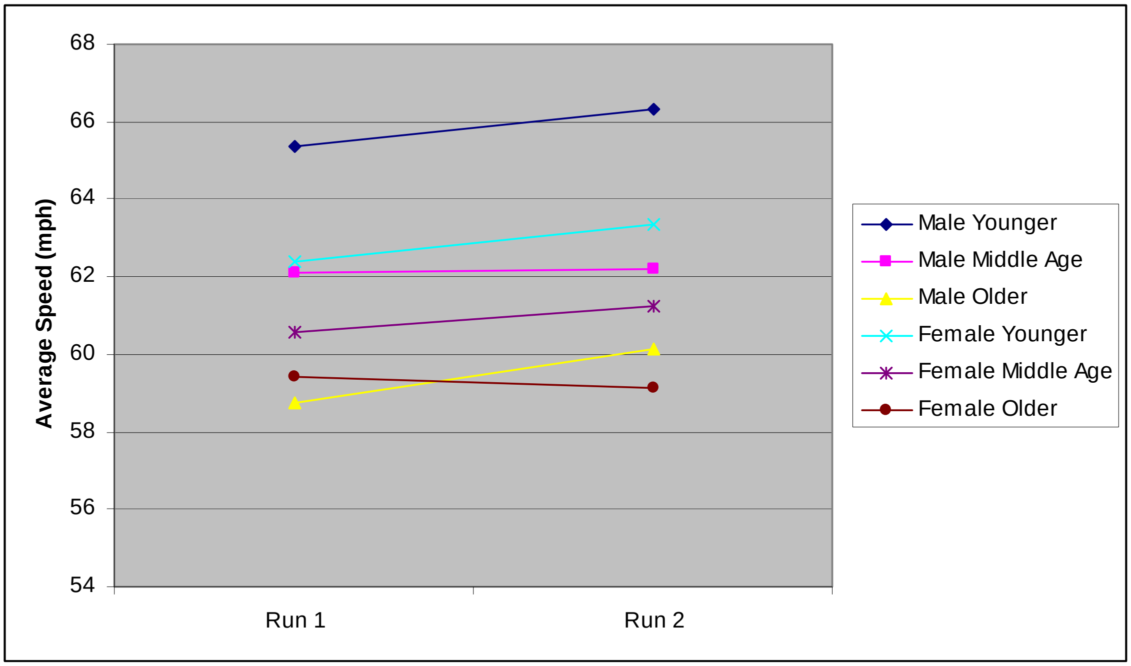

Figure E.3. Average speed in the first and second drives as a function of the gender and age of the participants

Table E.2 and Figure E.3 show that there was an increase in average speed from the first to the second drive for the younger males and females, for the middle age females and for the older males. However, for the other two sub-groups—i.e., the middle-age males and the older females—there was no change in average speed between the first drive and the second drive.

E.4 Interaction between Age, CMS Condition, and Segment

Finally, there was also a three-way interaction between the age of the participants, the CMS condition, and the five highway segments. This interaction is reported in Table E.3 and illustrated in Figure E.4 below.

Table E.3. Average speed as a function of the age of the participants, the CMS condition, and the highway segments

Condition	**Age**	**Seg. 1**	**Seg. 2**	**Seg. 3**	**Seg. 4**	**Seg. 5**
Dual-Phase	**Young**	65.03	65.70	65.29	64.49	64.39
	Middle	61.13	60.86	60.80	60.62	60.02
	Older	59.98	60.29	60.66	60.41	59.13
Static	**Young**	63.58	63.71	63.82	63.84	63.39
	Middle	62.39	62.65	62.79	62.31	61.73
	Older	59.84	60.13	59.07	57.89	56.24

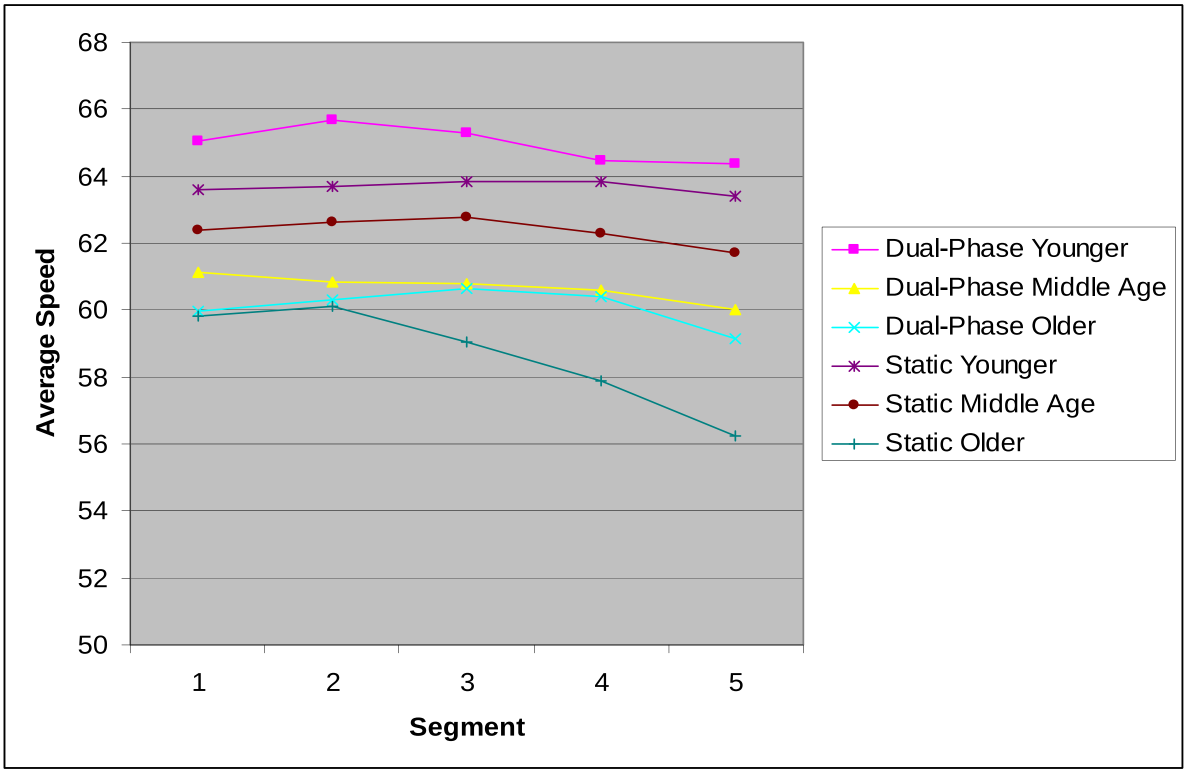

Table E.4. Average speed as a function of the age of the participants, the CMS condition, and the highway segments

Table E.3 and Figure E.4 show that for the sub group involving older participants assigned to the static CMS condition there was a decrease in average speed from the first two segments, where it was approximately 60 mph, to 59 mph in the third segment, approximately 58mph in the fourth segment, and 56 mph in the fifth segment.