Final Report 2002-05

Research

Investigating the Effect on Driver Performance of Advanced Warning Flashers at Signalized Intersections

Technical Report Documentation Page

1. Report No. MN/RC – 2002-05	2.	3. Recipients Accession No.
4. Title and Subtitle INVESTIGATING THE EFFECT ON DRIVER PERFORMANCE OF ADVANCED WARNING FLASHERS AT SIGNALIZED INTERSECTIONS		5. Report Date July 2001 6.
7. Author(s) Thomas J. Smith, Curtis Hammond and Michael G. Wade		8. Performing Organization Report No.
9. Performing Organization Name and Address Human Factors Research Laboratory Division of Kinesiology, University of Minnesota 141 Mariucci Arena, 1901 Fourth Street S.E. Minneapolis, MN 55414		10. Project/Task/Work Unit No. 11. Contract (C) or Grant (G) No. C) 74708 wo) 71
12. Sponsoring Organization Name and Address Minnesota Department of Transportation 395 John Ireland Boulevard Mail Stop 330 St. Paul, Minnesota 55155		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract (Limit: 200 words)

This report summarizes the findings of a human factors analysis to determine the effects of advanced warning flashers (AWFs) on simulated driving performance. The Minnesota Department of Transportation sponsored the project.

Researchers used the flat-screen simulator at the University of Minnesota Human Factors Research Laboratory to conduct experiments. They measured vehicle speed, braking, and acceleration/deceleration during simulated driving and visually observed stopping behavior. In addition, they analyzed responses to a post-test questionnaire. They created a 11.3-mile simulated driving environment with 10 signalized intersections and configured four experimental models: low speed limit (SL) of 50 miles per hour with no AWFs, low SL with AWF at each intersection, high SL of 65 miles per hour with no AWFs, and high SL with AWF at each intersection

Researchers set different vehicle-signal proximity intervals, with all green/no yellow as the control, and zero seconds with the vehicle adjacent to the signal, two seconds, three-and-a-half seconds, or five seconds. With each model, they assigned two intersections each proximity interval, with the sequence of intersection proximity intervals ordered differently for each model. Each of 24 subjects completed duplicate driving trials with each model.

The study revealed that, relative to intersections with no AWFs, drivers who encountered yellow signals at AWFs intersections: stopped more frequently at low SLs but not at high SLs, drove more slowly while approaching intersections with two and three-and-a-half second proximity intervals, and displayed less inconsistent behavior at intersections with short proximity intervals. Researchers concluded that AWFs assist drivers with decision-making behavior and promote safer driving behavior. They recommended field research to study an actual environment.

17. Document Analysis/Descriptors Advanced Warning Flashers Signalized Intersections Decision Zone	Driver Behavior Driving Performance Driving Safety Driving Simulators	18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 214	22. Price

Funding Acknowledgment

This project was conducted with funding provided by the Minnesota Department of Transportation (Mn/DOT) Guidestar Office. Minnesota Guidestar's mission is to provide leadership and coordination for an Intelligent Transportation System (ITS) program that provides the greatest benefits to travelers in Minnesota.

INVESTIGATING THE EFFECT ON DRIVER PERFORMANCE OF ADVANCED WARNING FLASHERS AT SIGNALIZED INTERSECTIONS

Final Report

Prepared by:

Thomas J. Smith
Curtis Hammond
Michael Wade

Human Factors Research Laboratory
Division of Kinesiology
University of Minnesota

141 Mariucci Arena
1901 Fourth Street S.E.
Minneapolis, MN 55414

July, 2001

Published by

Minnesota Department of Transportation
Office of Research Services
MS 330
395 John Ireland Boulevard
St. Paul MN 55155

ACKNOWLEDGMENTS

The authors would like to acknowledge the assistance of the following people whose contributions were instrumental to completion of the project. We particularly wish to recognize the key assistance of Gloria Martinez-Arizala, who wrote a series of MatLab software routines that greatly facilitated reduction and processing of simulated driving data, and to Randy Harney, who assisted with the ANOVA.

Mn/DOT Personnel
Beverly Ann B. Farraher, Division Traffic Engineer, Project Technical Liaison
Jay Koski, Project Administrative Liaison
Benjamin Osemenam, Program Development Engineer
Gary Ries, State Signal Engineer
Dan Warzala, Project Administrative Liaison

University of Minnesota Human Factors Research Laboratory Personnel
Peter Easterlund, Systems Programmer
Peter Hancock, Director
James Klinge, Former Systems Analyst/Programmer
Michelle Pieper, Laboratory Administrator
Steve Scallen, Former Director of Research

University of Minnesota Division of Kinesiology Personnel
Gloria Martinez-Arizala, Research Associate
Randy Harney, Graduate Program

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

Page

TABLE OF CONTENTS (continued)

Page

List of Tables

TABLE OF CONTENTS (continued)

Page

List of Tables (continued)

TABLE OF CONTENTS (continued)

Page

List of Figures

TABLE OF CONTENTS (continued)

Page

List of Figures (continued)

TABLE OF CONTENTS (continued)

Page

List of Figures (continued)

ABBREVIATIONS, ACRONYMS AND DEFINITIONS

3D	three-dimensional
accel	acceleration
AG	All Green (control VPTY condition, in which light signal remains green as vehicle traverses intersection)
ANOVA	analysis of variance
AR	all-red interval in seconds
AWF	advanced warning flasher
AWFBT	AWF braking time, defined as the time interval between actuation of the AWF signal and first actuation of the brake pedal for a given intersection
BDI	braking distance from intersection, defined as the distance of the vehicle from a given intersection when the brake pedal first is actuated
Bonferroni adjustment	statistical procedure used to adjust univariate ANOVA, with >1 dependent measures involved, to circumvent Type I errors [17]
clearance interval	the time elapsed during which a driver visually perceives the change in signal status of a signalized intersection from green to yellow, makes a decision about the necessity of stopping, and acts upon that decision [5] (also termed yellow interval)
consistent stopping behavior	for intersections with a given VPTY condition, S always stops or does not stop
control condition	intersections in simulated driving trials are not preceded by AWFs
CTS	University of Minnesota Center for Transportation Studies
d	deceleration rate in ft/sec/sec
D	distance
dangerous stop	vehicle stops either within or beyond intersection
decel	deceleration
decision zone	the space-time region prior to a signalized intersection for which it is difficult for a driver to make a decision about stopping or proceeding, even though a real dilemma zone may not be present [5]
df	degrees of freedom
dilemma zone	the space-time region prior to a signalized intersection for which there may be neither enough signal yellow time for a driver to legally enter the intersection before the signal turns red, nor enough distance for a driver to decelerate to a stop [5]
ESDT	elapsed simulated driving time
Excel	Microsoft spreadsheet program
F / F-crit	value for F statistic / critical F value for $p<.05$.
ft	feet/foot
first-order effect	2-way interactive effect of an independent on a dependent variable, as established by ANOVA
G	green signal light

HSLC	high speed limit control, defined as that SDTE combining the high speed limit (hsl) condition of 65 mph with the control (c) condition of no intersection AWFs present
HSLT	high speed limit test, defined as that SDTE combining the high speed limit (hsl) condition of 65 mph with the test (t) condition of AWFs present at each intersection
HF; HF/E	human factors; human factors/ergonomics
HFRL	University of Minnesota Division of Kinesiology Human Factors Research Laboratory
hr	hour
hz	herz
I	intersection
in	inch
inconsistent stopping behavior	for intersections with a given VPTY condition, S sometimes stops and sometimes does not stop
km	kilometers
kph	kilometers per hour
l	length of vehicle in ft
Linux	operating system for PC - alternative system to Windows 95/98/2000
LOI	line of identity
LSLC	low speed limit control, defined as that SDTE combining the low speed limit (lsl) condition of 50 mph with the control (c) condition of no intersection AWFs present
LSLT	low speed limit test, defined as that SDTE combining the low speed limit (lsl) condition of 50 mph with the test condition of AWFs present at each intersection
LSR	least squares regression
m	meters
MAX	maximum
MBP	mean braking pressure, calculated by averaging successive values of braking pressure over a selected time interval
mi	miles
MIN	minimum
min	minutes
mm	millimeters
Mn/DOT	State of Minnesota Department of Transportation
mph	miles per hour
MS	mean sum of squares
MVS	mean vehicle speed, calculated by averaging successive vehicle speed values over a selected time interval
N	number of subjects
N/A	not applicable
no.	number
p	probability
Pearson correlation	coefficient of correlation for paired values in a sample population
PC	IBM-compatible personal computer

post hoc analysis	
	the data analysis procedure employed to investigate and interpret the basis of statistically significant interactive effects revealed by ANOVA
PTQ	post-test questionnaire
Q	question
R	red signal light
Rd.	road
rpms	revolutions per minute
rt	perception-reaction time of driver in seconds
running red light	
	vehicle enters and continues through intersection after light signal turns red
S, Ss	subject, subjects
SD	standard deviation
SE	standard error
sec	seconds
second-order effect	
	3-way interactive effect of an independent on a dependent variable, as established by ANOVA
SGI	name of company that manufactures computer employed for simulation modeling (formerly Silicon Graphics, Inc.)
SDP	simulated driving performance
SDTE	simulated driving task environment, comprising 4 simulated driving environments corresponding to the LSLC, LSLT, HSLC, and HSLT conditions
SL	speed limit
SPSS	software platform used for statistical analysis of data
SS	sum of squares
t	time
T	trial
test condition	simulated driving trials with each intersection preceded by AWF
T.H.	trunk highway
t-stat / t-crit	value for t statistic / critical t value (two-tailed) for $p<.05$
type I error	statistical analysis indicates significant effect, when in fact the effect is due to chance
UM	University of Minnesota
v	vehicle approach speed in ft/sec
V	volts
VDTI	vehicle distance to intersection
VPTY	vehicle proximity to yellow, defined as the time in sec that it will take the vehicle to reach the intersection (at its prevailing speed) when the signal turns yellow
vs	versus
w	width of intersection in ft
Y	yellow interval in sec/yellow signal light
yellow interval	
	see clearance interval
yrs	years

EXECUTIVE SUMMARY

This is the final report for a study conducted by the University of Minnesota (UM) Division of Kinesiology Human Factors Research Laboratory to investigate possible effects of advanced warning flashers (AWFs) at signalized intersections on driver behavior. The study was carried out under a contract administered by the State of Minnesota Department of Transportation (Mn/DOT) and the UM Center for Transportation Studies.

There are a variety of roadway settings in which drivers may not be provided with much advanced warning regarding the signal status of an upcoming signalized intersection. Such settings can pose a driving safety hazard and may be associated with an elevated accident risk. Normally, road signs and warning signs are provided to warn drivers of problematic intersections. However, signs may not reduce the elevated accident risk associated with such intersections, possibly because signs do not provide a real time indication of signal status. In order to provide drivers with advanced indication of the signal status of an upcoming intersection, Mn/DOT has installed AWFs in front of selected signalized intersections on some mainline roadways in Minnesota.

Effects of AWFs on traffic safety and driver performance have been documented in a series of field research projects conducted by Mn/DOT and others. Results indicate that AWFs: (1) are strongly preferred by the public; (2) reduce the incidence of red light running, with the percent reduction in violations observed for trucks over double that observed overall; but (3) do not consistently and significantly reduce accident frequency. Because of the field settings of these studies, it is impossible to rigorously control for a variety of extraneous variables that conceivably could influence the interaction of driving performance and safety with AWFs. Consequently, a number of human factors issues pertaining to AWFs remain unresolved, particularly regarding the interaction of AWFs and driver performance.

This study addresses some of these unresolved questions with an experimental design that evaluates the main effects of AWF presence, speed limit, and 5 different vehicle-proximity-to-yellow times on dependent measures that comprise visual observations and objective measures of simulated driving performance, coupled with responses to a post-test questionnaire. Research was conducted at the UM Human Factors Research Laboratory, using a fixed-base, flat-screen driving simulator. A closed-circuit, 11.3 mi roadway simulation model with 10 intersections was created. Using the model, 4 simulated driving task environments were developed with the following combinations of

speed limit and intersection AWFs: (1) low speed limit control - 50 mph, no AWFs; (2) low speed limit test - 50 mph, AWFs at each intersection; (3) high speed limit control - 65 mph, no AWFs; and (4) high speed limit test - 65 mph, AWFs at each intersection. Each intersection in each task environment was assigned 1 of 5 vehicle-proximity-to-yellow levels, namely all green, or 0, 2, 3.5, or 5 sec. Thus, for each task environment, there were 2 intersections at each vehicle-proximity-to-yellow level. Subjects (Ss; 24 Ss, 13 female, 11 male, mean age 26.3 yrs, age range 19-48 yrs) were asked to traverse each task environment twice. Each S participated in a total of 8 trials, with a total of 16 (8 x 2) intersection interactions at each vehicle-proximity-to-yellow level.

Compared with S interactions with non-AWF intersections, the study documented the following major changes in S stopping behavior and SDP during interactions with AWF intersections: (1) fewer red lights run during low speed limit trials, but more at high speed limit trials; (2) more cautious driving behavior in some Ss, but more risk-taking behavior in others; (3) reductions in vehicle speed and acceleration, and increased braking, at intersections with vehicle-proximity-to-yellow levels of 2 and 3.5 sec; and (4) more consistent reduction in speed at 2 sec vehicle-proximity-to-yellow intersections, compared with effects at 3.5 sec intersections. These results suggest that, relative to control intersections, the presence of AWFs generally encouraged slowing and stopping behavior by Ss during interaction with test intersections, for vehicle-proximity-to-yellow levels (e.g., 2 and 3.5 sec) for which drivers may be uncertain about stopping or proceeding through the intersection.

The interpretation advanced for the more consistent reductions in speed observed at 2 sec vehicle-proximity-to-yellow intersections, compared with 3.5 sec vehicle-proximity-to-yellow intersections, is that the longer decision time between AWF and yellow signal actuation provided by the 3.5 sec vehicle-proximity-to-yellow condition promotes the emergence of individual differences in both cautious and risk-taking behavioral responses to the yellow signal based on cognitive decision-making, whereas decision-making at 2 sec vehicle-proximity-to-yellow intersections essentially is relegated to the psychomotor domain, resulting in a more limited spectrum of behavioral responses that largely emphasize cautious driving behavior.

Results of this study point to two broad conclusions. First, AWFs appear to assist some drivers with decision-making behavior in the decision zone, and thereby promote safer driving behavior by these drivers. Second, field research is needed to ascertain if the findings apply to actual driving environments, particularly as regards individual differences in how drivers interact with AWFs.

CHAPTER 1
INTRODUCTION AND BACKGROUND

1.1. INTRODUCTION

This is the final report for a study conducted by the University of Minnesota (UM) Division of Kinesiology Human Factors Research Laboratory to investigate possible effects of advanced warning flashers (AWFs) at signalized intersections on driver behavior. The study was carried out under a contract administered by the State of Minnesota Department of Transportation (Mn/DOT) and the UM Center for Transportation Studies (CTS). The report outlines the background to the project, describes research methods and results, and discusses conclusions supported by the findings.

The report is divided into four chapters. Chapter 1 introduces and summarizes the background for the project. Chapter 2 describes the experimental design and methods, and Chapter 3 the results. Chapter 4 discusses some of the implications of the study, and summarizes conclusions supported by the findings.

1.2. BACKGROUND

There are a variety of roadway settings in which drivers may not be provided with much advanced warning regarding the signal status of an upcoming signalized intersection. One example of such a setting would be a signalized intersection located immediately following a curve in a road. Such settings can pose a driving safety hazard and may be associated with an elevated accident risk.

Normally, road signs and warning signs are provided to warn drivers of upcoming signalized intersections for problematic intersection locations. However, signs may not reduce the elevated accident risk associated with such intersections, possibly because signs do not provide a real time indication of signal status. In order to provide drivers with advanced indication of the signal status of an upcoming intersection, Mn/DOT has installed AWFs in front of selected signalized intersections on some mainline roadways in Minnesota.

Mn/DOT has issued a uniform set of guidelines for the installation of AWFs [2] (Appendix A). Summarized in Table 1-1, the guidelines specify conditions and considerations under which AWF

Table 1-1. Mn/DOT guidelines for considering installation of an AWF [2] (Appendix A).

Guideline	Critera
Speed	85^{th} percentile speed greater or equal to 50 mph
Isolated or unexpected signalized intersection	Where a long distance occurs from the last intersection at which the mainline roadway is controlled, or the intersection otherwise is unexpected.
Limited sight distance	Where the distance to the signal stop bar, with two signal heads visible, is insufficient (see Appendix A for details).
Dilemma zone	Where a dilemma zone exists for all traffic or for heavy vehicles (see Appendix A for details).
Accidents	If an intersection has an accident problem, it should be examined for existence of dilemma zone or sight distance restriction.
Engineering judgment	Based on additional considerations such as complaints, violations, conformity of practice, and traffic conflicts.

installation should be considered. As detailed in Appendix A, the guidelines emphasize, for signalized intersections, the existence of an isolated or unexpected intersection, a limited sight distance, and/or a dilemma zone for all traffic or heavy vehicles as key considerations.

Illustrated in the detailed schematic diagrams on the last page of Appendix A, an AWF consists of a pole-mounted, flashing dual yellow light system, accompanied by a warning sign ('Be Prepared to Stop When Light is Flashing') also mounted on the pole. For those signalized intersections with AWFs, the AWF is installed at a specified distance from the intersection, and is actuated at a specified time before the yellow signal is actuated. That is, before the traffic light signal itself turns yellow, the AWF is actuated at the specified time, and its dual yellow lights flash on and off in alternate fashion.

Mn/DOT specifications for the placement and timing of AWFs at signalized intersections for different speed limits (SLs) on mainline roadways are summarized in Appendix A (p. 4) [3]. Appendix B [3] presents the same information (2^{nd} page), but also provides Mn/DOT guidelines for

Table 1-2. Mn/DOT specifications for AWF placement and timing, and for yellow signal duration, for 50 and 65 mph roadway SLs [2,3] (Appendices A & B).

SL (mph)	AWF Placement in Front of Traffic Signal (m & ft)	Timing of AWF Actuation Prior to Yellow Signal Actuation	Duration of Yellow Signal
50 mph	215 m / 705 ft	8.0 sec	5.5 sec
65 mph	260 m / 853 ft	7.5 sec	6.0 sec

the duration of the yellow signal at signalized intersections at different SLs (Appendix B, rightmost column of table on 1st page). For the two SLs employed in this study, 50 and 65 mph (Section 2.3.1), Table 1-2 summarizes Mn/DOT specifications for AWF placement and timing specifications, and for yellow signal duration, based on information in Appendices A and B [2,3].

1.2.1. The Dilemma and Decision Zone Concepts

The purpose of an AWF at a signalized intersection is to aid decision-making by a driver about stopping or proceeding prior to the onset of a yellow signal, and prior to arriving in a yellow interval zone termed the 'dilemma zone' [4,5]. The dilemma zone is defined as the region prior to yellow at a signalized intersection in which there may be neither enough time for the driver to legally enter the intersection before the onset of red (by maintaining or accelerating vehicle speed), nor enough distance for the driver to decelerate to a stop (by braking).

During interaction with a yellow signal, a visual reaction time period occurs before the driver decides either to maintain or accelerate vehicle speed, or to brake. Thus, properties of both driver behavior and vehicle momentum contribute to the overall space-time characteristics of vehicle interaction with a yellow signal, creating what is termed the 'decision zone.' The decision zone is defined as that zone of proximity to a yellow signal which may include the dilemma zone, and within which the driver faces uncertainty as to whether to stop or to proceed, and therefore confronts alternate decision-making choices. Variable driver behavior under these circumstances may disrupt the smoothness of traffic flow and, as noted above, may also pose a traffic safety hazard.

Drawing upon the seminal observations of Gazis and colleagues regarding dilemma zones [4], Mn/DOT [5] provides a detailed analysis and discussion of the meaning and derivation of dilemma

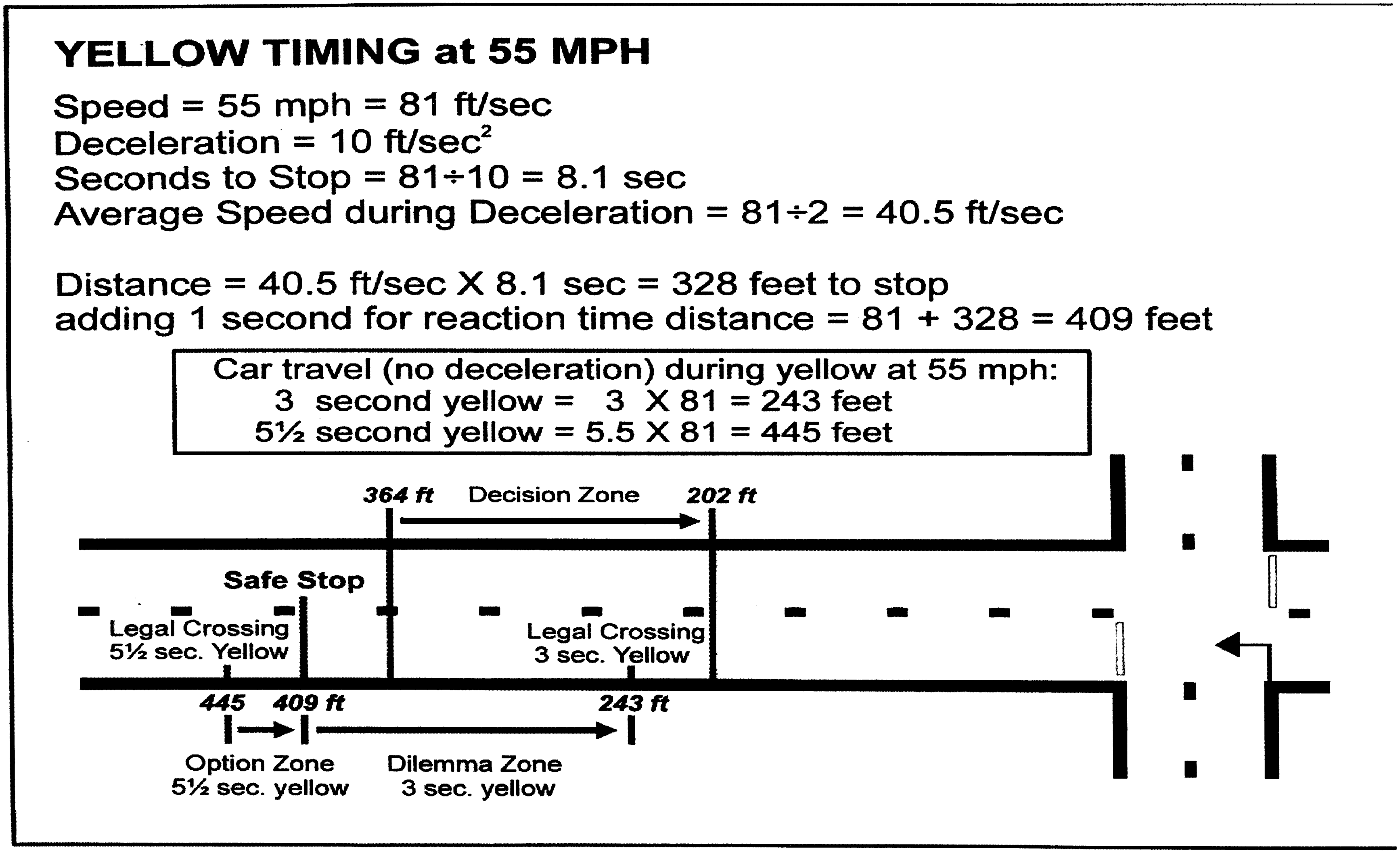


Figure 1-1. Depiction of decision and dilemma zones in relation to timing of yellow signal at 55 mph, with key calculations summarized [6].

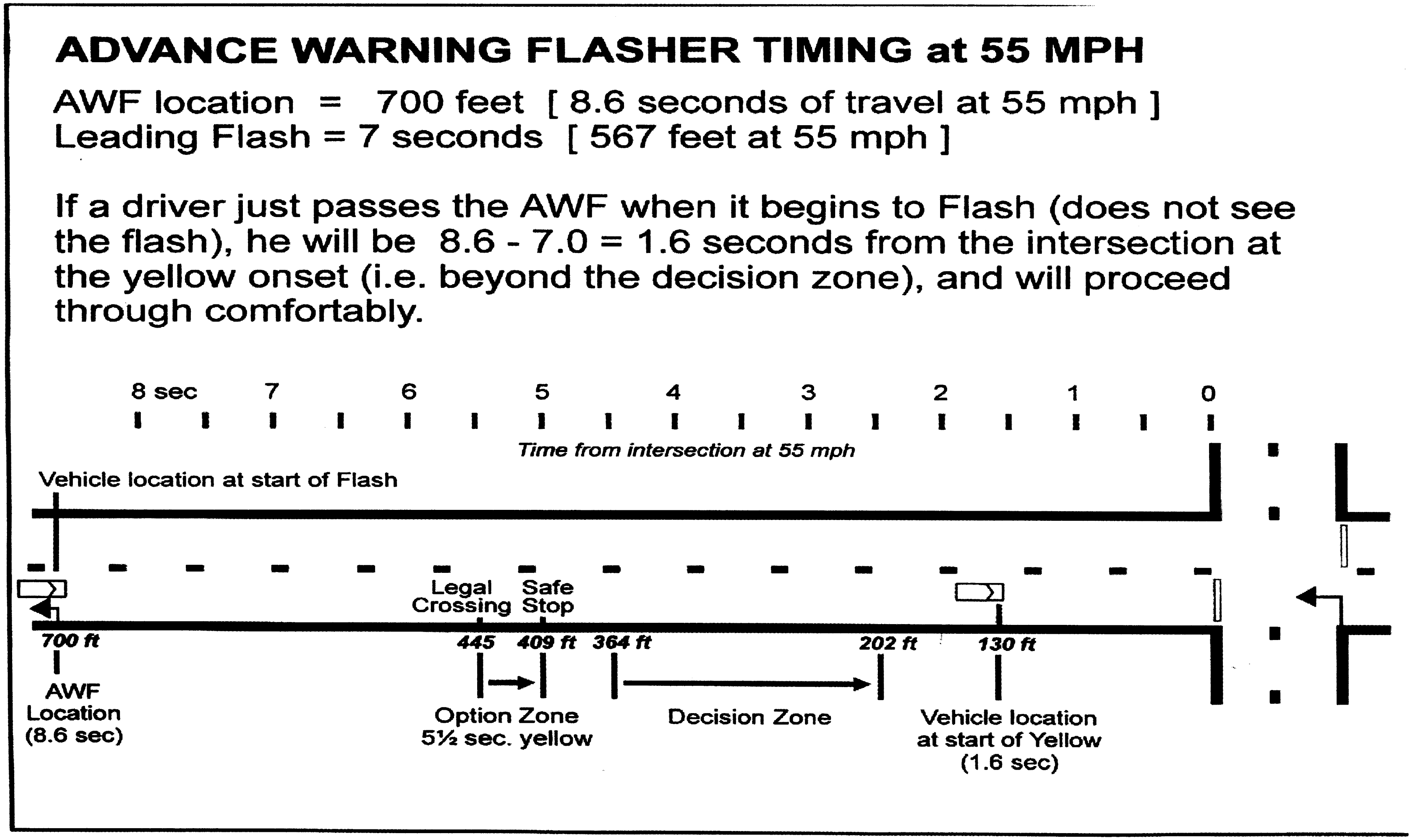


Figure 1-2. Depiction of decision zone in relation to AWF timing at 55 mph for a signalized intersection with an AWF installed, with timing assumptions summarized [6].

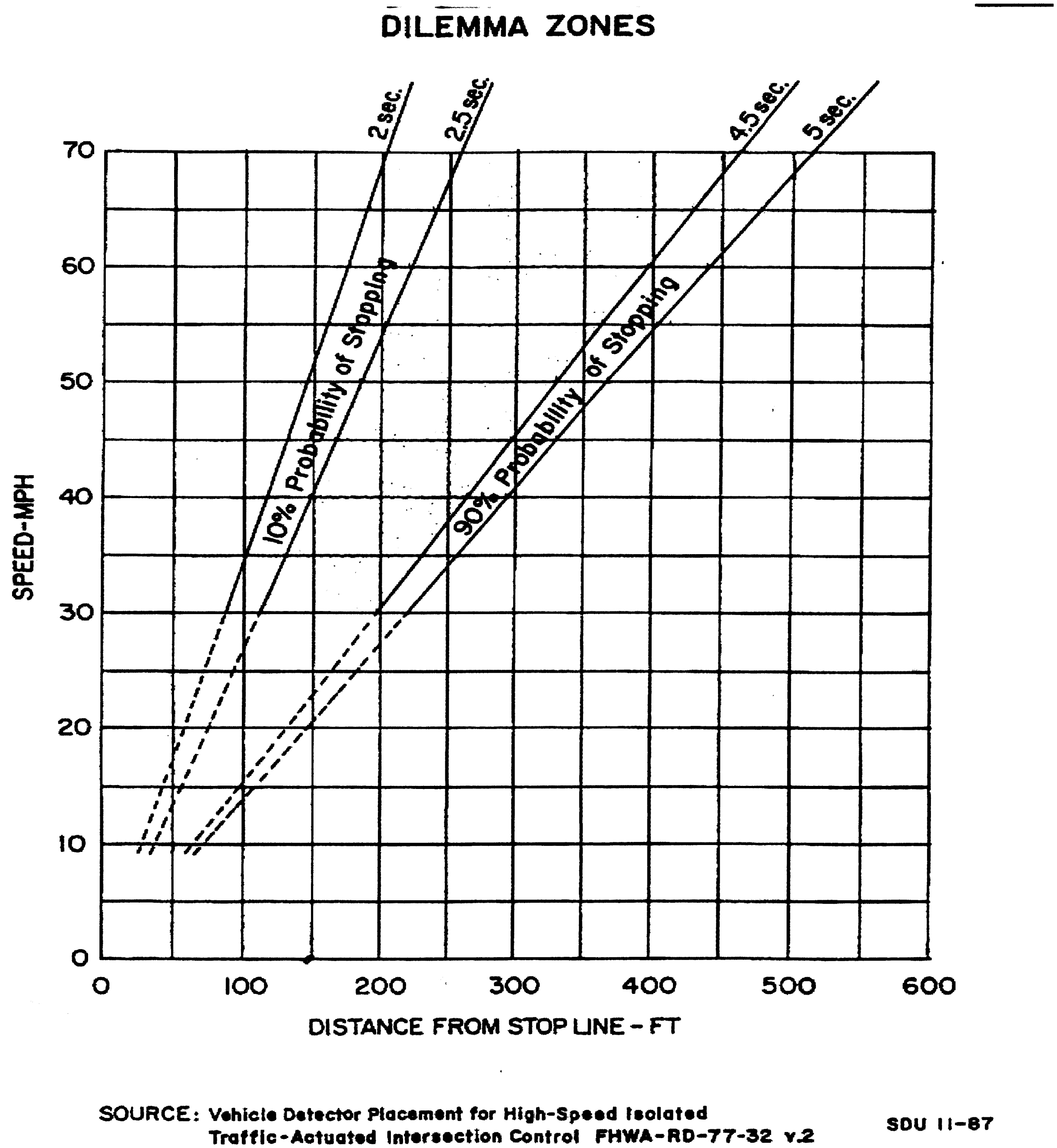
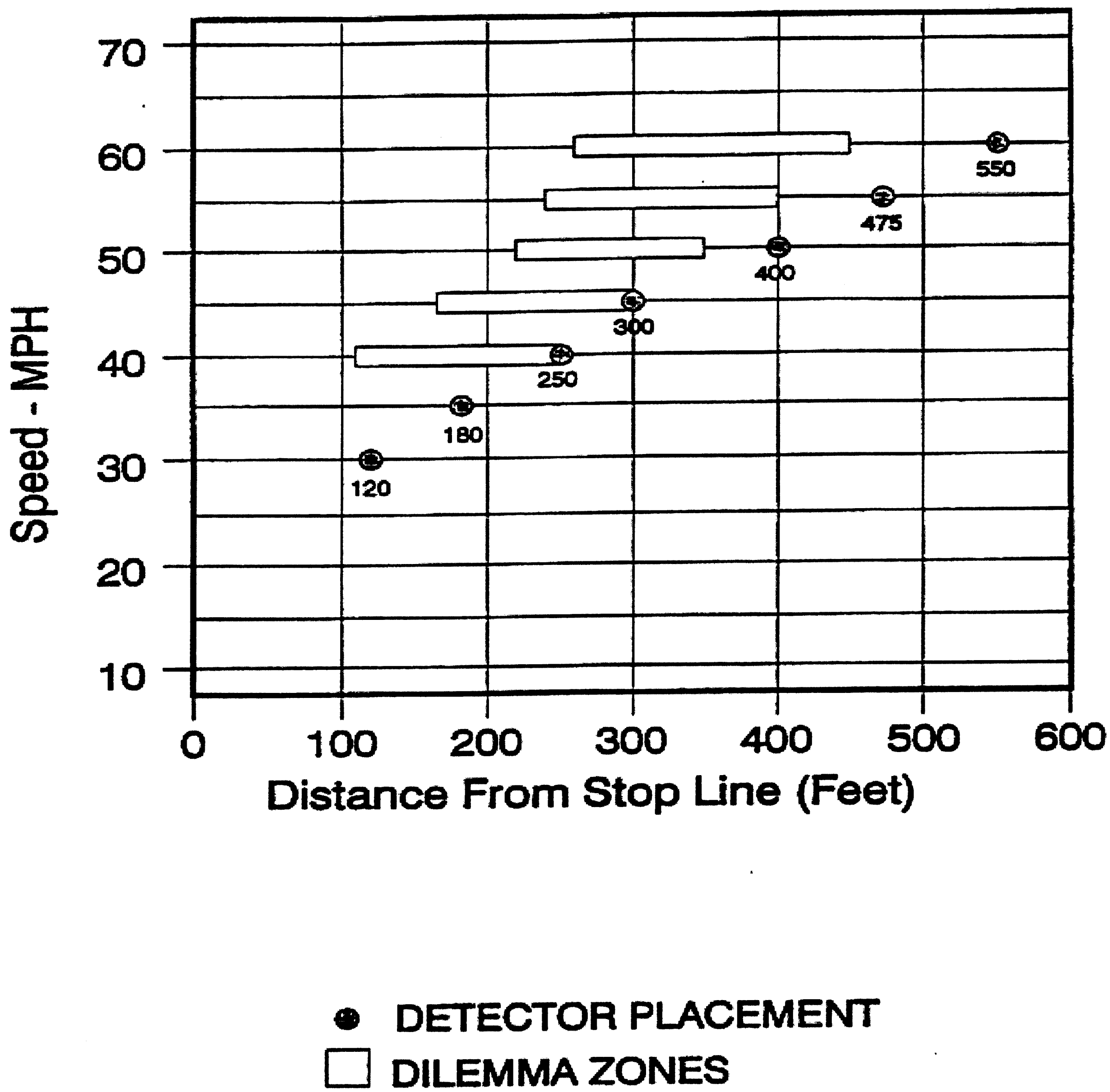


Figure 1-3. Combinations of SL and distances from stop line for which the probability of stopping lies between 10% and 90% [6]. Data are based on empirical studies of stopping behavior. The decision zone exists between the 2.5 and 4.5 sec probability lines, within which stopping behavior is unpredictable. Because the data reflect driver behavior, the zones shown represent neither theoretical braking performance, nor the stop line distance for which legal crossing at speed is possible.



Note: Grades and other factors may require adjustment from normal.
Note: Detector spacing outside the limits shown may require additional detectors.

Figure 1-4. Actual dimensions of dilemma zones plotted as distances from stop line for different SLs [6].

and decision zones for a given SL. Figures 1-1 and 1-2, furnished courtesy of Gary Ries [6], schematically illustrate these concepts for a SL of 55 mph. The dilemma and decision zones related to yellow timing at 55 mph for signal without an AWF are depicted in Figure 1-1, and Figure 1-2 depicts AWF timing under the same conditions for a signal with an AWF installed. Figures 1-3 and 1-4, also furnished by Mr. Ries [6], provide graphical depictions of the dilemma zone concept.

The dilemma and decision zone concepts addressed by Mn/DOT [5], and summarized in Figures 1-1 through 1-4 [6], are reviewed below because they clarify derivation of the dimensions for these zones, and they also provide a rationale for the vehicle-proximity-to-yellow (VPTY) times evaluated in this study (Section 2.3.2).

1. Gazis and colleagues [4] originally concluded that decision zones at signalized intersections are mainly the result of inadequate yellow clearance interval timing. Mn/DOT [5] notes that from a practical perspective, the yellow clearance interval is defined as the time elapsed during which a driver visually perceives a change in signal status of a signalized intersection from green to yellow, makes a decision about the necessity of stopping, and acts upon that decision.
2. The yellow clearance interval is defined by the following equation [4,5]:

$$Y + AR = rt + v/2d + (w + l)/v \qquad \text{(Equation 1)}$$

where:

Y	=	yellow interval in sec
AR	=	all-red interval in sec, representing time for vehicle to clear intersection, after entering intersection just as signal changes from yellow to red
rt	=	perception-reaction time of driver in sec
v	=	vehicle approach speed in ft/sec
d	=	deceleration rate in ft/sec/sec
w	=	width of intersection in ft
l	=	length of vehicle in ft

3. Although rt can vary over a substantial range, it is usually considered to be 1.0 sec for timing yellow clearance intervals [5].
4. The term v/2d represents the time required for a vehicle to come to a stop from its approach speed, v.

5. The term (w+l)/v represents the time for the vehicle to cross an intersection of width, w. Vehicle length, l, is normally considered to be 20 ft [5], longer than most cars but shorter than most trucks.
6. Equation 1 conforms to the Uniform Vehicle Code definition for the yellow clearance interval, which assumes that a vehicle may legally enter an intersection on yellow, even though the signal may turn red before the vehicle clears the intersection. The AR term accounts for such vehicles, and the (w+l)/v term represents the AR interval.
7. A dilemma zone may exist between the distance a vehicle requires to decelerate to a stop, and the distance it would travel at approach speed during the clearance interval. To illustrate derivation of the <u>timing</u> for a dilemma zone [5], assume that a vehicle is approaching a signalized intersection at 81 ft/sec (55 mph). Assume further that: (1) d=10 ft/sec/sec; (2) rt=1 sec; (3) w=40 ft; and (4) l=20 ft. From Equation 1, using these assumptions, Y+AR=4.8 sec. Thus, a dilemma zone for an approaching vehicle exists under these conditions if the signal has a yellow clearance time less than 4.8 sec.
8. As shown in Figure 1-1, the stopping <u>time</u> for a given approach speed is calculated by dividing the approach speed by the deceleration rate. The stopping <u>distance</u> is calculated by multiplying half the approach speed (assumed to represent the average speed during deceleration from v to 0 ft/sec) by the stopping time, and then adding the additional distance traveled by the vehicle during the rt interval. Using this derivation, Figure 1-1 calculates a stopping distance of 409 ft, for v=81 ft/sec (55 mph), d=10 ft/sec/sec, and rt=1 sec. Thus, 409 ft represents the upper dilemma zone distance for these conditions. Upper dilemma zone distances shown for different approach speeds in Figure 1-4 are derived using the same approach.
9. The lower dilemma zone <u>distances</u> depicted in Figures 1-1 and 1-4 are based on a yellow time of 3 sec, and are calculated by multiplying 3 sec by the approach speed.
10. Summaries in Points 7-9 provide an explanation for the dilemma zone depicted in Figure 1-1. With a 3-sec yellow and an approach speed of 55 mph: (1) for a vehicle to legally enter the intersection (Point 6), the vehicle must be at or within 243 ft from the intersection; or (2) for a vehicle to safely stop, the vehicle must be at or beyond 409 ft from the intersection. At positions between these 2 distances, the vehicle will neither be able to safely stop, nor to legally enter the intersection by maintaining speed. Hence the term dilemma zone.

11. Conversely, with a 5.5-sec yellow and an approach speed of 55 mph, the stopping distance (409 ft) is less than the signal clearance distance (445 ft), and the driver has the option (option zone in Fig. 1-1) of either maintaining speed to legally enter the intersection, or of stopping safely. At 55 mph with a 5.5-sec yellow therefore, a dilemma zone does not exist.

12. Given the yellow signal duration times of 5.5 sec (50 mph SL) or 6.0 sec (65 mph SL) used for simulation modeling (Table 1-2), no dilemma zone exists for any SDTE intersection used in this study (Point 11). However, there is a decision zone for every intersection that Ss interacted with. Unlike dilemma zones, whose boundaries rest upon calculations of vehicle travel and stopping distances at different SLs (Figs. 1-1,1-4), determination of decision zones is based upon empirical observations of driver stopping behavior. Observational data used for this purpose are presented in Figure 1-3 [6]. The figure provides a behaviorally representative depiction of the decision zone concept by indicating that the inclination of drivers to stop at signalized intersections in fact shows a statistical distribution that depends upon the approach speed (Y axis in the figure), the distance from the intersection (X axis in the figure), and the vehicle times from the intersection at different SLs associated with the specified stopping probabilities. Stopping probability data such as those shown in Figure 1-3 are derived from empirical observations of the sort reported by Williams [7]. As this author notes, actual stopping probabilities may vary from intersection to intersection, and field observations may be necessary to determine stopping probability isolevels for a given intersection.

13. Upper and lower decision zone limits are defined by vehicle-intersection distances associated, respectively, with the 4.5 sec (90% stopping probability) and 2.5 sec (10% stopping probability) lines in Figure 1-3. For example, the decision zone distances of 202 to 364 ft shown in Figure 1-1 for 55 mph are derived as follows: (1) 202 ft corresponds to the distance from the intersection at which the zone for 10% probability of stopping begins (81 ft/sec x 2.5 sec); and (2) 364 ft corresponds to the distance from the intersection at which the zone for 90% probability of stopping begins (81 ft/sec x 4.5 sec). Because a probability of stopping can be assumed never to equal either 0 or 100% exactly, a decision zone exists for all signalized intersections (unlike the case for a dilemma zone, Point 11). Decision zone limits for a given SL may be taken from Figure 1-3, or calculated for 2.5 and 4.5 sec (see Fig. 1-3) based on vehicle travel distances at

Table 1-3. Decision zone limit and vehicle-intersection distances for SL and VPTY conditions employed in this study.

Speed Limit	Decision Zone and Vehicle-Intersection Distances					
	Decision Zone Limits[1]		Vehicle Distance from Intersection at Specified VPTY Times			
	Upper Limit	Lower Limit	0 sec	2.0 sec	3.5 sec	5.0 sec
50 mph (73.3 ft/sec)	330 ft 101 m	183 ft 56 m	0 ft 0 m	147 ft 45 m	257 ft 78 m	367 ft 112 m
65 mph (95.3 ft/sec)	429 ft 131 m	238 ft 73 m	0 ft 0 m	191 ft 58 m	334 ft 102 m	477 ft 145 m

[1]Upper and lower limits based on stopping distances for 2.5 sec (10% stopping probability) and 4.5 sec (90% stopping probability) proximities of vehicle to intersection - see Fig. 1-3.

the SL specified.

14. Table 1-3 summarizes distances for upper and lower decision zone limits, and vehicle-intersection distances, for SL and VPTY conditions employed in this study. The two SLs are 50 and 65 mph (Chap. 2). At each SL, upper and lower limits for decision zone distances are based, respectively, on the 4.5 sec line (90% stopping probability) and the 2.5 sec line (10% stopping probability) in Figure 1-3. Using the 50 mph SL as an example, the lower limit distance for the decision zone is 73.3 ft/sec x 2.5 sec, or 183 ft, and the upper limit distance for the decision zone is 73.3 ft/sec x 4.5 sec, or 330 ft. Likewise, the vehicle-intersection distance values for 4 of the VPTY conditions employed in this study (Chap. 2) (0, 2.0, 3.5, and 5.0 sec) are calculated by multiplying the VPTY by the SL in ft/sec. Data in Table 1-3 show that, for either SL: (1) only the 3.5 sec VPTY time places the vehicle within the decision zone distances specified; and (2) the 2.0 and 5.0 sec VPTY times place the vehicle, respectively, just inside and just outside the decision zone distances specified. These relationships provide the rationale for the choice of the VPTY levels used in the study. That is, using 2.0, 3.5, and 5.0 sec VPTY intersections allows effects of AWFs on dependent measures of SDP to be evaluated, respectively, with the vehicle approaching, within, and just inside of the decision zone at either SL.

Table 1-4. Time and distance parameters for AWF relative to yellow signal actuation, for vehicle SLs of 50 and 65 mph.

SL	AWF Location from Signal (Table 1-2)		AWF Actuation Prior to Yellow Signal (Table 1-2)		Proximity of Vehicle to Signal at Yellow Onset, with Vehicle Adjacent to AWF at Onset of AWF Actuation	
	Time (sec)	Distance	Time (sec)	Distance	Time (sec)	Distance
50 mph	9.6	705 ft 215 m	8.0	586 ft 179 m	1.6	117 ft 36 m
65 mph	8.9	853 ft 260 m	7.5	715 ft 218 m	1.4	133 ft 41 m

15. As Figure 1-2 suggests, an AWF is introduced to aid driver decision-making prior to arrival of the vehicle in the decision zone. The calculation shown in the figure for an approach speed of 55 mph indicates that if the vehicle is just adjacent to the AWF when it begins to flash, the vehicle will be beyond the decision zone at the onset of yellow. If the vehicle is in front of the AWF when it begins to flash, the driver will be able to anticipate the onset of yellow within the decision zone, which in turn will assist decision-making prior to traversal of the vehicle into the zone.

16. Table 1-4 summarizes timing and distance parameters for AWF relative to yellow signal actuation, with the vehicle approaching the AWF at 50 and 65 mph, the two SLs employed in this study (Section 2.3.1). Comparing the last column in Table 1-4 with data in Table 1-3, it can be seen that if the vehicle is adjacent to the AWF at the onset of AWF actuation: (1) maintaining a 50 mph SL places the vehicle (D=117 ft, Table 1-4) just inside of the lower decision zone limit of 183 ft for this SL (Table 1-3). ; and (2) maintaining a 65 mph SL places the vehicle (D=133 ft, Table 1-4) just inside of the lower decision zone limit of of 238 ft for this SL (Table 1-3).

1.2.2. Human Factors and Driving Performance Issues Associated With Use Of Advanced Warning Flashers

Effects of AWFs on traffic safety and driver performance have been documented in a series of field research projects conducted by Mn/DOT and others (see bibliography of publications compiled by Klugman and colleagues [1]). Results indicate that AWFs: (1) are strongly preferred by the public [9]; (2) reduce the incidence of red light running, with the percent reduction in violations observed for trucks over double that observed overall [10]; but (3) do not consistently and significantly reduce accident frequency [1,5,11,12].

All of the studies cited above have involved collection of survey and/or direct observational data under field conditions. In the field, it is impossible to rigorously control for a variety of extraneous variables that conceivably could influence the interaction of driving performance and safety with AWFs. Factors such as variable viewing, intersection layout, traffic, vehicle speed, driver distraction, and weather conditions can be cited. No systematic studies appear to have been performed to date under carefully controlled simulated driving conditions that have addressed directly the influence of AWFs on detailed attributes of driving performance and driver behavior.

Consequently, a number of human factors (HF) issues pertaining to AWFs remain unresolved, particularly regarding the interaction of AWFs and driver performance. For example, field research has documented an interaction between control of vehicle speed and AWF proximity to the intersection [1], but the possible interaction between control of vehicle speed and braking behavior, and proximity of the vehicle to the flasher and yellow signal when they are actuated, remains to be evaluated. This same research [1, Fig. 6] suggests that under certain combinations of vehicle speed, AWF-intersection proximity, and vehicle-AWF proximity at AWF actuation, drivers may actually speed up when the AWF is actuated, a finding with obvious traffic safety implications. As detailed in Chapter 2, this study addresses some of these unresolved questions with an experimental design that evaluates the main effects of AWF presence, SL, and VPTY level on a series of dependent measures that comprise visual observations plus objective measures of simulated driving performance (SDP), coupled with subjective responses to a post-test questionnaire (PTQ).

1.2.3. Research Objectives, Work Plan and Contract

The availability of a fixed-base, flat-screen driving simulator at the UM Division of Kinesiology Human Factors Research Laboratory (HFRL) offers the opportunity to use an experimental approach based on analysis of SDP to address HF/E and driving performance issues associated with use of AWFs. The overall objective of the study therefore is to conduct a HF/E analysis of the effects of AWFs on SDP and behavior, during driver interaction with simulated signalized intersections as they traverse a simulated driving task environment (SDTE). Specific research objectives are to use this approach to: (1) clarify how driver control of vehicle speed and braking may be influenced by AWF absence/presence, SL, and VPTY level, during driver interaction with signalized intersections; (2) use a subjective response questionnaire to assess the familiarity of each subject (S) with, and S opinions regarding, use of AWFs at signalized intersections; and (3) use findings from the research to target possible traffic engineering design improvements to AWF-intersection systems that may benefit traffic safety as well as AWF utilization decision-making.

The research is intended to address the following questions; (1) how is SDP influenced by AWF absence/presence, SL, and VPTY level? and (2) can results from the study be used to target possible strategies for improving the traffic engineering design of AWF-intersection systems, with possible long-term benefits for AWF utilization decision-making and traffic safety?

The following five tasks are specified in the project work plan: (1) specify design features for the signalized intersection and AWF to be employed in the SDTE; (2) develop and implement SDTE and experimental control software; (3) conduct S testing and data collection; (4) analyze data collected under Task 3; and (5) prepare and submit final report. Findings obtained from the research form the basis for a series of conclusions presented in Chapter 4 pertaining to effects of AWFs on simulated driving behavior and performance, and related traffic safety implications of using AWFs at signalized intersections.

CHAPTER 2
EXPERIMENTAL DESIGN AND METHODS

2.1. INTRODUCTION

This chapter describes the experimental approach and methods employed, and S characteristics, for project research. Sections below deal with development of a SDTE (project work plan Tasks 1 and 2), and experimental design, protocol, and S characteristics (project work plan Task 3), for the research.

2.2. DEVELOPMENT AND IMPLEMENTATION OF SDTE

This section describes the approach used to develop and implement the SDTE, which involved the following stages: (1) selection of desired driving environment to model; (2) specification of layout, dimensions, and ancillary features for selected driving environment; and (3) selection of driving simulator platform. Each of these stages is described in subsections below.

2.2.1. Driving Environment Employed for Simulation Modeling

Five basic considerations governed selection of a driving environment acceptable for simulation modeling: (1) to allow for case-control comparison of AWF versus no AWF conditions on driver interaction with signalized intersections (Section 2.3), the driving environment should present a series of intersections for the driver to interact with; (2) each experimental session should last about 1 hr, to reduce the likelihood of possible confounding effects of fatigue on driver performance during the latter stages of a given session; (3) there should be a reasonable distance between intersections, such that driver interaction with each intersection can be treated as essentially an independent event; (4) given the choice of 5 VPTY levels (Section 2.3), the total number of intersections encountered by a driver during a given simulated driving trial should be some multiple of 5; and (5) at least some of the intersections modeled in the driving environment should be based on real world intersections equipped with AWFs, to allow for direct comparison of simulated versus actual intersections with identical designs in any future effort to validate the simulated driving observations by collecting real world field observations of driver interactions with AWF intersections.

An additional consideration regarding choice of a driving environment was whether to create a completely artificial environment (not based on any real world route), or to base the simulation model on a real world route. Point 5 above prompted the latter choice. After evaluation of a variety of alternatives, the decision was made to model the SDTE after a real world route that traverses the cities of Mendota Heights, Sunfish Lake, and West Saint Paul, Minnesota.

Figure 2-1 is a traffic map that shows the real world route (dark line) used for modeling purposes. It consists of an oblong circular route encompassing Minnesota Trunk Highway (T.H.) 110 to the north, T.H. 55 to the west, and I-494 to the south. Arrows in the figure indicate the counter-clockwise direction that Ss traversed the route during simulated driving trials, from a start (S) point to an end (E) point. Circles in the figure indicate the intersections (1-10) modeled in the SDTE (Fig. 1-6A). A topographical map of the area was obtained from Mn/DOT to allow the 3-D topography of the route to be incorporated into the model.

Figures 2-2A and 2-2B illustrate successive stages in the development of the simulation model for the actual real world route. Figure 2-2A is a simplified concept sketch of the actual route, showing: (1) the start and end points; (2) the 10 intersections (I1,I2...I10) included in the model. For each simulated driving trial, Ss started driving from a standing start at a start line situated prior to the first intersection, and finished by crossing an end line situated after the tenth intersection.

Figure 2-2B illustrates the SDTE as actually modeled, superimposed on (x,y) coordinates (in meters) used in the model for the course, with positions of the data collection start point (♦), the AWF (■), and the signal (▲) indicated for each intersection. It is apparent from this figure that both the orientation of the intersections and the road layout featured in the actual route (Fig. 2-1) have been altered for modeling purposes. For example, to simplify data collection (such that vehicle movement is in one coordinate direction only at each intersection), each of the 10 intersections in the course is oriented in either the horizontal (I1..I4, I6...I9) or the vertical (I5,I10) direction.

The total distance from start line to end line for the route depicted in Figures 2-1 and 2-2A is 18.2 km (11.3 mi). Table 2-1 summarizes characteristics of each intersection along the route, in terms of the real world intersection modeled, and distances of each intersection from the start line and from each other.

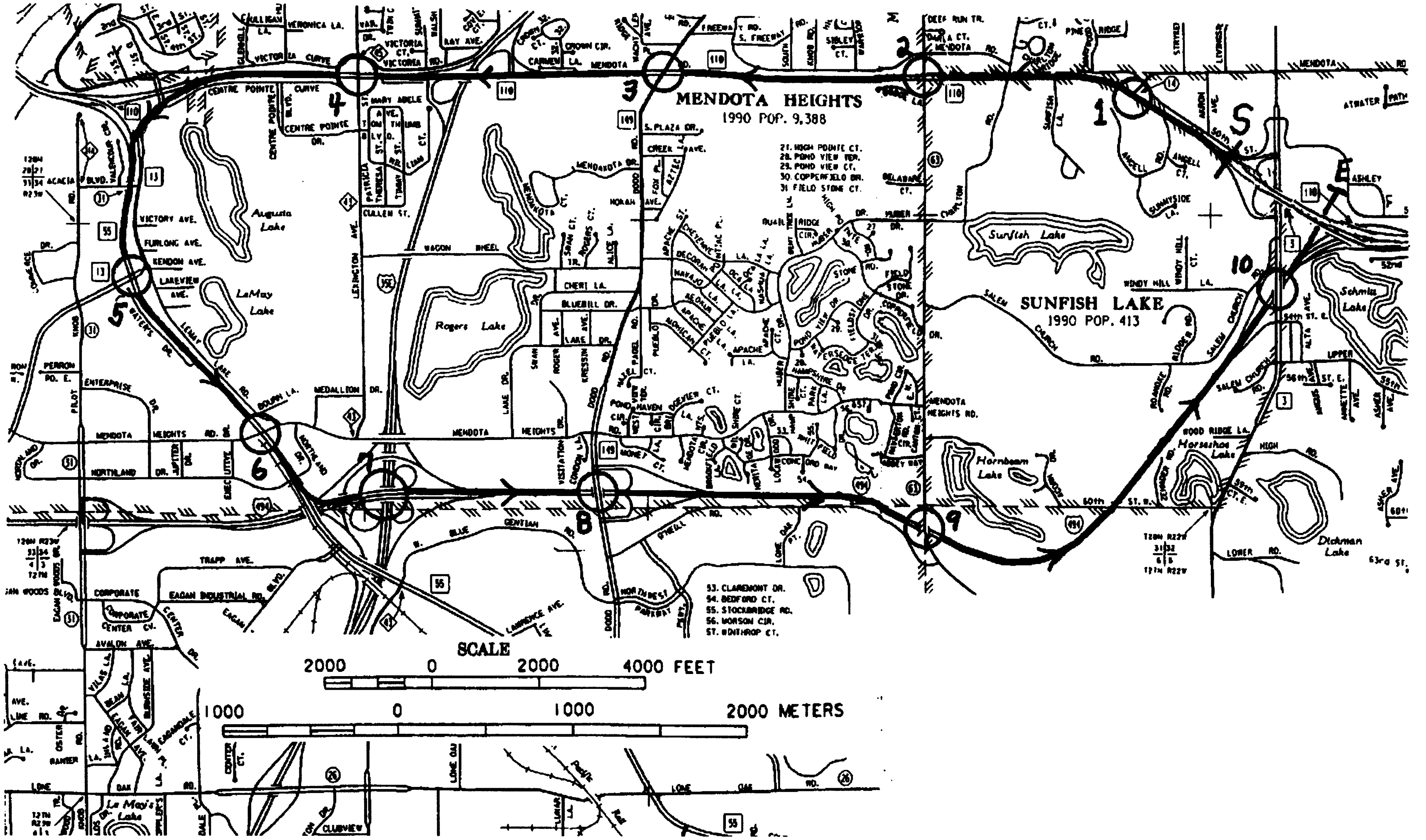


Figure 2-1. Map of real world route (dark line) used to model SDTE. Arrows indicate direction that Ss traversed the route during simulated driving trials. Circles indicate intersections modeled in SDTE (Fig. 2-2A).

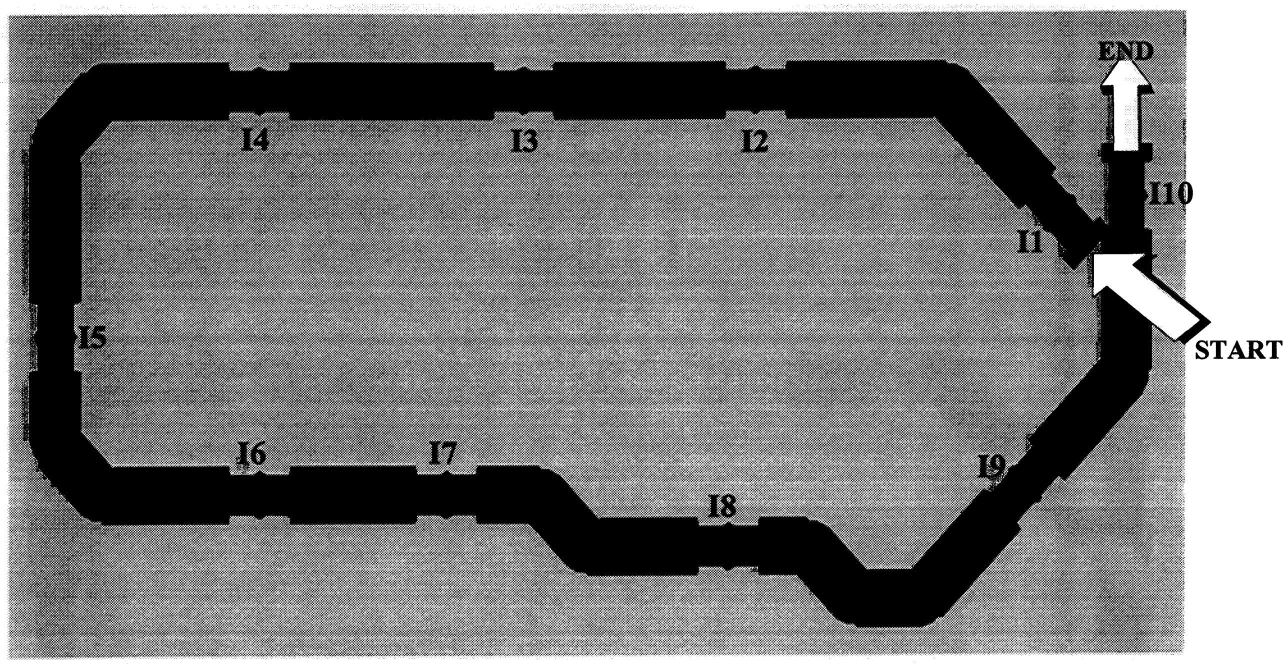


Figure 2-2A. Simplified concept sketch of the route used for simulation modeling, showing start and end points, and the 10 intersections (I1,I2...I10) included in the model.

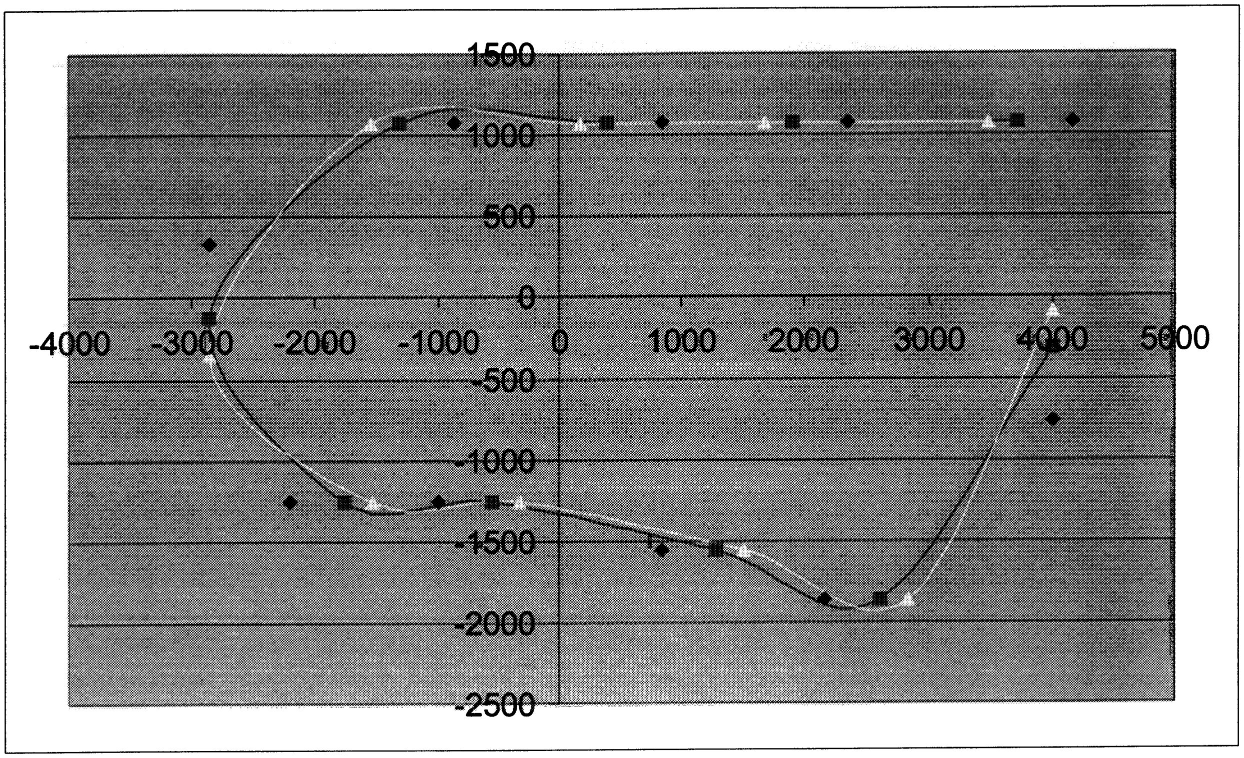


Figure 2-2B. SDTE as actually modeled, superimposed on (x,y) coordinates (in meters) used in the model for the course, with positions of the data collection start point (♦), the AWF (■), and the signal (▲) indicated for each intersection.

Table 2-1. Characteristics of intersections modeled in SDTE.

Inter-section	Real World Intersection Modeled	Distance from Start Line (m)	Distance From Previous Signal (m)	Real World AWF?
1	T.H. 110 @ Mendota Rd.	1780	N/A	Yes
2	T.H. 110 @ Delaware Rd.	3586	1806	Yes
3	T.H. 110 @ Dodd Rd.	5092	1506	Yes
4	TH. 110 @ Lexington Rd.	6805	1713	No
5	T.H. 55 @ T.H. 13	9139	2334	No
6	T.H. 55 @ Mendota Heights Rd.	11,018	1879	No
7	I-494 @ I-35E	12,224	1206	No
8	I-494 @ Dodd Rd.	14,103	1879	No
9	I-494 @ Delaware Rd.	15,515	1412	No
10	I-494 @ Robert St.	18,034	2519	No
End Line	N/A.	18,234	200	N/A

Table 2-1 indicates that for Intersections 1-3, actual AWFs are installed along the real world route. The designs of these intersections, therefore, are generally aligned with Mn/DOT guidelines governing AWF installation (Table 1-1). The mean distance between intersections in the SDTE is 1806 m (5925 ft; 1.12 mi), with a range of 1206 m (3957 ft; 0.75 mi) to 2519 m (8265 ft; 1.57 mi). At a SL of 50 mph, Ss thus should average 1.35 min elapsed simulated driving time (ESDT) between intersections; at a SL of 65 mph, the ESDT between intersections should average 1.04 min. For purposes of this project, it is assumed that with average ESDTs of 1 min or more between intersections, driver interactions with successive intersections in the SDTE represent independent episodes.

To traverse the entire 18.2 km (11.3 mi) course, the total ESDT should be 13.6 min with no stops at 50 mph, and 10.5 min with no stops at 65 mph. During an actual simulated driving trial, Ss would encounter red lights and therefore probably stop at some intersections, thereby extending these ESDTs by an amount that will vary from subject to subject. Nevertheless, the ESDTs are of a magnitude to allow 4 simulated driving trials to be completed within a 1-hr period at either SL. Pilot studies established that this expectation in fact was realized (Section 2.3.2). Collectively, the information in Table 2-1 suggests that the route depicted in Figure 2-1 satisfies all of the considerations set forth at the outset of this section for developing an acceptable and appropriate model of a SDTE for the study.

The simulated driving course was modeled as a 4-lane divided highway, although Ss only used the two outside, one-way lanes to traverse the course counter-clockwise (Ss were told that they could drive in either lane). Each of the 2-lane, one-way roadways in the course were modeled using standard dimensions for such roadways in the state of Minnesota, namely 3.6 m lane widths and 2 m shoulder widths, with a dashed white line separating the two lanes.

2.2.2. Intersection Model and Ancillary Features for SDTE

As with the simulated driving course (previous section), it was decided that the intersections depicted in the SDTE should be modeled on an actual real world intersection at which an AWF is installed. For this purpose, the intersection of Minnesota T.H. 61 at 12th Street in Newport, MN was selected. The two figures in Appendix C show the design features and simulation model for the intersection. Figure C-1 shows Mn/DOT design specifications for the actual intersection, and Figure C-2 shows an overhead view of the simulation model of the intersection, based on these specifications. The intersection simulation model shown in Figure C-2 was used for all 10 intersections in the SDTE.

The simulation model for the AWFs is based on design specifications shown on the last page of Appendix A. Prior to each intersection, one simulated AWF is placed just off the right hand shoulder of the roadway at a distance from the intersection specified in Table 1-2. During simulated AWF actuation, the two lights on the AWF are programed to flash in an alternating fashion at a frequency of 1 hz.

A simulated pole and mast arm traffic signal, positioned just off the right hand shoulder adjacent to the intersection entrance, with the mast arm extending to the left over both roadway lanes and with dual one-way signals suspended from the mast arm, was modeled for each intersection using standard Mn/DOT design specifications [13,14]. Figure 2-3 shows a visual perspective from the simulation model, looking towards the simulated intersection, with the simulated AWF in the foreground and the simulated pole and mast arm traffic signal in the background. During simulated yellow signal actuation, standard Mn/DOT specifications for yellow light duration were employed, namely 5.5 sec for the 50 mph SL, and 6.0 sec for the 65 mph SL (Table 1-2). An arbitrary duration of 10 sec for red light actuation was employed, a period long enough to encourage 'normal' red light stopping behavior but short enough to avoid inordinate delay of the driving task during a trial.

A simulated SL sign (50 or 65 mph), based on standard Mn/DOT design specifications for such signs, was placed just off the right hand shoulder at the Start line, and at distances of 213.5 m (700 ft) beyond Intersections 1 to 9.

The driving simulator system employed in this study cannot vary the luminance levels of projected light sources. Therefore, visibilities of the AWF and traffic light signals and the SL signs were enhanced by scaling up the <u>sizes</u> (rather than the luminance levels) of these features in the SDTE, relative to their actual real world dimensions. Specifically, sizes of the AWF lights were scaled up by 300%, those of the traffic light signals were scaled up by a varying scale (becoming smaller as the driver approached them), and those of the SL signs were scaled up by 100%.

The simulated Start line, at which the vehicle was positioned at the initiation of each simulated driving trial, was modeled as a white line across the roadway crossing both roadway lanes, at a distance before Intersection 1 specified in Table 2-1. The simulated End line was modeled as both a white line across the roadway crossing both roadway lanes, and as an overhead pylon. The roadway was extended about 100 m beyond the End line to allow Ss an adequate distance to stop at the end of a simulated driving trial after crossing the End line.

2.2.3. Driving Simulator Platform

The HFRL fixed-base, flat screen driving simulator was employed to project the SDTE for the course shown in Figure 2-1. This simulator comprises: (1) a flat screen that is 2.13 m (7 ft) high and 3.05 m (10 ft) in wide; (2) an SGI, Inc. Indigo computer with a Reality Engine 2 graphics board; (3) one projector (NEC Model MT830), controlled by the SGI Indigo, providing a forward image subtending a 60 deg horizontal field of view and a 55 deg vertical field of view; (4) a full-sized 1990 Honda Accord sedan positioned in front of the screen, with data input from accelerator, brake, and

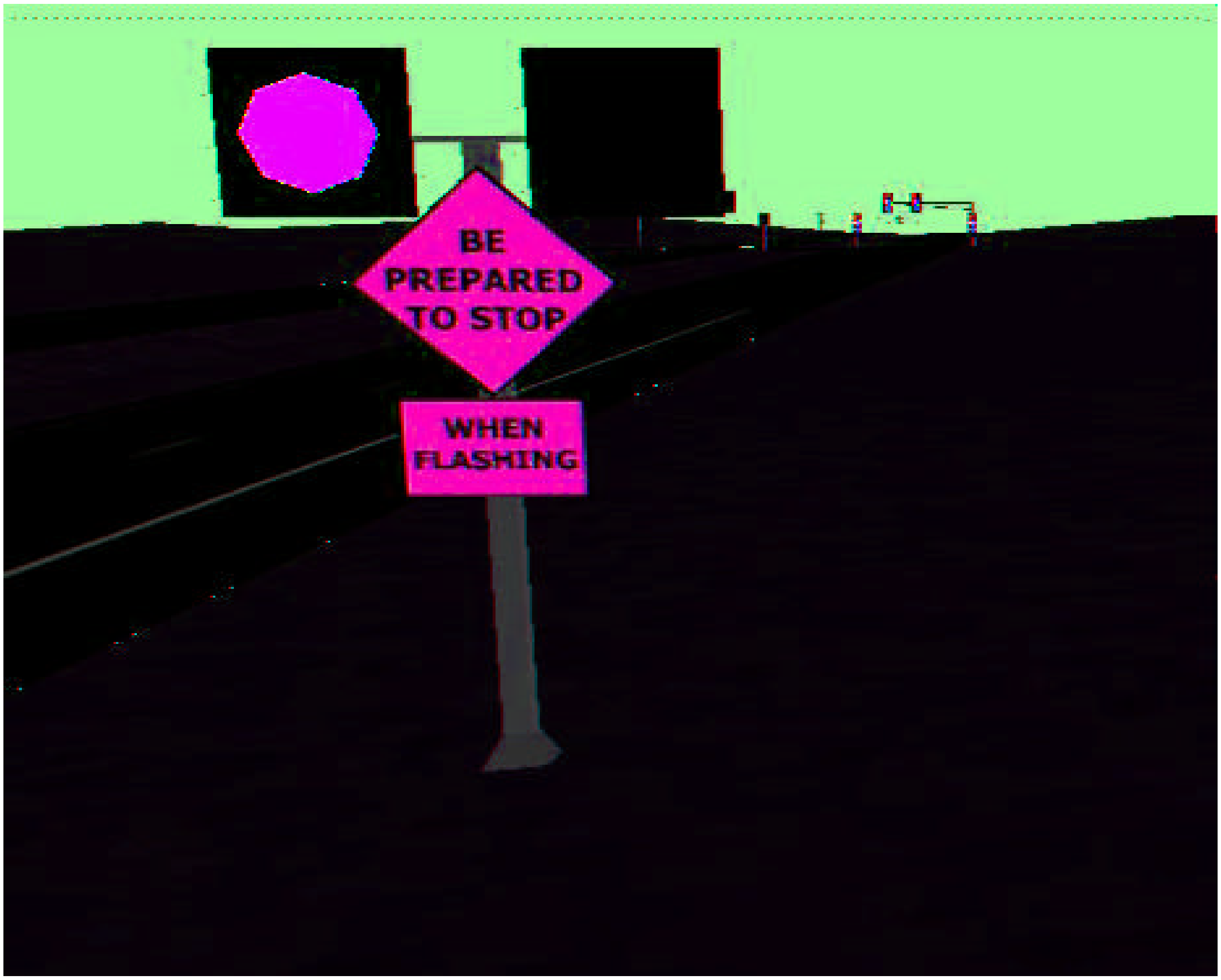


Figure 2-3. Perspective from SDTE showing simulated AWF in foreground, and simulated pole and mast arm with dual traffic signal in background.

---

generates simulated road and engine noise that is broadcast on speakers within the Honda---volume of road and engine noise is varied proportionally with simulated vehicle speed and rpms respectively. Simulation programming was carried out by Peter Easterlund using MEDIT software, a three-dimensional (3D) modeling platform designed primarily for use with SGI systems.

2.3. EXPERIMENTAL DESIGN

The controlled environment of the driving simulator allows more rigorous control of experimental

2.3. EXPERIMENTAL DESIGN

The controlled environment of the driving simulator allows more rigorous control of experimental conditions than is possible with real world driving environments. However, it may impede efforts to develop a realistic profile of variability in driving performance, in that Ss are less likely to vary their driving behavior in a manner comparable to real world patterns if experimental conditions governing the SDTE are rigorously controlled in a way that does not conform to variability in the driving environment that prevails in the real world. This is an important consideration for this study, in that Ss may not respond much differently to AWFs under different prevailing vehicle speed and AWF proximity conditions if they perceive from the outset that interaction with the AWF represents the main object of the experiment. Accordingly, a key premise of the experimental design set forth here is that the major focus of the research---variable interaction of the S with signalized intersections equipped or not equipped with AWFs---must be **disguised** if the major objectives of the research are to be realized and if the research is to have meaningful criterion validity.

The experimental design approach adopted therefore is to emphasize to Ss that control of vehicle **speed** is the major objective of the experiment. Subsections below delineate the objectives and independent and dependent measures of the study, describe driving task conditions and requirements, and outline the experimental protocol employed to implement this approach.

2.3.1. Research Objectives

The overall objective of the study is to conduct a HF/E analysis of the effects of a signalized intersection AWF on control of vehicle speed and braking behavior by drivers under simulated driving conditions. Specific research objectives are to: (1) clarify how driver control of vehicle speed and braking is influenced by prevailing vehicle speed and VPTY levels with and without AWFs installed prior to each intersection; and (2) target possible traffic engineering design improvements to AWF-intersection systems that may benefit traffic safety as well as AWF utilization decision-making.

2.3.2. Independent Measures

The bullets below, and Tables 2-2 and 2-3, describe the following independent measures for the study: AWF presence, vehicle speed, VPTY, SDTE, trial schedule, and Ss.

- ***AWF Presence***. Simulated AWFs were either not installed (control), or installed using design specifications outlined above (Section 2.2.2)(test), prior to each of the 10 SDTE intersections.
- ***Vehicle Speed***. Two different vehicle SLs were evaluated: 50, and 65 mph.
- ***Vehicle Proximity to Yellow***. VPTY is defined as the proximity in sec of the vehicle to the traffic signal when the signal turns yellow. Five VPTY conditions were evaluated: (1) all green (signal remained green as vehicle traversed intersection); (2) 0 sec (vehicle adjacent to signal when signal turns yellow); (3) 2 sec; (4) 3.5 sec; and (5) 5 sec. As shown in Table 1-3, at either SL the VPTY interval of 5 sec is just outside, that of 3.5 sec is within, and that of 2 sec is just inside, the intersection decision zone. For a given intersection, the yellow signal light was actuated at a desired VPTY interval using programing techniques to calculate instantaneous vehicle speed at a frequency of 12-15 hz, and to project time of arrival of the vehicle at the intersection based on this calculation. When the projected time of arrival matched the desired VPTY interval, the yellow signal light was actuated.
- ***Trial***. Because separate means for the 3 objective dependent measures of SDP (e.g., vehicle speed, braking pressure, and acceleration/deceleration, Table 2-4) are calculated for Trial 1 and Trial 2 data blocks (Section 2.5), trial is treated as an independent measure.
- ***SDTE***. To present Ss with all of the different combinations of AWF presence, vehicle speed, and VPTY outlined above, the experimental design required Ss to traverse four different SDTEs. Each SDTE employs the same simulated driving route (Section 2.2.1) and intersection model for the 10 intersections (Section 2.2.2). However, as summarized in Table 2-2, each SDTE differs in terms of AWF absence or presence, vehicle SL conditions, and sequence and level of VPTY employed at each intersection.

  Specifically, two of the SDTEs feature the low 50 mph SL (LSL), without (control) or with (test) AWFs at each intersection. These are termed respectively the LSLC and the LSLT SDTEs (Table 2-2).

  The two remaining SDTEs feature the high 65 mph SL (HSL), without (control) or with (test) AWFs at each intersection. These are termed respectively the HSLC and the HSLT SDTEs (Table 2-2).

  Each of the SDTEs also features replicate levels of each of the 5 VPTY conditions assigned,

Table 2-2. Combinations of independent measures employed in four different SDTEs.

SDTE[1]	AWF[2]	SL	VPTY Level at Each Intersection[3]									
			I1	I2	I3	I4	I5	I6	I7	I8	I9	I10
LSPC	Absent	50 mph	5 sec	3.5 sec	AG	2 sec	0 sec	AG	3.5 sec	2 sec	5 sec	0 sec
LSPT	Present	50 mph	3.5 sec	2 sec	0 sec	5 sec	2 sec	AG	5 sec	AG	0 sec	3.5 sec
HSLC	Absent	65 mph	0 sec	5 sec	5 sec	3.5 sec	AG	3.5 sec	2 sec	0 sec	2 sec	AG
HSLT	Present	65 mph	AG	0 sec	2 sec	AG	5 sec	5 sec	3.5 sec	2 sec	3.5 sec	0 sec

[1]LSLC - Low Speed Limit Control SDTE; LSLT - Low Speed Limit Test SDTE; HSLC - High Speed Limit Control SDKE; HSLT - High Speed Limit Test SDTE

[2]AWF absent - none of the intersections in SDTE provided with AWFs; AWF present - all intersections in SDTE provided with AWFs

[3]I1...I10 - Intersection (I) order in SDTE (see Table 2-1); AG - All Green (light signal remains green as vehicle traverses intersection)

Table 2-3. Characteristics of Ss participating in study.

Statistic[1]	All Ss	Male Ss	Female Ss
Number	24	11	13
Mean Height	68.0	70.4	66.1
SD, Height	3.4	2.8	2.5
SE, Height	0.7	0.8	0.7
Median Height	68	71	66
Height Range	12	10	7
Minimum Height	63	65	63
Maximum Height	75	75	70
Mean Age	26.3	26.3	26.4
SD, Age	8.3	8.6	8.5
SE, Age	1.7	2.6	2.3
Median Age	23	23	25
Age Range	29	27	29
Minimum Age	19	19	19
Maximum Age	48	46	48

[1]height statistics in inches; age statistics in yrs

in random order, to the 10 intersections in each SDTE. The intersection-to-intersection sequence of VPTY levels is different for each of the 4 SDTEs (Table 2-2).

- ***Trial Schedule.*** Replicate simulated driving trials for each of the 4 SDTEs described in Table 2-2 were administered to each S during two experimental sessions, of about 1 hr each, scheduled on separate testing days. Four trials, each lasting approximately 12-15 min, were scheduled during each session, with a 1-2 min rest break between trials. A different sequential order of replicate trials for the 4 SDTEs across the 8 trails was used for each S. Replicate trials of the same SDTE were not scheduled in immediate succession for any S.

With this schedule, each S participated in a total of 8 simulated driving trials covering a total simulated start-finish driving distance of 153.9 km (96 mi), during which a total of 80 subject-intersection interactions occurred, or a total of 16 interactions at each of the 5 VPTY levels. The 24 Ss participating in the study (below) therefore traversed an aggregate total start-finish driving distance of 3,694 km (2,304 mi), during which a total of 1,920 subject-intersection encounters occurred. These comprised a total of 960 control (no AWF) and 960 test (AWF) encounters, and a total of 384 encounters at each of the 5 VPTY levels.

- ***Subjects.*** A total of 24 Ss participated in the study, 11 males and 13 females. Table 2-3 summarizes S height and age statistics. Mean height is 68±3.4 (±SD) in for all Ss, 70.4±2.8 in for males, and 66.1±2.5 in for females. Mean age is 26.3±8.3 (±SD) yrs for all Ss, 26.3±8.6 yrs for males, and 26.4±8.5 yrs for females. Age range is 19 to 48 yrs for all Ss, 19 to 46 yrs for males, and 19-48 yrs for females. These statistics indicate comparable height and age characteristics and distributions for male and female Ss participating in the study.

2.3.3. Dependent Measures

Three categories of dependent measures were collected: (1) visual observations of SDP; (2) objective measures of SDP; and (3) PTQ responses. Measures in each of these categories are summarized in Table 2-4, and described in paragraphs below.

Visual Observations of Simulated Driving Performance. Dependent measures in this category were collected by the study researcher (the senior author of this report) through visual observations of each S, for each of their eight simulated driving trials, as the S traversed the SDTE. For each trial, the objective was to record the actual ESDT (from start line to end line) and the estimate by the S of ESDT, as well as to document stopping behavior of the S at each intersection during a trial. For this purpose, the researcher sat on a chair placed near the open window of the front passenger door of the Honda Accord, and manually recorded these measures during each trial.

To facilitate recording of the visual observation measures, four different visual observation forms were developed, corresponding to the LSLC, LSLT, HSLC, and HSLT SDTEs (Table 2-2). These are illustrated in Appendix D. Each of the forms provides space for manually recording the following information: (1) S characteristics; (2) trial information; (3) actual and judged (based on S estimates) ESDT for completing the trial; (4) subjective impressions of vehicle speed approaching each intersection; and (5) whether or not the vehicle stopped at each intersection. Actual ESDT was measured using a stop watch.

Because there are two intersections within each simulated driving trial for each VPTY condition, and also because each S completed replicate trials for each SDTE (Table 2-2), the stopping observations also are evaluated in terms of whether the S displayed consistent or

Table 2-4. Dependent measures collected during study.

Category	Dependent Measure	Units	Derivation
Simulated Driving Performance			
Visual Observations	- Actual ESDT	sec	observed
	- S Estimate of ESDT	sec	S report
	- Stopping Behavior at Each Intersection	stopped did not stop unsafe stop ran red light consistent or inconsistent	observed
Objective Measures			
Vehicle Speed	- Mean Vehicle Speed (MVS)	m/sec	calculated
	- Mean Acceleration/Deceleration	m/sec/sec	calculated
Vehicle Braking	- Mean Braking Pressure (MBP)	V	calculated
PTQ Responses	- See Appendix E	various	S report

inconsistent stopping behavior both within and between trials. Stopping behavior is consistent if, for those intersections with the same VPTY condition, the S always stopped or did not stop. Stopping behavior is inconsistent if, for those intersections with the same VPTY condition, the S sometimes stopped and sometimes did not stop. The 'Stop at Signal' observations include a special notation if the S stopped either within or beyond the intersection (termed an 'unsafe stop'), or proceeded into and continued through the intersection after the signal turned red (termed 'running red light'). Because of the availability of quantitative speed data (below), data pertaining to subjective judgments of vehicle speed are not considered in this report.

Objective Measures of Simulated Driving Performance. During a trial, the SGI Indigo computer continuously monitors input from sensors in the Honda that monitor driver actuation of the vehicle accelerator, brakes, and steering wheel, along with continuous time values. These data are transferred in real time, via an Ethernet connection, from the SGI Indigo to a coupled IBM-compatible PC that is used for file storage of SDP data. Specifically, these data are recorded automatically in the PC into a Microsoft Excel-compatible output text file updated continuously at a rate of 1 hz. The text file generated for each testing session contains the following data by column: (1) Column 1 - trial number; (2) Column 2 - time mark in approximate intervals of 1 sec; (3) Column 3-5 - X, Y, and Z coordinates (in m) of vehicle position in SDTE; (4) Column 6 - vehicle heading in deg; (5) Column 7 - vehicle speed in m/sec; (6) Column 8 - vehicle braking pressure in volts (V); (7) Column 9 - vehicle accelerator pressure in V; (8) Column 10 - steering wheel angle, in radians; and (9) Column 11 - AWF and signal light status indicator flags.

The X and Y coordinate values, which indicate vehicle position, are used to: (1) extract blocks of data pertaining to driver performance as the vehicle approaches each intersection (Section 2.5); and (2) calculate vehicle distance from the intersection, in m, at successive 1-sec intervals as the vehicle approaches the intersection. The vehicle speed, braking pressure, and accelerator actuation data are used to derive dependent objective measures of SDP. The light indicator flags in Column 11 of the output file are used to determine the timing of changes in these measures in relation to actuation of the AWF and signal warning light. Detailed below are methods used to acquire these vehicle performance data, and the dependent measures of driving performance calculated therefrom.

- ***Vehicle Speed.*** Readout from the Honda accelerator is used to control how rapidly projected visual feedback of the SDTE is updated by the SGI Indigo software for presentation to the driver. From known dimensions of the simulation model, the software is able to determine successive positions of the vehicle in the SDTE to an accuracy of 1 mm during a driving task. From this information, successive measures of vehicle speed in m/sec (Column 7) are recorded in the text file.
- ***Vehicle Acceleration/Deceleration.*** Successive values of vehicle acceleration/deceleration (in units of m/sec/sec) are calculated from the vehicle speed data by subtracting vehicle speed at time=t sec from vehicle speed at time=t+1 sec, and dividing this difference by 1 sec (based on recording rate of 1 hz).
- ***Vehicle Braking.*** A potentiometer coupled to the brake pedal shaft of the Honda, with a 0-1 V readout, provides continuous input to the SGI Indigo on the status of the brake pedal. Readout of depression of the brake pedal is provided when the potentiometer voltage increases above 0 V. Brake pressure values are recorded in volts in Column 8 of the text file. A high voltage value indicates a large displacement of the brake pedal and therefore represents a high braking pressure. A low voltage value indicates a small pedal displacement and a low braking pressure.

The braking pressure data are used to determine mean braking pressure (MBP), calculated by averaging successive values of braking pressure over selected time intervals during a particular trial---compared with a low mean value, a high mean value for a particular time interval indicates that the brake pedal is depressed for a longer period, to a greater degree, or both, during that interval; Because of ambient levels of noise in readouts from the brake pedal potentiometer, voltage levels below 0.02 V were changed to 0 V in the braking pressure data, before MBP was calculated.

- ***Light Indicator Flags***. Integer values between 0 and 4 were generated by software in Column 11 of the output data file to indicate the status of the AWF and signal lights. In particular: (1) 0 indicates green signal light on with AWF off; (2) 2 indicates AWF light on; (3) 3 indicates yellow signal light on; and (4) 4 indicates red signal light on. Once the AWF light is actuated, it remains flashing until the green signal light is actuated.

PTQ Responses. Following completion of the second experimental session, each S was asked to complete a PTQ, a copy of which is provided in Appendix E. The questionnaire comprises a total of 20 questions (Q) that solicit S responses in three different areas: (1) S characteristics (Q1-Q4); (2) typical on-road driving behavior that a S exhibits when approaching intersections (Q5-Q7); and (3) S knowledge of and opinions about AWFs (Q8-Q20). The last 10 questions (Q11-Q20) in the questionnaire consist of 5-choice, Likert-scale questions. For each of these questions the S is asked to indicate, on a scale of 1 to 5, agreement or disagreement with a statement about AWFs, with a response of 1 indicating strong disagreement, and a response of 5 indicating strong agreement, with the question statement.

The PTQ in Appendix E is entitled 'Perceived Driving Time Study,' with no indication that the study was concerned with AWFs. This title is used for purposes of consistency with the experimental protocol (Section 2.4)---as noted earlier (Section 2.3), prior to their first trial each S was told that control of vehicle **speed** was the major objective of the experiment.

2.3.4. Null Hypotheses

The experimental design outlined above enables testing of a series of null hypotheses pertaining to the dependent measures. Specifically, the null hypotheses predict that for the dependent measures listed in Table 2-4, no main or interactive effects of the following independent measures will be observed: (1) AWF condition (control or test); (2) SL level; (3) VPTY condition; and (4) trial.

2.3.5. Pilot Studies and ESDT Targets

Prior to testing the regular experimental Ss, SDP of 9 pilot Ss (3 females, 6 males, mean age 28.2 yrs, age range 22-38 yrs) was evaluated with the four different SDTEs (Table 2-2). The primary purpose of the pilot testing was to make observations on how long different Ss would take to traverse both the low and high SL SDTEs, so that sample population estimates for ESDTs for each SL condition could be derived. This information, in turn, was used to specify target ESDTs for the low and high SL trials. As described in Section 2.4, for each trial Ss were asked to match these target times with their actual start to end ESDTs.

Pilot Ss were asked to complete one simulated driving trial for each of the four LSLC, LSLT, HSLC, and HSLT SDTEs (Table 2-2). Not all pilot Ss completed trials for all of these conditions. The forms shown in Appendix D were used to record visual observations of simulated driving behavior. Dependent measures other than visual observations were not collected for the pilot Ss.

ESDT results for the pilot Ss indicate the following mean values (mean ± SD): (1) 853 ± 106 sec for the low SL trials (N=7; 14 trials); and (2) 740 ± 77 sec for the high SL trials (N=7; 14 trials). At each SL, differences in mean ESDTs for control versus test trials are not statistically significant.

Based on the mean ESDTs derived from the pilot studies, the following ESDT targets were specified: (1) 13 min, 45 sec (825 sec) for the low SL trials; and (2) 11 min, 45 sec (705 sec) for the high SL trials. As noted earlier (Section 2.2.1), estimated ESDTs for the simulated route are 13.6 min (816 sec) with no stops at 50 mph, and 10.5 min (630 sec) with no stops at 65 mph. Thus, the specified target ESDT of 825 sec for the 50 mph SL trials is intermediate between the mean ESDT of 853 sec observed in the pilot studies, and the estimated no stop ESDT of 816 sec. Similarly the specified target ESDT of 705 sec for the 65 mph SL trials is intermediate between the mean ESDT of 740 sec observed in the pilot studies, and the estimated no stop ESDT of 630 sec.

The rationale for selecting target ESDTs for each SL that are intermediate between those actually observed in the pilot studies and the estimated no stop times was to encourage real world driving behavior at intersections. Ss were told (Section 2.4) that the objective of the study was for them to control their speed to match a specified target time for completing the task at each SL. However, the actual purpose of the study was to evaluate S interaction with control versus test intersections. Under real world driving conditions, when their vehicle is in the decision zone, drivers sometimes decide to stop, and sometimes decide to enter and drive through the intersection, when the signal turns yellow. There is no such thing as uniform, consistent, predictable driving stopping behavior for a vehicle in the decision zone when it comes to driver interaction with a yellow signal, either within or between drivers. Thus the target ESDTs at each SL should encourage neither stopping at every intersection (e.g., target times to long), nor running every yellow signal (e.g., target times too short). It was judged that the intermediate target ESDTs specified above would instead encourage indeterminate, unpredictable driver stopping behavior with the vehicle in the decision zone when the signal turns yellow. As described in Sections 3.1 and 3.2, this expectation was in fact realized.

2.4. EXPERIMENTAL PROTOCOL

Simulation testing of Ss was initiated in December, 1999, and was completed in January, 2000. The experimental protocol followed for testing driving performance of Ss under simulated driving conditions comprises the following steps.

1. A schedule was drawn up for testing volunteers for the study. For each S, two 1-hr experimental sessions were scheduled on two different days. To the extent possible, the two sessions for each S were scheduled at about the same time of day on successive weekdays.
2. Prior to beginning their first experimental session, each individual volunteering to serve as a S in the study was asked to read and sign an informed consent form introducing and explaining the study. A copy of this form is in Appendix F.
3. A series of steps were required to initialize the HFRL flat screen driving simulator computers, projectors, and equipment prior to simulation testing. While the S was reading and completing the informed consent form, these initialization procedures were carried out.
4. After the informed consent form had been signed by the S and the researcher, the S was asked to complete a pre-test questionnaire, shown in Appendix G. The purpose of this questionnaire is to collect information about the driving experience of the S, plus any evidence of S susceptibility to dizziness, nausea, and/or emotional disturbance while driving. A S who reports a history of these conditions also may be susceptible to queasiness during simulated driving, thereby warning the researcher to pay close attention to problems with queasiness that may emerge during a test. Based on pre-test questionnaire responses, all Ss who completed simulation testing for the project reported little or no past history of dizziness, nausea, and emotional reactions while driving. One volunteer reported a history of susceptibility to motion

sickness on the pre-test questionnaire, did in fact become queasy during the practice drive (Point 5), and decided to drop out of the study. The pre-test questionnaire was administered only once, prior to the control session. S responses to the pre-test questionnaire are not evaluated in this report.

5. The S then was asked to complete a practice drive in the simulator. The following procedures used to carry out a simulated driving session were the same for both the pilot and regular testing trials:
   - The S was asked to be seated in the Honda Accord and to adjust the seat to a comfortable setting;
   - The researcher started a trial by initializing projection of the SDTE, which showed the vehicle positioned in front of the simulated start line, and not moving;
   - The researcher than asked if the S was ready to begin a trial---if the answer was affirmative the researcher put the Honda in 'drive' (using a computer command);
   - At this point simulated movement of the vehicle through the SDTE was initiated, and it was up to the S to traverse the SDTE from the start to the end line with no further communication from the researcher;
   - During each simulated driving trial, the researcher sat on a chair placed near the open window of the front passenger door of the Honda Accord, and manually recorded visual observations during the trial;
   - Once the vehicle crossed the end line, the researcher terminated projection of the SDTE, and prepared to initialize another trial, or to end the testing session;
   - After each trial, the S was given the opportunity to leave the vehicle for a short break---most Ss chose to remain in the vehicle from trial to trial;
   - The ESDT between trials was 1-2 min if the S remained in the vehicle, and an additional 1-2 min if the S chose to leave the vehicle between trials.
   - Mint candies were made available to Ss during each session.
6. For every S, the LSLC SDTE (Table 2-2) was used for the practice drive. The practice drive serves as a training session, and also allows the researcher to judge the suitability of the S for continuing with simulation testing. Both SDP, and any S feelings of discomfort, were monitored by the researcher during the practice session. Criteria used to judge acceptable SDP by a S are:

(1) lack of serious discomfort (particularly queasiness or nausea) and/or disorientation reported by S; (2) ability to stop consistently and accurately at red lights; (3) ability to maintain reasonably steady and consistent SL control; and (4) ability to keep vehicle consistently and accurately positioned in one lane while driving. Performance was monitored by a researcher in a chair positioned just to the right of the open window of the front passenger door of the Honda Accord. A practice drive typically lasted 5-10 min. A practice drive was administered prior to the first experimental session, and also prior to the second experimental session if the S requested it. Dependent measures (Table 2-4) were not collected during practice drives. All but one volunteer (Point 4) displayed acceptable driving performance during the practice drives and went on to serve as Ss for the study.

7. Upon successful completion of the practice drive, the S left the driving simulator and was introduced to the study with a series of instructions, shown in Appendix H. The S was asked to examine the instructions while the researcher read each instruction out loud. The instructions emphasized the following distinctive features of the study:
   - the task objective is to drive from a start point to an end point through a SDTE;
   - the S should try to drive normally, comparable to real world driving;
   - the S will participate in two experimental sessions, each comprising 4 simulated driving trials;
   - the S is free to terminate a session at any time;
   - one of two SL is posted;
   - the S should complete each trial within 30 sec faster or slower (i.e., within a 1 min window) of the target ESDT;
   - for the 50 mph SL trials, the target ESDT is 13 min, 45 sec (825 sec); the S therefore should try to complete each of these trials with a time that falls between 13 min, 15 sec (795 sec) and 14 min, 15 sec (855 sec);
   - for the 65 mph SL trials, the target ESDT is 11 min, 45 sec (705 sec); the S therefore should try to complete each of these trials with a time that falls between 11 min, 15 sec (675 sec) and 12 min, 15 sec (735 sec);
   - the ESDT for a trial depends upon vehicle speed maintained by the S during the trial; to finish a trial within plus or minus 30 sec of the target time, the S cannot drive too fast or too

slow;

- the S should comply with normal traffic laws, namely stopping at red lights, driving on the roadway, and not stopping on the roadway during a trial;
- at the end of each trial, the S should estimate the ESDT for the trial and inform the researcher of this estimate;
- the S will be paid $20 for completing the two study sessions, and will be paid an extra $20 bonus if, for 6 of 8 trials, the actual elapsed ESDT falls within plus or minus 30 sec of the target ESDT for the trial;
- the last instruction (Appendix H) explains details of the bonus payment to the S---the ESDTs for the first 50 mph and the first 65 mph trials are not counted, and to earn the bonus, the S must achieve an actual ESDT within plus or minus 30 sec of the target time for 4 of the 6 remaining trials.

8. After the instructions had been read and explained to the S (Point 7), the S was asked to raise possible questions about the instructions and/or about the study. Once these were dealt with, the simulated driving trial was initiated (Step 5). The order of administration of SDTEs (e.g., LSLC, LSLT, HSLC, HSLT) was varied from S to S---duplicate trials of the same SDTE were not administered in immediate succession for any S.
9. During each driving trial, the researcher made visual observations of speed and stopping behavior by the S at each intersection and entered this information on the appropriate visual observation recording form (Appendix D). A stop watch was used to record actual ESDT from the start to end line---this time also was entered on the recording form at the end of the trial.
10. After completing each driving trial, the S was asked what their estimated ESDT for the trial had been. This was entered on the appropriate visual observation recording form (Appendix D). The S then was told by the researcher by how many seconds faster or slower their actual ESDT differed from the target time for the trial (Section 2.3.5).
11. Based on the instructions provided (Step 7), the understanding of each S was that they had to achieve an actual ESDT within plus or minus 30 sec of the target time for 4 of the 6 trials remaining after completing the first LSL and HSL trials, in order to earn the bonus. If 2 failures to satisfy this target time window occurred before the S completed the 6 remaining trials, the S was told that their actual ESDT for subsequent trials DID satisfy the target time window, whether

or not this was in fact true. The rationale for this deception was to sustain the belief in each S until the end of the 8th trial that they were eligible for the bonus, thereby minimizing a possible confounding effect of differences in driving performance motivation among Ss. All Ss in fact were paid the bonus (Step 14). Among the 24 Ss, 6 failed to match the target time window for fewer than 4 of the remaining 6 trials.

12. After a S completed a 4-trial experimental session, output data files generated during the session for that S were backed up on a diskette.
13. Prior to their second experimental sessions, Ss were asked if they wished to take another practice drive. Most Ss chose not to do so. The instructions (Step 7) then were reviewed for the S, and the first simulated driving trial of the second session was initiated (Step 8).
14. After completing the second 4-trial session, each S was asked by the researcher what the purpose of the study had been. The S then was asked to complete the PTQ (Section 2.3.3), after which the response to the 'purpose of study' question also was recorded by the researcher on the questionnaire. Any comments or questions the S had about the study then were discussed. Finally, each S was paid a fee of $40 (regular fee plus bonus) as remuneration for their participation in the study.

2.5. DATA REDUCTION AND ANALYSIS

Both visual observation and PTQ data (Table 2-4) were entered into an Excel spreadsheet for purposes of analysis: As noted previously, separate files of SDP data were generated at the end of each trial for each S as Excel-compatible text files. Because the purpose of the study is to evaluate the effect of the lack or presence of AWFs on simulated driving behavior as a S approaches a intersection, it was decided to focus analysis of SDP exclusively on those periods of a simulated driving trial when the S was approaching each intersection. The distance of the AWF from the center of the intersection---225 m for the LSL trials, and 270 m for the HSL trials---is used to define these blocks of data (the intersection centers are 10 m further from the AWF than the 215 m (LSL) and 260 m (HSL) AWF-signal distances specified in Table 1-2). Specifically, extraction of blocks of SDP data was initiated at a simulated vehicle distance to the intersection of 675 m (3 x 225 m), or 0.42 mi, for the LSL trials, and 810 m (3 x 270 m), or .50 mi, for the HSL trials. Extraction of data blocks at each intersection was terminated at a simulated vehicle position in the SDTE corresponding to the center of the intersection. Table 2-5 summarizes the distance intervals (calculated from the start line) for successive intersections for both the LSL and HSL SDTEs from which these blocks of SDP data were extracted for purposes of analysis.

The rationale for using different distance intervals for intersection data block extraction for the LSL versus the HSL trials is that a common data sampling rate (1 hz) was used to acquire SDP data for all trials. Using longer distance intervals for the HSL intersection data blocks (Table 2-5) results in roughly comparable numbers of data samples for each intersection data block, regardless of SL. This, in turn, facilitates comparison of profiles of changes in speed, accelerator actuation, and braking behavior of Ss approaching different intersections at different Sls.

Difficulty and delay were encountered in using either the Excel or SPSS software packages to extract the intersection blocks of SDP data described above and summarized in Table 2-5. It was decided that the most feasible approach to accomplishing the task was to write a separate software routine in MATLAB for this purpose. Appendix I lists a routine written by Gloria Martinez-Arizala that was used to successfully complete the intersection data block extraction task. This routine generates a separate text data file for each trial, consisting of 10 successive blocks of SDP data sampled over the distance intervals specified in Table 2-5 for the 10 successive intersections. The MATLAB program listed in Appendix I was used to generate a total of 192 intersection data block files, corresponding to the original 192 raw data files (24 Ss x 2 trials/S x 4 SDTEs).

To facilitate data analysis, a decision subsequently was made to partition each intersection data block file into 5 separate sets of 2 VPTY data blocks each, corresponding to duplicate intersections for each of the 5 VPTY levels (0, 2, 3.5, 5 sec, and all green) presented in each trial (Table 2-2). Again, difficulty and delay were encountered in using either the Excel or SPSS software packages to partition the intersection data block files into separate sets of VPTY data blocks. Ultimately, it was decided that the most feasible approach to accomplishing the task was to write a second software routine in MATLAB for this purpose. Appendix J lists a routine written by Gloria Martinez-Arizala that was used to successfully complete the task of generating VPTY data block files. From each intersection data block file for a given S, this routine generates 5 separate sets of VPTY data blocks, each consisting of 2 blocks of SDP data for each of the duplicate levels of VPTY presented in each trial. The MATLAB program listed in Appendix J was used to generate a total of 20 VPTY data block files, corresponding to 5 files for each of the 4 SDTEs (Table 2-2). Each file contains SDP

Table 2-5. Distances from each intersection at which blocks of data were extracted for purposes of evaluating SDP as a S approaches the intersection.

Intersection	Distance from Start Line (m)	50 mph SL	65 mph SL
		Distance Intervals (From Start Line) for Successive Blocks of Data (m)	Distance Intervals (From Start Line) for Successive Blocks of Data (m)
1	1780	1105 - 1780	970 - 1780
2	3586	2911 - 3586	2776 - 3586
3	5092	4417 - 5092	4282 - 5092
4	6805	6130 - 6805	5995 - 6805
5	9139	8464 - 9139	8329 - 9139
6	11,018	10,343 - 11,018	10,208 - 11,018
7	12,224	11,549 - 12,224	11,414 - 12,224
8	14,103	13,428 - 14,103	13,293 - 14,103
9	15,515	14,840 - 15,515	14,705 - 15,515
10	18,034	17,359 - 18,034	17,224 - 18,034

data for 24 Ss at one of the five VPTY levels for a given SDTE, and comprises 96 successive blocks of VPTY level data (24 Ss x 2 VPTY levels/trial x 2 trials/S for each SDTE).

2.5.1. Analysis of Variance for Objective Dependent Measures of SDP

Based on the experimental design outlined in Section 2.3, analysis of variance (ANOVA) is used to evaluate the main and interactive effects of the independent measures on the objective dependent measures of SDP (e.g., vehicle speed, braking pressure, and acceleration/deceleration, Table 2-4). Table 2-6 summarizes the ANOVA table for the study, with the main effects of the 4 independent measures specified in Section 2.3.2., and a total of 11 first-order (2-way) and second-order (3- and 4-way) interactive effects of these measures, indicated.

ANOVA for the effects of the independent measures specified in Table 2-6 is carried out in 3 steps [17]: (1) multivariate ANOVA for main and interactive effects on grouped (familywise) objective dependent measures of SDP; (2) separate univariate ANOVA for main and interactive

Table 2-6. ANOVA table for main and interactive effects on objective dependent measures of SDP.

Main Effects	Definition	Number of Conditions
AWF	Advanced Warning Flasher	2 (absent; present)
SL	Speed Limit	2 (50 mph (low); 65 mph (high))
VPTY	Vehicle Proximity to Yellow	5 (all green; 0 sec; 2 sec; 3.5 sec; 5 sec)
T	Trial	2 (Trial 1 & 2)

Interactive Effects - 2-way		
AWF x SL	AWF x VPTY	AWF x T
SL x VPTY	SL x T	
VPTY x T		

Interactive Effects - 3- and 4-way		
AWF x SL x VPTY	AWF x SL x T	AWF x VPTY x T
SL x VPTY x T	AWFxSLxVPTYxT	

effects on each of the 3 objective dependent measures of SDP, using the Bonferroni procedure [17] to correct for potential Type I error; and (3) post hoc analysis of statistically significant interactive effects revealed under Step 2 (Section 2.5.2).

2.5.2. Post Hoc Analysis of Objective Dependent Measures of SDP

Post-hoc analyses of statistically significant interactive effects (Table 2-6) are carried out using a 2-tailed paired-t test, involving within-subject comparisons of selected dependent measures of SDP under non-AWF versus AWF SDTE conditions, across different SL and VPTY levels. This analysis involved: (1) averaging values for each S across the 2 blocks of intersection data within a trial for each VPTY level (Table 2-5); and (2) evaluating the statistical significance of within-subject differences in means under non-AWF versus AWF SDTE conditions, using the 2-tailed paired-t test.

For other selected dependent measures, chi-squared analysis is used to assess the possible statistical significance of disproportionate distributions observed. Both Excel and SPSS are used for statistical analysis. In the remainder of this report, mean values are reported ±1 SD.

CHAPTER 3

RESULTS

3.1. INTRODUCTION

Sections below detail results for: (1) visual observations of S stopping behavior and ESDTs (Section 3.2); (2) objective measures of simulated driving performance (Section 3.3); and (3) the PTQ (Section 3.4).

3.2. VISUAL OBSERVATIONS OF SIMULATED DRIVING PERFORMANCE

Results for the visual observations of SDP are categorized in the subsections below in terms of the ESDT results (Section 3.2.1) and stopping behavior (Section 3.2.2).

3.2.1. Elapsed Simulated Driving Times

As noted earlier (Section 2.3.3), the ESDT that a S required to traverse the SDTE from start to end line was recorded for each trial. After completion of each trial, Ss also were asked to judge their ESDT.

Table 3-1 summarizes mean ESDTs, averaged across all Ss and all simulated driving trials, observed for each of the 4 SDTEs, along with results from paired-t test analyses of mean ESDTs for the control versus test LSL and HSL trials. Mean ESDTs for the 4 conditions also are presented in graphical form in Figure 3-1.

Results in Table 3-1 and Figure 3-1 indicate that for both the low and the high SL trials, mean ESDTs are slightly longer for the test relative to the control conditions. These results suggest that the presence of AWFs at each intersection may encourage somewhat more cautious (and therefore somewhat slower) driving behavior. However, by paired-t test analysis (Table 3-1), the differences are not statistically significant at the $p<.05$ level. At high SL, the mean ESDT for the HSLT trials is significantly longer than that for the HSLC trials at the $p<.1$ level.

Table 3-1. Mean ESDTs (sec) and two-tailed paired t-test results for LSLC vs LSLT, and for HSLC vs HSLT, SDTEs.

STATISTIC	SDTE			
	LSLC	**LSLT**	**HSLC**	**HSLT**
Mean ESDT (sec)	824.0	834.7	728.0	741.7
SD	28.5	33.2	32.2	25.2
N	24	24	24	24
Hypothesized Mean Difference	0		0	
df	23		23	
t-stat	0.128		-1.958	
t-crit (two-tailed)	2.069		2.069	
p (two-tailed)	0.256		0.0625	

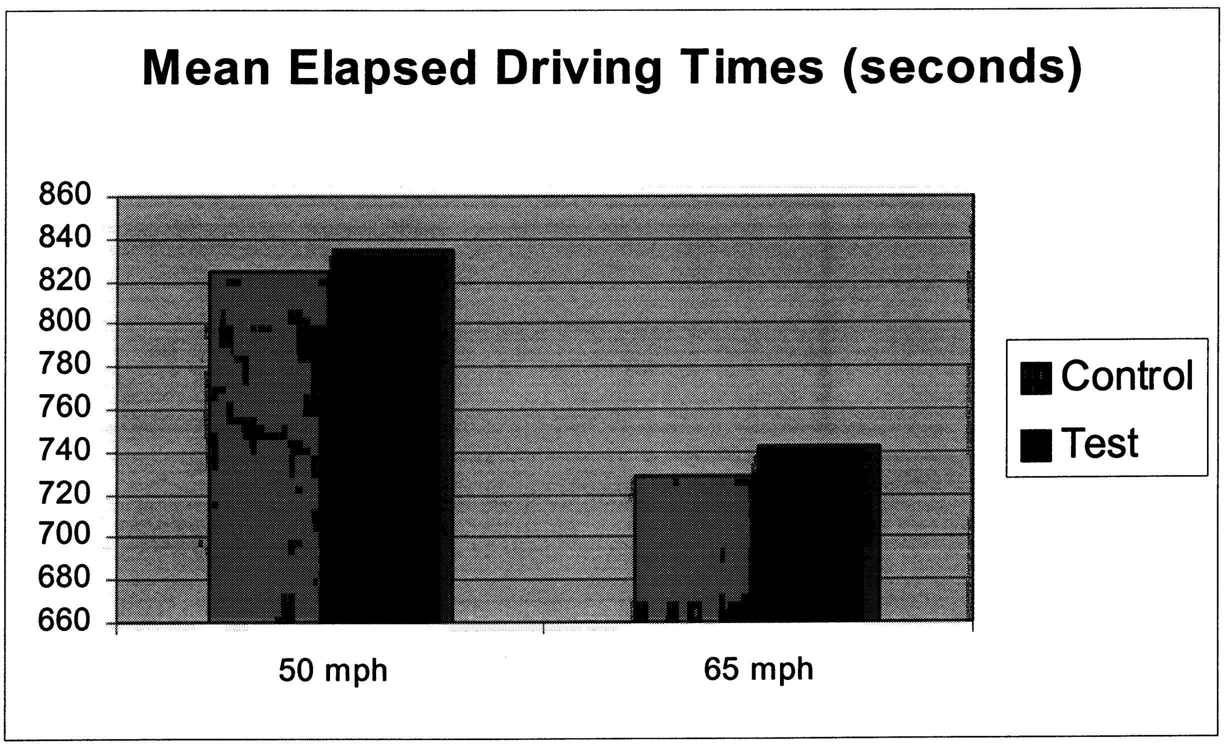


Figure 3-1. Mean ESDTs (sec) for control (AWFs absent) and test (AWFs present) simulated driving trials at low (50 mph) and high (65 mph) SL conditions. Mean values are averaged across all Ss and trials.

Table 3-2. Actual and judged ESDTs (sec), and two-tailed paired t-test results, for LSL SDTEs.

STATISTIC	ACTUAL AND JUDGED MEAN ESDTs FOR LSL SDTES			
	LSLC Actual ESDT	**LSLC Judged ESDT**	**LSLT Actual ESDT**	**LSLT Judged ESDT**
Mean ESDT (sec)	824.0	827.1	834.7	822.4
SD	28.5	28.0	33.2	26.8
N	24		24	
Hypothesized Mean Difference	0		0	
df	23		23	
t-stat	-0.410		1.490	
t-crit (two-tailed)	2.069		2.069	
p (two-tailed)	0.685		0.150	

Table 3-3. Actual and judged ESDTs (sec), and two-tailed paired t-test results, for HSL SDTEs.

STATISTIC	ACTUAL AND JUDGED MEAN ESDTs FOR HSL SDTES			
	HSLC Actual ESDT	**HSLC Judged ESDT**	**HSLT Actual ESDT**	**HSLT Judged ESDT**
Mean ESDT (sec)	728.0	708.1	741.7	724.1
SD	32.2	33.7	25.2	31.1
N	24		24	
Hypothesized Mean Difference	0		0	
df	23		23	
t-stat	2.880		2.524	
t-crit (two-tailed)	2.069		2.069	
p (two-tailed)	0.00845		0.0189	

Paired-t test results in Table 3-2 for the LSL trials indicate that mean actual ESDTs do not differ significantly from mean judged ESDTs at the $p>.05$ level for both the LSLC and the LSLT trials. However, as shown by the paired-t test results in Table 3-3 for the HSL trials, mean judged ESDTs are significantly shorter than mean actual ESDTs for both the HSLC and the HSLT trials. One interpretation of these results is that during the high SL trials, the SDTE employed in the study conveys the subjective impression that speed and passage of time are somewhat elevated relative to actual levels, an impression that is not affected by the absence or presence of intersection AWFs.

Figure 3-2 depicts the percentages of Ss under each of the 4 SDTE conditions who succeeded or failed in completing simulated driving trials within a 1 min window (±30 sec) of the target times for trial completion (825 sec for the LSL trials; 705 sec for the high SL trials). Percentages are calculated based on 2 trials completed by each of 24 Ss for each of the 4 SDTEs. For the LSL trials, percent success in matching the target time is comparable for both the control and test conditions. For the HSL trials, percent success in matching the target time is higher for the test than for the control conditions. These results complement those in Table 3-1 and Figure 3-1 in suggesting that, relative to the control trials, AWFs at each intersection during the test trials not only encouraged somewhat slower driving (Table 3-1), they also enabled Ss to gauge their speed and ESDT relative to the target time with somewhat greater accuracy.

3.2.2. Stopping Behavior

This subsection summarizes visual observations of stopping behavior of Ss at different signalized intersections encountered during their simulated driving trials, as influenced by AWF absence/presence, SL, and VPTY conditions prevailing at each intersection.

Figure 3-3 illustrates the percentages of Ss stopping at simulated signalized intersections. in relation to AWF absence/presence and VPTY level, for both the LSL (Fig. 3-3A) and the HSL (Fig. 3-3B) trials (N=96, based on 2 intersections for each VPTY level per trial, 2 trials per S, and 24 Ss). Results in the figure indicate that: (1) almost no stops are observed for either SL at intersections with the all green and 0 sec VPTY levels; (2) the percentages of intersections at which stops occur increase progressively for VPTY=2, VPTY=3.5, and VPTY=5 sec intersections; (3) over 90 pct of Ss stop at VPTY=5 sec intersections, across all SDTE and SL conditions; and (4) for VPTY=2 and VPTY=3.5 sec intersections, stop percentages are higher for the HSL compared with the LSL trials. These observations support of the ecological validity of the study (Section 4.2), in that comparable stopping behavior would be expected under actual driving conditions.

Figure 3-3 also shows that for trials at either SL, with one exception (VPTY=5 sec intersections for HSL trials), higher percentages of Ss stopped at test compared with control intersections, for intersection VPTY levels either within (3.5 sec) or near the outside boundaries of (2 and 5 sec) the decision zone (Table 1-3).

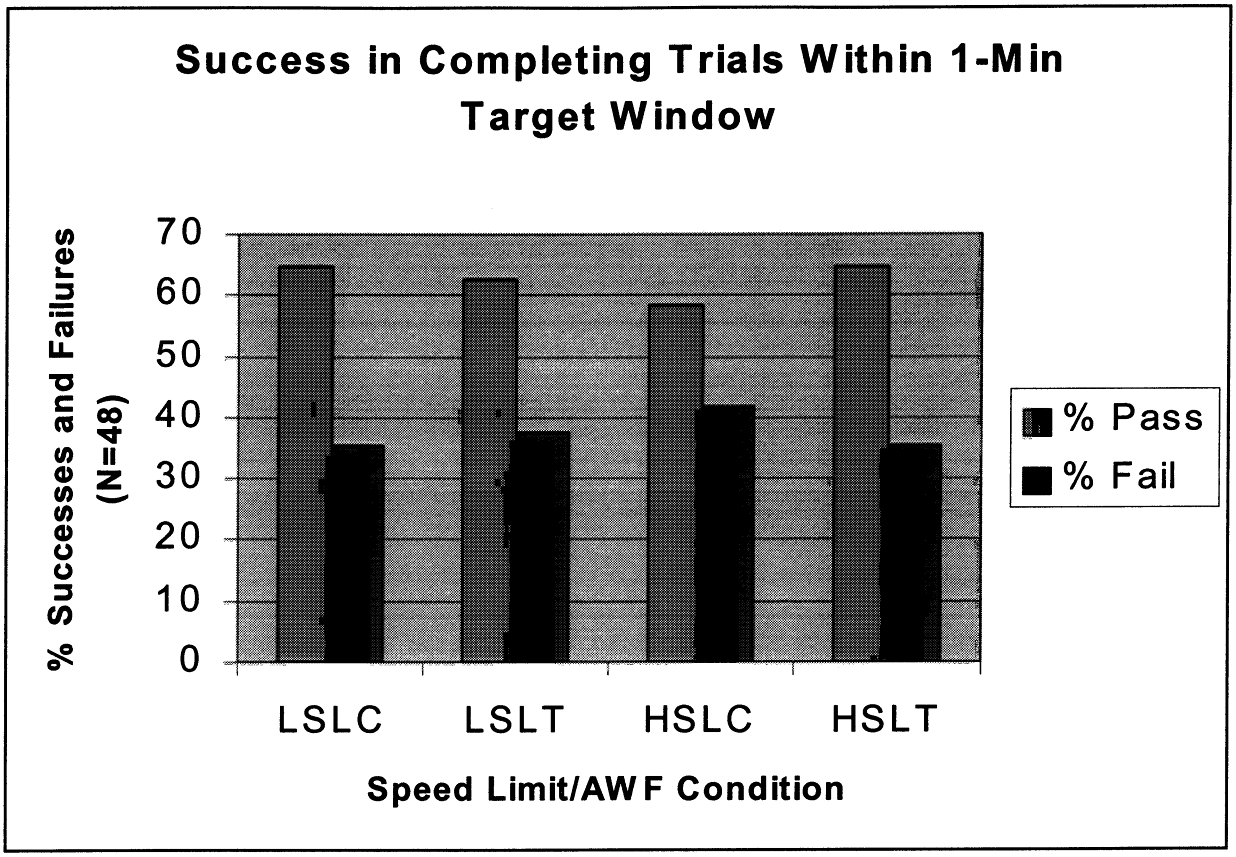
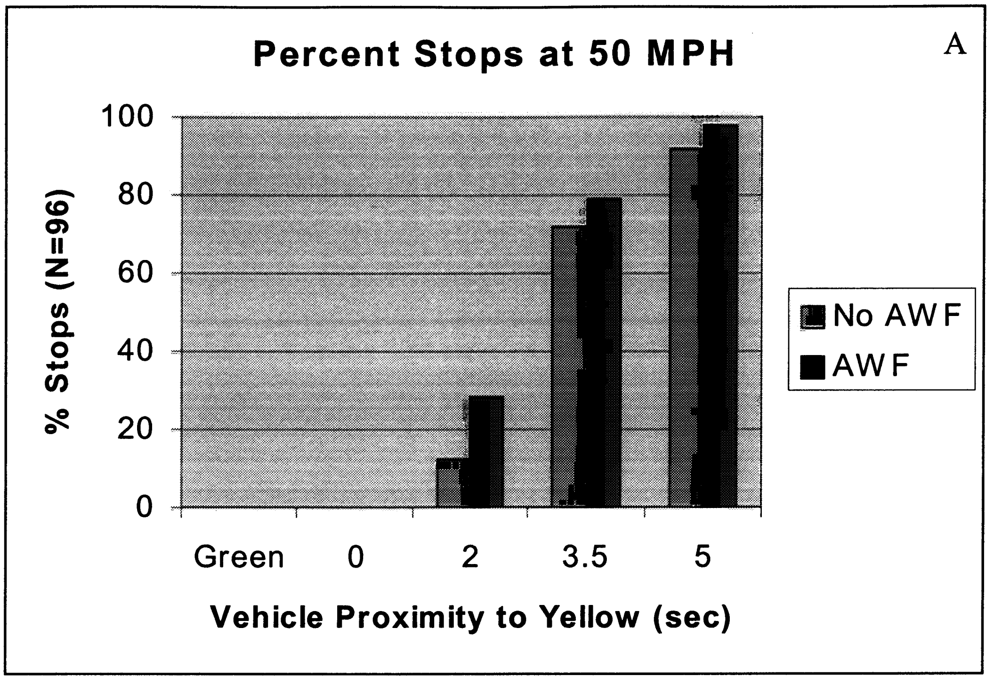


Figure 3-2. Percentages of Ss under each of the 4 SDTEs who succeeded or failed in completing simulated driving trials within a 1 min window (±30 sec) of the target times (825 sec for LSL trials; 705 sec for HSL trials).

Figure 3-4 illustrates the percentages of Ss who either performed a dangerous stop (Fig. 3-4A), or ran a red light (Fig. 3-4B), in relation to AWF absence/presence and SL (N=96, based on 2 intersections for each VPTY level per trial, 2 trials per S, and 24 Ss). A dangerous stop is defined as a stop by the vehicle that occurs either within or beyond the simulated intersection. Running a red light is defined as a vehicle entering and continuing through a simulated intersection after the light signal turns red.

Results in Figure 3-4 for both dangerous stops and red lights run indicate that for the LSL trials, a higher percentage of Ss engaged in this dangerous driving behavior during control trials, but for the HSL trials, a higher percentage of dangerous stops/red lights run occurred during the test trials. By chi-squared analysis, the disproportionate distribution of dangerous stops by AWF absence/presence and SL is not statistically significant (p=.25), but the disproportionate distribution



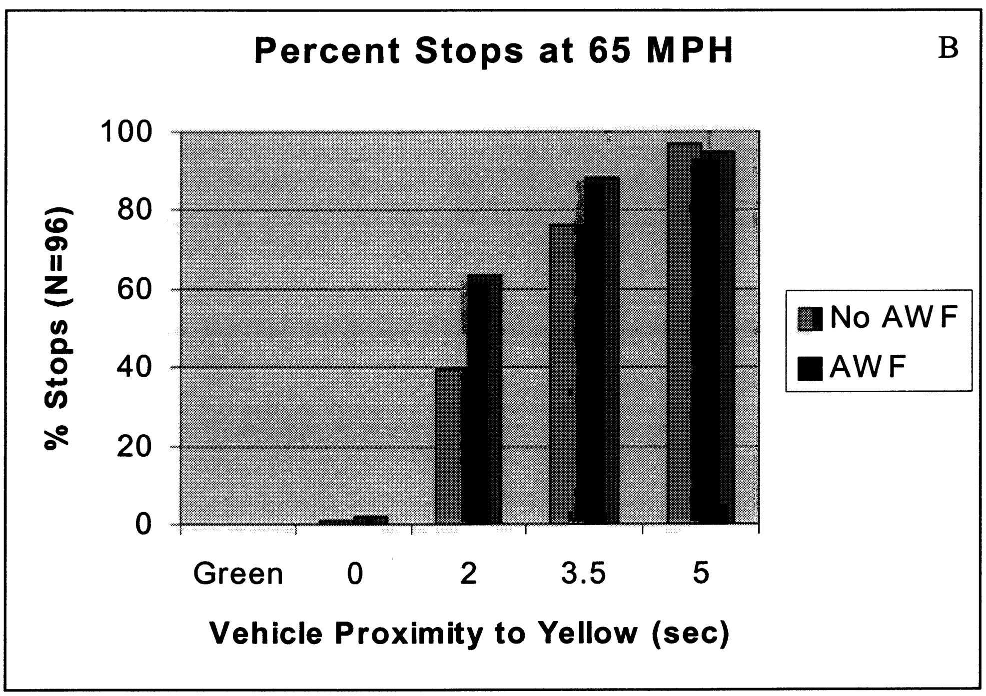
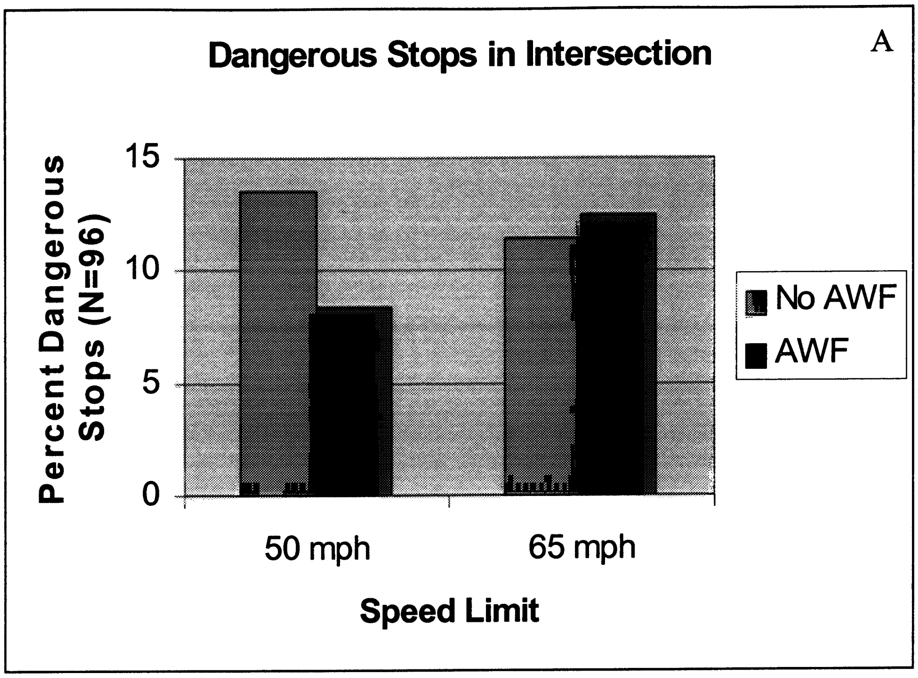


Figure 3-3. Percentages of Ss stopping at simulated signalized intersections in relation to SDTE condition and VPTY level: A - results for LSL trials; B - results for HSL trials (percentages based on 96 intersection interactions at each VPTY level across 48 trials for 24 Ss).



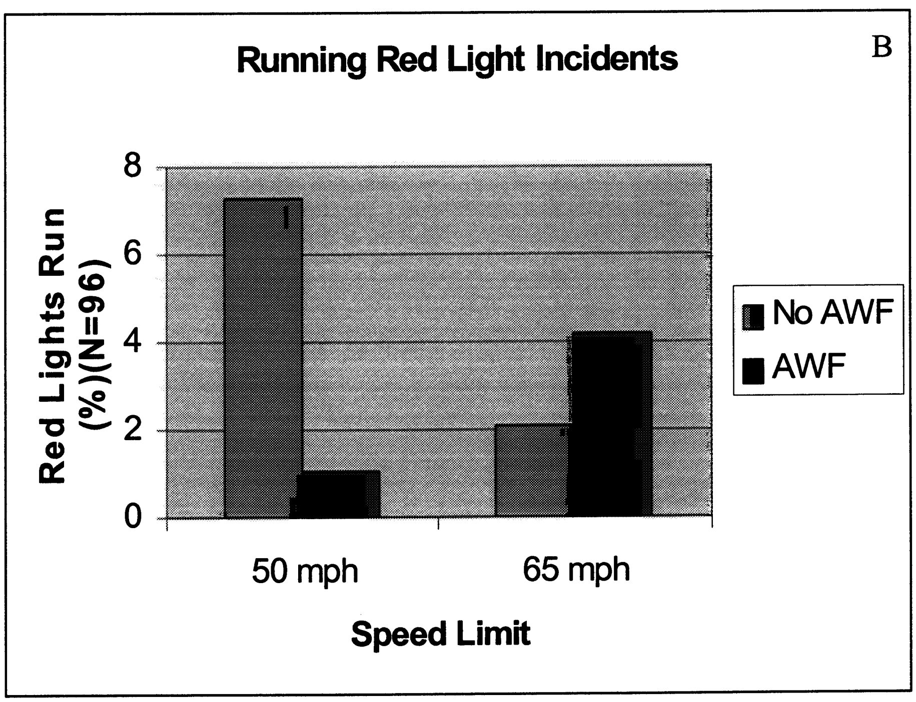
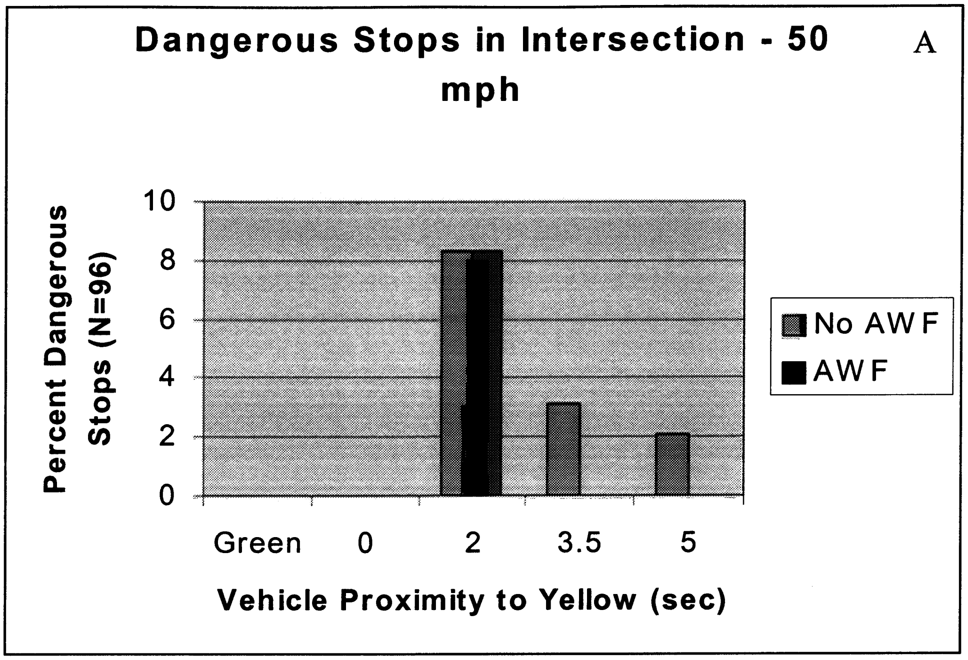


Figure 3-4. Percentages of Ss performing dangerous stops and running red lights, categorized by AWF absence/presence and SL: A - dangerous stops; B - running red lights (percentages based on 96 intersection interactions at each SL level across 48 trials for 24 Ss).

of red lights run in relation to these conditions is statistically significant (p=.012). The results indicate that at the lower SL, relative to the control trials, the presence of AWFs promotes safer stopping behavior, but at the higher SL, by providing advance warning of an impending change in signal light status, AWFs may encourage Ss to disregard rather than slow for the yellow signal, which sometimes results in a running red light incident.

Figure 3-5 illustrates the percentages of Ss performing dangerous stops, in relation to SDTE condition and VPTY level, for both the LSL (Fig. 3-5A) and the HSL (Fig. 3-5B) trials (N=96, based on 2 intersections for each VPTY level per trial, 2 trials per S, and 24 Ss). Results in the figure indicate that, regardless of AWF absence/presence and under both SL conditions, almost all of the dangerous stops occur at the VPTY=2 sec level (across all trials at both SLs, 75 pct of the 44 dangerous stops observed occur at VPTY=2 sec). At the VPTY interval of 2 sec, the vehicle is both just inside of the decision zone (Table 1-3), and close to the intersection. Results in Figure 3-5 again tend to support the ecological validity of the study (Section 4.2), in that dangerous stops would be expected to occur during actual driving when a vehicle is both near the decision zone and in close proximity to the signal when the yellow signal light is actuated.

Figure 3-6 illustrates the percentages of Ss running red lights, in relation to SDTE condition and VPTY level, for both the LSL (Fig. 3-6A) and the HSL (Fig. 3-6B) trials (N=96, based on 2 intersections for each VPTY level per trial, 2 trials per S, and 24 Ss). Results in the figure indicate that, regardless of AWF absence/presence and under both SL conditions, almost all of the running red lights incidents occur at the VPTY=5 sec level (across all trials at both SLs, 79 pct of the 14 running red light incidents observed occur at VPTY=5 sec). However, during LSL trials (Fig. 3-6A), most running red light incidents at VPTY=5 sec occur under the control condition, whereas during HSL trials (Fig. 3-6B), most occur under the test condition. These results indicate that the disproportionate distribution of running light incidents shown in Figure 3-4 largely is attributable to running red light behavior for VPTY=5 sec intersections. The results also suggest that when Ss are at VPTY=5 sec, near the outside boundary of the decision zone, during LSL trials the advance warning of signal status provided by AWFs reduces the temptation for Ss to gamble that they can enter the intersection before the signal turns red, whereas during HSL trials the opposite occurs.



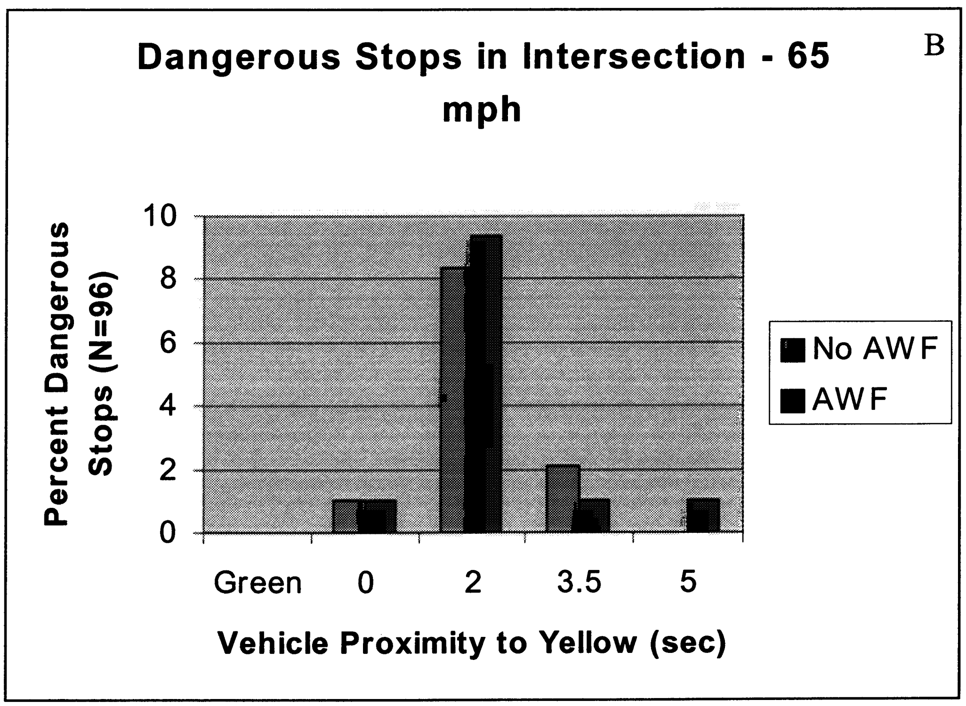
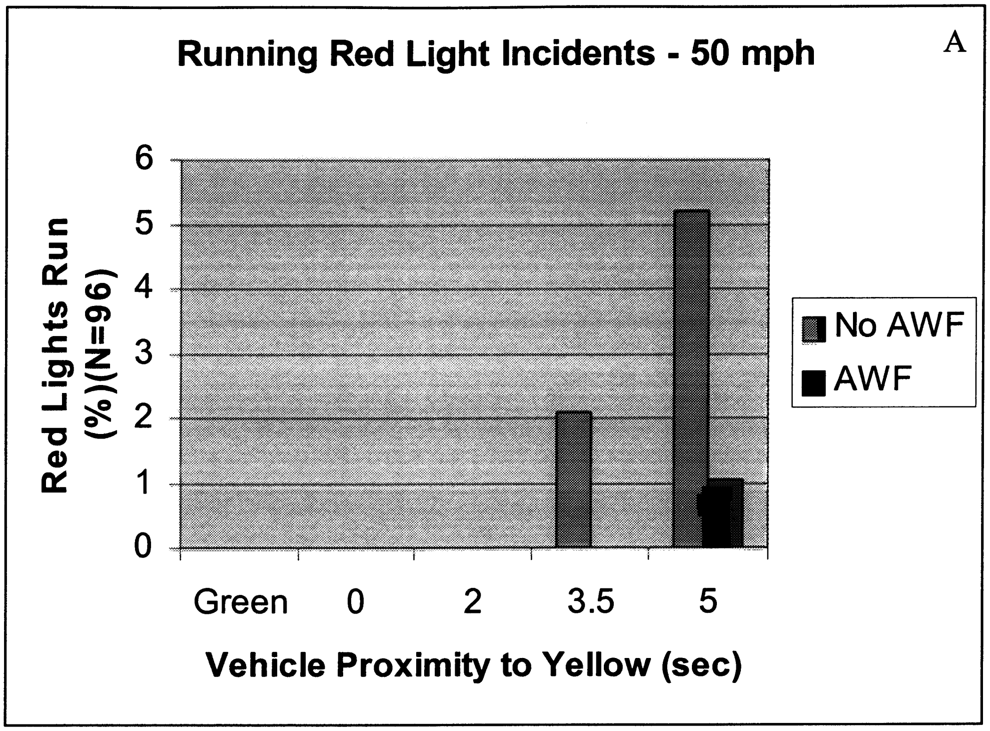


Figure 3-5. Percentages of Ss performing dangerous stops, categorized by SDTE condition and VPTY level: A - results for LSL trials; B - results for HSL trials (percentages based on 96 intersection interactions at each VPTY level across 48 trials for 24 Ss).



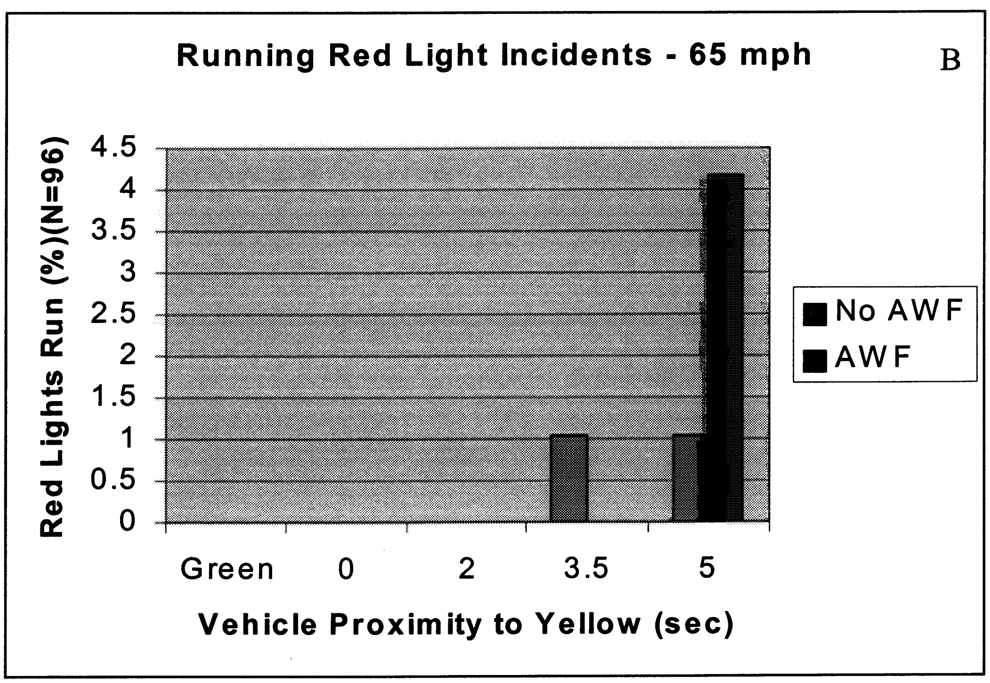


Figure 3-6. Percentages of Ss running red lights, categorized by SDTE condition and VPTY level: A - results for LSL trials; B - results for HSL trials (percentages based on 96 intersection interactions at each VPTY level across 48 trials for 24 Ss).

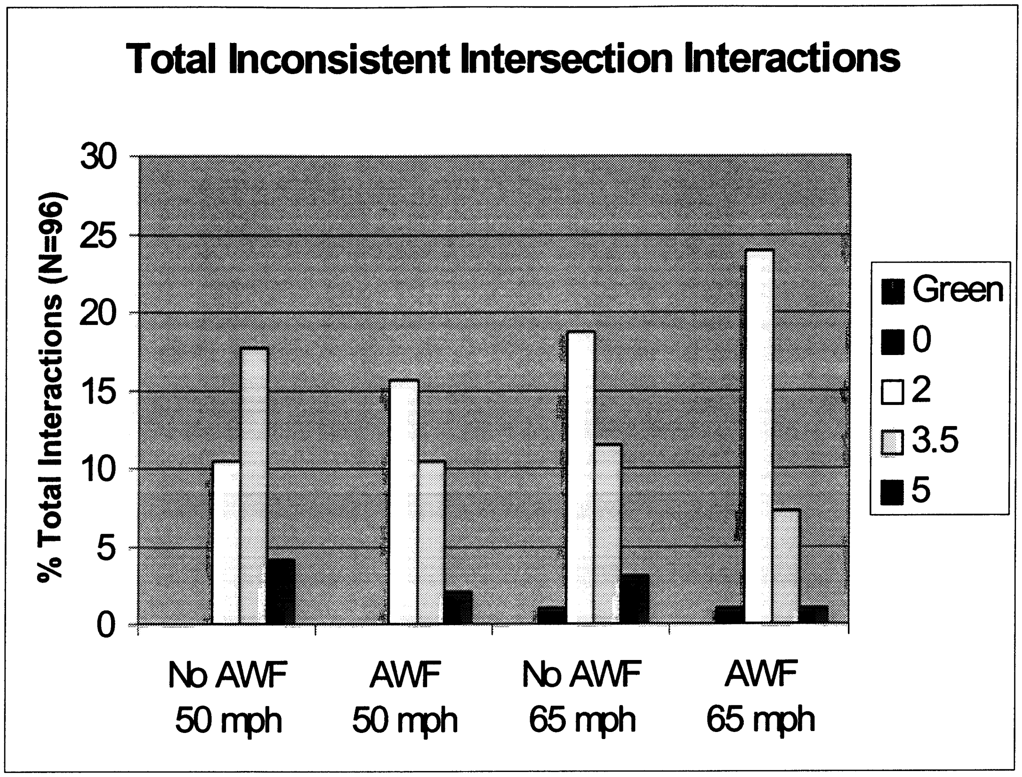


Figure 3-7. Percentages of inconsistent S stopping behavior across all Ss and trials, in relation to SDTE condition and VPTY level (percentages based on 96 intersection interactions at each SL and VPTY level across 48 trials for 24 Ss).

Figure 3-7 illustrates the percentages of inconsistent S stopping behavior, across all Ss and trials, in relation to SDTE condition and VPTY level (N=96 for each SDTE condition, based on 2 intersections for each VPTY level per trial, 2 trials per S, and 24 Ss). A pattern of intersection interaction in which a S sometimes stops and sometimes does not stop, for intersections with a given VPTY condition, is defined as inconsistent stopping behavior. For a given SDTE condition, each S encountered a total of 4 intersections at each of the 5 VPTY levels. Stopping behavior is classified as inconsistent if, across 4 intersection encounters for a S at a given SDTE condition and VPTY level, the S sometimes stopped and sometimes did not stop during interactions with these intersections.

Results in Figure 3-7 indicate that, across all 4 SDTE conditions, the preponderance of inconsistent S stopping behavior occurs at intersections with VPTY levels of 2 and 3.5 sec.

Specifically, across all trials for all SDTE conditions (384 intersection interactions at each VPTY level), 90 pct of the total of 123 instances of inconsistent stopping behavior observed occur at VPTY levels of 2 and 3.5 sec. Because these 2 VPTY levels are, respectively, near and inside of the decision zone (Table 1-3), the findings in Figure 3-7 further support the ecological validity of the study (Section 4.2). That is, during actual driving one also would expect to observe inconsistent stopping behavior at VPTY levels of 2 and 3.5 sec.

Results in Figure 3-7 do not show any distinct effect of AWF absence/presence on inconsistent stopping behavior at either SL. Across both control and test trials, the results in Figure 3-7 show a higher pct of inconsistent stops during HSL trials for VPTY=2 sec intersections, but a lower pct of inconsistent stops during HSL trials for VPTY=3.5 sec intersections.

3.2.3. Individual Differences in Behavioral Strategies During Driver Interaction With AWF Intersections

Past research [1,4,7] on driver interaction with AWFs at signalized intersections, particularly when the vehicle is in the decision zone, suggests that actuation of an AWF as a driver approaches an intersection may elicit one of two behavioral strategies: caution (the AWF is flashing, which means the signal will turn red soon, so I better slow down and prepare to stop), or risk-taking (the AWF is flashing, which means the signal will turn red soon, so I can maintain or increase speed and perhaps enter or traverse the intersection before the red light). Potential driving safety problems associated with the latter strategy have represented a source of concern about the overall driving safety benefits of AWFs at signalized intersections [1,4,7,10].

Results presented in Sections 3.2.1 and 3.2.2 above indicate that, relative to control conditions, AWFs encourage a higher percentage of stops and slightly slower ESDTs, although the control- test difference observed with the latter measure is not statistically significant. For test compared with control trials, the incidence of red light running is higher for HSL trials, but lower for LSL trials (Figs. 3-4B, 3-6). Collectively, these results point to a distribution of individual differences in the manner with which Ss interact with AWF intersections.

To more carefully examine this question, control versus test ESDTs for individual Ss at each SL level are compared in this section using a scatter-diagram approach. Using this approach, four alternative distribution patterns for the data are possible for either SL condition: (1) control and test paired ESDT values for each S are identical or closely comparable, such that all points lie on or close to the line of identity (LOI)(slope=1) on a scatter diagram, a pattern consistent with the ESDT two-tailed paired t-test statistics summarized in Table 3-1; (2) test ESDT values are consistently higher than control ESDT values for each S (suggesting that Ss are consistently more cautious at AWF relative to control intersections), a pattern that contradicts the ESDT paired-t test statistics for the LSL trials, but is marginally supported by ESDT paired-t test statistics for the HSL trials summarized in Table 3-1; (3) test ESDT values are consistently lower than control ESDT values for each S (suggesting that Ss consistently engage in risk-taking behavior at AWF compared with control intersections), a pattern that contradicts the ESDT paired-t test statistics for both the LSL and HSL trials summarized in Table 3-1; or (4) mixed results for different Ss (some test ESDT values higher than, some lower than, and some comparable to control ESDT values), a pattern also consistent with the ESDT two-tailed paired t-test statistics summarized in Table 3-1.

Results of scatter diagram analysis of paired control and test ESDT results for each S are illustrated in Figure 3-8A and Figure 3-8B, for LSL and HSL trials respectively. In each Figure 3-8 panel, control ESDT values are plotted on the X axis, and test values on the Y axis. Each point represents paired mean control and test ESDT values from the two trials that each S completed at each SDTE condition. Also illustrated in each of the Figure 3-8 panels are: (1) the LOI; (2) 20 sec offset lines from the LOI (these lines parallel the LOI, but points on the former differ from the latter by 20 sec increments); and (3) the point corresponding to paired mean control and test ESDT values for all Ss (Table 3-1). For both the LSL and HSL scatter diagrams, each point on the 20 sec offset lines corresponds to a vehicle speed difference of about 1 mph from vehicle speeds corresponding to ESDT values on the LOI.

Results in Figures 3-8A and 3-8B are consistent with a mixed pattern of distribution of paired ESDT results, specified in alternative 4 above. However, the preponderance of points outside the 20 sec offset lines are above the LOI, suggesting that more Ss at either SL favored cautious rather than risk-taking behavior at test compared with control intersections. In particular, paired ESDT

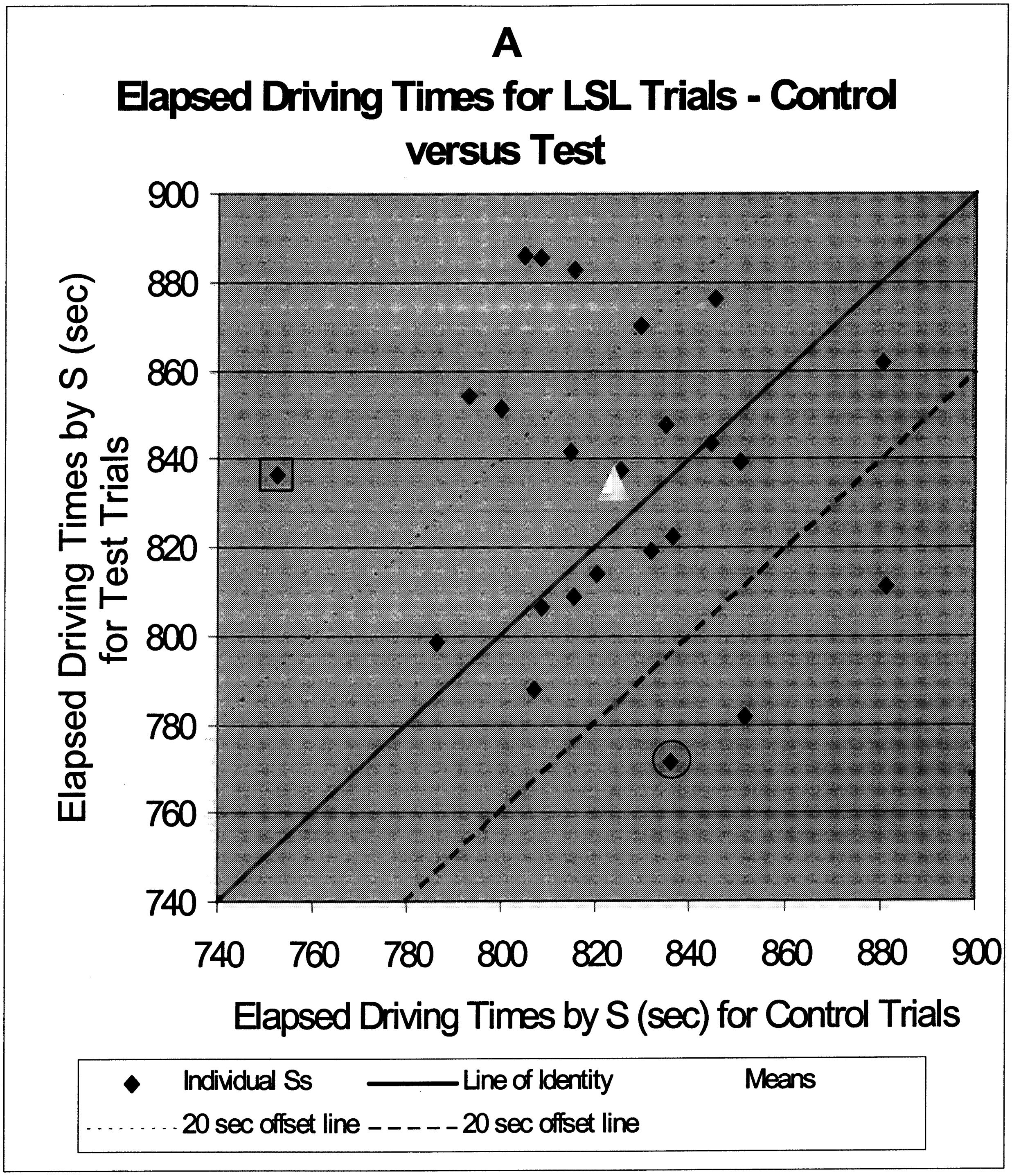


Figure 3-8A. Comparison of ESDTs during LSL trials for control versus test conditions for individual Ss, with line of identity and 20 sec offset lines shown. Large solid triangle denotes means for all Ss. A circle (O) marks the S19 data point. A square (□) marks the S23 data point.

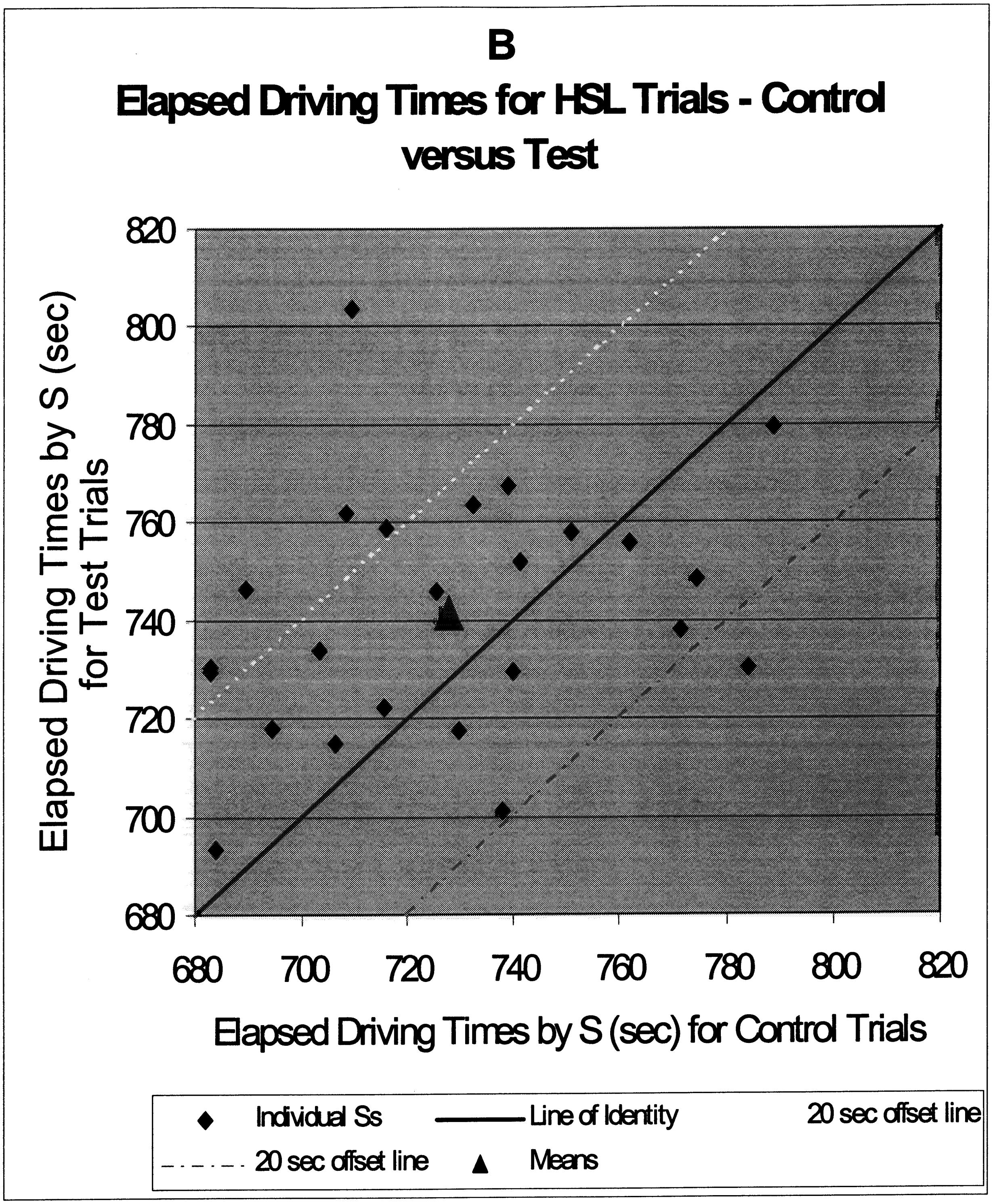


Figure 3-8B. Comparison of ESDTs during HSL trials for control versus test conditions for individual Ss, with line of identity and 20 sec offset lines shown. Large solid triangle denotes means for all Ss.

results for most Ss at either SL are near the LOI, on or within the domain formed by the 20 sec offset lines: (1) for LSL trials (Fig. 3-8A), paired results for 6 Ss are outside the 20 sec offset line above the LOI, whereas those for only 3 Ss are outside the 20 sec offset line below the LOI; and (2) for HSL trials (Fig. 3-8B), paired results for 6 Ss are outside the 20 sec offset line above the LOI, whereas those for only 1 S are outside the 20 sec offset line below the LOI.

Collectively therefore, results depicted in Figure 3-8 suggest that at either SL, cautious rather than risk-taking behavior is a more prevalent pattern of driving behavior at AWF compared with control intersections, but that some Ss are prompted to increase vehicle speed with the AWF warning. These results are aligned with observations of real-world driving behavior at AWF intersections, and further underscore the ecological validity of the study (Section 4.2).

3.3. OBJECTIVE MEASURES OF SIMULATED DRIVING PERFORMANCE

Subsections below present results for objective measures of SDP (Table 2-4), specifically vehicle speed, acceleration/ deceleration, and braking. After representative results for two individual Ss are described (Section 3.3.1), subsequent subsections present ANOVA results for main and interactive effects (Section 3.3.2), followed by results for post hoc analysis of interactive effects (Section 3.3.3).

3.3.1. Representative Results for Individual Ss

To follow up individual difference results presented in Section 3.2.3 (Figs. 3-8A, 3-8B), this section describes simulated driving results for two Ss that exhibited contrasting behavioral strategies in approaching AWF intersections. Compared with the HSL trials (Fig. 3-8B), the LSL trials (Fig. 3-8A) resulted in greater numbers of Ss whose ESDTs are both notably slower (N=6 Ss outside of 20 sec offset line above LOI) and notably faster (N=3 Ss outside of 20 sec offset line below LOI) than remaining Ss in the sample population. Accordingly, presented here are vehicle-distance-to-intersection (VDTI) profiles of vehicle speed, braking, and acceleration/deceleration during LSL trials for one representative S in each of these contrasting behavioral groups---S19 and S23. Data points in Figure 3-8A for these two Ss are marked by a circle and a square, respectively.

As summarized in Table 3-4, mean ESDT levels for S19 are close to the overall mean for control LSL trials, but faster than the overall mean for test LSL trials. The interpretation is that for this S,

Table 3-4. Mean control and test ESDT values for S19 and S23 during LSL trials, compared with mean ESDT values for all Ss.

SDTE	Sample	N*	Mean ESDT (sec)	SD	Comments
LSLC	S19	2	836.0	104.6	Mean ESDT close to overall mean.
	S23	2	752.5	17.7	Mean ESDT faster than overall mean.
	All Ss	48	824.0	28.5	
LSLT	S19	2	771.5	17.7	Mean ESDT faster than overall mean.
	S23	2	836.5	109.6	Mean ESDT close to overall mean.
	All Ss	48	834.7	33.2	

*N refers to the number of trials averaged to yield the ESDT mean and SD statistics indicated.

the presence of AWFs promoted more pronounced risk-taking driving behavior during interaction with intersections, compared with most of the Ss participating in the study.

A contrasting pattern is observed for S23. For this S, mean ESDT levels are faster than the overall mean for control LSL trials, but close to the overall mean for test LSL trials. The interpretation is that for this S, the presence of AWFs promoted driving behavior during interaction with intersections that was more cautious than most of the Ss participating in the study.

Appendices K and L provide a series of figures, for S19 and S23 respectively, that illustrate different attributes of SDP that underlie the differential patterns of driving behavior for these two Ss suggested by data in Figure 3-8A and Table 3-4. Figures in both appendices are ordered by SDP measure and by VPTY level for the LSL intersection at which the data were collected. Specifically, VDTI profiles for vehicle speed and braking are illustrated, for S19 and S23 respectively, in: (1) Figures K-1A and L-1A, for VPTY=AG LSL intersections; (2) Figures K-1C and L-1C, for VPTY=0 sec LSL intersections; (3) Figures K-1E and L-1E, for VPTY=2 sec LSL intersections; (4) Figures K-1G and L-1G, for VPTY=3.5 sec LSL intersections; (3) Figures K-1I and L-1I, for VPTY=5 sec LSL intersections. Similarly, VDTI profiles for vehicle acceleration/deceleration profiles are illustrated, for S19 and S23 respectively, in: (1) Figures K-1B and L-1B, for VPTY=AG LSL intersections; (2) Figures K-1D and L-1D, for VPTY=0 sec LSL intersections; (3) Figures K-1F and L-1F, for VPTY=2 sec LSL intersections; (4) Figures K-1H and L-1H, for VPTY=3.5 sec LSL intersections; (3) Figures K-1J and L-1J, for VPTY=5 sec LSL intersections. Each figure plots four

VDTI profiles each for control and test trials (2 control and 2 test trials, and 2 intersections at each VPTY level per trial) for the dependent measure indicated, along with the light actuation flags (1=G light; 2=AWF actuated; 3=Y signal light actuated; 4=red signal light actuated) for each trial.

VDTI profiles for vehicle speed for S19 in Appendix K show that the slowest speeds for interactions with VPTY=AG (Fig. K-1A), VPTY=0 sec (Fig. K-1C), VPTY=2 sec (Fig. K-1E), VPTY=5 sec (Fig. K-1I) intersections occur during one or two of the control trials (diamonds). For interactions with VPTY=3.5 sec intersections however (Fig. K-1G), speeds for all four of the control trials are slower than those for the test trials (squares). Their are no pronounced differences in braking pressure levels between the control and test conditions for interactions with VPTY intersections (2, 3.5, and 5 sec; Figs. K-1E, K-1G, and K-1I) at which vehicle braking occurred.

VDTI profiles for vehicle acceleration/deceleration for S19 in Appendix K show that vehicle acceleration/deceleration levels are comparable under both the control and test conditions for interactions with VPTY=2 sec (Fig. K-1F), VPTY=3.5 sec (Fig. K-1H), and VPTY=5 sec (Fig. K-1J) intersections. For interactions with VPTY=AG (Fig. K-1B) and VPTY=0 sec (Fig. K-1D) intersections however, vehicle acceleration levels for three of four test trials are higher than those for the corresponding control trials.

Collectively, results for S19 in Appendix K indicate a consistent tendency for the S to approach AWF intersections at a higher vehicle speed across all VPTY levels, and to maintain vehicle acceleration at higher levels for interactions with AWF intersections at 2 of 5 VPTY levels. These results provide insight into the ESDT results for this S described above in suggesting that the presence of AWFs had the effect of encouraging faster speeds during intersection interactions.

SDP results essentially opposite to those for S19 are shown for S23 in Appendix L. In particular, VDTI profiles for vehicle speed show that the slowest speeds for interactions with VPTY=AG (Fig. L-1A), VPTY=0 sec (Fig. L-1C), VPTY=2 sec (Fig. L-1E), VPTY=5 sec (Fig. L-1I) intersections occur during one or two of the test trials (squares). For interactions with VPTY=3.5 sec intersections(Fig. L-1G), speeds for three of the four test trials are slower than those for the control trials (diamonds). Their are no pronounced differences in braking pressure levels between the control and test conditions for interactions with VPTY intersections (2, 3.5, and 5 sec; Figs. L-1E, L-1G, and L-1I) at which vehicle braking occurred.

VDTI profiles for vehicle acceleration/deceleration for S23 in Appendix L show that vehicle acceleration/deceleration levels are comparable under both the control and test conditions for interactions with VPTY=2 sec (Fig. L-1F), VPTY=3.5 sec (Fig. L-1H), and VPTY=5 sec (Fig. L-1J) intersections. For interactions with VPTY=AG (Fig. L-1B) and VPTY=0 sec (Fig. L-1D) intersections however, vehicle acceleration levels for two and two control trials respectively are higher than those for the corresponding test trials.

Collectively, results for S23 in Appendix L indicate a consistent tendency for the S to approach control intersections at a higher vehicle speed across all VPTY levels, and to maintain vehicle acceleration at higher levels for interactions with control intersections at 2 of 5 VPTY levels. These results provide insight into the ESDT results for this S described above in suggesting that the presence of AWFs had the effect of encouraging slower speeds during intersection interactions.

3.3.2. ANOVA Results for Main and Interactive Effects

Results for stopping behavior (Section 3.2.2) and ESDT levels (Sections 3.2.1, 3.2.3), coupled with those for the two individual Ss in Appendices K and L, indicate a considerable variability in within- and between-subject simulated driving behavior across all SL and VPTY conditions. VDTI profiles for vehicle speed, braking pressure, and acceleration/deceleration (Appendices K,L) can be readily examined visually to support interpretation of how drivers interact with intersections during SDP. However, results presented in this and the following section indicate that overall variability, rather than time-dependent changes, in these measures provides more meaningful understanding and statistical interpretation of AWF effects on SDP in relation to different SL and VPTY conditions.

Therefore, to analyze sources of overall variability in dependent measures of SDP, the following approach is used.

1. For each S and each of the three SDP measures of vehicle speed, braking pressure, and acceleration/deceleration (Table 2-4), means were calculated for data collected across the two intersection data blocks in a given trial (Section 2.5) corresponding to a given VPTY level. This process was repeated for the two intersection data blocks in the same trial corresponding to each of the other VPTY levels (Table 2-2). The outcome of this analysis is a total of 5 mean values per S per trial for each measure, each mean corresponding to one of the 5 different VPTY levels.

Table. 3-5. Results from multivariate four-way ANOVA for main and interactive effects on objective dependent measures of SDP.

Type of Effect	Source	Hypothesis df	Error df	F	p
Main	AWF	3	918	5.98	<.000
	SL	3	918	183.1	<.000
	VPTY	12	2760	170.2	<.000
	T	3	918	10.0	<.000
Interactive	AWF x SL	3	918	.741	.527
	AWF x VPTY	12	2760	3.97	<.000
	AWF x T	3	918	.387	.763
	SL x VPTY	12	2760	51.1	<.000
	SL x T	3	918	1.01	.388
	VPTY x T	12	2760	.744	.709
	AWF x SL x VPTY	12	2760	2.50	.003
	AWF x SL x T	3	918	.524	.666
	AWF x VPTY x T	12	2760	.846	.602
	SL x VPTY x T	12	2760	.781	.671
	AWF x SL x VPTY x T	12	2760	.299	.990

2. For each measure and each VPTY level, the outcome of Step 1 for all Ss and all trials is a total of 48 mean values for control and test trials respectively (24 Ss, 2 trials per SDTE). These data then are analyzed using: (1) ANOVA for main and interactive effects (below); (2) post hoc analysis of interactive effects (Section 3.3.3); (3) paired-t test analysis (Sections 3.3.3.1 through 3.3.3.6); and (4) scatter diagram plots (Appendices M and N).
3. Paired-t test and scatter diagram analyses for results from both LSL (Sections 3.3.3.1 through 3.3.3.3) and HSL (Sections 3.3.3.4 through 3.3.3.6) trials are carried out as follows. First, the 48 control and test means for each measure at each VPTY level are compared by pairing T1

control means with T1 test means for S1, T2 control means with T2 test means for S1, and continuing this pairing pattern for the remaining 23 Ss. These paired data then are analyzed with paired-t tests and scatter diagrams.

Table 3-5 summarizes results from a multivariate four-way ANOVA for main and interactive effects on objective dependent measures of SDP. For purposes of this analysis, all 3 dependent measures are grouped, family-wise, in order to assess main and interactive effects. From left to right, columns in the table list the type of effect (main or interactive), source of effect (independent measure), degrees of freedom (df) for source, df for error, F value, and probability (p). Results in Table 3-5 indicate statistical significance ($p<.05$) for all four main effects and for 3 interactive effects, each of which includes VPTY level: AWF x VPTY, SL x VPTY, and AWF x SL x VPTY.

To delineate the multivariate effects shown in Table 3-5 in terms of individual dependent measures, separate univariate ANOVA was carried out for vehicle speed, acceleration/deceleration, and braking. Results are in Tables 3-6 through 3-8, respectively, for these measures. Compared with Table 3-5, each of these latter tables contains 2 additional columns, namely the sum of squares (SS) and the mean square (MS), for each source effect indicated.

Results in Tables 3-6 through 3-8 indicate statistically significant main effects of SL and VPTY on all three dependent measures; main effects of AWF and trial on vehicle speed also are significant (Table 3-6). Across all 3 dependent measures, the same two statistically significant second-order interactive effects are observed: AWF x VPTY and SL x VPTY. Post hoc analysis to investigate the basis of these interactions is provided in the next section.

3.3.3. Post Hoc Analysis of Interactive Effects

Univariate ANOVA results presented in the preceding section indicate that, for each of the 3 objective dependent measures of SDP, the same two statistically significant interactive effects are observed, namely AWF x VPTY and SL x VPTY. In this section, the basis of these interactions first is investigated using graphical analysis. Then paired-t test analysis is used to compare control versus test levels of these measures at each VPTY level, for both LSL and HSL trials (Sections 3.3.3.1 through 3.3.3.6), accompanied by scatter diagram plots of the paired results (Appendices M and N).

Figures 3-9 through 3-11, respectively, illustrate the interactive effects of intersection AWF

Table. 3-6. Results from univariate four-way ANOVA for main and interactive effects on vehicle speed.

Type of Effect	Source	SS	df	MS	F	p
Main	AWF	115.9	1	115.9	17.8	<.000
	SL	2391.7	1	2391.7	367.7	<.000
	VPTY	11548.0	4	2887.0	443.8	<.000
	T	107.9	1	107.9	16.6	<.000
Inter-active	AWF x SL	4.14	1	4.14	.637	.425
	AWF x VPTY	215.6	4	53.9	8.29	<.000
	AWF x T	1.91	1	1.91	.294	.588
	SL x VPTY	302.4	4	75.6	11.6	<.000
	SL x T	5.36	1	5.36	.825	.364
	VPTY x T	36.0	4	8.99	1.38	.238
	AWF x SL x VPTY	31.8	4	7.95	1.22	.300
	AWF x SL x T	2.36	1	2.36	.363	.547
	AWF x VPTY x T	10.8	4	2.70	.088	.798
	SL x VPTY x T	42.2	4	10.6	1.62	.166
	AWF x SL x VPTY x T	2.29	4	.572	.088	.986
	Error	5984.6	920	6.51	N/A	N/A

absence/presence and VPTY level on vehicle speed, acceleration/deceleration, and braking pressure. In each of the figures, mean values averaged across both trials are plotted on the Y axis in relation to both AWF condition and VPTY level.

Results for vehicle speed in Figure 3-9 show that for the VPTY levels of AG and 0 sec, mean speed levels at either SL are closely comparable for control and test trials. At the 'stop likely' VPTY

Table. 3-7. Results from univariate four-way ANOVA for main and interactive effects on vehicle acceleration/deceleration.

Type of Effect	**Source**	**SS**	**df**	**MS**	**F**	**p**
Main	AWF	.0341	1	.0341	3.02	.083
	SL	.115	1	.115	10.15	.001
	VPTY	21.4	4	5.36	475.0	<.000
	T	.0131	1	.0131	1.16	.281
Inter-active	AWF x SL	.00539	1	.00539	.477	.490
	AWF x VPTY	4.48	4	1.12	4.00	.003
	AWF x T	.00100	1	.00100	.089	.766
	SL x VPTY	4.48	4	1.12	99.2	<.000
	SL x T	.0339	1	.0339	3.01	.083
	VPTY x T	.0602	4	.0151	1.33	.255
	AWF x SL x VPTY	.168	4	.0420	3.72	.005
	AWF x SL x T	.0167	1	.0167	1.48	.224
	AWF x VPTY x T	.0684	4	.0171	1.52	.196
	SL x VPTY x T	.0238	4	.00596	.528	.715
	AWF x SL x VPTY x T	.0179	4	.00448	.397	.811
	Error	10.4	920	.0113	N/A	N/A

level of 5 sec, the same is true for HSL trials (Fig. 3-9B), but control mean speed levels are higher than test levels for LSL trials (Fig. 3-9A) at VPTY=5 sec. At VPTY levels of 2 and 3.5 sec (just inside of and within the decision zone, respectively), control levels of mean vehicle speed are higher than test levels for trials at either SL.

Results in Figure 3-10 show that control and test levels of mean vehicle acceleration/deceleration

Table. 3-8. Results from univariate four-way ANOVA for main and interactive effects on vehicle braking.

Type of Effect	Source	SS	df	MS	F	p
Main	AWF	.00252	1	.0333	2.11	.147
	SL	.0369	1	.0369	30.9	<.000
	VPTY	1.154	4	.289	241.6	<.000
	T	.000921	1	.000921	.771	.380
Inter-active	AWF x SL	1.69E-06	1	1.69E-06	.001	.970
	AWF x VPTY	.0239	4	.00597	5.00	.001
	AWF x T	.000303	1	.000303	.253	.615
	SL x VPTY	.0643	4	.0161	13.4	<.000
	SL x T	.00129	1	.00129	1.08	.299
	VPTY x T	.00416	4	.00104	.870	.481
	AWF x SL x VPTY	.000209	4	5.23E-05	.044	.996
	AWF x SL x T	.000960	1	.000960	.803	.370
	AWF x VPTY x T	.00654	4	.00164	1.369	.243
	SL x VPTY x T	.00264	4	.000661	.553	.697
	AWF x SL x VPTY x T	.000849	4	.000212	.178	.950
	Error	1.10	920	.00119	N/A	N/A

are comparable across all VPTY levels for HSL trials (Fig. 3-10B), and for 4 of the 5 VPTY levels for LSL trials, namely VPTY=AG and 0, 3.5, and 5 sec (Fig. 3-10A). At VPTY=2 sec for the LSL trials (Fig. 3-10A), the control level of mean vehicle acceleration/deceleration is notably higher than the test level.

Results in Figure 3-11 show that for the VPTY levels of 3.5 and 5 sec, mean braking pressure

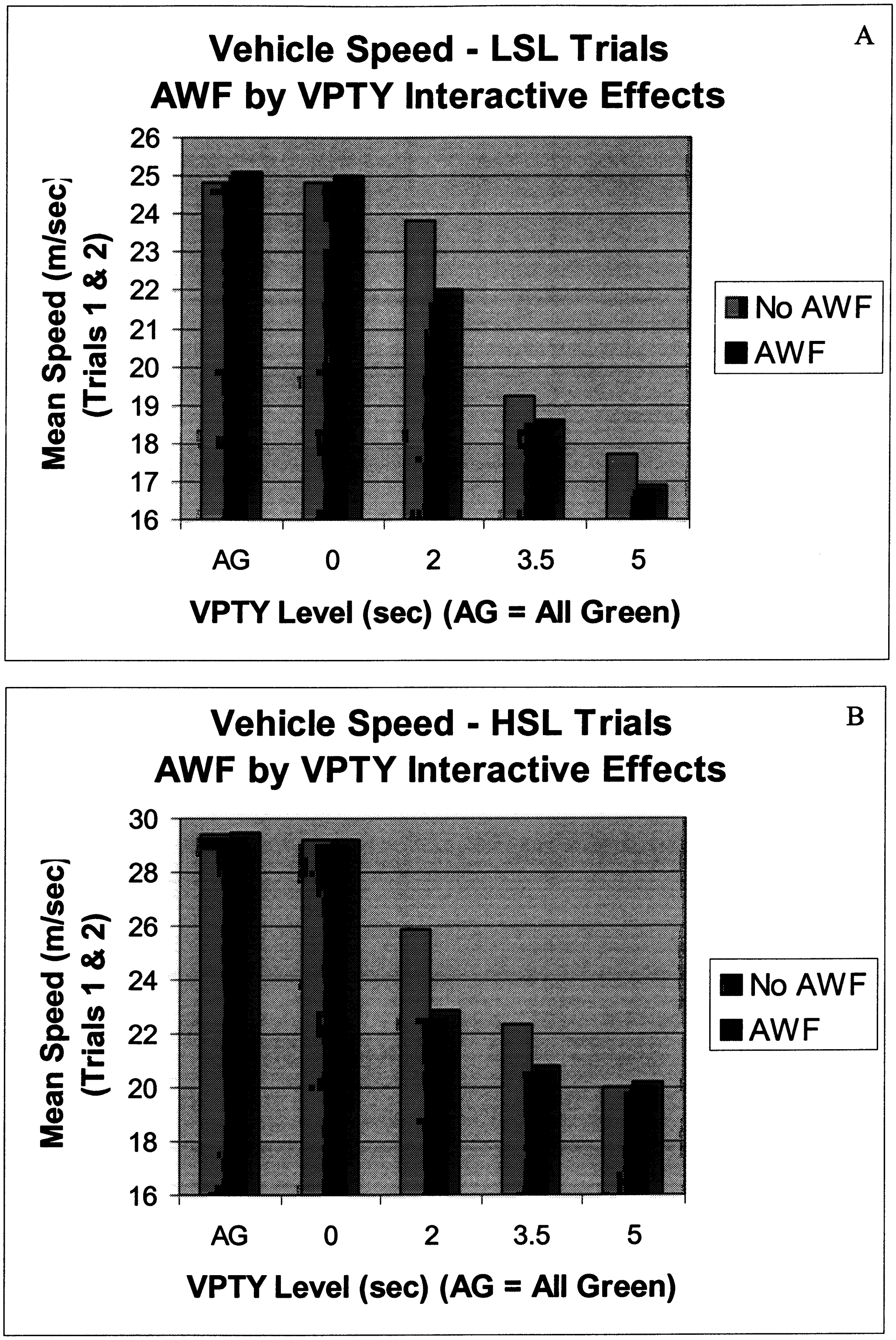
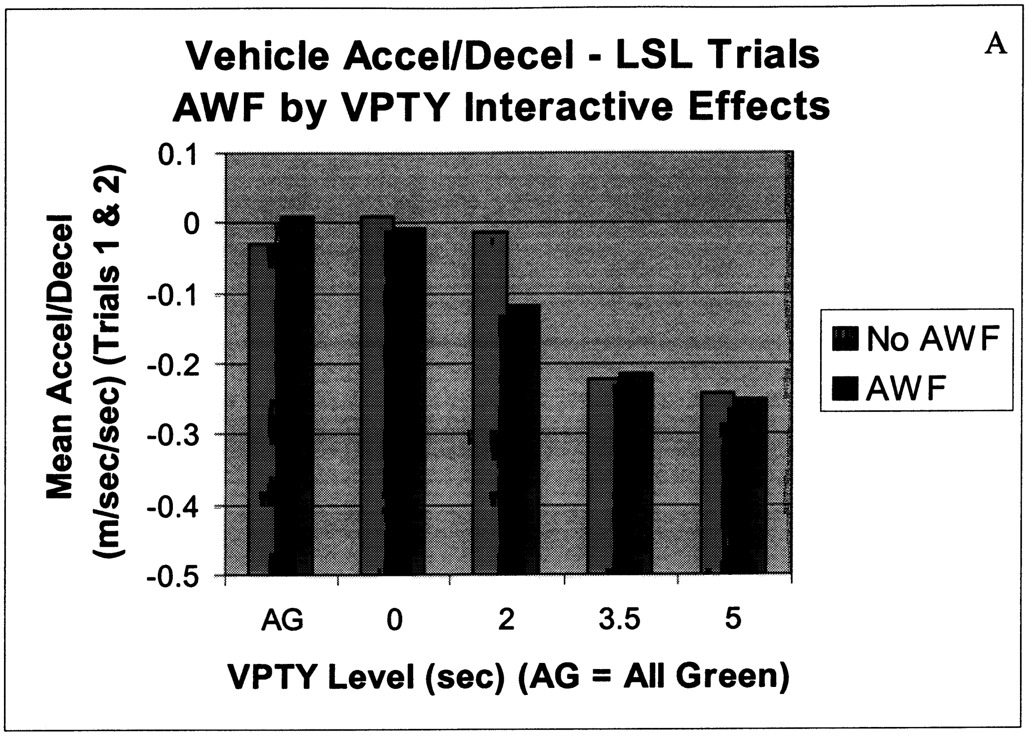


Figure 3-9. Effects of intersection AWF absence/presence and VPTY level on mean vehicle speed, for LSL (Fig. 3-9A) and HSL (Fig. 3-9B) trials, averaged over Trials 1 and 2.



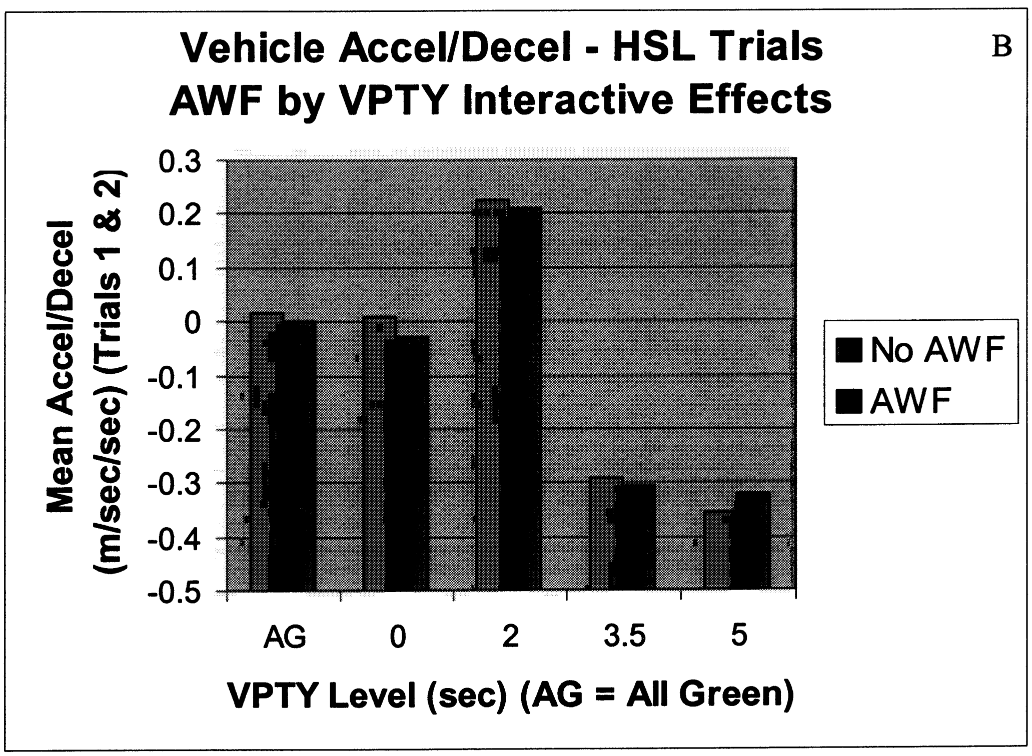
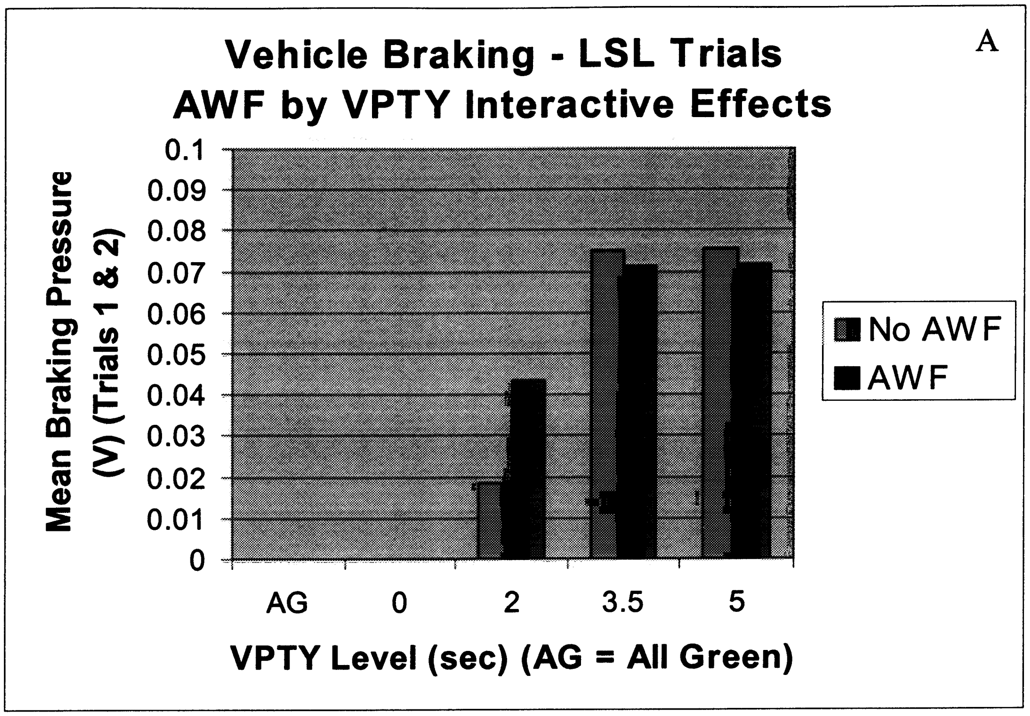


Figure 3-10. Effects of intersection AWF absence/presence and VPTY level on mean vehicle accel/decel, for LSL (Fig. 3-10A) and HSL (Fig. 3-10B) trials, averaged over Trials 1 and 2.



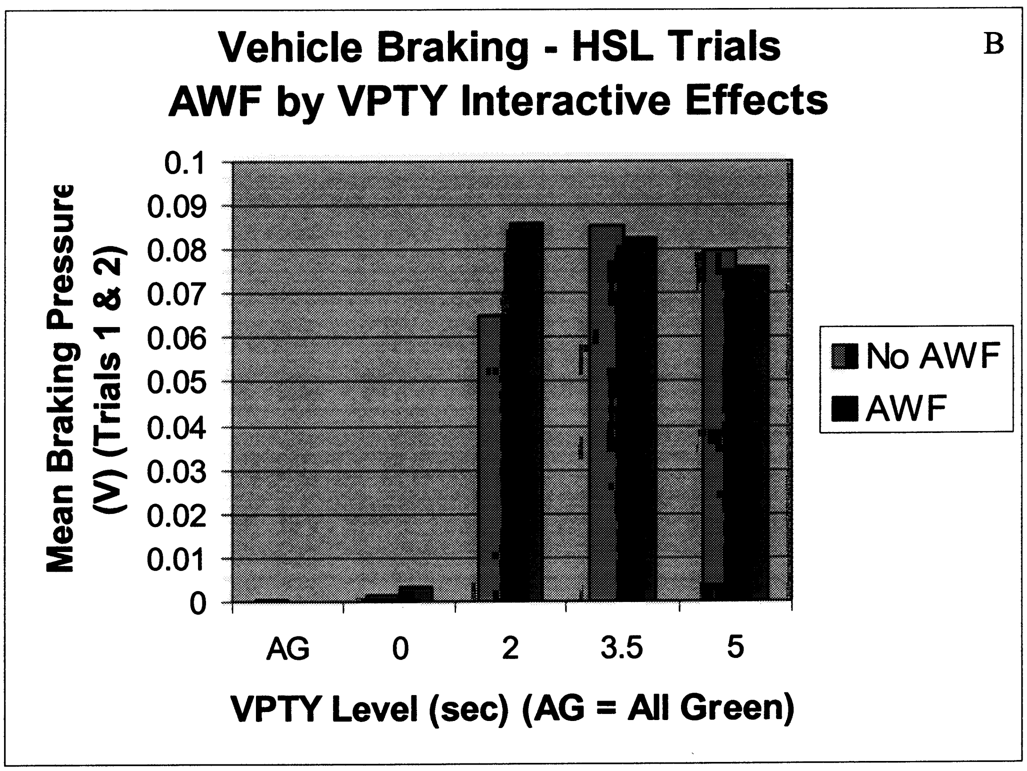


Figure 3-11. Effects of intersection AWF absence/presence and VPTY level on mean vehicle braking pressure, for LSL (Fig. 3-11A) and HSL (Fig. 3-11B) trials, averaged over Trials 1 and 2.

levels are comparable for both control and test trials at either SL. However, for the VPTY level of 2 sec at either SL, mean braking pressure is notably higher for test than for control trials.

Results shown in Figures 3-9 through 3-11 account for the second-order interactive AWF x SL and AWF x VPTY effects documented by the univariate ANOVA results in Tables 3-6 through 3-8. Specifically, except for acceleration/deceleration results for HSL trials, mean vehicle speed and acceleration/deceleration levels at VPTY=2 sec intersections are notably lower, and braking pressure levels notably higher, for test compared with control trials at either SL. Higher vehicle speeds for control compared with test trials also are observed for VPTY=3.5 sec intersections at either SL (Fig. 3-9). Collectively, these results indicate that during interaction with intersections at VPTY levels of 2 and 3.5 sec, at which uncertain driver decision-making in interacting with the Y light may be expected, drivers tend to display more cautious driving behavior when AWFs are present (e.g., lower vehicle speed and acceleration/deceleration, accompanied by more braking), relative to when AWFs are not present.

Post-hoc analysis is continued in the subsections below, with two-tailed paired-t test analyses of within-subject, control versus test mean levels of each of the 3 objective dependent measures of SDP at each VPTY level. The purpose of these analyses is to ascertain whether the difference in control versus test levels of each measure at each VPTY level is statistically significant. Results are grouped by both SL and VPTY level. Specifically, for LSL and HSL trials respectively, Sections 3.3.3.1 and 3.3.3.4 present results for control VPTY intersections of AG and 0 sec, Sections 3.3.3.2 and 3.3.3.5 present results for VPTY intersections of 2 and 3.5 sec, and Sections 3.3.3.3 and 3.3.3.6 present results for'stop likely' VPTY intersections of 5 sec. Scatter plots of control versus test distributions of these measures for LSL and HSL trials are in Appendices M and N respectively.

3.3.3.1. SDP Results for LSL Trials and Control VPTY Intersections

Two-tailed paired-t test results for comparison of within-subject, control versus test mean levels of vehicle speed and acceleration/deceleration measures of SDP, for AG and 0 sec VPTY intersection data acquired during LSL trials, are presented in Table 3-9. Braking pressure data are not presented because vehicle braking was observed during only 1 of 48 LSL trials for each of these VPTY conditions. The approach used to pair control and test data for two-tailed paired t-test analysis is described in Section 3.3.2 above.

Table 3-9. Within-subject control versus test two-tailed paired t-test results for means of vehicle speed and acceleration/deceleration SDP measures by trial, LSL trials, VTPY=AG and 0 sec intersections. See text for description of approach used for paired t-test analysis.

SDP DEPENDENT MEASURE	AWF CONDITION/ TWO TAILED PAIRED-t TEST STATISTIC	CONTROL VS TEST FOR AG AND 0 sec VPTY INTERSECTIONS, LSL TRIALS			
		VPTY = AG		VPTY = 0 sec	
		Control	Test	Control	Test
Vehicle Speed (m/sec)	Mean	24.83856	25.07355	24.81359	24.95651
	SD	1.51496	1.75024	1.55607	1.79452
	N	24		24	
	Pearson Correlation	0.59162		0.321617	
	Hypothesized Mean Difference	0		0	
	df	47		47	
	t-stat	-1.09245		-0.50493	
	t-crit (two-tailed)	2.011739		2.011739	
	p (two-tailed)	0.280202		0.615965	
Vehicle Acceleration/ Deceleration (m/sec/sec)	**AWF CONDITION/ STATISTIC**	**Control**	**Test**	**Control**	**Test**
	Mean	-0.03119	0.009891	0.009694	-0.00775
	SD	0.04700	0.06492	0.03600	0.05140
	N	24		24	
	Pearson Correlation	0.197706		-0.02461	
	Hypothesized Mean Difference	0		0	
	df	47		47	
	t-stat	-3.94028		1.903531	
	t-crit (two-tailed)	2.011739		2.011739	
	p (two-tailed)	0.000269		0.063105	

Results in Table 3-9 show that no significant differences in vehicle speed exist between paired, within-subject mean values for control and test trials at either the AG or the 0 sec VPTY intersections. However, relative to control trials, paired mean vehicle acceleration/deceleration levels are higher for test trials for VPTY=AG intersections, but lower for VPTY=0 sec intersections. The difference in paired means is highly significant for VPTY=AG intersections ($p<.001$), and marginally significant for VPTY=0 sec intersections ($p=.063$).

Scatter plots of paired, within-subject means for vehicle speed and acceleration/deceleration for VPTY=AG and 0 sec intersections are in Appendix M, Figures M-1 and M-2. The approach used to pair control and test data for scatter plot analysis is described in Section 3.3.2 above. The plots in Figures M-1 and M-2 show the distributions of paired results for individual Ss that underlie the paired-t results in Table 3-9. In these figures: (1) each point represents within-subject, paired control and test means by trial for VPTY levels of AG (Fig. M-1) and 0 sec (Fig. M-2); (2) the solid line is the least squares regression (LSR) line fit to the data; and (3) the dashed line is the LOI---all points would lie on this line if the paired mean control and test values were identical for each S.

The Figure M-1 and M-2 scatter plots in Appendix M illustrate the basis for the paired-t test results in Table 3-9 in showing that within-subject, paired control and test means by trial have the following distributions: (1) for vehicle speed, more or less even distribution of paired mean values about the LOI for both VPTY=AG (Fig. M-1A) and VPTY=0 sec (Fig. M-2A) intersections; (2) for vehicle acceleration/deceleration approaching VPTY=AG intersections, more paired mean values above the LOI (Fig. M-1B), indicating a greater number of Ss with higher mean values during test compared with control trials; and (3) for vehicle acceleration/deceleration approaching VPTY= 0 sec intersections, more paired mean values below the LOI (Fig. M-1B), indicating a greater number of Ss with higher mean values during control compared with test trials.

3.3.3.2. SDP Results for LSL Trials and 2 and 3.5 sec VPTY Intersections

Two-tailed paired-t test results for comparison of within-subject, control versus test mean levels of vehicle speed, acceleration/deceleration, and braking pressure measures of SDP, for 2 and 3.5 sec VPTY intersection data acquired during LSL trials, are presented in Table 3-10. Results in the table show pronounced differences between the 2 and 3.5 sec VPTY intersections in terms of AWF effects on all three of these measures. Specifically, at VPTY=2 sec intersections, there are statistically

Table 3-10. Within-subject, control versus test two-tailed paired t-test results for means of vehicle speed, acceleration/deceleration, and braking pressure SDP measures by trial, LSL trials, VTPY=2 and 3.5 sec intersections. See text for description of approach used for paired t-test analysis.

SDP DEPENDENT MEASURE	AWF CONDITION/ TWO-TAILED PAIRED-t TEST STATISTIC	CONTROL VS TEST FOR 2 AND 3.5 sec VPTY INTERSECTIONS, LSL TRIALS			
		VPTY = 2 sec		VPTY = 3.5 sec	
		Control	Test	Control	Test
Vehicle Speed (m/sec)	Mean	23.59003	21.31393	18.10534	17.7815
	SD	2.88852	4.45823	3.55426	3.65659
	N	24		24	
	Pearson Correlation	0.064092		0.405529	
	Hypothesized Mean Difference	0		0	
	df	47		47	
	t-stat	3.059328		0.57057	
	t-crit (two-tailed)	2.011739		2.011739	
	p (two-tailed)	0.003658		0.571009	
Vehicle Acceleration/ Deceleration (m/sec/sec)	AWF CONDITION/ STATISTIC	Control	Test	Control	Test
	Mean	-0.01188	-0.11907	-0.22411	-0.21431
	SD	0.13679	0.15464	0.14606	0.16438
	N	24		24	
	Pearson Correlation	0.27179		0.413117	
	Hypothesized Mean Difference	0		0	
	df	47		47	
	t-stat	4.209359		-0.40195	
	t-crit (two-tailed)	2.011739		2.011739	
	p (two-tailed)	0.000115		0.689543	

Table 3-10 (continued).

SDP DEPENDENT MEASURE	AWF CONDITION/ TWO-TAILED, PAIRED-t TEST STATISTIC	CONTROL VS TEST FOR 2 AND 3.5 sec VPTY INTERSECTIONS, LSL TRIALS			
		VPTY = 2 sec		VPTY = 3.5 sec	
		Control	Test	Control	Test
Braking Pressure (V)	Mean	0.018622	0.042145	0.075216	0.071519
	SD	0.04123	0.05450	0.05116	0.04715
	N	24		24	
	Pearson Correlation	0.211151		0.551615	
	Hypothesized Mean Difference	0		0	
	df	47		47	
	t-stat	-2.67147		0.548742	
	t-crit (two-tailed)	2.011739		2.011739	
	p (two-tailed)	0.010344		0.58578	

significant differences ($p<.05$) between control and test trials for paired, within-subject means of vehicle speed, acceleration/deceleration, and braking pressure, with control levels higher for the first two, and lower for the third, of these measures relative to test levels. However, at VPTY=3.5 sec intersections, there are no statistically significant differences between control and test trials for paired, within-subject means of these same measures.

Scatter plots of paired, within-subject means from LSL trials for control versus test levels of vehicle speed, acceleration/deceleration, and braking pressure for VPTY=2 and 3.5 sec intersections are in Appendix M, Figures M-3 and M-4. The plots show the distributions of paired results for individual Ss that illustrate the basis for the paired-t test results in Table 3-10. Specifically, scatter plots in Figure M-3 for within-subject, paired control and test means by trial for VPTY=2 sec intersections show the following distributions: (1) for both vehicle speed (Fig. M-3A) and acceleration/deceleration (Fig. M-3B), more paired mean values lie below the LOI, indicating a greater number of Ss with higher mean values during control compared with test trials; and (3) for braking pressure, more paired mean values lie above the LOI (Fig. M-3C), indicating a greater number of Ss with higher mean values during test compared with control trials.

Conversely, scatter plots in Appendix M for within-subject, paired control and test means from HSL trials for VPTY=3.5 sec intersections show that distributions of SDP measures of vehicle speed (Fig. M-4A), acceleration/deceleration (Fig. M-4B), and braking pressure (Fig. M-4C) have more or less even distributions of paired mean values about the LOI.

3.3.3.3. SDP Results for LSL Trials and 'Stop Likely' VPTY Intersections

Two-tailed paired-t test results for comparison of within-subject, control versus test mean levels of vehicle speed, acceleration/deceleration, and braking pressure measures of SDP, for VPTY=5 sec intersection data acquired during LSL trials, are presented in Table 3-11. As described earlier (Fig. 3-3), almost all Ss stopped at VPTY=5 sec intersections during LSL trials. Results in Table 3-11 show that at these intersections, the difference between control and test trials for paired, within-subject means of vehicle speed is statistically significant, with control levels higher than test levels. However, differences in paired, within-subject control versus test means for measures of vehicle acceleration/deceleration and braking pressure are not statistically significant.

Scatter plots of paired, within-subject means for control versus test levels of vehicle speed,

Table 3-11. Within-subject, control versus test two-tailed paired t-test results for means of vehicle speed, acceleration/deceleration, and braking pressure SDP measures by trial, LSL trials, VTPY=5 sec intersections. See text for description of approach used for paired t-test analysis.

SDP DEPENDENT MEASURE	AWF CONDITION/ TWO-TAILED, PAIRED-t TEST STATISTIC	CONTROL VS TEST FOR 5 sec VPTY INTERSECTIONS, LSL TRIALS	
		Control	**Test**
Vehicle Speed (m/sec)	Mean	17.08381	16.37256
	SD	1.73642	0.70911
	N	24	
	Pearson Correlation	0.378119	
	Hypothesized Mean Difference	0	
	df	47	
	t-stat	3.063789	
	t-crit (two-tailed)	2.011739	
	p (two-tailed)	0.003613	
Vehicle Acceleration/ Deceleration (m/sec/sec)	**AWF CONDITION/ STATISTIC**	**Control**	**Test**
	Mean	-0.24292	-0.2524
	SD	0.12476	0.08246
	N	24	
	Pearson Correlation	0.654983	
	Hypothesized Mean Difference	0	
	df	47	
	t-stat	0.696917	
	t-crit (two-tailed)	2.011739	
	p (two-tailed)	0.489288	

Table 3-11 (continued).

SDP DEPENDENT MEASURE	AWF CONDITION/ TWO-TAILED PAIRED-t TEST STATISTIC	CONTROL VS TEST FOR 5 sec VPTY INTERSECTIONS, LSL TRIALS	
		Control	Test
Braking Pressure (V)	Mean	0.075461	0.071512
	SD	0.03470	0.03423
	N	24	
	Pearson Correlation	0.506076	
	Hypothesized Mean Difference	0	
	df	47	
	t-stat	0.798634	
	t-crit (two-tailed)	2.011739	
	p (two-tailed)	0.42852	

acceleration/deceleration, and braking pressure for VPTY=5 sec intersections are in Appendix M, Figure M-5. The plots show the distributions of paired mean results for individual Ss that illustrate the basis for the paired-t test results in Table 3-11. Specifically, scatter plots in Figure M-5 show that for vehicle speed (Fig. M-5A), more paired mean values lie below the LOI, indicating a greater number of Ss with higher mean values during control compared with test trials. Indeed, the distribution in Figure M-5A is highly skewed in this manner, with 6 Ss maintaining notably higher vehicle speeds while approaching VPTY=5 sec intersections during control as compared with test trials. However, scatter plots for paired mean values of vehicle acceleration/ deceleration (Fig. M-5B) and braking pressure (Fig. M-5C) data at VPTY=5 sec intersections show that distributions of these measures have more or less even distributions about the LOI.

3.3.3.4. SDP Results for HSL Trials and Control VPTY Intersections

Two-tailed paired-t test results for comparison of within-subject, control versus test mean levels of vehicle speed and acceleration/deceleration measures of SDP, for AG and 0 sec VPTY intersection data acquired during HSL trials, are presented in Table 3-12. Braking pressure data are not presented because vehicle braking was only observed during: (1) 1 of 48 HSL trials for VPTY=AG intersections; (2) 3 of 48 HSL trials for control VPTY=0 sec intersections; and (3) 5 of 48 HSL trials for test VPTY=0 sec intersections. The approach used to pair control and test data for two-tailed paired t-test analysis is described in Section 3.3.2. Results in Table 3-12 show that no significant differences in vehicle speed and acceleration/deceleration exist between paired, within-subject mean values for control and test trials at either the AG or the 0 sec VPTY intersections.

Scatter plots of paired, within-subject means for vehicle speed and acceleration/deceleration for VPTY=AG and 0 sec intersections are in Appendix N, Figures N-1 and N-2. The approach used to pair control and test data for scatter plot analysis is described in Section 3.3.2. The Figure N-1 and N-2 scatter plots in Appendix N illustrate the basis for the paired-t test results in Table 3-12 in showing that within-subject, paired control and test means by trial have more or less even distributions of paired mean values about the LOI for measures of both vehicle speed and acceleration/deceleration for both the AG and 0 sec VPTY intersections.

Table 3-12. Within-subject control versus test two-tailed paired t-test results for means of vehicle speed and acceleration/deceleration SDP measures by trial, HSL trials, VTPY=AG and 0 sec intersections. See text for description of approach used for paired t-test analysis.

SDP DEPENDENT MEASURE	AWF CONDITION/ TWO TAILED PAIRED-t TEST STATISTIC	CONTROL VS TEST FOR AG AND 0 sec VPTY INTERSECTIONS, HSL TRIALS			
		VPTY = AG		VPTY = 0 sec	
		Control	Test	Control	Test
Vehicle Speed (m/sec)	Mean	29.36601	29.51413	29.22773	29.21123
	SD	1.48841	1.28192	1.31467	1.61365
	N	24		24	
	Pearson Correlation	0.041202		0.162431	
	Hypothesized Mean Difference	0		0	
	df	47		47	
	t-stat	-0.53338		0.059913	
	t-crit (two-tailed)	2.011739		2.011739	
	p (two-tailed)	0.596287		0.952479	
Vehicle Acceleration/ Deceleration (m/sec/sec)	AWF CONDITION/ STATISTIC	Control	Test	Control	Test
	Mean	0.016006	-0.00091	-0.00776	-0.03088
	SD	0.05464	0.05903	0.08491	0.07904
	N	24		24	
	Pearson Correlation	-0.02986		0.230328	
	Hypothesized Mean Difference	0		0	
	df	47		47	
	t-stat	1.435446		1.573701	
	t-crit (two-tailed)	2.011739		2.011739	
	p (two-tailed)	0.157782		0.122265	

Table 3-13. Within-subject, control versus test two-tailed paired t-test results for means of vehicle speed, acceleration/deceleration, and braking pressure SDP measures by trial, HSL trials, VTPY=2 and 3.5 sec intersections. See text for description of approach used for paired t-test analysis.

SDP DEPENDENT MEASURE	AWF CONDITION/ TWO-TAILED PAIRED-t TEST STATISTIC	CONTROL VS TEST FOR 2 AND 3.5 sec VPTY INTERSECTIONS, HSL TRIALS			
		VPTY = 2 sec		VPTY = 3.5 sec	
		Control	Test	Control	Test
Vehicle Speed (m/sec)	Mean	24.93759	21.83673	21.16993	19.92223
	SD	4.83640	3.91500	4.06987	2.35137
	N	24		24	
	Pearson Correlation	0.087469		0.441158	
	Hypothesized Mean Difference	0		0	
	df	47		47	
	t-stat	3.610492		2.339797	
	t-crit (two-tailed)	2.011739		2.011739	
	p (two-tailed)	0.00074		0.023593	
Vehicle Acceleration/ Deceleration (m/sec/sec)	**AWF CONDITION/ STATISTIC**	**Control**	**Test**	**Control**	**Test**
	Mean	-0.1675	-0.28284	-0.29195	-0.30733
	SD	0.19150	0.17315	0.18889	0.11893
	N	24		24	
	Pearson Correlation	0.371627		0.493057	
	Hypothesized Mean Difference	0		0	
	df	47		47	
	t-stat	3.898958		0.640881	
	t-crit (two-tailed)	2.011739		2.011739	
	p (two-tailed)	0.000306		0.524713	

Table 3-13 (continued).

SDP DEPENDENT MEASURE	AWF CONDITION/ TWO-TAILED, PAIRED-t TEST STATISTIC	CONTROL VS TEST FOR 2 AND 3.5 sec VPTY INTERSECTIONS, HSL TRIALS			
		VPTY = 2 sec		VPTY = 3.5 sec	
		Control	Test	Control	Test
Braking Pressure (V)	Mean	0.055563	0.077139	0.085419	0.082734
	SD	0.06005	0.04997	0.05224	0.03658
	N	24		24	
	Pearson Correlation	0.276476		0.495989	
	Hypothesized Mean Difference	0		0	
	df	47		47	
	t-stat	-2.24238		0.399179	
	t-crit (two-tailed)	2.011739		2.011739	
	p (two-tailed)	0.029693		0.691569	

3.3.3.5. SDP Results for HSL Trials and 2 and 3.5 sec VPTY Intersections

Two-tailed paired-t test results for comparison of within-subject, control versus test mean levels of vehicle speed, acceleration/deceleration, and braking pressure measures of SDP, for 2 and 3.5 sec VPTY intersection data acquired during HSL trials, are presented in Table 3-13. As with the LSL trials (Table 3-10), results in Table 3-13 show notable differences between the 2 and 3.5 sec VPTY intersections in terms of AWF effects on two of these measures. Specifically, at VPTY=2 sec intersections, there are statistically significant differences ($p<.05$) between control and test trials for paired, within-subject means of vehicle speed, acceleration/deceleration, and braking pressure, with control levels higher for the first two, and lower for the third, of these measures relative to test levels.

Conversely, as Table 3-13 shows, at VPTY=3.5 sec intersections there are no statistically significant differences between control and test trials for paired, within-subject means of vehicle acceleration/ deceleration and braking pressure measures of SDP. For vehicle speed at VPTY=3.5 sec intersections however, paired within-subject means are different at a statistically significant level ($p=.024$; Table 3-13), a difference that is not observed for vehicle speed during LSL trial encounters with VPTY=3.5 sec intersections (Table 3-10).

Scatter plots of paired, within-subject means from HSL trials for control versus test levels of vehicle speed, acceleration/deceleration, and braking pressure for VPTY=2 and 3.5 sec intersections are in Appendix N, Figures N-3 and N-4. The plots show the distributions of paired results for individual Ss that illustrate the basis for the paired-t test results in Table 3-13. Specifically, scatter plots in Figure N-3 for within-subject, paired control and test means by trial for VPTY=2 sec intersections show the following distributions: (1) for both vehicle speed (Fig. N-3A) and acceleration/deceleration (Fig. N-3B), more paired mean values lie below the LOI, indicating a greater number of Ss with higher mean values during control compared with test trials; and (3) for braking pressure, more paired mean values lie above the LOI (Fig. N-3C), indicating a greater number of Ss with higher mean values during test compared with control trials.

Conversely, scatter plots in Appendix N for within-subject, paired control and test means from HSL trials for VPTY=3.5 sec intersections show that distributions of SDP measures of vehicle acceleration/deceleration (Fig. N-4B), and braking pressure (Fig. N-4C) have more or less even distributions of paired mean values about the LOI. In the scatter plot distribution of paired mean values vehicle speed at VPTY=3.5 sec intersections (Fig. N-3A), however, there are more paired mean values lie below the LOI, indicating a greater number of Ss with higher mean values during control compared with test trials.

3.3.3.6. SDP Results for HSL Trials and 'Stop Likely' VPTY Intersections

Two-tailed paired-t test results for comparison of within-subject, control versus test mean levels of vehicle speed, acceleration/deceleration, and braking pressure measures of SDP, for VPTY=5 sec intersection data acquired during HSL trials, are presented in Table 3-14. As described earlier (Fig. 3-3), almost all Ss stopped at VPTY=5 sec intersections during HSL trials. Results in Table 3-14 show that at these intersections, differences in paired, within-subject control versus test means for measures of vehicle speed, acceleration/deceleration, and braking pressure are not statistically significant at the $p<.05$ level. However, the difference between control and test trials for paired, within-subject means of vehicle acceleration/deceleration is marginally significant at the $p<0.1$ level, with mean control levels lower than test levels.

Scatter plots of paired, within-subject means from HSL trials for control versus test levels of vehicle speed, acceleration/deceleration, and braking pressure for VPTY=5 sec intersections are in Appendix N, Figure N-5. The plots show the distributions of paired mean results for individual Ss that illustrate the basis for the paired-t test results in Table 3-14. Specifically, scatter plots in Figure N-5 for paired mean values of vehicle speed (Fig. N-5A), acceleration/deceleration (Fig. N-5B), and braking pressure (Fig. N-5C) at VPTY=5 sec intersections show that distributions of these measures have more or less even distributions of the values about the LOI.

3.4. POST-TEST QUESTIONNAIRE RESULTS

This section describes results for the PTQ (Appendix E), which Ss completed after completing their second experimental session (Section 2.3.5). Subsections below describe results for PTQ responses as follows: (1) S opinions about AWFs (Section 3.4.1); (2) S self-reports on driving behavior at signalized intersections (Section 3.4.2); and (3) S narrative responses (Section 3.4.3).

3.4.1. Subject Opinions About and Driving Experiences With AWFs

PTQ Q9-Q20 ask Ss about their past driving experiences with, and their opinions regarding, AWFs (Appendix E). Figures 3-12 through 3-23 are histograms showing the distribution of S

Table 3-14. Within-subject, control versus test two-tailed paired t-test results for means of vehicle speed, acceleration/deceleration, and braking pressure SDP measures by trial, HSL trials, VTPY=5 sec intersections. See text for description of approach used for paired t-test analysis.

SDP DEPENDENT MEASURE	AWF CONDITION/ TWO-TAILED, PAIRED-t TEST STATISTIC	CONTROL VS TEST FOR 5 sec VPTY INTERSECTIONS, HSL TRIALS	
		Control	**Test**
Vehicle Speed (m/sec)	Mean	19.39587	19.62817
	SD	1.27831	2.05552
	N	24	
	Pearson Correlation	0.58565	
	Hypothesized Mean Difference	0	
	df	47	
	t-stat	-0.96502	
	t-crit (two-tailed)	2.011739	
	p (two-tailed)	0.339473	
Vehicle Acceleration/ Deceleration (m/sec/sec)	**AWF CONDITION/ STATISTIC**	**Control**	**Test**
	Mean	-0.35644	-0.3216
	SD	0.10298	0.13653
	N	24	
	Pearson Correlation	0.487376	
	Hypothesized Mean Difference	0	
	df	47	
	t-stat	-1.93618	
	t-crit (two-tailed)	2.011739	
	p (two-tailed)	0.058872	

Table 3-14 (continued).

SDP DEPENDENT MEASURE	AWF CONDITION/ TWO-TAILED PAIRED-t TEST STATISTIC	CONTROL VS TEST FOR 5 sec VPTY INTERSECTIONS, HSL TRIALS	
		Control	**Test**
Braking Pressure (V)	Mean	0.079687	0.075247
	SD	0.02748	0.03146
	N	24	
	Pearson Correlation	0.372255	
	Hypothesized Mean Difference	0	
	df	47	
	t-stat	0.926906	
	t-crit (two-tailed)	2.011739	
	p (two-tailed)	0.358711	

responses for these 12 questions. The chi-squared test is used to assess the statistical significance of any non-uniformity observed in the distribution of responses for each question---chi-squared probabilities are indicated in the legends to the figures.

Q9 is preceded by a statement noting for the respondent that during some of the simulated driving trials, the traffic signal was preceded by an AWF. This is the first time during the study that AWFs are explicitly mentioned in information provided to Ss, only after Ss have completed their second experimental session and have been asked what the purpose of the study was. As noted previously, Ss were led to believe prior to their first experimental session that control of vehicle speed was the ostensible purpose of the study (Section 2.3). Prior to administration of the PTQ, awareness by Ss of AWFs occurred exclusively as a result of visual observations made during completion of half of the simulated driving trials. These considerations suggest that Ss did not necessarily anticipate PTQ questions about AWFs, and that S responses to PTQ questions concerning AWFs therefore may be considered spontaneous and likely not based on any advance preparation or forethought.

PTQ Q9 asks respondents about past experience with encountering AWFs during actual driving. The responses to Q9 (Fig. 3-12) indicate that half of the Ss participating in the study previously encountered AWFs on a regular basis as part of their driving experience, whereas half did not. By chi-squared analysis, the non-uniform distribution of the responses is statistically significant ($p=.0137$). Keeping in mind the limited size of the sample population employed as Ss in the study, there are at least three interesting implications of these results. First, they suggest that routine driver familiarity with AWFs during actual driving is by no means universal. Second, they suggest that variability in prior S familiarity with AWFs may have contributed, as a confounding factor, to observed variability in different measures of SDP during S interaction with AWF intersections. However, they also suggest that possible effects of AWFs observed in the study are not biased, in a consistent manner across all Ss, by prior S familiarity with AWFs.

PTQ Q10 through Q20 (Appendix E) solicit respondent opinions about AWFs using a Likert scale, with a response of '1' denoting that the respondent strongly disagrees, and that of '5 denoting that the respondent strongly agrees, with the question. These questions ask respondents to comment on how their driving performance is influenced by interacting with AWFs as they approached signalized intersections. It is <u>not</u> specified whether actual or SDP is being addressed by each of these questions. Therefore, it is reasonable to suggest that responses to the questions may apply to actual as well as simulated driving experience.

PTQ Q11, and Q15-Q18, solicit S opinions about how AWFs influence their stopping behavior at signalized intersections. More than half of Ss agree or strongly agree with the statement that AWFs help them stop at traffic signals (PTQ Q11, Fig. 3-14, p=.063), a non-uniform distribution of responses that is statistically significant at the 0.1, but not at the .05, level. Responses to PTQ Q16 and Q18 provide insight into the marginal significance of non-uniform responses provided to Q11.

Responses to PTQ Q15 and Q17 are consistent, in that the preponderance of Ss disagree with the statement that they speed up for traffic signals with AWFs (PTQ Q15, Fig. 3-18, p<001), whereas the preponderance of Ss agree with the statement that AWFs encourage them to slow down when approaching traffic signals (PTQ Q17, Fig. 3-20, p=.0266). However, Ss respond in a non-consistent manner when asked about how AWFs influence their stopping behavior when approaching traffic signals at different speeds. The preponderance of Ss agree with the statement that AWFs help them stop at traffic signals when driving fast (PTQ Q16, Fig. 3-19, p<.001), whereas S responses to the statement that AWFs help them stop at traffic signals when driving slow are mixed (PTQ Q18, Fig. 3-21, p=.123). The pattern of these responses suggests that the perceived benefit of AWFs in aiding stopping behavior (PTQ Q11, Fig. 3-14) is actually somewhat speed-dependent, in that 62.5 pct of Ss agree or strongly agree that during high speed driving, AWFs benefit stopping (PTQ Q16, Fig. 3-19), whereas only 21 pct of respondents share these sentiments under slow driving conditions (PTQ Q18, Fig. 3-21). These PTQ results are aligned with those from visual observations of stopping behavior, which show for the VPTY=2 and VPTY=3.5 sec intersections that the percentages of Ss stopping at intersections are higher for the HSL compared with the LSL trials (Fig. 3-3).

PTQ Q10, Q12-Q14, and Q20 ask Ss to respond to generic statements about their interaction with AWFs. The preponderance of Ss disagree or strongly disagree with the statement that AWFs are distracting (PTQ Q10, Fig. 3-13, p<.001). Ss provide mixed responses to the statement that they did not pay much attention to the AWFs (PTQ Q12, Fig. 3-15, p=.199), although over half of respondents disagree or strongly disagree with this statement. All but 3 Ss agree or strongly agree that they like AWFs (PTQ Q14, Fig. 3-17, p<.001), and over half of Ss agree or strongly agree that most traffic signals should be preceded by AWFs (PTQ Q13, Fig. 3-16, p=.00363). All but 2 Ss disagree or strongly disagree with the statement that they dislike AWFs (PTQ Q20, Fig. 3-23, p<.0001). These responses are consistent in indicating that most Ss like AWFs, do not find them distracting, and feel that they should be installed at most signals. However, responses to PTQ Q12 indicate that just because Ss are favorably disposed towards AWFs does not always mean that they pay attention to them while driving.

Over half of Ss agree or strongly agree with the statement that the purpose of an AWF is inherently obvious (PTQ Q19, Fig. 3-22, p=.0317). Thus, although half of Ss participating in the study had previously encountered AWFs either rarely or not at all during driving (PTQ Q9, Fig. 3-12), only 5 Ss disagree with the statement that the purpose of AWFs is obvious (PTQ Q19, Fig. 3-22). This pattern of responses supports the conclusion that AWFs have good human-centered design, a design that appears to support establishment of an accurate conceptual model [15] of the actual purpose of AWFs among most drivers.

3.4.2. Subject PTQ Self-Reports on Driving Behavior at Signalized Intersections

Q5 through Q7 of the PTQ (Appendix E) solicit S self-reports on their driving behavior at signalized intersections, in terms of what a driver is supposed to do when a traffic signal turns yellow (Q5), and also in terms of how the S interacts with a green traffic signal when approaching on a roadway at either high (Q6) or low (Q7) speed. Figures 3-24 through 3-26 are histograms showing the distribution of S responses for these 3 questions. For each of the 3 questions: (1) there are a series of parts, explained below; and (2) the number of responses exceeds the number of respondents (N=24), because a S could answer more than one part; and (3) chi-squared probabilities are indicated in the legends to the figures.

PTQ Q5 asks Ss what they are supposed to when they approach a traffic signal and the signal turns yellow. The following 5 parts to Q5 indicate possible alternative driving behaviors in this situation---the behavior stipulated under Minnesota law is that listed in Part 5b:

- 5a - Always slow down, and try to stop at the intersection when the signal turns red;
- 5b - Always slow down, but only stop at the intersection if you can do so safely by the time the signal turns red;
- 5c - Proceed through the intersection, if you can do so before the signal turns red;

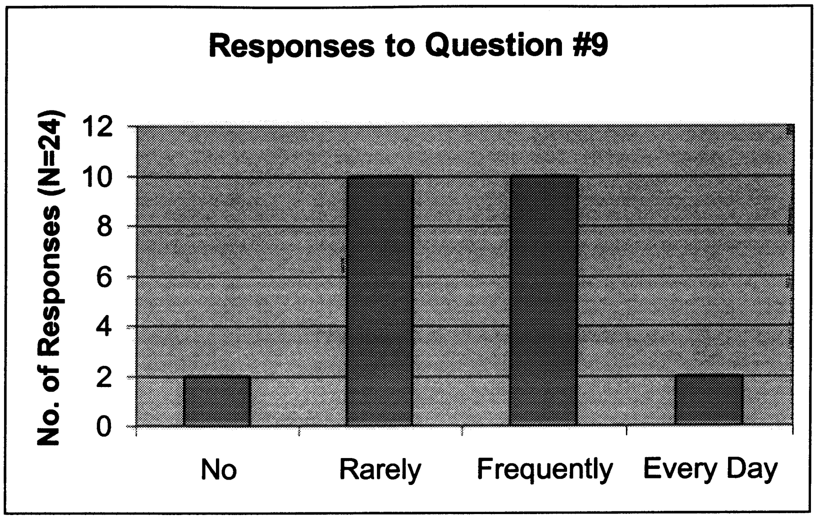


Figure 3-12. Distribution of responses to Q9 in PTQ: 'Have you ever encountered AWFs while driving before?' (chi-squared p=.0137).

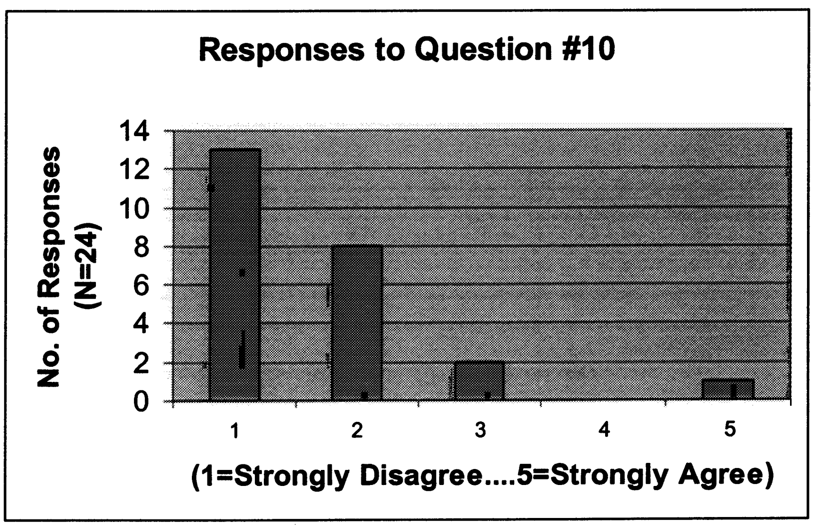


Figure 3-13. Distribution of responses to Q10 in PTQ: 'I found the AWFs distracting' (chi-squared p<.0001).

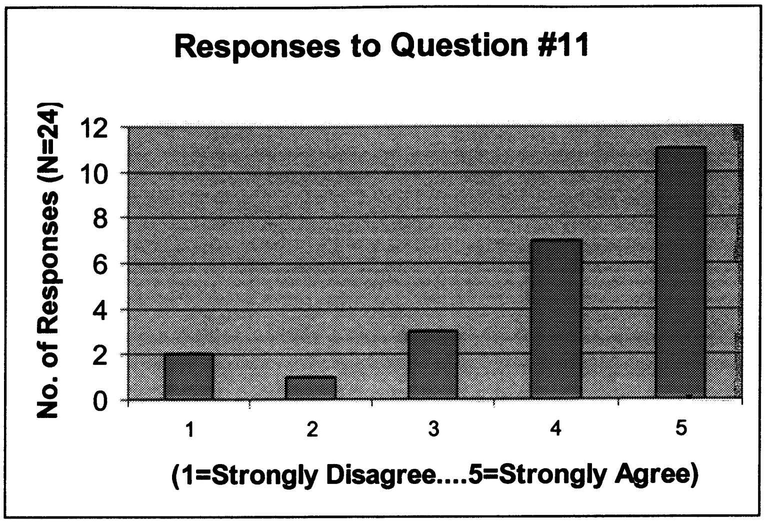


Figure 3-14. Distribution of responses to Q11 in PTQ: 'The AWFs helped me stop at the traffic signals' (chi-squared p=.0630).

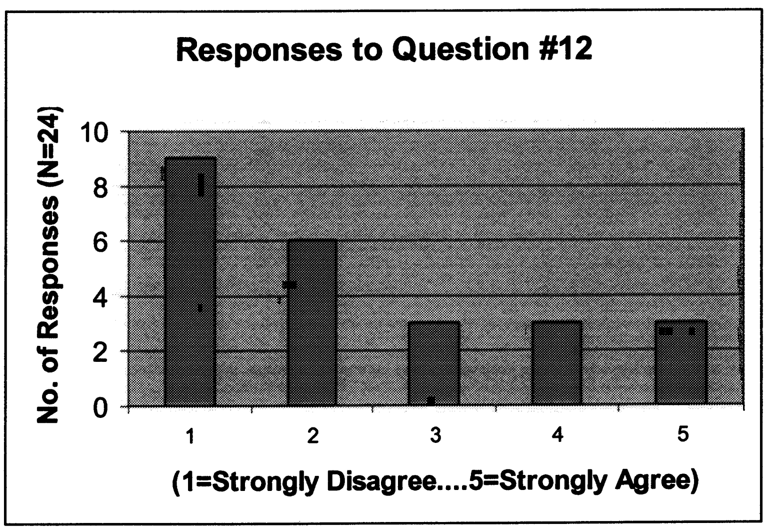


Figure 3-15. Distribution of responses to Q12 in PTQ: 'I didn't pay much attention to the AWFs' (chi-squared p=.199).

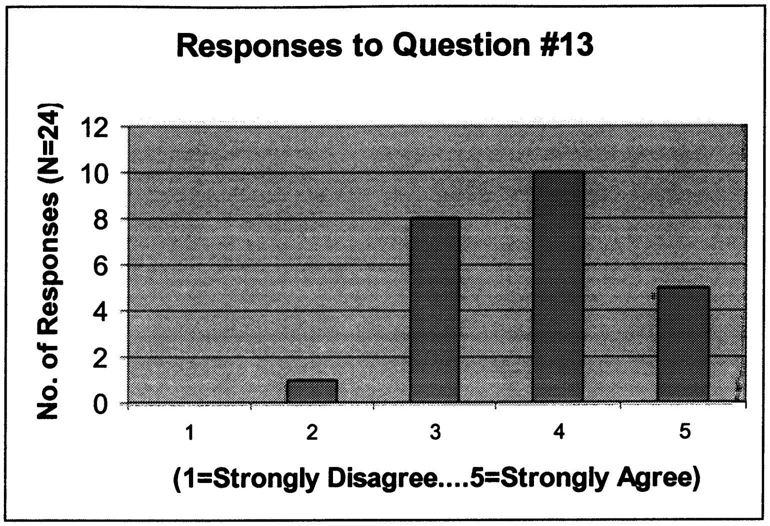


Figure 3-16. Distribution of responses to Q13 in PTQ: 'Most traffic signals should be preceded by AWFs' (chi-squared p=.00363).

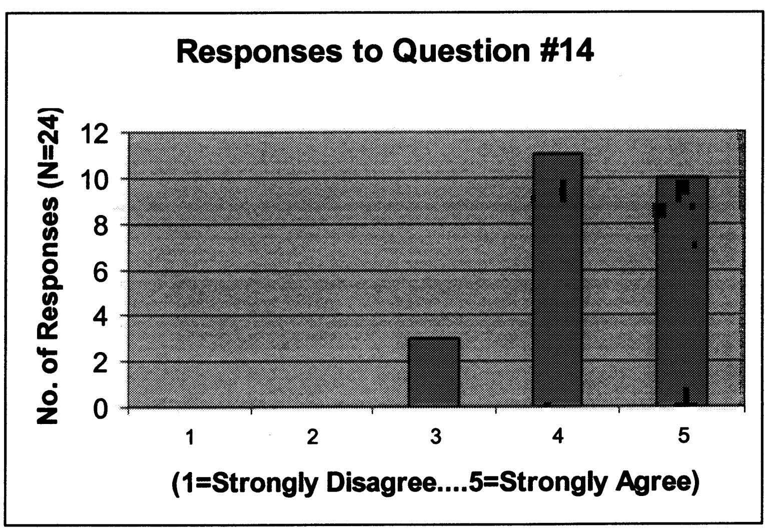


Figure 3-17. Distribution of responses to Q14 in PTQ: 'I like AWFs' (chi-squared p<.0001).

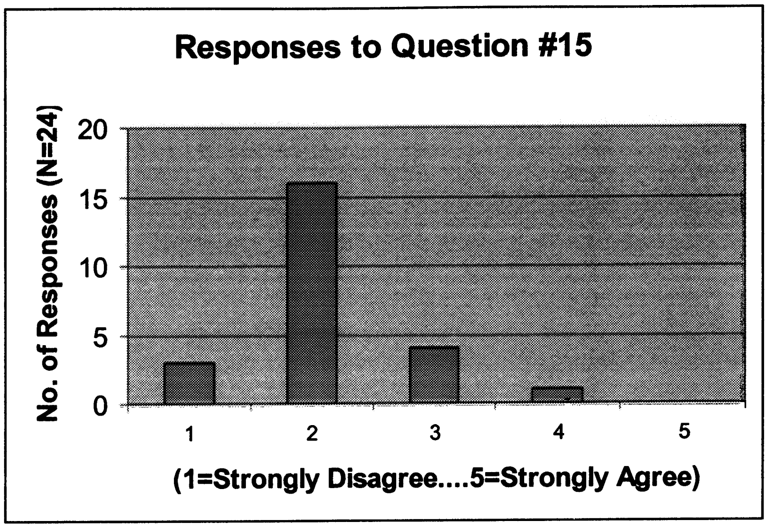


Figure 3-18. Distribution of responses to Q15 in PTQ: 'I tend to speed up for traffic signals with AWF warnings' (chi-squared $p<.000001$).

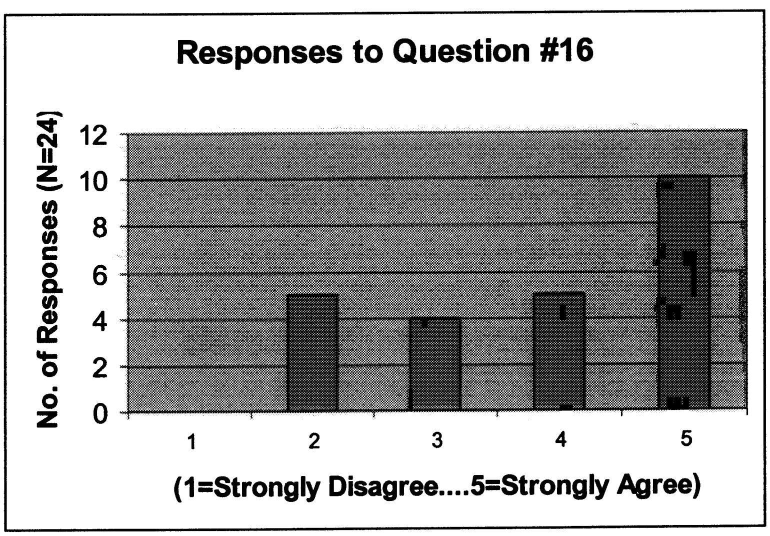


Figure 3-19. Distribution of responses to Q16 in PTQ: 'An AWF helps me to stop at traffic signals when I am driving fast' (chi-squared $p<.001$).

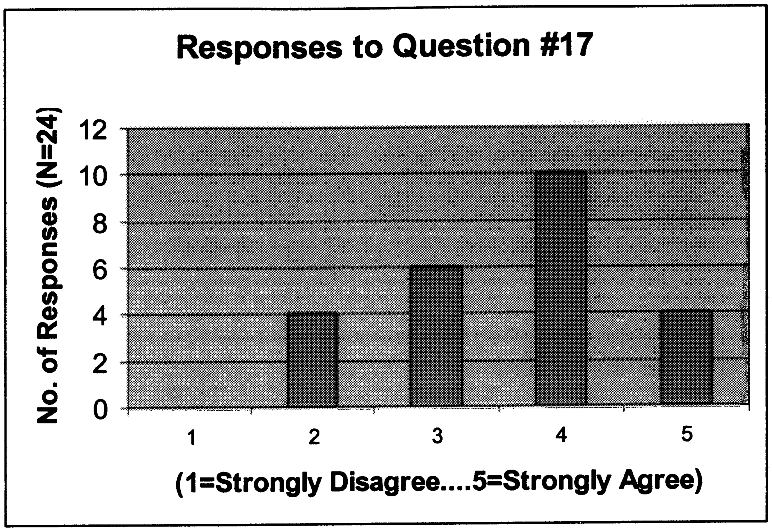


Figure 3-20. Distribution of responses to Q17 in PTQ: 'I tend to slow down for traffic signals with AWF warnings' (chi-squared p=.0266).

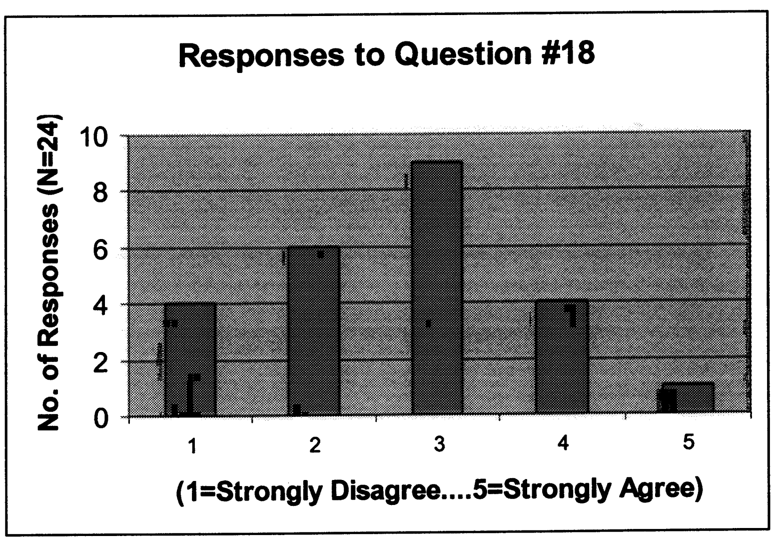


Figure 3-21. Distribution of responses to Q18 in PTQ: 'An AWF helps me to stop at traffic signals when I am driving slow' (chi-squared p=.123).

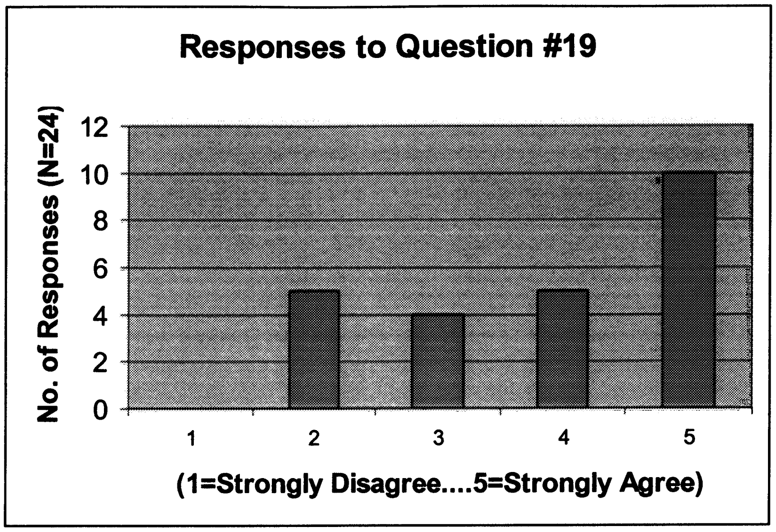


Figure 3-22. Distribution of responses to Q19 in PTQ: 'It is inherently obvious what the purpose of an AWF is' (chi-squared p=.0317).

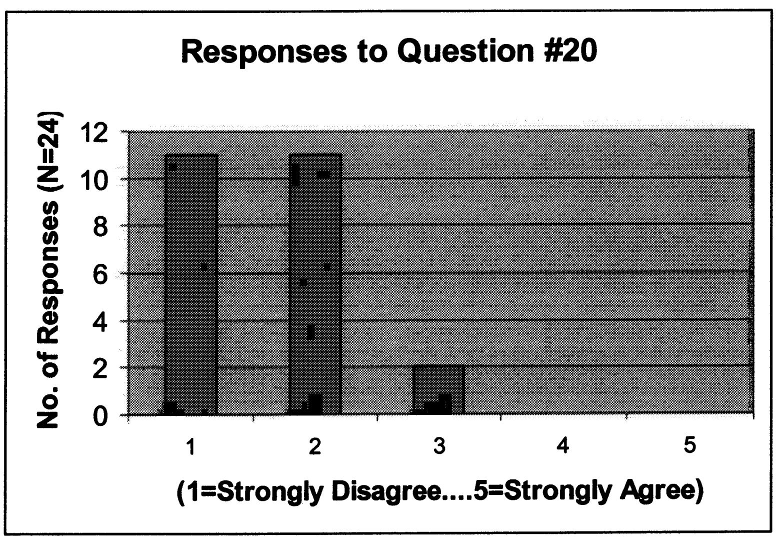


Figure 3-23. Distribution of responses to Q20 in PTQ: 'I dislike AWFs (chi-squared p<.0001).

- 5d - Maintain a constant speed, and proceed through the intersection if you can do so before the signal turns red;
- 5e - Speed up, and proceed through the intersection if you can do so before the red signal.

Figure 3-24 illustrates the distribution of S responses to PTQ Q5. There is at least one response to each part of the question except Part 5e. However, the responses are disproportionately distributed (chi-squared $p<.0001$), with Part 5b receiving over half (18) of the 34 responses. This result suggests that 75 pct of the 24 Ss are familiar with Minnesota law regarding stipulated driving behavior when approaching a traffic signal that turns yellow. Nevertheless, the fact that there are 10 more responses to the question than there are Ss also suggests variability, and/or uncertainty, in understanding among study participants regarding appropriate driving behavior when approaching a traffic signal that turns yellow.

PTQ Q6 asks Ss what they tend to do when they approach a green traffic signal on a roadway with a high SL. The following 6 parts to Q6 indicate possible alternative driving behaviors in this situation:

- 6a - Always slow down, and prepare to brake to a stop if the signal turns yellow;
- 6b - Maintain a constant speed, but prepare to brake to a stop if the signal turns yellow;
- 6c - Speed up, but prepare to brake to a stop if the signal turns yellow;
- 6d - Always slow down, but speed up through the intersection if I can do so before the signal turns red;
- 6e - Maintain a constant speed through the intersection if I can do so before the signal turns red;
- 6f - Speed up so that I can make it through the intersection before the signal turns red.

Figure 3-25 illustrates the distribution of S responses to PTQ Q6. There is at least one response to each part of the question. However, the responses are disproportionately distributed (chi-squared $p=.000129$), with Parts 6b and 6e receiving the most responses. Specifically, 25 of the total of 35 responses favor the behavior of maintaining a constant speed and either preparing to brake when the signal turns yellow (Part 6b), or trying to traverse the intersection at constant speed before the signal turns red (Part 6e). As with Q5, the fact that there are 11 more responses to Q6 than there are Ss suggests variability, and/or uncertainty, in driving behavior adopted by study participants when

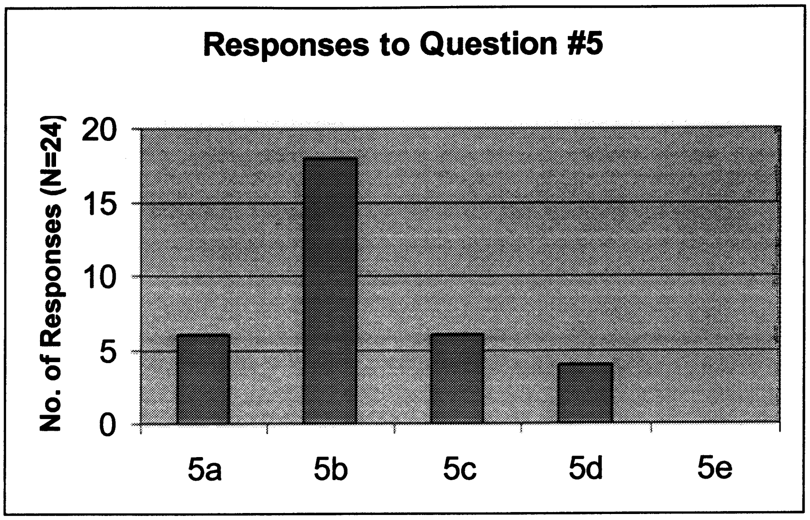


Figure 3-24. Distribution of responses to Q5 in PTQ. Refer to text for meanings of parts 5a through 5e of question. Number of responses exceeds number of Ss (N=24), because a S could answer more than one part. Chi-squared p<.0001.

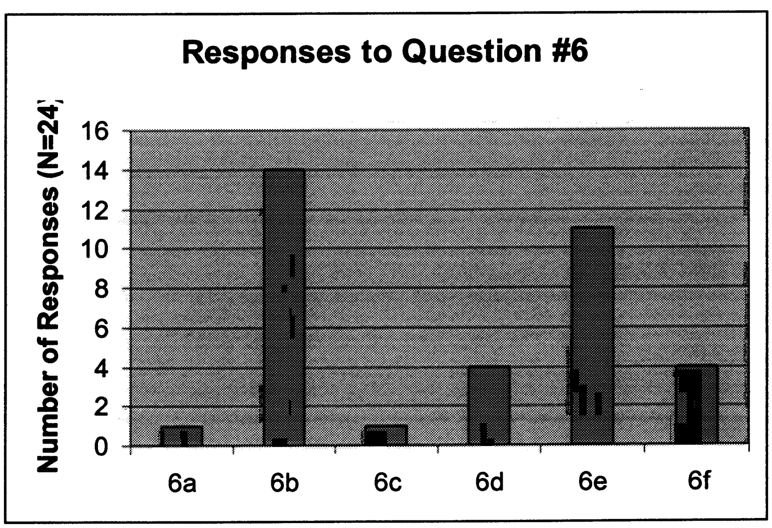


Figure 3-25. Distribution of responses to Q6 in PTQ. Refer to text for meanings of parts 6a through 6f of question. Number of responses exceeds number of Ss (N=24), because a S could answer more than one part. Chi-squared p=.000129.

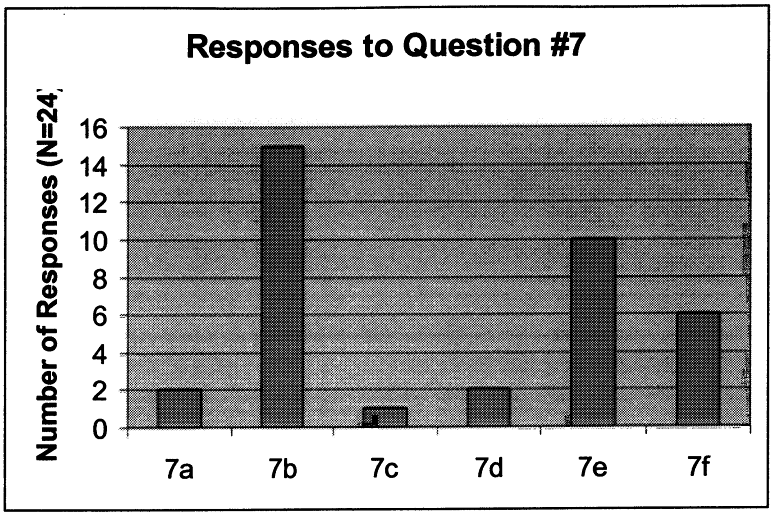


Figure 3-26. Distribution of responses to Q7 in PTQ. Refer to text for meanings of parts 7a through 7f of question. Number of responses exceeds number of Ss (N=24), because a S could answer more than one part. Chi-squared p=.000104.

approaching a green traffic signal on a roadway with a high SL.

PTQ Q7 asks Ss what they tend to do when they approach a green traffic signal on a roadway with a lower SL. The following 6 parts to Q7 indicate possible alternative driving behaviors in this situation, which are identical to those specified for Q6:

- 7a - Always slow down, and prepare to brake to a stop if the signal turns yellow;
- 7b - Maintain a constant speed, but prepare to brake to a stop if the signal turns yellow;
- 7c - Speed up, but prepare to brake to a stop if the signal turns yellow;
- 7d - Always slow down but, if possible, speed up through the intersection before the signal turns red;
- 7e - If possible, maintain a constant speed through the intersection before the signal turns red;
- 7f - Speed up to make it through the intersection before the signal turns red.

Figure 3-26 illustrates the distribution of S responses to PTQ Q7. The results essentially parallel those for Q6. That is, there is at least one response to each part of the question. However, the responses are disproportionately distributed (chi-squared p=.000104), with Parts 7b and 7e receiving the most responses. As with behavior on high SL roadways (Q6), these responses indicate that Ss on lower SL roadways also favor the behavior of maintaining a constant speed and either preparing to brake when the signal turns yellow (Part 7b), or trying to traverse the intersection at constant speed before the signal turns red (Part 7e). Again, the fact that there are 12 more responses to Q7 than there are Ss suggests variability, and/or uncertainty, in driving behavior adopted by study participants when approaching a green traffic signal on a roadway with a lower SL.

Responses to PTQ Q5-Q7 are generally consistent in indicating that most Ss favor cautious behavior when approaching a traffic signal that is either yellow (Fig. 3-24) or green (Figs. 3-25, 3-26). That is, the most prevalent response to Q5 specifies always slowing down when approaching a yellow signal, and the most prevalent responses to Q6 and Q7 specify maintaining a constant speed when approaching a green signal. However, there is a small but interesting disparity in responses to Q5, compared with those to Q6 and Q7. No respondent favors speeding up when approaching a traffic signal that turns yellow (Fig. 3-24, Part 5e). Conversely, a total of 10 responses for Q6 and Q7 specify speeding up when approaching a green signal at either a high or a lower SL (Fig. 3-25, Part 6f; Fig. 3-26, Part 7f).

Keeping in mind the limited size of the sample population employed as Ss in the study, there are at least three interesting implications of the results for PTQ Q5-Q7. First, they suggest that there is some consistency, but a lack of complete uniformity, in the manner in which Ss participating in the study interact with either yellow or green signals. Second, they suggest that the variability observed with such interaction may have contributed, as a confounding factor, to observed variability in different measures of SDP during S interaction with intersections during the study. However, they also suggest that possible effects of AWFs observed in the study were not biased, in a consistent manner across all Ss, by uniform S behavior while interacting with yellow and green traffic signals.

3.4.3. Subject PTQ Narrative Responses

After completing their second experimental session, each S was given two opportunities to provide narrative responses about the study. First, before completing the PTQ, each S was asked to respond verbally to a question from the researcher as to what the purpose of the study had been. Subsequently, while completing Q8 of the PTQ, each S was asked to explain their understanding of the purpose of AWFs. S narrative responses to these two questions are summarized in Tables 3-15 and 3-16. In addition, after completing the PTQ, some Ss volunteered additional comments about the study and AWFs. These additional comments are summarized in Table 3-17.

Table 3-15. Subject verbal responses to the question, 'Please explain what you believe the purpose of the study is.'

Subject	Verbal Response Regarding Purpose of Study
1	To evaluate AWFs and how they help drivers slow down at different distances from intersections.
2	Half the trials were with flashing lights, half were without. Therefore, the purpose is to see how drivers adjust their speed, braking etc. at intersections with these devices.
3	Study of people interacting with traffic lights---do they speed through them or slow down.
4	To study how drivers control their speed.
5	To show how you adjust your speed at traffic signals to achieve target time.
6	Study of flashing lights before signals.
7	To study how people control their speed at different speed limits when they interact with traffic signals.
8	To study how people behave with flashing lights.
9	To study the precision of driver decision-making at traffic signals and with controlling vehicle speed.
10	To help the Department of Transportation improve safety by improving timing of yellow lights.
11	To study how well you can control your time.
12	To study how well you can adjust your time.
13	To study the difference between signals with flashing lights, and signals without.
14	To study the tendency of drivers to stop at traffic lights and how that affects time.
15	The study had something to do with stop lights.
16	I don't know. Maybe how well you perceive your speed and your total time.
17	To study driver reaction to stop lights and how that affects your time.
18	To study how the flashing lights prior to the intersection affect whether you stop or not.
19	To study how people react to different traffic conditions at different speeds.
20	To study driver concentration during driving, and how well drivers obey laws.
21	To study my reaction to intersections - speeding up, slowing down, etc.
22	I think the simulation model is a road around here. I noticed that some trials had flashing lights, some didn't. I think the study has something to do with how the flashing lights affected driving.
23	The study has something to do with stop lights. Does it have something to do with those flashing lights?
24	To study driver estimation of elapsed time.

Verbal responses summarized in Table 3-15 indicate that only 8 of 24 Ss (33.3 pct) accurately recognize that the purpose of the study is to assess the influence of AWFs on driver behavior at intersections. The remaining 16 Ss believe that the study deals with how drivers interact with traffic signals, and/or how well they are able to estimate and control their time and/or speed during a trial.

Table 3-16. Narrative responses to PTQ Q8: 'Please explain the purpose of AWFs, as you understand what their purpose is.'

Subject	Narrative Response to Q8
1	'To notify the driver that the light will change to yellow before the driver will reach the intersection, if the driver is going the speed limit.'
2	'To warn that the light will be turning, and this will give advance warning to slow down.'
3	'To warn you that stop lights are ahead and to be prepared to stop.'
4	'Notifies drivers of controlled intersection ahead - typically used in areas of obscured vision (hills/turns) or problem areas where accidents frequently occur.'
5	'To warn that you will have to stop at the next traffic light.'
6	'To warn drivers to prepare to stop.'
7	'The light ahead is going to turn yellow so be prepared to slow down and stop.'
8	'To indicate that you will have to stop at the stop light ahead.'
9	'As a caution that lights ahead will turn red by the time you get to them, if you're maintaining the speed limit or going slower.'
10	'To warn a driver that if they are going the speed limit the light will be red when you get to the intersection, so slow down [because] you will have to stop soon.'
11	'They flashed when the light was about to turn yellow, to warn you to slow down/stop ahead.'
12	'They give a forewarning as to what the signal lights are going to do so you can adjust accordingly.'
13	'Warn you that you may hit a yellow or red light if you are moving at the posted speed.'
14	'I think that the purpose of AWFs is to warn the driver that an intersection is up ahead. Probably to make the driver aware that he/she might need to stop in the near future.'
15	'They tell you the light is going to turn red soon.'
16	'To warn drivers that the light is going to change and if you can see the lights flashing you should prepare to stop.'
17	'AWFs alert a driver that the signal lights will soon be turning yellow. The AWFs in this experiment gave me more of an assurance that the light was going to be turning yellow when the AWFs were activated.'
18	'To alert the driver that the light will be changing before they will cross the intersection.'
19	'The purpose is to get high-speed traffic to slow down and be aware of oncoming yellow and red lights.'
20	'I didn't perceive them as being there for any reason, just that they were there. I am not familiar with them, but if I were educated as to their purpose I think they would help me drive better.'
21	'To indicate to the driver that the traffic signal will soon be turning yellow and to be prepared to stop.'
22	'AWFs give you an advanced warning so that you will know to slow down for the signals ahead.'
23	'To warn drivers of light change ahead, from green to red.'
24	'To alert drivers that there are traffic lights ahead.'

Table 3-17. Additional comments volunteered by some Ss about the study and about AWFs, after completing the PTQ.

Subject	Voluntary Comment
1	S familiar with AWFs along Minnesota T.H. 110. Upon first moving here, S believed that drivers would speed up along Minnesota T.H. 110 when encountering AWFs, but observation is that AWFs cause drivers slow down along Minnesota T.H. 110. S likes AWFs.
5	I like AWFs. They are along Minnesota T.H. 110, where I live. If the AWF isn't flashing I don't slow down, but if it is, I know that I should. AWFs help me stop safely. To make it through a signal if you see the AWF start to flash, you have to drive unsafely.
7	I really like AWFs. They should be at every signal.
8	In Ohio, traffic signals turn red just after AWFs start flashing - you never could get through.
10	Father-in-law of S is traffic engineer.
20	I had no idea what the AWFs were for. I didn't even notice them. Are they on the roads?

Since introductory instructions to each S specified the latter explanation as the ostensible purpose of the study, results in Table 3-15 indicate that the true purpose of the study (e.g., study of AWFs) was successfully disguised for two-thirds of study participants, a result that again supports the ecological validity of the study (Section 4-1).

Among those Ss that do perceive the true purpose of the study (Table 3-15), all but one refer to the AWFs as 'flashing lights,' and only one (S1) explicitly uses 'AWF' in the verbal response. Keeping in mind the limited size of the sample population employed as Ss in the study, this result suggests that the term 'advanced warning flasher' may not be commonly known to Minnesota drivers.

Nevertheless, results in Table 3-16 indicate that 23 of 24 Ss understand what the purpose of an AWF is. Four of these Ss even point out that the warning benefit of AWFs is dependent upon the driver approaching the intersection at or below the posted SL. Only one S (Table 3-16, S20) indicates a lack of understanding of the nature and purpose of AWFs. Given that half of the Ss participating in the study had only limited previous exposure to AWFs during actual driving (Fig. 3-12), results in Table 3-16 again underscore the good human-centered design of AWFs, in that the design appears to support an accurate conceptual model [15] of the actual purpose of AWFs among Ss with a wide range of previous experience with AWFs.

Comments volunteered by Ss after completing the PTQ (Table 3-17) reveal an interesting disparity. Comments of S1, S5, S7, and S8 in Table 3-17 suggest that these Ss had experience with and understanding of AWFs that preceded their participation in the study. Nevertheless, two of the Ss (S5 and S7) did not divine the true purpose of the study (Table 3-15), suggesting that prior understanding of AWFs may not have biased S interaction with AWF intersections during the study.

CHAPTER 4
DISCUSSION AND CONCLUSIONS

4.1. INTRODUCTION

This study carried out a HF/E analysis of the effects of AWFs on SDP and behavior, during driver interaction with simulated signalized intersections as they traversed a SDTE. The objectives of the research are to: (1) clarify how driver control of vehicle speed and braking may be influenced by AWF presence/absence, SL, and VPTY level, during driver interaction with signalized intersections; (2) use a subjective response questionnaire to assess the familiarity of each S with, and S opinions regarding, use of AWFs at signalized intersections; and (3) use findings from the research to target possible traffic engineering design improvements to AWF-intersection systems that may benefit traffic safety as well as AWF utilization decision-making.

The research is intended to address the following questions; (1) how is SDP influenced by the presence, as compared with the absence, of AWFs at signalized intersections? and (2) can results from the study be used to target possible strategies for improving the traffic engineering design of AWF-intersection systems? The results therefore should improve our understanding of the human and societal implications related to use of AWFs at signalized intersections, in relation to both driving performance and traffic safety. Sections below address: (1) the ecological validity and limitations of the study; (2) summary and discussion of AWF effects on SDP documented by observations made during the study; and (2) conclusions supported by study results.

4.2. ECOLOGICAL VALIDITY AND LIMITATIONS OF STUDY

In the context of the present study, the term 'ecological validity' refers to the degree to which driver behavior and performance observed during simulated driving accurately predicts that which might be expected to occur under actual, real-world driving conditions. As noted above, the purpose of the study is to ascertain how driver interaction with signalized intersections may be influenced by AWFs. Clearly, in order to be able to generalize study findings and conclusions to actual driving conditions, the study should have a reasonable degree of ecological validity.

It should be kept in mind that observations of driver interaction with AWFs under real-world driving conditions were not made during this study. Therefore, conclusions about ecological validity summarized below are not based on a case-control design, in which observations under actual versus SDP are compared. Rather, the conclusions represent informed judgment that observations made during the study might also reasonably be expected to occur under actual driving conditions.

With this limitation in mind, a number of lines of evidence gathered during the study support the conclusion that the study was successful in achieving a moderate to high level of ecological validity. Specifically, the following observations of simulated driving behavior and performance may be cited to suggest that comparable driving behavior and performance would be expected under real-world conditions.

1. Stopping behavior. Results in Figure 3-3 indicate that: (1) almost no stops are observed for either SL at intersections with the all green and 0 sec VPTY levels; (2) the percentages of intersections at which stops occur increase progressively for VPTY=2, VPTY=3.5, and VPTY=5 sec intersections; and (3) over 90 pct of Ss stop at VPTY=5 sec intersections, across all SDTE and SL conditions. These observations indicate that the greater the VPTY level for a given intersection, the more likely it is that Ss will stop at the intersection, regardless of SDTE and SL condition. Comparable stopping behavior might be expected under actual driving conditions.
2. Stopping behavior. Based on ESDT results (Fig. 3-8), relative to control intersections a mixed pattern of both more cautious and riskier driving behavior is observed at AWF intersections, a pattern comparable to that observed at real-world AWF intersections.
3. Dangerous stops. Results in Figure 3-5 indicate that, regardless of SDTE and SL condition, almost all of the dangerous stops occur at the VPTY=2 sec level. Given that 2 sec represents the VPTY level for which the vehicle is both just inside the decision zone (Table 1-3) and close to the intersection, dangerous stops might be expected to occur during actual driving under similar circumstances when the yellow light is actuated.
4. Inconsistent stops. Results in Figure 3-7 indicate that, across all 4 SDTE conditions, the preponderance of inconsistent S stopping behavior occurs at intersections with VPTY levels of 3.5 and 2 sec. Respectively, these 2 VPTY levels are within and just inside of the decision zone (Table 1-3). During actual driving, inconsistent stopping behavior might also be expected to

occur with the vehicle similarly positioned when the yellow light is actuated.

5. Simulated driving performance. Although SDP results (Section 3.3) offer some unanticipated surprises, in general they broadly support the ecological validity of the study. Specifically, as might be expected during actual driving, Ss in this study under both SL conditions: (1) rarely decelerated, braked, and stopped at VPTY=AG and 0 sec intersections (Sections 3.3.3.1, 3.3.3.4); (2) almost always decelerated, braked, and stopped at VPTY=5 sec intersections (Sections 3.3.3.3, 3.3.3.6); and (3) displayed variable acceleration/deceleration, braking and stopping behavior at VPTY=2 and 3.5 sec intersections (Sections 3.3.3.2, 3.3.3.5).
6. Lack of recognition by over half of Ss of true purpose of study. Verbal responses in Table 3-4 indicate that only 33.3 pct of Ss accurately recognized that the purpose of the study was to assess the influence of AWFs on driver behavior at intersections. Introductory instructions to each S specified that control of vehicle time and speed during a trial was the ostensible purpose of the study. That the true purpose of the study was successfully disguised for two-thirds of study participants suggests that, at least for these Ss, their observed simulated driving behavior and performance was not unduly biased by an awareness of AWFs being the primary focus of experimental testing.

A number of limitations of the study should be addressed. First, as noted above, observations of driver interaction with AWFs under real-world driving conditions were not made during the study. Therefore, conclusions derived from study results pertaining to how S interaction with AWFs influences simulated driving behavior and performance cannot be directly validated by reference to real-world observations. This limitation means that generalization of study conclusions to the real world should be treated cautiously.

In this regard, a difference in how yellow lights are actuated between simulated intersections modeled in this study, and real-world intersections, should be explained. In Minnesota, yellow lights are actuated (using specifications listed in Table 1-2) on the assumption that every driver is driving at the 85^{th} percentile of the posted speed (Appendix A). In the simulation model, yellow lights are actuated based on computation of instantaneous vehicle speed, which is used to project when the vehicle will be in proximity to the intersection at the desired VPTY level (Section 2.3.2). The latter approach was adopted to ensure that for each of the 5 VPTY levels used, the VPTY time interval was the same for each subject.

There are a number of additional limitations to the experimental design based on simulation testing employed for the study. Older Ss were not included in the sample cohort. The small number of Ss evaluated (N=24) limits the generalizability of the results. The simulation testing approach is designed to assess the main effect of AWFs on simulated driving behavior and performance. Nevertheless, other confounding factors may have contributed to observed variability in the results obtained. For example, S unfamiliarity and lack of skill with simulated driving, and/or S anxiety associated with trying to traverse a SDTE within a ±30 sec window of a specified target time, also may have contributed to observed individual differences in dependent measures, apart from the AWF effect. Notable differences between real-world and simulated driving vehicle operation are a dramatically different 'feel' to the brakes, and more difficulty with depth perception, under the latter conditions.

Another confounding factor that also may have influenced the simulation testing results is the small delay in visual feedback of driver steering wheel movements that was present for each trial, and that may have degraded the ability of Ss to accurately maintain the position and trajectory of their vehicle on the roadway. This delay, inherent to the simulation technology employed for the study, results in a small temporal discrepancy between the timing of steering wheel adjustments by drivers, and the timing of updates to the projected visual image of the simulated environment to reflect those adjustments. Training sessions prior both experimental sessions were designed to help Ss acclimate to the simulated driving task before actual testing was initiated. The steering delay factor was present for all SDTE trials, and the order of SDTE trials was varied for different Ss. This design suggests that the delay factor should not have systematically biased any observed AWF effect. Nevertheless, the possible confounding influence of delay in visual feedback of steering wheel movements on the main effect of AWFs on study results cannot be ruled out.

4.3. SUMMARY OF AWF EFFECTS ON SIMULATED DRIVING PERFORMANCE

The purpose of this session is to summarize the major effects of AWFs on SDP. The analysis in the subsections below will focus on stopping behavior (Section 3.2.2) and vehicle speed (Section 3.3).

4.3.1. Effects of AWFs on Stopping Behavior

The discussion here focuses here on curious asymmetries observed in different measures of stopping behavior for results of LSL versus HSL trials. In particular: (1) for AWF intersections at VPTY levels of 2 and 3.5 sec, Ss stopped at a higher percentage of intersections during HSL trials (Fig. 3-3); (2) AWFs reduced dangerous stops during LSL trials but not during HSL trials (Fig. 3-4A), an effect that is not statistically significant but is nevertheless consistent with others summarized here; (3) AWFs reduced red light running during LSL trials but increased this behavior during HSL trials (Fig. 3-4B), an effect that is statistically significant and is largely attributable to differential results for the two SL conditions at VPTY=5 sec intersections (Fig. 3-6); and (4) relative to LSL trials, inconsistent stopping behavior was reduced for HSL trials at VPTY=2 sec intersections, but increased for HSL trials at VPTY=3.5 sec intersections, regardless of AWF condition (Fig. 3-7).

An interpretation for the latter finding is provided as part of the discussion in Section 4.3.2 below. Observations of the other asymmetries in stopping behavior at the two different SLs are not aligned with field observations of AWF effects on red light running conducted by Mn/DOT [10], which found no differential effects at different vehicle SLs. This raises the question of why these results are observed during the simulated driving conditions evaluated here.

The interpretation offered is that AWFs aid stopping decision-making at both SL conditions (Fig. 3-3), but that the effect is more pronounced during high SL trials because of the narrower decision zones for high SL intersections (Table 1-3). That is, provision of advance warning about yellow signal actuation is differentially beneficial in aiding stopping decision-making for intersections with smaller, relative to larger, decision zones. At the same time however, relative to LSL intersections, more Ss in this study also were encouraged by the narrower decision zone that they encountered during HSL intersections to engage in what can be termed aggressive or risk taking driving behavior, resulting in the dangerous stops and running red light results cited above. That similar results were not observed during field observations [10] suggests that: (1) the SDP results are an artifact arising from the artificial nature of simulated driving; (2) driving behavior of the relatively small number of Ss evaluated in this study is not representative of the real-world driving behavior of the driving public; and/or (3) results for both this and the field study [10] are valid, but the substantial differences in a broad range of study conditions account for the differences in results observed.

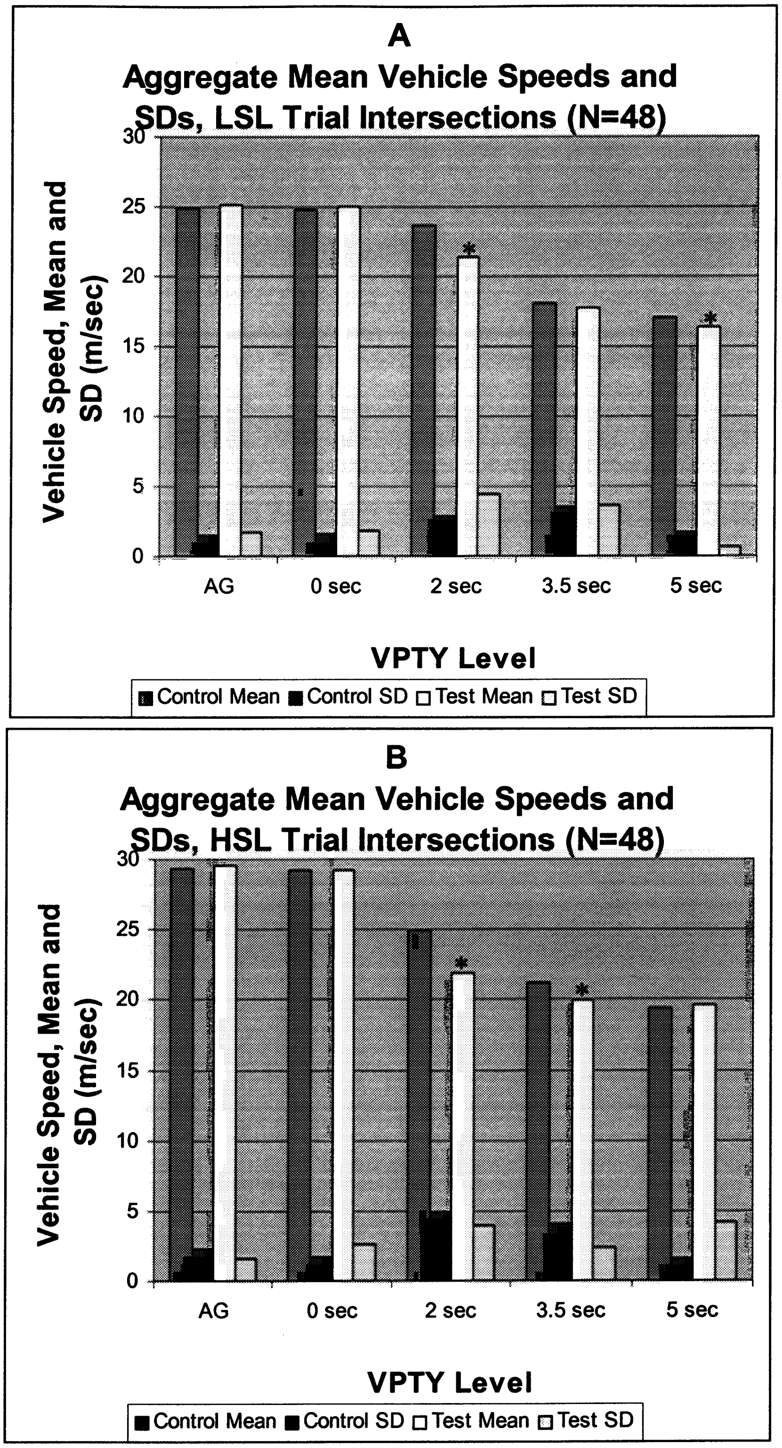


Figure 4-1. Results for vehicle speed aggregate means and standard deviations for LSL (A) and HSL (B) trials, based on speed data averaged across trial intersection blocks at the VPTY levels indicated on the X axis of each figure (means based on averages for 2 intersection blocks at each VPTY level per trial, N=48 control and test trials for 24 Ss at each SL level) (*=p<.05).

4.3.2. Effects of AWFs on Vehicle Speed

A synopsis of mean vehicle speed results in relation to SL and VPTY levels is provided below. The analysis confined to the dependent SDP measure of speed, given that the influence of AWFs on driver control of this SDP attribute may be assumed to represent a critical determinant of the putative driving safety benefit of these warning systems.

Post hoc analysis of univariate ANOVA results for vehicle speed in Figure 3-9 show that mean vehicle speed levels at VPTY=2 and 3.5 sec intersections are notably lower for test compared with control trials at either SL. These results, accompanied by those for vehicle acceleration/deceleration and braking in Figures 3-10 and 3-11, indicate that while approaching intersections with VPTY intervals for which uncertain decision-making in interacting with the Y light may be expected, drivers tend to display more cautious driving behavior when AWFs are present (e.g., lower vehicle speed and acceleration/deceleration, accompanied by more braking), relative to when AWFs are not present.

Figure 4-1 presents a more detailed analysis of this observation for vehicle speed. The figure shows aggregate mean results for vehicle speed for LSL (Fig. 4-1A) and HSL (Fig. 4-1B) trials, based on speed data averaged across trial intersection blocks at the VPTY levels specified on the X axis of each panel. The mean and SD data shown in the figure panels portray in graphical form the same data presented in Tables 3-9, 3-10, and 3-11 for the LSL trials, and Tables 3-12, 3-13, and 3-14 for the HSL trials.

Histograms in Figure 4-1 for both SL conditions show that, without exception, for intersections at which stopping is either advisable (VPTY=2 and 3.5 sec) or likely (VPTY=5 sec), the mean aggregate speed at test intersections is lower than that at control intersections. As shown by the asterisks in the Figure 4-1 panels, this difference is statistically significant in four cases: for VPTY=2 sec intersections in trials at either SL, for VPTY=3.5 sec intersections in HSL trials, and for VPTY=5 sec intersection in LSL trials. This pattern suggests that AWFs had a consistently salutary effect in reducing driver speed in approaching the Y signal.

Another noteworthy feature of the data in Figure 4-1, shown by the magnitudes of SDs to the means for speed at either SL, is that the highest variability in levels of vehicle speed across Ss occurs with intersections at VPTY levels of 2 and 3.5 sec. This is not unexpected, given that driver behavior in interacting with Y signals is predicted to be more uncertain at intersections with VPTY levels within or just beyond the decision zone, as contrasted with more consistent behavior predicted for interaction either with control intersections (VPTY=AG or 0 sec), or with 'stop likely' intersections (VPTY=5 sec).

However, there is an intriguing distinction in the patterns of S interaction with VPTY=2 sec versus VPTY=3.5 sec intersections. Specifically, findings in Figure 4-1 show that control versus test differences in mean vehicle speed are notably less for VPTY=3.5 sec intersections, as compared with VPTY=2 sec intersections. The VPTY level of 3.5 sec is solidly in the decision zone, whereas the VPTY level of 2 sec is just inside the decision zone (Table 1-3). Compared with the control trials, why do AWFs have less of an influence on reducing vehicle speeds at VPTY=3.5 intersections, compared with VPTY=2 sec intersections?

Possible insight into this question is provided by comparing the Pearson correlation coefficients for paired, within-subject means of test versus control levels of vehicle speed averaged for intersections at different VPTY levels for both LSL and HSL trials. Results are illustrated in Figure 4-2---this figure displays in graphic form the vehicle speed Pearson correlation coefficients listed in Tables 3-9, 3-10, and 3-11 for the LSL trials, and in Tables 3-12, 3-13, and 3-14 for the HSL trials.

Data in Figure 4-2 show that, for trials at either SL, the lowest correlation coefficients for paired, within-subject test versus control levels of vehicle speed occur at VPTY=2 sec intersections, whereas coefficients for VPTY=3.5 sec intersections are approximately four- to five-fold higher. The basis of this distinction is provided by scatter plots in Appendix M, Figures M-3 and M-4, for the LSL trials, and Appendix N, Figures N-3 and N-4, for the HSL trials. At VPTY=2 sec intersections, Figures M-3 (LSL trials) and N-3 (HSL trials) show that a disproportionate number of test versus control paired mean values for speed lie below the LOI, indicating (as noted previously) that compared with VPTY=2 sec test intersections, more Ss maintained a higher speed approaching control VPTY=2 sec intersections. This pattern of driving behavior at control versus test VPTY=2 sec intersections is associated with the almost flat LSR lines shown in each of these figures, and with the low correlation coefficients for this VPTY level displayed in Figure 4-2.

Conversely, at VPTY=3.5 sec intersections, Figures M-4 (LSL trials) and N-4 (HSL trials) show that the test versus control paired mean values for speed are more evenly distributed about the LOI, indicating (as noted previously) that compared with control VPTY=3.5 sec intersections, the

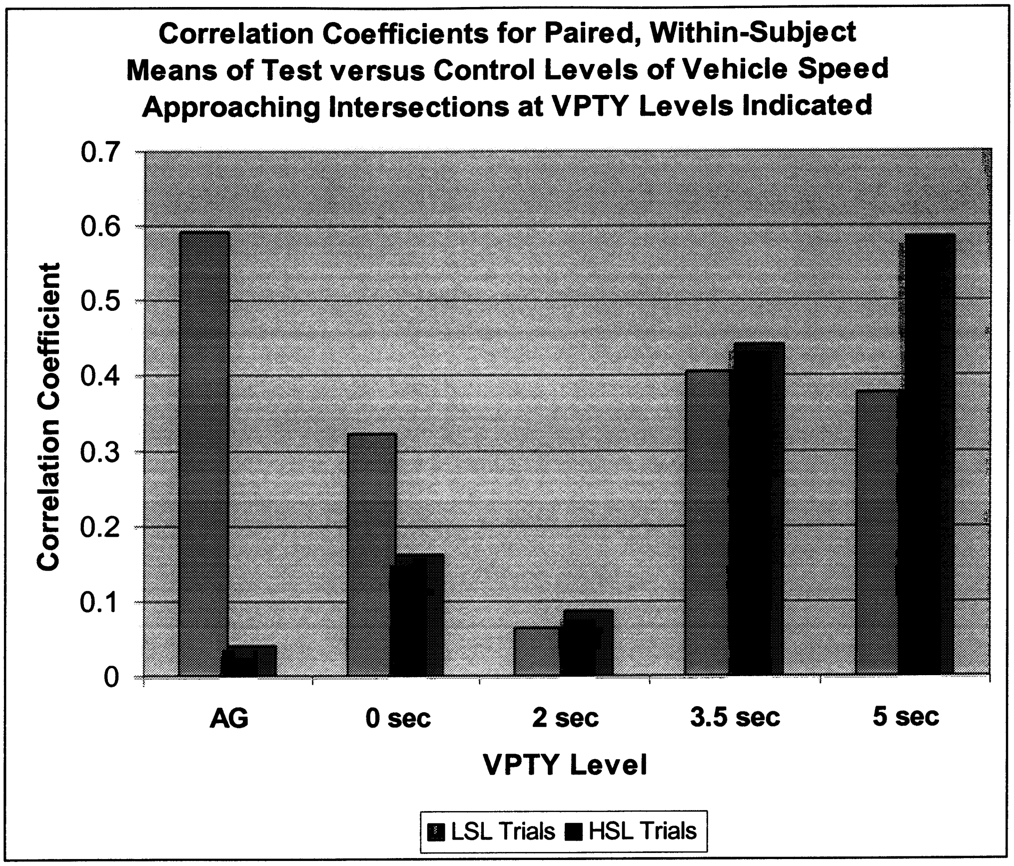


Figure 4-2. Pearson correlation coefficients for paired, within-subject means of test versus control levels of vehicle speed averaged for intersections at different VPTY levels for both LSL and HSL trials.

numbers of Ss choosing either to slow down or to speed up approaching test VPTY=3.5 sec intersections is more or less balanced. This more bimodal pattern of driving behavior is associated with slopes for LSR lines in each of these figures that are closer to the LOI slope of 1.0, and with the higher correlation coefficients for VPTY=3.5 sec intersections displayed in Figure 4-2.

The interpretation offered here of the markedly different patterns of driving behavior observed at VPTY=2 sec versus 3.5 sec intersections is that, at either SL, an advance warning provided with VPTY=2 sec intersections evokes forced choice responses among different Ss in interacting with the imminent Y signal that are likely to be cautious (e.g., slowing) in nature, whereas an advance warning provided with VPTY=3.5 sec intersections evokes a broader spectrum of dual choice responses among different Ss in interacting with the imminent Y signal that are more evenly distributed between cautious and risk-taking (e.g., speeding up) driving behaviors. As noted in

Table 1-4, for test trials at either SL, at VPTY=2 sec intersections AWF actuation occurred when vehicles were less than 1 sec from the AWF, whereas at VPTY=3.5 sec intersections AWF actuation occurred when vehicles were about 2 sec from the AWF. The thesis is that the longer decision time provided at VPTY=3.5 sec intersections enabled a greater degree of cognitive analysis of the implications of the advance warning, resulting in a more balanced distribution of both cautious and risk-taking S responses in interacting with the subsequent Y signal. Conversely, the shorter decision time provided at VPTY=2 sec intersections relegates the decision-making process essentially to the non-cognitive, psychomotor domain (recall that the original clearance interval analysis of Gazis and colleagues [4] assumes a rt to the Y signal of 1 sec (Section 1.2.1), about 0.5 sec longer than the proximity of the vehicle to the AWF at AWF actuation at VPTY=2 sec intersections). Thankfully, the results of this study suggest that the psychomotor response under these circumstances largely favors cautious rather than risk-taking behavior by Ss in interacting with the Y signal.

Of course this interpretation is entirely speculative---the present study is designed to assess SDP responses by Ss during interaction with AWF versus non-AWF intersections, not to probe the cognitive and/or psychomotor behavioral origins of these responses. Other interpretations are possible. However the interpretation offered here, if correct, has important implications for design of AWF intersections. First, it fleshes out and extends our understanding of the behavioral concomitants of risk-taking behavior as one of the important person variable factors associated with warning compliance [16]. That is, it suggests that individual differences in propensities for risk-taking (as identified, for example, in risk-taking attitude questionnaires) may be associated largely if not entirely with decision-making in the cognitive as opposed to the psychomotor domain of behavioral response. Obviously, further research will be required to assess the validity of this thesis. Nevertheless, in terms of design of AWF intersections, the implication of the thesis is that relative to non-AWF intersections, AWFs will not predictably and consistently evoke more cautious (and therefore safer) driving behavior during driver interaction with Y signals unless decision zone timing is reduced to a level that relegates driver decision-making largely if not entirely to the psychomotor domain.

4.4. CONCLUSIONS

Major conclusions supported by this study are summarized below, in relation to visual observations of SDP, objective measures of SDP, and the PTQ results.

Conclusions From Visual Observations of Simulated Driving Performance

1. Various lines of evidence support the ecological validity of the study (Section 4.2).
2. At either speed limit, subjects took slightly longer to complete the driving task with AWFs present at each intersection (Fig. 3-1). This suggests that AWFS may encourage somewhat more cautious (and therefore somewhat slower) driving behavior.
3. Subjects were better able to judge elapsed driving times during low speed limit trials, compared with high speed limit trials (Tables 3-2, 3-3), regardless of the absence or presence of intersection AWFs. One interpretation of these results is that simulated driving at a higher speed, compared with that at lower speed, conveys the subjective impression that speed and passage of time are somewhat elevated relative to actual levels,
4. Unlike the case for low speed limit trials, the percentage of subjects who matched the target time (±30 sec) during high speed limit trials is higher for the test than for the control trials (Fig. 3-2). This suggests that with higher vehicle speeds, AWFs at each intersection not only encouraged somewhat slower driving (Conclusion 2), they also enabled Ss to gauge their speed and elapsed driving times with somewhat greater accuracy.
5. The further away that a subject is from the intersection when the signal light turns yellow, the more likely is the subject to stop (Fig. 3-3), a result aligned with expectations about actual driving behavior under real-world driving conditions.
6. When AWFs are present, subjects are more likely to stop at intersections during high speed limit trials, compared with low speed limit trials, for intersections with VPTY levels of 2 and 3.5 sec (Fig. 3-3). This result is aligned with the subjective responses of subjects to Questions 16 and 18 on the post-test questionnaire, which indicate that subjects largely agree that AWFs help them stop at traffic signals when they are driving fast (Fig. 3-19) but not necessarily when they are driving slow (Fig. 3-21). A plausible interpretation of these results is that at 50 mph, the dilemma and decision zones for the VPTY=2 and VPTY=3.5 sec intersections are substantially narrower than those at 65 mph (Table 1-3), a design condition that results in somewhat higher percentages of stops at these intersections for the HSL compared with the LSL trials.

7. Asymmetries are observed in different measures of stopping behavior between results for LSL trials, and those for HSL trials., related to stopping percentages, dangerous stops, running red lights, and inconsistent stops. Section 4.3.1 provides an interpretation of these results.
8. Cautious driving behavior is more prevalent at AWF compared with control intersections (Fig. 3-8).

Conclusions From Objective Measures of Simulated Driving Performance

9. ANOVA results indicate that during interaction with intersections at VPTY levels of 2 and 3.5 sec, at which uncertain driver decision-making in interacting with the Y light may be expected, drivers tend to display more cautious driving behavior when AWFs are present (e.g., lower vehicle speed and acceleration/deceleration, accompanied by more braking), relative to when AWFs are not present (Figs. 3-9 through 3-11).
10. A series of limitations of the study may limit the generalizability of the results. These include the lack of a representative sample population, a relatively small number Ss, and the presence of a small feedback delay between steering wheel movements and update of visual display during simulation testing.
11. At VPTY=2 sec intersections, a disproportionate number of Ss slowed at test compared with control intersections, whereas at VPTY=3.5 sec intersections, a more balanced distribution of both reductions and increases in vehicle speed is observed at test compared with control intersections. Section 4.3.2 provides an interpretation of this result.

Conclusions From Post-Test Questionnaire Results

12. Half of the Ss participating in the study previously encountered AWFs on a regular basis as part of their driving experience, whereas half did not. This result suggests that: (1) routine driver familiarity with AWFs during actual driving is by no means universal; (2) variability in prior S familiarity with AWFs may have contributed, as a confounding factor, to observed variability in different measures of SDP during S interaction with AWF intersections; and (3) possible effects of AWFs observed in the study are not biased, in a consistent manner across all Ss, by prior S familiarity with AWFs.
13. Responses indicate that subjects largely agree that AWFs beneficially influence their stopping behavior at signalized intersections.

14. Subject responses to the statement that AWFs help them stop at traffic signals when they are driving slow are mixed.
15. Subjects tend to agree that AWFs help them stop at traffic signals when they are driving fast.
16. Responses indicate that subjects have generally favorable viewpoints about their interactions with AWFs at signalized intersections.
17. Subject responses to the statement that they do not pay much attention to the AWFs are mixed. The pattern of these responses suggests that just because Ss are favorably disposed towards AWFs does not always mean that they pay attention to them while driving.
18. Over half the subjects agree or strongly agree with the statement that the purpose of an AWF is inherently obvious, despite the fact that half of subjects participating in the study had previously encountered AWFs either rarely or not at all during driving. This pattern of responses supports the conclusion that AWFs have good human-centered design, a design that appears to support establishment of an accurate conceptual model of the actual purpose of AWFs among most drivers.
19. When asked what they are supposed to when they approach a traffic signal and the signal turns yellow, three-fourths of the respondents provided the following answer to the question: 'Always slow down, but only stop at the intersection if you can do so safely by the time the signal turns red.' This result suggests most of the study participants are familiar with Minnesota law regarding stipulated driving behavior when approaching a traffic signal that turns yellow. However, there are 10 more responses to the question than there are subjects. This suggests some variability, and/or uncertainty, in understanding among study participants regarding appropriate driving behavior when approaching a traffic signal that turns yellow.
20. When subjects were asked what they are supposed to when they approach a green traffic signal on a roadway with either a low or a high speed limit, the following two answers received the most responses: (1) 'Maintain a constant speed, but prepare to brake to a stop if the signal turns yellow;' and (2) 'Maintain a constant speed through the intersection if I can do so before the signal turns red.' There are more responses to this question than there are subjects. This suggests variability, and/or uncertainty, in driving behavior adopted by study participants when approaching a green traffic signal on a roadway with a either a low or a high speed limit.

21. Most subjects indicate that they favor cautious behavior when approaching a traffic signal that is either yellow or green.
22. There are at least two interesting implications of responses to Questions 5-7 in the questionnaire. First, they suggest that there is some consistency, but a lack of complete uniformity, in the manner in which Ss participating in the study interact with either yellow or green signals. Second, they suggest that the variability observed with such interaction may have contributed, as a confounding factor, to observed variability in different measures of simulated driving performance during subject interaction with intersections during the study.
23. When asked after concluding their second experimental session, only one-third of the study participants accurately recognized that the purpose of the study was to assess the influence of AWFs on driver behavior at intersections. This suggests that for the remaining subjects, findings pertaining to simulated driving performance was not unduly biased by an awareness of AWFs being the primary focus of experimental testing.
24. Among those subjects that perceived the true purpose of the study, all but one referred to the AWFs as 'flashing lights.' This result suggests that the term 'advanced warning flasher' may not be commonly known to Minnesota drivers.
25. All subjects but one understood what the purpose of an AWF is, again underscoring the good human-centered design of AWFs.
26. In comments volunteered after completion of the questionnaire, four subjects indicated experience with and understanding of AWFs that preceded their participation in the study, but two of these respondents did not divine the true purpose of the study. This result suggests that prior understanding of AWFs may not have biased subject interaction with AWF intersections during the study.

REFERENCES

(As part of a previous Mn/DOT project dealing with AWFs, Klugman and colleagues [1] carried out a comprehensive review of AWF literature published up to 1992. This report will update this earlier review with AWF references published during or after 1992.)

1. Klugman, A., Boje, B., and Belrose, M., A Study of the Use and Operation of Advance Warning Flashers at Signalized Intersections. Final Report, Report MN/RC-93/01, State of Minnesota Department of Transportation, Saint Paul, MN, 1992.
2. Ekern, D.S., Guidelines for the Installation of Advanced Warning Flashers, Technical Memorandum No. 97-04-T-02, State of Minnesota Department of Transportation Engineering Services Divisions, Saint Paul, MN, January 21, 1997.
3. Misgen, S., Signal Operations at High Speed Locations, Memorandum to District Traffic Engineers, State of Minnesota Department of Transportation Office of Traffic Engineering, Roseville, MN, June 18, 1997.
4. Gazis, D., Herman, R., and Maradudin, A., The problem of the amber signal light in traffic flow, Operations Research, Vol. 8, No. 1, 1966, pp. 112-132.
5. State of Minnesota Department of Transportation, Dynamic Signing for Signal Change Intervals, Report No. 07043-286, State of Minnesota Department of Transportation, Saint Paul, MN, 1986.
6. Reis, G., Office of Traffic Engineering, Mn/DOT, Personal communication.
7. Williams, W.L., Driver behavior during the yellow interval, Transportation Research Record, Vol. 644, 1977, pp. 75-78.
8. Institute of Traffic Engineers, Transportation and Traffic Engineering Handbook,, Prentice-Hall, Englewood Cliffs, NJ, 1976.
9. State of Minnesota Department of Transportation, Motorist Survey of Dynamic Signing for Traffic Signal Change Intervals, Technical Memorandum No. 07043-186, State of Minnesota Department of Transportation, Saint Paul, MN, 1986.

10. Farraher, B.A.B., Weinholzer, R., and Kowski, M.P., The Effect of Advanced Warning Flashers on Red Light Running - A Study Using Motion Imaging Recording System Technology at Trunk Highway 169 and Pioneer Trail in Bloomington, Minnesota, State of Minnesota Department of Transportation, Saint Paul, MN, 1999.

11. Ries, G.L., Evaluation of Dynamic Signing Used To Alert Motorists To Traffic Signal Change Intervals. Summary of Agency Survey Response, Technical Memorandum No. 07043-185, State of Minnesota Department of Transportation, Saint Paul, MN, 1985.

12. Sayed, T., Vahidi, H., and Rodriguez, F., Advance warning flashers: do they improve safety?, Transportation Research Record, TRB, National Research Council, Washington, D.C., 1999.

13. State of Minnesota Department of Transportation, Pole and Mast Arm Luminaires and Traffic Lights Assembly (Standard Plate No. M8123D), State of Minnesota Department of Transportation, Saint Paul, MN, 1995.

14. State of Minnesota Department of Transportation, Traffic Signal Bracketing (Standard Plate No. M8111C), State of Minnesota Department of Transportation, Saint Paul, MN, 1996.

15. Norman, D., The Design of Everyday Things, Currency Doubleday, New York, 1990.

16. Rogers, W.A., Lamson, N., and Rosseau, G.K., Warning research: an integrative perspective, Human Factors, Vol. 42, No. 1, 2000, pp. 102-139.

17. Huck, S.W., Reading Statistics and Research, Longman, New York, 2000.

APPENDIX A

Mn/DOT GUIDELINES AND SPECIFICATIONS FOR INSTALLATION OF AWFs [2]

MINNESOTA DEPARTMENT OF TRANSPORTATION
Engineering Services Divisions
Technical Memorandum No. 97-04-T-02
January 21, 1997

TO: Distribution 57, 382, 612, 618, and 650

FROM: David S. Ekern
Director, Engineering Services Division
Assistant Chief Engineer

SUBJECT: Guidelines for the Installation of Advanced Warning Flashers

EXPIRATION

This technical memorandum will expire on April 1, 2000, or when this information is included in the Minnesota Traffic Engineering Manual.

IMPLEMENTATION

The guidelines contained in this Technical Memorandum are to be implemented for new and revised installations immediately. Inplace systems will be updated through attrition, except that this memorandum gives flasher timing adjustments to provide consistent operation of inplace systems with new and revised systems.

INTRODUCTION

Mn/DOT has concluded that at certain high speed locations, providing additional information to the motorist describing the operation of the traffic signal can assist the driver in making safer and more efficient driving decisions. The additional information includes a visual indication to get the driver's attention and a specific notice that the driver must prepare to stop. The Advanced Warning Flasher (AWF) is a device which Mn/DOT uses to convey this information.

The Mn/DOT AWF system consists of a flasher and a sign located on main street approaches to a high speed signalized intersection. The AWF is connected to the traffic signal in such a way that when the main street green is about to change to yellow, the flasher is turned on to warn the approaching drivers of the impending change. Basically, the purpose of an optimally designed combination of traffic signal and AWF system is twofold: 1) to inform the driver in advance of a required drive decision (prepare to stop) and 2) to minimize the number of drivers that will be required to make that decision.

The Traffic Engineering Organization recently reviewed Mn/DOT practice and recommended that guidelines be developed in the interest of consistency and uniformity statewide.

AL PINT
ADE
WATERS EDGE

- More -

PURPOSE

The purpose of this Technical Memorandum is to provide uniform guidelines to all Mn/DOT traffic personnel for the design and operation of Advanced Warning Flashers.

GUIDELINES FOR CONSIDERATION

The following guidelines indicate when the installation of advanced warning flashers(AWF) for signal change interval should be considered. Due to the complex nature of traffic flow characteristics, these guidelines should be applied along with engineering judgement. Guidelines should be reviewed for each prospective installation.

AWF should only be installed in response to a specifically correctable problem, not in anticipation of a future problem. Generally, AWF implementation is appropriate only at high speed locations. Before AWF are installed, other remedial action should be considered.

	CATEGORY	CRITERIA	COMMENT
1.	Speed	85th percentile speed greater or equal to 50 mph	Meeting this guideline alone is not usually sufficient justification for the installation of AWF.
2.	Isolated or unexpected signalized intersection	Where there is a long distance from the last intersection at which the mainline is controlled, or the intersection is otherwise unexpected.	This guideline may be applicable where the distance from the last intersection is greater than 15 km, a freeway terminus, or at other locations where the intersection is unexpected.
3.	Limited sight distance	Where the distance to the stop bar, D, with two signal heads visible is insufficient: $D \leq 0.45vt + \frac{v^2}{10(a+9.8s)}$	See Graphs of Limited Sight Distance, Figure I & Figure II A sight distance falling below the lines for the given speed and grade indicates the possible need for AWF.

Where:
D = distance to stop bar in meters
v = 85th percentile speed in mph
t = reaction time, 2.5 seconds
a = deceleration rate
2.4 m/s^2 (trucks)
3 m/s^2 (all traffic)
s = decimal gradient

- More -

CATEGORY	CRITERIA	COMMENT
4. Dilemma Zone	Where a dilemma zone exists for all traffic or for heavy vehicles. A dilemma zone exists if: $$Y \le t + \frac{0.45v}{2(a+9.8s)}$$ Where: Y = yellow interval in seconds; v = 85th percentile speed in mph; t = 1 second; a = deceleration rate: 2.4 m/s^2 (trucks), 3 m/s^2 (all traffic); s = decimal gradient	See Graphs on Minimum Yellow Intervals, Figure III & Figure IV. If the yellow interval is less than indicated AWF may be considered (longer yellow should be considered first).
5. Accidents	If an approach has an accident problem, the intersection should be examined for existence of dilemma zone or sight distance restriction.	
6. Engineering Judgment		

Combinations of above guidelines or other considerations may justify the installation of AWF.

If no sight distance or dilemma zone problems exist, AWF may not be an appropriate countermeasure to accident problems.

Engineering judgment should be based on additional data such as complaints, violations, conformity of practice, and traffic conflicts. Prior to installing AWF, consideration should be given to other countermeasures including but not limited to: adjustment of timing parameters which may include increasing yellow and/or all red intervals, improving detection, modification of the signal system as by adding signal heads, adjusting speed limits, and installing continuously operating flashers with standard "signal ahead" warning signs.

GUIDELINES FOR INSTALLATION

1. **Advanced Warning Flasher** - The Advanced Warning Flasher is as shown in the MUTCD, section 2C-17.2. The flasher shall flash yellow in a wig-wag manner prior to the termination of the green (See number 3, below), and during the yellow and red periods of the signal. The flasher will also flash if the signal goes into flashing operation. Power shall be supplied to the AWF from the signal control cabinet.

- More -

2. **Advanced Warning Flasher Sign Placement** - The AWF shall be set back from the intersection in accordance with the Table I, shown below. At locations on four lane divided roadway, the AWF shall be placed on both sides of the approach.

TABLE I

Posted Speeds (mph)	AWF Placement (meters)	Leading Flash (seconds)
40	170	8.0
45	170	7.0
50	215	8.0
55	215	7.0
60	260	8.0
65	260	7.5

3. **Leading Flash** - The Leading Flash is the amount of time, prior to the signal turning yellow, that the AWF flashes. The AWF shall flash during the Leading Flash Period and continue flashing through the signal's yellow clearance interval and the red. The Leading Flash time is shown in Table I.

For existing systems where the placement is other than what is listed in Table 1, the Leading Flash Time can be computed by the following formula:

$$F=\frac{2.24D}{v}-1.5$$

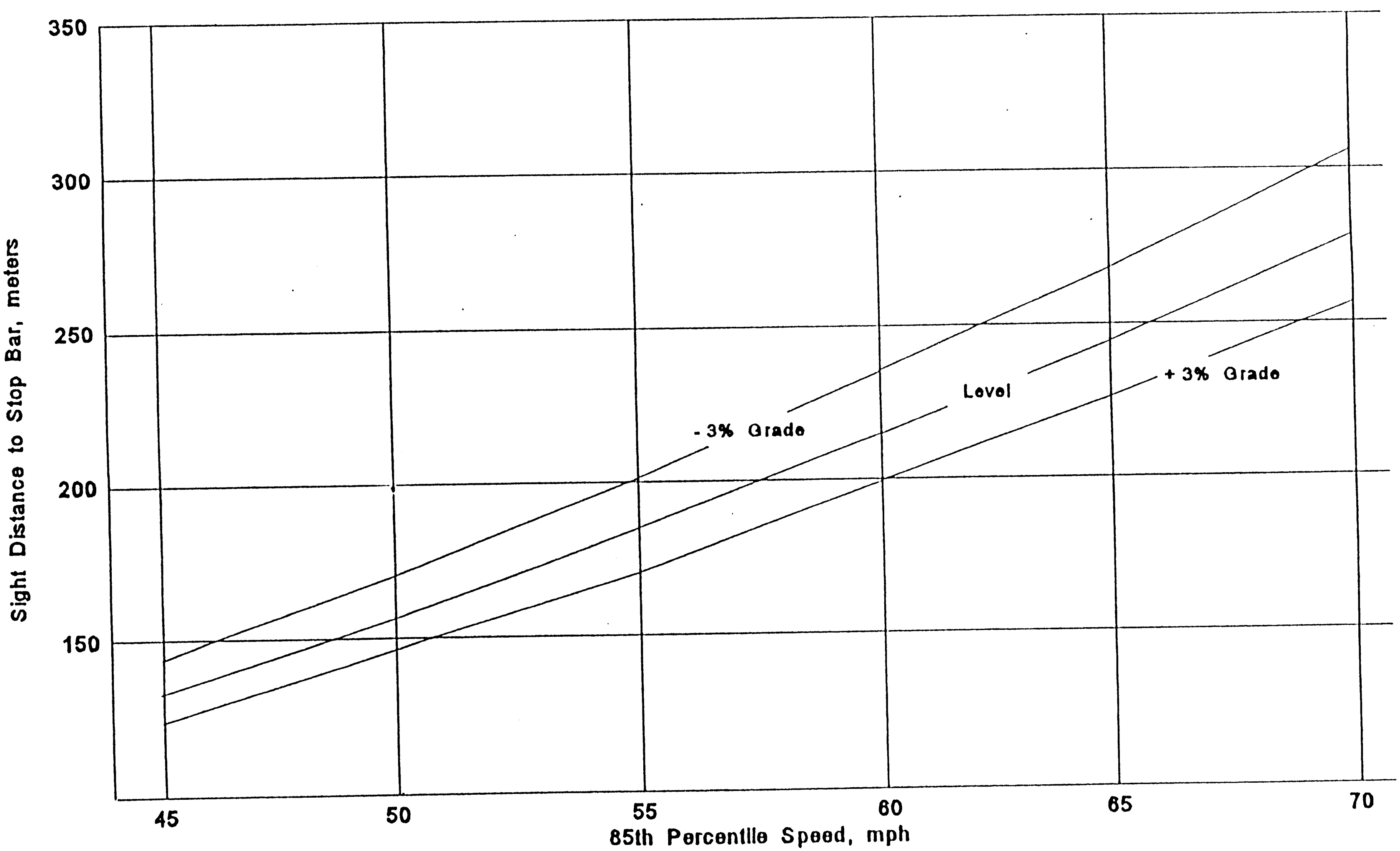
Where:
F = Leading Flash Time, seconds
D = AWF Placement, meters
v = posted speeds, mph

4. **Detector Placement** - The detection of the intersection shall be determined without regard to the AWF.

- End -

Limited Sight Distance

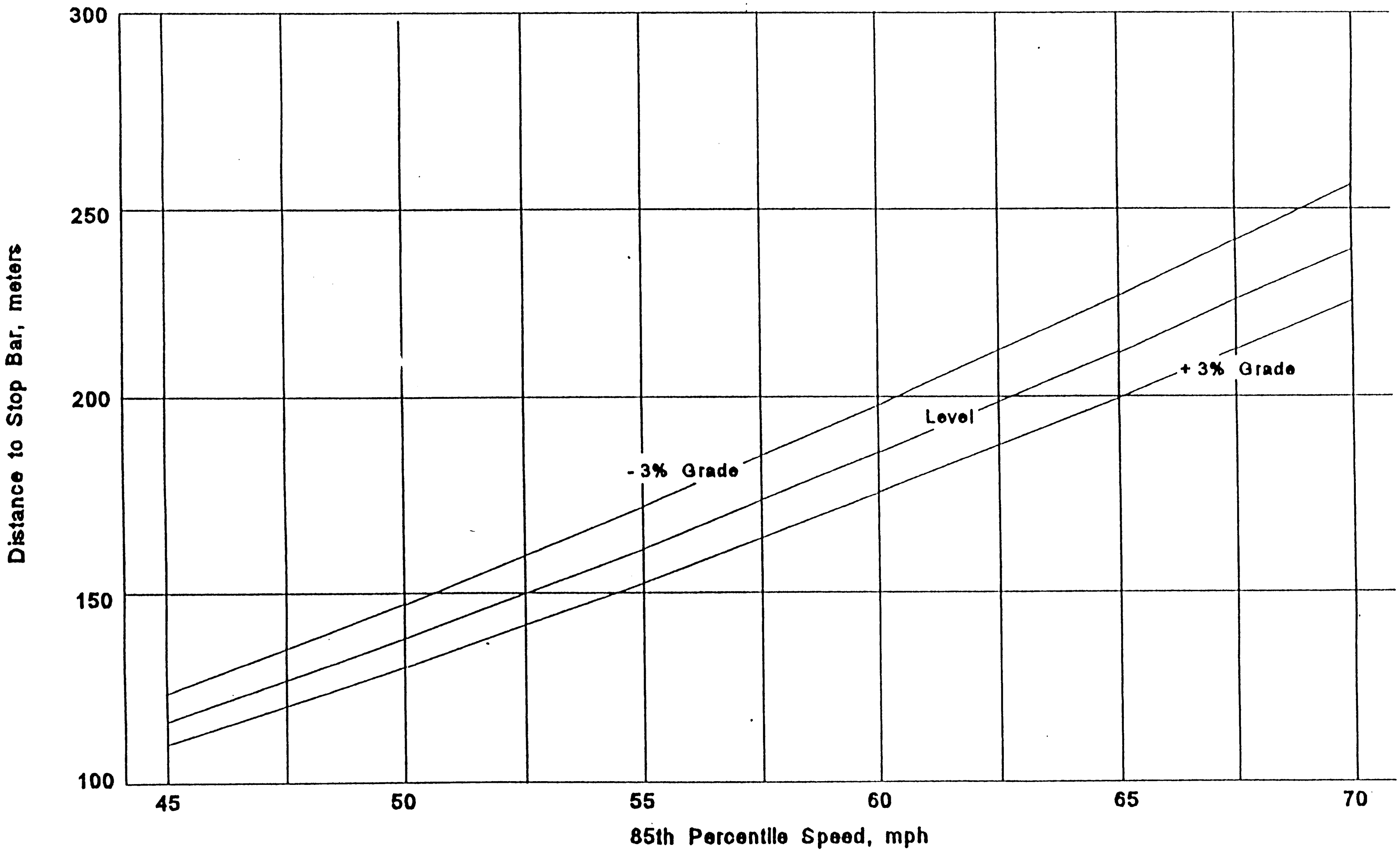
a = 2.4 meters per second squared (> 15% trucks)



A sight distance falling below the lines for the given speed and grade indicates the possible need for an AWF.

Limited Sight Distance

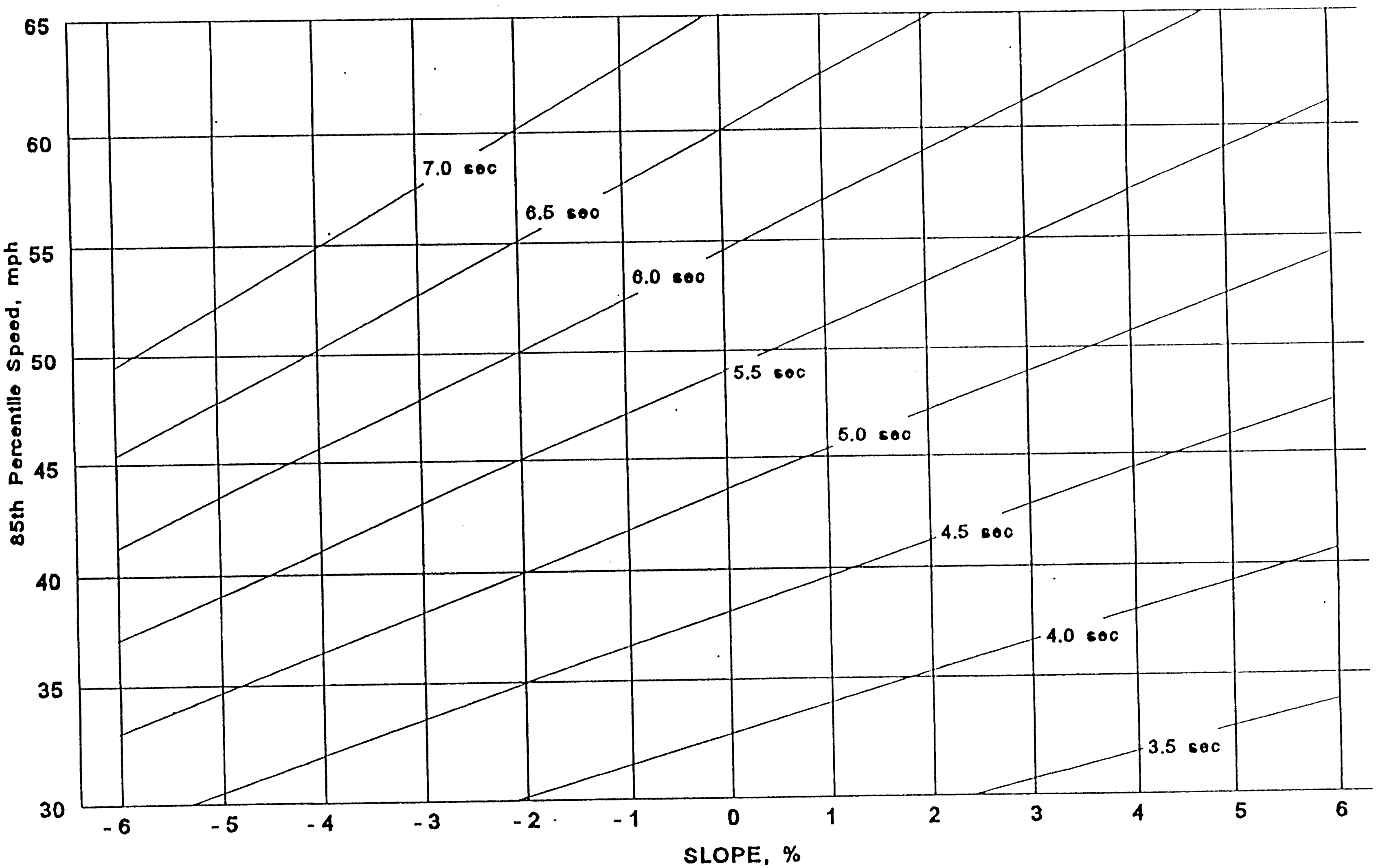
a = 3 meters per second squared (< 15% trucks)



A sight distance falling below the lines for the given speed and grade indicates the possible need of an AWF.

Minimum Yellow Intervals

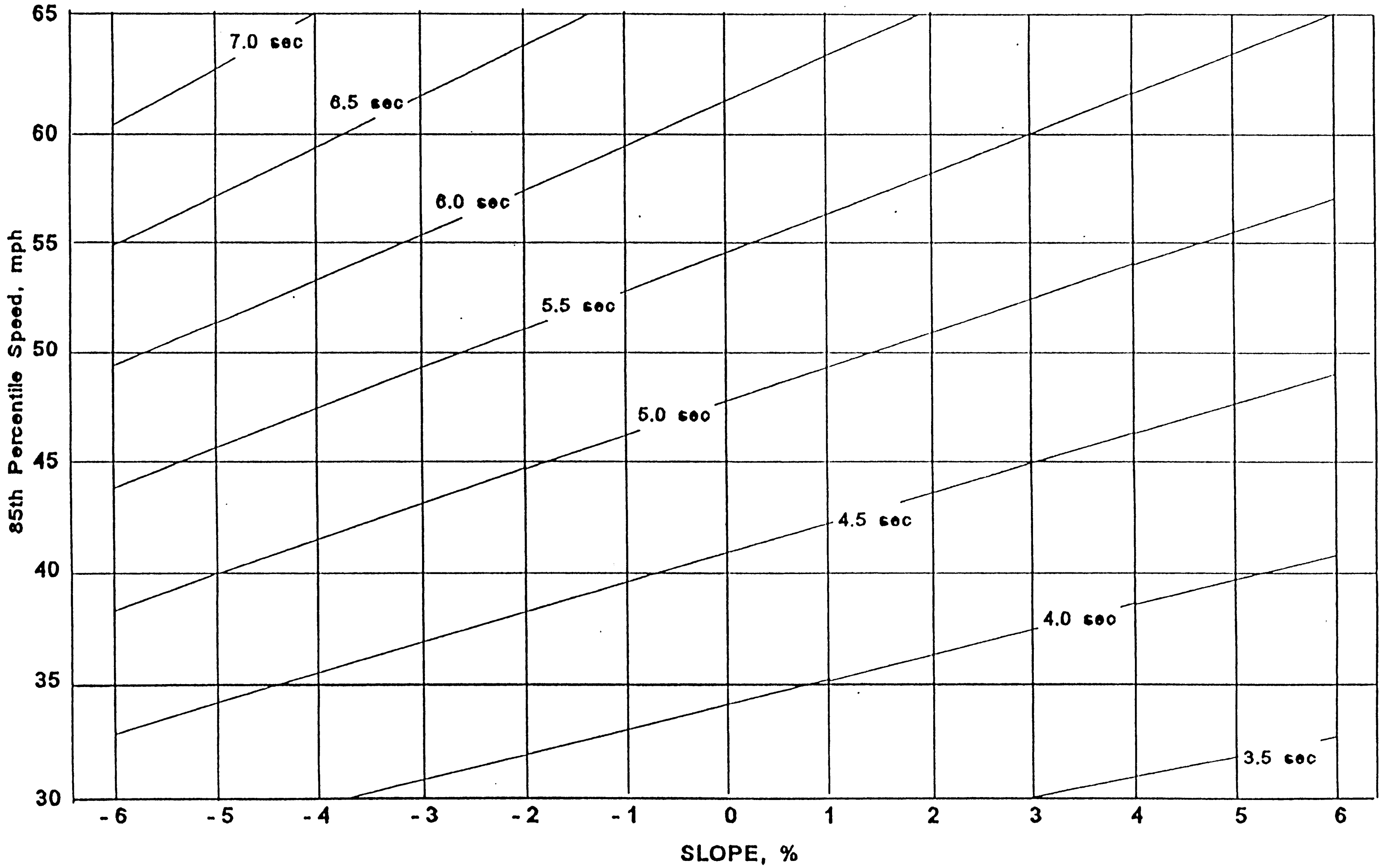
a = 2.4 meters per second squared (> 15% trucks)



If the yellow interval is less than indicated, AWF may be considered, (longer yellows should be considered first).

Minimum Yellow Intervals

a = 3 meters per second squared (< 15% trucks)



If the yellow interval is less than indicated, AWF may be considered, (longer yellows should be considered first).

APPENDIX B

Mn/DOT SPECIFICATIONS FOR AWF PLACEMENT AND TIMING RELATIVE TO SIGNALIZED INTERSECTION [3]

Minnesota Department of Transportation

Memo

Office of Traffic Engineering
Mail Stop 725, Suite 250
1500 W. County Road B2
Roseville, MN 55113

Office Tel: 612-582-1072
Fax: 612-582-1033

June 18, 1997

To: District Traffic Engineers

From: Steve Misgen
Traffic Engineering, MS 725

Subject: Signal Operations at high speed locations

With the pending increase of speed limits, some signals may require adjustment. There are four items that should be looked at before the roadway speed can be increased; yellow time, all-red time, detector spacing and AWF spacing.

Yellow Clearance Interval

The yellow timing for the approach should conform to the following table. The 85th percentile speed at the intersection is in the left column, grade in percent along the top and Mn/DOT's recommended yellow timings in the right column. Note that the previously published material may have called for 6.5 seconds of yellow at 65 mph, rather than the 6.0 seconds required here.

85th % Speed (mph)	Percent Grade							Mn/DOT
	+3	+2	+1	Level	-1	-2	-3	
25	2.7	2.7	2.8	2.8	2.9	3.0	3.0	**3.0**
30	3.0	3.1	3.1	3.2	3.3	3.4	3.4	**3.5**
35	3.3	3.4	3.5	3.6	3.7	3.7	3.8	**4.0**
40	3.7	3.8	3.8	3.9	4.0	4.1	4.3	**4.0**
45	4.0	4.1	4.2	4.3	4.4	4.5	4.7	**4.5**
50	4.4	4.5	4.6	4.7	4.8	4.9	5.1	**5.0**
55	4.7	4.8	4.8	5.0	5.2	5.3	5.5	**5.5**
60	5.0	5.1	5.1	5.4	5.6	5.7	5.9	**6.0**
65	5.4	5.5	5.5	5.8	5.9	6.1	6.3	**6.0**

Yellow time in seconds.

All Red

The all-red should be adjusted according the following formula:

$$R = \frac{w+l}{.28v}$$

Where:
R = all-red interval in seconds
W = width of intersection in meters
L = Length of vehicle, 6 meters
V = 85th percentile speed,

Detector Spacings

Enclosed are updated detector placement charts. These are also being included in the next TEM revision. Each intersection should be inspected to see if the present detectors are placed adequately.

Advanced Warning Flasher

At locations where an advance warning flasher is installed, the leading flash time must be adjusted to account for the higher speeds. The following formula will provide the proper amount of leading flash for the given speed and placement:

$$F = \frac{2.24D}{v} - 1.5$$

Where:
F = Leading Flash Time, seconds
D = AWF Placement, meters
v = Posted speeds, mph

Through attrition, the AWF placement should be adjusted to conform with the tech memo.

Posted Speeds (mph)	AWF Placement (meters)	Leading Flash (seconds)
40	170	8.0
45	170	7.0
50	215	8.0
55	215	7.0
60	260	8.0
65	260	7.5

APPENDIX C

DESIGN FEATURES OF INTERSECTION MODEL FOR SIMULATED DRIVING ENVIRONMENT

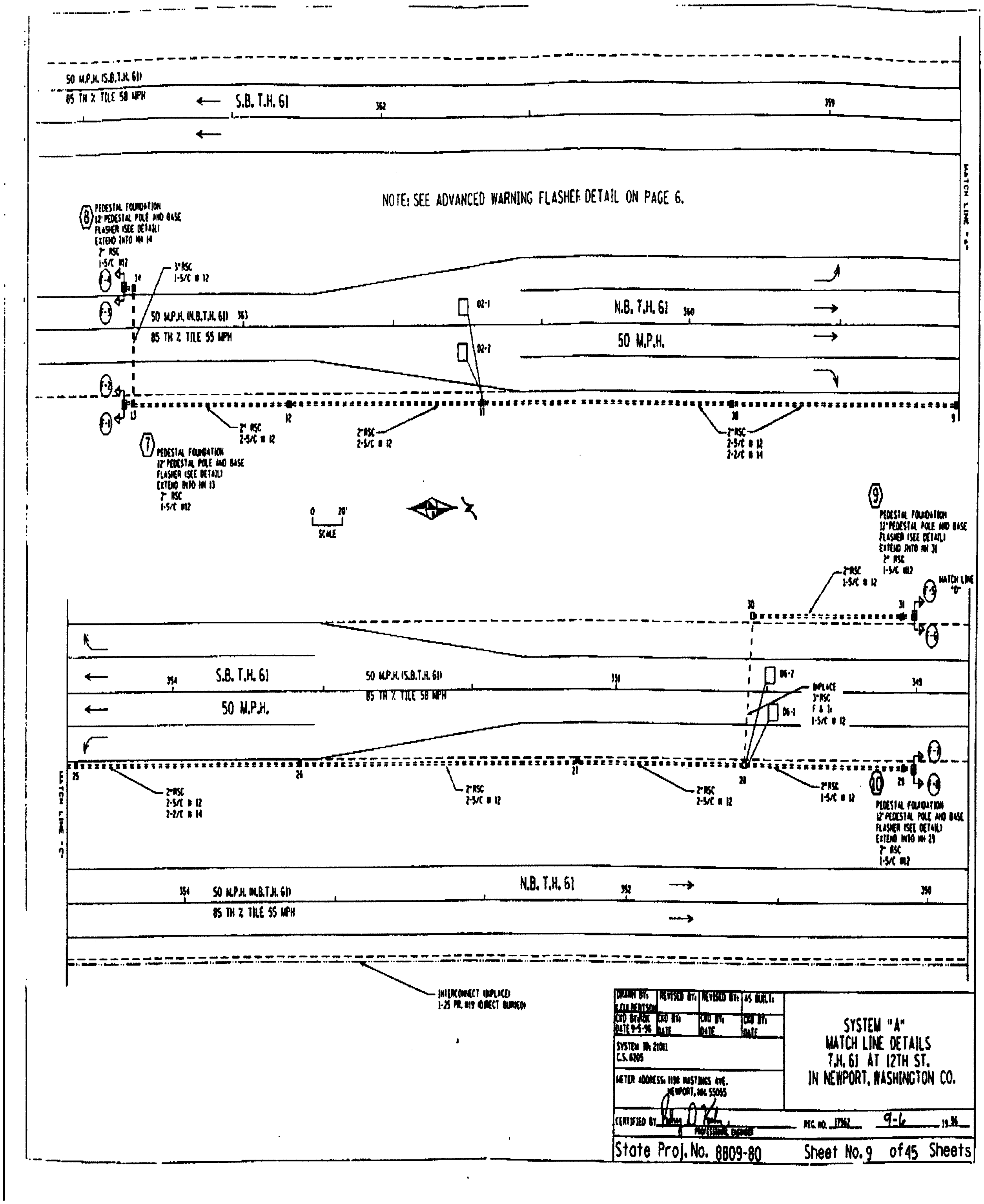


Figure C-1. Mn/DOT design specifications for intersection model for simulated driving environment.

Figure C-2. Overhead view of simulation model for intersections employed in simulated driving environment.

APPENDIX D

RECORDING FORMS FOR VISUAL OBSERVATIONS OF SIMULATED DRIVING PERFORMANCE

AWF STUDY - REGULAR TESTING VISUAL OBSERVATIONS - LSLC CONDITION

SUBJECT NO ______ NAME ________________________ AGE ______ GENDER _____ TARGET TIME 13' 45"

TRIAL 1: Date _____________ Time ________ File Name ______________ // TRIAL 2: Date ___________ Time ________ File Name ______________

Trial	Inter-section	Vehicle Proximity	Vehicle Speed Before Signal	SPEED BEFORE SIGNAL Constant	Slow	Increase	SPEED AT YELLOW Constant	Slow	Increase	Stop at Signal? NO	YES	TIME Elapsed	Judged
1	1	5 sec											
	2	3.5											
	3	All Green											
	4	2											
	5	0											
	6	All Green											
	7	3.5											
	8	2											
	9	5											
	10	0											
2	1	5 sec											
	2	3.5											
	3	All Green											
	4	2											
	5	0											
	6	All Green											
	7	3.5											
	8	2											
	9	5											
	10	0											

AWF STUDY - REGULAR TESTING VISUAL OBSERVATIONS - LSLT CONDITION

SUBJECT NO ______ NAME ____________________________ AGE ______ GENDER _____ TARGET TIME 13' 45"

TRIAL 1: Date _____________ Time ________ File Name ______________ // TRIAL 2: Date ___________ Time ________ File Name ______________

Trial	Inter-section	Vehicle Proximity	Veh. Speed at AWF	SPEED BEFORE AWF			SPEED AFTER AWF			Stop at Signal?		TIME	
				Constant	Slow	Increase	Constant	Slow	Increase	NO	YES	Elapsed	Judged
1	1	3.5 sec											
	2	2											
	3	0											
	4	5											
	5	2											
	6	All Green											
	7	5											
	8	All Green											
	9	0											
	10	3.5											
2	1	3.5 sec											
	2	2											
	3	0											
	4	5											
	5	2											
	6	All Green											
	7	5											
	8	All Green											
	9	0											
	10	3.5											

AWF STUDY - REGULAR TESTING VISUAL OBSERVATIONS - HSLC CONDITION

SUBJECT NO ______ NAME ________________________ AGE ______ GENDER _____ TARGET TIME 11' 45"

TRIAL 1: Date _____________ Time ________ File Name ______________ // TRIAL 2: Date ___________ Time ________ File Name ______________

Tria l	Inter- sectio n	Vehicle Proximity	Vehicle Speed Before Signal	SPEED BEFORE SIGNAL			SPEED AT YELLOW			Stop at Signal?		TIME	
				Constant	Slow	Increase	Constant	Slow	Increase	NO	YES	Elapsed	Judged
1	1	0 sec											
	2	5											
	3	5											
	4	3.5											
	5	All Green											
	6	3.5											
	7	2											
	8	0											
	9	2											
	10	All Green											
2	1	0 sec											
	2	5											
	3	5											
	4	3.5											
	5	All Green											
	6	3.5											
	7	2											
	8	0											
	9	2											
	10	All Green											

AWF STUDY - REGULAR TESTING VISUAL OBSERVATIONS - HSLT CONDITION

SUBJECT NO ______ NAME ______________________ AGE ______ GENDER _____ TARGET TIME 11' 45"

TRIAL 1: Date ____________ Time ________ File Name ____________ // TRIAL 2: Date ___________ Time ________ File Name ____________

Trial	Inter-section	Vehicle Proximity	Veh. Speed at AWF	SPEED BEFORE AWF			SPEED AFTER AWF			Stop at Signal?		TIME	
				Constant	Slow	Increase	Constant	Slow	Increase	NO	YES	Elapsed	Judged
1	1	All Green											
	2	0 sec											
	3	2											
	4	All Green											
	5	5											
	6	5											
	7	3.5											
	8	2											
	9	3.5											
	10	0											
2	1	All Green											
	2	0 sec											
	3	2											
	4	All Green											
	5	5											
	6	5											
	7	3.5											
	8	2											
	9	3.5											
	10	0											

APPENDIX E

POST-TEST QUESTIONNAIRE

PERCEIVED DRIVING TIME STUDY

POST-TEST QUESTIONNAIRE

- **Please answer the following questions about the study that you have just completed.**
- **Please complete this questionnaire immediately after you complete the second testing session.**
- **For questions 7-17, please circle the preferred number to indicate how much you agree or disagree with the statement.**
- **Please return your completed questionnaire to Thomas Smith.**

Name ___________________________

1. AGE ____   2. SEX   __M   __F   3. DATE ________   4. HEIGHT _______

5. When you approach a traffic signal and the signal turns **yellow**, you are supposed to (check all that apply):
5a. ___ Always slow down, and try to stop at the intersection when the signal turns red
5b. ___ Always slow down, but only stop at the intersection if you can do so safely by the time the signal turns red
5c. ___ Proceed through the intersection, if you can do so before the signal turns red
5d. ___ Maintain a constant speed, and proceed through the intersection if you can do so before the signal turns red
5e. ___ Speed up, and proceed through the intersection if you can do so before the signal turns red

6. When I am driving on a roadway with a **high** speed limit (60-70 mph) and I approach a traffic signal ahead, I tend to do the following if the signal is **green** (check all that apply):
6a. ___ Always slow down, and prepare to brake to a stop if the signal turns yellow
6b. ___ Maintain a constant speed, but prepare to brake to a stop if the signal turns yellow
6c. ___ Speed up, but prepare to brake to a stop if the signal turns yellow
6d. ___ Always slow down, but speed up through the intersection if I can do so before the signal turns red
6e. ___ Maintain a constant speed through the intersection if I can do so before the signal turns red
6f. ___ Speed up so that I can make it through the intersection before the signal turns red

7. When I am driving on a roadway with a **lower** speed limit (45-55 mph) and I approach a traffic signal ahead, I tend to do the following if the signal is **green** (check all that apply):
7a. ___ Always slow down, and prepare to brake to a stop if the signal turns yellow
7b. ___ Maintain a constant speed, but prepare to brake to a stop if the signal turns yellow
7c. ___ Speed up, but prepare to brake to a stop if the signal turns yellow
7d. ___ Always slow down, but speed up through the intersection if I can do so before the signal turns red
7e. ___ Maintain a constant speed through the intersection if I can do so before the signal turns red
7f. ___ Speed up so that I can make it through the intersection before the signal turns red

You may have noticed that in some of the trials, the traffic signals were preceded by flashing yellow lights. These are termed Advanced Warning Flashers (AWFs). The following questions pertain to AWFs.

8. PLEASE EXPLAIN THE PURPOSE OF AWFs, AS YOU UNDERSTAND WHAT THEIR PURPOSE IS.

____

____

____

____

9. HAVE YOU EVER ENCOUNTERED AWFs WHILE DRIVING BEFORE?
___ NO ___ RARELY ___ FAIRLY REGULARLY ___ EVERY DAY

10. I FOUND THE AWFs DISTRACTING	Strongly Disagree 1	2	3	4	5	Strongly Agree
11. THE AWFs HELPED ME STOP AT THE TRAFFIC SIGNALS	Strongly Disagree 1	2	3	4	5	Strongly Agree
12. I DIDN'T PAY MUCH ATTENTION TO THE AWFs	Strongly Disagree 1	2	3	4	5	Strongly Agree
13. MOST TRAFFIC SIGNALS SHOULD BE PRECEDED BY AWFs.	Strongly Disagree 1	2	3	4	5	Strongly Agree
14. I LIKE AWFs.	Strongly Disagree 1	2	3	4	5	Strongly Agree
15. I TEND TO SPEED UP FOR TRAFFIC SIGNALS WITH AWF WARNINGS.	Strongly Disagree 1	2	3	4	5	Strongly Agree
16. AN AWF HELPS ME TO STOP AT TRAFFIC SIGNALS WHEN I AM DRIVING FAST.	Strongly Disagree 1	2	3	4	5	Strongly Agree
17. I TEND TO SLOW DOWN FOR TRAFFIC SIGNALS WITH AWF WARNINGS.	Strongly Disagree 1	2	3	4	5	Strongly Agree

18. AN AWF HELPS ME TO STOP AT TRAFFIC SIGNALS WHEN I AM DRIVING SLOW.

Strongly Disagree	1	2	3	4	5	Strongly Agree

19. IT IS INHERENTLY OBVIOUS WHAT THE PURPOSE OF AN AWF IS.

Strongly Disagree	1	2	3	4	5	Strongly Agree

20. I DISLIKE AWFs.

Strongly Disagree	1	2	3	4	5	Strongly Agree

THANK YOU FOR YOUR HELP IN COMPLETING THIS QUESTIONNAIRE.

APPENDIX F

INFORMED CONSENT FORM

DIVISION OF KINESIOLOGY HUMAN FACTORS RESEARCH LABORATORY SIMULATED DRIVING RESEARCH STUDY

HUMAN SUBJECTS CONSENT FORM

You are invited to be in a research study aimed at evaluating simulated driving performance with different simulated driving conditions. You are being considered as a participant for the study because you are aged between 18 and 55 and possess a valid driver's license. We ask that you read this form and ask any questions you may have before agreeing to serve as a volunteer subject in the study.

This study is being conducted at the University of Minnesota Division of Kinesiology Human Factors Research Laboratory (HFRL). Thomas J. Smith is conducting the study, with assistance from the HFRL staff.

Background Information: The purpose of this project is to conduct a human factors analysis of your ability to perceive elapsed simulated driving time under different simulated driving conditions. You will be asked to drive a simulated vehicle at different speeds through a simulated driving environment that contains signalized intersections that will be actuated in different ways.

Procedures: If you volunteer for this study, we will ask you to do the following things:

You will be asked to participate in an experimental session that will involve driving in a driving simulator. The session will last about 1 to 1.5 hour. You will be paid $20 for completing the session. The session will consist of a series of 8 trials. Each trial will last about 5-10 minutes. During each trial, you will drive through a simulated driving environment that contains signalized intersections that will be actuated in different ways as you approach them. We will ask you to obey all traffic laws during a session. Before a given trial begins, you will be informed of a target time for completing the trial. You will be asked to complete the trial within 30 seconds of the target time. At the end of the trial, we will ask you to estimate how long it took you to complete the trial.

Risks and Benefits of Being in the Study: The study has minimal risk. The project will involve two experimental sessions administered on two successive days. We ask that you volunteer for both days. You may become somewhat bored during the driving task as you encounter the same intersection a number of different times.

You will be paid $20 for completing the experimental session. If you are successful in matching the target time for 90% or more of all trials, you will be paid an additional bonus of $20. There are no direct benefits to you for participating in the study.

Alternatives to Participating in This Study: Participation in the study is completely voluntary. You are free to drop out of the study at any time after participation has begun. If you have reservations about the time and effort that will be required for the study, you should not volunteer to participate.

Compensation: In the event that this research activity results in an injury, treatment will be available, including first aid, emergency treatment and follow-up care as needed. Payment for any such treatment must be provided by you or your third party payor, if any (such as health insurance, Medicare, etc.).

DIVISION OF KINESIOLOGY HUMAN FACTORS RESEARCH LABORATORY SIMULATED DRIVING RESEARCH STUDY

HUMAN SUBJECTS CONSENT FORM (continued)

Confidentiality: The records of this study will be kept private. In any sort of report we might publish, we will not include any information that will make it possible to identify a subject. Research records will be kept in a locked file; only the research co-investigator will have access to the records.

Voluntary Nature of the Study: Your decision whether or not to participate will not affect your current or future relations with the University of Minnesota. If you decide to participate, you are free to withdraw at any time without affecting those relationships.

Contacts and Questions: The researcher conducting this study is Dr. Thomas J. Smith. You may ask any questions you have now. If you have questions later, you may contact him at the Division of Kinesiology, University of Minnesota, Room 310E, 1901 University Ave. S.E., Minneapolis, MN 55455. Phone: 612-625-2044 (office)/651-688-7444 (home). Fax: 612-626-7700. Email: smith293@tc. umn.edu.

If you have any questions or concerns regarding the study and would like to talk to someone other than the researcher(s), contact **Research Subjects' Advocate Line**, D528 Mayo, 420 Delaware Street Southeast, Minneapolis, Minnesota 55455; telephone (612) 626-1650.

You Will Be Given A Copy of This Form To Keep For Your Records.

Statement of Consent:

I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

Signature ____

Date ______________

Signature of Investigator ____________________________________

Date ______________

APPENDIX G

PRE-TEST QUESTIONNAIRE

University of Minnesota Human Factors Driving Simulation Study
Pre-Test Survey Questionnaire

Q1.

Name	
Age	
Gender	**M / F**
Phone Number	

Q2. Do you currently have a valid drivers license? (Circle one.)
1. **Yes**
2. **No**

Q3. Years driving experience (likely to be age-16=_). Number of years ___________.

Q4. Do you have any visual impairments?
1. **Yes** If Yes please describe.-___________________________________
2. **No**

Q5. Are you currently taking any medications?
1. **Yes** If Yes please describe.-____________________________________
2. **No**

Q6. Have you experienced dizziness in the past (circle one.)
1. **Yes** 2. **No** (If you answered yes , what caused the dizziness?)

a. 5 years? 1 2 ____
b. 1 year? 1 2 ____
c. 6 months? 1 2 ____

Q7.

Do you experience nausea in any of the following situations?	YES	NO	If YES describe situation (where, how often, etc.).
Driving a car.	1	2	
Riding in a car as a passenger.	1	2	
During plane trips.	1	2	
Carnival rides.	1	2	
Other.(Watching TV, movies, etc.)	1	2	

Q8. Please answer Y or N and the frequency (Circle one response for each item.)

Do you experience-	always	sometimes	rarely	never
Claustrophobia (fear of closed spaces)	1	2	3	4
Acrophobia (fear of heights)	1	2	3	4
Driving fatigue (white line fever)	1	2	3	4
Panic attacks (while driving)	1	2	3	4
Driving aggression. (Anger while driving)	1	2	3	4

Time on Road

How much time do you spend on the road per week (average)?

AS DRIVER			
	In town (About 25-35 mph)	In town highways (50 mph+)	Out of town highways (65 mph+)
Weekdays			
Weekends			
TOTALS			

AS PASSENGER			
	In town (About 25-35 mph)	In town highways (50 mph+)	Out of town highways (65 mph+)
Weekdays			
Weekends			
TOTALS			

Any notable variations (ie. Trips, varying commutes etc.)

____

____

____

Do you have any other concerns you would like to address before continuing?

____

____

____

____

____

____

APPENDIX H

SUBJECT PRE-TEST INSTRUCTIONS

SIMULATED DRIVING STUDY - INSTRUCTIONS TO SUBJECTS

1. **The task is to drive from a start point to an end point through a simulated driving environment. The length of the simulated driving environment from the start to the end point is 11.3 miles.**

2. **Try to drive as you normally drive in the real world.**

3. **There will be 2 experimental sessions. During the 2 sessions, you will be asked to complete a total of 8 driving trials.**

4. **You are free to terminate a session early, if you feel you cannot continue driving.**

5. **One of 2 speed limits will be posted for a each trial: 50 mph or 65 mph.**

6. **You will be asked to complete each trial within 30 seconds faster or slower than the target completion time.**

7. **For each 50 mph trial, the target completion time is 13 minutes, 45 seconds. You should therefore try to finish each 50 mph trial in an elapsed time of between 13 minutes, 15 seconds and 14 minutes 15 seconds.**

8. **For each 65 mph trial, the target completion time is 11 minutes, 45 seconds. You should therefore try to finish each 65 mph trial in an elapsed time of between 11 minutes, 15 seconds and 12 minutes 15 seconds.**

9. **Your elapsed driving time for the trial will depend, in part, on the speed you maintain during the trial. To finish within 30 seconds of the target time, you can't drive too fast or too slow.**

10. **Please obey normal traffic laws:**
    - **Stop at red lights**
    - **Try to drive on roadway**
    - **Do not pull over and stop during task**

11. **At the end of each trial, will be asked to inform the researcher of your estimated driving time for the trial. You will then be told what your actual driving time was.**

12. **You will be paid a $20 regular fee for completing the two sessions.**

13. **You will be paid an extra $20 bonus fee if your actual driving time is within 30 sec faster or slower than the target time for enough trials. Specifically:**

    - **The first 50 mph trial will not count.**
    - **The first 65 mph trial will not count.**
    - **If your actual driving time is within 30 sec of the target time for 4 of the remaining 6 trials, you will be paid an additional bonus of $20.**

APPENDIX I

MATLAB PROGRAM USED TO EXTRACT INTERSECTION BLOCKS OF SIMULATED DRIVING PERFORMANCE DATA

```
%load data file and enter output data filename and high or low track
clear
fname=input('Enter Data Filename   ','s');
sl=input('Enter speed limit in miles/hour   ');
filename=input('Enter Name for Output Datafile   ','s');
data=load([fname '.txt']);
%delimiters for intersections
if sl==50
        bint=[4157.1 2350.8 844.6 -867.9 327.7 -2207.5 -1001.2 835 2165.1 -768.1];
        eint=[3484.2 1677.9 171.7 -1540.8 -345.2 -1534.6 -328.3 1507.9 2838 -96.4];
        bint=bint';
  eint=eint';
elseif sl==65
  bint=[4294.2 2487.9 981.7 -730.8 464.8 -2344.6 -1138.3 697.9 2028 -906.4];
        eint=[3484.2 1677.9 171.7 -1540.8 -345.2 -1534.6 -328.3 1507.9 2838 -96.4];
        bint=bint';
  eint=eint';
end
x=data(:,3);
y=data(:,4);
nrows=zeros(10,1);
n=1;
%Find indices for the 10 intersections
for i=1:10
  if i <= 4
    while x(n) > bint(i)
            n=n+1;
            end
        i1int(i)=n;
            while x(n)> eint(i)
            n=n+1;
    end
  elseif i == 5
    while y(n) > bint(i)
            n=n+1;
            end
        i1int(i)=n;
            while y(n)> eint(i)
            n=n+1;
    end
  elseif i>=6 & i<=9
    while x(n) < bint(i)
            n=n+1;
            end
        i1int(i)=n;
            while x(n)< eint(i)
            n=n+1;
    end
```

```
  elseif i==10
    while y(n) < bint(i)
            n=n+1;
            end
        i1int(i)=n;
            while y(n)< eint(i)
            n=n+1;
    end
end
i2int(i)=n;
nrows(i)=(i2int(i)-i1int(i))+1;
end
sum(nrows);
dataf=zeros(ans,11);
int=zeros(ans,1);
count=1;
for i=1:10
  int(count:(nrows(i)-1)+count)=i;
  count=count+nrows(i);
end
count=1;
for i=1:10
  if i==1
            intdata(count:nrows(i),:)=data(i1int(i):i2int(i),:);
    count=count+nrows(i);
  else
    intdata(count:nrows(i)-1+count,:)=data(i1int(i):i2int(i),:);
        count=count+nrows(i);
        end
end
intdata(:,1)=int;
dlmwrite([filename '.txt'],intdata,'\t')
```

APPENDIX J

MATLAB PROGRAM USED TO EXTRACT VPTY BLOCKS OF SIMULATED DRIVING PERFORMANCE DATA FROM INTERSECTION DATA BLOCKS

```
clear
fs=input('Enter first subject   ');
ls=input('Enter last subject   ');
cond=['lslc'; 'lslt'; 'hslc'; 'hslt'];
pag1=[3 6 5 1];
pag2=[6 8 10 4];
p0s1=[5 3 1 2];
p0s2=[10 9 8 10];
p2s1=[4 2 7 3];
p2s2=[8 5 9 8];
p35s1=[2 1 4 7];
p35s2=[7 10 6 9];
p5s1=[1 4 2 5];
p5s2=[9 7 3 6];
count=1;
for s=fs:ls %subject loop
        for c=1:4 %condition loop
            for k=1:2%trial loop
                data=dlmread(['awf0' int2str(s) cond(c,:) int2str(k) 'Rblks.txt'],'\t');
    %find all green proximities
                sec1=zeros(70,11);
                        sec2=zeros(70,11);
                    first=find(data(:,1)==pag1(c));
                    size(first);
            sec1(1:ans(1,1),:)=data(first,:);
            second=find(data(:,1)==pag2(c));
            size(second);
            sec2(1:ans(1,1),:)=data(second,:);
            totag=[sec1; sec2];
            filename=['awf0' int2str(s) cond(c,:) '1Rblks'];
            aag(:,:,k)=totag;
   %find 0 second proximities
            sec1=zeros(70,11);
                        sec2=zeros(70,11);
                    first=find(data(:,1)==p0s1(c));
                    size(first);
            sec1(1:ans(1,1),:)=data(first,:);
            second=find(data(:,1)==p0s2(c));
            size(second);
            sec2(1:ans(1,1),:)=data(second,:);
            tot0s=[sec1; sec2];
            filename=['awf0' int2str(s) cond(c,:) int2str(k) 'Rblks'];
            a0s(:,:,k)=tot0s;
   %find 2 second proximities
            sec1=zeros(70,11);
                        sec2=zeros(70,11);
                    first=find(data(:,1)==p2s1(c));
                    size(first);
```

```
                    sec1(1:ans(1,1),:)=data(first,:);
                    second=find(data(:,1)==p2s2(c));
                    size(second);
                    sec2(1:ans(1,1),:)=data(second,:);
                    tot2s=[sec1; sec2];
                    filename=['awf0' int2str(s) cond(c,:) '1Rblks'];
                    a2s(:,:,k)=tot2s;
%find 3.5 second proximities
                    sec1=zeros(70,11);
                                        sec2=zeros(70,11);
                              first=find(data(:,1)==p35s1(c));
                              size(first);
                    sec1(1:ans(1,1),:)=data(first,:);
                    second=find(data(:,1)==p35s2(c));
                    size(second);
                    sec2(1:ans(1,1),:)=data(second,:);
                    tot35s=[sec1; sec2];
                    filename=['awf0' int2str(s) cond(c,:) '1Rblks'];
                    a35s(:,:,k)=tot35s;
%find 5 second proximities
                    sec1=zeros(70,11);
                                        sec2=zeros(70,11);
                                        first=find(data(:,1)==p5s1(c));
                              size(first);
                    sec1(1:ans(1,1),:)=data(first,:);
                    second=find(data(:,1)==p5s2(c));
                    size(second);
                    sec2(1:ans(1,1),:)=data(second,:);
                    tot5s=[sec1; sec2];
                    filename=['awf0' int2str(s) cond(c,:) int2str(k) 'Rblks'];
                    a5s(:,:,k)=tot5s;
          end %trial loop
                    dataagt(:,:,count)=[aag(:,:,1); aag(:,:,2)];
                    data0st(:,:,count)=[a0s(:,:,1); a0s(:,:,2)];
                    data2st(:,:,count)=[a2s(:,:,1); a2s(:,:,2)];
                              data35st(:,:,count)=[a35s(:,:,1); a35s(:,:,2)];
     data5st(:,:,count)=[a5s(:,:,1); a5s(:,:,2)];
  if c==1
   lslcdagt(:,:,count)=dataagt(:,:,count);
   lslcd0st(:,:,count)=data0st(:,:,count);
   lslcd2st(:,:,count)=data2st(:,:,count);
   lslcd35st(:,:,count)=data35st(:,:,count);
   lslcd5st(:,:,count)=data5st(:,:,count);
  elseif c==2
   lsltdagt(:,:,count)=dataagt(:,:,count);
   lsltd0st(:,:,count)=data0st(:,:,count);
   lsltd2st(:,:,count)=data2st(:,:,count);
   lsltd35st(:,:,count)=data35st(:,:,count);
   lsltd5st(:,:,count)=data5st(:,:,count);
```

```
        elseif c==3
          hslcdagt(:,:,count)=dataagt(:,:,count);
          hslcd0st(:,:,count)=data0st(:,:,count);
          hslcd2st(:,:,count)=data2st(:,:,count);
          hslcd35st(:,:,count)=data35st(:,:,count);
          hslcd5st(:,:,count)=data5st(:,:,count);
        else
          hsltdagt(:,:,count)=dataagt(:,:,count);
          hsltd0st(:,:,count)=data0st(:,:,count);
          hsltd2st(:,:,count)=data2st(:,:,count);
          hsltd35st(:,:,count)=data35st(:,:,count);
          hsltd5st(:,:,count)=data5st(:,:,count);
       end
     end %condition loop
     count=count+ 1;
end %subject loop
                lslcdag=lslcdagt(:,:,1);
                lslcd0s=lslcd0st(:,:,1);
        lslcd2s=lslcd2st(:,:,1);
        lslcd35s=lslcd35st(:,:,1);
        lslcd5s=lslcd5st(:,:,1);
        lsltdag=lsltdagt(:,:,1);
                lsltd0s=lsltd0st(:,:,1);
        lsltd2s=lsltd2st(:,:,1);
        lsltd35s=lsltd35st(:,:,1);
        lsltd5s=lsltd5st(:,:,1);
        hslcdag=hslcdagt(:,:,1);
                hslcd0s=hslcd0st(:,:,1);
        hslcd2s=hslcd2st(:,:,1);
        hslcd35s=hslcd35st(:,:,1);
        hslcd5s=hslcd5st(:,:,1);
        hsltdag=hsltdagt(:,:,1);
                hsltd0s=hsltd0st(:,:,1);
        hsltd2s=hsltd2st(:,:,1);
        hsltd35s=hsltd35st(:,:,1);
        hsltd5s=hsltd5st(:,:,1);
    if count>1
        for l=2:(count-1)
          lslcdag=[lslcdag ;lslcdagt(:,:,l)];
                lslcd0s=[lslcd0s;lslcd0st(:,:,l)];
                lslcd2s=[lslcd2s; lslcd2st(:,:,l)];
                lslcd35s=[lslcd35s;lslcd35st(:,:,l)];
          lslcd5s=[lslcd5s;lslcd5st(:,:,l)];
          lsltdag=[lsltdag ;lsltdagt(:,:,l)];
                lsltd0s=[lsltd0s;lsltd0st(:,:,l)];
                lsltd2s=[lsltd2s; lsltd2st(:,:,l)];
                lsltd35s=[lsltd35s;lsltd35st(:,:,l)];
          lsltd5s=[lsltd5s;lsltd5st(:,:,l)];
```

```
          hslcdag=[hslcdag ;hslcdagt(:,:,l)];
                hslcd0s=[hslcd0s;hslcd0st(:,:,l)];
                hslcd2s=[hslcd2s; hslcd2st(:,:,l)];
                hslcd35s=[hslcd35s;hslcd35st(:,:,l)];
          hslcd5s=[hslcd5s;hslcd5st(:,:,l)];
          hsltdag=[hsltdag ;hsltdagt(:,:,l)];
                hsltd0s=[hsltd0s;hsltd0st(:,:,l)];
                hsltd2s=[hsltd2s; hsltd2st(:,:,l)];
                hsltd35s=[hsltd35s;hsltd35st(:,:,l)];
          hsltd5s=[hsltd5s;hsltd5st(:,:,l)];
       end
    end
%get rid of empty lines
    empty=find(lslcdag(:,1)==0);
    lslcdag(empty,:)=[];
    empty=find(lslcd0s(:,1)==0);
    lslcd0s(empty,:)=[];
    empty=find(lslcd2s(:,1)==0);
    lslcd2s(empty,:)=[];
    empty=find(lslcd35s(:,1)==0);
    lslcd35s(empty,:)=[];
    empty=find(lslcd5s(:,1)==0);
    lslcd5s(empty,:)=[];
    empty=find(lsltdag(:,1)==0);
    lsltdag(empty,:)=[];
    empty=find(lsltd0s(:,1)==0);
    lsltd0s(empty,:)=[];
    empty=find(lsltd2s(:,1)==0);
    lsltd2s(empty,:)=[];
    empty=find(lsltd35s(:,1)==0);
    lsltd35s(empty,:)=[];
    empty=find(lsltd5s(:,1)==0);
    lsltd5s(empty,:)=[];
    empty=find(hslcdag(:,1)==0);
    hslcdag(empty,:)=[];
    empty=find(hslcd0s(:,1)==0);
    hslcd0s(empty,:)=[];
    empty=find(hslcd2s(:,1)==0);
    hslcd2s(empty,:)=[];
    empty=find(hslcd35s(:,1)==0);
    hslcd35s(empty,:)=[];
    empty=find(hslcd5s(:,1)==0);
    hslcd5s(empty,:)=[];
    empty=find(hsltdag(:,1)==0);
    hsltdag(empty,:)=[];
    empty=find(hsltd0s(:,1)==0);
    hsltd0s(empty,:)=[];
    empty=find(hsltd2s(:,1)==0);
```

```
    hsltd2s(empty,:)=[];
    empty=find(hsltd35s(:,1)==0);
    hsltd35s(empty,:)=[];
    empty=find(hsltd5s(:,1)==0);
    hsltd5s(empty,:)=[];
%write data to ascii files
    dlmwrite([cond(1,:) 'allgreen.txt'], lslcdag ,'\t')
                dlmwrite([cond(1,:) '0sec.txt'], lslcd0s ,'\t')
                dlmwrite([cond(1,:) '2sec.txt'], lslcd2s ,'\t')
                dlmwrite([cond(1,:) '35sec.txt'], lslcd35s ,'\t')
    dlmwrite([cond(1,:) '5sec.txt'], lslcd5s ,'\t')
    dlmwrite([cond(2,:) 'allgreen.txt'], lsltdag ,'\t')
                dlmwrite([cond(2,:) '0sec.txt'], lsltd0s ,'\t')
                dlmwrite([cond(2,:) '2sec.txt'], lsltd2s ,'\t')
                dlmwrite([cond(2,:) '35sec.txt'], lsltd35s ,'\t')
    dlmwrite([cond(2,:) '5sec.txt'], lsltd5s ,'\t')
    dlmwrite([cond(3,:) 'allgreen.txt'], hslcdag ,'\t')
                dlmwrite([cond(3,:) '0sec.txt'], hslcd0s ,'\t')
                dlmwrite([cond(3,:) '2sec.txt'], hslcd2s ,'\t')
                dlmwrite([cond(3,:) '35sec.txt'], hslcd35s ,'\t')
    dlmwrite([cond(3,:) '5sec.txt'], hslcd5s ,'\t')
    dlmwrite([cond(4,:) 'allgreen.txt'], hsltdag ,'\t')
                dlmwrite([cond(4,:) '0sec.txt'], hsltd0s ,'\t')
                dlmwrite([cond(4,:) '2sec.txt'], hsltd2s ,'\t')
                dlmwrite([cond(4,:) '35sec.txt'], hsltd35s ,'\t')
    dlmwrite([cond(4,:) '5sec.txt'], hsltd5s ,'\t')
```

APPENDIX K

SPEED, BRAKING, AND ACCELERATION/DECELERATION PROFILES FROM LSL TRIALS FOR SUBJECT 19 DURING INTERACTIONS WITH INTERSECTIONS AT DIFFERENT VPTY LEVELS

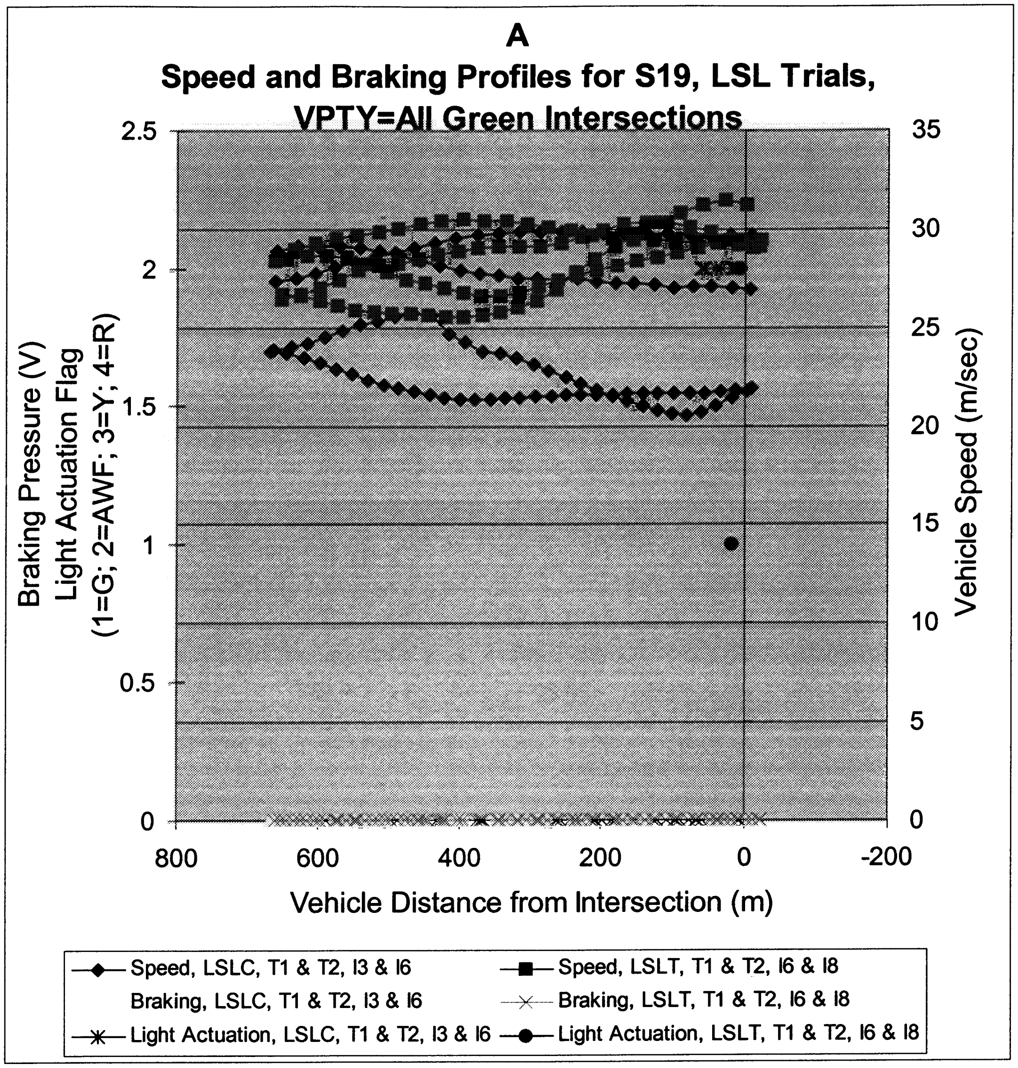


Figure K-1A. Speed and braking profiles for interactions of S19 with VPTY=AG intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=AG intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

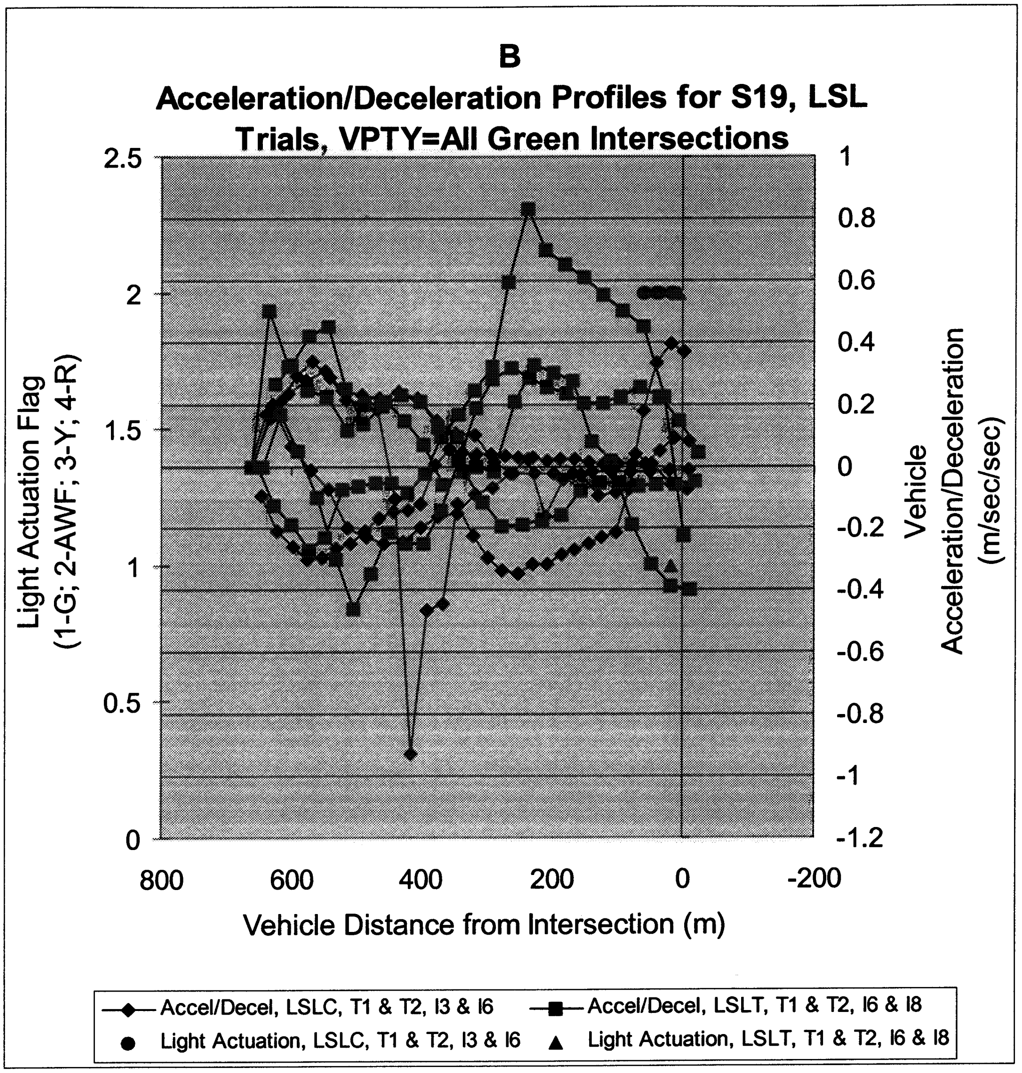


Figure K-1B. Acceleration/deceleration profiles for interactions of S19 with VPTY=AG intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=AG intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

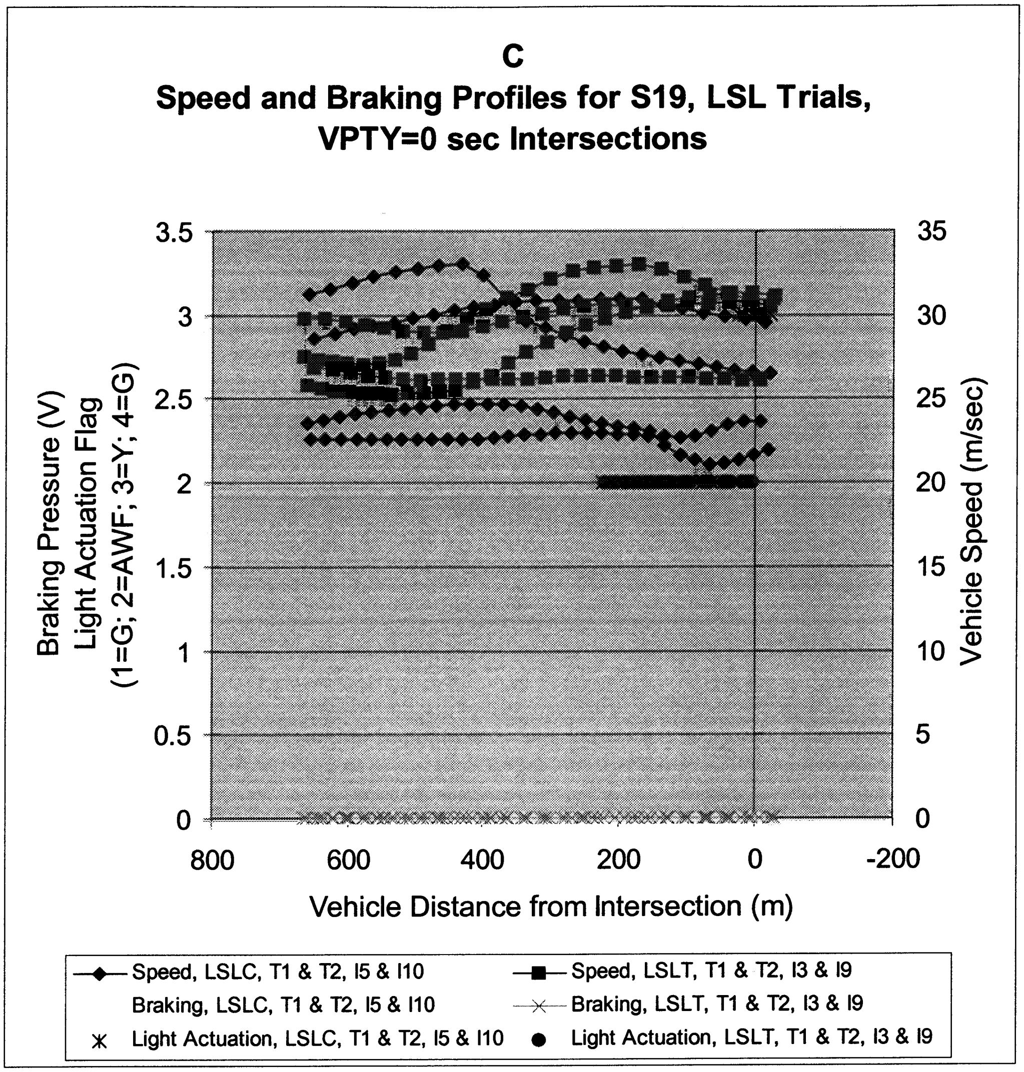


Figure K-1C. Speed and braking profiles for interactions of S19 with VPTY=0 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=0 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

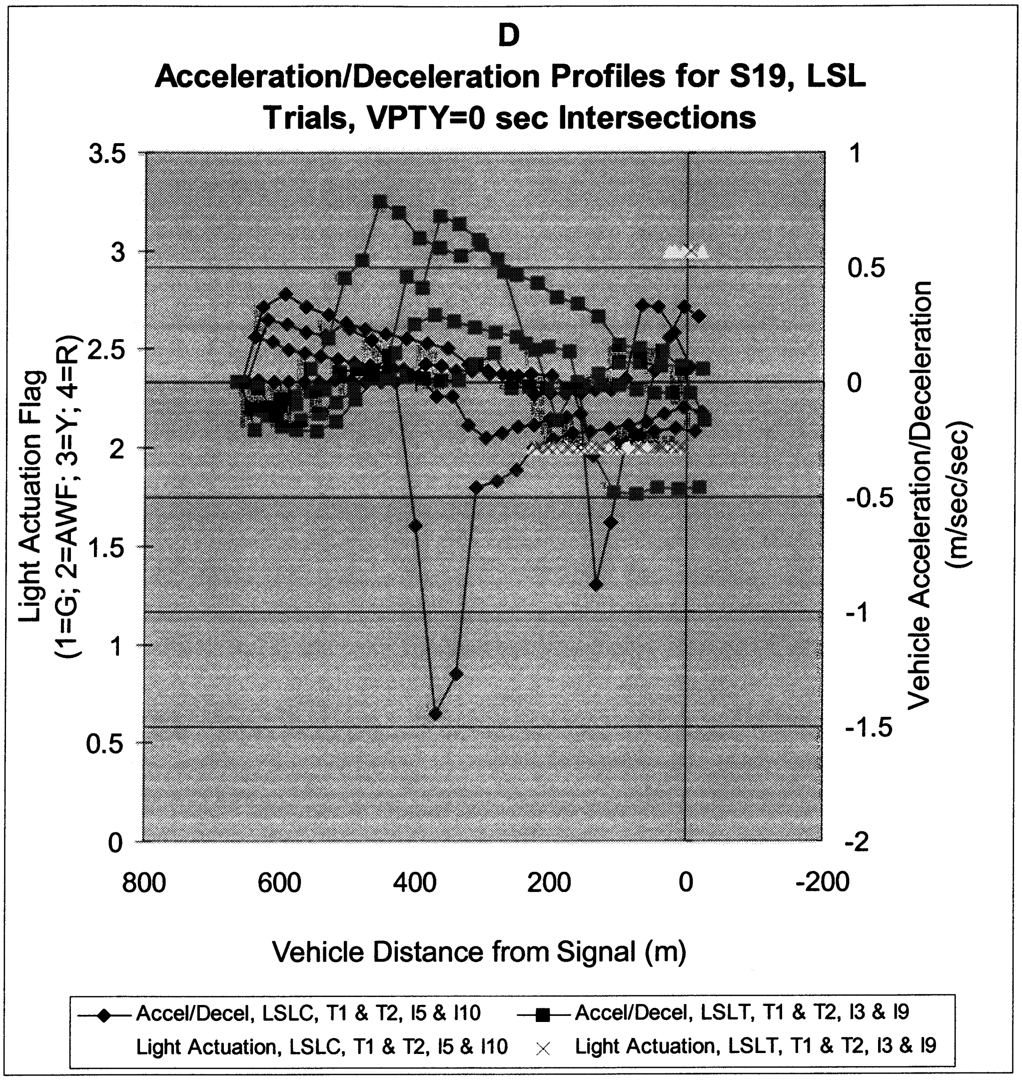


Figure K-1D. Acceleration/deceleration profiles for interactions of S19 with VPTY=0 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=0 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

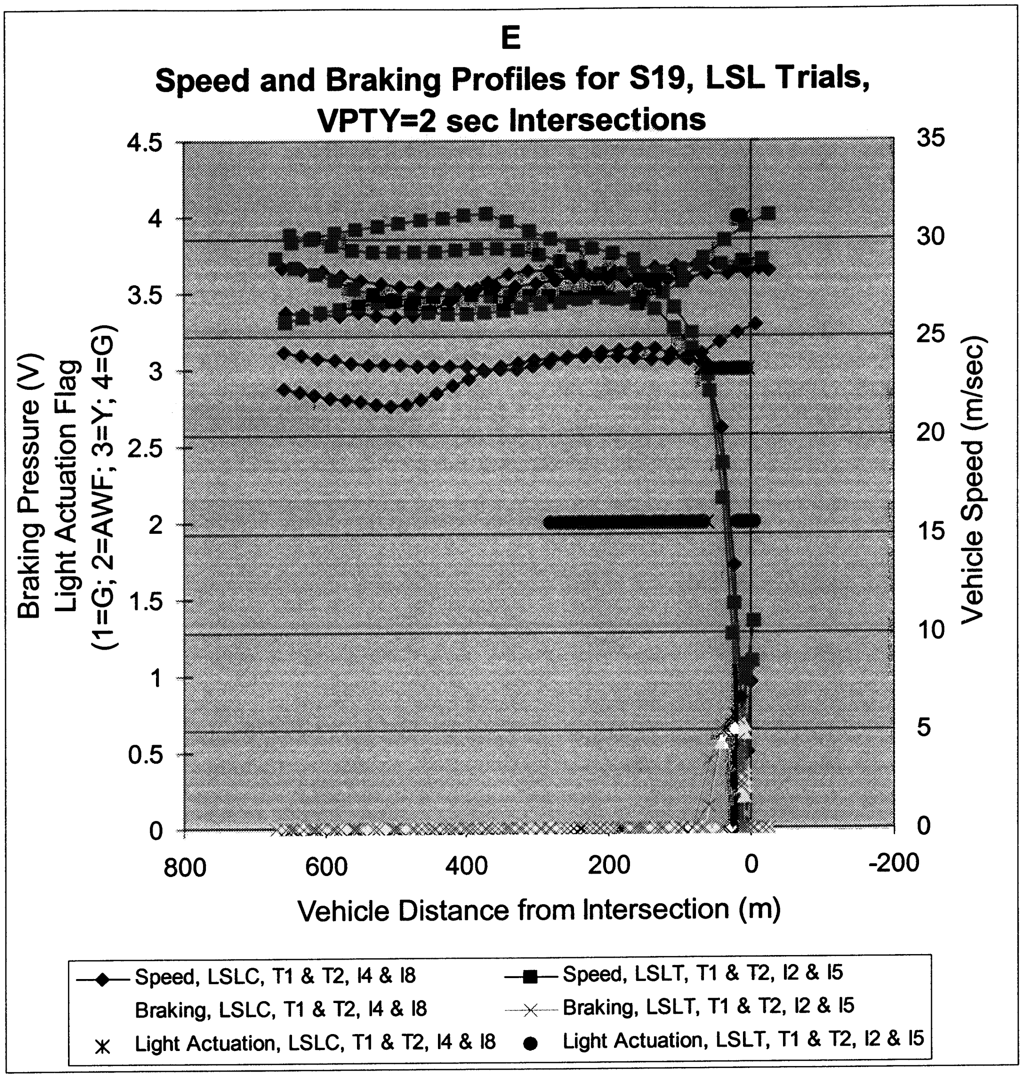


Figure K-1E. Speed and braking profiles for interactions of S19 with VPTY=2 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=2 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

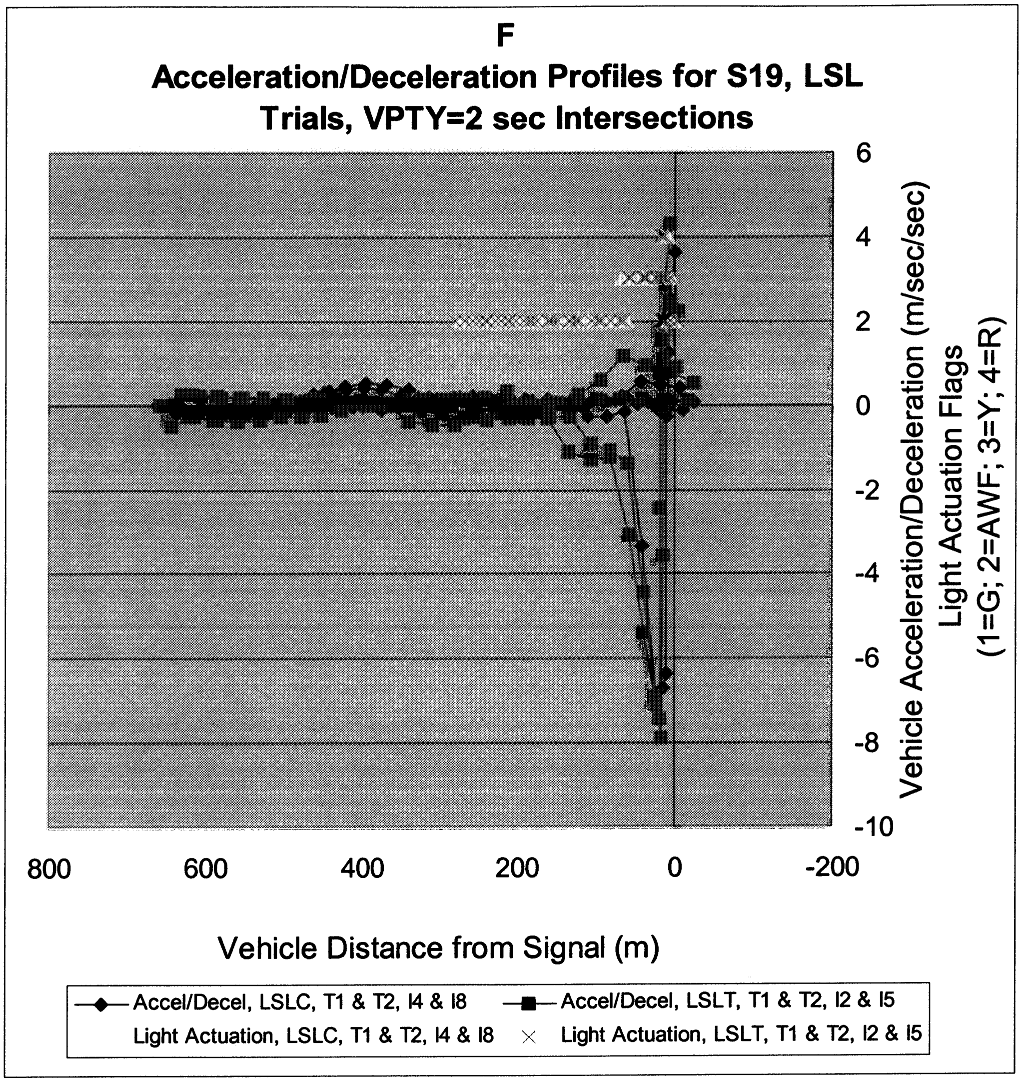


Figure K-1F. Acceleration/deceleration profiles for interactions of S19 with VPTY=2 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=2 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

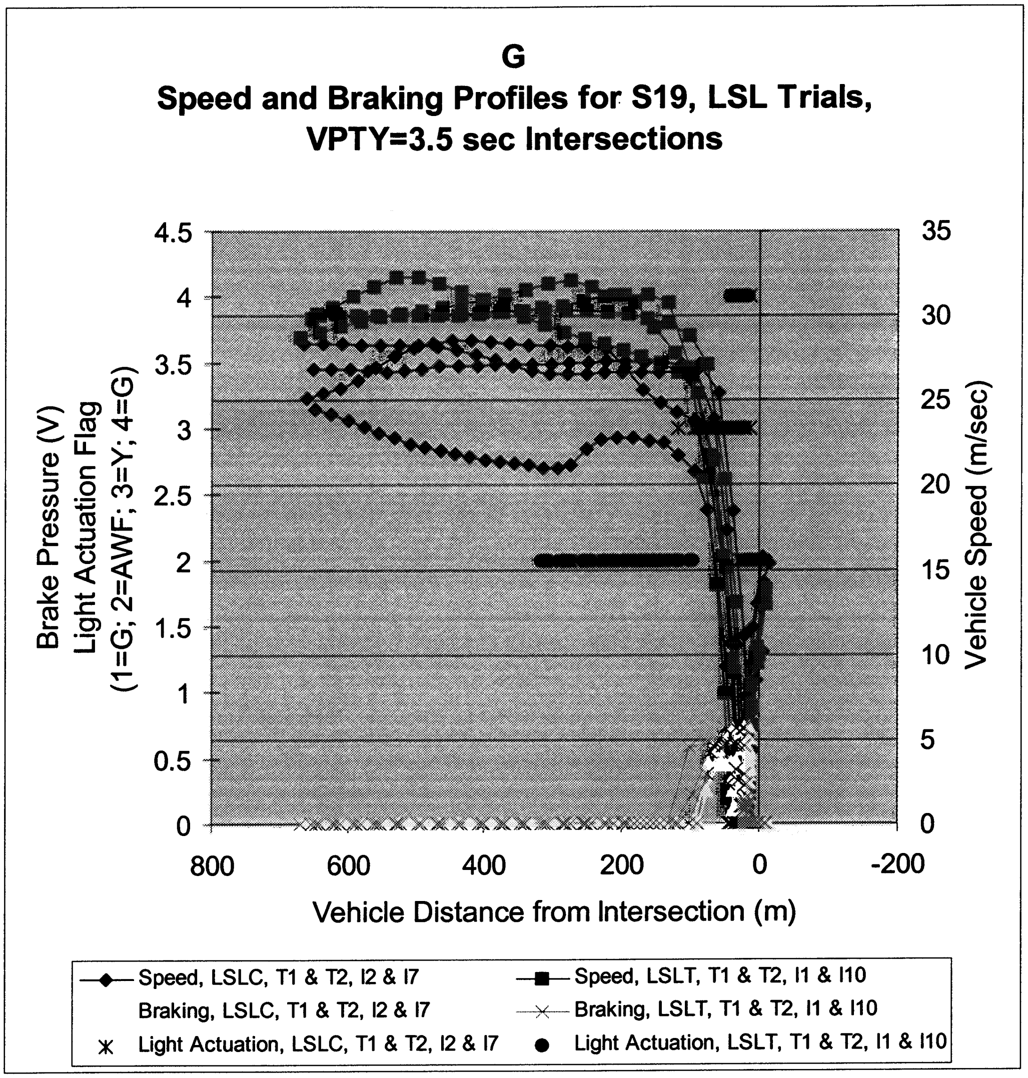


Figure K-1G. Speed and braking profiles for interactions of S19 with VPTY=3.5 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=3.5 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

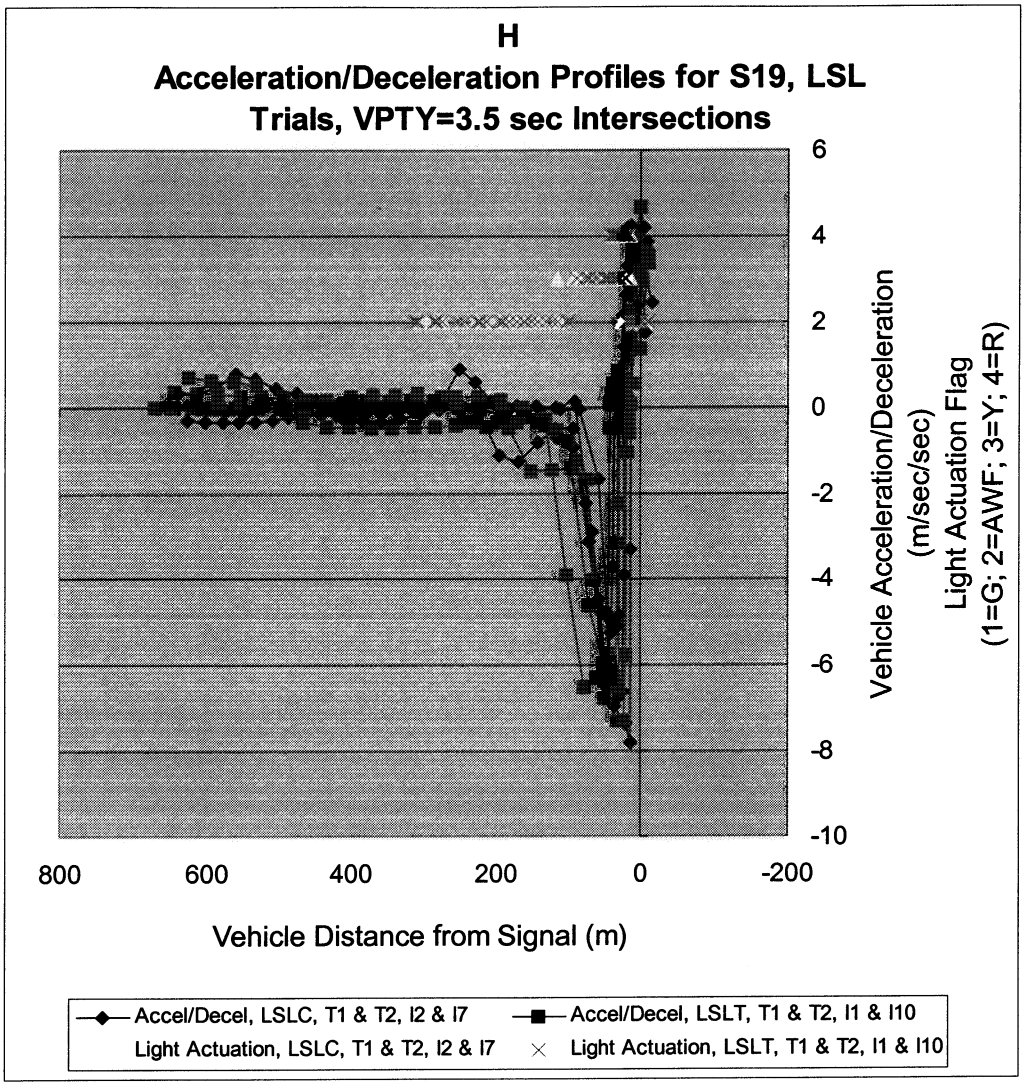


Figure K-1H. Acceleration/deceleration profiles for interactions of S19 with VPTY=3.5 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=3.5 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

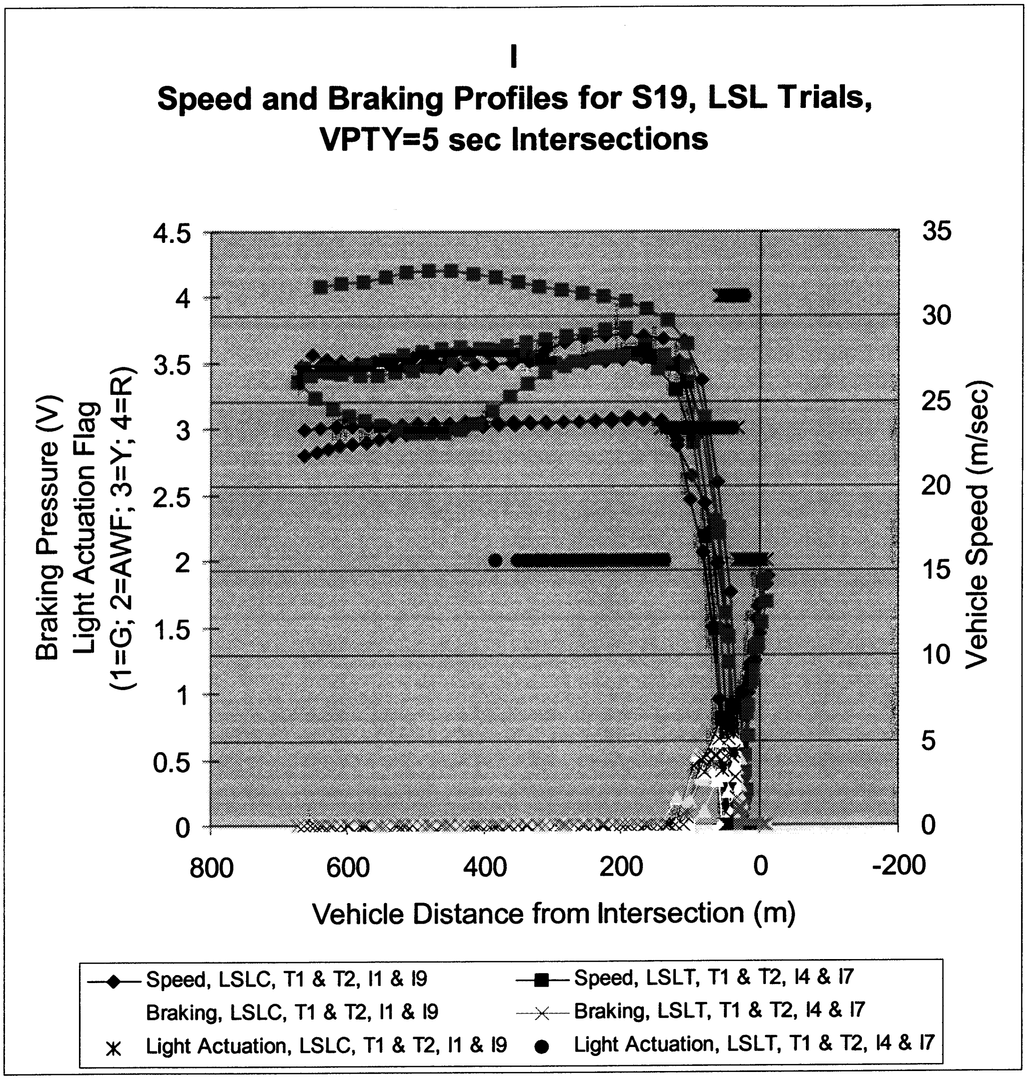


Figure K-1I. Speed and braking profiles for interactions of S19 with VPTY=5 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=5 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

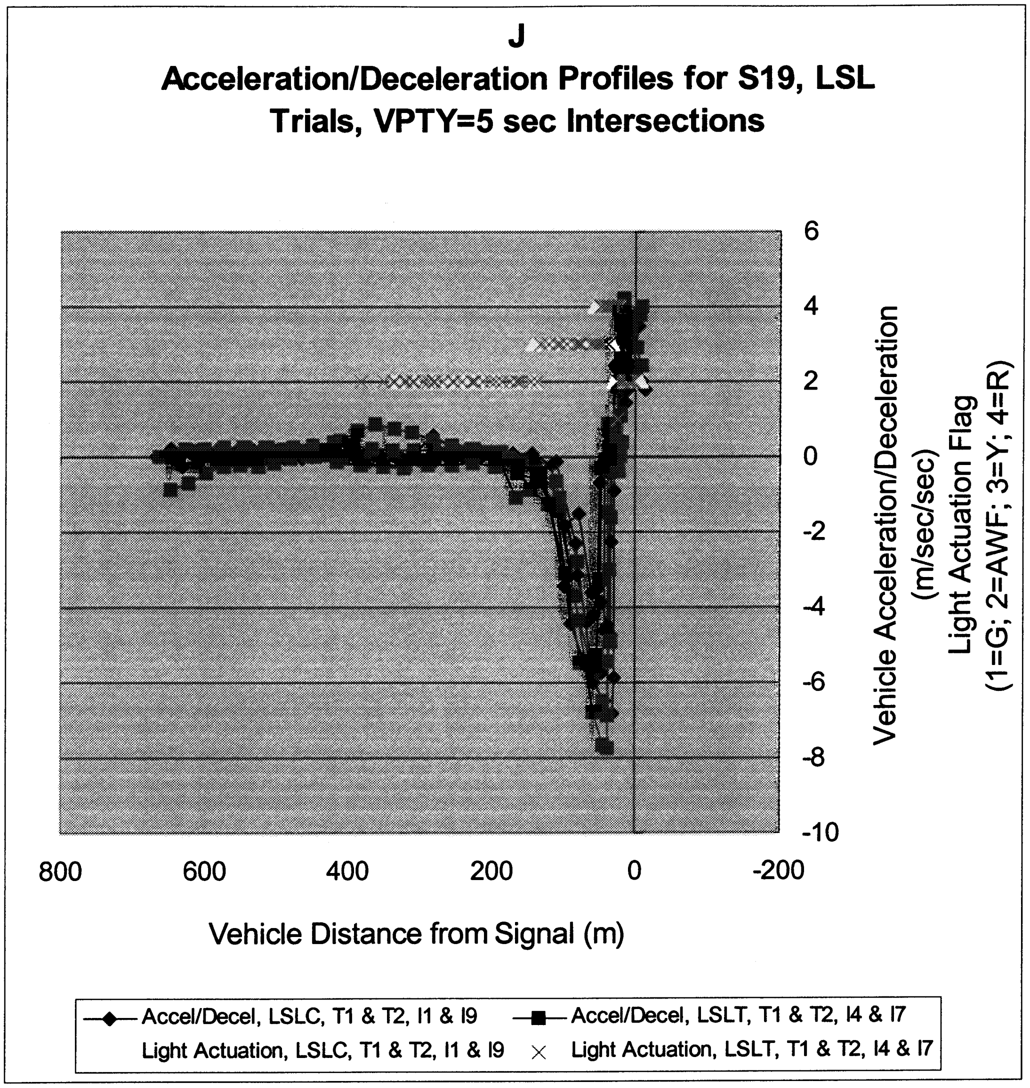


Figure K-1J. Acceleration/deceleration profiles for interactions of S19 with VPTY=5 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=5 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

APPENDIX L

SPEED, BRAKING, AND ACCELERATION/DECELERATION PROFILES FROM LSL TRIALS FOR SUBJECT 23 DURING INTERACTIONS WITH INTERSECTIONS AT DIFFERENT VPTY LEVELS

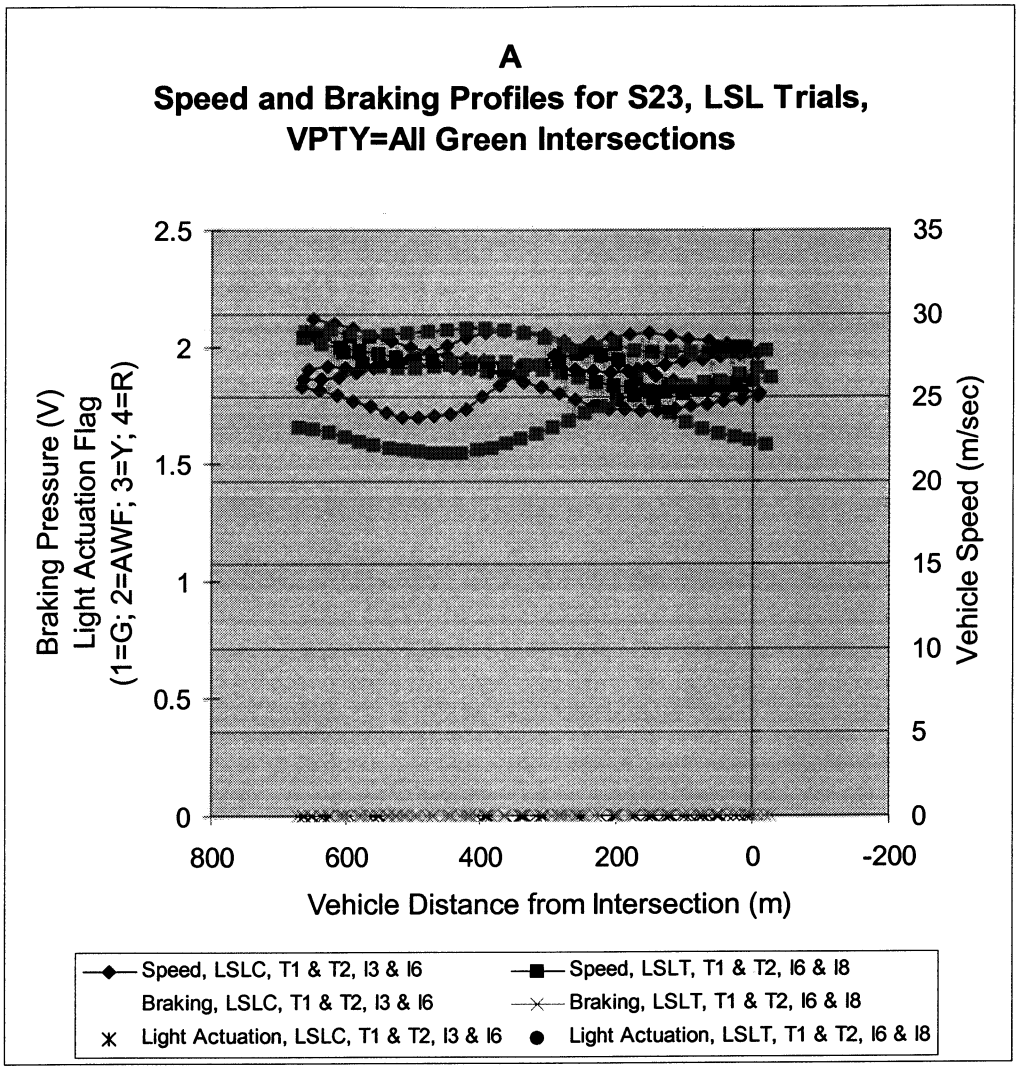


Figure L-1A. Speed and braking profiles for interactions of S23 with VPTY=AG intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=AG intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

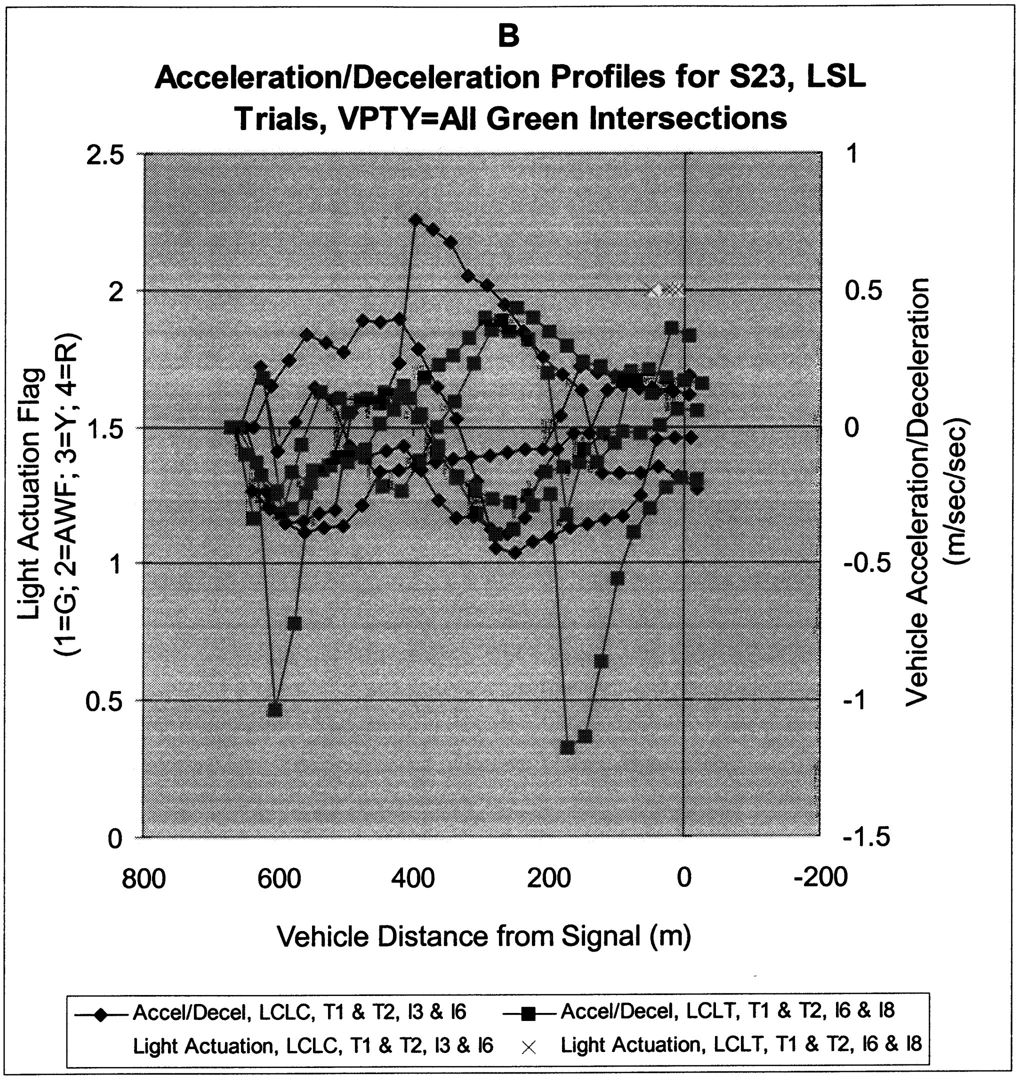


Figure L-1B. Acceleration/deceleration profiles for interactions of S23 with VPTY=AG intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=AG intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

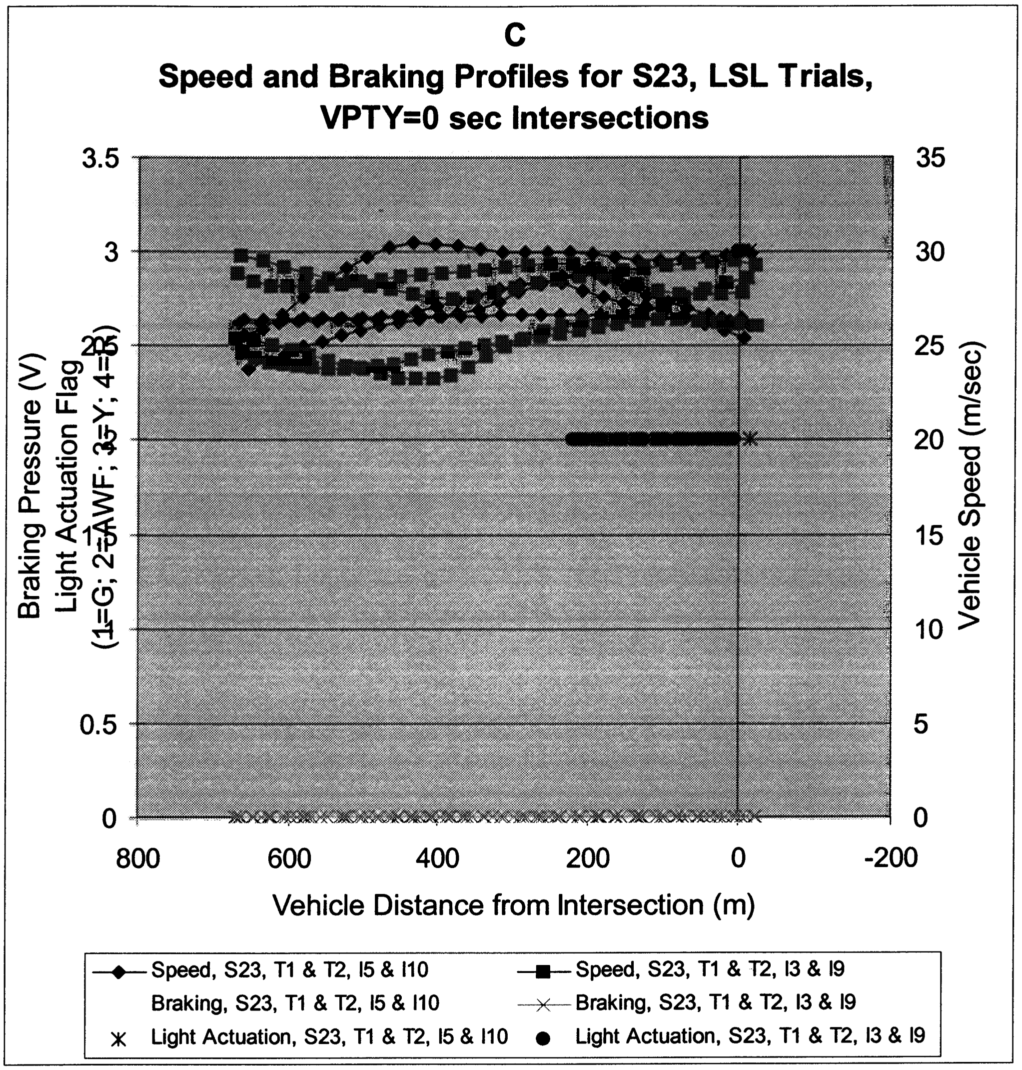


Figure L-1C. Speed and braking profiles for interactions of S23 with VPTY=0 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=0 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

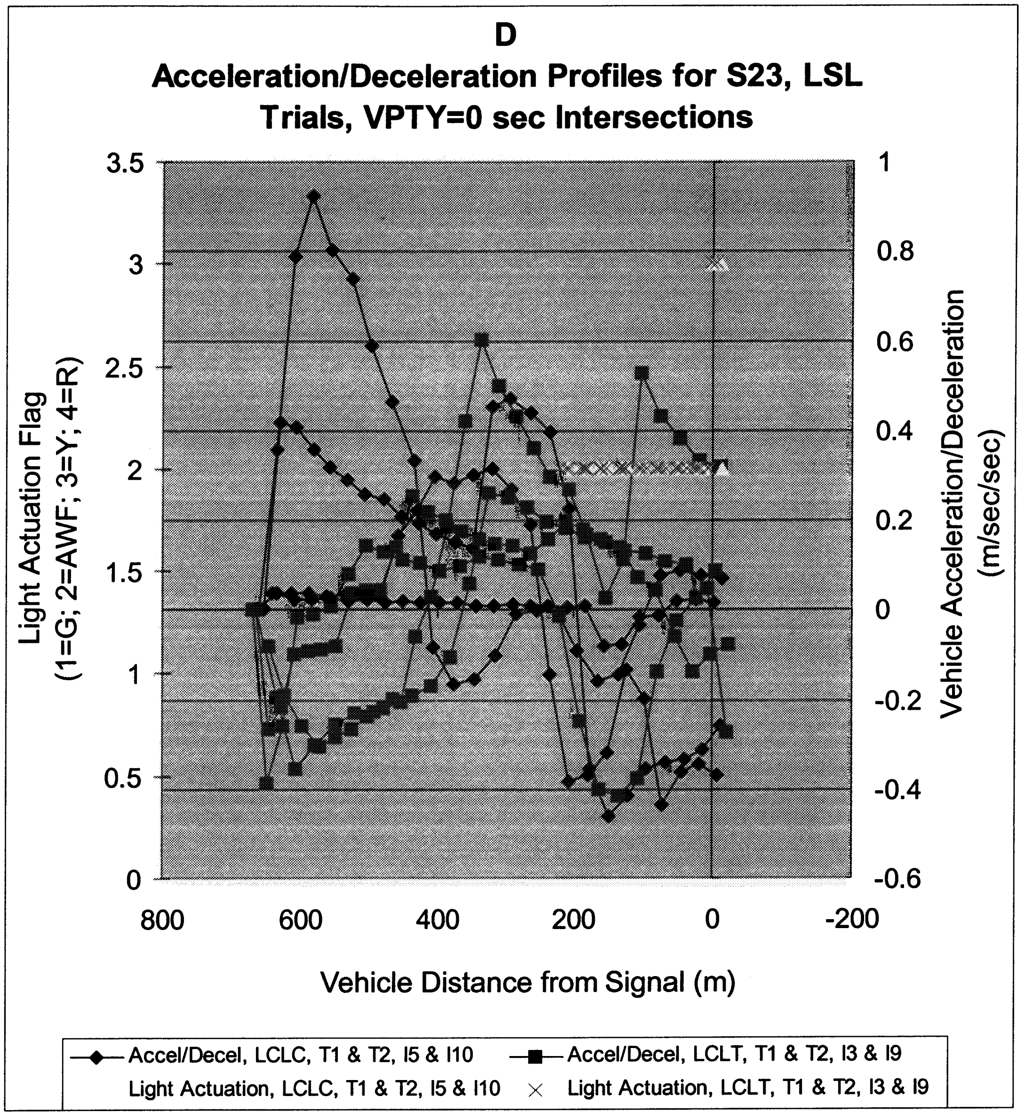


Figure L-1D. Acceleration/deceleration profiles for interactions of S23 with VPTY=0 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=0 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

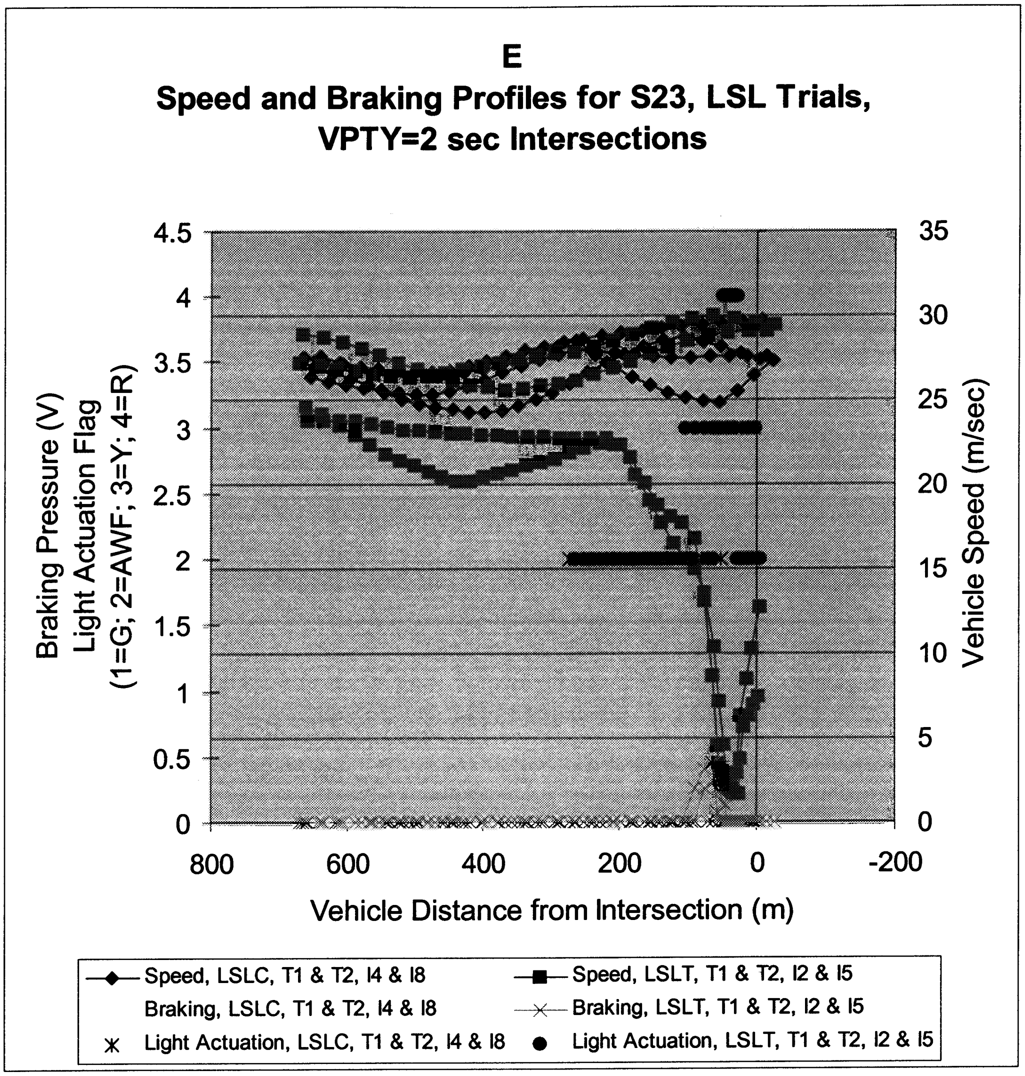


Figure L-1E. Speed and braking profiles for interactions of S23 with VPTY=2 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=2 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

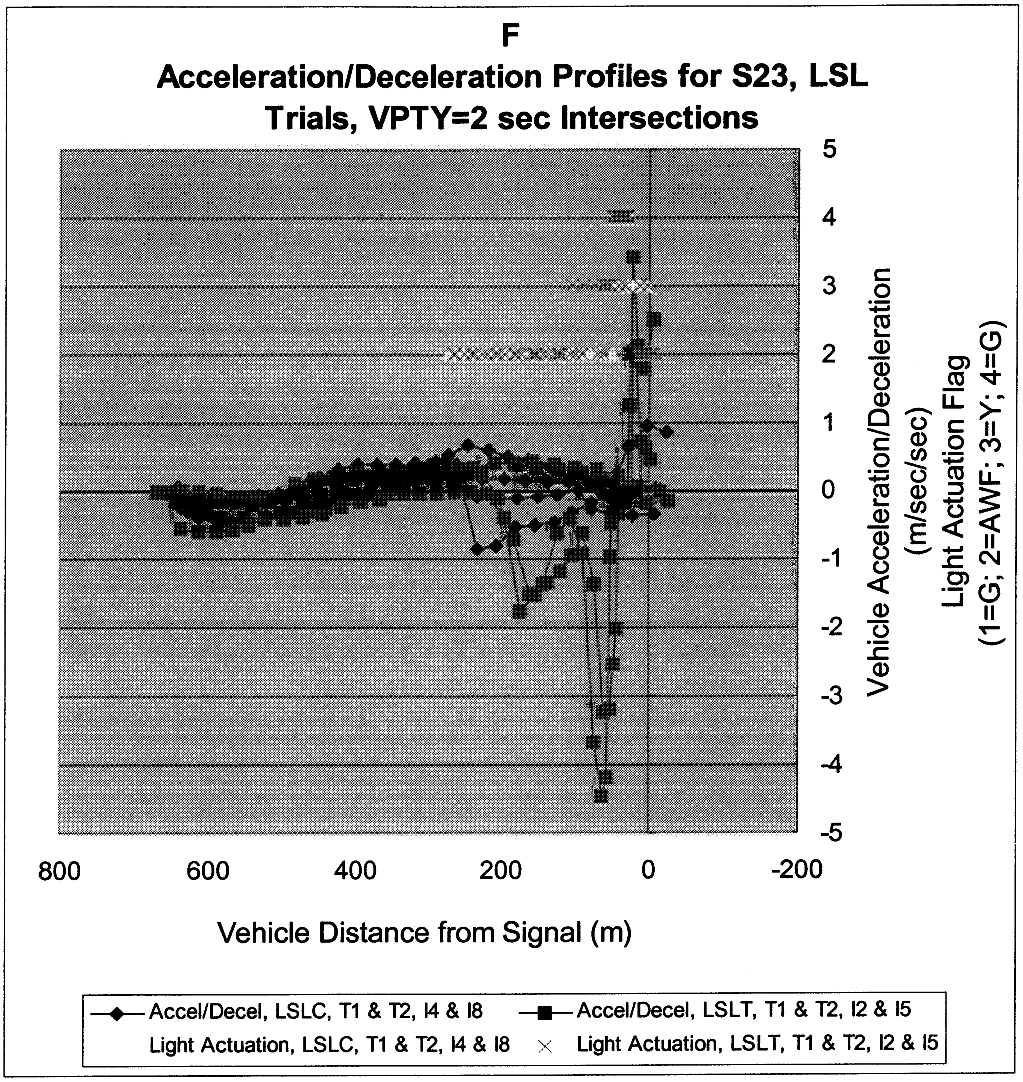


Figure L-1F. Acceleration/deceleration profiles for interactions of S23 with VPTY=2 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=2 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

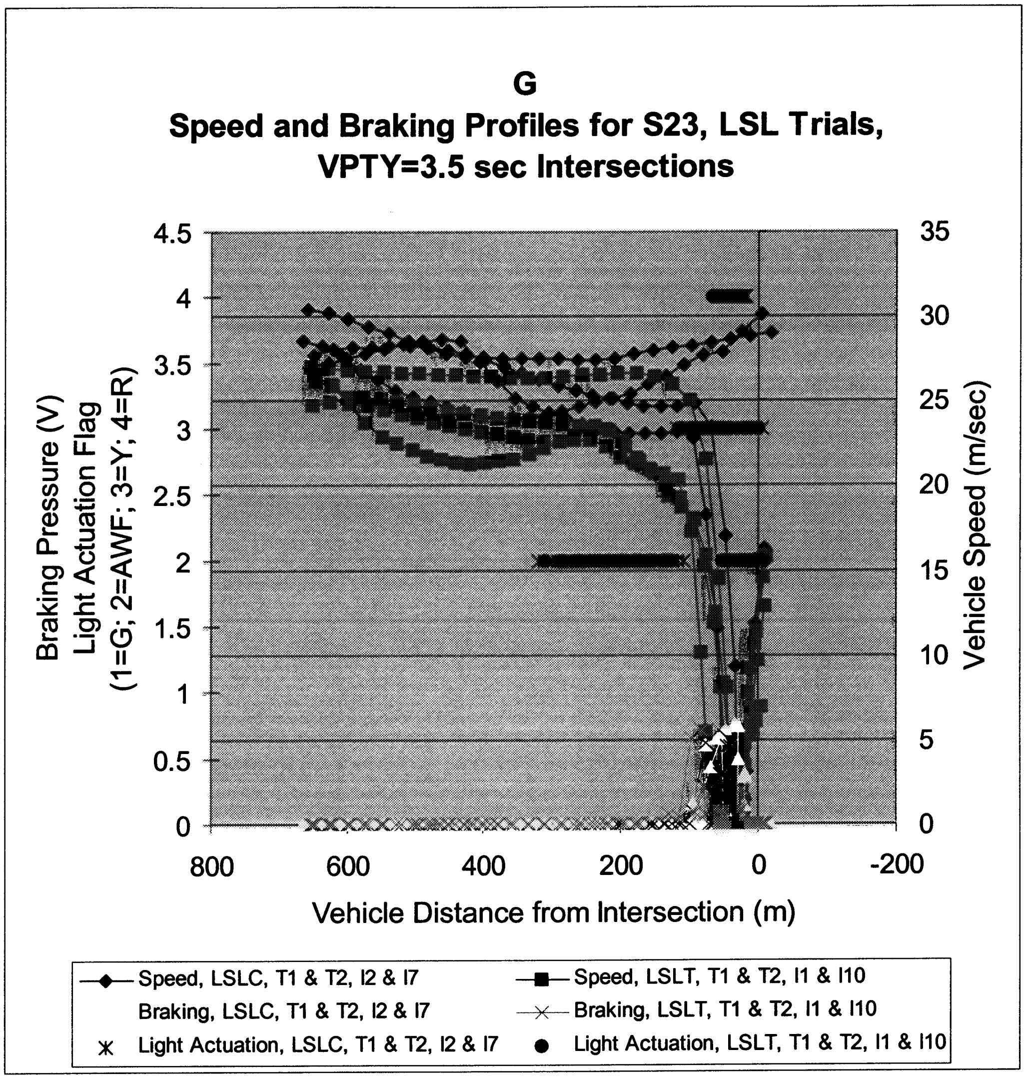


Figure L-1G. Speed and braking profiles for interactions of S23 with VPTY=3.5 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=3.5 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

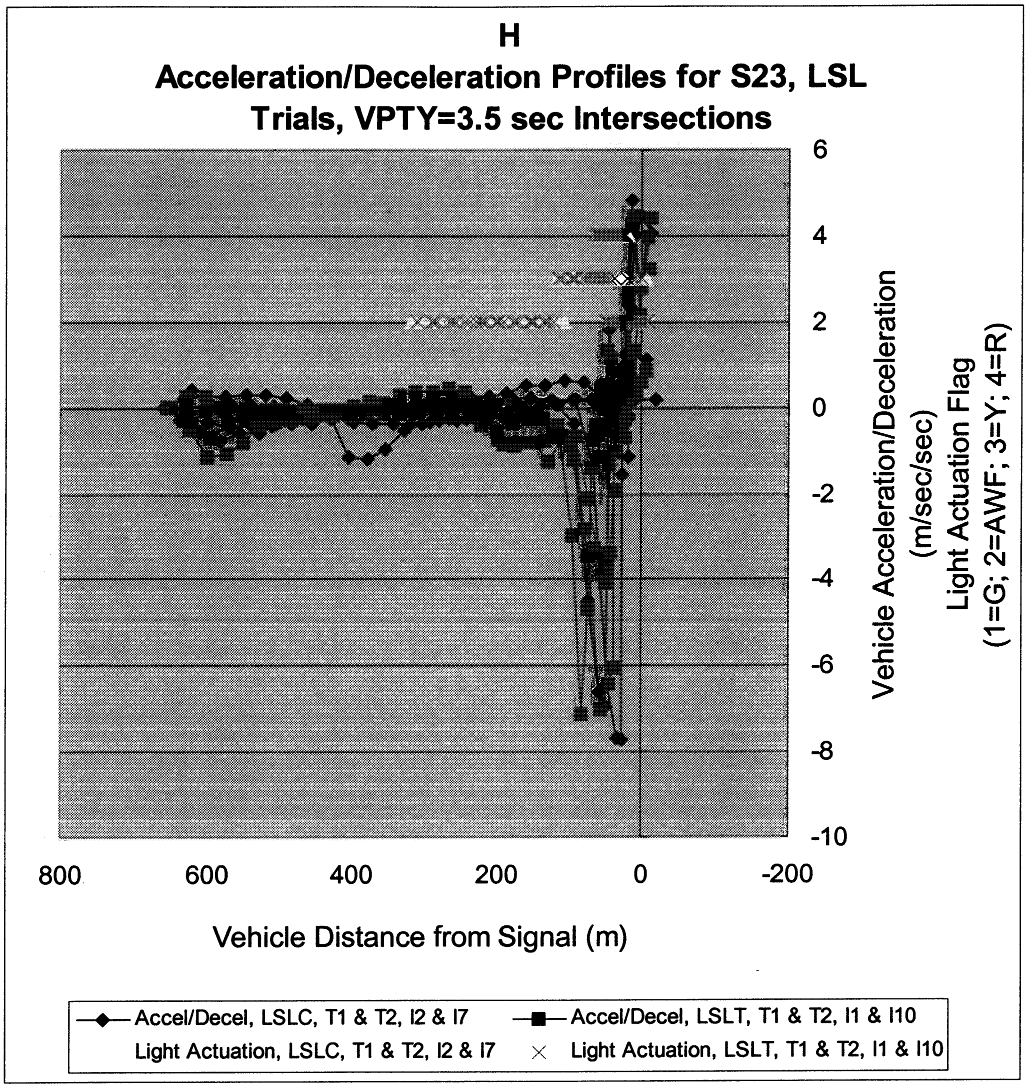


Figure L-1H. Acceleration/deceleration profiles for interactions of S23 with VPTY=3.5 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=3.5 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

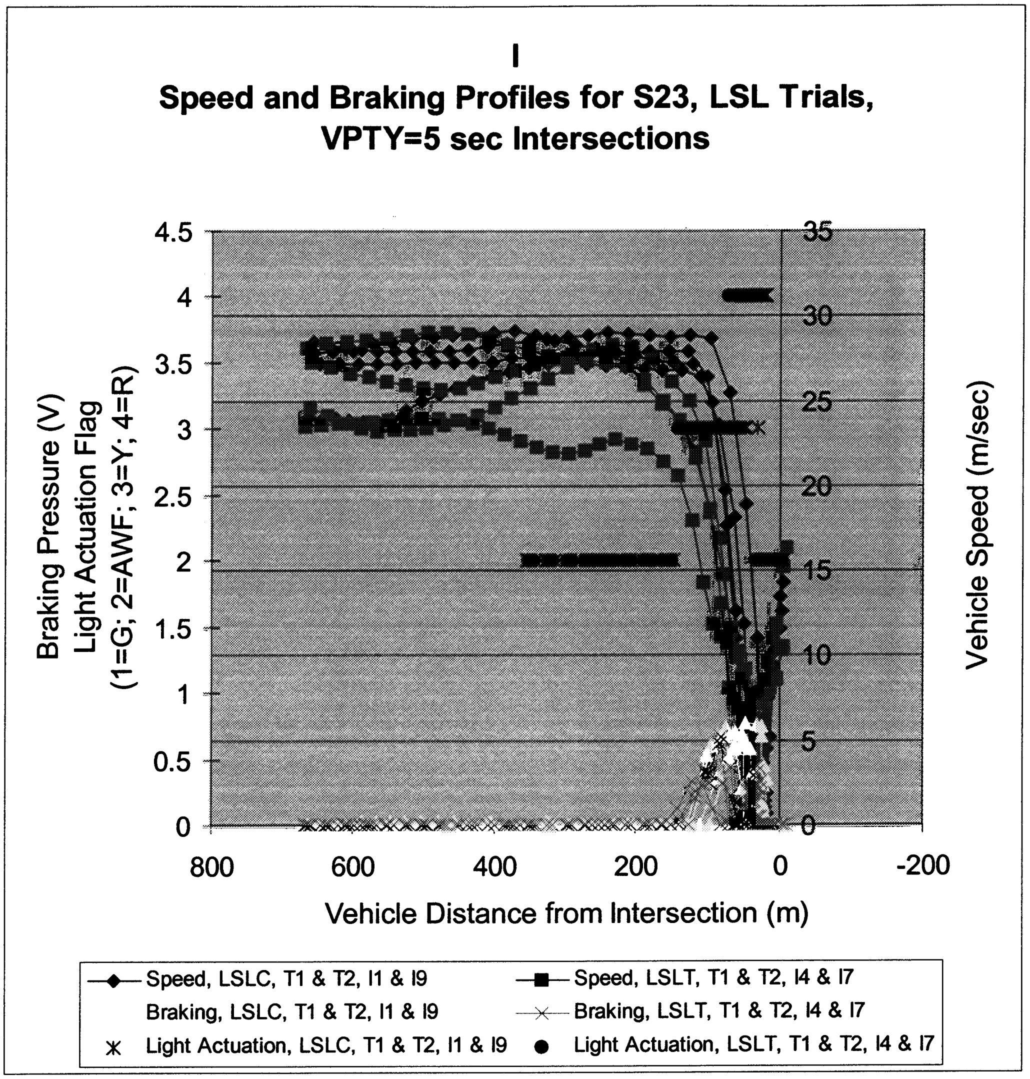


Figure L-1I. Speed and braking profiles for interactions of S23 with VPTY=5 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=5 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

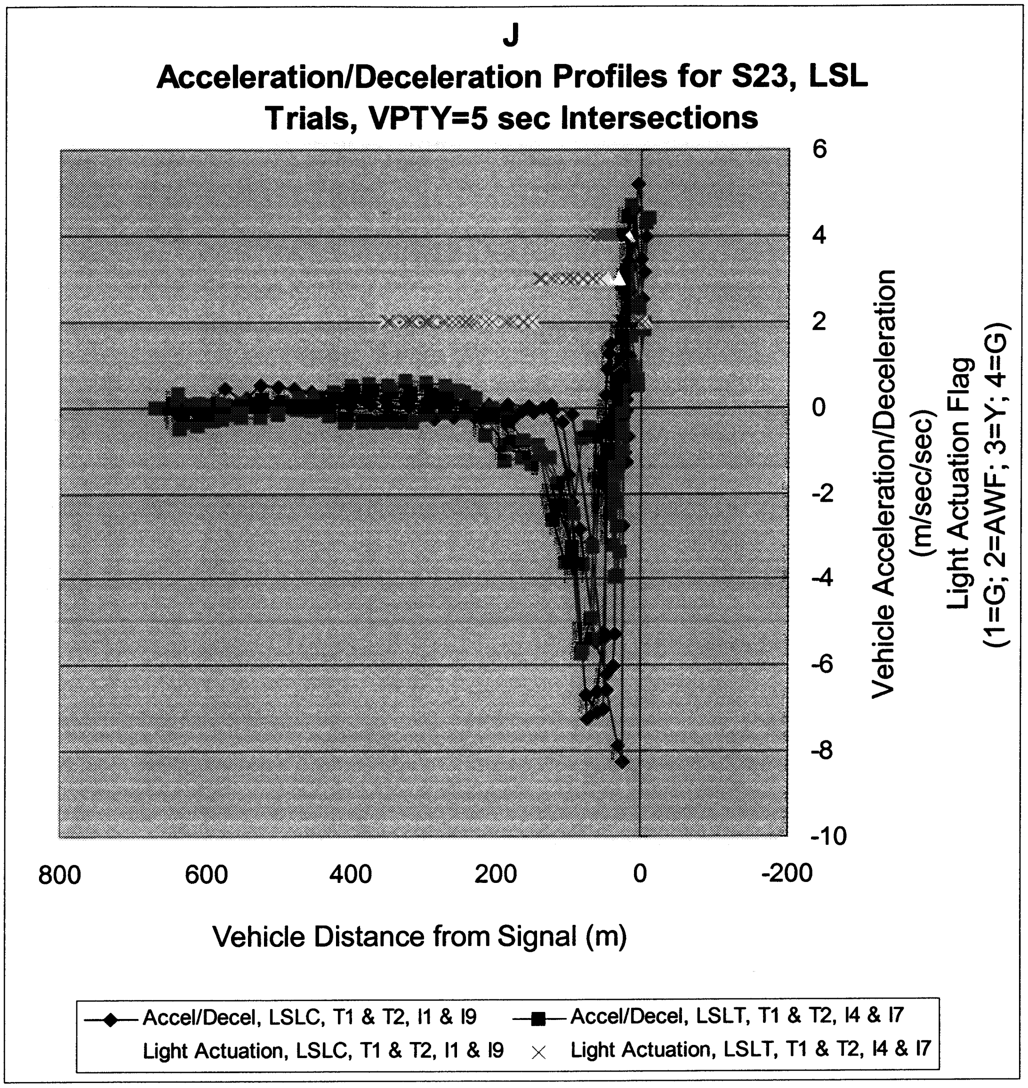
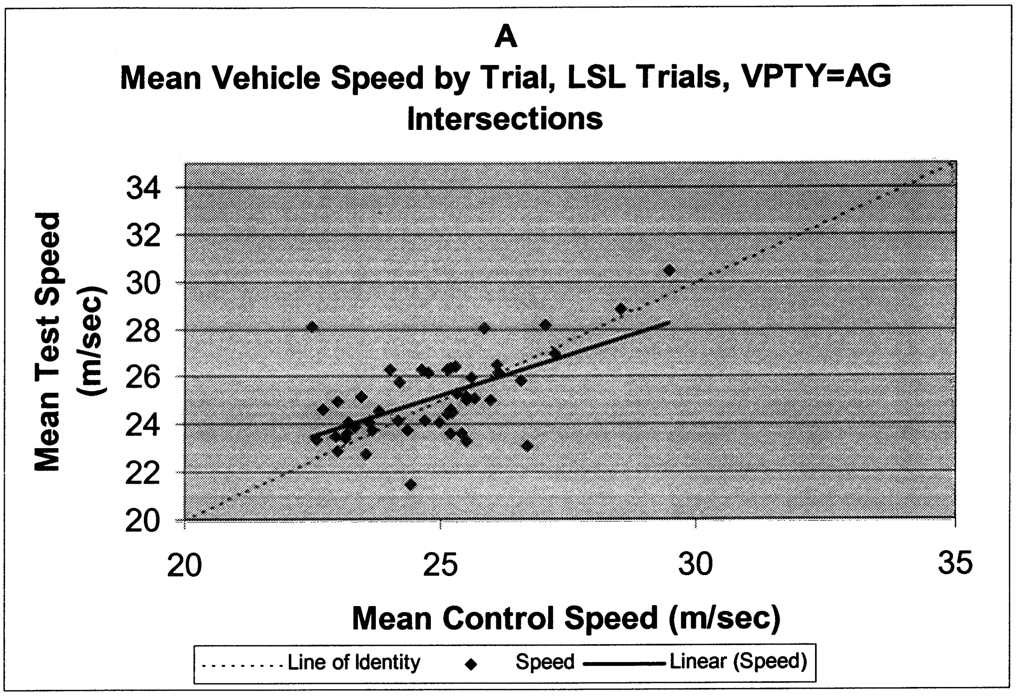


Figure L-1J. Acceleration/deceleration profiles for interactions of S23 with VPTY=5 sec intersections during LSL trials. Four profiles each for control and test trials (2 control and 2 test trials, and 2 VPTY=5 sec intersections per trial), along with light actuation flags for each trial, are plotted in relation to vehicle distance from the intersection.

APPENDIX M

SCATTER PLOTS OF PAIRED, WITHIN-SUBJECT MEANS BY TRIAL FOR CONTROL VERSUS TEST MEASURES OF SIMULATED DRIVING PERFORMANCE FOR LSL TRIALS



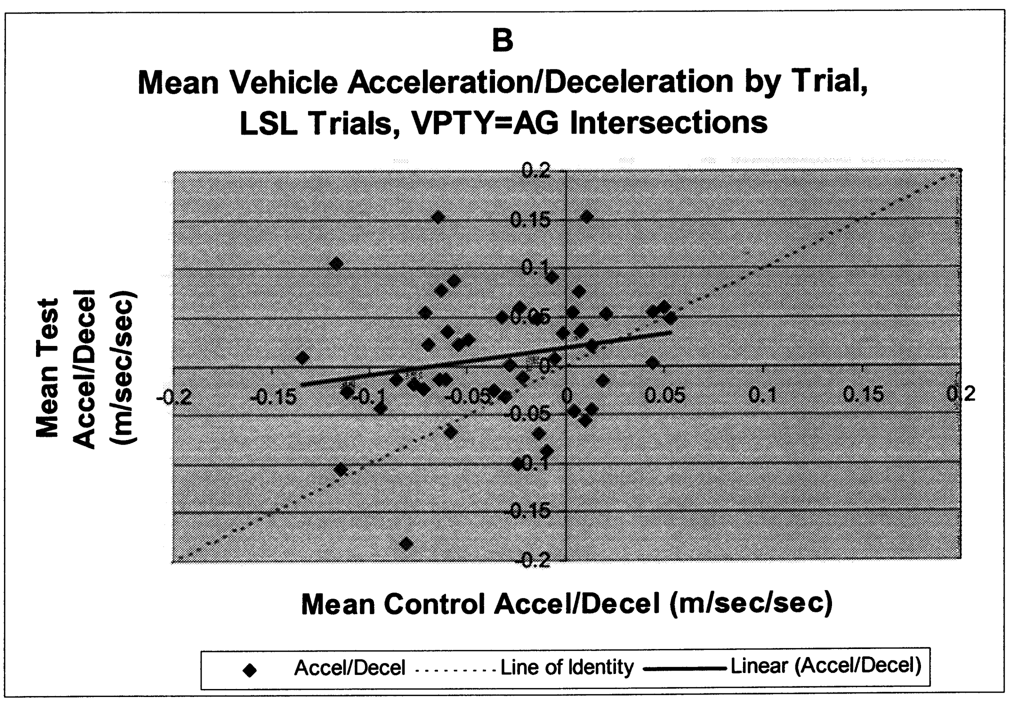
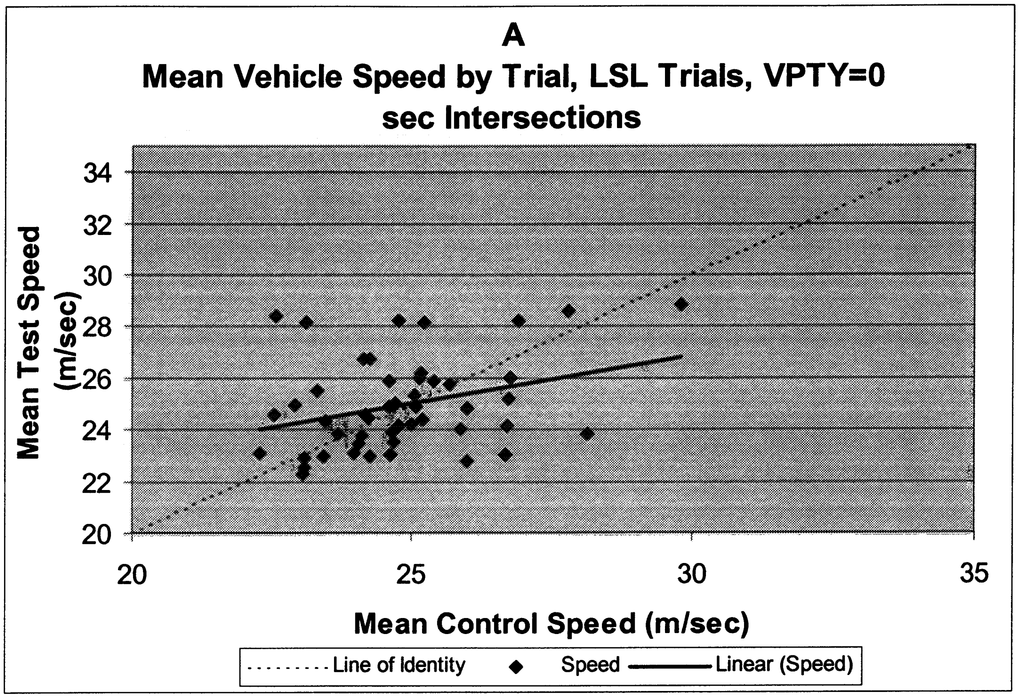


Figure M-1. Scatter plots of paired, within-subject control versus test mean results by trial for speed (A) and acceleration/deceleration (B) SDP measures, LSL trials, VTPY=AG intersections. Each point represents control-test paired means for 1 S. Solid line is LSR fit to data. Dashed line is line of identity.



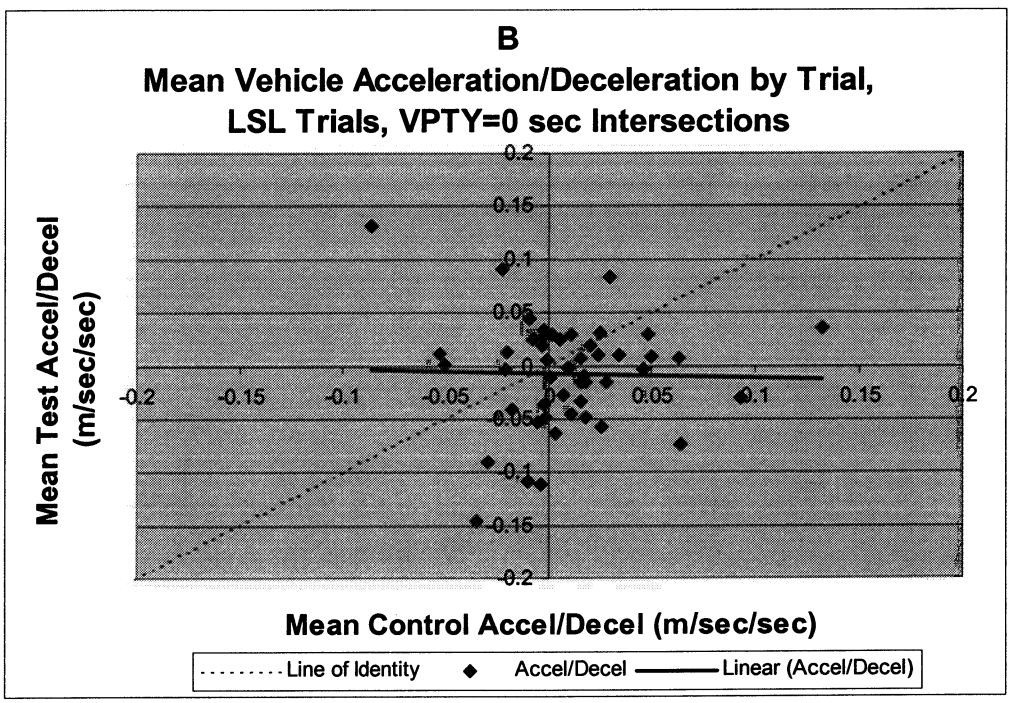
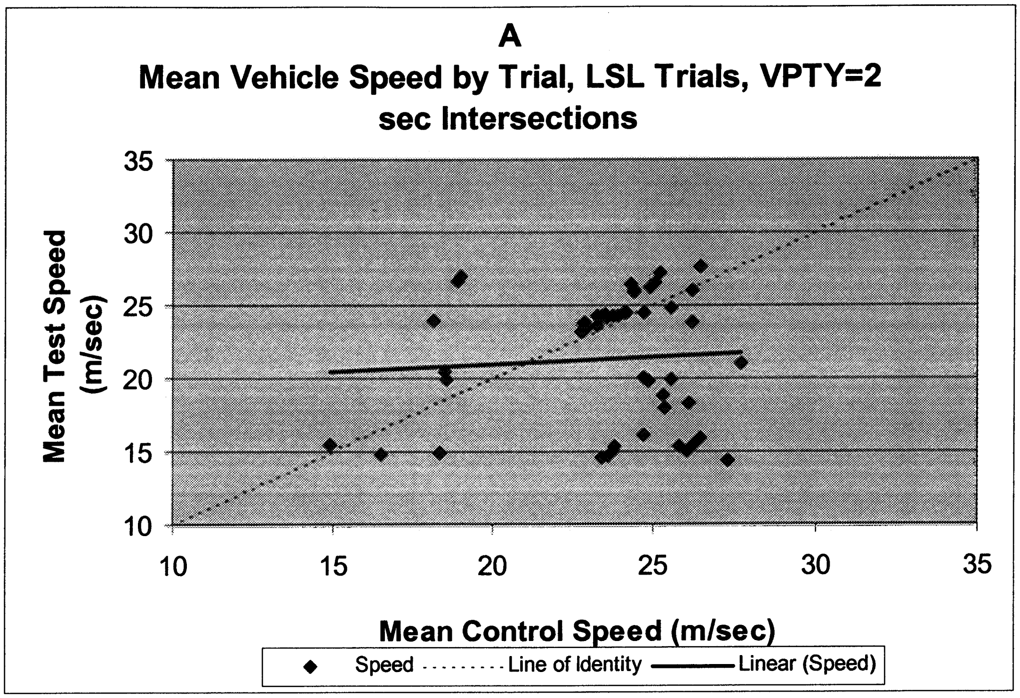
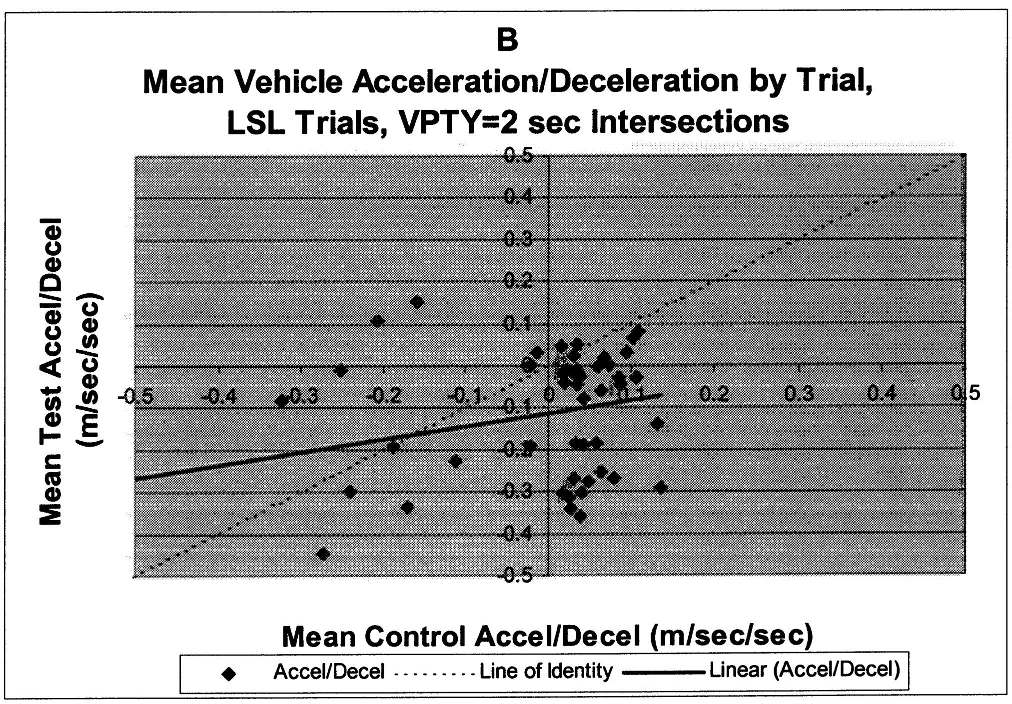


Figure M-2. Scatter plots of paired, within-subject control versus test mean results by trial for speed (A) and acceleration/deceleration (B) SDP measures, LSL trials, VTPY=0 sec intersections. Each point represents control-test paired means for 1 S. Solid line is LSR fit to data. Dashed line is line of identity.


A
Mean Vehicle Speed by Trial, LSL Trials, VPTY=2 sec Intersections
Mean Test Speed (m/sec)
35
30
25
20
15
10
10
15
20
25
30
35
Mean Control Speed (m/sec)
Speed
Line of Identity
Linear (Speed)


B
Mean Vehicle Acceleration/Deceleration by Trial, LSL Trials, VPTY=2 sec Intersections
Mean Test Accel/Decel (m/sec/sec)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
Mean Control Accel/Decel (m/sec/sec)
Accel/Decel
Line of Identity
Linear (Accel/Decel)

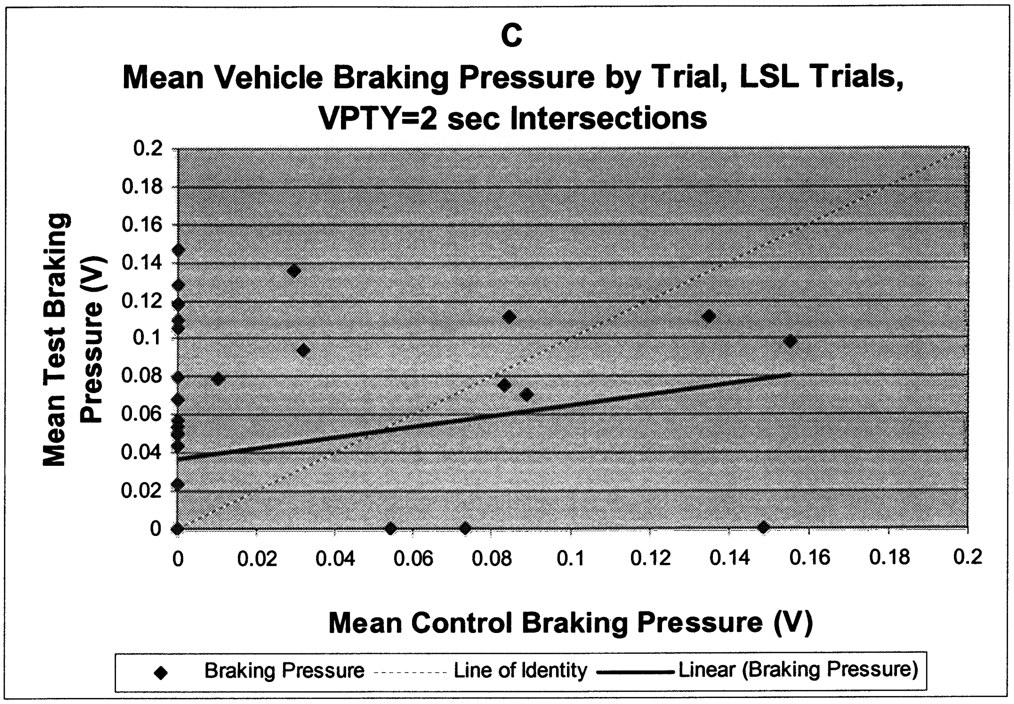
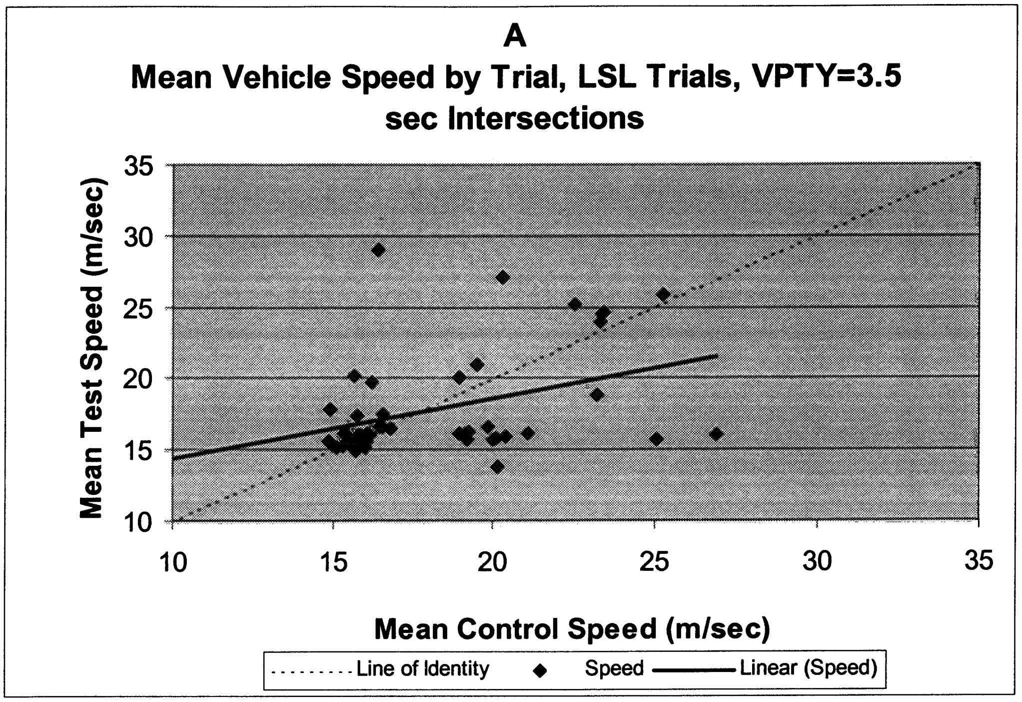
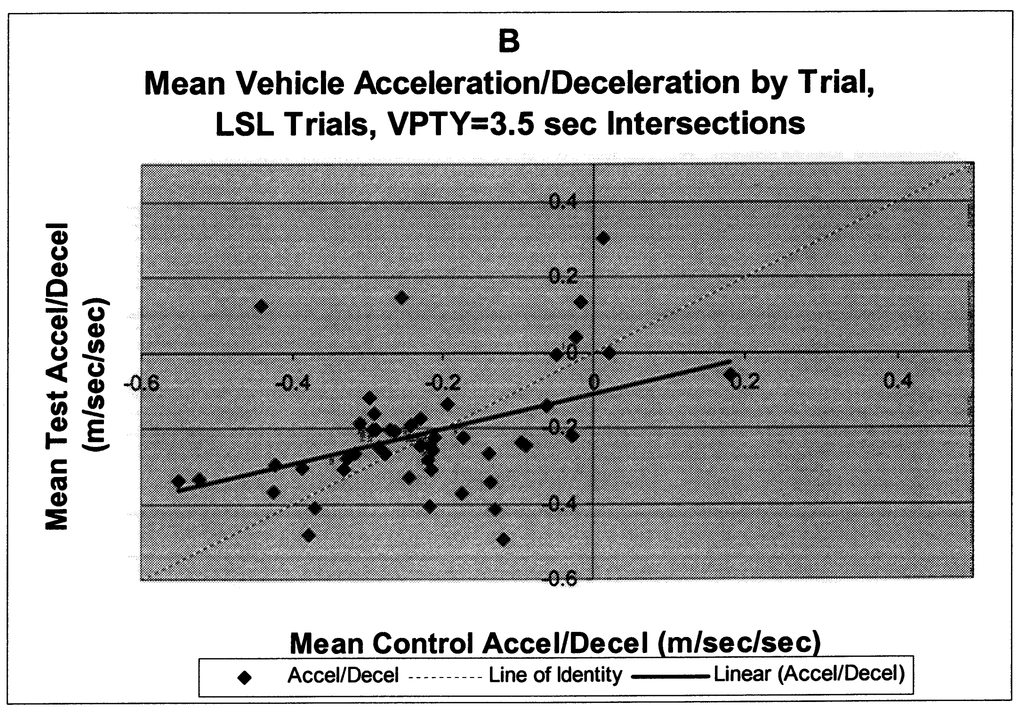


Figure M-3. Scatter plots of paired, within-subject control versus test mean results by trial for speed (A), acceleration/deceleration (B), and braking pressure (C) SDP measures, LSL trials, VTPY=2 sec intersections. Each point represents control-test paired means for 1 S. Solid line is LSR fit to data. Dashed line is line of identity. See text for description of approach used for scatter plot analysis.



A
Mean Vehicle Speed by Trial, LSL Trials, VPTY=3.5 sec Intersections
Mean Test Speed (m/sec)
35
30
25
20
15
10
10
15
20
25
30
35
Mean Control Speed (m/sec)
Line of Identity
Speed
Linear (Speed)



B
Mean Vehicle Acceleration/Deceleration by Trial, LSL Trials, VPTY=3.5 sec Intersections
Mean Test Accel/Decel (m/sec/sec)
0.4
0.2
0
-0.2
-0.4
-0.6
-0.6
-0.4
-0.2
0
0.2
0.4
Mean Control Accel/Decel (m/sec/sec)
Accel/Decel
Line of Identity
Linear (Accel/Decel)

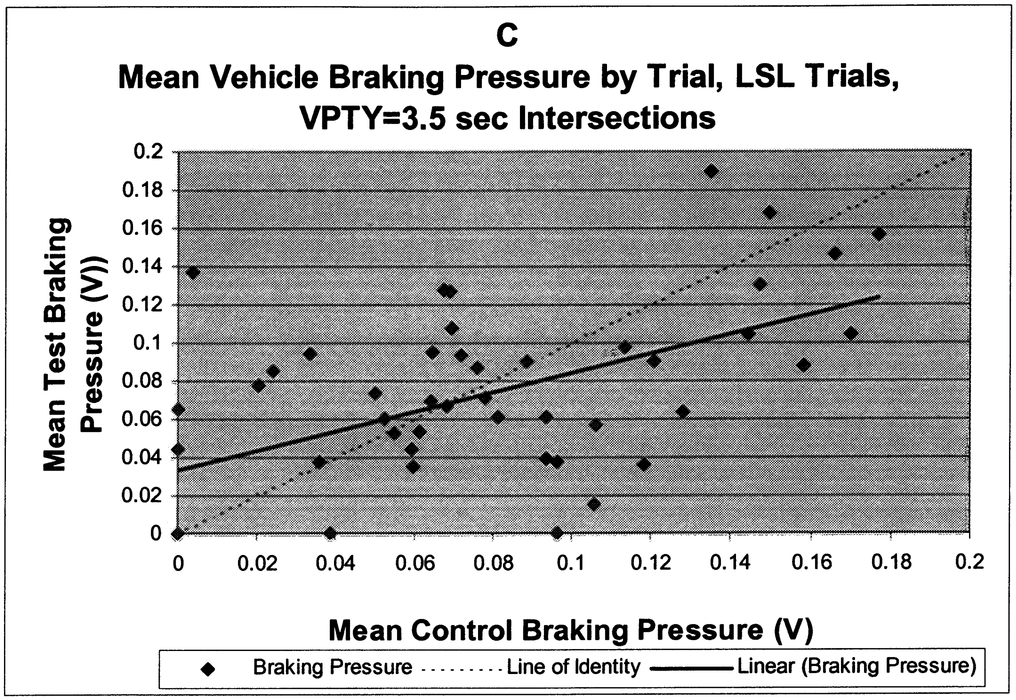
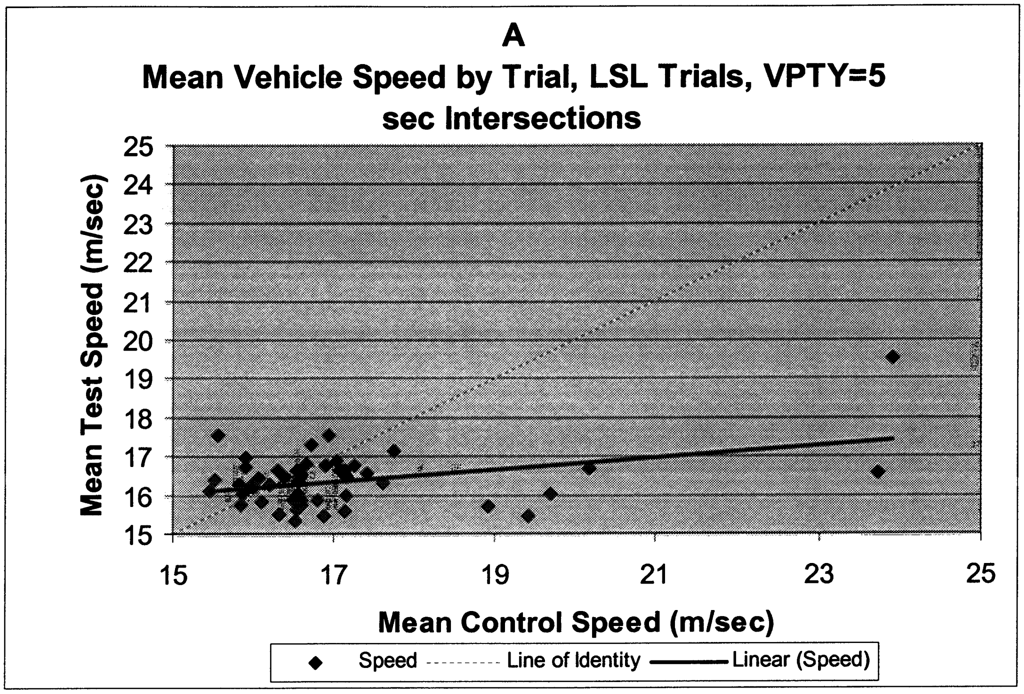
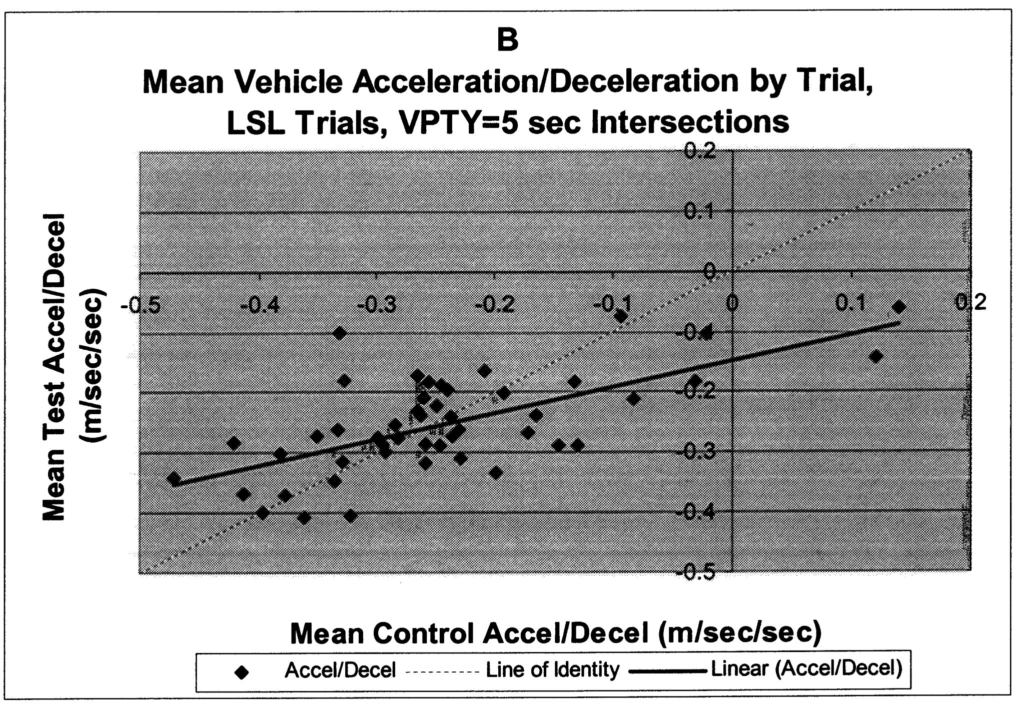


Figure M-4. Scatter plots of paired, within-subject control versus test mean results by trial for speed (A), acceleration/deceleration (B), and braking pressure (C) SDP measures, LSL trials, VTPY=3.5 sec intersections. Each point represents control-test paired means for 1 S. Solid line is LSR fit to data. Dashed line is line of identity.


A
Mean Vehicle Speed by Trial, LSL Trials, VPTY=5 sec Intersections
Mean Test Speed (m/sec)
25
24
23
22
21
20
19
18
17
16
15
15
17
19
21
23
25
Mean Control Speed (m/sec)
Speed
Line of Identity
Linear (Speed)


B
Mean Vehicle Acceleration/Deceleration by Trial, LSL Trials, VPTY=5 sec Intersections
Mean Test Accel/Decel (m/sec/sec)
0.2
0.1
0
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
-0.1
-0.2
-0.3
-0.4
-0.5
Mean Control Accel/Decel (m/sec/sec)
Accel/Decel
Line of Identity
Linear (Accel/Decel)

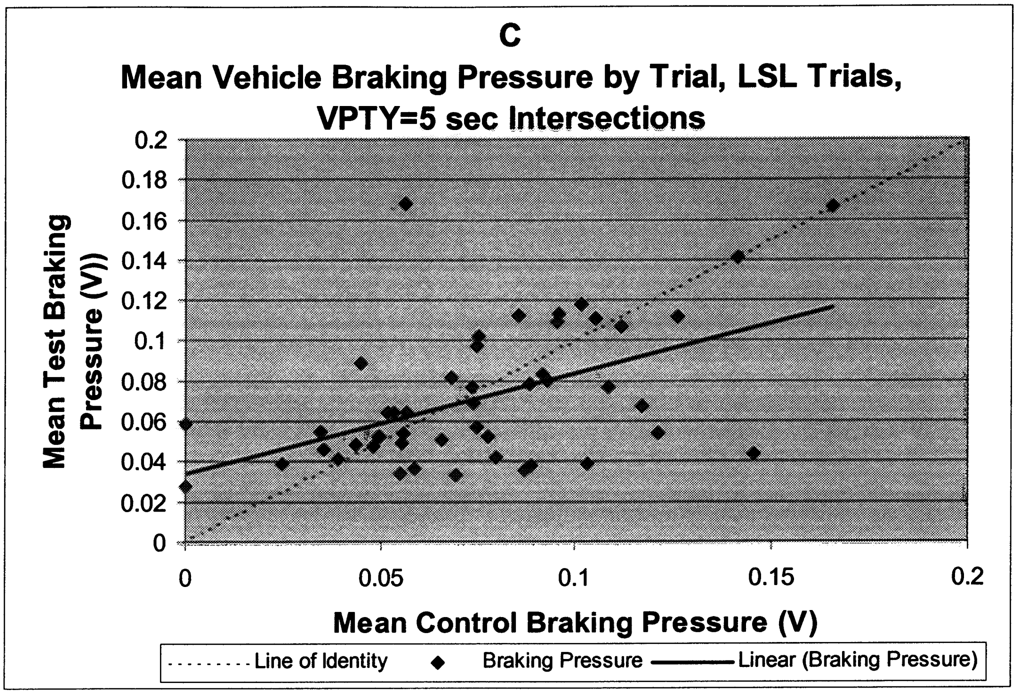
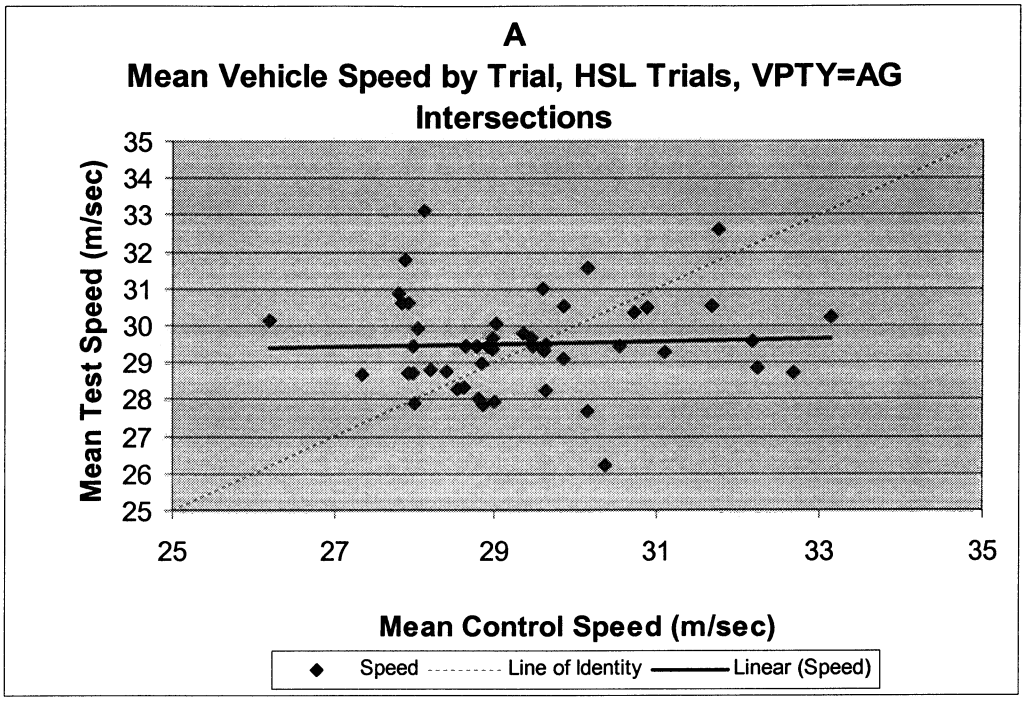


Figure M-5. Scatter plots of paired, within-subject control versus test mean results by trial for speed (A), acceleration/deceleration (B), and braking pressure (C) SDP measures, LSL trials, VTPY=5 sec intersections. Each point represents control-test paired means for 1 S. Solid line is LSR fit to data. Dashed line is line of identity.

APPENDIX N

SCATTER PLOTS OF PAIRED, WITHIN-SUBJECT MEANS BY TRIAL FOR CONTROL VERSUS TEST MEASURES OF SIMULATED DRIVING PERFORMANCE FOR HSL TRIALS



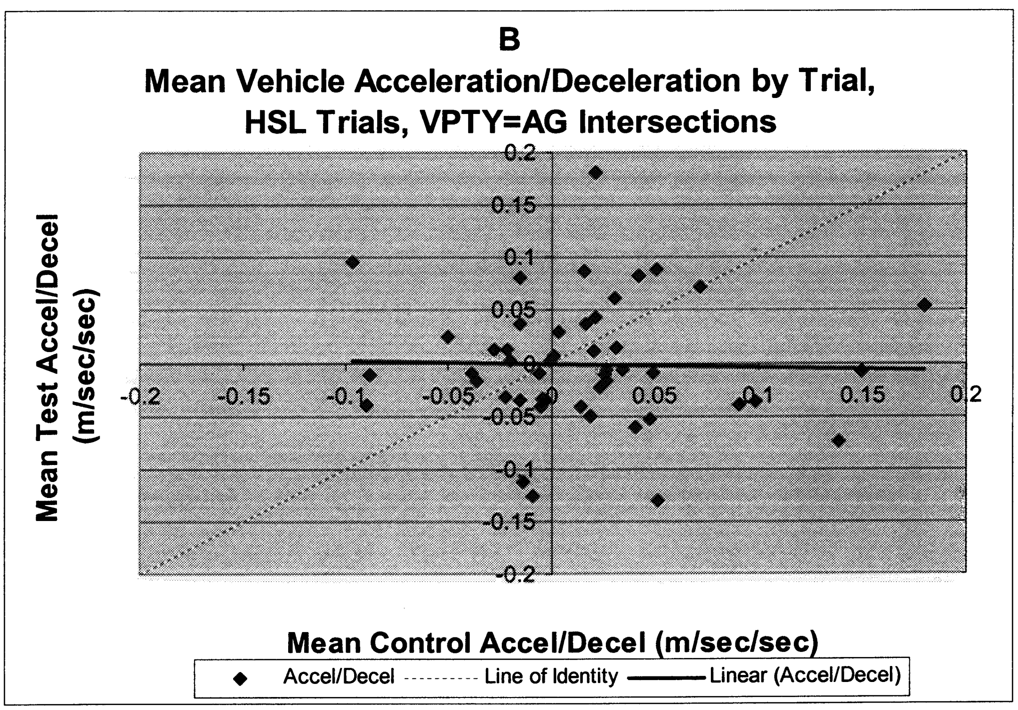
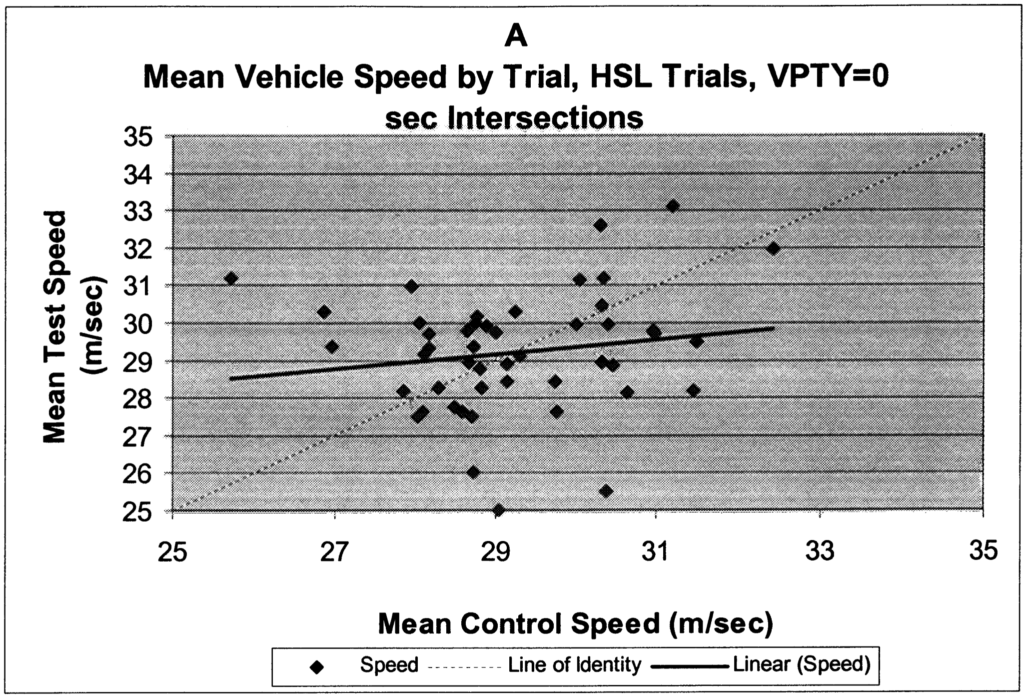


Figure N-1. Scatter plots of paired, within-subject control versus test mean results by trial for speed (A) and acceleration/deceleration (B) SDP measures, HSL trials, VTPY=AG intersections. Each point represents control-test paired means for 1 S. Solid line is LSR fit to data. Dashed line is line of identity.



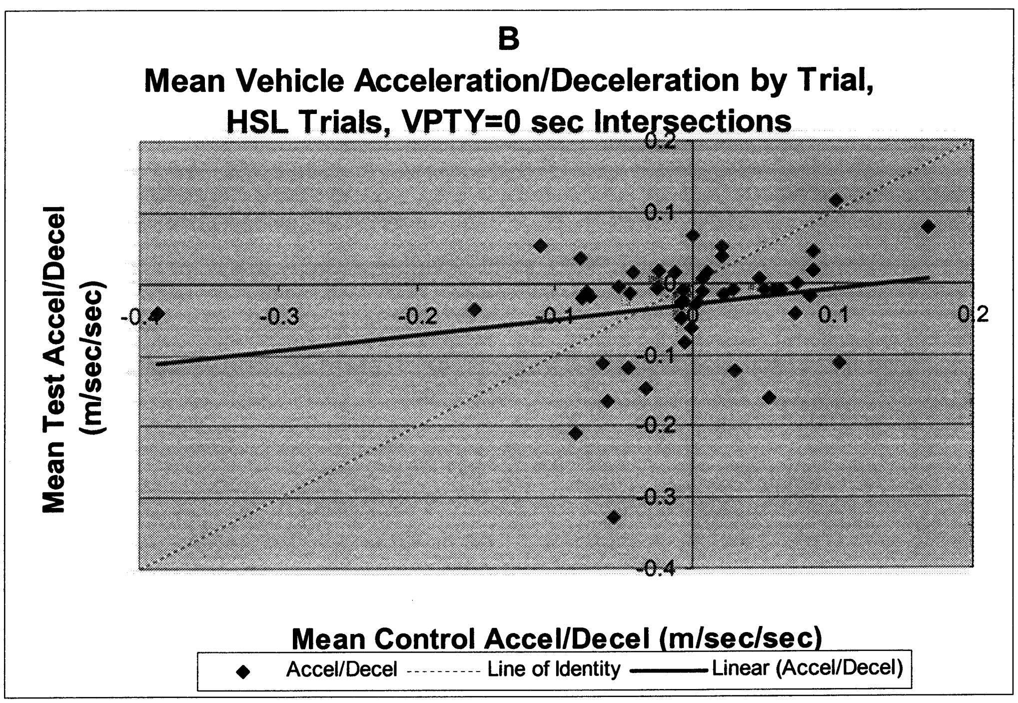
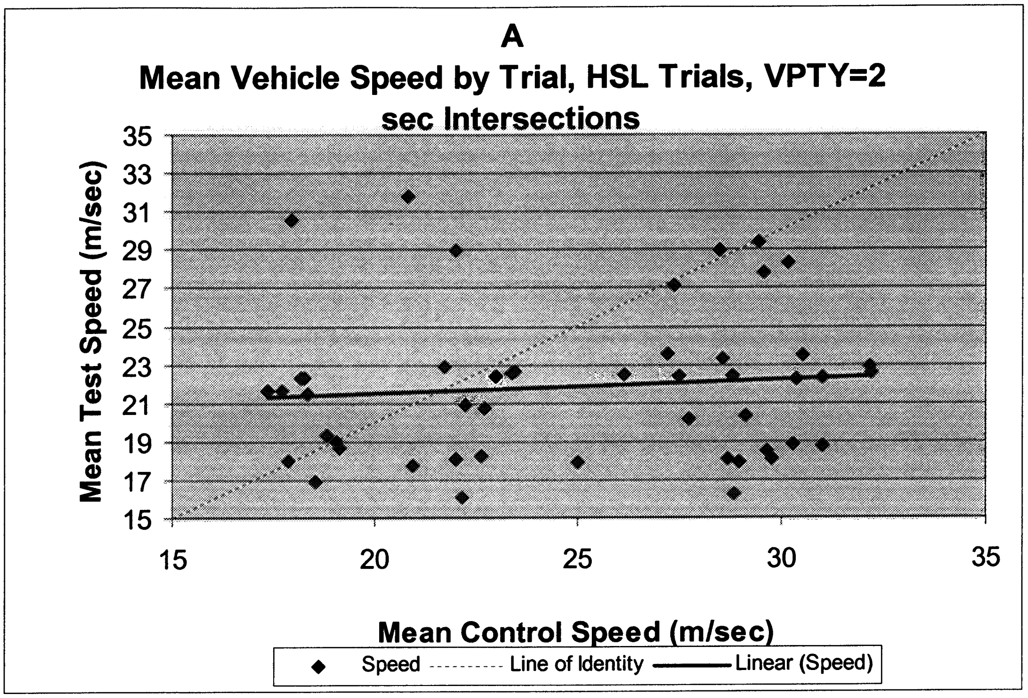
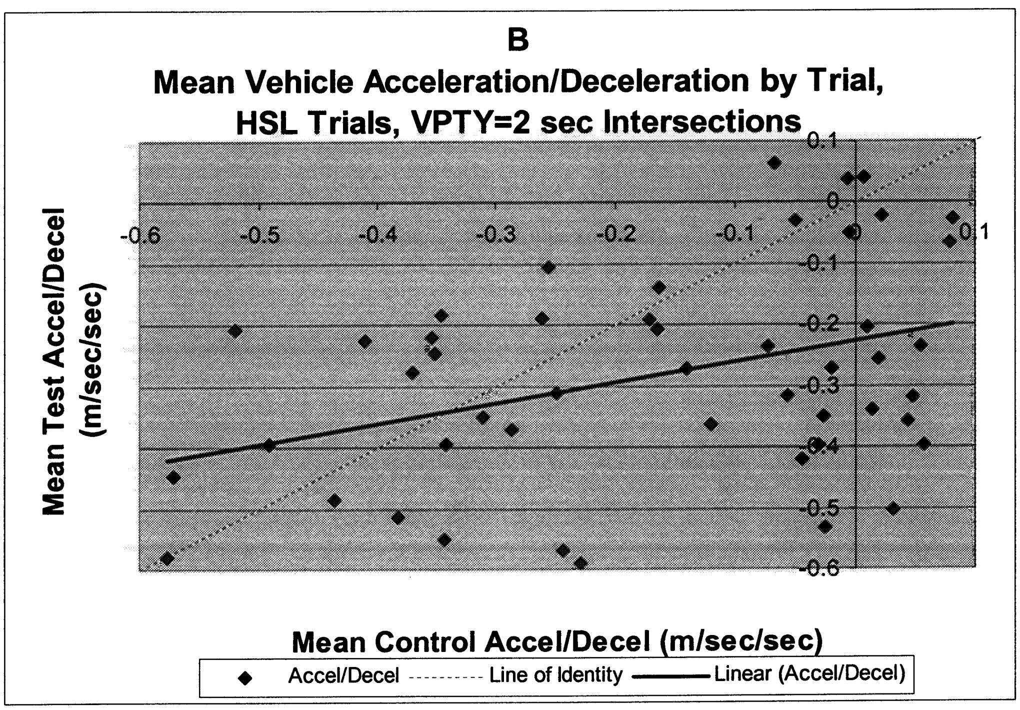


Figure N-2. Scatter plots of paired, within-subject control versus test mean results by trial for speed (A) and acceleration/deceleration (B) SDP measures, HSL trials, VTPY=0 sec intersections. Each point represents control-test paired means for 1 S. Solid line is LSR fit to data. Dashed line is line of identity.


A
Mean Vehicle Speed by Trial, HSL Trials, VPTY=2 sec Intersections
Mean Test Speed (m/sec)
35
33
31
29
27
25
23
21
19
17
15
15
20
25
30
35
Mean Control Speed (m/sec)
Speed
Line of Identity
Linear (Speed)


B
Mean Vehicle Acceleration/Deceleration by Trial, HSL Trials, VPTY=2 sec Intersections
Mean Test Accel/Decel (m/sec/sec)
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
Mean Control Accel/Decel (m/sec/sec)
Accel/Decel
Line of Identity
Linear (Accel/Decel)

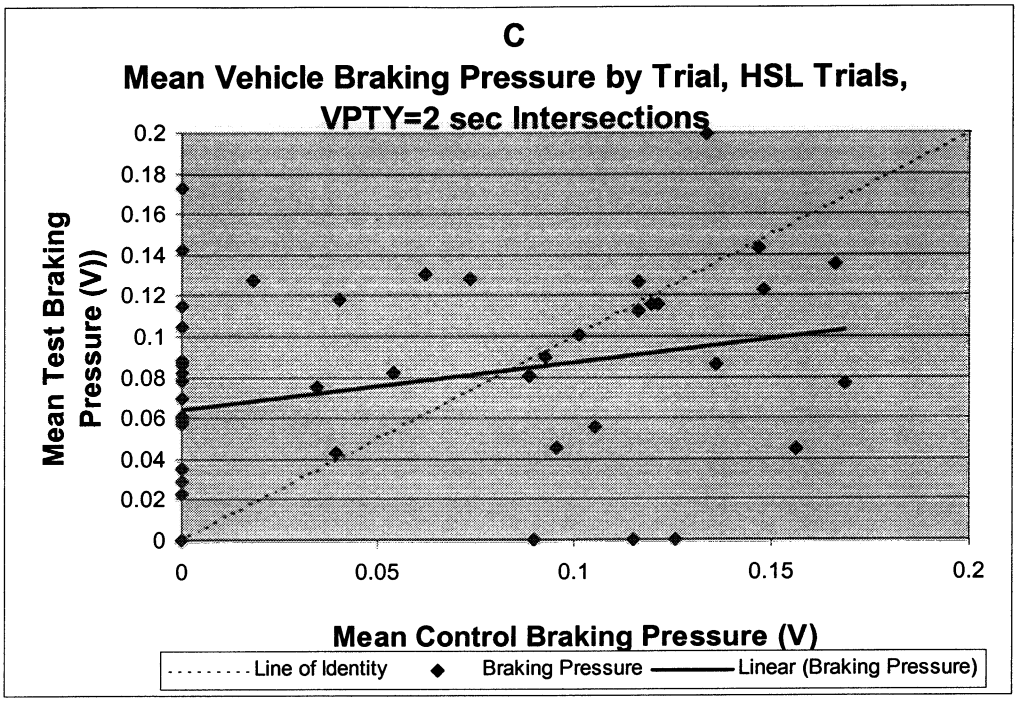
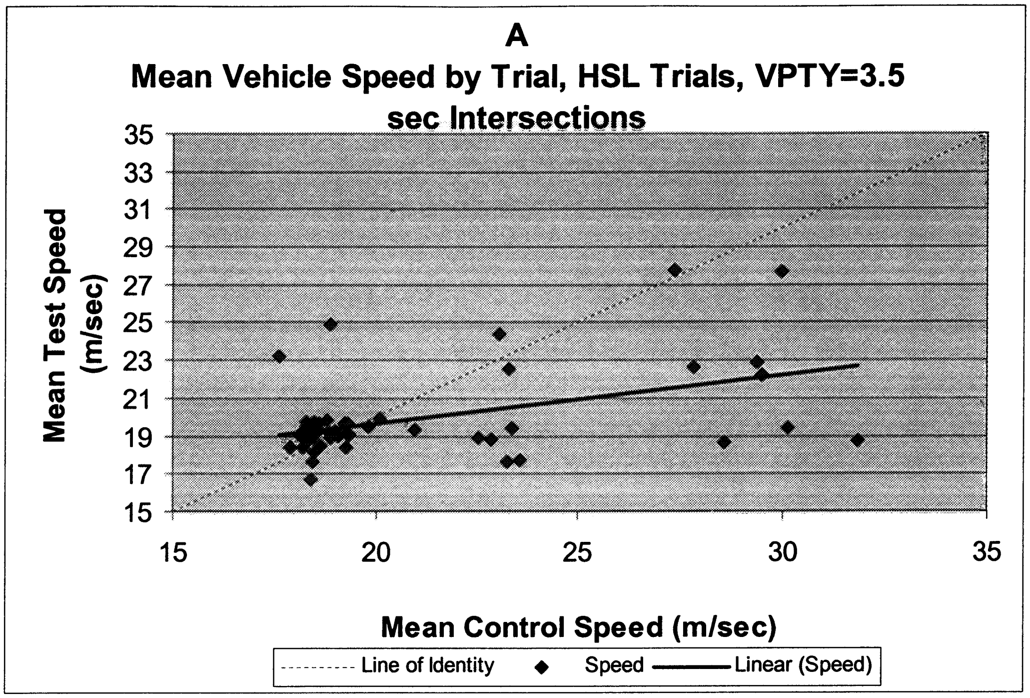
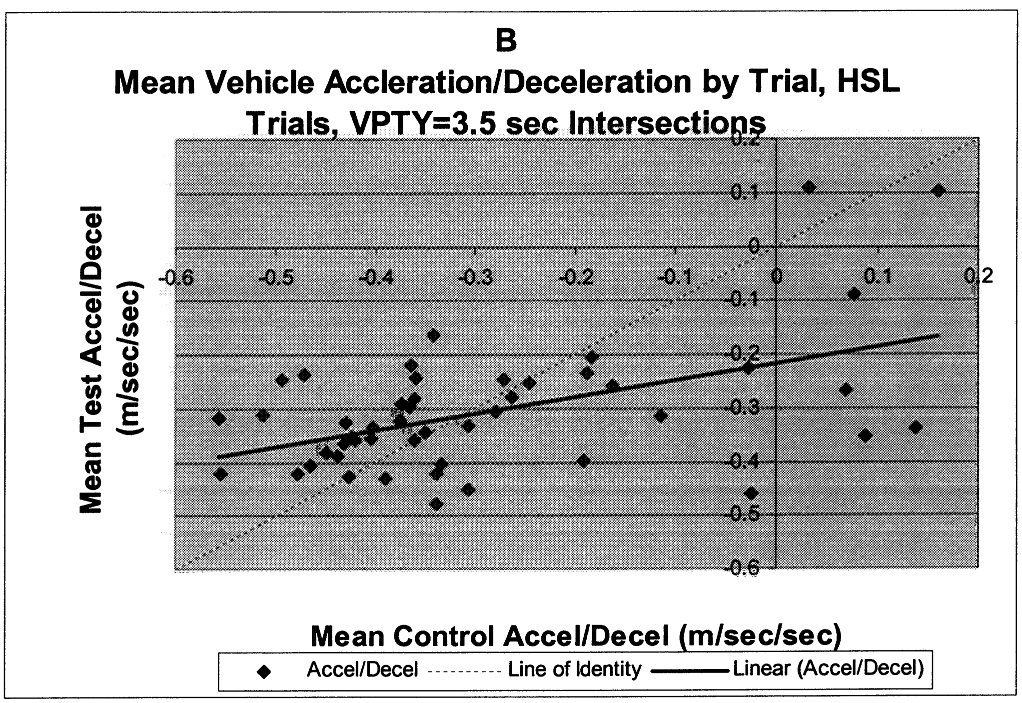


Figure N-3. Scatter plots of paired, within-subject control versus test mean results by trial for speed (A), acceleration/deceleration (B), and braking pressure (C) SDP measures, HSL trials, VTPY=2 sec intersections. Each point represents control-test paired means for 1 S. Solid line is LSR fit to data. Dashed line is line of identity.


A
Mean Vehicle Speed by Trial, HSL Trials, VPTY=3.5 sec Intersections
Mean Test Speed (m/sec)
35
33
31
29
27
25
23
21
19
17
15
15
20
25
30
35
Mean Control Speed (m/sec)
Line of Identity
Speed
Linear (Speed)


B
Mean Vehicle Accleration/Deceleration by Trial, HSL Trials, VPTY=3.5 sec Intersections
Mean Test Accel/Decel (m/sec/sec)
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
Mean Control Accel/Decel (m/sec/sec)
Accel/Decel
Line of Identity
Linear (Accel/Decel)

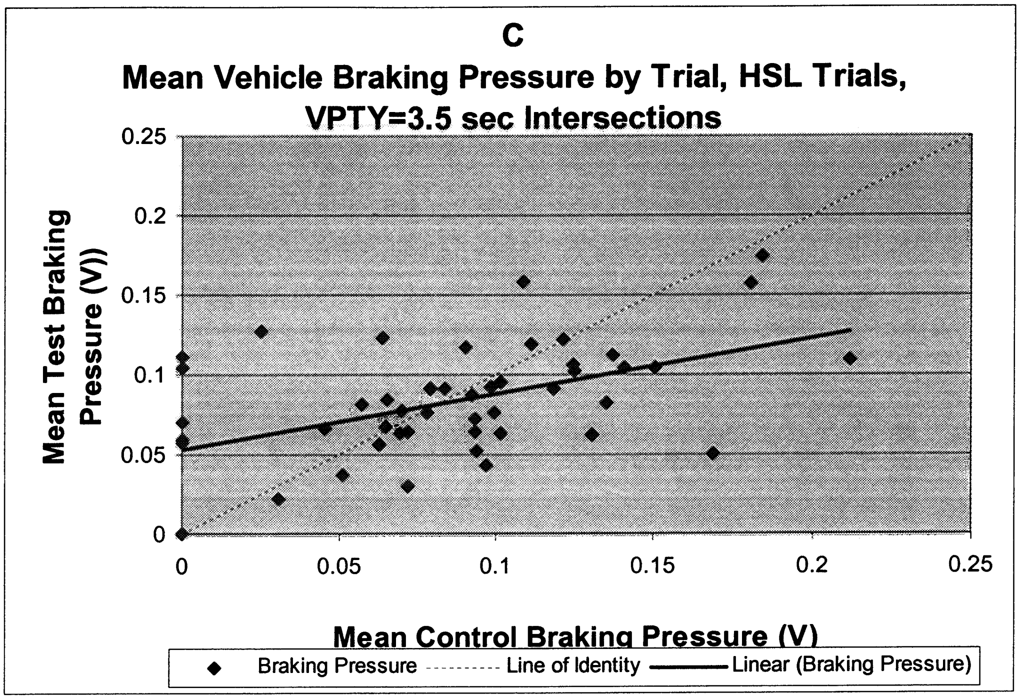
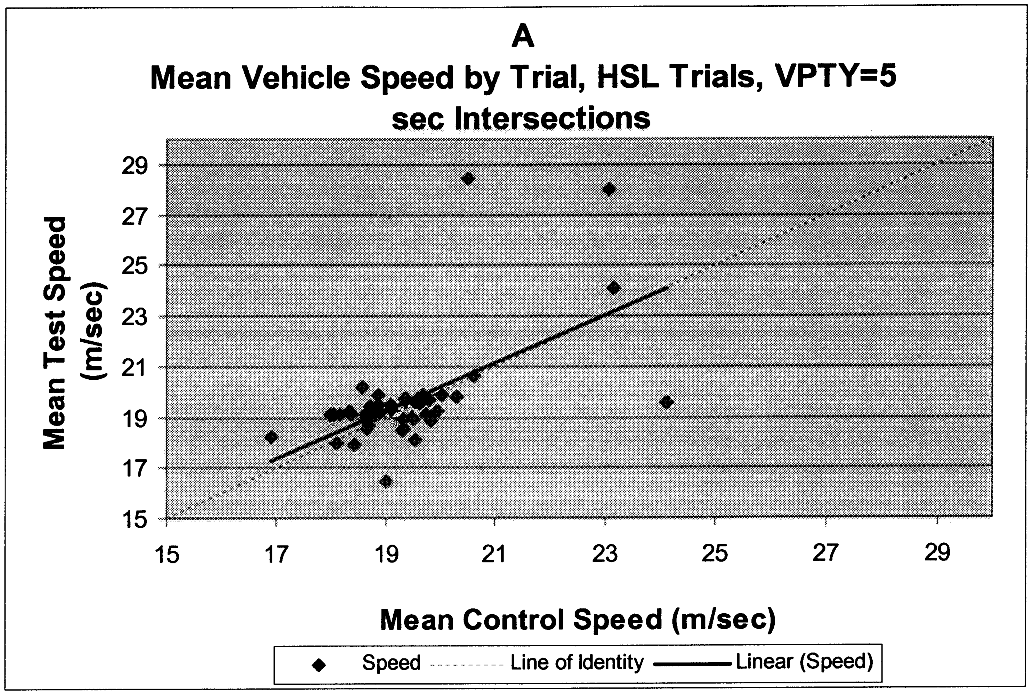
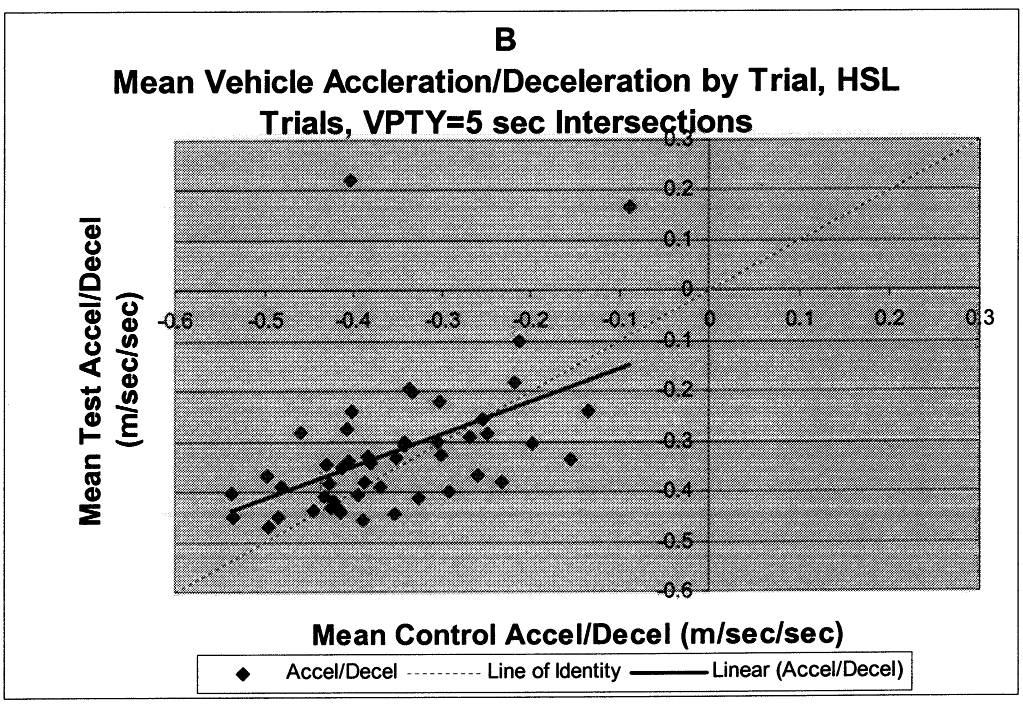


Figure N-4. Scatter plots of paired, within-subject control versus test mean results by trial for speed (A), acceleration/deceleration (B), and braking pressure (C) SDP measures, HSL trials, VTPY=3.5 sec intersections. Each point represents control-test paired means for 1 S. Solid line is LSR fit to data. Dashed line is line of identity.


A
Mean Vehicle Speed by Trial, HSL Trials, VPTY=5 sec Intersections
Mean Test Speed (m/sec)
29
27
25
23
21
19
17
15
15
17
19
21
23
25
27
29
Mean Control Speed (m/sec)
Speed
Line of Identity
Linear (Speed)


B
Mean Vehicle Accleration/Deceleration by Trial, HSL Trials, VPTY=5 sec Intersections
Mean Test Accel/Decel (m/sec/sec)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
Mean Control Accel/Decel (m/sec/sec)
Accel/Decel
Line of Identity
Linear (Accel/Decel)

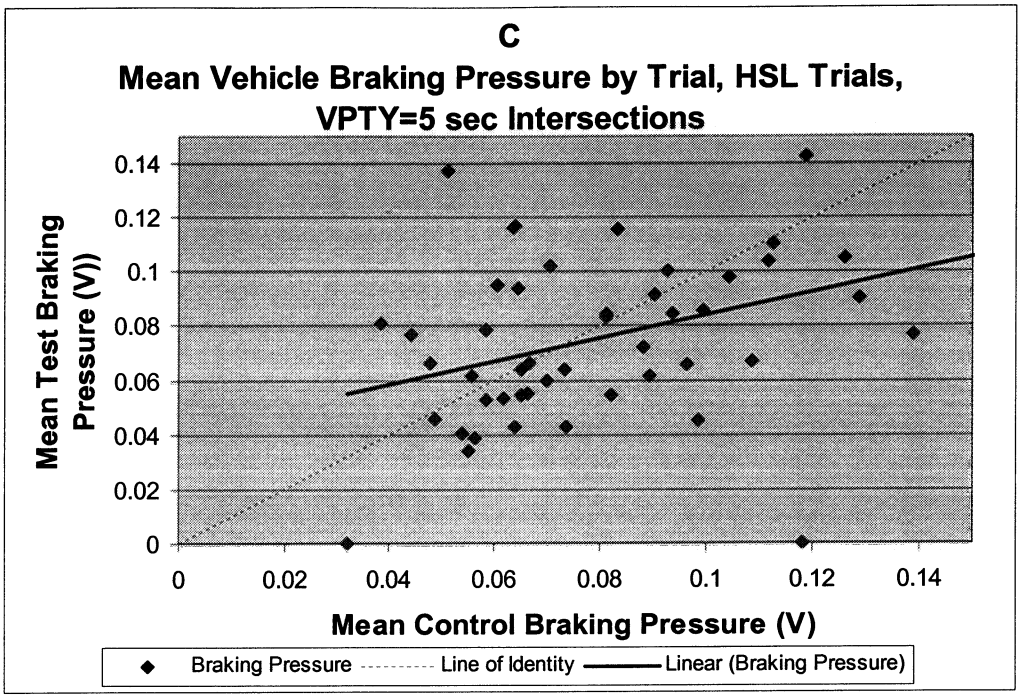


Figure N-5. Scatter plots of paired, within-subject control versus test mean results by trial for speed (A), acceleration/deceleration (B), and braking pressure (C) SDP measures, HSL trials, VTPY=5 sec intersections. Each point represents control-test paired means for 1 S. Solid line is LSR fit to data. Dashed line is line of identity.