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Reducing Risk Taking At Passive Railroad Crossings With Active Warnings

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16. Abstract (Limit: 200 words)

This simulated driving study evaluates driver interaction with a low cost active warning system being considered by Mn/DOT for potential installation at passive highway-rail intersections (HRIs). The objective of the study is to ascertain if, relative to HRIs with passive signage, drivers interact in a more cautious manner with HRIs equipped with active warning system technology.

The experimental design comprised: (1) 0.65 mi simulated roadway, with simulated HRI 0.644 km (0.4 mi) from start line; (2) 1 trial (start to end line) lasts about 1 min; (3) 120 trials/subject; (4) simulated train encountered in 13.3% of trials; (5) 25 subjects (Ss) (15 females, 10 males); (6) independent measures are: 4 control/test conditions; train absent/present; visibility clear/fog; (7) 2 control conditions: Control #1—advance passive warning sign (WS)/ crossing (Xing) passive WS; Control #2—advance passive WS/Xing active WS (flashing red lights); (8) 2 Test Conditions: Test #1—advance active WS (flashing yellow lights)/Xing active WS; Test #2—advance active flashing variable message sign (VMS)/Xing active WS; and (9) dependent measures are visually observed unsafe incidents and objective simulated driving measures (speed, braking, acceleration), plus responses to a post-test questionnaire (PTQ).

Major results are: (1) statistically significant main effects of train (present/absent), visibility (clear/foggy), and Xing WS conditions; (2) incidents of vehicle beating train or hitting train are higher for trials with a passive advance WS, relative to those with an active advance WS; (3) with a train present and clear visibility, for all measurement intervals, active advance WS are associated with lower mean vehicle speeds, compared to mean speeds observed with passive advance WS; (4) active advance and Xing WS are perceived by PTQ respondents to be more usable and more conspicuous than passive advance and Xing WS ; and (5) flashing words (e.g., a VMS) are perceived by PTQ respondents to be more conspicuous than flashing lights on an active advance HRI WS.

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Abbreviations, Acronyms and Definitions

A	active
accel	acceleration
active sign	an advance HRI warning sign with flashing yellow lights or VMS, or an HRI Xing crossbuck sign with flashing red lights
active Xing	an HRI with an active flashing warnings (lights or VMS) installed before the Xing
AdvWS	advance warning sign
ANOVA	analysis of variance
AWF	advanced warning flasher
Bonferroni procedure	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)
control condition	simulated driving trials with HRI preceded by a Xing crossbuck sign (passive or active) and and advance passive warning sign
crossbuck	an HRI Xing sign (MUTCD Type R15-1) that can be either active (with flashing red lights) or passive
CTS	University of Minnesota Center for Transportation Studies
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 session driving time
Excel	Microsoft spreadsheet program
F / F-crit	value for F statistic / critical F value for $p<.05$.
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
first-order effect	2-way interactive effect of an independent on a dependent variable, as established by ANOVA
ft	feet/foot
Hawk	an HFRL PC, used for storing driving simulation models and data collected from simulated driving studies

Abbreviations, Acronyms and Definitions

HF; HF/E	human factors; human factors/ergonomics
HFRL	University of Minnesota Division of Kinesiology Human Factors Research Laboratory
hr	hour
HRI	highway-rail intersection
hz	herz
ID	identification
in	inch
IntSL-HRI; IntWS-HRI; IntWS-200; Int200-100; Int100-SL	roadway intervals in simulated driving task environment, defined respectively as: SL to HRI; advance warning sign to HRI; advance warning sign to 200 m from HRI; 200 to 100 m from HRI; 100 m to HRI
Kelly	an HFRL PC, used for controlling experimental conditions, initiation, and termination, of simulated driving sessions
km	kilometers
kph	kilometers per hour
LabVIEW	a software platform specialized for acquiring and analyzing experimental data—the platform makes use of symbolic (VI) rather than text-based programming. Each LabView program consists of a front panel and a VI diagram (Appendix G).
Linux	operating system for PC - alternative system to Windows 95/98/2000
m	meters
MATLAB	a software platform specialized for use in experimental laboratory programming environments
mi	miles
min	minutes
mm	millimeters
Mn/DOT	State of Minnesota Department of Transportation
mph	miles per hour
MUTCD	FHWA Manual on Uniform Traffic Control Devices
MUTCD Type R15-1 sign	standard HRI grade Xing crossbuck sign [25, p. 8B-2]
MUTCD Type W10-1 sign	standard HRI advance passive warning sign [25, p. 8B-4]
N	number of subjects
N/A	not applicable
no.	number
NTSB	National Transportation Safety Board
p	probability
P	Passive
passive HRI sign	an advance or Xing HRI sign with only words and symbols
PC	IBM-compatible personal computer

Abbreviations, Acronyms and Definitions

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
S, Ss	subject, subjects
SD	standard deviation
sec	seconds
second-order effect	3-way interactive effect of an independent on a dependent variable, as established by ANOVA
SDP	simulated driving performance
SDTE	simulated driving task environment
Selma	an HFRL PC, used for downloading and backing up simulated driving data stored on Hawk
SGI	name of company that manufactures computer employed for simulation modeling (formerly Silicon Graphics, Inc.)
sight distance	the approximate distance at which a motorist can clearly see a train, in order to be able to either cross the track safely or halt while the train passes by
SL	speed limit / start line
SPSS	software platform used for statistical analysis of data
t	time
T	trial
TC	task condition
TCD	traffic control device
test condition	simulated driving trials with HRI preceded by advance active warning signs
Tr	train
type I error	statistical analysis indicates significant effect, when in fact the effect is due to chance
UM	University of Minnesota
unsafe driving behavior	driver either hits train or beats train in approaching HRI during trials with train present
V	volts
Vi	visibility
VI	virtual instrument panel
VMS	variable message sign
WS	warning sign
Xing	railroad crossing
yrs	years

Executive Summary

This is the final report for a study conducted by the University of Minnesota (UM) School of Kinesiology Human Factors Research Laboratory (HFRL) to investigate driver interaction with different types of warning signs at highway-rail intersections (HRIs). 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.

This simulated driving study involves a human factors evaluation of driver interaction with a low cost active warning system being developed for potential installation at HRIs currently equipped with passive signage. The objective of the study is to ascertain if drivers interact in a more cautious manner with HRIs equipped with active warning system technology, compared to HRIs with passive signage. A disproportionate number of vehicle-train accidents in Minnesota occur at passively signed HRIs (about 100 in 1999). About 70% of HRI fatalities occur at passively signed HRIs, representing a $14 billion problem nationwide. Thus, we investigated whether the use of active warning system technology to abate driver risk-taking at HRIs will yield driving safety benefits. The high percentage of (mostly rural) passively signed HRIs is attributable to the high cost of conventional active warning technology. However, Mn/DOT is sponsoring a project to develop a low cost active warning system ($10-15K/crossing projected) that makes use of solar-powered active warnings that are respectively started and stopped via detection of start- and end-of-train radio signals from a train approaching the HRI. A distinctive feature of the system is that both the advance warning signs and grade crossing (crossbuck) signs are active (with flashing lights)---the former currently are not used at HRIs.

The study was conducted using a fixed-base driving simulator with an Acura car and 3 forward projectors. A simulated driving environment was developed for the study, comprising: (1) a 1 km course with start and end line, and HRI in between; (2) advance and crossing (Xing) HRI Warning signs; (3) railroad tracks at a right angle to the roadway; (4) a train with engine and 16 cars; (4) train emerges from behind trees to right of HRI, as vehicle approaches Xing; (5) 40 mph train speed and 55 mph roadway speed limit; (6) at these train and vehicle speeds, arrival times at HRI after train emerges are same for vehicle and train; and (7) clear or limited (91.5 m (300 ft), using simulated fog) visibility.

Major results show: (1) statistically significant main effects of train (present/absent), visibility (clear/foggy), and Xing signage conditions (Figs. 3-4, 3-5, 3-10, 3-11; Table 3-1); (2) incidents of vehicle beating train or hitting train are higher for trials with a passive advance warning sign, relative to those with an active advance warning sign (Fig. 3-3); (3) with a train present and clear visibility for all measurement intervals, active advance warning signs are associated with lower mean vehicle speeds, compared to mean speeds observed with passive advance warning signs (Figs. 3-5, 3-10); (4) active advance warning signs and active Xing crossbuck signs are perceived by post-test questionnaire respondents to be more usable and more easily understood than passive advance warning signs and passive Xing crossbuck signs (Figs. 3-24 through 3-37); and (5) flashing words (e.g., a variable message sign) are perceived by post-test questionnaire respondents to be more perspicuous than flashing lights on an active advance HRI warning sign (Figs. 3-38, 3-39).

The summary conclusions of this study, based on observations from train-present trials, are that relative to HRIs with passive Xing crossbuck signs and passive advance warning signs, HRIs with active Xing crossbuck signs and active advance warning signs are associated with: (1) fewer incidents of unsafe vehicle-train interactions; (2) more cautious simulated driving performance as the vehicle approaches the HRI ; and (3) more favorable subject perceptions regarding warning sign usability and meaning. These conclusions suggest that field deployment of both active advance warning signs and active Xing crossbuck signs at HRIs will benefit driving safety during vehicle-train interactions. The findings therefore tend to validate the decision by Mn/DOT to support development of a low-cost active warning system, targeted for installation at currently passive HRIs.

Chapter 1
Introduction and Background

1.1. Introduction

This is the final report for a study conducted by the University of Minnesota (UM) School of Kinesiology Human Factors Research Laboratory (HFRL) to carry out a human factors evaluation of driver interaction with different warning sign (WS) configurations at highway-rail intersections (HRIs). 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 presents conclusions and recommendations supported by the findings.

The report is divided into four chapters. Chapter 1 introduces and summarizes the background for the project, as well as the research objectives and work plan. 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 and recommendations supported by the findings.

1.2. Background

The impetus for this study is a Mn/DOT-sponsored project termed the HRI project. The goal of the HRI project is development of a low-cost active warning system for potential installation at HRIs currently equipped with passive signage. The goal of this study is to ascertain if, relative to HRIs with passive signage, drivers interact in a more cautious manner with HRIs equipped with active warning devices.

The basic rationale for the HRI project is to improve safety at passive HRIs. A passive grade crossing (Xing) is defined as an HRI with traffic control devices (TCDs), such as crossbuck signs, stop signs or pavement markings, that do not change to give the driver an active visual and/or auditory warning of an approaching train [1, p. 1]. Various studies (reviewed in [2]; see Section 1.2.2) indicate that, relative to passive signage, use of active warning sign technology is associated with a substantial reduction in accidents and fatalities at HRIs (active TCDs, such as flashing lights, bells or gates, give the driver active visual and/or auditory warning of an approaching train [1, p. 1]). However, the substantial cost associated with installation of active TCDs has precluded replacing passive signage with active warning sign technology at passive grade crossings [1,3]. The HRI project assumes that these costs will be markedly reduced by the active warning technology being developed by the project, thereby holding out the promise that it will become more cost effective to replace passive signage with active warning sign technology at currently passive grade Xings, with a consequent improvement in HRI safety. The present study has been carried out using simulated driving methodology to ascertain if the predicted driving safety benefits of HRI active warning sign technology are in fact likely to be realized.

Subsections below expand upon these themes by providing: (1) a summary of the HRI project (Section 1.2.1); (2) a synopsis of the literature pertaining to grade Xing warning signage

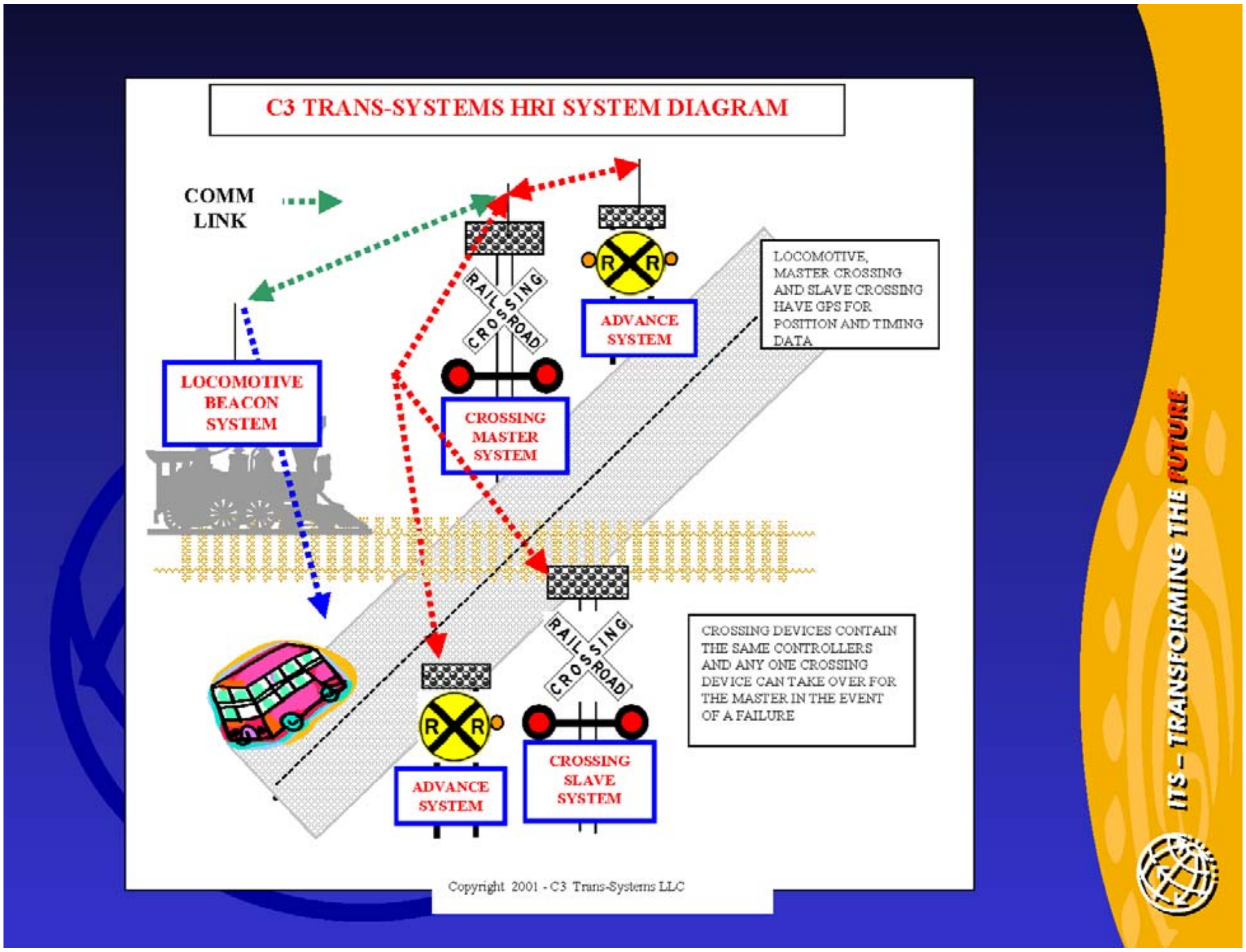


Figure 1-1.Technical design schematic of HRI system

(Section 1.2.2); and (3) a synopsis of the literature pertaining to the efficacy of advance active warning sign technology (Section 1.2.3).

1.2.1. Description of Active Warning HRI System

The technical and engineering design features of the HRI project have been described in recent presentations by Mn/DOT [4,6] and contract [5] personnel involved with the project. Figure 1-1 illustrates a technical design schematic of the HRI system. Major features are:

- A Primary Goal is Installation of Active Warning System Technology at Low Volume HRIs
- Features Active Advance Warning Sign
- Low Cost (estimated 10% of current active warning systems)
- Red Flashers on Crossbucks
- Amber Flashers on Advance Warning Sign
- Solar Power
- Radio Communications
- Locomotive Based / Smart Crossing
- GPS Data Exchange
- Shared Network (multiple locomotives)
- Self Update / Fault Reporting

In addition to Mn/DOT and HFRL, other cooperators on the HRI project are local Minnesota transportation agencies, the U.S. Federal Highway Administration (FHWA) and Federal Railroad Administration (FRA), C3 Trans Systems (project system developer), TC&W Railroad (systems field implementation and testing), SRF Consulting (project management assistance), and URS Corp. (independent evaluator).

For purposes of this study, the key feature of the system illustrated in Figure 1-1 is the active advance warning sign. Although active advance warnings have been used for some time with selected roadway signalized intersections [7], their use for HRIs in the U.S. currently is expressly prohibited by the FHWA Manual on Uniform Traffic Control Devices (MUTCD) [1]. Consequently, two key objectives of the present study are to ascertain: (1) if the nature of driver interaction with HRIs equipped with active advance warnings is comparable to that observed with signalized intersections equipped with active advance warnings [7]; and (2) if driver risk-taking behavior during interaction with trains at HRIs equipped with active advance warnings is mitigated, relative to that observed at HRIs equipped with standard advance passive warning sign.

1.2.2. Relevant Findings Pertaining to HRI Warning Signage

Risk factors associated with HRI accidents, injuries and fatalities, and the role of HRI warning signage in HRI accident prevention, have been reviewed in a series of reports [1-3, 8-10]. Relevant observations and findings from these reports are summarized below.

1. According to FRA statistics for 1996 [1, p. 3], there were 265,721 HRIs in the U.S., 75% (198,985) of which were passive HRIs. In 1996, 4,054 vehicle-train accidents occurred at HRIs. About 54% of these incidents and about 60% of all grade crossing fatalities occurred at passive HRIs.
2. According to FRA statistics [11, Chap. 7, p. 13], in 1998 there were 3508 HRI vehicle-train incidents in the U.S., of which about 49% occurred at passive HRIs, and about 21% occurred at HRIs equipped with flashing light warnings[11]. Among these incidents, about 52% of fatalities and of nonfatal injuries occurred at passive HRIs, and about 26% of fatalities and of nonfatal injuries occurred at HRIs equipped with flashing light warnings on crossbucks.
3. Therefore, in terms of total incidents, injuries and fatalities, the percentage of passive HRI vehicle-train incidents, relative to total HRI vehicle-train incidents, is less than the percentage of passive HRIs relative to total HRIs. Mortimer [8, p. 42] reports concordant 1976 data showing that the HRI accident rate per crossing-year (referring to the number of years a crossing with a particular type of warning has been in place): (1) for urban Xings is double for HRIs with flashing light relative to passive warning signs; and (2) for rural Xings is triple for HRIs with flashing light relative to passive warning signs. However, this author also points out these rates do not control for the extent of either train or vehicle HRI traffic. Given that passive signage typically is deployed at HRIs with low vehicle and train volume [2], the more relevant statistic is the number of HRI incidents and fatalities per vehicle-train encounter, at HRIs with passive versus active signage. The author is unaware of published data regarding this statistic.

4. Replacing passive with active signage at HRIs has been found to be associated with a substantial reduction in HRI vehicle-train accidents [2,8,10]. For example, intervention studies in which passive was replaced with flashing light warning signage at HRIs found reductions of 64%, 84% and 83%, in accidents, injuries and fatalities respectively [12,13]. These findings provide support for the suggestion in Point 3 that HRI incident statistics normalized to vehicle-train encounters might also point to possible advantages of active over passive HRI signage in terms of driving safety.
5. In Minnesota, according to various sources [4,5,14], as of 2002 there were 4,684 HRIs, of which about half featured passive signage, and about 75% of total HRI accidents and 70% of fatalities occurred at HRIs with passive signage. These statistics indicate that, in Minnesota at least, HRIs with passive signage pose a disproportionate risk for HRI accidents and fatalities.

Collectively, the above observations support the prediction that replacement of passive signage with active warning system technology at HRIs is likely to abate driver risk-taking at HRIs, and thereby yield driving safety benefits. However, as noted above, the Mn/DOT HRI project proposes active advance warning signs as part of the active warning system technology (Fig. 1-1). Experience with active advance warning flashers (AWFs) at signalized intersections [7] indicates that advance warning of a pending event evokes increased caution in most drivers, but increased risk-taking in some (next section). Therefore, a key goal of the present study is to document whether or not a similar pattern is likely to emerge during vehicle-train encounters at HRIs featuring advance warning that a train will be arriving at the Xing.

1.2.3. Relevant Findings Pertaining to Active Advance Warning System Technology

Given that the HRI project proposes to incorporate active advance warning signs at HRIs (Fig. 1-1), experience to date with such warnings at signalized intersections may provide some insight into their likely impact on driving safety and performance at HRIs. There are a variety of roadway settings in which drivers may not be provided with much advance 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, passive warning signs may not reduce the elevated accident risk associated with such intersections, because such signs do not provide a real time indication of signal status. In order to provide drivers with advance indication of the signal status of an upcoming intersection, AWFs have been installed in front of selected signalized intersections on some mainline roadways in Minnesota and other states.

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 [16]; (2) reduce the incidence of red light running, with the percent reduction in violations observed for trucks more than double that observed overall [17]; but (3) do not consistently and significantly reduce accident frequency [15,18-20].

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’ [18,21]. 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 either dilemma or decision-zone conditions may pose a driving safety hazard.

Gazis and colleagues [21] originally concluded that decision zones at signalized intersections are mainly the result of inadequate yellow clearance interval timing. Mn/DOT [18] provides a detailed analysis and discussion of the meaning and derivation of dilemma and decision zones for a given speed limit (SL). This analysis 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.

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. However, there is a decision zone for every intersection that a driver may interact with. Unlike dilemma zones, whose boundaries rest upon calculations of vehicle travel and stopping distances at different SLs, determination of decision zones is based upon empirical observations of driver stopping behavior [18]. The inclination of drivers to stop at signalized intersections in fact shows a statistical distribution that depends upon the approach speed, the distance from the intersection, and the vehicle times from the intersection at different SLs associated with the specified stopping probabilities [ibid]. Empirical observations of Williams [22] indicate that actual stopping probabilities may vary from intersection to intersection, and that field observations may be necessary to determine stopping probability isolevels for a given intersection.

Because a probability of stopping can be assumed never to equal exactly either 0 or 100%, a decision zone exists for all signalized intersections. An AWF is introduced to aid driver decision-making prior to arrival of the vehicle in the decision zone. 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.

A number of human factors/ergonomic (HF/E) 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 [15], 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 also 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 driving safety implications.

Field settings cannot rigorously control for a variety of extraneous variables that conceivably could influence the interaction of driving performance and safety with AWFs. This consideration prompted the study of Smith [7], who evaluated subject (S) interaction with signalized intersections equipped or not equipped with AWFs. Responses to a post-test questionnaire indicated that most subjects understood the meaning and purpose of an AWF. Compared with subject interactions with non-AWF intersections, the study documented the following major changes in subject stopping behavior and simulated driving performance (SDP) during interactions with AWF intersections: (1) fewer red lights run during low SL trials, but more at high SL trials; (2) more cautious driving behavior in some Ss, but more risk-taking behavior in others; and (3) more consistent reductions in speed at vehicle-proximity-to-yellow (VPTY) intervals of 2.0 sec, compared with VPTY intervals of 3.5 sec. The interpretation advanced for the latter finding [ibid] is that the longer decision time between AWF and yellow signal actuation provided by the 3.5 sec VPTY condition promotes the emergence of individual differences in both cautious and risk-taking behavioral responses to the yellow signal, based on cognitive decision-making. In contrast, decision-making at 2 sec VPTY intersections essentially is relegated to the psychomotor domain, resulting in a more limited spectrum of behavioral responses that largely emphasize cautious driving behavior.

Generally, the results of this simulated driving study suggest that, relative to non-AWF intersections, the presence of AWFs encourages slowing and stopping behavior by subjects during interaction with AWF intersections, for decision-zone conditions (namely, VPTY intervals of 2 and 3.5 sec) for which drivers may be uncertain about stopping or proceeding through the intersection.

As with every signalized intersection, a decision zone also exists for every HRI [2,8-10]. Factors identified by various observers [ibid] that may influence HRI decision-zone behavior include: (1) propensity for risk-taking behavior; (2) individual differences in driving behavior; (3) train visibility; (4) type of HRI warning system in place; and (5) physical constraints governing driver interaction with the HRI. With passive HRIs, neither the Xing crossbuck sign, nor the advance warning sign, provide any active indication as to whether or not a train is approaching the HRI. Therefore, decision-zone behavior at passive HRIs is likely to be influenced more by train visibility than by types of warning signage. With active HRI warning signage however, both sets of factors are likely to play a more balanced role in influencing HRI decision-zone behavior. This in turn suggests that AWFs are likely to influence driver interaction with active HRIs in a manner comparable to their effects on driver interaction with signalized intersections.

There is one important distinction between the two types of intersections however. When an active Xing warning is actuated, the unequivocal legal meaning is that the vehicle should stop at the HRI, whether or not the train is visible [8-10]. That is, there is no clearance zone, and thus no dilemma zone, at an active HRI. The consequent lack of dilemma zone influence of pure vehicle factors (e.g., vehicle travel and stopping distances at different SLs) on driver interaction with active HRIs means that driver interaction with an actuated active Xing crossbuck sign, relative to that with a roadway intersection with traffic signals, is likely to be more prominently influenced by purely behavioral propensities, idiosyncracies, and individual differences.

The author is aware of one prior study of active advance warning signs at HRIs, that of Ruden and colleagues [22]. This study developed four designs of HRI active advance warning signs (different symbols and message texts, each accompanied by a pair of yellow flashing lights), and tested interaction of 330 subjects with each design using a film projection system. A limited field test of three of the designs then was carried out at three field sites. Each field site featured one of the three active advance warning sign designs accompanied by an active flashing light crossbuck sign at the Xing,. During the field test, dependent measures of vehicle speed, braking location, and driver looking behavior were collected using each of the three active advance warning sign designs. Because of the infrequency of vehicle-train encounters at the field sites, the dependent measures were observed following actuation of both the active advance warning sign and the active Xing crossbuck sign without a train actually being present.

Major findings from both the film and field testing phases of this study are that: (1) drivers decelerated in the vicinity of the active advance warning sign (field test); (2) driver perception of and reaction time to the active Xing crossbuck sign were improved and reduced, respectively, with the active advance warning sign actuated, relative to behavior observed when the active advance warning sign was not actuated (field test); and (3) most drivers properly interpreted the meaning of the active advance warning sign (film test). These findings generally are in accord with findings for AWFs at signalized intersections cited above.

1.3. Research Objectives and Work Plan

The experimental approach for this study involves analysis of simulated driving performance with the HFRL fixed-base, wrap-around driving simulator, to assess HF/E and driving performance issues associated with driver interaction with different HRI warning sign configurations. The overall objective of the study therefore is to conduct a HF/E analysis of the effects of different HRI warning sign configurations on simulated driving performance, as drivers interact with a simulated train during traversal of a simulated driving task environment (SDTE). The findings should provide insight into possible driving safety benefits associated with the active advance warning sign featured as part of the low-cost HRI technology described above. This information, in turn, should help guide Mn/DOT decision-making regarding possible further development and deployment of this technology.

The following 5 tasks are specified in the project work plan: (1) develop and implement simulation models for design and layout of HRI, train, roadway, and different HRI warning sign configurations; (2) usability analysis of different HRI warning sign configurations, based on responses to usability preference questions in post-test questionnaire (PTQ); (3) develop experimental design and protocol for simulated driving performance assessment; (4) carry out subject testing and data collection; 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 different HRI warning sign configurations on simulated driving behavior and performance, and related driving safety implications of deploying low-cost active warning system technology at HRIs currently equipped only with passive signage.

Chapter 2
Experimental Design and Methods

2.1. Introduction

This chapter describes the experimental approach and methods employed, and subject characteristics, for project research. Sections below deal with a description of the simulated driving platform, development of the simulated driving task environment (project work plan Task 1), and experimental design, protocol, and subject characteristics (project work plan Task 3), for the research.

2.2. Driving Simulator System, and Development and Implementation of Simulated Driving Task Environment

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

2.2.1. Driving Simulator System

For simulated driving testing, the HFRL fixed-base wrap around driving simulator was employed. It comprises: (1) a 360 deg concave screen that is 2.5 m (8.2 ft) high, 4.7 m (15.5 ft) in diameter at floor level, and 5.5 m (18 ft) at its widest concave diameter; (2) a Silicon Graphics (SGI) Onyx computer with a Reality Engine 2 graphics board; (3) 3 forward projectors (NEC Model MT830) driven by the Onyx, providing a forward image subtending a 165 deg horizontal field of view and a 55 deg vertical field of view; (4) a full-sized 1990 Acura Integra positioned in the center of the simulator, with signal input from accelerator, brake, and steering wheel actuation provided to the Onyx and used to update the projected image in real time; (5) a stereo system that generates engine noise broadcast on speakers within the Acura---volume of engine noise is varied directly with simulated vehicle speed. Simulation programming was carried out by Peter Easterlund using MEDIT software, a three-dimensional (3D) modeling platform designed primarily for use with SGI systems. During subject testing sessions for this study, the interior lights in the wrap around driving simulator were turned off, to enhance visibility of the warning signs and the train.

Three IBM-compatible PC computers are used to control simulated driving experimental sessions (hereafter termed a testing session), and for data management, with the HFRL driving simulator, as follows: (1) 'Kelly' is used to control testing sessions, involving: (a) selection of the simulated driving model to be used for the session, and signaling 'Hawk' (Point 2) to transfer the model to the SGI Onyx; (b) specification of experimental parameters for the model; (c) specification of the file name for storage of data collected during the session; and (d) signaling the SGI Onyx to initiate and terminate a session; (2) 'Hawk' is used for: (a) storing driving simulation models and transmitting selected testing session model to the SGI Onyx; and (b) acquiring simulated driving performance data for a testing session from the SGI Onyx, and storing data in a file specified with 'Kelly' (Point 1c); and (3) 'Selma' is used to download and back up simulated driving performance data files stored on 'Hawk.' An HFRL Ethernet intranet system allows communication between these computers.

2.2.2. Simulated Driving Task Environment

Five basic considerations governed development of the model for the simulated driving task environment. Specifically, the simulated driving task environment was designed to allow for (Section 2.3): (1) HRI and warning sign design features that conform to real world specifications; (2) comparison of driver interaction with an HRI under train present versus train absent (case-control) conditions; (2) evaluation of effects of different HRI warning sign configurations on vehicle-train interactions during simulated driving performance; (3) assessment of train/no train and warning sign effects on simulated driving performance under limited versus unlimited visibility conditions; (4) lack of awareness on the part of subjects that the study is explicitly concerned with HRI warning sign; (5) a duration for each testing session of about 1 hr, to reduce the likelihood of possible confounding effects of fatigue on driver performance during the latter stages of a given testing session.

To satisfy these considerations, a simulated driving task environment was developed for the study, comprising: (1) a 1.05 km (0.65 mi) roadway course, with a start and end line; (2) an HRI 644 m (2112 ft) from the start line; (3) an advance warning sign 293.3 m (962 ft) from the HRI, on the right shoulder; (4) a grade Xing crossbuck sign 3.7 m (12 ft) from the HRI, on the right shoulder; (5) HRI railroad tracks at a right angle to the roadway; (6) a simulated TC&W train with engine and 16 cars; (7) a train that emerges from behind trees to the right in some trials as the vehicle approaches the HRI, at 150.9 m (495 ft) from HRI, when vehicle is 206.6 m (677.7 ft) from Xing; (8) a 40 mph train speed; (9) a 55 mph roadway speed limit; (10) 2 types of grade Xing crossbuck sign, a standard passive HRI crossbuck sign (MUTCD Type R15-1 sign [26, p. 8B-2]), and a standard crossbuck with 2 active alternatively flashing red lights (MUTCD flashing-light signal [26, p. 8D-3]) (1 hz alternate flashing rate); (11) 3 types of advance HRI warning sign, a standard passive advance warning sign (MUTCD Type W10-1 sign [26, p. 8B-4]), an advance MUTCD Type W10-1 sign affixed with active alternatively yellow flashing lights (1 hz alternate flashing rate), and an advance MUTCD Type W10-1 sign affixed with an active VMS that flashes the word 'TRAIN' at a 1 hz flashing rate; (12) identical arrival times at HRI after train emerges from trees of 8.4 sec for vehicle and train, at vehicle speed of 55 mph and train speed of 40 mph; (13) clear or limited (91.5 m (300 ft), using simulated fog) visibility; and (14) simulated fallen tree across both lanes of road shortly before end line. Details of these simulated driving task environment features are provided in the paragraphs below.

Simulated Roadway and HRI. The simulated roadway was modeled as a 2-lane undivided highway, using standard dimensions for such roadways in the state of Minnesota---3.66 m (12 ft) lane widths and 1.83 m (6 ft) shoulder widths, with a dashed white line separating the two lanes.

A start- to end-line roadway length of 1.05 km (0.65 mi) was specified, after pilot testing, to provide a length for each trial of approximately 1 min (0.65 mi x 55 mph x 3600 sec/hr = 42.5 sec; elapsed time per trial extended to approximately 60 sec because of delays attributable to the stationary start, vehicle slowing related to the advance warning sign and the Xing crossbuck sign, vehicle stopping for the occasional train, vehicle slowing for a roadway S-curve beyond the Xing, and vehicle slowing because of the tree hazard near the end line).

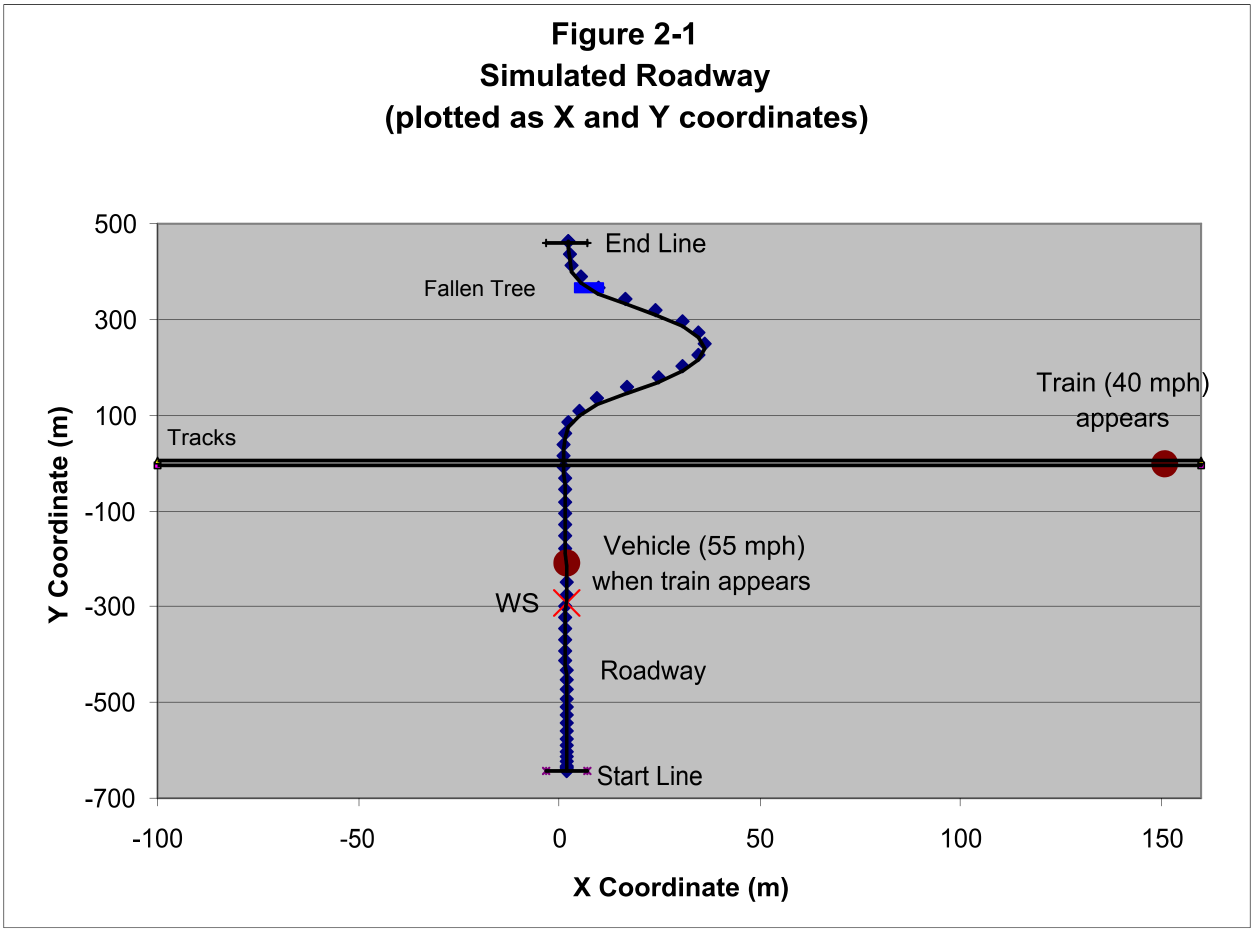


Figure 2-1. Schematic illustration of simulated roadway, HRI, advance warning sign placement, relative vehicle and train positions when train appears, and fallen tree position

Figure 2-1 provides a schematic illustration of the simulated roadway, plotted using the (X,Y) coordinates (in meters) adopted by the simulation model for the roadway. The HRI intersection of the roadway and the railroad tracks (depicted as double horizontal lines) occurs at (X,Y) coordinates of (0,0). The roadway begins with a start line 644 m (2112 ft) before the HRI, proceeds as a straight road up to and slightly beyond the HRI, then features an S-curve to the right and left before terminating at an end line. The distance scale for the X axis is expanded relative to that for the Y axis—the roadway curve only deviates about 36 m (118 ft) from the linear alignment of the roadway that prevails before the HRI. Also shown in Figure 2-1 are the positions of: (1) the advance warning sign (293 m (962 ft) in front of the track); (2) the train when it emerges from some trees to the right (151 m (495 ft) before HRI); (3) the vehicle when the train emerges (207 m (679 ft) from HRI); and (4) the fallen tree, shortly before the end line.

The distances specified above and in Figure 2-1, pertaining to the HRI layout and warning sign placement, are based on HRI design specifications contained in the FHWA MUTCD [25] and in the Minnesota Traffic Engineering Manual. Figures A-1 through A-5 in Appendix A present the relevant specifications.

Figure A-1 in Appendix A [25, Chap. 2A, p. 2A-18, Fig. 2A-7] is a schematic illustration of an HRI and placement of HRI warning sign, that provides a guide for the simulated driving task environment modeled in this study (Fig. 2-1). Shown in Figure A-1 are a passive Xing crossbuck sign, a passive advance warning sign, and a roadway pavement sign.

Figures A-2 and A-3 in Appendix A illustrate recommended placement distances for the advance warning sign, and the Xing crossbuck and roadway pavement signs prior to an HRI. Figure A-2 [23, State Project no. 8809-107 & 8809-108, Sheet No. 79] is a modified version of the FHWA MUTCD HRI design specifications shown in Figure A-3 [25, Chap. 8, p. 8B-13]. The table in the upper right corner of Figure A-2 is a modified version of FHWA MUTCD specifications for advance placement of a warning sign [25, Chapter 2C, p. 2C-7, Table 2C-4].

As noted above, the simulation model uses a distance of 3.7 m (12 ft) between the Xing crossbuck sign and the track (unlike the depiction in the figure, a Xing Stop sign was not used in this study). A distance of 293.3 m (962 ft) between the track and the advance warning sign was modeled, based on the following specifications in Figure A-2: (1) distance of 213.4 m (700 ft) between Xing and first advance warning sign (the first advance warning sign shown in figure is a stop sign), using the Condition A specification for a vehicle speed of 55 mph shown in Table II-1 in upper right-hand corner of Figure A-1; (2) additional 76.2 m (250 ft) between first advance warning sign and advance warning sign for rural settings; and (3) 3.7 m (12 ft) between crossbuck sign and track. These 3 distances (700 + 250 + 12 ft) yield the total of 293.3 m (962 ft) between the advance warning sign and the track used in the model.

Figure A-4 in Appendix A [23, Minnesota Traffic Engineering Manual, Figure 13.7A, Jan. 1, 1996] shows the equations employed, with an accompanying diagram, for computing sight line distances between a moving vehicle and a train for a right-angle HRI. The table shown in Figure A-5 in Appendix A [23, Minnesota Traffic Engineering Manual, Figure 13.4, July 1, 1992] provides a tabulation of results from the computation equation shown in Figure A-4. For a train speed of 40 mph and a vehicle speed of 55 mph, the table in Figure A-3 specifies a required sight line distance along the track from the Xing of (137.8 m) (452 ft) for the train, with a vehicle distance on the highway from the Xing of 170.7 m (560 ft) at this sight line distance.

The sight line specifications in Figures A-4 and A-5 in Appendix A are established to allow a moving vehicle to safely <u>cross</u> the HRI after a train becomes visible. In this study however, the purpose was to ascertain how different types of advance warning sign and Xing crossbuck signs influenced driver interaction with an HRI when <u>stopping</u> at the HRI was the 'safe' behavior. Thus, the simulation model provided for arrival of the vehicle and the train at the HRI at the same elapsed time after the train emerged from some trees to the right and became visible to the driver.

This was accomplished by having the train become visible with the vehicle <u>further back</u> from the HRI than the vehicle-HRI distance specified in the table in Figure A-5. As noted above, when the simulated train first becomes visible, the train is 151 m (495 ft) from the HRI (495 ft x 1 mi/5,280 ft x 1hr/40 mi x 3600 sec/hr = 8.4 sec), and the vehicle is 207 m (679 ft) from the HRI (679 ft x 1 mi/5,280 ft x 1 hr/55 mi x 3600 sec/hr = 8.4 sec). This timing condition provides an option for the driver to: (1) display cautious behavior by slowing down and stopping for the train at the HRI; or (2) display risk-taking behavior by speeding up and trying to beat the train across the HRI.

Figure 2-2. Photo of TC&W Railroad engine

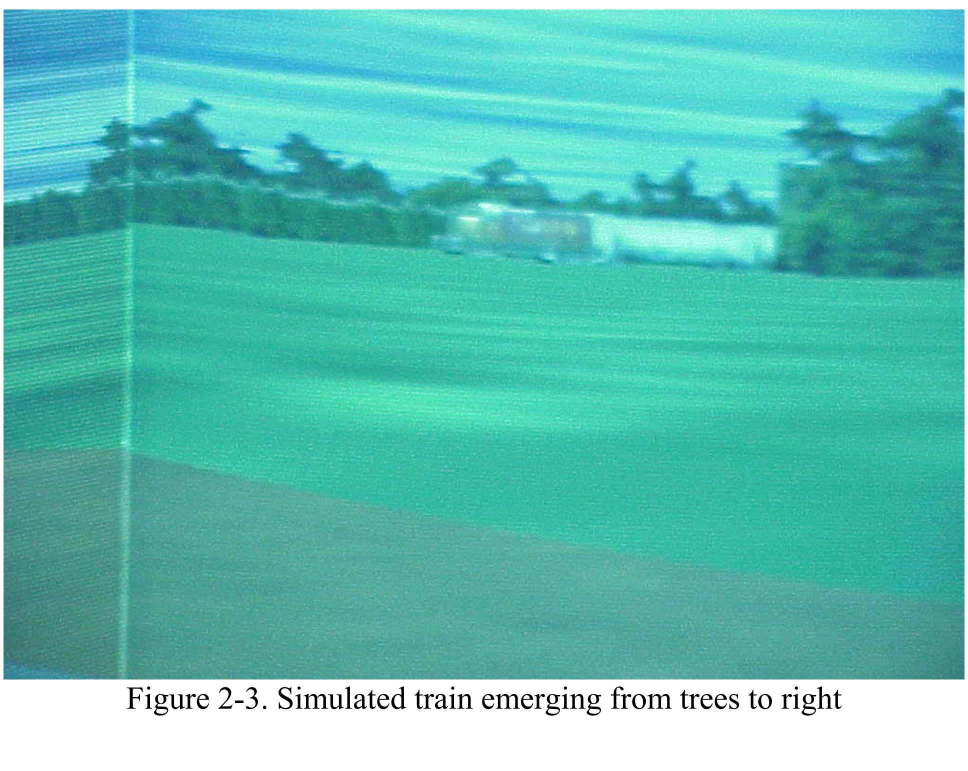


Figure 2-3. Simulated train emerging from trees to right

Figure 2-4. Simulated train crossing HRI with passive Xing crossbuck sign

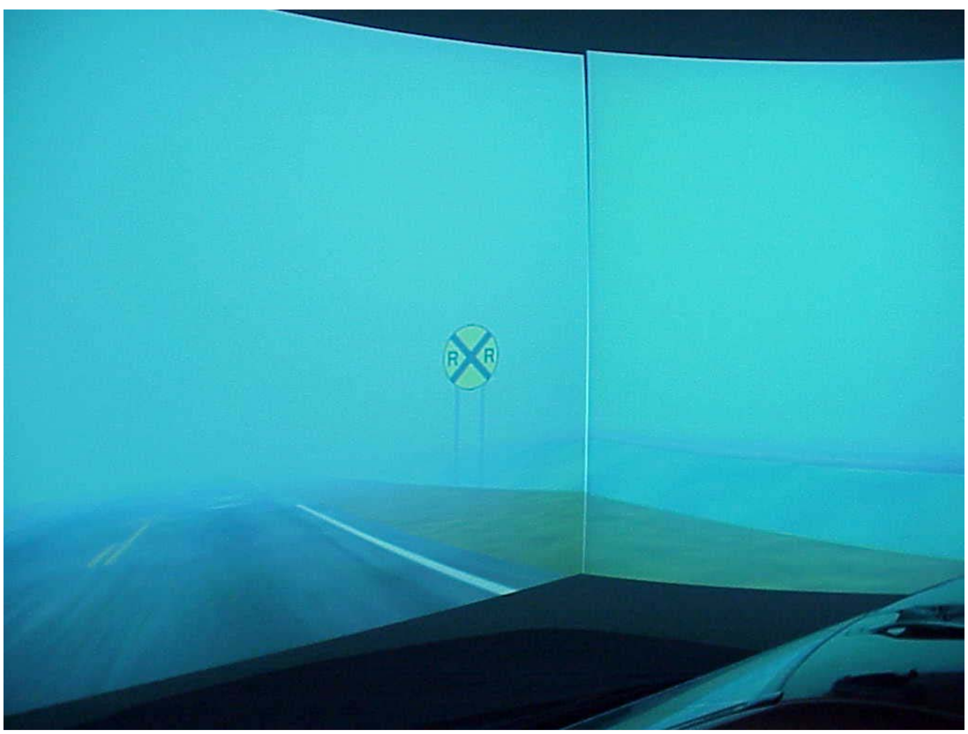


Figure 2-5. Simulated passive advance warning sign (fog)

Figure 2-6. Simulated active Xing flashing red light crossbuck sign in fog, with train

Figure 2-7. Simulated active advance flashing yellow light warning sign

Figure 2-8. Simulated active advance VMS


Figure 2-9. Simulated fallen tree in fog

Simulated Limited Visibility. The simulated viewing distance for the unlimited visibility condition was 700 ft. The limited visibility condition was implemented by simulating fog that limited visibility to 350 ft in front of the driver (see Figs. 2-6, 2-7, and 2-9 above).

Simulated HRI warning sign. Six different types of HRI warning sign were developed with the simulation model: (1) a standard Xing crossbuck sign (MUTCD Type R15-1 sign [25, p. 8B-2]); (2) a standard passive advance warning sign (MUTCD Type W10-1 sign [25, p. 8B-4]); (3) a grade Xing roadway pavement marking [25, p. 8B-13, Fig. 8B-2]; (4) a standard active Xing flashing red light crossbuck sign [25, p. 8D-3]; (5) an active advance flashing yellow light warning sign; and (6) an active advance flashing text VMS. Each of these is described below.

Grade Xing Pavement Marking. As depicted in Appendix A, Figures A-1 through A-3, this marking is a white 'X' symbol positioned on the roadway pavement just beyond the advance warning sign towards the track [25, p. 8B-13, Fig. 8B-2]. Positioning specifications for the pavement marking are shown in Appendix A, Figure A-3 [IBID]. The FHWA MUTCD also provides design specifications for the size of this marking [25, p. 8B-14, Fig. 8B-3].

Passive Xing Crossbuck Sign. As depicted in Figures A-1 through A-3 in Appendix A, a passive Xing crossbuck sign consists of 2 crossed elongated white rectangles with the words 'Railroad Crossing' in black text on them. This sign is catalogued as Sign R15-1 by the FHWA MUTCD [26, Chap. 1 (Regulatory Signs), p. 1-146]. Design specifications for the crossbuck and support pole are shown in Appendix A, Figures A-6 and A-7 [25, p. 8B-2; 24]. A photo of the simulation model of the sign, along with the simulated train, is shown in Figure 2-4.

Passive Advance Warning Sign. As depicted in Figures A-1 through A-3 in Appendix A, the advance passive warning sign consists of a circular sign with a yellow background and a black X symbol separating the letters 'R' and 'R' (FHWA MUTCD design specifications for this sign are shown in Appendix A, Figure A-8 [26, Chap. 3 (Warning Signs), p. 2-99]. This sign is catalogued as Sign W10-1 by the FHWA MUTCD [25, p. 8B-4]. Figure 2-5 is a photo of the simulation model for this sign, shown under limited visibility (simulated fog) conditions.

Active Xing Crossbuck Sign With Flashing Red Lights. The active Xing crossbuck sign consists of a crossbuck positioned above 2 red warning lights positioned on each side of the support pole [24]—FHWA MUTCD design specifications for the sign are shown in Appendix A, Figure A-6 [25, p. 8D-3]. A photo of the simulation model of this sign, with the simulated train in the background, is in Figure 2-6. During simulated driving performance testing, with a train present, the red warning lights on the sign were programmed to flash on and off alternatively at a frequency of 1 hz.

Active Advance Flashing Yellow Light Warning Sign. Because the FHWA prohibits an advance active warning sign at an HRI [1], the design for this sign was adapted from AWFs used at signalized intersections [7]. Specifically, as shown in the photo of the simulation model for this sign in Figure 2-7, the sign was implemented with yellow warning lights positioned on either side of a circular yellow passive warning sign. During simulated driving performance testing, with a train present, the yellow warning lights on the sign were programmed to flash on and off alternatively at a frequency of 1 hz.

Active Advance VMS. Because the FHWA prohibits an active advance warning sign at an HRI [1], the design for this sign was created *de novo*, based on input from Mn/DOT and SRF project collaborators (see Acknowledgments). Specifically, as shown in the photo of the simulation model for this sign in Figure 2-8, the sign was implemented with a circular yellow passive warning sign positioned above a black rectangle. During simulated driving performance testing, with a train present, the word 'TRAIN,' in white letters, was programmed to flash on and off on the black rectangle at a frequency of 1 hz (a photo of the simulation model for the sign with the word 'TRAIN' showing could not successfully be acquired).

Because visual images in the simulation model had a fidelity inferior to real world images (apparent in the photos in Figs. 2-2 through 2-9 above), the sizes of the HRI warning sign were magnified in the simulation model relative to their actual real world sizes. The purpose was to attempt to match the visibility properties of the signs with those that prevail under real world viewing conditions.

Simulated Train. A simulation model of a TC&W Railroad engine with 16 freight cars was developed, based on design specifications provided by Dan Rickel (Personal Communication). Figure 2-2 is a photo of the side view of an actual TC&W engine provided by Mr. Rickel, which was used to guide the modeling of the shape, appearance, color, and logo appearance of the engine. Figures 2-3, 2-4, and 2-6 are photos of the simulation model of the train from different perspectives.

According to design specifications provided, the length, width, and height of a TC&W engine are 18.0 m, 3.125 m, and 4.8 m (59.17 ft, 10.25 ft, and 15.75 ft) respectively. The corresponding dimensions for a TC& W freight car are 18.32 m, 3.18 m, and 4.19 m (60.08 ft, 10.42 ft, and 13.75 ft) respectively. The gap between the engine and the first freight car is approximately 1m (see Fig. 2-4). That between each freight car is approximately 0.3 m (1 ft). These dimensions yield a total length for a TC&W train with an engine and 14 freight cars of approximately 279.4 m (916.4 ft). Given the 40 mph train speed, this length means that the train will take approximately 15-16 sec to cross the HRI. Thus, trials with a train present (next section) will take this much time longer than those without a train present.

Simulated Fallen Tree. In some trials (next section), the driver encountered a simulated fallen tree across the roadway, shortly before the end line (Fig. 2-1). The tree was positioned on a curved portion of the roadway, such that it did not become visible until the driver had traversed part of the curve. Figure 2-9 showarning sign a photo of the simulation model of the tree under limited visibility (simulated fog). It covers all of the right lane and most of the left lane of the roadway. To avoid the tree, drivers could steer into the lefthand shoulder and drive around the tip of the tree.

Simulated Speed Limit Sign. A simulated speed limit (SL) sign (55 mph), based on FHWA MUTCD design specifications for Sign R2-1 [26, Chap. 1 (Regulatory Signs), p. 1-5], was placed just off the right hand shoulder just beyond the Start line.

2.2.3. Relative Timing of Vehicle and Train Interaction with HRI

Table 2-1 summarizes the relative timing of vehicle and train interaction with the HRI, based on specifications and distances for the simulated driving environment described in the preceding subsection (Fig. 2-1). Data in the table pertain to those trials in which a train is present (next section), and assume a train speed of 40 mph and a vehicle speed of 55 mph, the latter conforming to the posted speed limit. Listed in Table 2-1 are timing and distance specifications for sequential events culminating at time t=0 when the vehicle and the train meet at the HRI. Also included in the table are timing specifications for actuation of the active advance warning sign and the active Xing crossbuck sign—data in the table thus pertain to those train-present trials in which active warnings are used for either the advance warning sign or the Xing crossbuck sign, or both.

The data in Table 2-1 show that the active advance warning sign and the active Xing flashing red light crossbuck sign are actuated at -30 sec, before the trial starts and the vehicle leaves the start line. The vehicle arrives at the advance warning sign 11.9 sec before reaching the HRI. The train emerges from the trees to the right (Fig. 2-3) when both the vehicle and the train are 8.4 sec from the HRI.

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 subjects are less likely to vary their driving behavior in a manner comparable to real world patterns if experimental conditions governing the simulated driving task environment 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 subjects may not exhibit ecologically valid driving behavior (e.g., comparable to real world driving behavior), during interaction with different types of HRI warning sign under different experimental conditions, if they perceive from the outset that evaluating the influence of warning sign on driving behavior represents the main objective of the study.

Table 2-1. Relative timing of vehicle and train interaction with HRI

Event	Vehicle Status		Train Status		Timing of Active Advance Warning Sign Actuation[2]	Timing of Active Xing Crossbuck Sign Actuation[2]
	Time	Distance to Xing	Time	Distance to Xing		
1. Actuation of active advance warning sign and active Xing crossbuck sign					-30 sec	-30 sec
2. Trial starts. Vehicle leaves start line	-26.2 sec[1]	-644 m (-2112 ft)				
3. Vehicle arrives at advance warning sign	-11.9 sec	-293 m (-962 ft)				
4. Train emerges from trees to right (Fig. 2-3)	-8.4 sec	-207 m (-679 ft)	-8.4 sec	-151 m (-495 ft)		
5. Vehicle and train arrive at HRI	0 sec	0 m (0 ft)	0 sec	0 m (0 ft)		

[1]This time assumes a constant vehicle speed from the start line of 55 mph. Because the vehicle starts from a stationary position and must accelerate to 55 mph, the actual elapsed time for the vehicle from the start line to the HRI will be greater than 26.2 sec.
[2]For trials in which the advance warning sign and the Xing crossbuck sign are active.

Accordingly, a key premise of the experimental design set forth here is that the major focus of the research---variable driving behavior by subjects during interaction with different types of HRI warning sign---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 subjects that control of vehicle **speed** represents the major objective of the experiment (Section 2.4). Subsections below delineate the objectives, experimental conditions, and independent and dependent measures for 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 different types and combinations of HRI warning sign on control of vehicle speed, acceleration (accel)/deceleration (decel), and braking behavior by drivers during interaction with HRIs under simulated driving conditions. Specific research objectives are to: (1) clarify how simulated driving behavior during interaction with HRIs is influenced by different types and configurations of HRI warning sign, under train present or absent and high or low visibility conditions; and (2) target possible traffic engineering design improvements to HRI warning sign that may benefit the engineering design of HRIs and consequent driving safety during vehicle interaction with HRIs.

2.3.2. Experimental Conditions

A total of 24 different experimental conditions, comprising different combinations of train presence or absence, visibility, and HRI warning sign, were employed in the study. These are summarized in Table 2-2. Because each condition represented a different type of simulated driving task for subjects, henceforth the 24 conditions specified in Table 2-2 will be termed task conditions (TCs).

The 24 task conditions listed in Table 2-2 featured: (1) a total of 120 trials administered to each subject, each lasting about 1 min; (2) 2 separate testing sessions of 60 trials each for each S, administered on separate days; (3) 2 sets of control trials (30 trials in each set), featuring passive advance and Xing crossbuck signs (Control #1, see Figs. 2-4 and 2-5), or passive advance warning sign and active Xing flashing red light crossbuck sign (Control #2, see Figs. 2-5 and 2-6); (3) 2 sets of test trials (30 trials in each set), featuring active advance flashing yellow light warning sign and active Xing flashing red light crossbuck sign (Test #1, see Figs. 2-6 and 2-7), or active advance flashing VMS and active Xing flashing red light crossbuck sign (Test #2, see Figs. 2-7 and 2-8); (3) within each 30-trial set, 15 trials featuring unlimited visibility (see Figs. 2-3 or 2-8), and 15 trials featuring limited visibility (fog, see Figs. 2-5 or 2-6); (4) within each 30-trial set, 26 trials with train absent (advance and Xing active warning sign not actuated), and 4 trials with train present (advance and Xing active warning sign both actuated) (see Figs. 2-3 or 2-4); and (5) within each 30-trial set, 26 trials with no fallen tree, and 4 trials with a fallen tree present (see Fig. 2-9) (no trial featured both a train present and a fallen tree).

Across the 120 trials, each subject encountered a train during 16 trials, a train encounter rate of 13.3 percent. This train encounter rate represents a compromise between: (1) the lower encounter rate between vehicles and trains that prevails in the real world; and (2) the need to

Table 2-2. Task conditions employed in study

TC	Control/Test Category	Advance Sign	Xing Sign	Train	Fog	Fallen Tree	Number of Trials
1	Control #1	Passive	Passive	No	No	No	11
2	Control #1	Passive	Passive	Yes	No	No	2
3	Control #1	Passive	Passive	No	No	Yes	2
4	Control #1	Passive	Passive	No	Yes	No	11
5	Control #1	Passive	Passive	Yes	Yes	No	2
6	Control #1	Passive	Passive	No	Yes	Yes	2
7	Control #2	Passive	Active-Off	No	No	No	11
8	Control #2	Passive	Active-On	Yes	No	No	2
9	Control #2	Passive	Active-Off	No	No	Yes	2
10	Control #2	Passive	Active-Off	No	Yes	No	11
11	Control #2	Passive	Active-On	Yes	Yes	No	2
12	Control #2	Passive	Active-Off	No	Yes	Yes	2
13	Test #1	Active-Off	Active-Off	No	No	No	11
14	Test #1	Active-On	Active-On	Yes	No	No	2
15	Test #1	Active-Off	Active-Off	No	No	Yes	2
16	Test #1	Active-Off	Active-Off	No	Yes	No	11
17	Test #1	Active-On	Active-On	Yes	Yes	No	2
18	Test #1	Active-Off	Active-Off	No	Yes	Yes	2
Table 2-2. Task Conditions employed in study (continued)							

TC	Control/Test Category	Advance Sign	Xing Sign	Train	Fog	Fallen Tree	Number of Trials
19	Test #2	VMS-Off	Active-Off	No	No	No	11
20	Test #2	VMS-On	Active-On	Yes	No	No	2
21	Test #2	VMS-Off	Active-Off	No	No	Yes	2
22	Test #2	VMS-Off	Active-Off	No	Yes	No	11
23	Test #2	VMS-On	Active-On	Yes	Yes	No	2
24	Test #2	VMS-Off	Active-Off	No	Yes	Yes	2

incorporate enough vehicle-train encounters into the study to provide meaningful statistics regarding simulated driving performance during vehicle interaction with an HRI with a train present. The order of trials was randomized for each subject, so that no subject could predict when a given trial would feature a train encounter.

Given the experimental design described above, the study comprises the following key features for the 25 subjects tested: (1) 1,950 simulated miles driven; and (2) 400 vehicle-train encounters, half in clear and half in limited (fog) visibility, and 100 for each of the 4 control and test task conditions described in Table 2-2.

Although those trials with a fallen tree present are specified in Table 2-2 as representing separate task conditions, only data for simulated driving performance between the start line and the HRI was quantitatively analyzed (Section 2.5). Therefore, insofar as data analysis is concerned, results from the fallen tree present/train absent trials are considered equivalent to, and combined with results from, the fallen tree absent/train absent trials across different control and test conditions (Table 2-2).

2.3.3. Independent Measures

The bullets below, and Tables 2-2 and 2-3, describe the following independent measures for the study: (1) train absence or presence; (2) visibility; (3) type and combination of advance and Xing HRI warning sign; and (4) subjects. The order of trials was randomized for each subject (Section 2.4), so that no subject could predict when a given trial would feature a particular set of conditions.

- ***Train Absence or Presence***. For each set of 120 trials per subject, trains were encountered during 16 trials, and not encountered during 104 trials (Table 2-2).
- ***Visibility***. For each set of 120 trials per subject, 60 trials featured unlimited visibility, and 60 trials featured limited visibility (fog) (Table 2-2).

Table 2-3. Characteristics of subjects participating in study

Statistic[1]	All Ss	Male Ss	Female Ss
Number	25	10	15
Mean Age	22.2	21.9	22.4
SD, Age	2.8	2.9	2.7
Median Age	22	21.5	22
Age Range	11	10	11
Minimum Age	19	19	19
Maximum Age	30	29	30

[1]Age statistics in yrs

< ***Type and Combination of HRI Warning Sign***. For each set of 120 trials per subject: (1) 30 trials featured a passive advance warning sign and a passive Xing crossbuck sign; (2) 30 trials featured a passive advance warning sign and an active Xing flashing red light crossbuck sign; (3) 30 trials featured an active advance flashing yellow light warning sign and an active Xing flashing red light crossbuck sign; and (4) 30 trials featured an active advance VMS and an active Xing flashing red light crossbuck sign (Table 2-2).

< ***Subjects***. A total of 25 subjects participated in the study, 10 males and 15 females. Table 2-3 summarizes subject age statistics. Mean age is 22.2∀2.8 (∀SD) yrs for all subjects, 21.9∀2.9 yrs for males, and 22.4∀2.7 yrs for females. Age range is 19 to 30 yrs for all subjects, 19 to 29 yrs for males, and 19 to 30 yrs for females. These statistics indicate comparable age characteristics and distributions for male and female subjects participating in the study.

2.3.4. Dependent Measures

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

After data collection for all subjects had been completed, it was discovered that the simulated driving performance data for one subject (a 25-year old female) had been corrupted. However, this subject had completed the 120-trial study successfully, and also had completed the PTQ. Therefore, results (Section 3) reported for visual observations of simulated driving performance and for the PTQ are derived from all 25 subjects, whereas those reported for objective measures of simulated driving performance are derived from only 24 subjects.

Visual Observations of Simulated Driving Performance. Dependent measures in this category were collected by the study researcher (the Principal Investigator for the project) through visual observations of each S, for each of their 120 simulated driving trials, as the subject traversed the simulated driving task environment. Appendix B contains the observation form used for this purpose. To make visual observations, the researcher sat on a chair placed next to the open window of the front driver's side door of the Acura Integra, and manually recorded observations on the form during each trial.

Table 2-4. Dependent measures collected during study

Category	Dependent Measure	Units	Derivation
Simulated Driving Performance			
Visual Observations	- Stopping behavior at HRI	stopped for train beat train	observed
	- Accidents at HRI	vehicle hit train	observed
Objective Measures			
Within- and between-S averages for the vehicle speed and braking measures listed below were calculated for the following roadway intervals: • start line to HRI (interval distance = 644 m / 2112 ft) • advance warning sign to HRI (interval distance = 293.3 m / 962 ft) • advance warning sign to 200 m (656 ft) from HRI (interval distance = 93.3 m / 306 ft) • 200 m (656 ft) from HRI to 100 m (328 ft) from HRI (interval distance = 100 m / 328 ft) • 100 m (328 ft) from HRI to HRI (interval distance = 100 m / 328 ft)			
Vehicle Speed	- Mean Vehicle Speed (MVS)	m/sec	calculated
	- Mean Accel/Decel	m/sec/sec	calculated
Vehicle Braking	- Mean Braking Pressure (MBP)	V	calculated
PTQ Responses	- See Appendix C	various	S self-report

The leftmost column on the form lists the trial number—visual observations for Trials 1-60 were recorded on one set of forms during Testing Session 1 for the subject, and for Trials 61-120 on a separate set of forms during the Testing Session 2, which was administered to the subject on a separate day (Section 2.4). Successive columns on the form were checked appropriately to indicate, for each trial: (1) whether or not fog was present; (2) the type of advance warning, passive or active ('VMS' was entered in the 'Active' column for those trials in which the advance warning sign was a VMS); (3) the type of Xing crossbuck sign, passive or active; (4) whether or not a train was present; (5) whether or not the driver stopped at the HRI; (6) whether or not a fallen tree was present; and (7) whether or not an accident occurred, defined as a collision of the vehicle with the train. Collectively, the information entered in Columns 1-4 and 6 defined the task condition (Table 2-2) associated with each trial.

The rightmost column on the visual observation recording form (Appendix B) was used for two purposes. The first was to record any comments regarding distinctive driving behavior that may have been observed during a trial (an example is some subjects slowing almost to a stop when they encountered an active advance flashing warning sign in the fog). The second purpose was to record the cumulative elapsed time during the testing session at every 10 successive trials. These times also were reported verbally to the S, in order to provide guidance to the subject as to whether or not the subject was maintaining the targeted vehicle speed from trial to trial required to earn a bonus (Section 2.4).

For each testing session, the following information was recorded at the top of the first page of the visual observation form (Appendix B): (1) the date of the session; (2) the name, assigned ID number, age, and gender for the S; (3) the session number (1 or 2); (4) the start, stop, and elapsed times for the session; (5) the name of the computer file in which the simulated driving performance data were stored after completion of the session; and (6) the seed number, used for randomization of the order of trials for each subject (Section 2.4).

As indicated in Results (Section 3), a main purpose of the visual observations was to record, during trials with a train present, both stopping behavior and accidents at the HRI, in relation to the type of advance warning sign and Xing crossbuck sign present during the trial.

Objective Measures of Simulated Driving Performance. During a trial, the SGI Indigo computer continuously monitors input from sensors in the Acura Integra 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 ('Hawk,' Section 2.2.1) that is used for file storage of simulated driving performance data. Specifically, these data are recorded automatically by Hawk into a Microsoft Excel-compatible output text file updated continuously at a rate of 1 hz. Data from all 60 trials administered during a testing session for a subject were stored in 1 file.

In addition, for each testing session, a separate task sequence file was generated indicating the task condition (Table 2-2) associated with each trial. This precautionary measure was adopted because the task condition assigned to each trial had a different, random order for each subject. In addition to the visual observation form, the task sequence file thereby served as a second source of information as to the task condition assigned to each trial. For each subject completing the study therefore, a total of 4 data files were generated, 2 for each testing session.

The text file generated for each testing session contains the following data by column: (1) Column 1 - elapsed session time in sec, increasing by 1-sec (1 hz) intervals from the start time for the session; (2) Column 2-4 - X, Y, and Z coordinates (in m) of vehicle position in simulated driving task environment during each trial (see Fig. 2-1 for plot of X and Y coordinates of simulated roadway in simulated driving task environment); (3) Column 5 - vehicle heading in deg; (4) Column 6 - trial and experimental condition information, in the format <trial number>.<experimental condition>; (5) Column 7 - train and warning sign status information for time indicated, in the format <warning sign status>.<train status>,; (6) Column 8 - vehicle speed in m/sec; (7) Column 9 - vehicle accelerator pressure in V (0 = no accelerator pressure; 1 = accelerator fully depressed); (8) Column 10 - vehicle braking pressure in V; and (9) Column 11 - steering wheel position angle, in radians (0 = steering wheel centered).

The X and Y coordinate values, which indicate vehicle position, are used to: (1) extract blocks of data pertaining to driver performance between the start line and the HRI (Section 2.5); and (2) calculate vehicle distance from the intersection, in m, at successive 1-sec intervals as the vehicle approaches the intersection. In Column 6, the trial number increases sequentially from 1 to 60 from the start to the end of the data file, and identifies the trial number for each 1-sec data set, while the experimental condition is a number varying from 1 to 24 that identifies the experimental condition (Table 2-2) for each trial. The warning sign and train status information in Column 7 has the following definitions: (1) 0.0 = advance warning sign and Xing crossbuck sign not active, train not present (i.e., visible); (2) 0.1 = passive advance warning sign and passive Xing crossbuck sign, train present; 0; (3) 1.0 = active advance warning sign and active Xing crossbuck sign flashing, train not yet visible; and (4) 1.1 = active advance warning sign and active Xing crossbuck sign flashing, train visible. The vehicle speed and braking pressure data in Columns 8 and 10 are used to derive dependent objective measures of simulated driving performance. Detailed below are methods used to acquire these vehicle performance data, and the dependent measures of driving performance (Table 2-4) calculated therefrom.

< ***Vehicle Speed***. Readout from the Acura Integra accelerator is used to control how rapidly projected visual feedback of the simulated driving task environment 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 simulated driving task environment to an accuracy of 1 mm during a driving task. From this information, successive measures of vehicle speed in m/sec are recorded in Column 8 of the data text file.

< ***Vehicle Accel/Decel***. Successive values of vehicle accel/decel (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 Acura Integra, 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 10 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.

< ***Average Values of Objective Measures of Simulated Driving Performance***. During data analysis (Section 2.5), average values for each of the objective measures of simulated driving performance described above were calculated for the following roadway intervals: (1) start line to HRI (interval distance = 644 m / 2112 ft); (2) advance warning sign to HRI (interval

distance = 293.3 m / 962 ft); (3) advance warning sign to 200 m (656 ft) from HRI (interval distance = 93.3 m / 306 ft); (4) 200 m (656 ft) from HRI to 100 m (328 ft) from HRI (interval distance = 100 m / 328 ft); and (5) 100 m (328 ft) from HRI to HRI (interval distance = 100 m / 328 ft). Hereafter, these roadway intervals will be abbreviated as IntSL-HRI, Intwarning sign-HRI, Intwarning sign-200, Int200-100, and Int100-HRI respectively. The calculated averages for each of these intervals generate a profile of how vehicle speed, braking, and accel/decel varied as the vehicle approached the HRI, in relation to the different task conditions of train absence/presence, visibility, and type of HRI warning sign.

< ***PTQ Responses***. Following completion of the second testing session, each subject was asked to complete a PTQ, a copy of which is provided in Appendix C. The questionnaire comprises a total of 47 questions (Q) that solicit subject responses in 5 different areas: (1) subject characteristics and background (Q1-Q4,Q6); (2) a query of subject understanding of what the study was about (Q5); (3) a series of questions, each using a Likert scale, that gauge the degree of subject understanding of and agreement/disagreement with statements pertaining to the design, conspicuity, and usability of different types and configurations of HRI warning sign (Q7-Q42); (4) a series of questions that query how a subject is likely to behave in approaching a real world HRI (Q43-Q46); and (5) any comments the subject may have regarding their experiences with the study (Q47).

For each of the Likert-scale questions on the PTQ (Q7-Q42), the subject is asked to indicate, on a scale of 1 to 5, agreement or disagreement with a statement about HRI warning sign, with a response of 1 indicating strong disagreement, and a response of 5 indicating strong agreement, with the question statement.

The PTQ in Appendix C is entitled 'Simulated Driving Study,' with no indication that the study is concerned with HRI warning sign. This title is used for purposes of consistency with the experimental protocol (Section 2.4). As noted earlier (Section 2.3), prior to the first testing session each subject was told that control of vehicle **speed** was the major objective of the experiment.

2.3.5. 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) train presence or absence; (2) visibility level; and (3) type and configuration of HRI warning sign.

2.3.6. Pilot Studies and Elapsed Session Driving Time Targets

Prior to testing the regular experimental subjects, simulated driving performance of 6 pilot subjects (2 females, 4 males, mean age 28.2 yrs, age range 22-45 yrs) was evaluated. Each of these pilot subjects completed one 60-trial testing session. The primary goals of the pilot testing were to make observations on: (1) how long different subjects would take to traverse the simulated driving task environment during a trial (the target trial duration was about 1 min, to allow administration of 60 trials in about 1 hr); (2) total session completion times, to guide specification of session duration times that a subject should match to earn a bonus (Section 2.4); (3) features of the first iteration of the simulated driving task environment model that might require modification; and (4) the appropriate delay time between each trial. The observation form shown in Appendix B was used to record visual observations of simulated driving performance during the testing session for each pilot subject Dependent measures other than visual observations were not collected for the pilot subjects.

Based on observations made during pilot testing, the following modifications to the first iteration of the simulated driving task environment model were made: (1) the distance between the HRI and the end line (Fig. 2-1) was shortened, yielding subject trial completion times of about 1 min in length; (2) a targeted testing session duration time interval of 52-68 min, which a subject must meet to earn a bonus (Section 2.4), was specified; (3) the position of the fallen tree (Fig. 2-9) was modified to cover more of the oncoming lane of the simulated roadway; and (4) a delay time of 10 sec between each trial was specified.

Regarding the last point, it was observed that with a shorter delay time of 5 sec between each trial, 3 of the first 6 subjects enlisted for pilot testing reported feeling queasy after 15-30 1-minute trials, and were not able to complete the 60-trial pilot session. Based on comments of pilot subjects, the apparent problem was that this short between-trail delay interval gave a 'video game' feeling to testing across successive trials, such that subjects were not able to settle themselves between trials and prepare adequately for the next trial. It was evident that an appreciable number of pilot subjects found this experience unsettling. With a between-trial delay interval of 10 sec, 6 of 31 subjects recruited for regular testing dropped out during Testing Session 1 because of feeling queasy (typically after completing 15-30 trials), and 25 subjects finished the study successfully (Table 2-3).

2.4. Experimental Protocol

Simulation testing of subjects was initiated in January, 2002 and was completed in June, 2002. The experimental protocol followed for testing driving performance of subjects under simulated driving conditions comprises the following steps. These also are itemized in checklist form in Appendix F.

1. A schedule was drawn up for testing volunteers for the study. For each subject, two 1-hr testing sessions, each consisting of 60 experimental trials were scheduled on two different days.
2. Prior to beginning their first testing session, each individual volunteering to serve as a subject 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 D.
3. After the informed consent form had been signed by the subject and the researcher, the subject was asked to complete a pre-test questionnaire, shown in Appendix E. The pre-test questionnaire was administered only once, prior to the first testing session. The purpose of this questionnaire is to collect information about the driving experience of the S, plus any evidence of subject susceptibility to dizziness, nausea, and/or emotional disturbance while driving. A subject 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. Subject responses to the pre-test questionnaire are not evaluated in this report.
4. A series of steps were required to initialize the HFRL flat screen driving simulator computers, projectors, and equipment prior to simulation testing. While the subject

completing the informed consent form and the pre-test questionnaire, these initialization procedures were carried out. Instructions and a check list for initializing the driving simulation system prior to testing are contained in Appendix F. Key features of these procedures for the regular testing sessions that merit emphasis are:

< A simulation control panel on 'Kelly' (Section 2.2.1) was used to control initialization and administration of each testing session.

< Prior to each testing session, the 'seed' number for the session was entered on the simulation control panel. This number controlled the randomization of the task condition assigned to each trial (Section 2.3.4), for all 120 trials administered during the 2 sessions of testing for each subject The unique ID number assigned to each subject (Appendix F, Step 5) was used as the seed number for that subject

< Prior to each testing session, the name of the computer file in which the simulated driving performance data for the session would be stored was entered on the simulation control panel. Both the data file and the task sequence file (Section 2.3.4) for the session were stored on 'Hawk' (Section 2.2.1).

< Each subject was asked whether they wanted music playing softly in the background during their testing sessions. Most subjects made this choice. The same musical selection was used for all subjects.

< Before a session began, each subject also was given the choice of: (1) partaking of a candy treat; and (2) having a bottle of water available in the vehicle during the session.

5. The subject then was asked to complete a practice drive in the simulator. The simulation model used with this study (Section 2.2.2) was NOT used for the practice drive. Rather that employed for an earlier study, a model of a grid of streets in the southeast corner of Minneapolis applied to an evaluation of simulated driving performance with an in-vehicle navigation system [27], was used. The practice drive served as a training session, and also allowed the researcher to judge the suitability of the subject for continuing with simulation testing. The subject was asked to perform a series of maneuvers during the practice drive, such as: (1) speeding up to 55 mph; (2) slowing down; (3) stopping suddenly in the middle of the roadway; and (4) turning. Attention of the subject was called to the existence of a small, but noticeable, feedback delay between actuation of the vehicle controls and updated movement of the projected image. This delay caused some initial difficulty for most subjects in accurately steering the vehicle, until adaptation to the condition occurred. To help deal with the delay, it was recommended to subjects during vehicle steering that they position their hands at the base of the steering wheel and adjust the wheel in small increments, rather than larger excursions, to avoid steering overshoot. At intervals during the practice drive, the subject was asked how he/she was feeling. Particular attention was paid to signs of distress—such as an unhappy look, sweating, redness, and/or visible agitation—plus any reports by the subject of feeling queasy. Criteria used to judge acceptable simulated driving performance by a subject were: (1) lack of serious discomfort (particularly queasiness or nausea) and/or disorientation reported by S; (2) ability to stop effectively; (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. A practice drive typically lasted about 5 min. A practice drive was administered prior to the first testing session, and

also prior to the second testing session if the subject requested it. Dependent measures (Table 2-4) were not collected during practice drives. Four volunteers were not able to complete the practice drive because of feeling queasy—these 4 volunteers each were paid $5 for their efforts and dismissed from the study.

6. Upon successful completion of the practice drive, the subject left the driving simulator and was introduced to the study with a series of instructions, shown in Appendix G. The subject 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 simulated driving task environment.

    < The subject should try to drive normally, comparable to real world driving.

    < The subject will participate in two experimental sessions, each comprising 60 trials, with each trial lasting about 1 min.

    < The subject is free to terminate a session at any time.

    < The subject should comply with normal traffic laws, namely stopping at red lights, driving on the roadway, and not stopping on the roadway during a trial.

    < The target time for a subject completing a testing session (60 trials) is 1 hour, or 1 minute per trial.

    < After each 10 trials, the subject is informed of the time that has elapsed for the session. If the subject is on target, the elapsed times during a session should be as followarning sign: 10 minutes for 10 trials; 20 minutes for 20 trials; 30 minutes for 30 trials; 40 minutes for 40 trials; 50 minutes for 50 trials; and 60 minutes for 60 trials.

    < The elapsed driving time for the trial will depend, in part, on the speed the subject maintains during each trial. To meet the target time, the subject can't drive too fast or too slow during successive trials.

    < The time delay between each trial is NOT counted as part of the session elapsed time.

    < The subject is informed that, during some trials, a road hazard may be encountered. No information is provided as to what nature or type of road hazard this instruction alludes to—the actual road hazards were the train and the fallen tree.

    < The subject is informed that a payment of $20 will be provided for successful completion of 2 testing sessions.

    < The subject then is informed that an extra $20 bonus fee will be paid if her/his driving performance is acceptable for each session. 'Acceptable' refers to both meeting the session target time, and avoiding accidents, as follows:

        < an accident is defined as a collision with a road hazard;

        < one accident per session is acceptable;

        < for each additional accident per session, $4 will be subtracted from the bonus fee;

        < coming within 8 minutes of the target time of 60 minutes (i.e., 52-68 minutes total elapsed time) per session cancels out 1 accident per session;

        < coming within 4 minutes of the target time of 60 minutes (i.e., 56-64 minutes total elapsed time) per session cancels out 2 accidents per session;

        < if the total elapsed time for a session is outside of 8 minutes of the target time

(i.e., outside of 52-68 minutes), $10 will be subtracted from the bonus fee;

< all timing and accident occurrences are monitored automatically by the computer.

7. As noted earlier, the actual purpose of the study is to evaluate subject interaction with different types and configurations of HRI warning sign. The objectives of the instructions delineated under Point 6, and in Appendix G, therefore were to: (1) disguise the true purpose of the study to subjects; (2) make it appear to subjects that the actual purpose of the study was accurate control of vehicle speed; (3) encourage subjects not to drive either too fast (which might result in warning sign being ignored, and/or recurrent road hazard accidents) or too slow (which might encourage departure from how drivers interact with HRIs in the real world); (4) encourage subjects not to drive too recklessly; and (5) use the occasional presence of a fallen tree to make it appear to subjects that more than one road hazard existed. The actual protocol therefore employed for each subject was as follows:

   < Session timing and accidents were in fact monitored by the researcher, not the computer.

   < Each subject earned the bonus, regardless of the number of accidents or the elapsed time for a session. No subject experienced more than 3 accidents in a session, and most subjects met the elapsed time criterion for earning the bonus (Section 3). For sessions in which the latter was not true, the timing was ‘fudged’ by the researcher to make it appear to the subject (the only indication of elapsed time to the subject was verbal information provided by the researcher) that the ∀8 min window around the target time had, in fact, been satisfied.

   One finding (Section 3) tending to validate the approach embodied in the subject instructions described above is that most subjects, when asked in the PTQ to explain the actual purpose of the study, pointed to factors other than evaluation of interaction with warning sign or a train.

8. After the instructions had been read and explained to the subject (Point 6), the subject was asked to raise possible questions about the instructions and/or about the study. Once these were dealt with, the testing session was initiated (Step 9).

9. The following procedures used to carry out a regular testing session were the same for both the pilot and regular testing trials:

   < The subject was asked to be seated in the Acura Integra and to adjust the seat to a comfortable setting.

   < The researcher started a trial by using the simulation control panel to start projection of the simulated driving task environment. Simulated movement of the vehicle began as soon as the projected image appeared on the screen. Thereafter, it was up to the subject to traverse the simulated driving task environment 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 Acura Integra, and manually recorded visual observations during the trial using the form in Appendix B.

   < Once the vehicle crossed the end line, the screen went blank, a 10-sec delay elapsed, the projected image of the simulated driving task environment reappeared with the vehicle positioned at the start line, and simulated movement of the vehicle began

immediately. To finish the session, the subject was expected to complete the remaining 59 trials following this repetitious pattern of trial presentation.

10. During each session, the researcher made visual observations of session timing, warning sign conditions, and driving behavior by the S, using the form in Appendix B. A stop watch was used to record session elapsed times—at 10-trial intervals these times were entered on the recording form and verbally communicated to the subject At the end of a session, the subject was informed by the researcher whether they had met the bonus criteria for accidents and session elapsed time (Point 6).
11. Once a testing session had been completed, both the simulated driving performance data file and task sequence file generated for the session were transferred from 'Hawk' to an IBM-compatible PC termed 'Selma.' Files on 'Selma' also were backed up on a Zip disk.
12. Prior to their second experimental sessions, subjects were asked if they wished to take another practice drive. Most subjects chose not to do so. The instructions (Step 6) then were reviewed for the S, and the first simulated driving trial of the second session was initiated (Step 9).
13. After completing their second testing session, the subject was asked to complete the PTQ (Appendix C). Note in Appendix C that the first question in the PTQ asked the subject to explain the purpose of the study, and to write the answer down before moving on to the remaining questions in the PTQ. Because the remaining questions clearly revealed what the study was about, this approach tended to encourage an unbiased subject response about their understanding of the purpose of the study.
14. Any comments or questions the subject had about the study then were discussed. Finally, each subject was paid a fee of $40 (regular fee plus bonus) as remuneration for their participation in the study.
15. Some volunteers for the study completed the practice run successfully, but started feeling queasy part way through their first testing session and were forced to terminate their involvement in the study. These volunteers were paid $10 for their participation.

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, simulated driving performance data files were generated at the end of each session for each subject as Excel-compatible text files. Each such file contained simulated driving performance data from the 60 trials administered during the session. Because the purpose of the study is to evaluate the effect of different types and combinations of HRI warning sign on simulated driving performance as a subject approaches an HRI, it was decided to focus data analysis exclusively on simulated driving performance along the roadway section between the start line and the HRI.

2.5.1. Data Reduction

For data reduction purposes, the programming services of Gloria Martinez-Arizala were enlisted to develop 4 LabVIEW programs for reducing the data contained in the session files collected from the test subjects. Illustrations of the front control panels and virtual instrument flow charts for each of these programs are shown in Appendix H. Steps in data reduction carried out by these programs are as followarning sign.

1. Trial Sorting Program. This program sorted the 120 blocks of trial data contained in the 2 testing sessions completed by each subject into separate task condition categories (Table 2-2). Because simulated driving performance for the roadway section beyond the HRI is ignored, the train-absent trials with a fallen tree are considered equivalent to the train-absent trials without a fallen tree, within each of the 4 control and test experimental design categories (Table 2-2). This trial sorting approach resulted in a total of 4 task conditions within each of the experimental design categories, resulting in the following 16 task condition categories: (1) Control #1: TC 1 & 3 (13 trials), TC 2 (2 trials), TC 4 & 6 (13 trials), TC 5 (2 trials); (2) Control #2: TC 7 & 9 (13 trials), TC 8 (2 trials), TC 10 & 12 (13 trials), TC 11 (2 trials); (3) Test #1: TC 13 & 15 (13 trials), TC 14 (2 trials), TC 16 & 18 (13 trials), TC 17 (2 trials); and (4) Test #2: TC 19 & 21 (13 trials), TC 20 (2 trials), TC 22 & 24 (13 trials), TC 23 (2 trials).
2. Trial Data Extraction Program. Within each complete block of trial data, this program extracted that portion of simulated driving performance data applicable to the roadway section between the start line and the HRI.
3. Session Data Averaging Program. Across the 16 sets of task condition trials generated by the sorting program from the 2 testing sessions for each subject, this program computed average values for speed, braking pressure, and accel/decel for each of the roadway intervals specified in Table 2-4. Note in the virtual instrument flow chart for this program in Appendix H that a small MATLAB subroutine is included as part of the LabView program.
4. Between-Subject Data Averaging Program. This program took the average simulated driving performance data for each subject (Step 3) and computed between-S means for each of the 16 task condition categories (Step 1) and for each of the roadway intervals specified in Table 2-4.

2.5.2. Analysis of Variance for Objective Dependent Measures of Simulated Driving Performance

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 simulated driving performance (e.g., vehicle speed, braking pressure, and accel/decel), for each of the roadway intervals specified in Table 2-4. Table 2-5 summarizes the ANOVA table for the study, with the main effects of the 3 independent measures specified in Section 2.3.2., and a total of 3 first-order (2-way) interactive effects of these measures, indicated. Those first-order effects dealing with warning sign configuration are grouped into 2 categories: (1) effects of the type of advance warning sign (AdvWS) (passive, active flashing yellow light, VMS); and (2) effects of the type of Xing crossbuck sign (XingWS) (passive, active flashing red light). The central focus of this study is on the effects of different warning sign configurations on driver behavior in approaching an HRI with a train present, under unlimited versus limited visibility conditions. Therefore, as indicated in Table 2-5, for purposes of this report ANOVA for interactive effects is limited only to those interactive effects germane to this question.

ANOVA for the effects of the independent measures specified in Table 2-5 was carried out in 2 steps [17]: (1) multivariate ANOVA for main and interactive effects on grouped (familywise) objective dependent measures of simulated driving performance; and (2) post hoc analysis of statistically significant interactive effects revealed under Step 1, using the Bonferroni procedure

[17] (Section 2.5.3). Four different types of multivariate ANOVA tests [17] were used to assess the statistical significance of the main and interactive effects: Pillai's trace, Wilks' lambda, Hotelling's trace, and Roy's largest root. Of these, Pillai's trace provides the most stringent test of multivariate statistical significance, and results from this test are reported in Chapter 3 (Section 3.3.2).

2.5.3. Post Hoc Analysis of Objective Dependent Measures of Simulated Driving Performance

Post-hoc analyses of statistically significant interactive effects (Table 2-5) were carried out using the Bonferroni procedure [17]. Given the focus of this study on the influence of different warning sign configurations on simulated driving performance in approaching an HRI, post-hoc analysis focused on delineating the interactive effects of warning sign configuration on dependent measures of simulated driving performance for different roadway intervals (Section 3.3.3). For the PTQ results, 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.

Table 2-5. ANOVA table for main and interactive effects on objective dependent measures of simulated driving performance.

ANOVA for main and interactive effects of the following independent measures was carried out for simulated driving performance dependent measures computed for each of the following roadway intervals: IntSL-HRI, IntWS-HRI, IntWS-200, Int200-100, and Int100-HRI.

Main Effects	Abbreviation	Number of Conditions
Train	Tr	2 (train absent; train present)
Visibility	Vi	2 (unlimited visibility (clear); limited visibility (fog))
HRI warning sign	WS	3 AdvWS and 2 XingWS (Control #1 - passive AdvWS / passive XingWS) (Control #2 - passive AdvWS / red flashing light XingWS) (Test #1 - flashing yellow light AdvWS / flashing red light XingWS) (Test #2 - VMS AdvWS / flashing red light XingWS)

Interactive Effects - 2-way and 3-way[1]

Tr x Vi	Vi x AdvWS	Vi x XingWS

[1]ANOVA for interactive effects is limited only to those interactive effects dealing with the influence of different warning sign configurations on driver behavior in approaching an HRI with a train present, under unlimited versus limited visibility conditions.

Chapter 3
Results

3.1. Introduction

Sections below detail results for: (1) visual observations of vehicle-HRI interactions (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 simulated driving performance are categorized in the subsections below in terms of the elapsed session driving time (ESDT) results (Section 3.2.1), and safe versus unsafe driving behavior during subject interaction with HRIs for those trials with a train present (Section 3.2.2).

3.2.1. Elapsed Session Driving Times

As noted earlier (Section 2.3.3), the visual observation recording form (Appendix B) was used to record times elapsed during a session at 10-trial intervals for each subject and session. Every 10 trials, the subject was informed of these times as feedback to allow the subject to ascertain the degree of compliance with the 'bonus' requirements (Section 2.4). That is, finishing a session between 52-68 min cancelled 1 accident, and between 58 and 62 min 2 accidents, whereas finishing outside the 52-68 min window incurred a penalty (remember that in fact, all subjects received a full $40 payment for participation). This approach was adopted: (1) as a ruse to suggest to the subject that control of speed (not interaction with different types of warning signs) was the purpose of the study; and (2) to discourage excessively cautious or aggressive subject driving behavior, thereby encouraging the type of driving behavior that typically occurs during driver interaction with real world HRIs.

Given this experimental design strategy, it is of interest to review results for elapsed session driving times, in order to ascertain if the strategy was successful in achieving its goals. Accordingly, elapsed session driving time results are presented in Figures 3-1 and 3-2.

In Figure 3-1 are plotted average elapsed session driving time results for 50 sessions completed by N=25 subjects. From top to bottom, the histograms show mean and SD elapsed session driving time data for: (1) all sessions combined; (2) Session 1; and (3) Session 2.

Results in Figure 3-1 show about a 1 min difference in mean elapsed session driving times between Session 1 (61.25 ∀ 4.1 min) and Session 2 (60.4 ∀ 3.6 min). Across all sessions, the mean elapsed session driving time (60.8 ∀ 3.9 min) is within 1 min of the target time of 60 min. These results indicate that, on average, the experimental design adopted was largely successful in encouraging subjects to control their speed to meet the elapsed session driving time target of 60 min.

Figure 3-2 shows the distribution of elapsed session driving time results relative to the 'bonus' windows of 52-68 min and 58-62 min. In 48 of 50 sessions (96 %) for the 25 subjects (bottom histogram), the elapsed session driving time fell within the longer window of 52-68 min. The 2 sessions outside this window (completed by different subjects) both were completed in an elapsed session driving time longer than 68 min (4^{th} histogram from top). For just over half

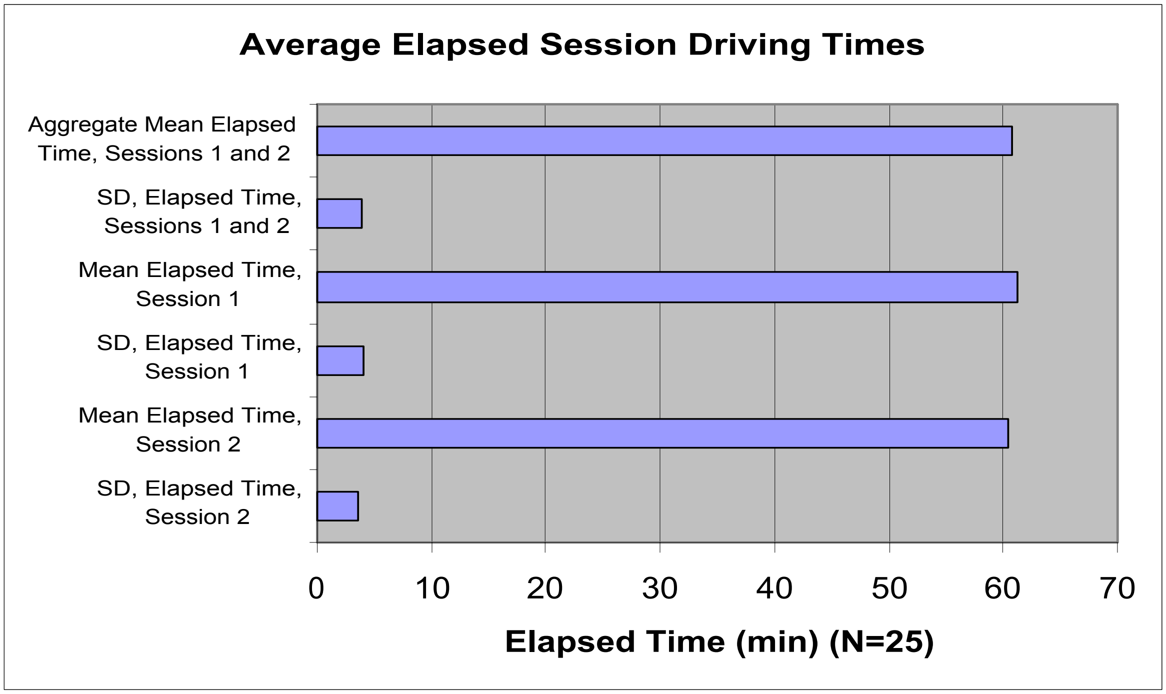


Figure 3-1. Average elapsed session driving times (N=25)

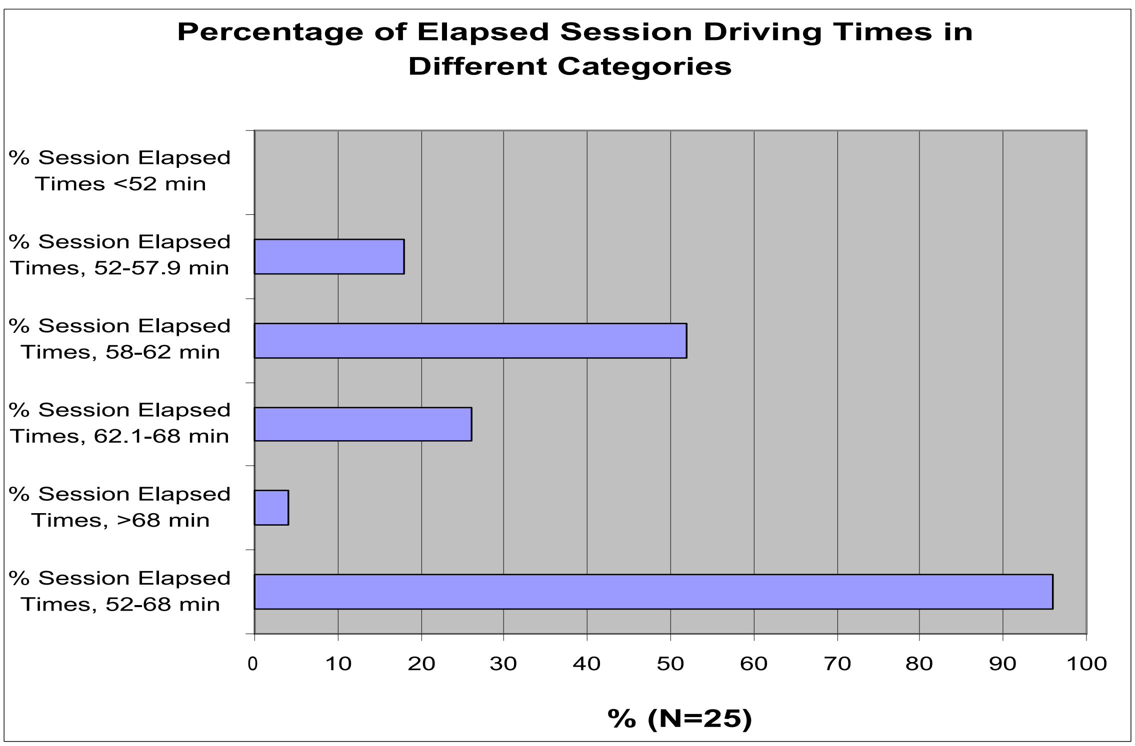


Figure 3-2. Percentage of elapsed session driving times in different categories (N=25).

(52%) of the sessions, the elapsed session driving time fell within the narrower window of 58-62 min (2nd histogram from top). These results extend those in Figure 3-1 in indicating that the experimental design adopted was largely successful in encouraging subjects to control their speed to satisfy the putative 'bonus' elapsed session driving time requirements. A reasonable interpretation of results in both figures is that the experimental design encouraged simulated driving behavior by subjects during interaction with HRIs that is comparable (i.e., typically neither excessively cautious nor aggressive) to that observed during driver interaction with real world HRIs.

3.2.2. Unsafe Driving Behavior During Subject Interaction with A Train

As noted in Section 2.3.4, the visual observation form (Appendix B) was used to record incidents of unsafe driving behavior during subject interaction with HRIs for those trials with a train present. For this purpose, two types of behavior are categorized as 'unsafe': (1) hitting a train; or (2) beating the train across the Xing, rather than stopping for the train (recall that if the vehicle matches the speed limit of 55 mph, the vehicle and train will arrive at the HRI at the same time for those trials with a train present).

Figure 3-3 plots the percentage of vehicle-train encounters that resulted in the vehicle either beating or hitting the train, categorized by both warning sign and visibility condition. The bottom legend refers to the advance WS/Xing crossbuck sign/visibility (clear/fog) condition. In this legend, 'P' refers to a passive warning sign, 'A' refers to active flashing light warning sign, and 'VMS' refers to a variable message warning sign.

Each of the 8 task conditions indicated in the bottom legend to Figure 3-3 involve a total of 50 vehicle-train encounters. The percentages plotted in the figure are based on the number of encounters out of 50 for each task condition specified that resulted in the vehicle beating or hitting the train.

Out of a total 400 vehicle-train encounters that occurred across the 6 task conditions specified in Table 3-3, 53 encounters (13.25%) resulted in the vehicle beating or hitting the train. The results in Table 3-3 indicate that the preponderance of these incidents are associated with: (1) passive signage for the advance warning sign, the Xing crossbuck sign, or both; and (2) limited (fog) visibility conditions. The 2 task conditions with the highest incidence of unsafe driving behavior are those with limited visibility with a passive advance warning sign and either a passive or active red flashing light Xing crossbuck sign. The 2 task conditions with the next highest incidence of unsafe driving behavior are those with clear viewing conditions with a passive advance warning sign and either a passive or active red flashing light Xing crossbuck sign. Out of the total of 53 unsafe vehicle-train encounters observed, these 4 task conditions accounted for 50 such incidents. In contrast, across the 200 vehicle-train encounters associated with task conditions featuring active flashing light or VMS advance warning sign, only 3 incidents of unsafe driving behavior occurred. These results clearly support the interpretation that relative to use of passive advance warning sign, use of active advance warning signs at HRIs (either flashing light or VMS) encouraged safer simulated driving behavior among subjects participating in this study.

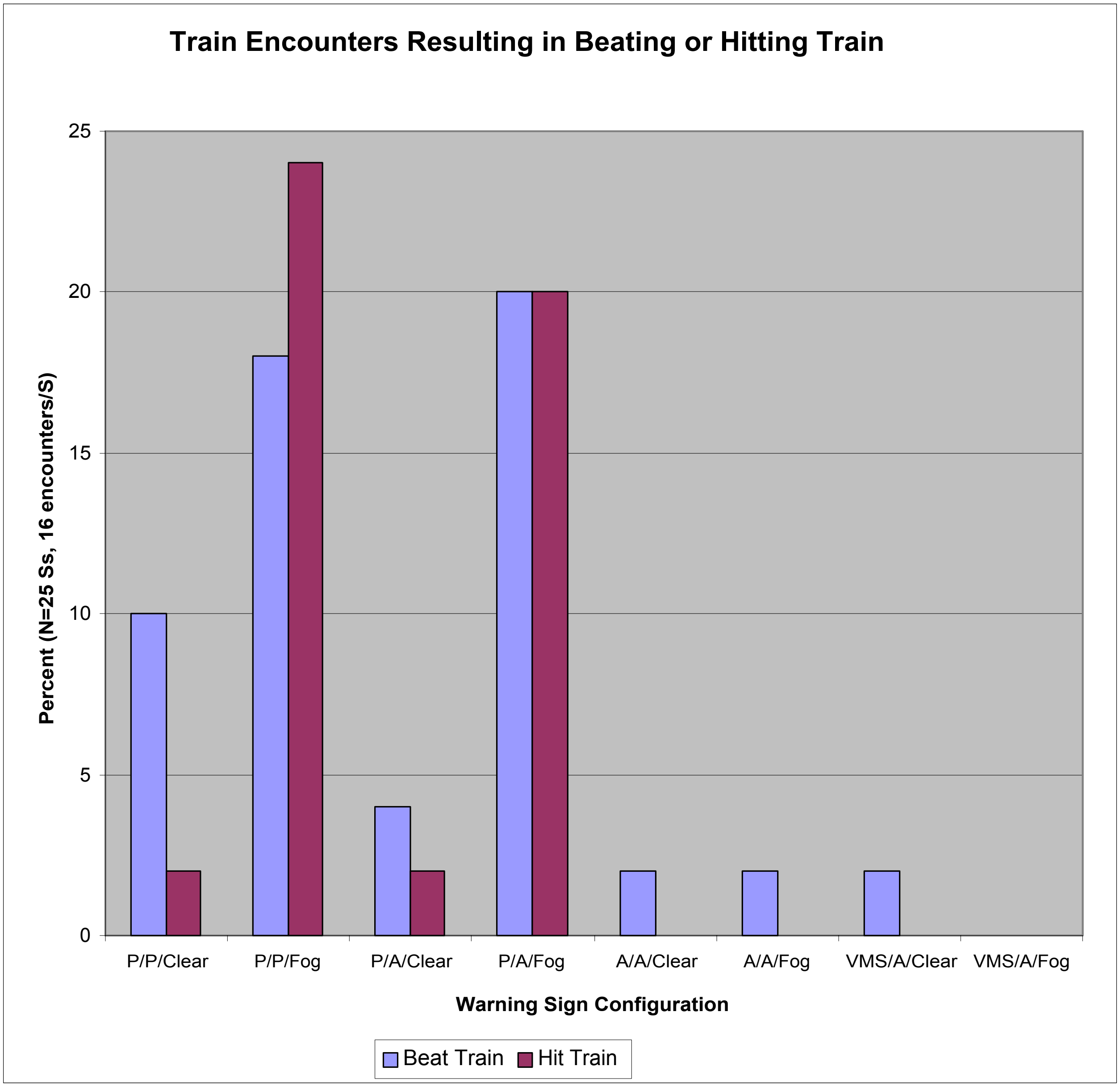


Figure 3-3. Vehicle-train encounters resulting in the vehicle either beating or hitting the train (bottom legend refers to advance warning sign/Xing crossbuck sign/visibility (clear/fog) condition: P = passive warning sign; A = active flashing light warning sign; VMS = variable message warning sign)

3.3. Objective Measures of Simulated Driving Performance

Subsections below present results for objective measures of simulated driving performance (Table 2-4), specifically vehicle speed, acceleration/deceleration (accel/decel), and braking pressure. Average vehicle speed, braking pressure, and accel/decel results for the 24 subjects, in relation to independent measures for each of the 5 roadway intervals (Table 2-4), are presented in Section 3.3.1. Section 3.3.2 presents ANOVA results for main and interactive effects of the independent measures.

3.3.1. Average Simulated Driving Performance Results

Figures 3-4 through 3-9 present plots of mean vehicle speed, braking pressure, and accel/decel levels for the 5 roadway intervals defined previously (Table 2-4): IntSL-HRI, IntWS-HRI, IntWS-200, Int200-100, and Int100-HRI. Results for train absent and train present trials, respectively, are shown in Figures 3-4 and 3-5 for mean vehicle speed levels, in Figures 3-6 and 3-7 for mean vehicle braking pressure levels, and in Figures 3-8 and 3-9 for mean vehicle accel/decel levels.

Recall (Section 2.3.2) that for each subject, the 4 control and test conditions (Table 2-4) each comprised 15 unlimited visibility and 15 limited (fog) visibility trials. For each visibility condition, there were 2 train present and 13 train absent trials, the latter consisting of 11 fallen tree absent and 2 fallen tree present trials. For each control/test and visibility condition, mean simulated driving performance results are calculated across the 2 train present trials, and across the 13 train absent trials (combining data from the 112 11 fallen tree absent and 2 fallen tree present trials). Once these trial means for each subject are calculated, the average results plotted in Figures 3-4 through 3-9 are derived by calculating the aggregate means of the trial means for all 24 subjects.

Figures 3-4 through 3-9 each consist of 5sets of 8 histograms each. From top to bottom in each figure, the successive histograms sets show results, respectively, for the IntSL-HRI, IntWS-HRI, IntWS-200, Int200-100, and Int100-HRI roadway intervals. Within each histogram set there are 4 pairs of histograms that, in descending order from above to below, show mean results for the following advance warning sign-Xing crossbuck sign combinations: (1) passive-passive (P-P) warning sign; (2) passive-active red flashing light (P-A) warning sign; (3) active yellow flashing light-active red flashing light (A-A) warning sign; and (4) VMS-active red flashing light (VMS-A) warning sign. For each of these warning sign combinations, there are a pair of histograms that show results for unlimited (clear) and limited (fog) visibility conditions. The error bars accompanying each histogram show 1 SD for the mean.

Average Vehicle Speed Results. Average vehicle speed results in Figure 3-4 for the train absent trials show that, for all 5 roadway intervals, mean vehicle speed for clear visibility conditions exceeds that for fog conditions for all warning sign configurations. For the clear visibility trials, across all warning sign conditions, average vehicle speed levels are comparable for the IntWS-HRI, Int200-100, and Int100-HRI roadway intervals, and somewhat lower for the Int200-100 roadway interval. For the limited visibility trials, across all warning sign conditions, average vehicle speed levels are roughly comparable for the IntWS-HRI, IntWS-200, and Int100-HRI roadway intervals, and somewhat higher for the Int200-100 roadway interval. Without exception, across different roadway interval and warning sign conditions, average vehicle speed SD levels for the limited visibility means are greater than those for the paired unlimited visibility means, indicating greater variability in subject control of vehicle speed under limited compared with unlimited visibility conditions.

In contrast to vehicle speed results for train absent trials, those for the train present trials (Fig. 3-5) show that with one exception (P-P warning sign for the Int200-100 roadway interval), average vehicle speed for the fog trials is greater than that for the clear visibility trials across all

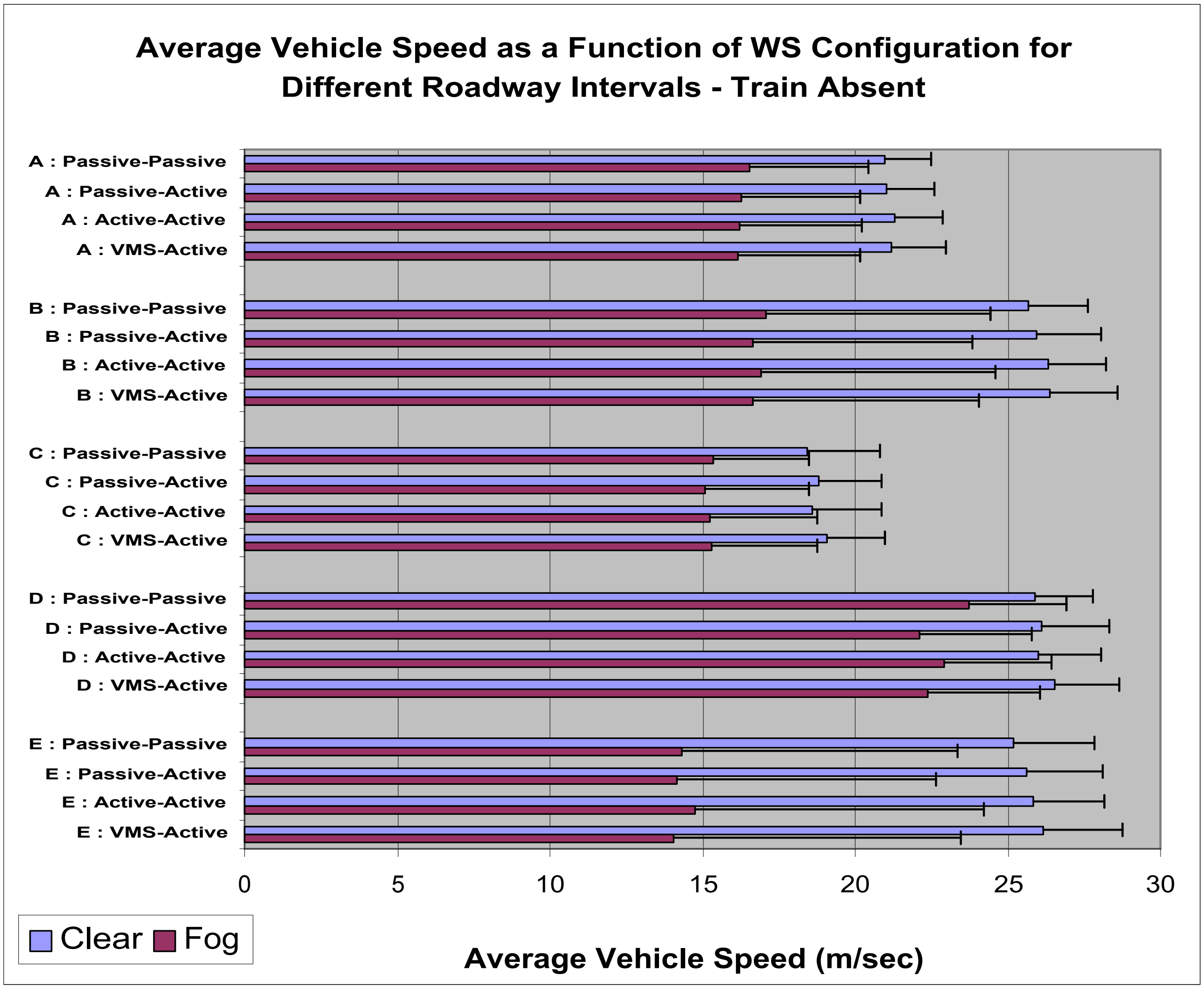


Figure 3-4. Average vehicle speed + 1 SD (error bars) for 5 different roadway intervals as a function of warning sign configuration for trials with train absent (N=24). Roadway intervals from top to bottom: A = IntSL-HRI; B = IntWS-HRI; C = IntWS-200; D = Int200-100; E = Int100-HRI

roadway interval and warning sign conditions. Chapter 4, Section 4.3, Conclusion 11 discusses this curious finding.

Under clear visibility conditions, for all 5 roadway intervals, average vehicle speed levels for the A-A and VMS-A warning sign combinations are lower than those for the P-P and P-A warning sign combinations. In contrast, under limited visibility conditions for all 5 roadway intervals, average vehicle speed levels for the A-A and VMS-A warning sign combinations are comparable to, or slightly higher than, those for the P-P and P-A warning sign combinations. Unlike the case for the train absent means, SD levels for train present means show no consistent differences in magnitude between unlimited and limited visibility conditions.

Average Vehicle Braking Pressure Results. Average vehicle braking pressure results in Figure 3-6 for the train absent trials show that average vehicle braking pressure for the fog trials is greater than that for the clear visibility trials across all roadway interval and warning sign

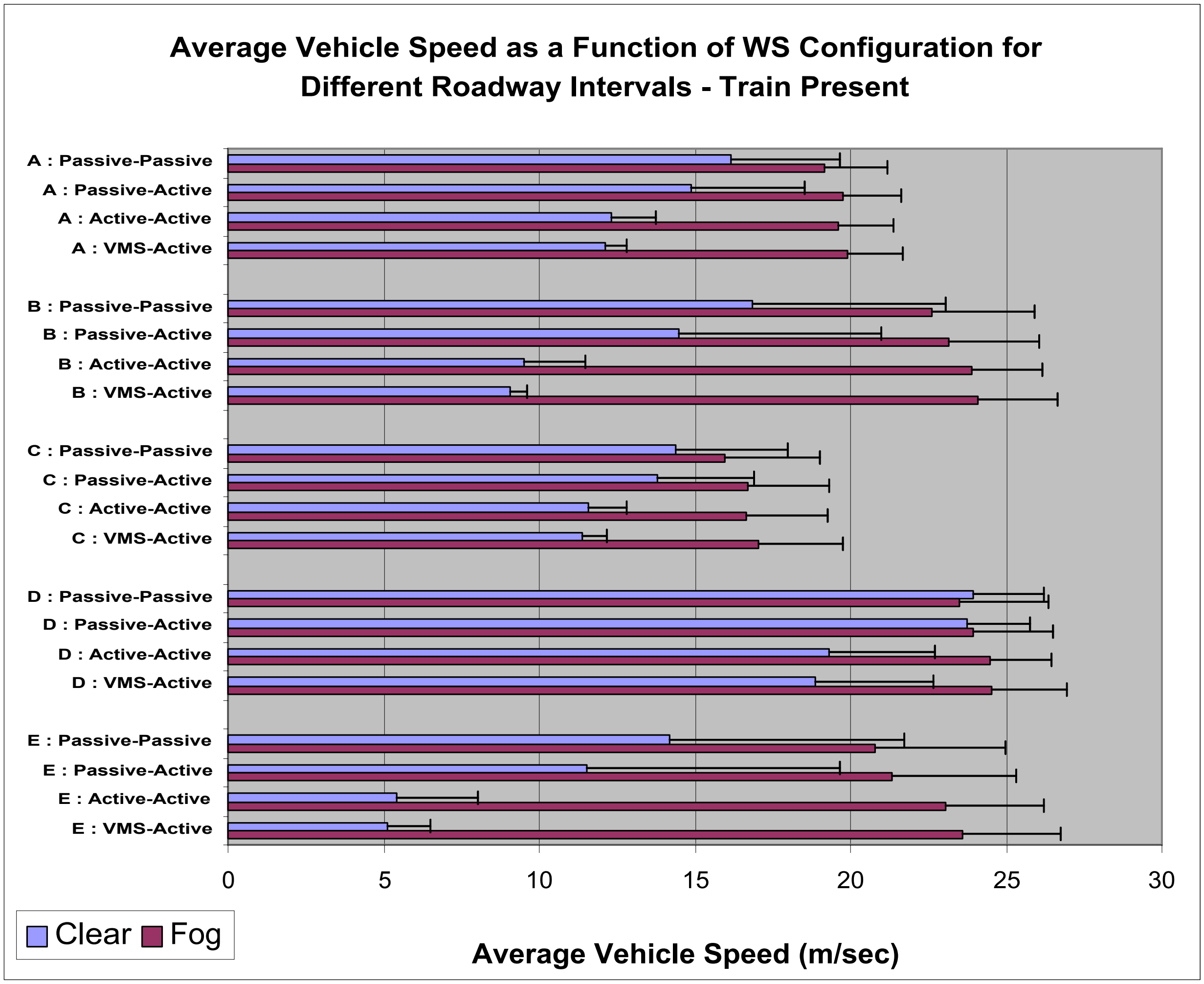


Figure 3-5. Average vehicle speed + 1 SD (error bars) for 5 different roadway intervals as a function of warning sign configuration for trials with train present (N=24). Roadway intervals from top to bottom: A = IntSL-HRI; B = IntWS-HRI; C = IntWS-200; D = Int200-100; E = Int100-HRI

conditions. For the clear visibility trials, average vehicle braking pressure is close to 0 for all roadway interval and warning sign conditions, except for the IntWS-200 roadway interval, average vehicle braking pressure is equal or close to .01 V for all 4 warning sign combinations. Under limited visibility conditions for all 5 roadway intervals, average vehicle braking pressure levels for the A-A and VMS-A warning sign combinations are comparable to, or slightly lower than, those for the P-P and P-A warning sign combinations. Without exception, across different roadway interval and warning sign conditions, average vehicle braking pressure SD levels for the limited visibility means are greater than those for the paired unlimited visibility means, indicating greater variability in subject control of vehicle braking pressure under limited compared with unlimited visibility conditions.

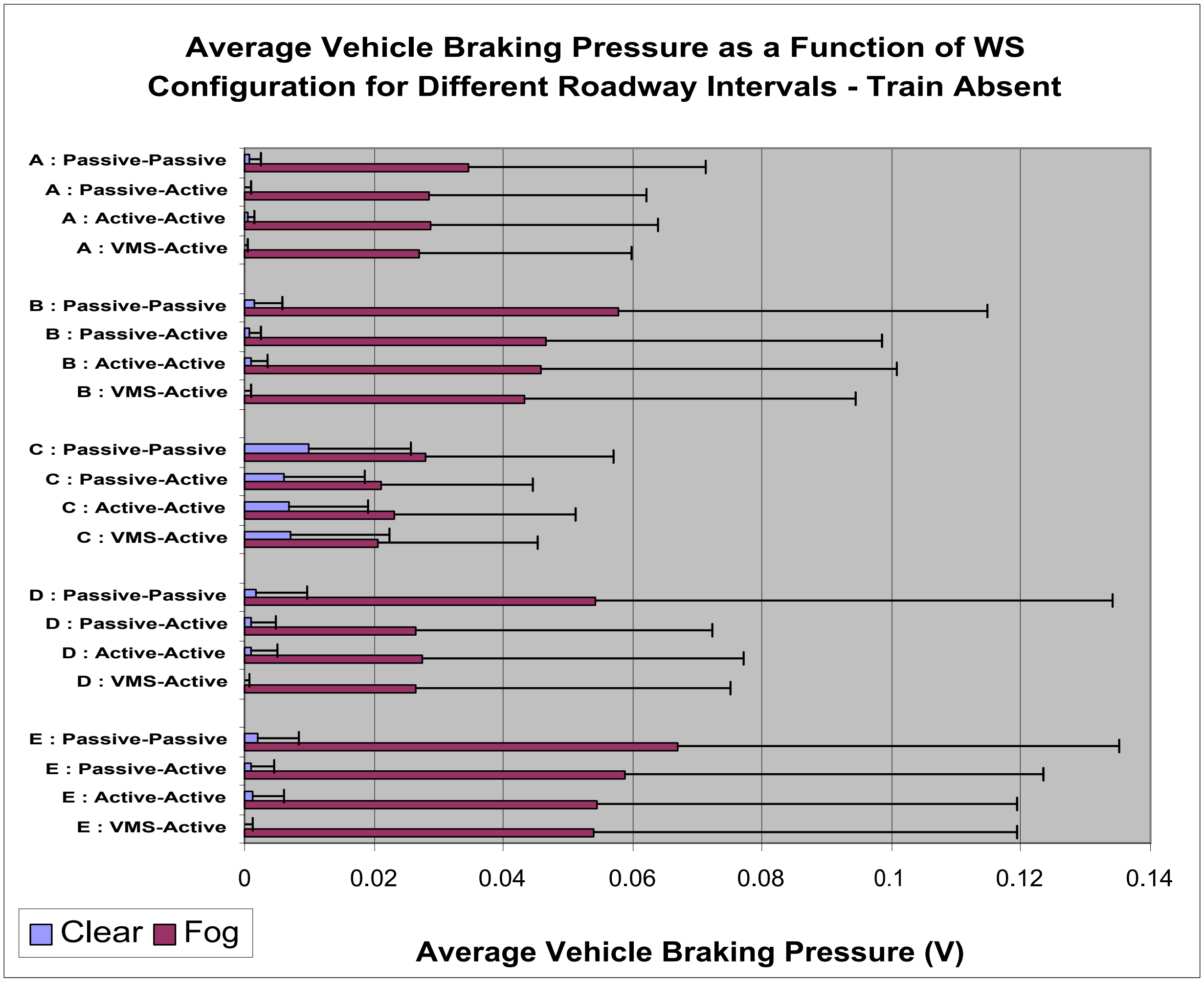


Figure 3-6. Average vehicle braking pressure + 1 SD (error bars) for 5 different roadway intervals as a function of warning sign configuration for trials with train absent (N=24). Roadway intervals from top to bottom: A = IntSL-HRI; B = IntWS-HRI; C = IntWS-200; D = Int200-100; E = Int100-HRI

In contrast to vehicle braking pressure results for the train absent trials, those for the train present trials (Fig. 3-7) show that with one exception (P-A warning sign for the Int200-100 roadway interval), average vehicle braking pressure for the clear visibility trials is greater than that for the limited visibility trials across all roadway interval and warning sign conditions. Under limited visibility conditions, average vehicle braking pressure for all roadway interval and warning sign conditions is under .03 V. Under clear visibility conditions, for all but the Int200-100 roadway interval, average vehicle braking pressure levels for the A-A and VMS-A warning sign combinations are lower than those for the P-P and P-A warning sign combinations. Except for the Int200-100 roadway interval means, average vehicle braking pressure SD levels for the clear visibility means are greater than those for the paired limited visibility means, indicating greater

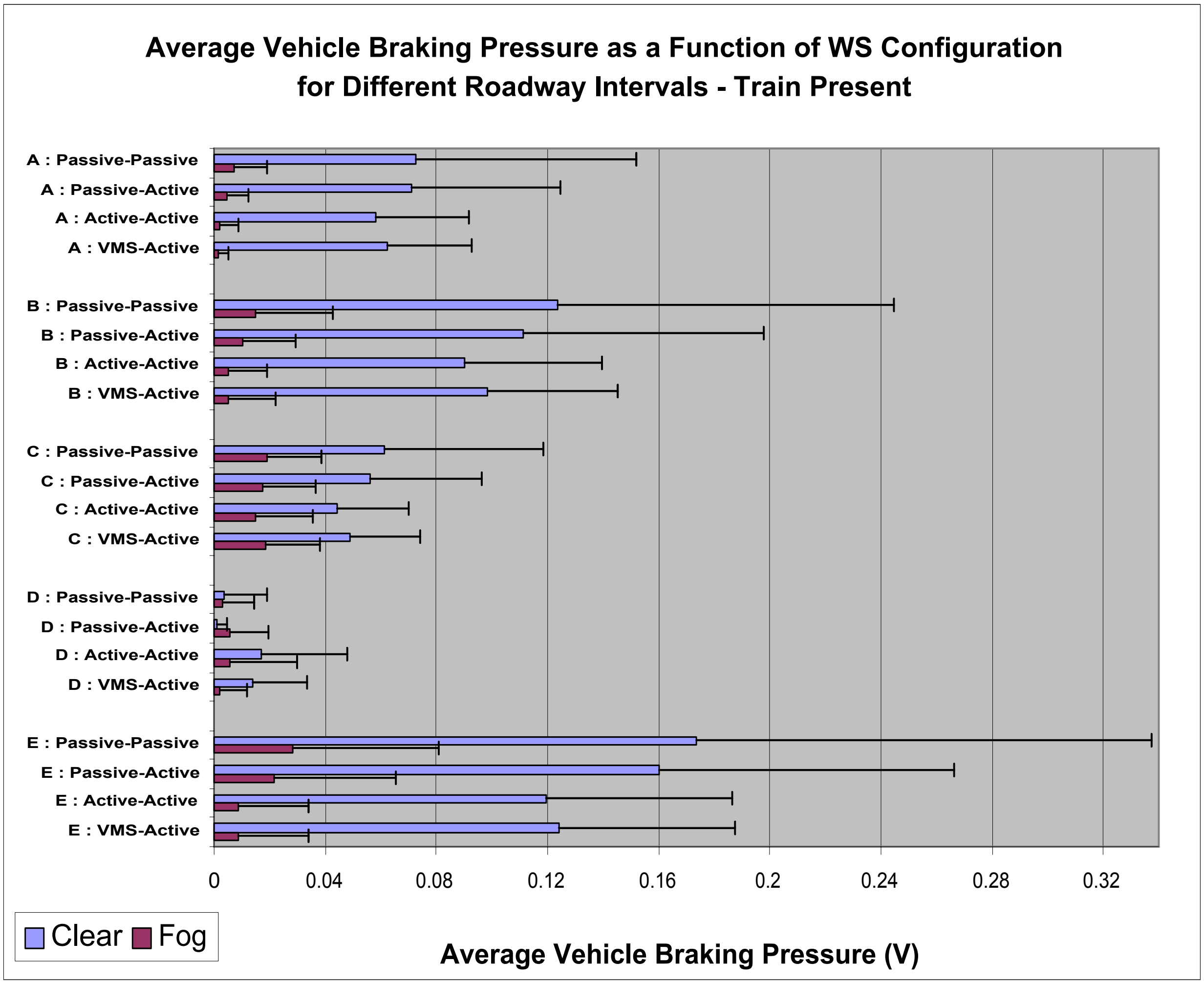


Figure 3-7. Average vehicle braking pressure + 1 SD (error bars) for 5 different roadway intervals as a function of warning sign configuration for trials with train present (N=24). Roadway intervals from top to bottom: A = IntSL-HRI; B = IntWS-HRI; C = IntWS-200; D = Int200-100; E = Int100-HRI

variability in subject control of vehicle braking pressure under unlimited compared with limited visibility conditions.

Average Vehicle Accel/Decel Results. Average vehicle accel/decel results in Figure 3-8 for the train absent trials show positive mean vehicle acceleration levels, across all warning sign combinations under both unlimited and limited visibility conditions, for the IntSL-HRI and INTWS-HRI roadway intervals (top 2 sets of histograms). For the IntWS-200, Int200-100, and Int100-HRI roadway intervals however (bottom 3 sets of histograms), mean vehicle accel/decel levels are negative for most warning sign combinations under clear visibility conditions, and for all warning sign combinations under limited visibility conditions. This indicates net vehicle deceleration under these circumstances.

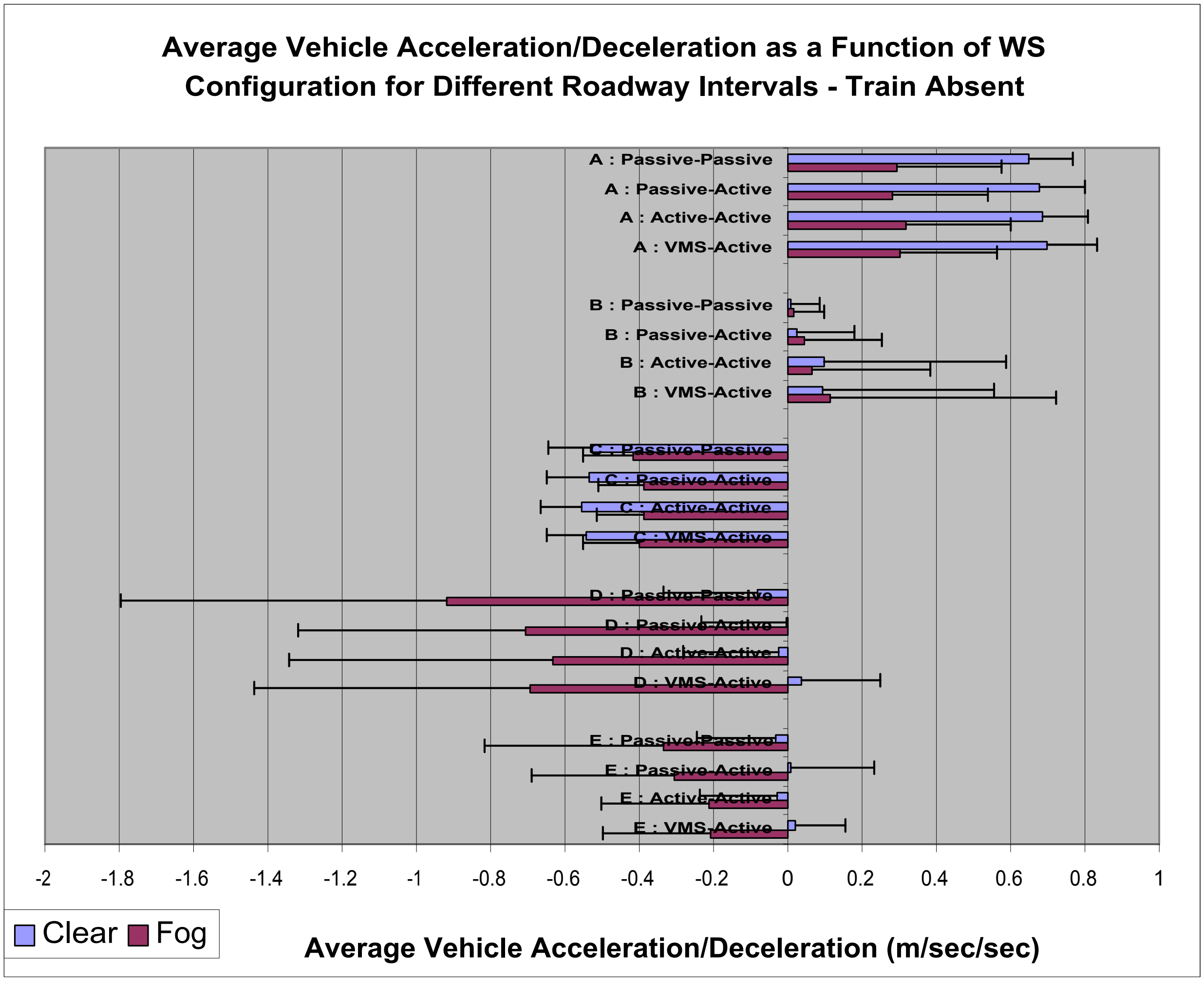


Figure 3-8. Average vehicle accel/decel + 1 SD (error bars) for 5 different roadway intervals as a function of warning sign configuration for trials with train absent (N=24). Roadway intervals from top to bottom: A = IntSL-HRI; B = IntWS-HRI; C = IntWS-200; D = Int200-100; E = Int100-HRI

With the train absent trials (Fig. 3-8), mean vehicle deceleration under clear visibility conditions exceeds that for limited visibility conditions across all warning sign combinations for the IntWS-200 roadway interval. For the next 2 roadway intervals however, the inverse is true. For the IntSL-HRI, Int 200-100, and Int100-HRI roadway intervals, average vehicle accel/decel SD levels for the limited visibility means are greater than those for the paired unlimited visibility means for all warning sign combinations, indicating greater variability in subject control of vehicle accel/decel under limited compared with unlimited visibility conditions for these roadway intervals, regardless of warning sign combination.

As with mean vehicle accel/decel observations for the train absent trials (Fig. 3-8), those for the train present trials (Fig. 3-9) also show positive mean vehicle acceleration levels for the

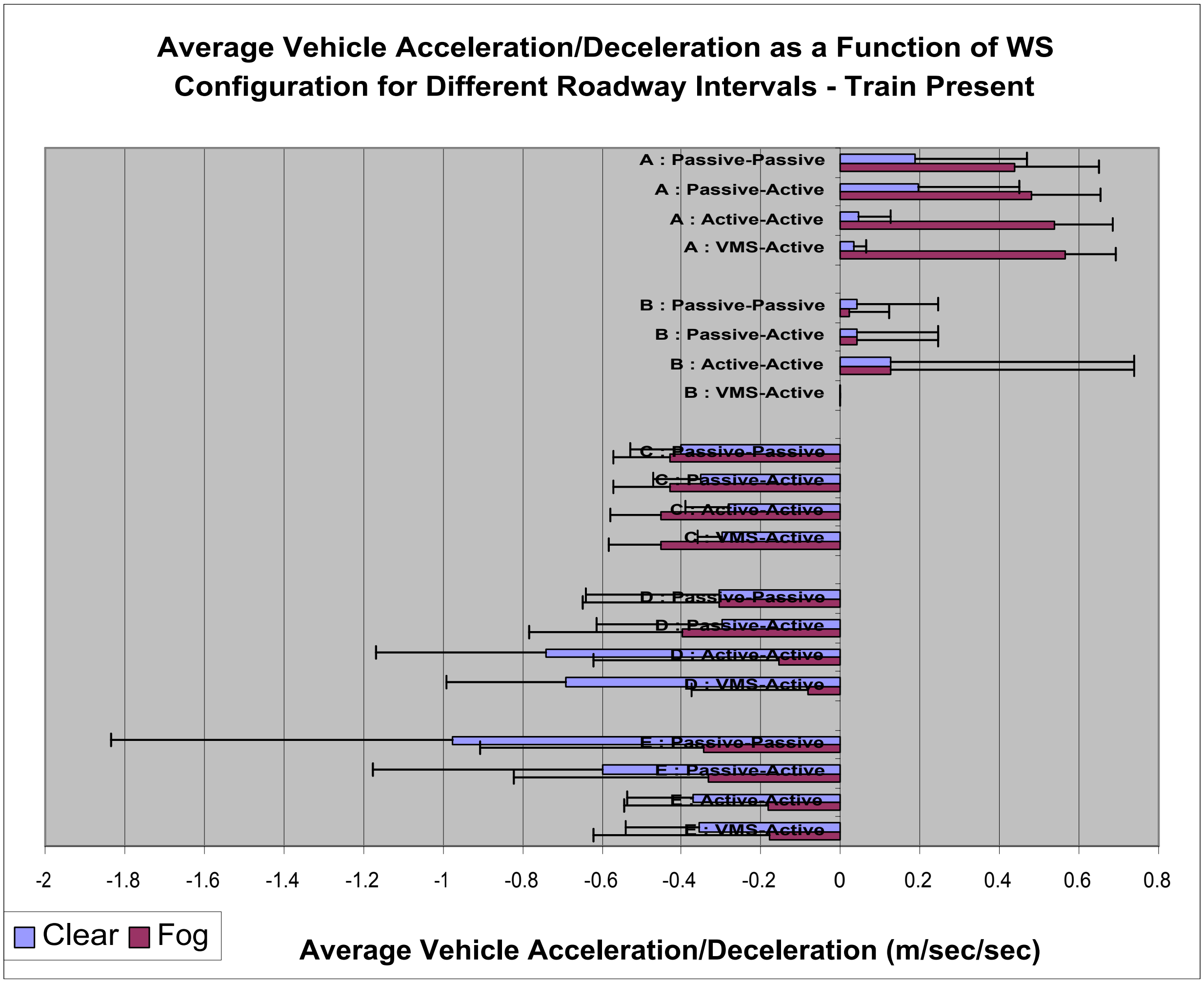


Figure 3-9. Average vehicle accel/decel + 1 SD (error bars) for 5 different roadway intervals as a function of warning sign configuration for trials with train present (N=24). Roadway intervals from top to bottom: A = IntSL-HRI; B = IntWS-HRI; C = IntWS-200; D = Int200-100; E = Int100-HRI

IntSL-HRI and INTWS-HRI roadway intervals (top 2 sets of histograms), and mean vehicle deceleration levels for the IntWS-200, Int200-100, and Int100-HRI roadway intervals (bottom 3 sets of histograms), across all warning sign combinations under both unlimited and limited visibility conditions.

However, in comparing mean vehicle accel/decel values for unlimited versus limited visibility conditions, the results for the train present trials (Fig. 3-9) exhibit a largely inverse relationship relative to those for the train absent trials. Thus, for the IntWS-200 roadway interval, mean vehicle deceleration under limited visibility conditions exceeds that for clear visibility conditions, across all warning sign combinations. For the Int200-100 roadway interval, mean vehicle deceleration is comparable for the 2 visibility conditions when the advance

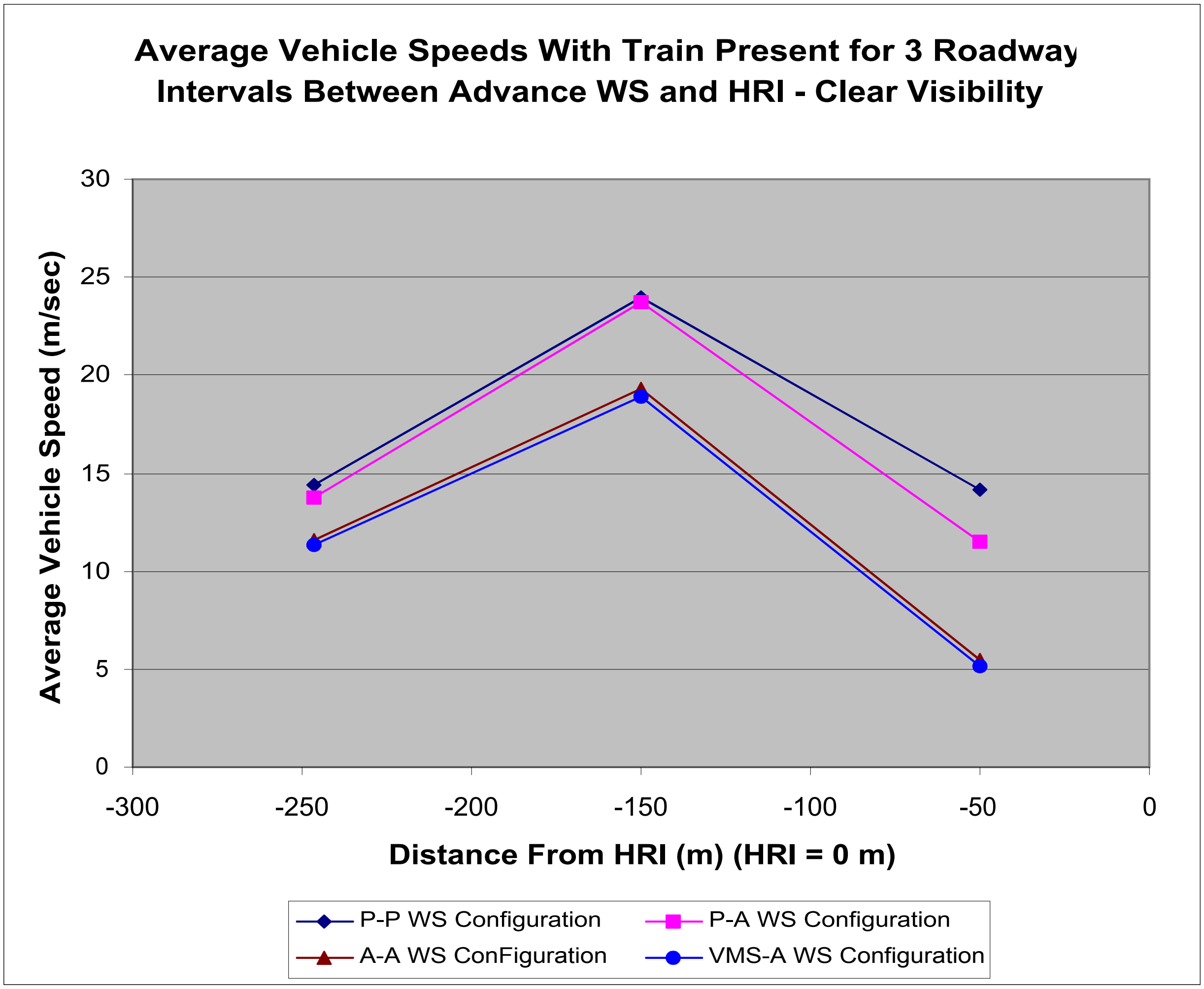


Figure 3-10. Average vehicle speeds with train present for 3 roadway intervals between advance warning sign and HRI, for unlimited visibility and 4 different warning sign configurations (N=24). Data plotted at midpoints of Int-WS-200, Int200-100, and Int100-HRI roadway intervals. Abbreviations in figure legend refer to [advance warning sign - Xing crossbuck sign] configuration: P = passive warning sign; A = active flashing light warning sign; VMS = variable message warning sign

warning sign is passive (P-P and P-A warning sign configurations), but mean vehicle deceleration is notably larger under clear relative to limited visibility conditions for this roadway interval when the advance warning sign is active (A-A and VMS-A warning sign configurations). The latter also is true, across all warning sign configurations, for the Int100-HRI roadway interval. Across all roadway intervals and warning sign configurations with a train present (Fig. 3-9), there are no consistent differences in the magnitudes of average vehicle accel/decel SD levels for the clear relative to the limited visibility means.

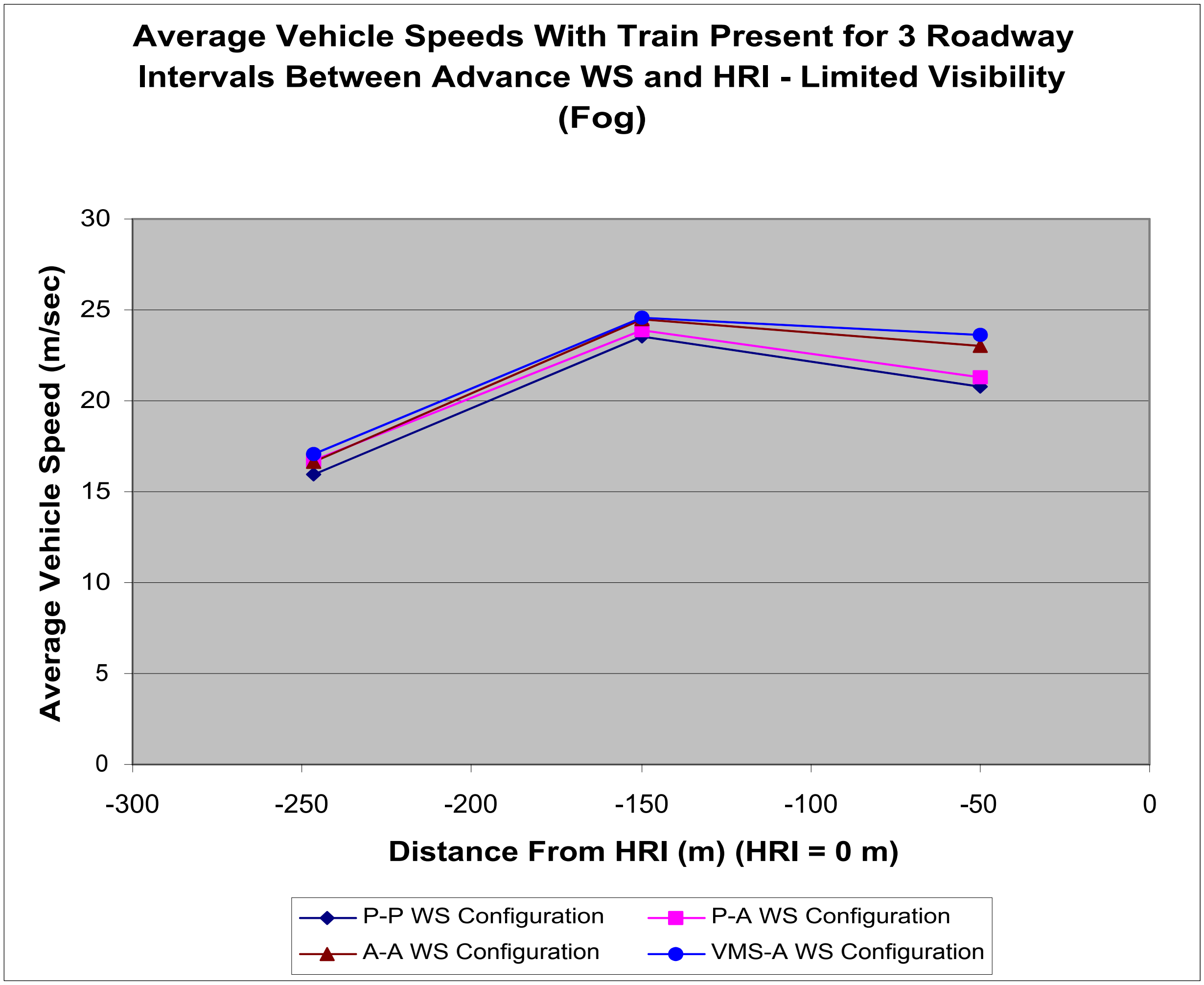


Figure 3-11. Average vehicle speeds with train present for 3 roadway intervals between advance warning sign and HRI, for limited visibility and 4 different warning sign configurations (N=24). Data plotted at midpoints of Int-WS-200, Int200-100, and Int100-HRI roadway intervals. Abbreviations in figure legend refer to [advance warning sign - Xing crossbuck sign] configuration: P = passive warning sign; A = active flashing light warning sign; VMS = variable message warning sign

It is of interest to examine how different warning sign configurations affect control of vehicle speed, braking, and accel/decel by the driver in approaching the HRI with a train present. Results regarding this question are presented in Figures 3-10 through 3-15. These figures illustrate mean vehicle speed (Figs. 3-10, 3-11), braking pressure (Figs. 3-12, 3-13), and accel/decel (Figs. 3-14, 3-15) levels with a train present for the 3 roadway intervals between the advance warning sign and the HRI, namely the IntWS-200, Int200-100, and Int100-HRI intervals. In each figure, results for the 4 different warning sign configurations are plotted together, namely the P-P, P-A, A-A, and VMS-A warning sign configurations. Results for unlimited visibility trials are presented in Figures 3-10, 3-12, and 3-14; those for the limited

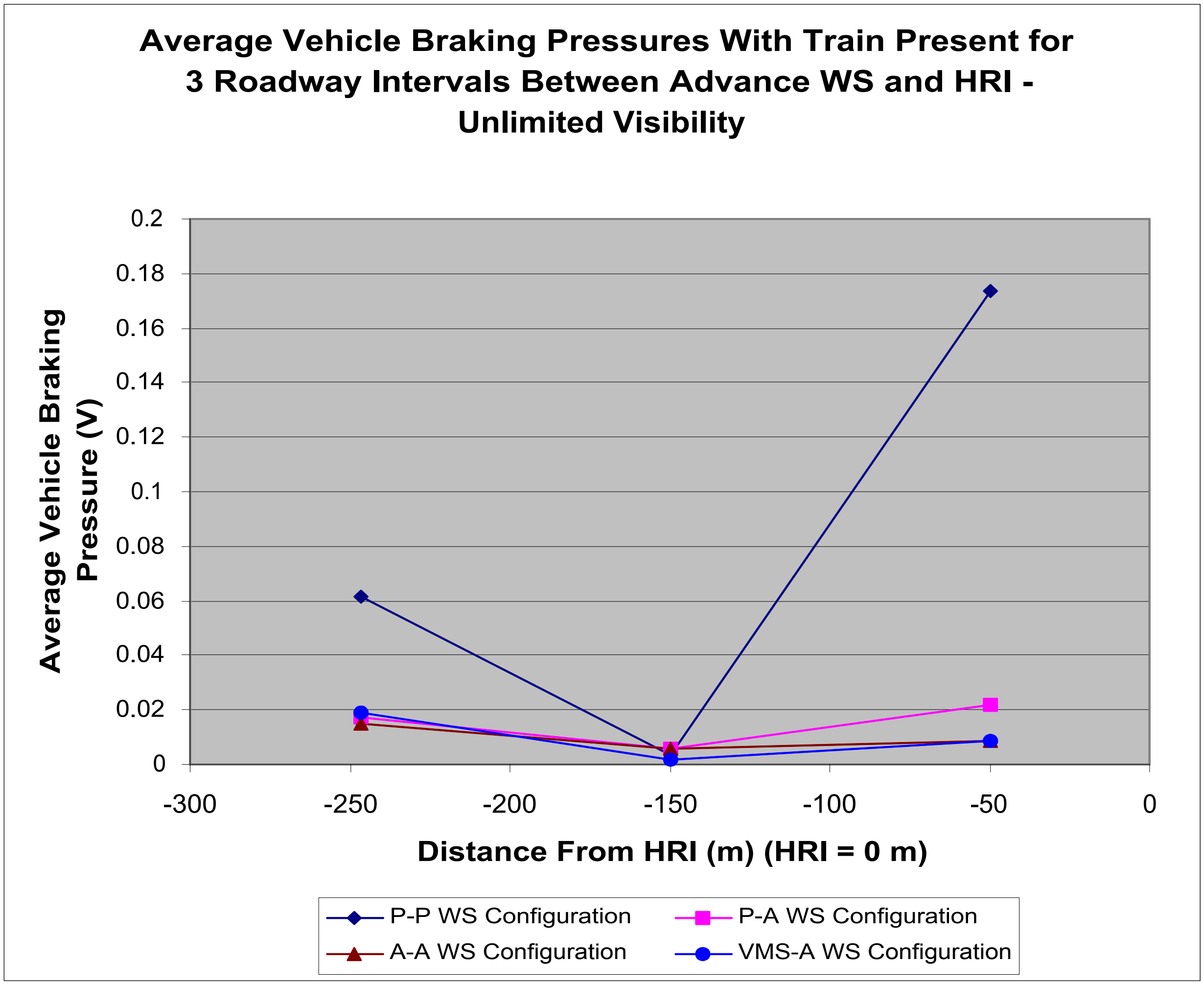


Figure 3-12. Average vehicle braking pressures with train present for 3 roadway intervals between advance warning sign and HRI, for unlimited visibility and 4 different warning sign configurations (N=24). Data plotted at midpoints of Int-WS-200, Int200-100, and Int100-HRI roadway intervals. Abbreviations in figure legend refer to [advance warning sign - Xing crossbuck sign] configuration: P = passive warning sign; A = active flashing light warning sign; VMS = variable message warning sign

visibility (fog) trials are presented in Figures 3-11, 3-13, and 3-15.

In Figures 3-10 through 3-15, the dimension plotted on the X axis is distance from the HRI, with the HRI defined as 0 m. In each figure, the data values are plotted on the midpoints of the 3 roadway intervals between the advance warning sign and the HRI, given that the mean vehicle speed, braking pressure, and accel/decel values are averaged over the entire road distance for each of these intervals. Midpoints for the IntWS-200, Int200-100, and Int100-HRI roadway intervals are, respectively, 246.7 m (809 ft), 150 m (492 ft), and 50 m (164 ft) from the HRI. These are the HRI distances at which data values are aligned in Figures 3-10 through 3-15.

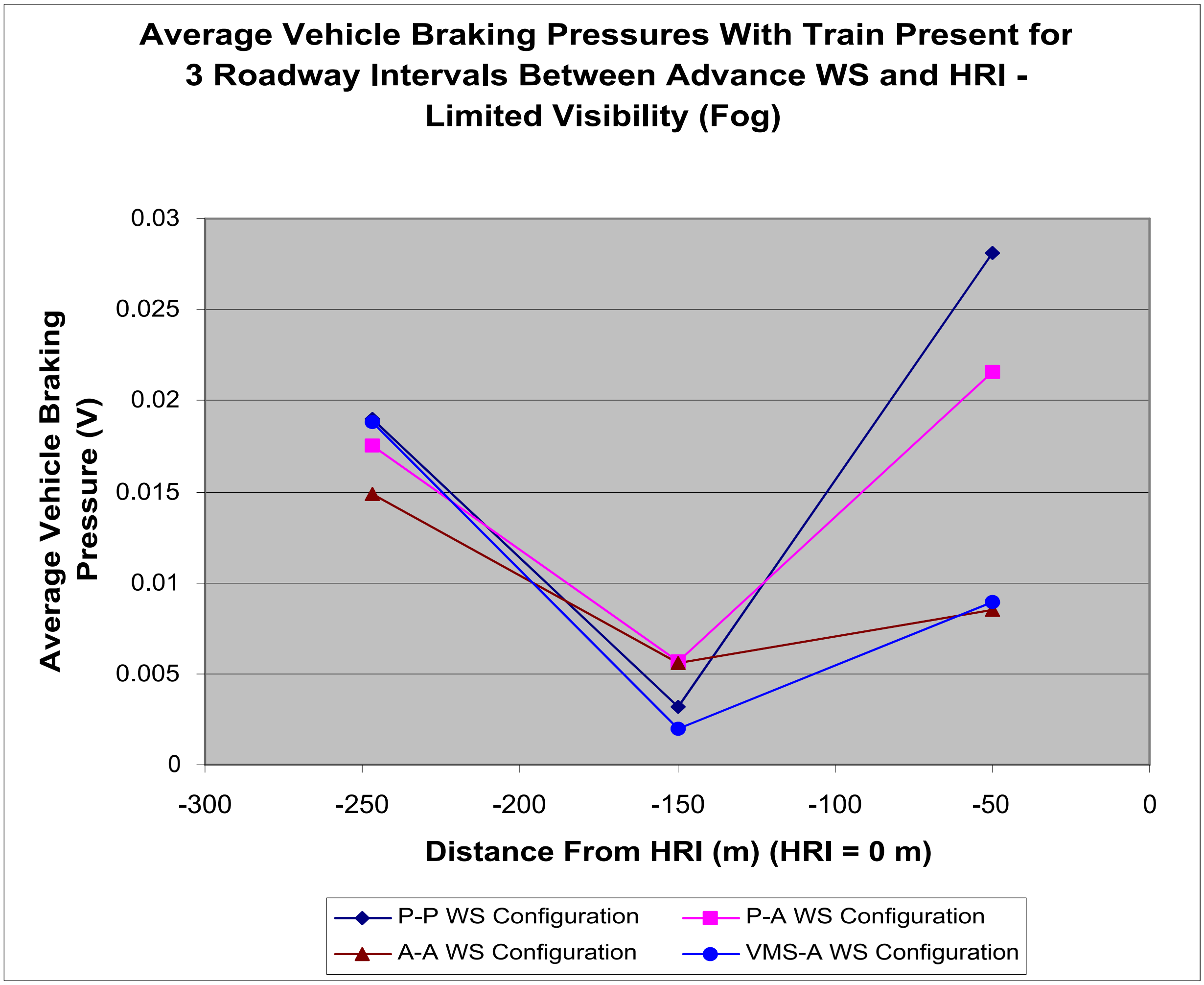


Figure 3-13. Average vehicle braking pressures with train present for 3 roadway intervals between advance warning sign and HRI, for limited visibility and 4 different warning sign configurations (N=24). Data plotted at midpoints of Int-WS-200, Int200-100, and Int100-HRI roadway intervals. Abbreviations in figure legend refer to [advance warning sign - Xing crossbuck sign] configuration: P = passive warning sign; A = active flashing light warning sign; VMS = variable message warning sign

Figures 3-10 and 3-11 profile changes in mean vehicle speeds with a train present for the 3 roadway intervals between the advance warning sign and the HRI, for unlimited and limited visibility conditions respectively. Results in Figure 3-10 indicate that across each of the 3 roadway intervals, with unlimited visibility, average vehicle speed levels are notably higher for those trials with a passive advance warning sign (P-P and P-A configurations), relative to levels observed for trials with an active advance warning sign (A-A or VMS-A configurations).

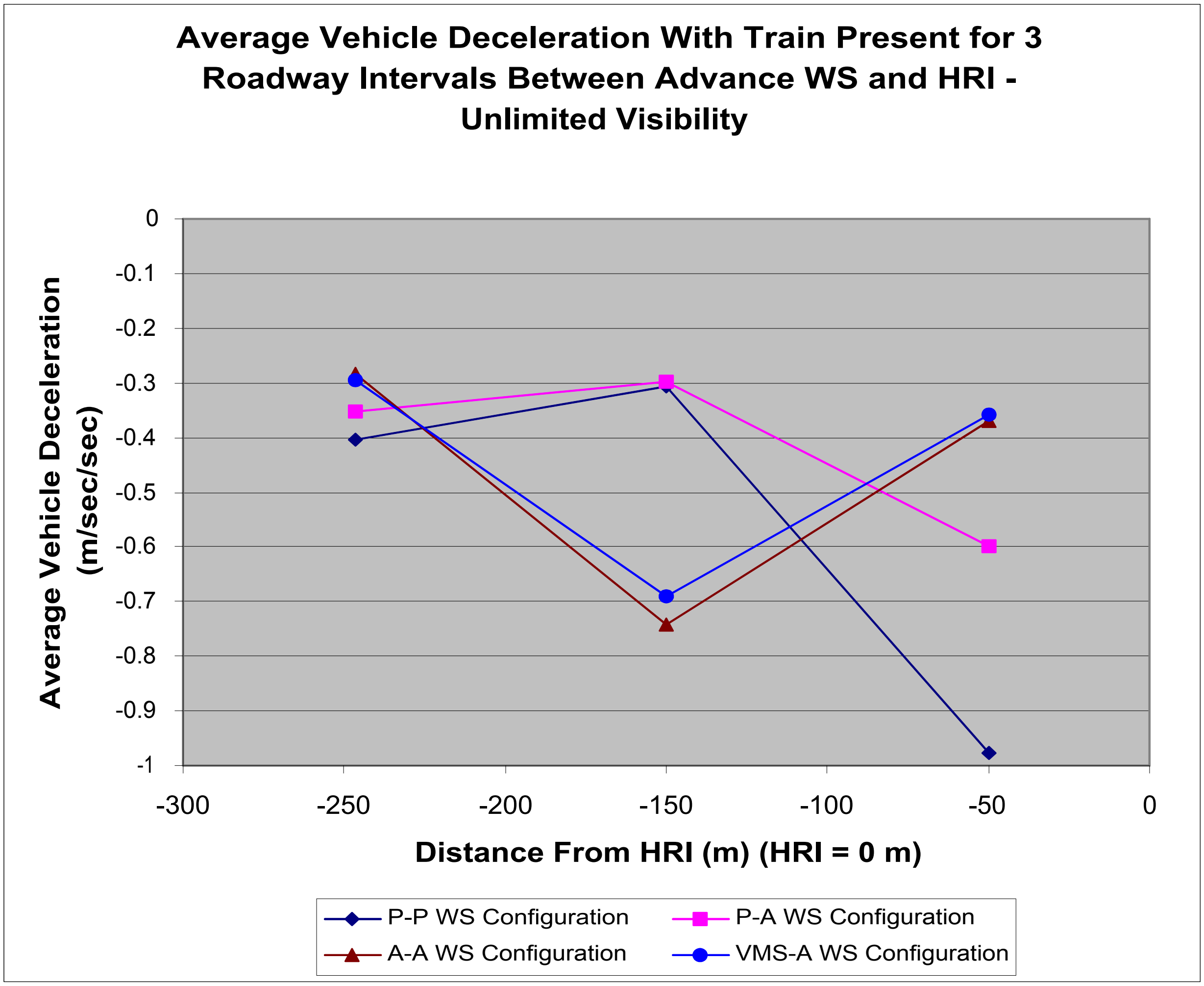


Figure 3-14. Average vehicle deceleration levels with train present for 3 roadway intervals between advance warning sign and HRI, for unlimited visibility and 4 different warning sign configurations (N=24). Data plotted at midpoints of Int-WS-200, Int200-100, and Int100-HRI roadway intervals. Abbreviations in figure legend refer to [advance warning sign - Xing crossbuck sign] configuration: P = passive warning sign; A = active flashing light warning sign; VMS = variable message warning sign

In contrast, as shown in Figure 3-11, under limited visibility conditions the warning sign configuration has much less influence on mean vehicle speed levels with a train present for the 3 roadway intervals. Indeed, for the roadway interval closest to the HRI (Int100-HRI), mean vehicle speeds for trials with an passive advance warning sign actually are somewhat lower than those for trials with an active advance warning sign.

Figures 3-12 and 3-13 profile changes in mean vehicle braking pressure levels with a train present for the 3 roadway intervals between the advance warning sign and the HRI, for unlimited and limited visibility conditions respectively. Results in Figure 3-12 indicate that across each of the 3 roadway intervals, with unlimited visibility, average vehicle braking pressure levels are comparable for all trials with an active Xing flashing red light crossbuck sign, namely the P-A,

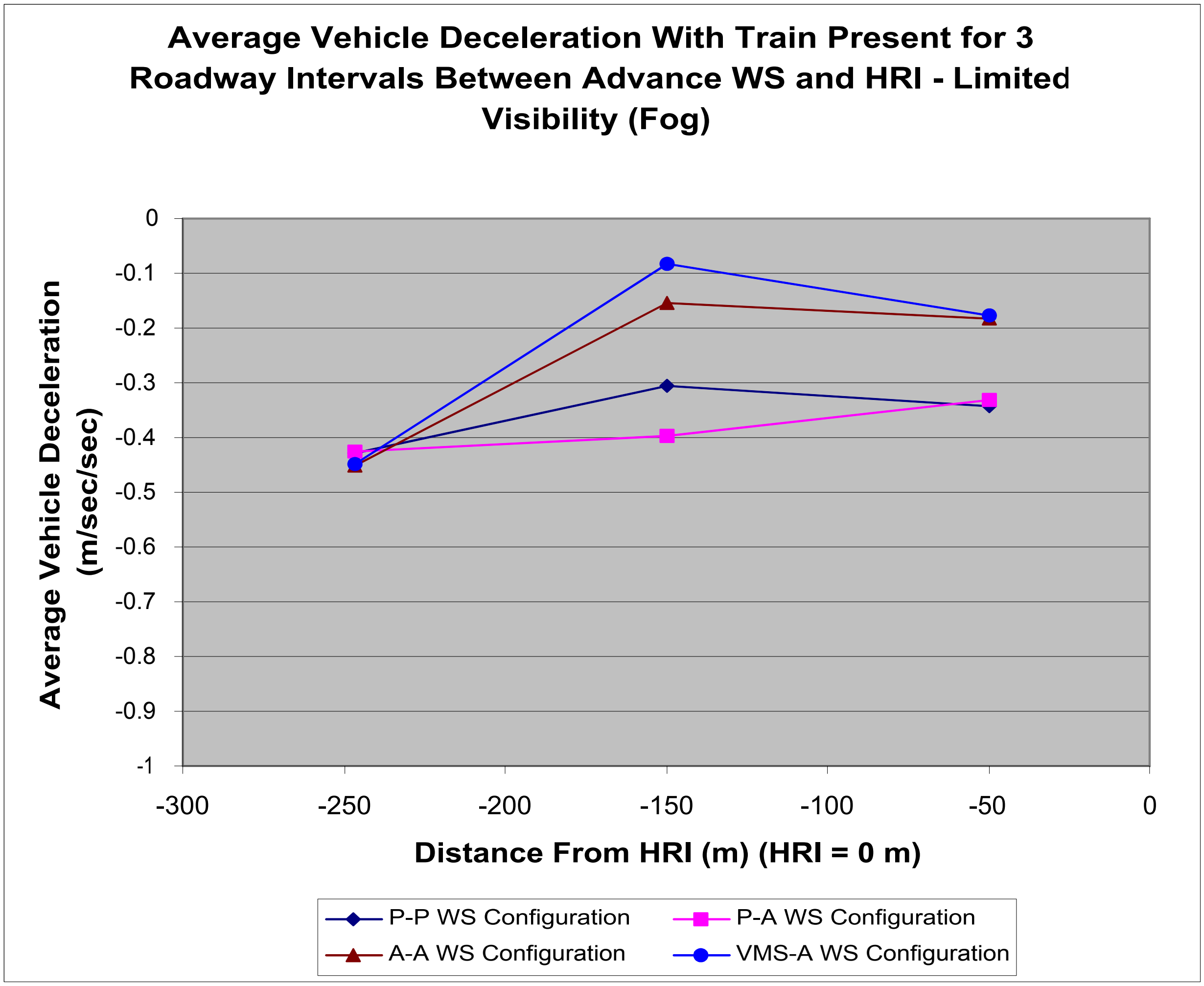


Figure 3-15. Average vehicle deceleration levels with train present for 3 roadway intervals between advance warning sign and HRI, for limited visibility and 4 different warning sign configurations (N=24). Data plotted at midpoints of Int-WS-200, Int200-100, and Int100-HRI roadway intervals. Abbreviations in figure legend refer to [advance warning sign - Xing crossbuck sign] configuration: P = passive warning sign; A = active flashing light warning sign; VMS = variable message warning sign

A-A, and VMS-A warning sign configurations. In contrast, for trials with all passive signage (P-P warning sign configuration), average vehicle braking pressure levels are substantially higher for 2 roadway intervals, namely the one just beyond the advance warning sign (IntWS-200), and the one closest to the HRI (Int100-HRI). A plausible interpretation of these findings is that even with unlimited visibility, the presence of an active HRI warning, either in advance of the HRI or at the Xing or both, encouraged more predictive and therefore more prudent braking behavior on the part of the driver just after the advance warning sign and near the HRI in anticipating that a train would be encountered at the Xing. Relative to average braking pressure results with a train present for unlimited visibility conditions (Fig. 3-12), those for limited visibility conditions (Fig. 3-13) show a different pattern. First, average braking pressure levels for all 4 warning sign configurations are under .03V, as is the case for the P-A, A-A, and VMS-A warning sign configurations under unlimited visibility conditions (Fig. 3-12). Next, for the first 2 roadway intervals beyond the advance warning sign, average braking pressure levels under limited visibility are comparable for all 4 warning sign configurations. For the roadway interval closest to the HRI (Int100-HRI) however, average braking pressure levels for trials with a passive advance warning sign (P-P and P-A warning sign configurations) are notably higher than those for trials with an active advance warning sign (A-A and VMS-A warning sign configurations). A plausible interpretation of these findings is that in the fog, the presence of an active advance HRI warning enabled more predictive, and therefore more prudent, braking behavior by the driver in anticipating that a train would be encountered at the Xing.

Figures 3-14 and 3-15 profile changes in mean vehicle deceleration with a train present for the 3 roadway intervals between the advance warning sign and the HRI, for unlimited and limited visibility conditions respectively. Results in Figure 3-14, for unlimited visibility conditions, indicate comparable average levels of vehicle deceleration for all 4 warning sign configurations for the roadway interval immediately beyond the advance warning sign (IntWS-200). For the next 2 roadway intervals however, contrasting patterns of change in mean vehicle deceleration are observed for trials with a passive advance warning sign (P-P and P-A warning sign configurations), relative to those with an active advance warning sign (A-A and VMS-A warning sign configurations). Specifically, with the former 2 configurations, mean vehicle deceleration remains about the same for the IntWS-200 and Int200-100 roadway intervals, and then increases markedly for the roadway interval closest to the HRI (Int100-HRI). In contrast, for trials with active advance warning sign, mean vehicle deceleration increases markedly for the intermediate roadway interval (Int200-100), and then moderates for the roadway interval closest to the HRI (Int100-HRI). A plausible interpretation of these findings is that the presence of an active advance warning sign enabled more anticipatory deceleration of the vehicle further from the Xing in preparation for arrival of the train, allowing more moderate deceleration behavior when the vehicle approached closer to the Xing.

Relative to average vehicle deceleration results with a train present for unlimited visibility conditions (Fig. 3-14), those for limited visibility conditions (Fig. 3-15) show a generally comparable pattern for all 4 warning sign configurations. Specifically, across all 4 warning sign configurations, mean vehicle deceleration levels are highest and almost identical for the roadway interval just beyond the advance warning sign (IntWS-200). They then decrease for the intermediate roadway interval (Int200-100), with a larger decrease observed for trials with an active advance warning sign (A-A and VMS-A warning sign configurations), relative to that observed for trials with a passive advance warning sign (P-P and P-A warning sign configurations). For the roadway interval closest to the HRI (Int100-HRI), across all 4 warning sign configurations, mean deceleration levels show little further change relative to levels observed for the intermediate roadway interval. One interpretation of these findings is that under limited visibility conditions, the presence of an active advance warning sign enabled anticipatory vehicle deceleration behavior by the driver further from the HRI in preparation for arrival of the train, whereas higher levels of vehicle deceleration were sustained throughout the Int200-100 and Int100-HRI roadway intervals when advance notice of arrival of the train was not provided.

Table 3-1. Results from multivariate ANOVA for main and interactive effects (see Table 2-5) on objective dependent measures of simulated driving performance

Type of Effect	Source	Hypothesis df	Error df	F	p
Main	Tr	15	538	14.48	< .000
	Vi	15	538	7.88	< .000
	AdvWS	60	2164	1.20	0.144
	XingWS	30	1078	2.59	< .000
Interactive	Tr x Vi	15	538	32.74	< .000
	Vi x AdvWS	60	2164	1.41	0.022
	Vi x XingWS	30	1078	2.27	< .000

3.3.2. ANOVA Results for Main and Interactive Effects

Table 3-1 summarizes results from a multivariate ANOVA for main and interactive effects on objective dependent measures of simulated driving performance (Table 2-5). The analysis is based on results for the IntSL-HRI roadway interval only (see Section 3.3.3 for a breakdown of results for the different roadway intervals). From left to right, columns in Table 3-1 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). As noted in Section 2.5.2, the latter 4 results are based on the Pillai's trace multivariate ANOVA test [17].

ANOVA results for main effects in Table 3-1 indicate that the effects of train presence or absence, visibility condition, and Xing warning sign condition all are statistically significant at the $p<.05$ level. However, the main effect of the advance warning sign condition is not statistically significant. It is important to note that when each of these main effects is tested, results for the remaining independent measures are pooled prior to analysis. For example, analysis of the main effect of the advance warning sign condition is based on pooled results from both train conditions, both visibility conditions, and both Xing crossbuck sign conditions.

The observation of a statistically significant main effect of train presence and absence is to be expected. Most subjects slowed before and stopping at the HRI with a train present (Section 3.2.2, Figure 3-3), a behavior that did not typically occur in the absence of a train. Accordingly, data in Figures 3-4 through 3-9 for the IntSL-HRI roadway interval (top set of histograms in each figure), across all 4 warning sign configurations under clear visibility conditions, show that relative to results for trials without a train (Figs. 3-4, 3-6, and 3-8), simulated driving performance during trials with a train features: (1) lower mean vehicle speeds (Fig. 3-5); (2) higher mean vehicle braking pressures (Fig. 3-7); and (3) lower mean vehicle accelerations (Fig. 3-9). These findings account for the observed main effect of train presence and absence.

That a statistically significant main effect of the visibility condition is observed also is aligned with expectation. Arguably, the *a priori* predicted effect would be that compared with unlimited visibility conditions, simulated driving performance under limited (foggy) visibility should be more cautious, and therefore slower. However, the actual results observed are not entirely aligned with this expectation.

In particular, data in Figures 3-4, 3-6 and 3-8, for the IntSL-HRI roadway interval (top set of histograms in each figure) across all 4 warning sign configurations for trials without a train, show that relative to results for trials with unlimited visibility, simulated driving performance during trials with limited visibility (fog) features: (1) lower mean vehicle speeds (Fig. 3-4); (2) higher mean vehicle braking pressures (Fig. 3-6); and (3) lower mean vehicle accelerations (Fig. 3-9). These results are aligned with *a priori* prediction, as outlined above. In contrast, data in Figures 3-5, 3-7 and 3-9, for the IntSL-HRI roadway interval (top set of histograms in each figure) across all 4 warning sign configurations for trials with a train, show that relative to results for trials with unlimited visibility, simulated driving performance during trials with limited visibility (fog) features: (1) higher mean vehicle speeds (Fig. 3-5); (2) lower mean vehicle braking pressures (Fig. 3-7); and (3) higher mean vehicle accelerations (Fig. 3-9). These results are exactly opposite to *a priori* expectation.

Why should foggy relative to clear conditions result in more cautious simulated driving performance during trials without a train, but more aggressive simulated driving performance during trials with a train? The answer lies with the fact that the presence of an active advance warning sign during a subset of the train present trials encouraged more confident, and therefore more aggressive, simulated driving performance in the fog during these trials. Thus, as shown in Figures 3-11, 3-13, and 3-15 for the 3 roadway intervals beyond the advance warning sign (IntWS-200, Int200-100, and Int100-HRI), during train present trials under limited (fog) visibility conditions, relative to simulated driving performance during trials without an active advance warning sign, simulated driving performance during trials with an active advance warning sign features: (1) slightly higher mean vehicle speeds for the Int100-HRI roadway interval (Fig. 3-11); (2) lower vehicle braking pressures for the Int100-HRI roadway interval (Fig. 3-13); and (3) lower decelerations for the Int200-100 and Int100-HRI roadway intervals.

Collectively, these findings account for the observed main effect of visibility conditions, an effect aligned with *a priori* expectation for unlimited visibility trials, but essentially opposite to expectation for limited visibility trials.

ANOVA results for interactive effects in Table 3-1 indicate that the effects of all 3 interactions indicated—train x visibility, visibility x advance warning sign, and visibility x Xing crossbuck sign—are statistically significant at the $p<.05$ level. All 3 of these significant interactions are explained by the contrasting findings for the 2 visibility conditions with the train absent versus the train present trials, as addressed above. These contrasting results directly account for the significant train x visibility interaction observed.

Figures 3-4 through 3-9 illustrate the basis of the significant interactions of the visibility condition with both and advance and Xing warning sign configurations specified in Table 3-1. Specifically, for the IntSL-HRI roadway interval (top sets of histograms in Figs. 3-4 through 3-9), contrasting effects of visibility condition during train absent compared with train present trials are observed for mean levels of vehicle speed (Figs. 3-4 versus 3-5), braking pressure (Fig. 3-6 versus 3-7), and accel/decel (Fig. 3-8 versus 3-9), across all 4 warning sign configurations.

Table 3-2. Post hoc analysis of interactive effects of different advance warning sign configurations on dependent measures of simulated driving performance, evaluated across different roadway intervals, based on pooled results from both visibility conditions for train present trials

Roadway Interval	**Dependent Measure of Vehicle Simulated Driving Performance**	**AdvWS Interaction[1]**		**Mean Difference[2]**	**p**
		I	**J**		
IntSL-HRI	Speed (m/sec)	P	A	2.33	< .000
		P	VMS	2.29	< .000
		A	VMS	-0.45	NS
	Braking Pressure (V)	P	A	-.0066	NS
		P	VMS	-.0084	NS
		A	VMS	-.0018	NS
	Accel/Decel (m/sec/sec)	P	A	.134	< .000
		P	VMS	.126	< .000
		A	VMS	-.008	NS
IntWS-HRI	Speed (m/sec)	P	A	3.95	< .000
		P	VMS	4.07	< .000
		A	VMS	.115	NS
	Braking Pressure (V)	P	A	-.0082	NS
		P	VMS	-.0124	NS
		A	VMS	-.0042	NS
	Accel/Decel (m/sec/sec)	P	A	-.098	NS
		P	VMS	.027	NS
		A	VMS	.125	NS
IntWS-200	Speed (m/sec)	P	A	2.23	< .000
		P	VMS	2.12	< .000
		A	VMS	-.10	NS
	Braking Pressure (V)	P	A	-.0061	NS
		P	VMS	-.0101	.033
		A	VMS	-.0041	NS

Table 3-2. (continued)					
Roadway Interval	**Dependent Measure of Vehicle Simulated Driving Performance**	**AdvWS Interaction[1]**		**Mean Difference[2]**	**p[1]**
		I	**J**		
IntWS-200 (continued)	Accel/Decel (m/sec/sec)	P	A	-.078	< .000
		P	VMS	-.073	.001
		A	VMS	.006	NS
Int200-100	Speed (m/sec)	P	A	2.31	< .000
		P	VMS	2.52	< .000
		A	VMS	0.21	NS
	Braking Pressure (V)	P	A	.0037	NS
		P	VMS	.0070	NS
		A	VMS	.0034	NS
	Accel/Decel (m/sec/sec)	P	A	.054	NS
		P	VMS	-.007	NS
		A	VMS	-.061	NS
Int100-HRI	Speed (m/sec)	P	A	4.63	< .000
		P	VMS	4.52	< .000
		A	VMS	-0.10	NS
	Braking Pressure (V)	P	A	-.0105	NS
		P	VMS	-.0132	NS
		A	VMS	-.0027	NS
	Accel/Decel (m/sec/sec)	P	A	-.021	NS
		P	VMS	-.031	NS
		A	VMS	-.010	NS

[1]P = passive advance warning sign; A = flashing yellow light advance warning sign; VMS = flashing variable message (‘TRAIN’) advance warning sign; NS = not significant (p>.05)
[2]Mean difference based on pooled results across both visibility conditions for train present trials, calculated as the difference between mean results for warning sign trials listed in the ‘I’ column and those for warning sign trials listed in the ‘J’ column (e.g., I minus J).

Table 3-3. Post hoc analysis of interactive effects of different Xing crossbuck sign configurations on dependent measures of simulated driving performance, evaluated across different roadway intervals, based on pooled results from both visibility conditions for train present trials

Roadway Interval	Dependent Measure of Vehicle Simulated Driving Performance	XingWS Interaction[1]		Mean Difference[2]	p[1]
		I	J		
IntSL-HRI	Speed (m/sec)	P	A	1.95	< .000
	Braking Pressure (V)	P	A	-.0083	.018
	Accel/Decel (m/sec/sec)	P	A	.110	< .000
IntWS-HRI	Speed (m/sec)	P	A	3.45	< .000
	Braking Pressure (V)	P	A	-.0106	NS
	Accel/Decel (m/sec/sec)	P	A	-.038	NS
IntWS-200	Speed (m/sec)	P	A	1.79	< .000
	Braking Pressure (V)	P	A	-.0074	.013
	Accel/Decel (m/sec/sec)	P	A	-.077	< .000
Int200-100	Speed (m/sec)	P	A	1.95	< .000
	Braking Pressure (V)	P	A	.0122	.002
	Accel/Decel (m/sec/sec)	P	A	-.0409	< .000
Int100-HRI	Speed (m/sec)	P	A	3.99	< .000
	Braking Pressure (V)	P	A	-.0172	.027
	Accel/Decel (m/sec/sec)	P	A	-.006	NS

[1]P = passive Xing crossbuck sign; A = flashing red light Xing crossbuck sign; NS = not significant (p>.05)
[2]Mean difference based on pooled results across both visibility conditions for train present trials, calculated as the difference between mean results for warning sign trials listed in the 'I' column and those for warning sign trials listed in the 'J' column (e.g., I minus J).

Post hoc analysis (Section 2.5.3) was carried out to evaluate the differential influence of different types of advance warning sign and Xing crossbuck sign on dependent measures of simulated driving performance. Results are presented in the next subsection.

3.3.3. Post Hoc Analysis of Interactive Effects of Warning Sign Configuration

Given the focus of this study on the influence of different warning sign configurations on simulated driving performance in approaching an HRI, this section confines itself to post hoc analysis of the differential influence of different types of advance warning signs and Xing crossbuck signs on dependent measures of simulated driving performance for the train present trials. Analysis was carried out using the Bonferroni procedure [17]. Results are presented for each of the 5 different roadway intervals (Table 2-4).

Tables 3-2 and 3-3 presents results from post hoc analysis of interactive effects of different types of advance warning signs (Table 3-2) and Xing crossbuck signs (Table 3-3) on dependent measures of simulated driving performance, evaluated across the 5 different roadway intervals. Data in both tables are based on pooled results from both visibility conditions for train present trials only, during which the active advance yellow light warning sign and/or the active Xing red light crossbuck sign both are flashing.

From left to right in both tables, successive columns list: (1) the roadway interval; (2) the dependent measure of simulated driving performance; (3) the 2 warning sign types being compared (Columns I and J) by post hoc analysis; (4) the difference in the means for the dependent measures of simulated driving performance and the 2 types of warning sign specified (= [mean result for warning sign type specified in 'I' column] minus [mean result for warning sign type specified in 'J' column]) based on pooled results across both visibility conditions for train present trials; and (5) the statistical significance of the difference in the means listed in the preceding column.

Differential Effects of Passive Versus Active Advance Warning Sign. Results in Table 3-2 for different types of advance warning sign, from pooled results for both visibility conditions with the train present trials, indicate that for all 5 roadway intervals without exception, average vehicle speeds for passive advance warning sign trials exceed those for active advance warning sign trials (when the active advance warning sign is either a flashing yellow light or a flashing VMS), and that in every case the difference is statistically significant. Figure 3-5 shows that this interactive effect is attributable entirely to lower mean vehicle speeds observed with active relative to passive advance warning sign trials under unlimited visibility conditions, for all 5 roadway intervals.

In contrast, for all roadway intervals except one (IntWS-200 interval), from pooled results for both visibility conditions with the train present trials, average vehicle braking pressure levels for trials with a passive advance warning sign do not differ in a statistically significant manner from levels for trials with an active advance warning sign, either flashing yellow light or flashing VMS. Figure 3-7 shows little influence of the type of advance warning sign on mean vehicle braking pressure levels for the limited visibility trials, whereas for unlimited visibility trials, levels for trials with an active advance warning sign are lower than those for trials with a passive advance warning sign for all roadway intervals except the Int200-100 interval. Therefore, the lack of statistical significance observed, from post hoc analysis of the differential influence of passive versus active advance warning sign conditions on mean vehicle braking pressure levels, is attributable to the high degree of variance in mean levels of vehicle braking pressure observed for the unlimited visibility trials (see error bars in Fig. 3-7).

Results in Table 3-2 for mean levels of vehicle accel/decel, from pooled results for both visibility conditions with the train present trials, indicate that for the IntSL-HRI roadway interval, average levels of vehicle acceleration for trials with a passive advance warning sign are significantly higher than levels for trials with an active advance warning sign, either flashing yellow light or flashing VMS (refer to top set of histograms in Fig. 3-9). Results in Figure 3-9 show that this effect is due to higher mean vehicle acceleration levels observed under unlimited visibility conditions for trials with a passive advance warning sign, relative to those observed for trials with an active advance flashing yellow light or flashing VMS warning sign.

Results in Table 3-2 for mean levels of vehicle accel/decel, from pooled results for both visibility conditions with the train present trials, indicate that for the IntWS-HRI, Int200-100, and Int100-HRI roadway intervals, average vehicle accel/decel levels for trials with a passive advance warning sign do not differ in a statistically significant manner from levels for trials with an active advance warning sign, either flashing yellow light or flashing VMS. Results in Figure 3-9 show that: (1) for the IntWS-HRI roadway interval (second set of histograms from top in Fig. 3-9), there is little difference in mean vehicle acceleration levels under unlimited or limited visibility, for trials with a passive versus an active advance warning sign: (2) for the Int200-100 roadway interval (4th set of histograms from top in Fig. 3-9), under unlimited visibility conditions mean vehicle deceleration levels for passive advance warning sign trials are lower than for active advance warning sign trials, but the opposite is true under limited visibility conditions; and (3) for the Int100-HRI roadway interval (bottom set of histograms in Fig. 3-9), under both unlimited and limited visibility conditions, mean vehicle deceleration levels for passive advance warning sign trials are higher than for active advance warning sign trials.

Results in Table 3-2 for mean levels of vehicle accel/decel, from pooled results for both visibility conditions with the train present trials, indicate that for the IntWS-200 roadway interval (middle set of histograms in Fig. 3-9), average levels of vehicle deceleration for trials with a passive advance warning sign are significantly higher than levels for trials with an active advance warning sign, either flashing yellow light or flashing VMS. Results in Figure 3-9 show that this effect is due to higher mean vehicle deceleration levels observed under unlimited visibility conditions for trials with a passive advance warning sign, relative to those observed for trials with an active advance flashing yellow light or flashing VMS warning sign.

Finally, results in Table 3-2 for all 3 dependent measures of simulated driving performance across all 5 roadway intervals, from pooled results for both visibility conditions with the train present, indicate that mean levels of simulated driving performance for trials with an active advance flashing yellow light warning sign do not differ in a statistically significant manner from levels for trials with an active advance VMS warning sign. Results in Figures 3-5, 3-7, and 3-9 indicate that, within each of the 2 visibility conditions, mean levels of vehicle speed, braking pressure, and accel/decel show little change for trials with an active advance flashing yellow light warning sign, relative to those with an active advance flashing VMS warning sign.

Differential Effects of Passive Versus Active Xing Crossbuck Sign. Results in Table 3-3 for different types of Xing crossbuck sign, from pooled results for both visibility conditions with the train present trials, indicate that for all 5 roadway intervals without exception, average vehicle speeds for passive Xing crossbuck sign trials exceed those for active Xing crossbuck sign trials (the active Xing crossbuck sign is a flashing red light). In every case, the difference is statistically significant. Figure 3-5 shows that this differential effect is attributable entirely to lower mean vehicle speeds observed with active relative to passive Xing crossbuck sign trials under unlimited visibility conditions, for all 5 roadway intervals.

Results in Table 3-3 for different types of Xing crossbuck signs, from pooled results for both visibility conditions with the train present trials, indicate that across the 5 different roadway intervals, mixed results are observed regarding differential effects of passive versus active Xing crossbuck signs on mean vehicle braking pressure levels.

Results in Figure 3-7 clarify these mixed results in showing that under unlimited visibility conditions, mean levels of vehicle braking pressure are consistently higher for trials with a passive Xing crossbuck sign, relative to those with an active Xing flashing red light crossbuck sign, for all roadway intervals except the Int200-100 interval.

Results in Table 3-3 for different types of Xing crossbuck signs, from pooled results for both visibility conditions with the train present trials, indicate that mixed results also are observed regarding differential effects of passive versus active Xing crossbuck signs on mean accel/decel levels. Results in Figure 3-9 also show a mixed pattern of observations, for the different roadway intervals, regarding differential effects of passive versus active Xing crossbuck sign conditions on mean vehicle accel/decel levels.

As described previously (Section 3.3.1), results in Figure 3-14 and 3-15 for mean vehicle deceleration levels for the IntWS-200, Int200-100, and Int100-HRI roadway intervals, for trials with a train present, provide some insight into the mixed pattern of results for this measure evident in Table 3-3 and Figure 3-9. For unlimited visibility conditions (Fig. 3-14), comparable average levels of vehicle deceleration are observed for all 4 warning sign configurations for the roadway interval immediately beyond the advance warning sign (IntWS-200). For the next 2 roadway intervals however, contrasting patterns of change in mean vehicle deceleration are observed for trials with a passive advance warning sign (P-P and P-A warning sign configurations), relative to those with an active advance warning sign (A-A and VMS-A warning sign configurations). Specifically, with the former 2 configurations, mean vehicle deceleration remains about the same for the IntWS-200 and Int200-100 roadway intervals, and then increases markedly for the roadway interval closest to the HRI (Int100-HRI). In contrast, for trials with active advance warning signs, mean vehicle deceleration increases markedly for the intermediate roadway interval (Int200-100), and then moderates for the roadway interval closest to the HRI (Int100-HRI). For limited visibility conditions (Fig. 3-15) however, a generally comparable pattern of changes in mean vehicle deceleration across these 3 roadway intervals is observed for all 4 warning sign configurations. Thus, for these 3 roadway intervals, it is the advance warning sign condition, rather than the Xing crossbuck sign condition, that appears to have more consistent and interpretable influences on mean vehicle accel/decel under each of the visibility conditions.

3.4. Post-Test Questionnaire Results

This section describes results for the PTQ (Appendix C), which subjects completed after completing their second experimental session (Section 2.3.5). Questions 7 through 42 on the PTQ ask respondents to express agreement or disagreement regarding statements pertaining to interaction with HRI warning signs. The response to each of these questions is registered on a 5-level Likert scale, with a ‘1' response denoting strong disagreement with the question statement, and a ‘5' response denoting strong agreement with the question statement.

Questions 43 through 46 on the PTQ present respondents with a series of options regarding driving behavior that should be adopted (Questions 43 and 44), or driving behavior that the respondent actually tends to adopt (questions 45 and 46), in approaching an HRI with a passive or an active Xing crossbuck sign, with a train present or absent.

Among Questions 7 through 42 on the PTQ there are 2 categories of questions, namely questions dealing with the usability and those dealing with the conspicuity of different types and configurations of HRI warning signs. The next 2 subsections present results for responses to questions in each of these categories. The 3rd subsection presents results for responses to Questions 43 through 46 on the PTQ. Open respondent comments are summarized in the last subsection.

3.4.1. Responses to PTQ Questions Regarding Usability of HRI Warning Signs

A total of 26 questions on the PTQ pertain to the usability of different types and configurations of HRI warning signs: Q8, Q9, Q11-Q15, Q17, Q19-Q21, Q24-Q27, Q29-Q31, Q33, Q34, Q36, Q38-Q42. These questions query the degree of respondent agreement or disagreement with statements regarding the utility, the appeal, and the preferred design of different HRI warning sign conditions. Results are presented below for groups of these questions that pertain to different aspects of usability.

PTQ questions Q19, Q26, Q25, and Q8 query the degree of respondent agreement with statements about how helpful a passive or an active advance warning sign, and a passive or an active Xing crossbuck sign, are to stopping for a train. Q19 and Q26 deal with passive versus active Xing crossbuck signs; Q25 and Q8 deal with passive versus active advance warning signs. The distributions of responses to these questions are illustrated in Figures 3-16 through 3-19.

Results in Figures 3-16 and 3-18 show a lack of consensus among respondents regarding whether or not passive signage at either the Xing (Fig. 3-16) or in advance of the HRI (Fig. 3-18) are helpful to stopping for a train. For both questions, the majority of responses indicate either a neutral position or disagreement regarding this assertion.

In contrast, as shown in Figures 3-17 and 3-19, most respondents either agree or strongly agree with the assertion that active flashing lights, either at the Xing (Fig. 3-17) or in advance of the HRI (Fig. 3-19), are helpful to stopping for a train. Indeed, all but 1 respondent strongly agree with the statement that active advance flashing warning signs are helpful to stopping for a train (Fig. 3-19).

PTQ questions Q9, Q20, Q33, and Q38 query the degree of respondent agreement with statements about what type and configuration of HRI warning signs are helpful in warning of a train. The distributions of responses to these questions are illustrated in Figures 3-20 through 3-24.

Q9 and Q33 deal with the question of whether passive or active warning signs are more helpful in serving as a train warning. All but 4 respondents strongly disagree with the statement that passive warning signs are more helpful than active flashing light warning signs in serving as a train warning (Fig. 3-20), whereas all 25 respondents strongly agree with the inverse statement (Fig. 3-21).

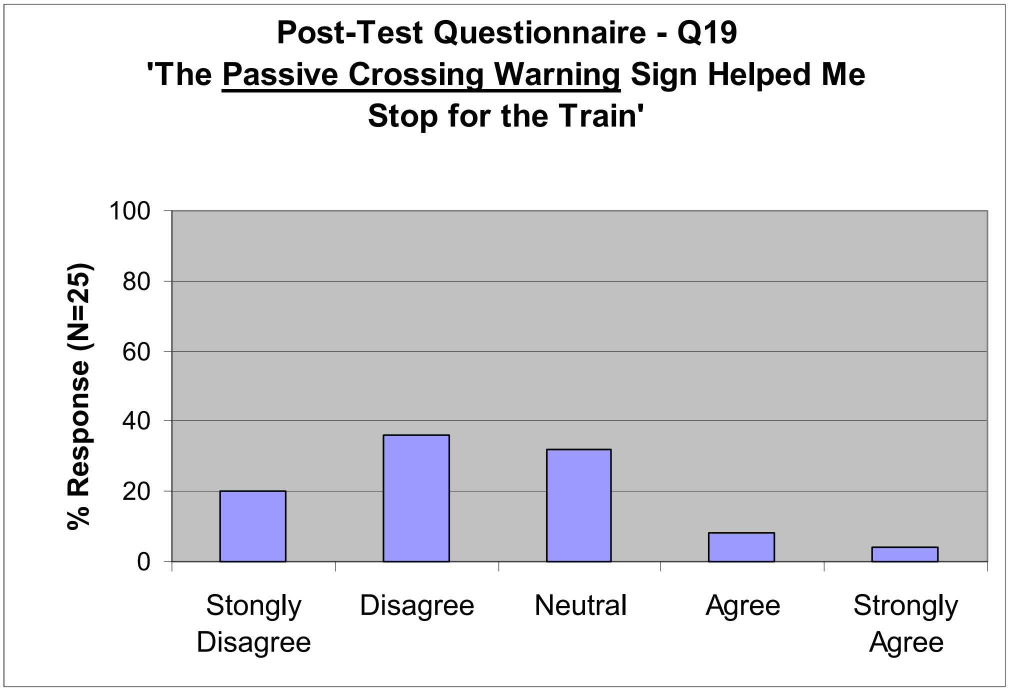


Figure 3-16. Distribution of responses (N=25) to Q19 in PTQ: 'The Passive Crossing Warning Sign Helped Me Stop for the Train'

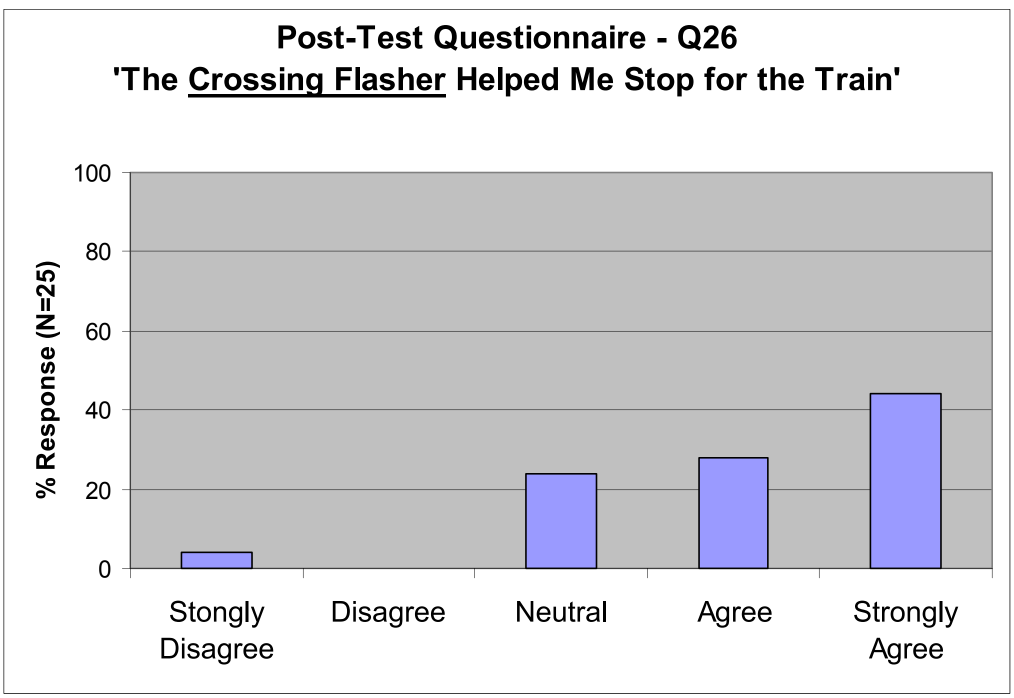


Figure 3-17. Distribution of responses (N=25) to Q26 in PTQ: 'The Crossing Flasher Helped Me Stop for the Train'

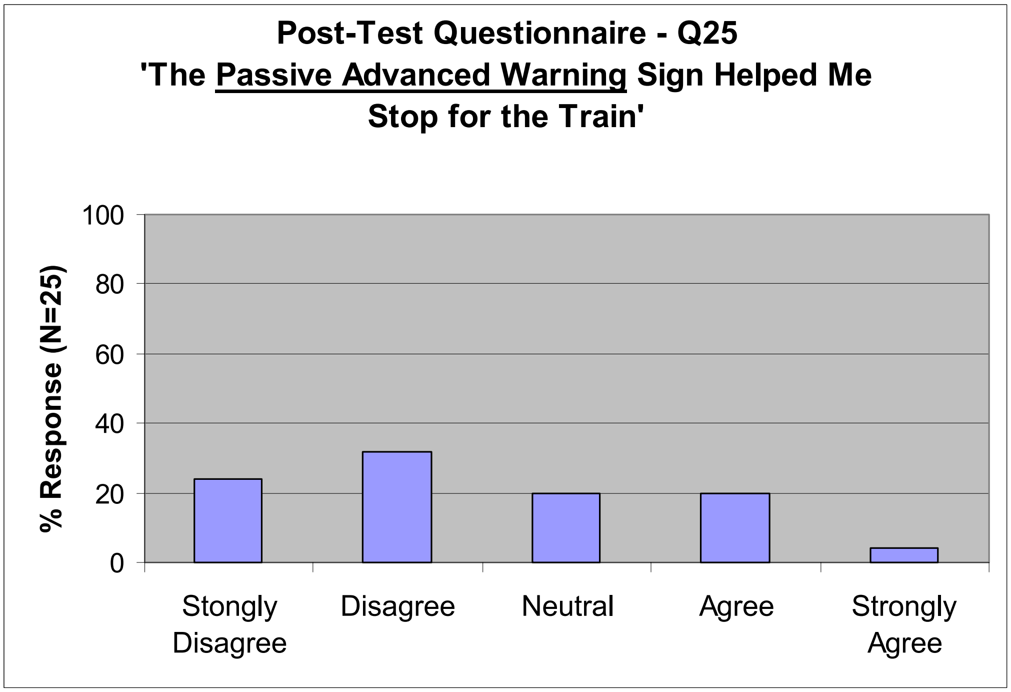


Figure 3-18. Distribution of responses (N=25) to Q25 in PTQ: 'The Passive Advanced Warning Sign Helped Me Stop for the Train'

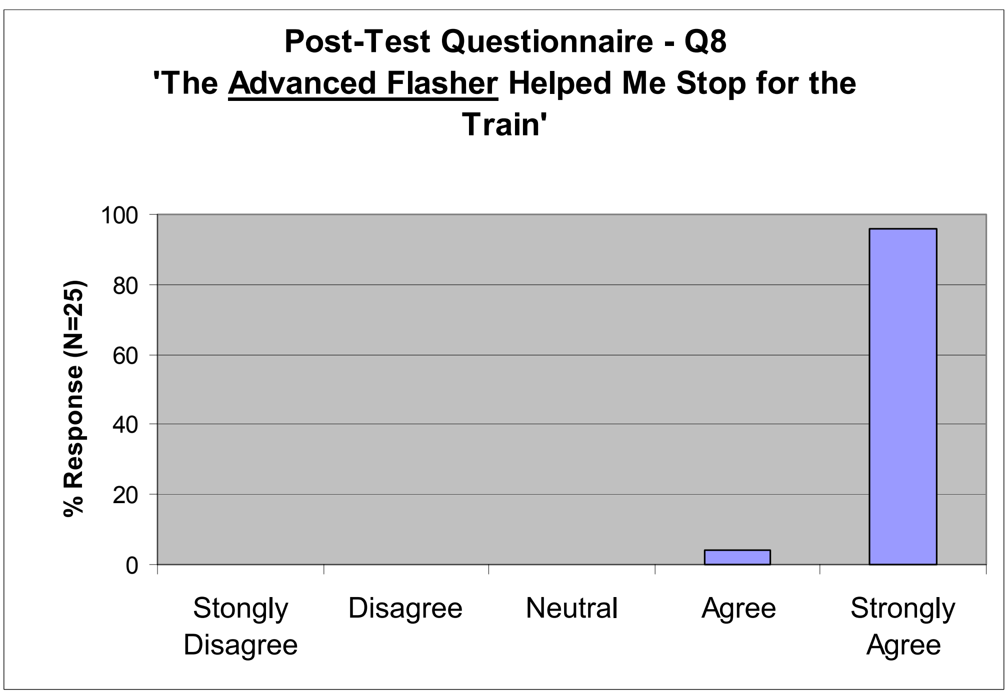


Figure 3-19. Distribution of responses (N=25) to Q8 in PTQ: 'The Advanced Flasher Helped Me Stop for the Train'

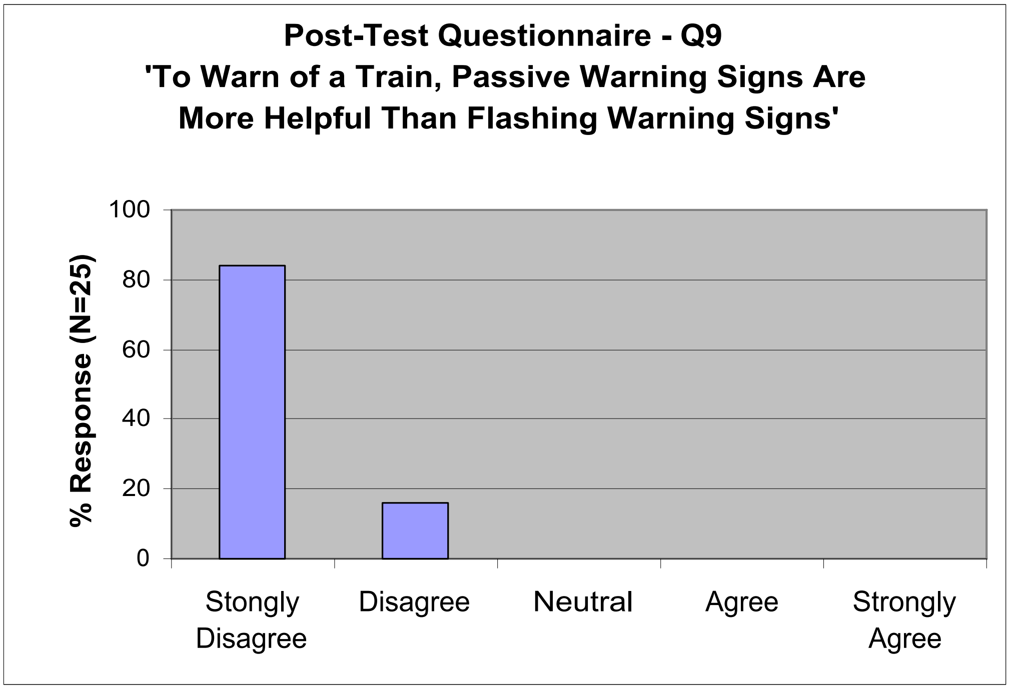


Figure 3-20. Distribution of responses (N=25) to Q9 in PTQ: ‘To Warn of a Train, Passive Warning Signs Are More Helpful Than Flashing Warning Signs’

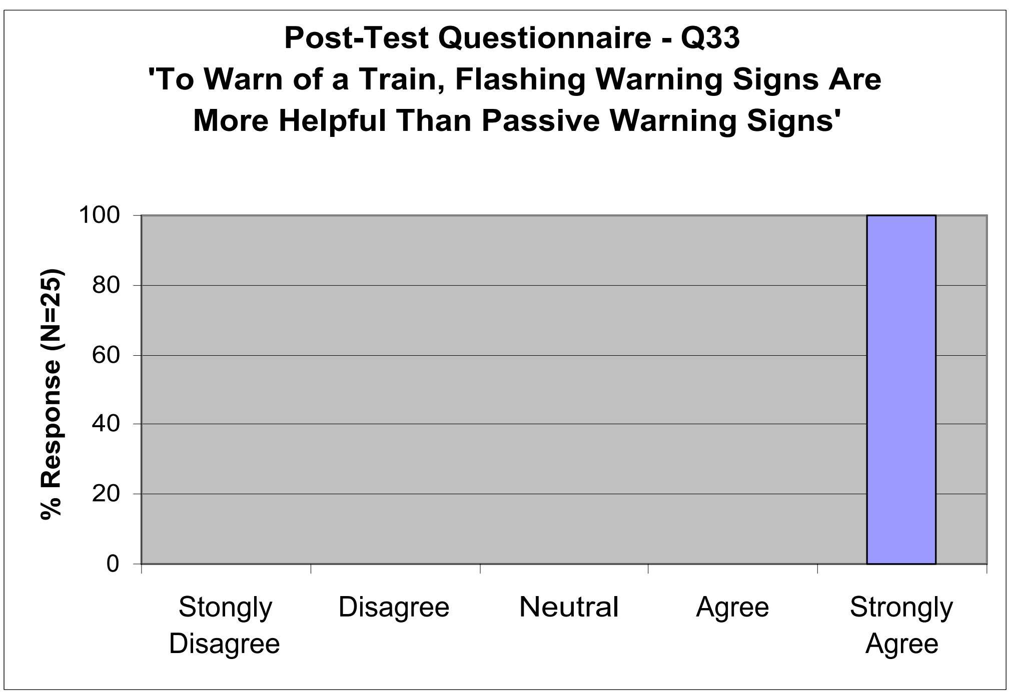


Figure 3-21. Distribution of responses (N=25) to Q33 in PTQ: ‘To Warn of a Train, Flashing Warning Signs Are More Helpful Than Passive Warning Signs’

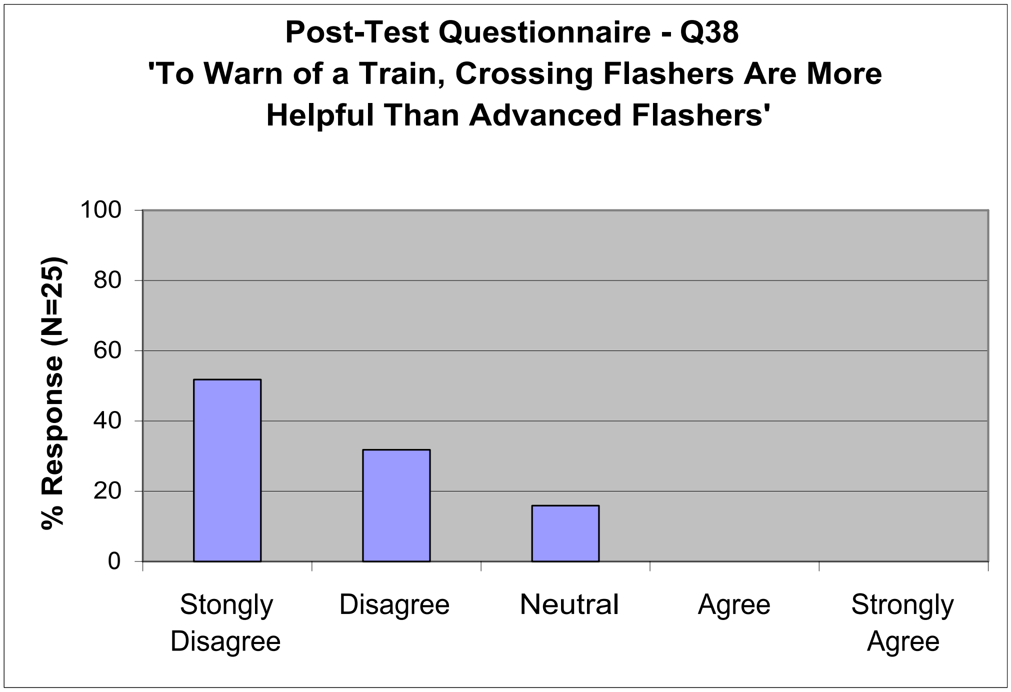


Figure 3-22. Distribution of responses (N=25) to Q38 in PTQ: 'To Warn of a Train, Crossing Flashers Are More Helpful Than Advance Flashers'

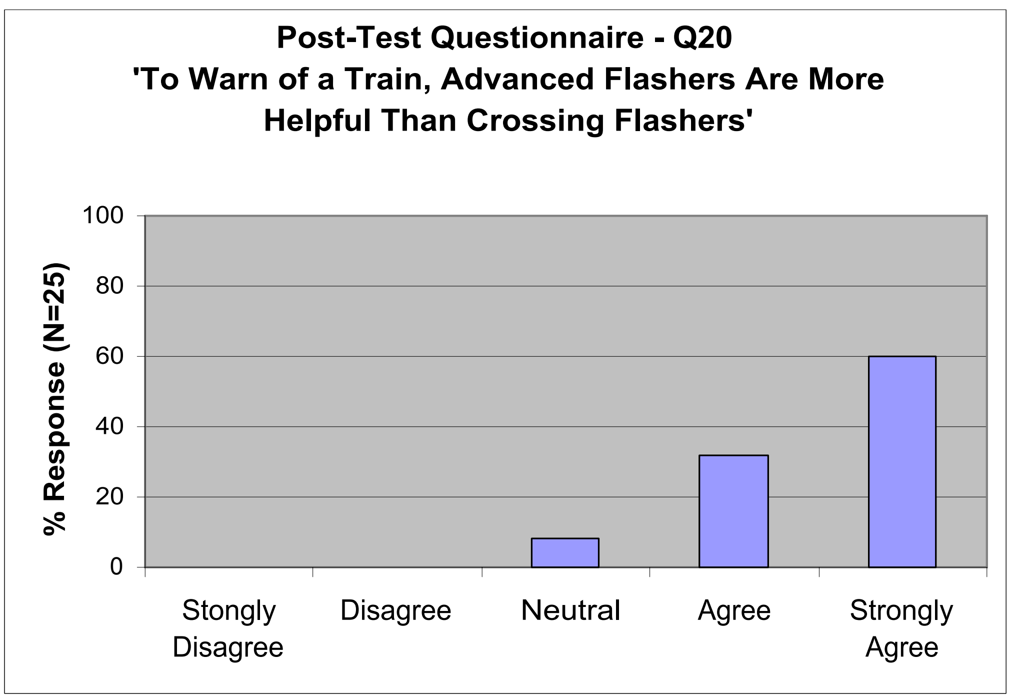


Figure 3-23. Distribution of responses (N=25) to Q20 in PTQ: 'To Warn of a Train, Advanced Flashers Are More Helpful Than Crossing Flashers'

Q20 and Q38 deal with the question of whether advanced or crossing active flashing light signs are more helpful in serving as a train warning. All respondents are neutral or disagree with the statement that active Xing flashing red light crossbuck signs are more helpful than active advance flashing yellow light warning signs in warning of a train (Fig. 3-22). In contrast, all but 2 respondents agree or strongly agree with the statement that active advance flashing yellow light warning signs are more helpful than active Xing flashing red light crossbuck signs in warning of a train (Fig. 3-23).

PTQ questions Q11, Q29, Q30, Q36, Q39, and Q42 query the degree of respondent agreement with statements about what type and configuration of HRI warning sign should be installed in front of most Xings. The distributions of responses to these questions are illustrated in Figures 3-24 through 3-29. Q11, Q30, and Q36 pertain to passive warning signs; Q 29, Q 39, and Q42 pertain to active warning signs.

Results in Figures 3-24 through 3-26 indicate a lack of respondent consensus regarding the question of whether most Xings should be preceded by a passive Xing crossbuck sign (Fig. 3-24), a passive advance warning sign (Fig. 3-25), or both (Fig. 3-26). With regard to the first 2 of these options, the majority of respondents are neutral or disagree. With regard to the last of these options however, the majority of respondents either agree or strongly agree.

In contrast, there is consensus agreement among respondents regarding the question of whether most Xings should be preceded by an active Xing flashing red light crossbuck sign (Fig. 3-27), an active advance warning sign (Fig. 3-26), or both (Fig. 3-29). With regard to the latter option, all but 2 respondents strongly agree that most Xings should be preceded by active signage at both the Xing and in advance of the HRI (Fig. 3-29).

PTQ questions Q13 through Q15, and Q 17, deal with the question of how subject control of vehicle speed and stopping is influenced by active flashing HRI warning signs. Q13 and Q15 query whether respondents speed up or slow down while approaching an HRI with active flashing light signs. Q14 and Q17 query whether an active HRI warning sign helps HRI stopping behavior when a subject is driving rapidly or slowly. The distributions of responses to these questions are illustrated in Figures 3-30 through 3-33.

Results in Figures 3-30 indicate that all but 1 respondent agrees or strongly agrees with the statement that they tend to slow down while approaching HRIs with active flashing light warning signs, to prepare to stop for the train. In contrast, results in Figures 3-31 indicate that all respondents disagree or strongly disagree with the statement that they tend to speed up while approaching HRIs with active flashing light warning signs, to get across before the train comes.

Results in Figures 3-32 and 3-33 indicate that most respondents agree or strongly agree with the statement that an active flashing light warning sign aids stopping behavior at an HRI, when vehicle speeds are either slow (Fig. 3-32) or fast (Fig. 3-33) in approaching the HRI. There is stronger respondent support for the latter assertion.

PTQ questions Q12, Q24, Q27, Q31, Q34, and Q40 deal with the appeal to respondents of different types and configurations of HRI warning signs. Q12 and Q31 deal with the appeal of passive HRI warning signs; the remainder of these questions deal with the appeal of active HRI warning signs. The distributions of responses to these questions are illustrated in Figures 3-34 through 3-39.

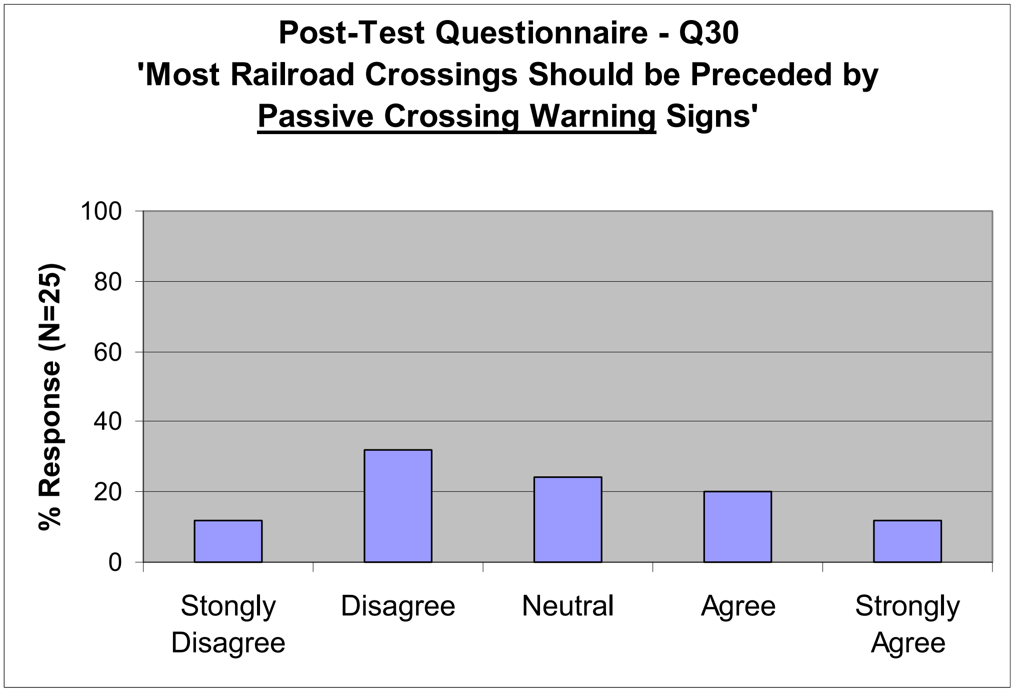


Figure 3-24. Distribution of responses (N=25) to Q30 in PTQ: 'Most Railroad Crossings Should be Preceded by Passive Crossing Warning Signs'

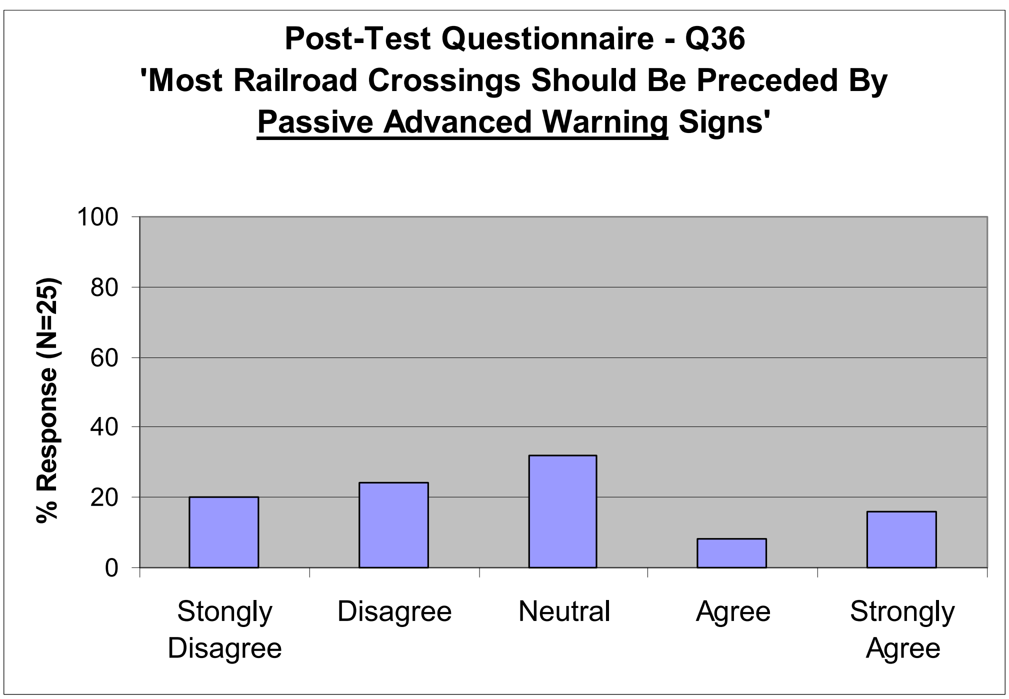


Figure 3-25. Distribution of responses (N=25) to Q36 in PTQ: 'Most Railroad Crossings Should be Preceded by Passive Advanced Warning Signs'

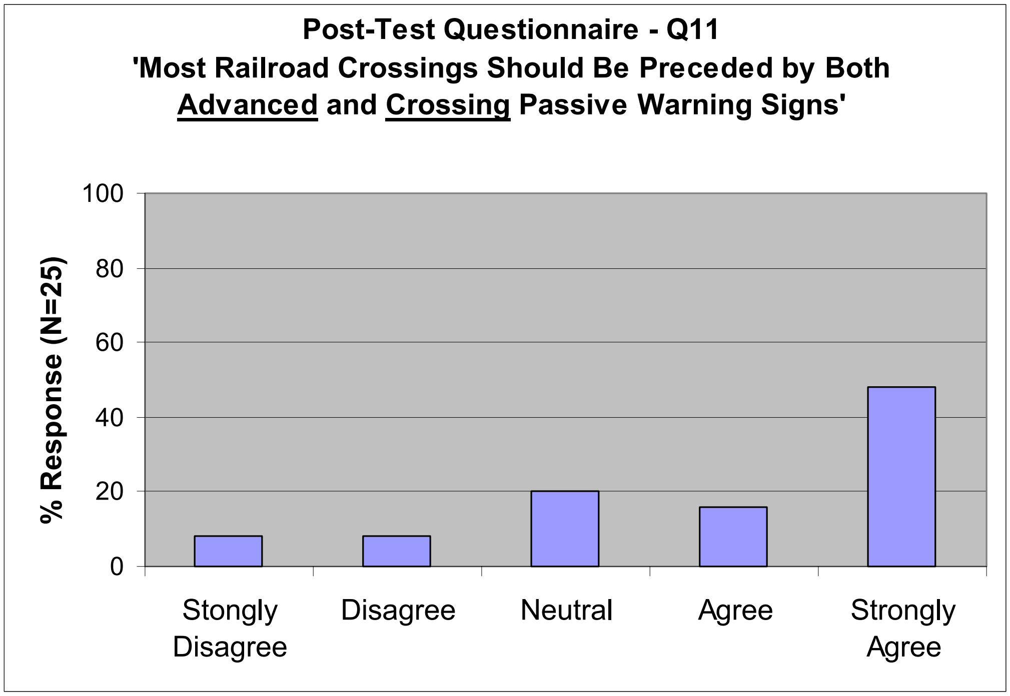


Figure 3-26. Distribution of responses (N=25) to Q11 in PTQ: 'Most Railroad Crossings Should be Preceded by Both Advanced and Crossing Passive Warning Signs'

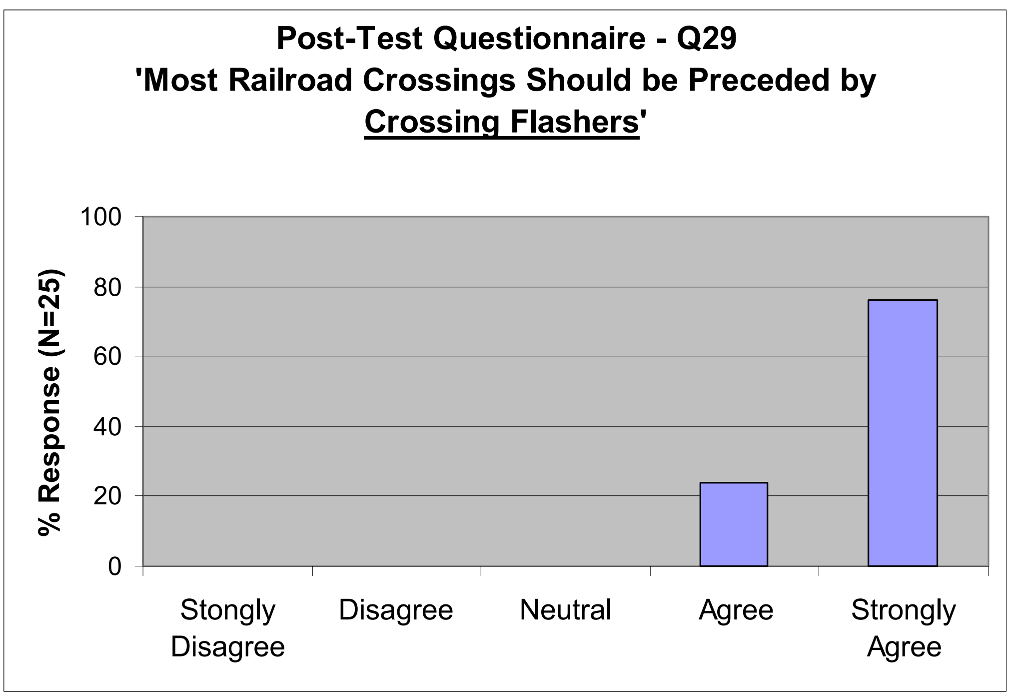


Figure 3-27. Distribution of responses (N=25) to Q29 in PTQ: 'Most Railroad Crossings Should be Preceded by Crossing Flashers'

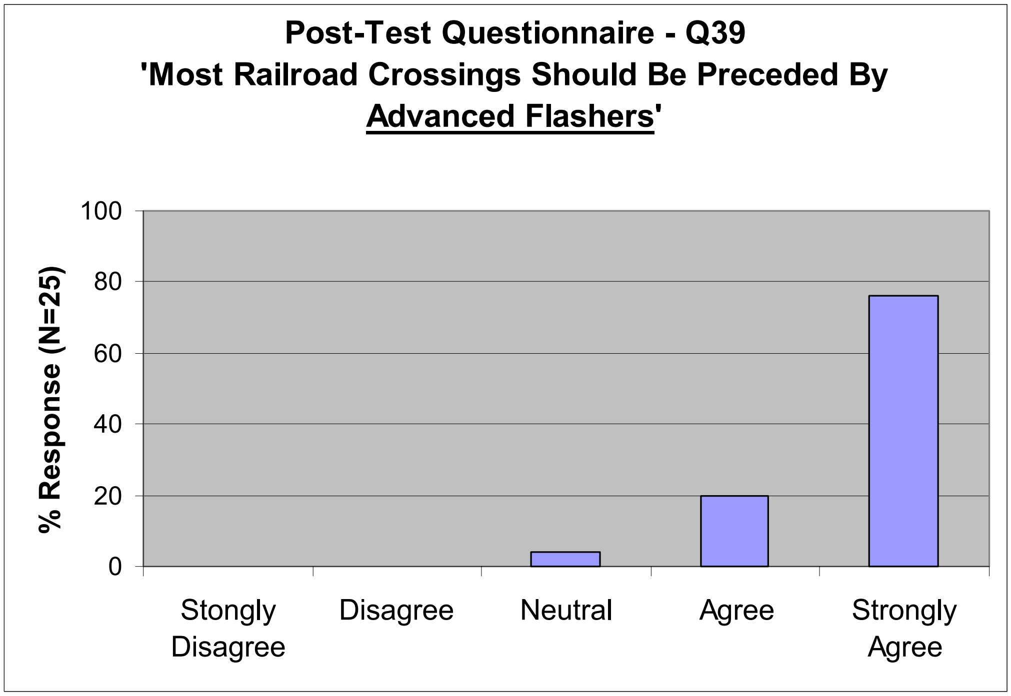


Figure 3-28. Distribution of responses (N=25) to Q39 in PTQ: 'Most Railroad Crossings Should be Preceded by Advanced Flashers'

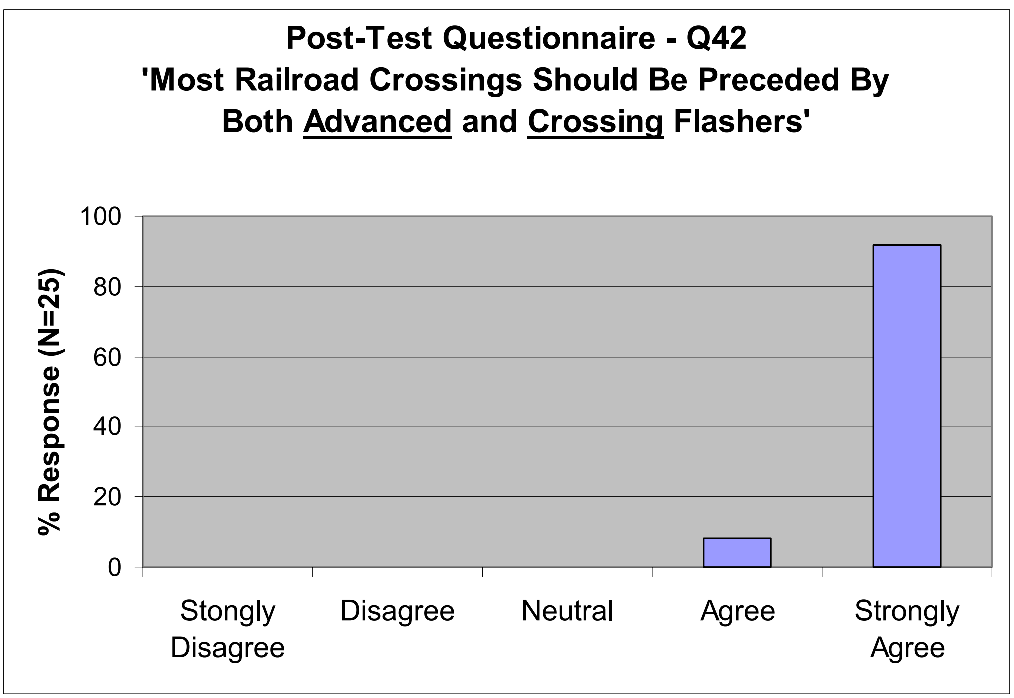


Figure 3-29. Distribution of responses (N=25) to Q42 in PTQ: 'Most Railroad Crossings Should be Preceded by Both Advanced and Crossing Flashers'

Results in Figures 3-34 and 3-35 indicate that the majority of respondents are neutral or disagree with statements that they like either passive Xing crossbuck signs (Fig. 3-34) or passive advance warning signs (Fig. 3-35).

In contrast, results in Figures 3-36 and 3-37 indicate that the majority of respondents are neutral or agree with statements that they like either active Xing flashing red light crossbuck signs (Fig. 3-36) or active advance flashing yellow light warning signs (Fig. 3-37). There is stronger respondent support for the latter assertion.

Results in Figure 3-38 indicate a lack of respondent consensus regarding the statement that they prefer active advance HRI warning signs with flashing lights. In contrast, all respondents are neutral or agree with the statement that they prefer active advance HRI warning signs with flashing words (e.g., a VMS).

The last set of usability results addressed in this subsection deal with whether the warning meaning of an active flashing light HRI warning sign is inherently obvious. PTQ questions Q21 and 41 pertain to this issue. The distributions of responses to these 2 questions are illustrated in Figures 3-40 through 3-41. Results in both figures indicate that, with 1 exception in each case, all respondents agree or strongly agree with the statements that the meanings of either an active Xing flashing red light crossbuck sign (Fig. 3-40), or an active advance flashing yellow light warning sign (Fig. 3-41), are inherently obvious.

Collectively, the HRI warning sign usability results presented above indicate that active advance warning signs and active Xing crossbuck signs are perceived by respondents to be more usable than passive advance warning signs and passive Xing crossbuck signs when it comes to: (1) serving as aids to warning of and stopping for a train (Figs 3-16 through 3-23); (2) being the preferred HRI warning sign design (Figs. 3-24 through 3-29, and 3-34 through 3-39); (3) aiding vehicle speed control and stopping behavior in approaching an HRI (Figs. 3-30 through 3-33); and (4) having an inherently obvious warning meaning (Figs. 3-40 and 3-41).

3.4.2. Responses to PTQ Questions Regarding Conspicuity of HRI Warning Signs

A total of 10 questions on the PTQ pertain to the conspicuity (i.e., noticeability) of different types and configurations of HRI warning signs: Q7, Q10, Q16, Q18, Q22, Q23, Q28, Q32, Q35, and Q37. These questions solicit the degree of respondent agreement or disagreement with statements pertaining to the conspicuity of different types of HRI warning signs. Eight of these questions ask respondents whether they noticed, or did not pay attention to, passive or active advance warning signs and Xing crossbuck signs. Two questions ask respondents whether an active advance flashing yellow light or VMS warning sign is more noticeable. The distributions of responses to these questions are illustrated in Figures 3-42 through 3-51.

PTQ questions Q22, Q35, Q18, and Q23 query respondents as to whether they noticed, or did not pay attention to, passive signage located at the Xing (Q22 and Q35) or in advance of the HRI (Q18 and Q23). Results are in Figures 3-42 through 3-45. All but 1 respondents are neutral or agree with the statement that they noticed the passive Xing crossbuck sign while driving (Fig. 3-42), but there is lack of respondent consensus regarding the statement that they did not pay much attention to this sign (Fig. 3-43).

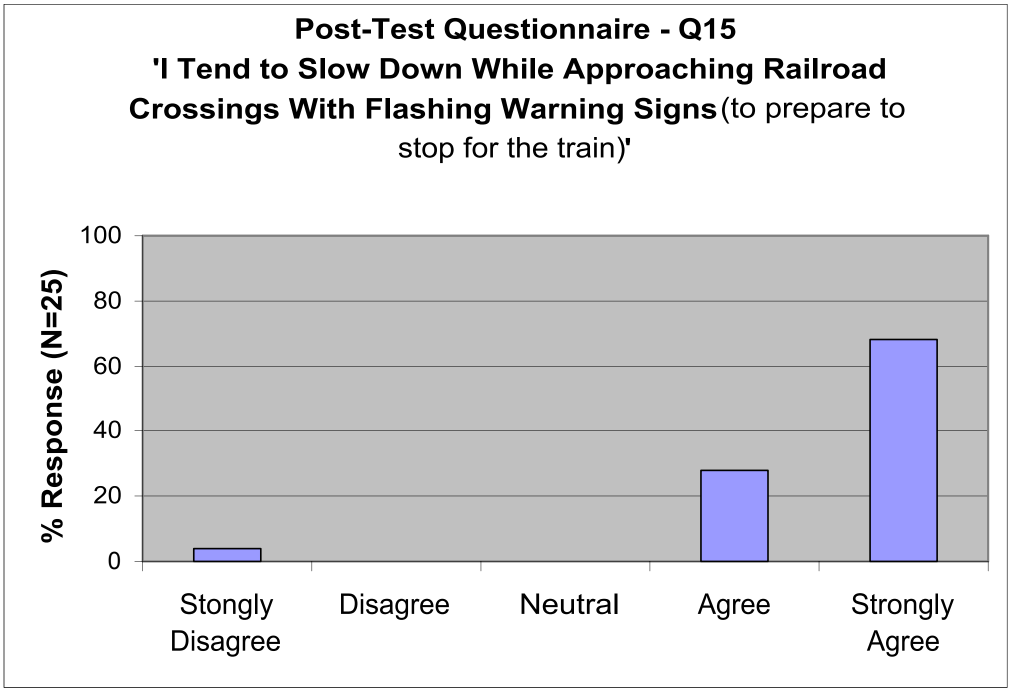


Figure 3-30. Distribution of responses (N=25) to Q15 in PTQ: ‘I Tend to Slow Down While Approaching Railroad Crossing With Flashing Warning Signs (to prepare to stop for the train)’

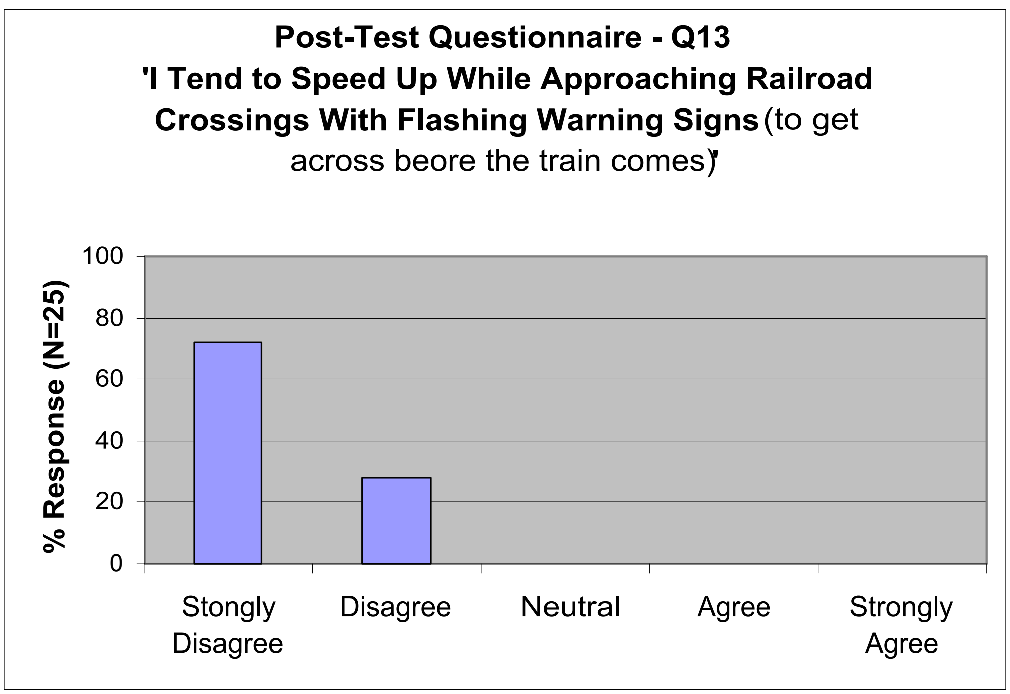


Figure 3-31. Distribution of responses (N=25) to Q13 in PTQ: ‘I Tend to Speed Up While Approaching Railroad Crossing With Flashing Warning Signs (to get across before train comes)’

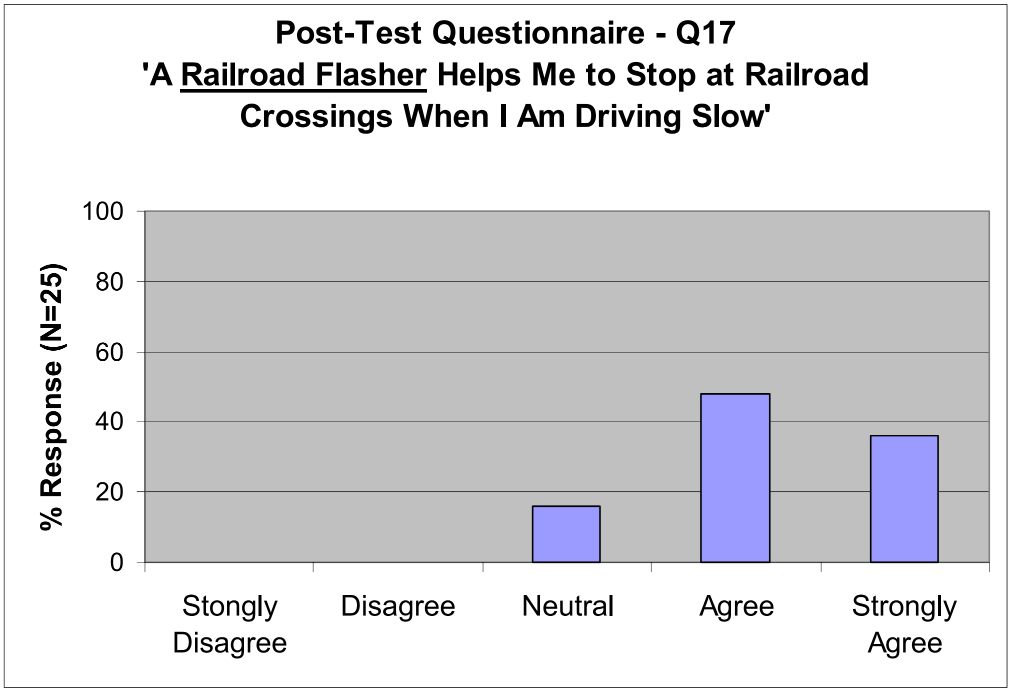


Figure 3-32. Distribution of responses (N=25) to Q17 in PTQ: 'A Railroad Flasher Helps Me to Stop at Railroad Crossings When I Am Driving Slow'

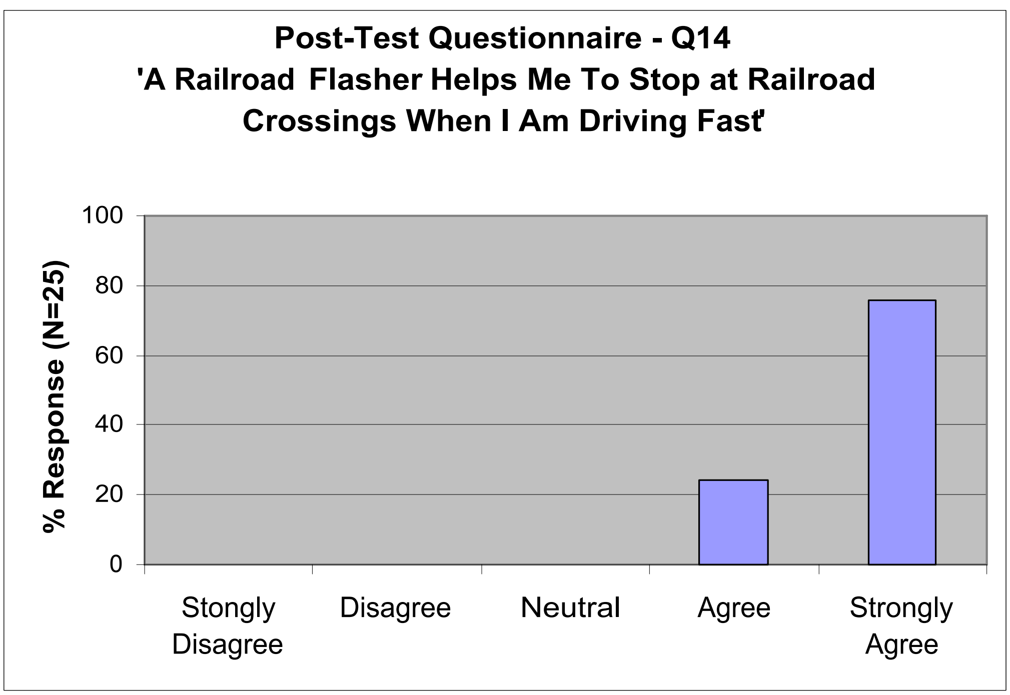


Figure 3-33. Distribution of responses (N=25) to Q14 in PTQ: 'A Railroad Flasher Helps Me to Stop at Railroad Crossings When I Am Driving Fast'

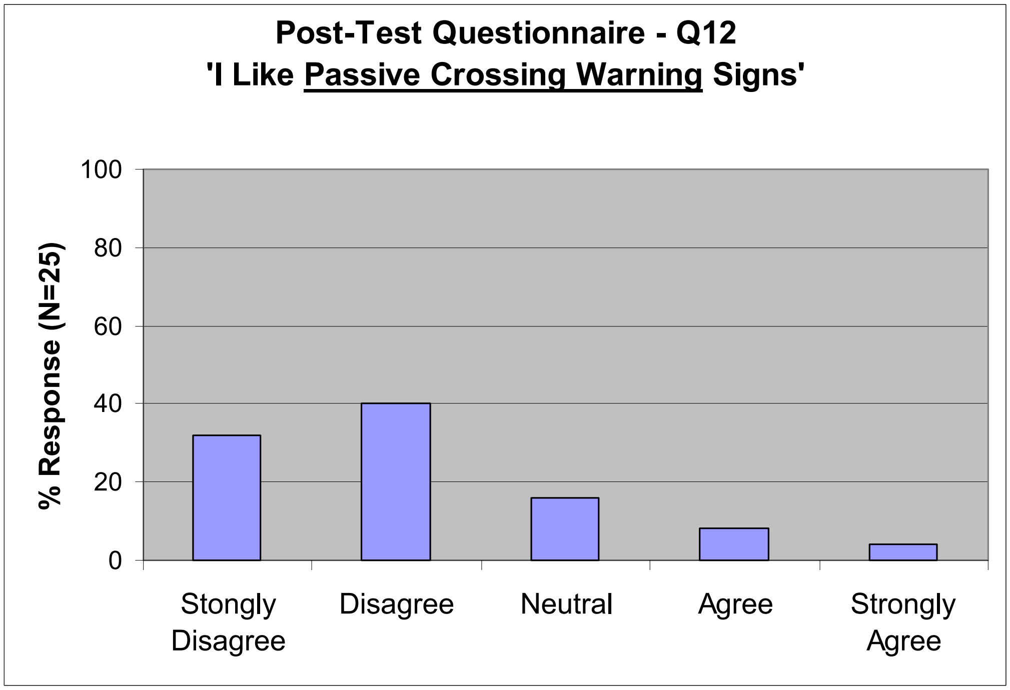


Figure 3-34. Distribution of responses (N=25) to Q12 in PTQ: 'I Like Passive Crossing Warning Signs'

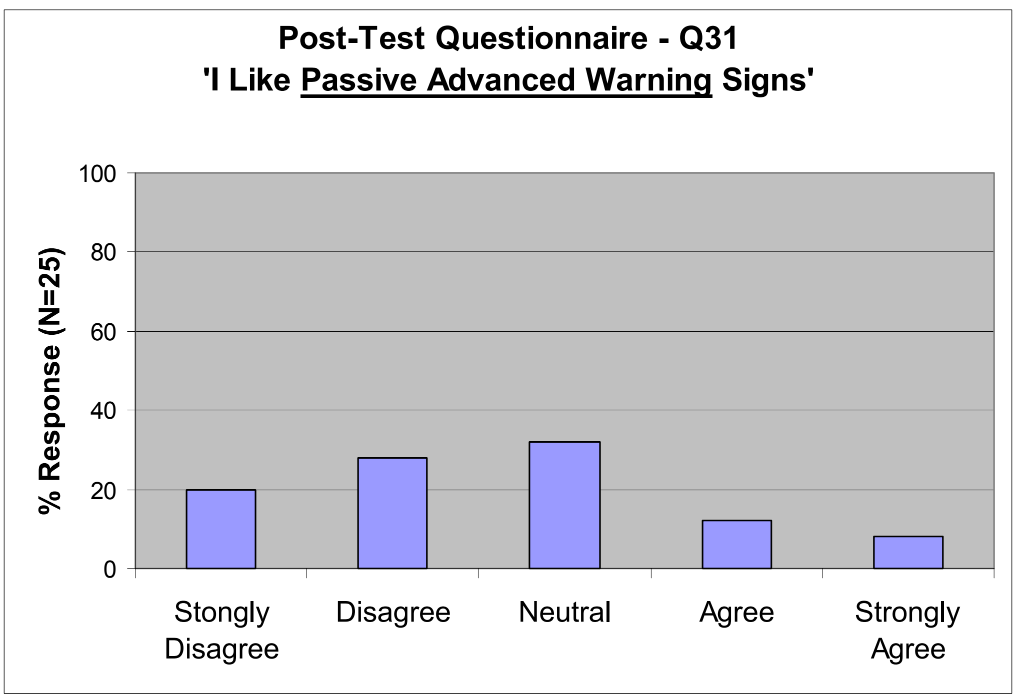


Figure 3-35. Distribution of responses (N=25) to Q31 in PTQ: 'I Like Passive Advanced Warning Signs'

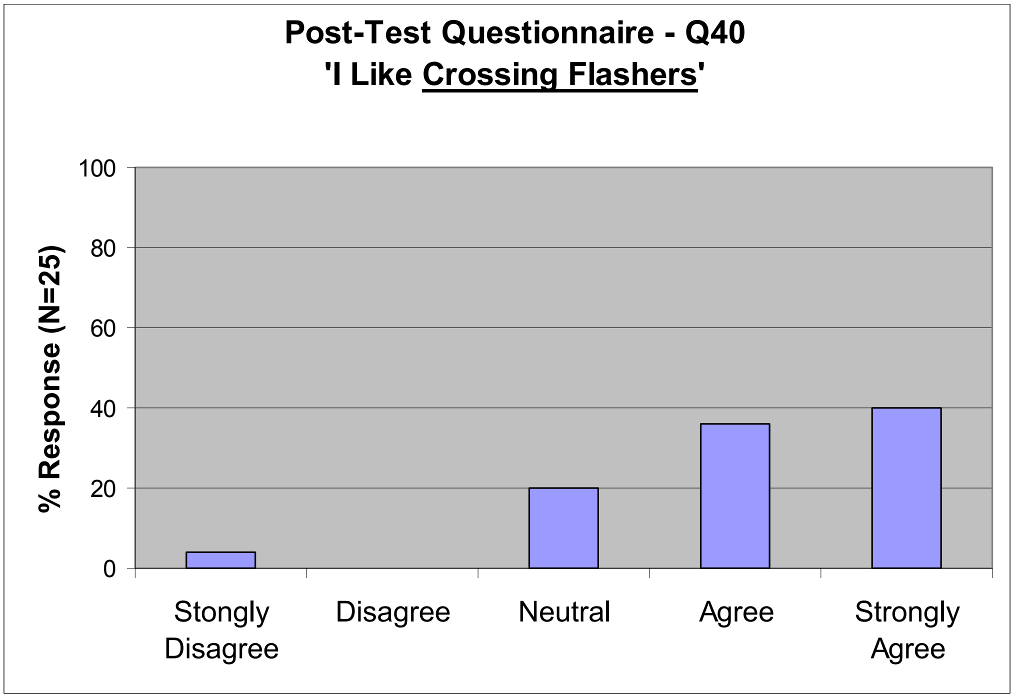


Figure 3-36. Distribution of responses (N=25) to Q40 in PTQ: 'I Like Crossing Flashers'

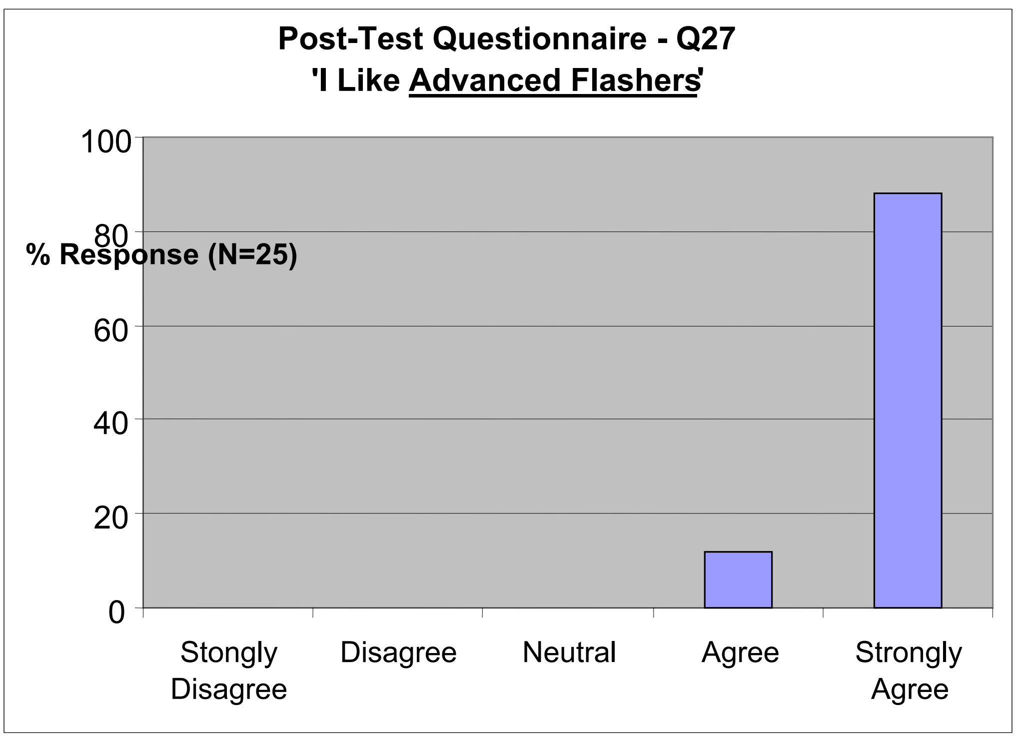


Figure 3-37. Distribution of responses (N=25) to Q27 in PTQ: 'I Like Advanced Flashers'

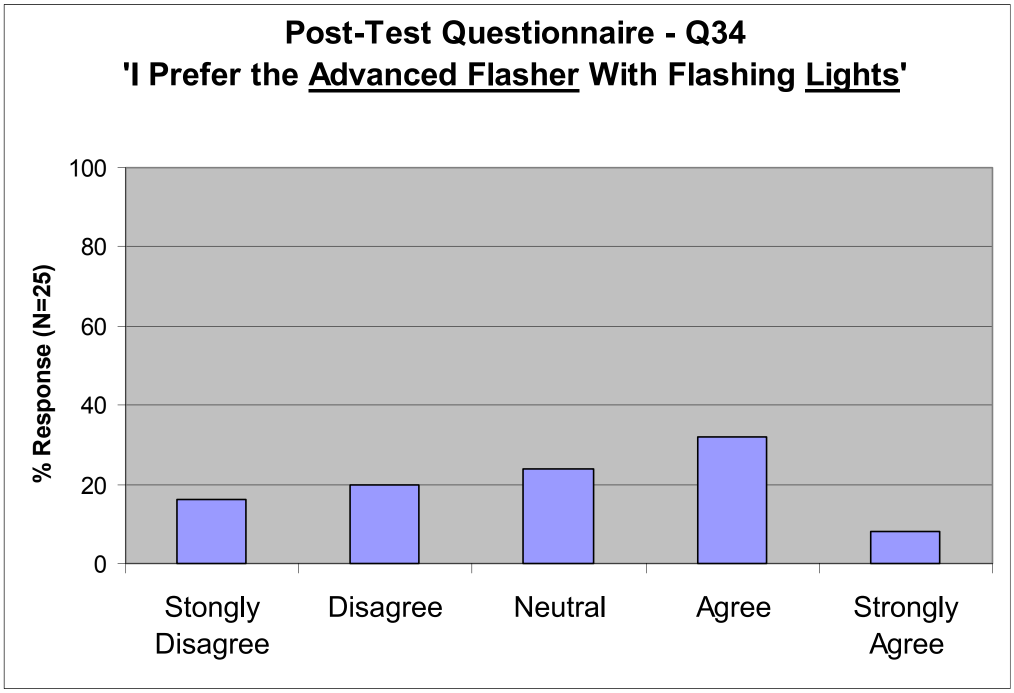


Figure 3-38. Distribution of responses (N=25) to Q34 in PTQ: 'I Prefer the Advanced Flasher With Flashing Lights'

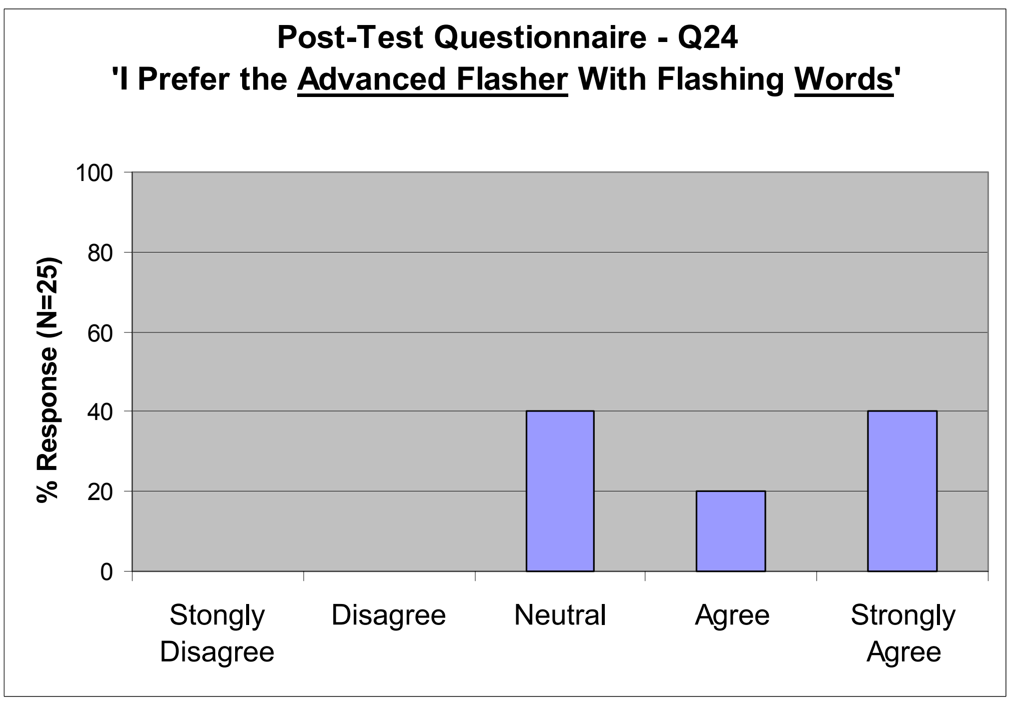


Figure 3-39. Distribution of responses (N=25) to Q24 in PTQ: 'I Prefer the Advanced Flasher With Flashing Words'

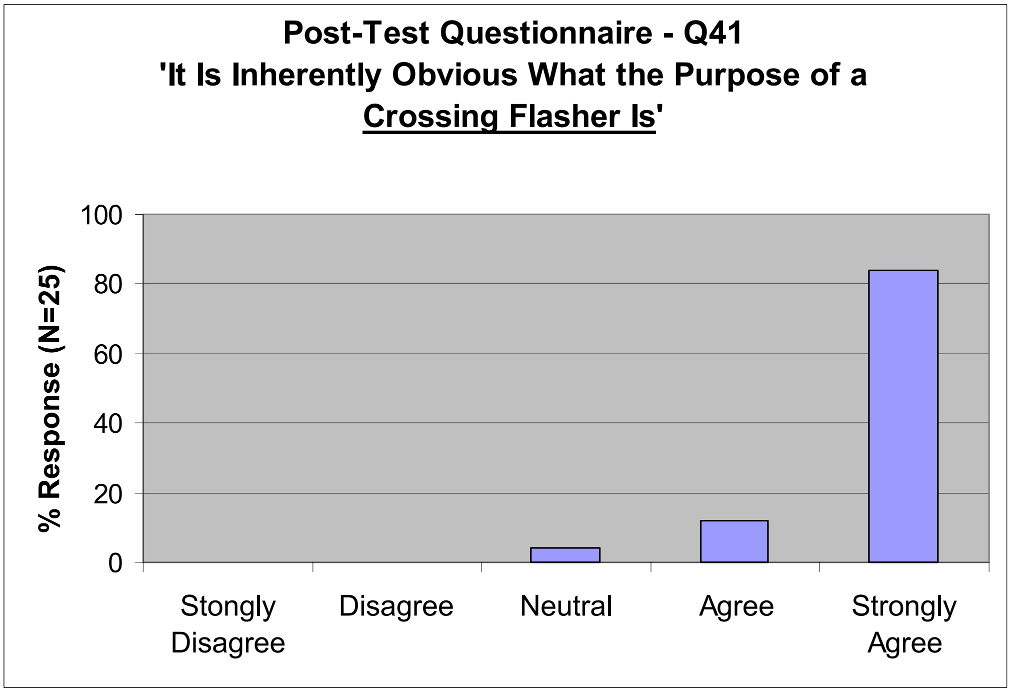


Figure 3-40. Distribution of responses (N=25) to Q41 in PTQ: 'It is Inherently Obvious What the Purpose of a Crossing Flasher Is'

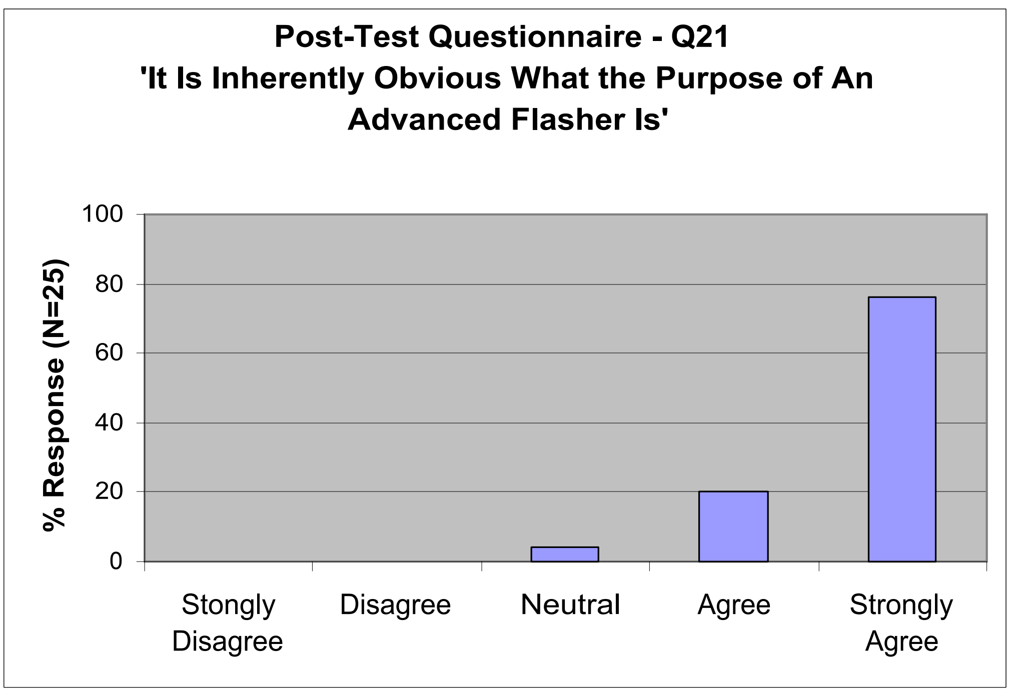


Figure 3-41. Distribution of responses (N=25) to Q21 in PTQ: 'It is Inherently Obvious What the Purpose of an Advanced Flasher Is'

A comparable pattern of responses is observed for questions regarding the conspicuity of the passive advance warning sign. Specifically, all but 2 respondents are neutral or agree with the statement that they noticed the passive advance warning sign while driving (Fig. 3-44), but there is lack of respondent consensus regarding the statement that they did not pay much attention to this sign (Fig. 3-45).

PTQ questions Q7, Q10, Q16, and Q32 query respondents as to whether they noticed or did not pay attention to active flashing light signage located at the Xing (Q7 and Q10) or in advance of the HRI (Q16 and Q32). Results are in Figures 3-46 through 3-49. All but 1 respondents agree or strongly agree with the statement that they noticed the active Xing flashing red light crossbuck sign while driving (Fig. 3-46). In contrast, all but 1 respondents are neutral or disagree with the statement that they did not pay much attention to this sign (Fig. 3-47).

Responses regarding the conspicuity of the active advance warning sign are notably pronounced. The preponderance of respondents strongly agree with the statement that they noticed the active advance warning sign while driving (Fig. 3-48). In contrast, the preponderance of respondents strongly disagree with the statement that they did not pay much attention to this sign (Fig. 3-49).

PTQ questions Q37 and Q28 query respondents as to whether flashing yellow lights or flashing words (e.g., VMS) are more noticeable on the active advance warning sign. Results are in Figures 3-50 and 3-51. There is lack of respondent consensus regarding the question of whether flashing yellow lights are more noticeable than flashing words on an advance warning sign (Fig. 3-50), with the highest percentage of respondents favoring a neutral position on this question. In contrast, there is a stronger degree of respondent agreement with the statement that flashing words are more noticeable than flashing yellow lights on an advance warning sign (Fig. 3-51), with the highest percentage of respondents strongly agreeing with this statement.

Collectively, results in Figures 3-42 through 3-49 indicate that active HRI warning signs are more noticeable, and attract more attention, than passive HRI warning signs at either the Xing or in advance of the HRI. The conspicuity of active advance HRI warning signs attracts the strongest positive responses. Results also indicate that flashing words are considered more conspicuous than flashing lights on an active advance HRI warning sign.

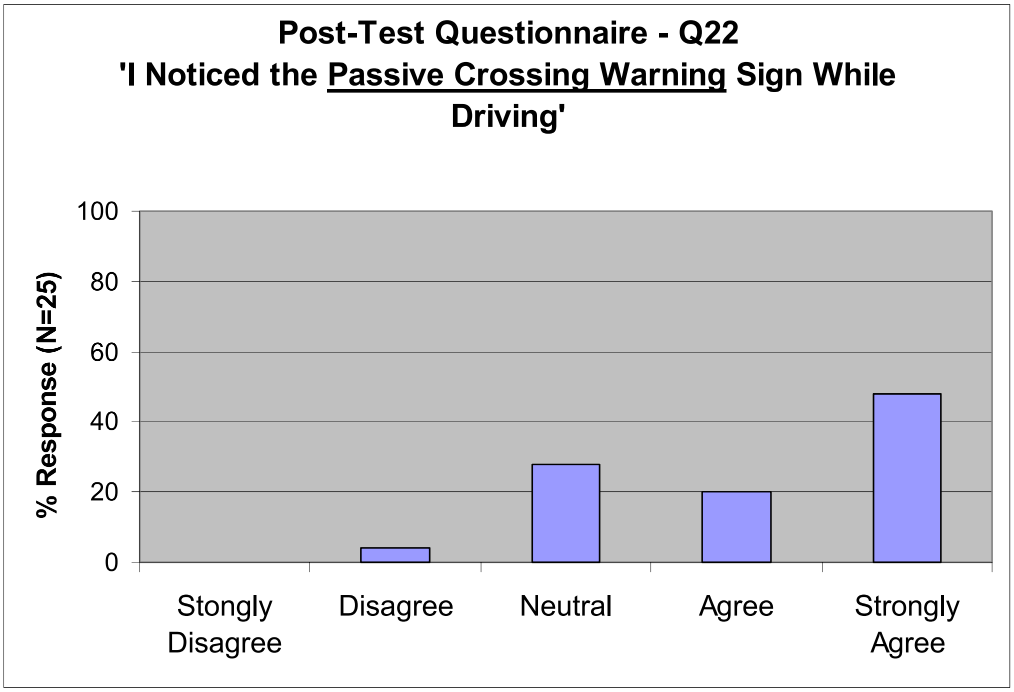


Figure 3-42. Distribution of responses (N=25) to Q22 in PTQ: 'I Noticed the Passive Crossing Warning Sign While Driving'

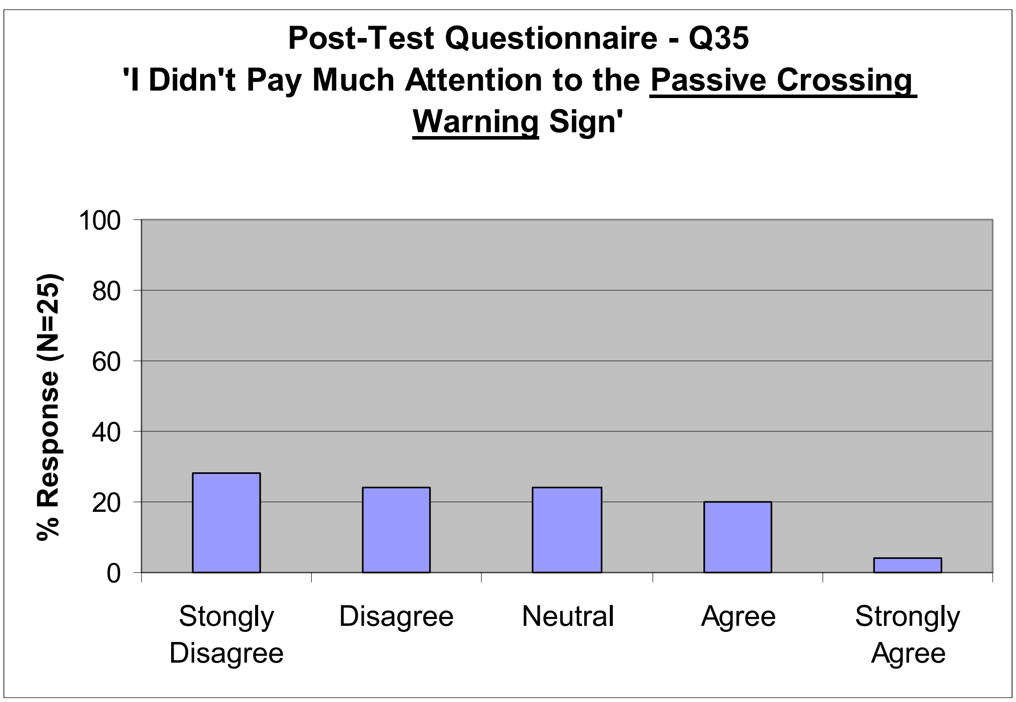


Figure 3-43. Distribution of responses (N=25) to Q35 in PTQ: 'I Didn't Pay Much Attention to the Passive Crossing Warning Sign'

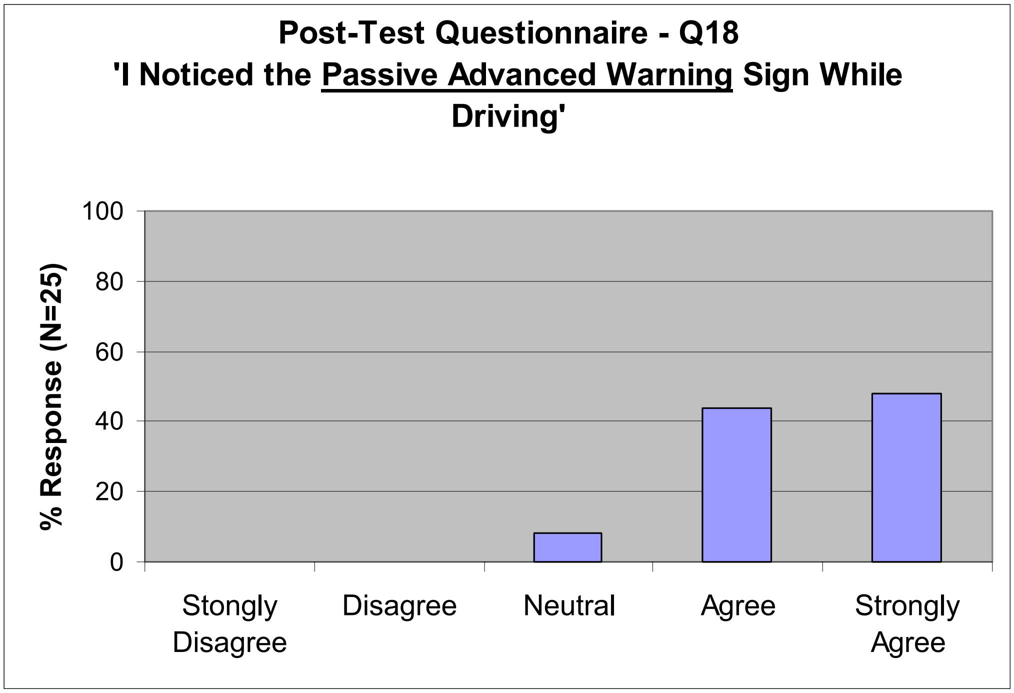


Figure 3-44. Distribution of responses (N=25) to Q18 in PTQ: 'I Noticed the Passive Advanced Warning Sign While Driving'

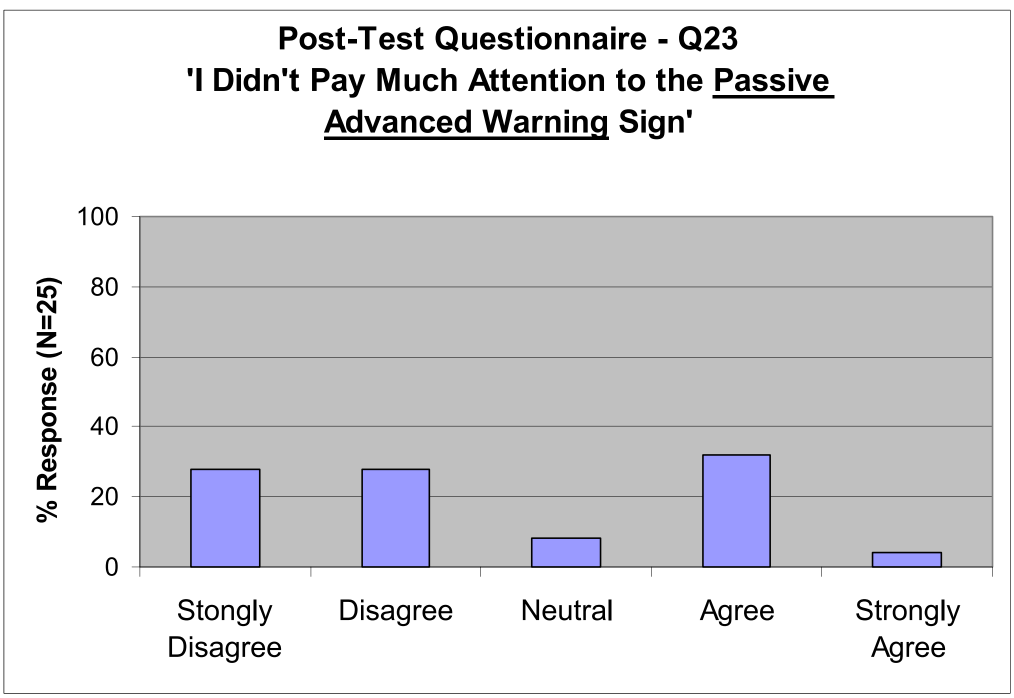


Figure 3-45. Distribution of responses (N=25) to Q23 in PTQ: 'I Didn't Pay Much Attention to the Passive Advanced Warning Sign'

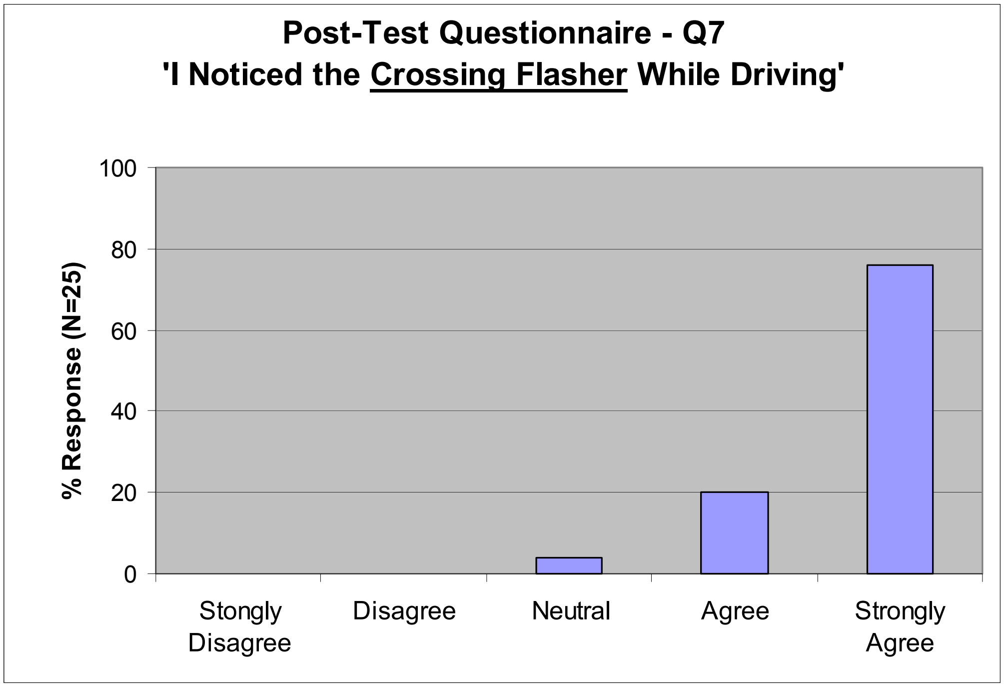


Figure 3-46. Distribution of responses (N=25) to Q7 in PTQ: 'I Noticed the Crossing Flasher While Driving'

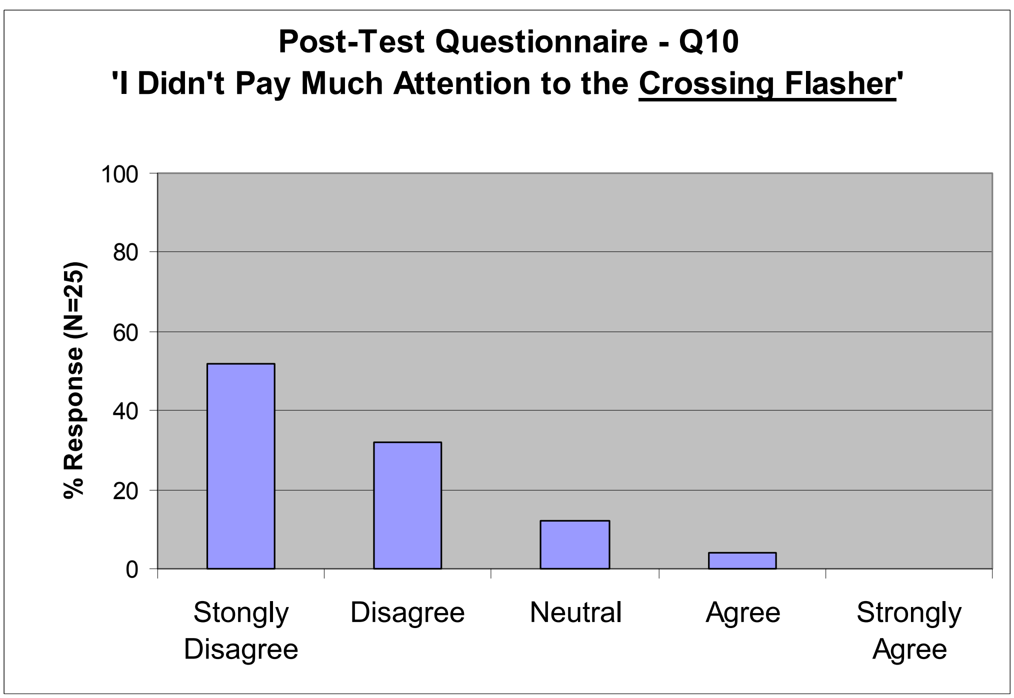


Figure 3-47. Distribution of responses (N=25) to Q10 in PTQ: 'I Didn't Pay Much Attention to the Crossing Flasher'

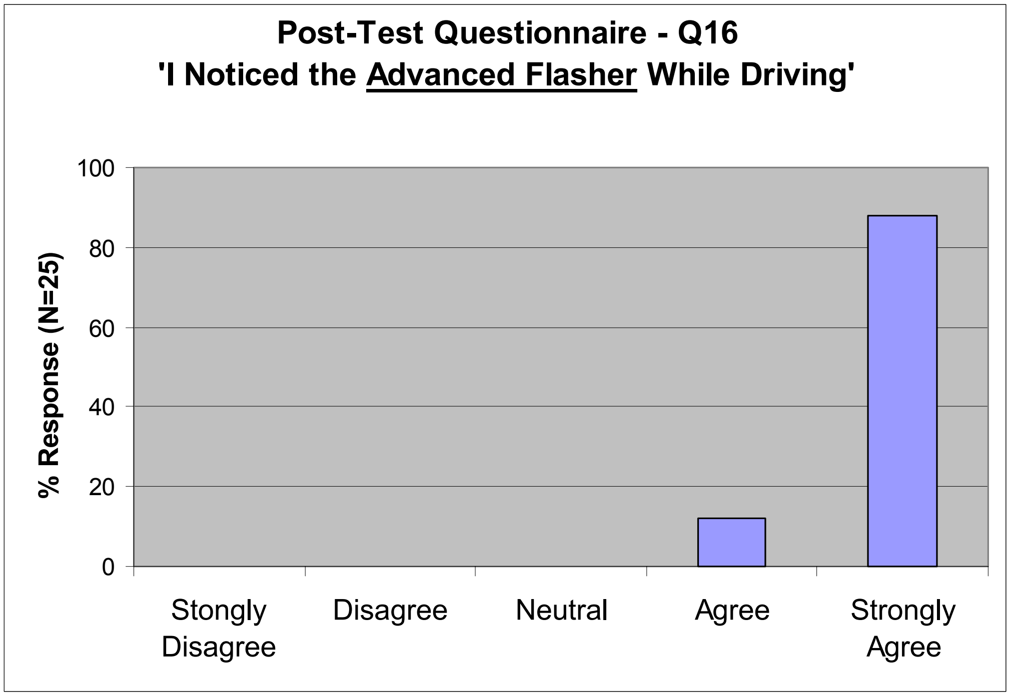


Figure 3-48. Distribution of responses (N=25) to Q16 in PTQ: 'I Noticed the Advanced Flasher While Driving'

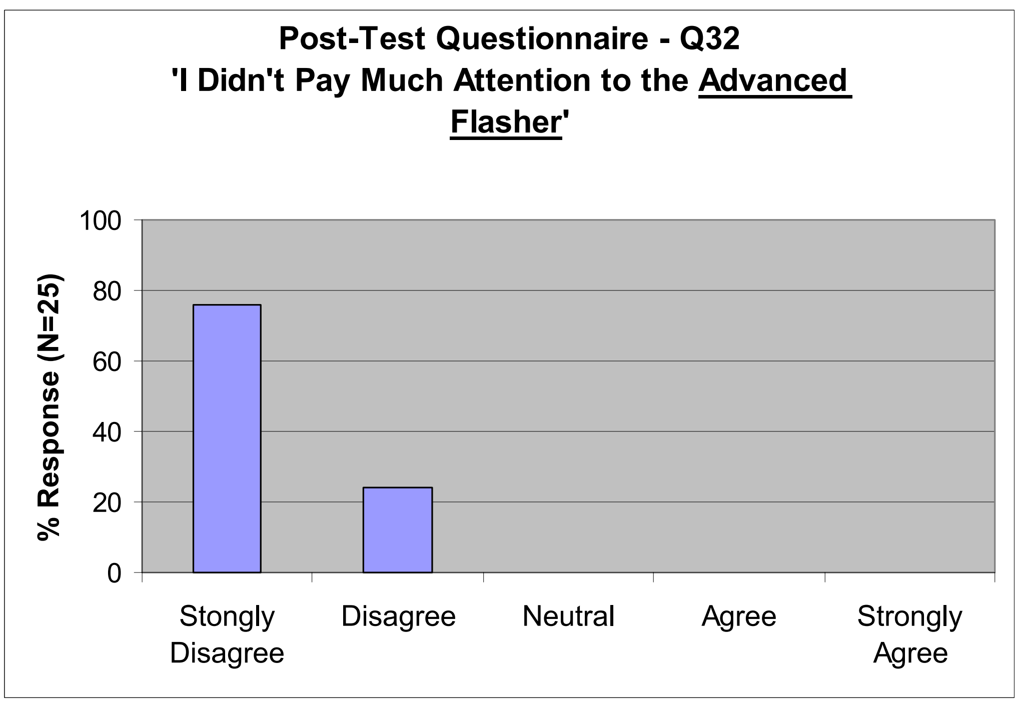


Figure 3-49. Distribution of responses (N=25) to Q32 in PTQ: 'I Didn't Pay Much Attention to the Advanced Flasher'

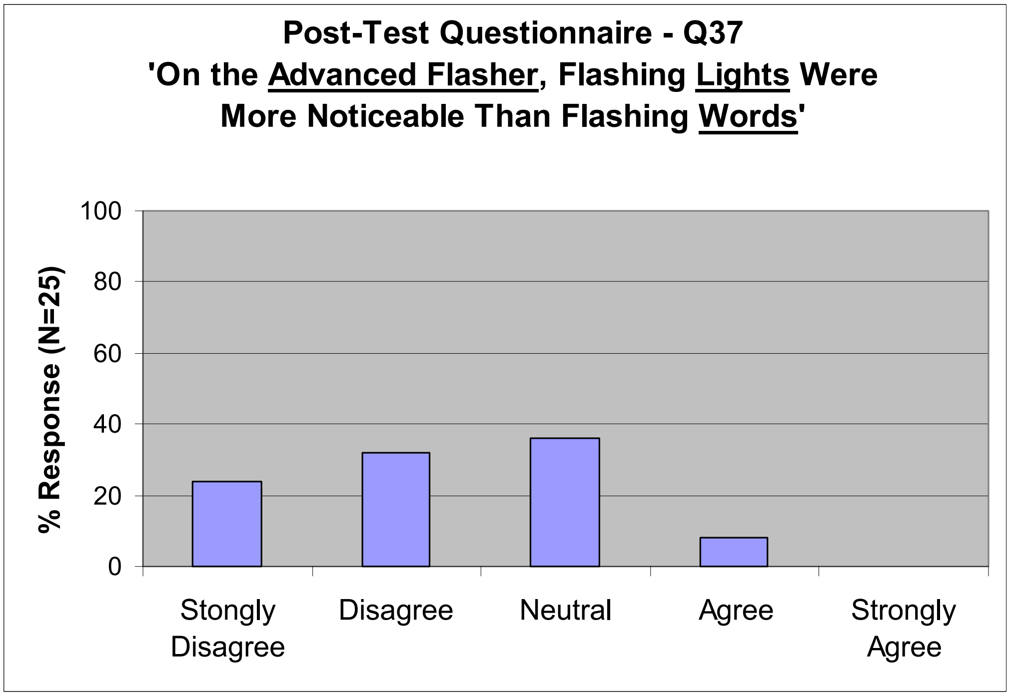


Figure 3-50. Distribution of responses (N=25) to Q37 in PTQ: 'On the Advanced Flasher, Flashing Lights Were More Noticeable Than Flashing Words'

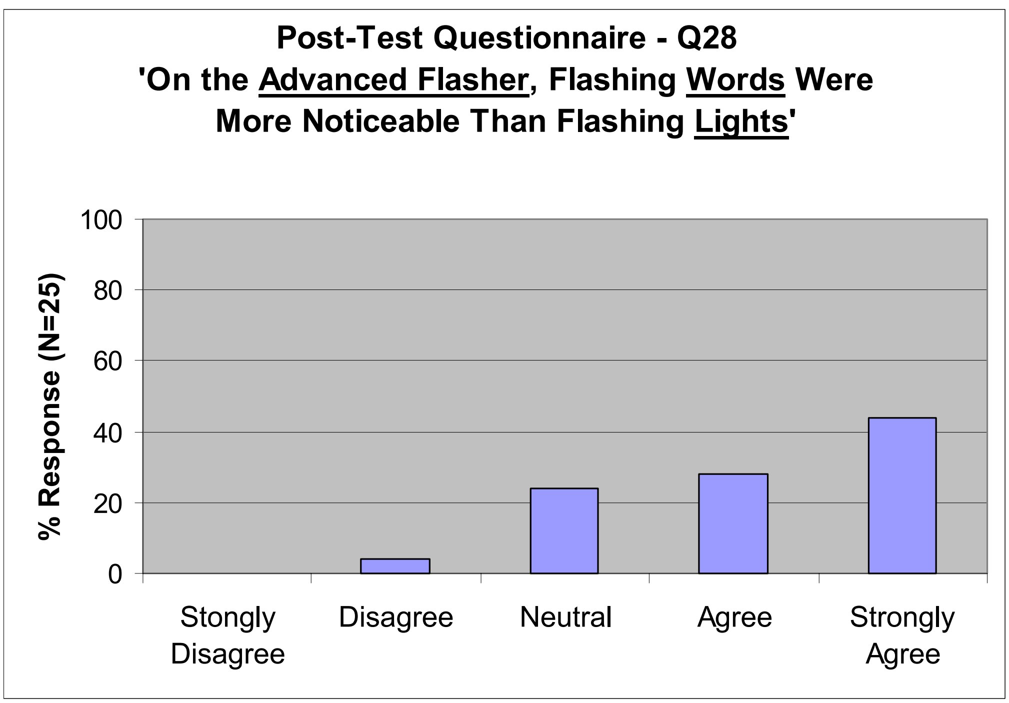


Figure 3-51. Distribution of responses (N=25) to Q28 in PTQ: 'On the Advanced Flasher, Flashing Words Were More Noticeable Than Flashing Lights'

3.4.3. Responses to PTQ Questions Regarding Driving Behavior in Approaching HRIs

Questions 43 through 46 on the PTQ present respondents with a series of options regarding driving behavior that should be adopted (Questions 43 and 44), or driving behavior that the respondent actually tends to adopt (questions 45 and 46), in approaching an HRI with a passive or active Xing crossbuck sign, with a train present. The distribution of responses to these questions are presented in Figures 52 through 55.

Results from PTQ question 43 regarding respondent understanding of driving behavior that should be adopted in approaching an HRI with an active Xing flashing red light crossbuck sign, with a train present or absent, are shown in Figure 3-52. The most prevalent responses are associated with the most appropriate behaviors: (1) slowing before crossing tracks, whether or not the active Xing crossbuck sign is flashing; or (2) stopping at Xing if the active Xing crossbuck sign is flashing, and waiting until train passes before crossing tracks. However, from just under 20 to just over 40 percent of respondents favor 3 options advocating somewhat more risky behavior, namely: (1) proceeding through Xing at normal speed if the active Xing crossbuck sign is not flashing; (2) stopping at Xing if the active Xing crossbuck sign is flashing, then crossing tracks if train is not visible; or (3) slowing at Xing if the active Xing crossbuck sign is flashing, then crossing tracks if train is not visible.

Results from PTQ question 44 regarding respondent understanding of driving behavior that should be adopted in approaching an HRI with a passive Xing crossbuck sign, with a train present or absent, are shown in Figure 3-53. As with responses for HRIs with an active Xing crossbuck sign, the most prevalent responses are associated with the 2 most appropriate behaviors: (1) slowing before crossing tracks, even if no train is visible; or (2) stopping at Xing if train is visible, and waiting until train passes before crossing tracks. Almost 30 percent of respondents favor a highly risk aversive behavior, namely actually stopping at the Xing even if a train is not visible, then crossing the tracks. However, almost 25 percent of respondents favor an option involving somewhat more risky behavior, namely proceeding through the Xing at normal speed if a train is not visible.

Figures 3-54 and 3-55 present results for PTQ questions 45 and 46 regarding driving behaviors that respondents would actually tend to adopt in approaching an HRI with either an active (Fig. 3-54) or a passive (Fig. 3-55) Xing crossbuck sign. The pattern of responses for these 2 questions essentially parallel those for responses to PTQ questions 43 and 44 (Figs. 3-52 and 3-53), respectively.

3.4.4. Open Respondent Comments about Study

PTQ question 47 invites respondents to enter any open comments they may have about their experiences with the study. Table 3-4 lists open comments registered by selected respondents. Comments 2, 4, 5, and 7 explicitly point to advantages of, or preferences for, active HRI warning signs, as opposed to passive HRI warning signs. Comments 5 and 7 explicitly support active advance active warning signs. Comment 4 favors an advance flashing VMS warning sign over an advance flashing yellow light warning sign.

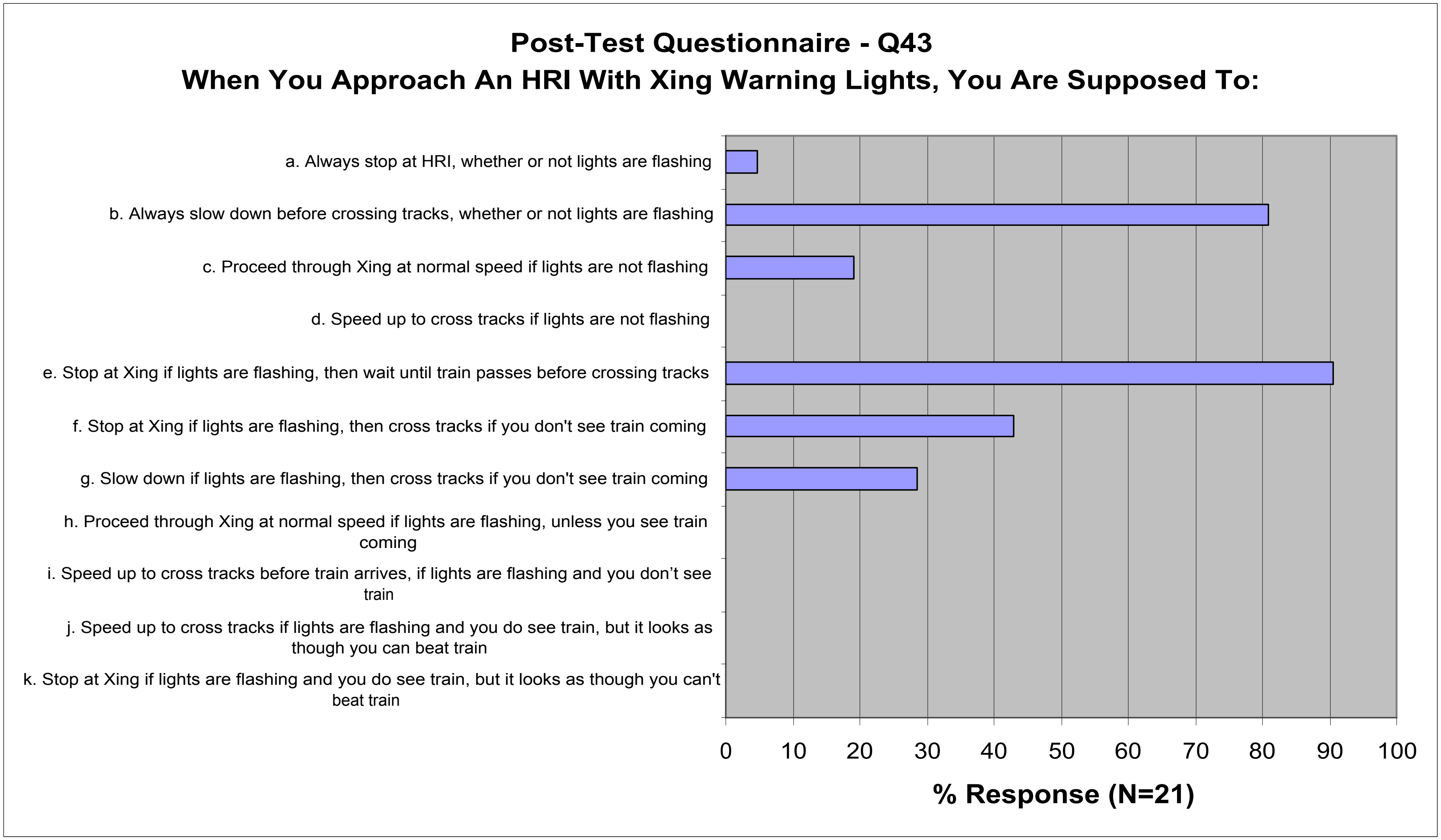


Figure 3-52. Responses to PTQ Q43 regarding driving behavior that should be adopted in approaching an HRI with an active Xing crossbuck sign, with a train present or absent

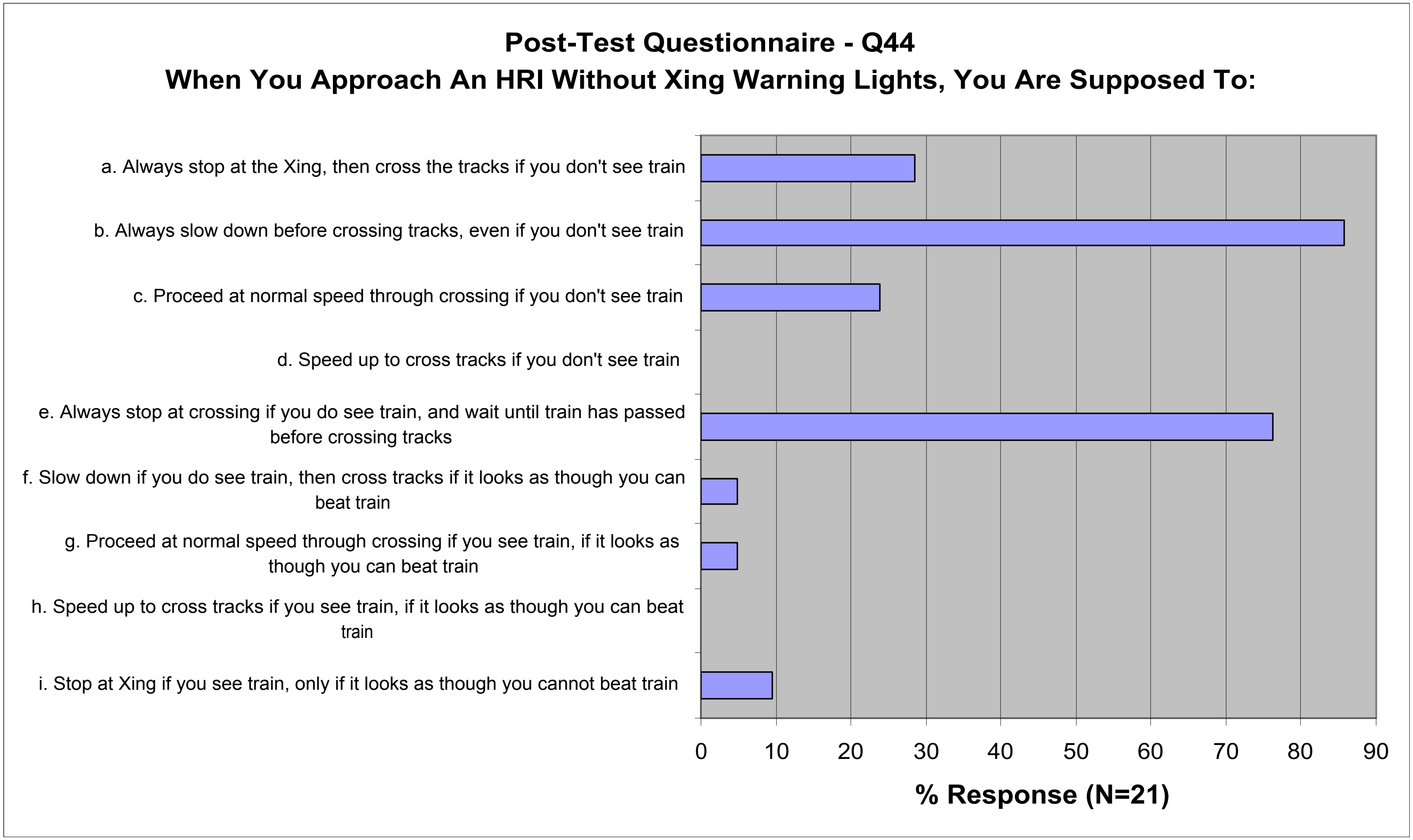


Figure 3-53. Responses to PTQ Q44 regarding driving behavior that should be adopted in approaching an HRI without an active Xing crossbuck sign, with a train present or absent

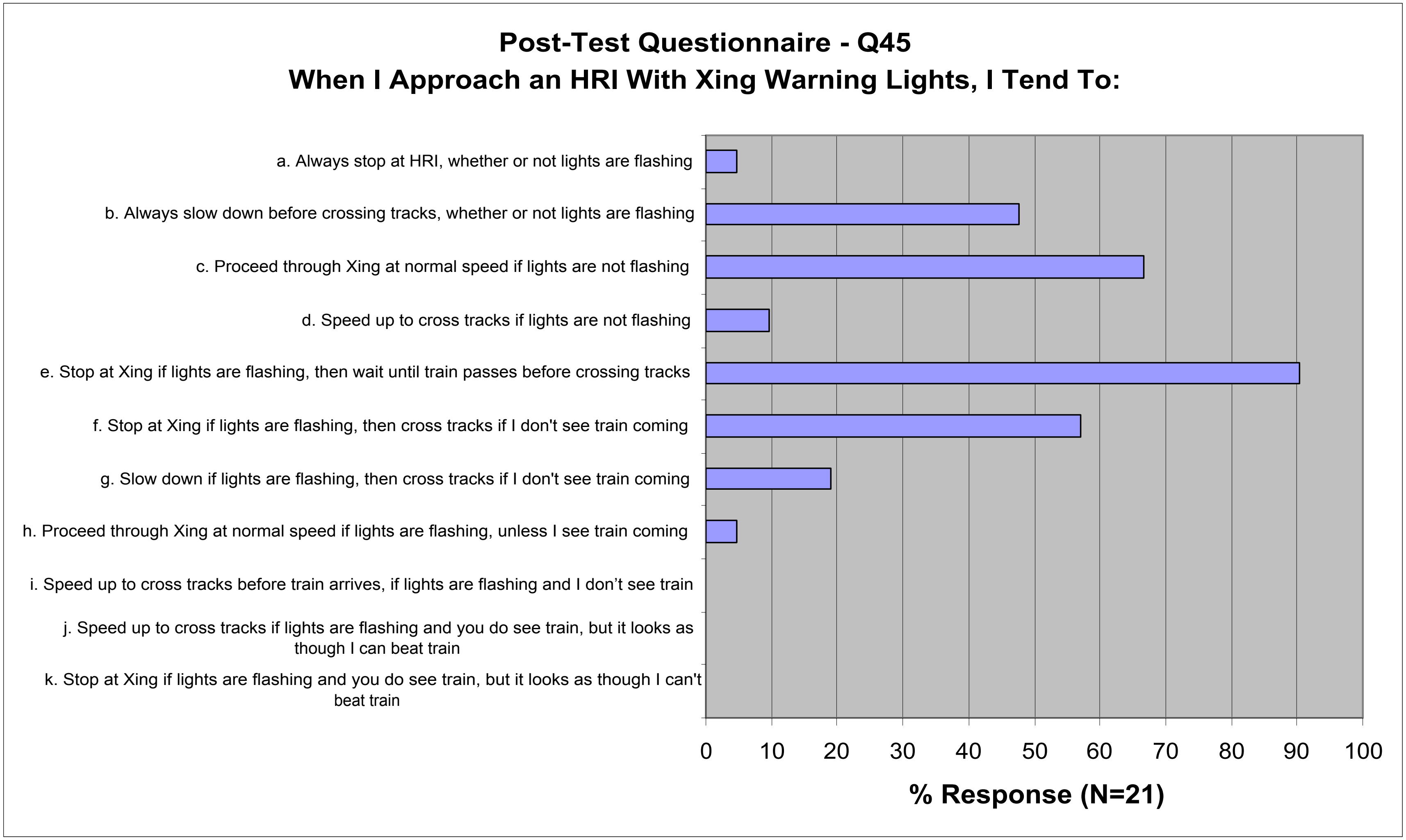


Figure 3-54. Responses to PTQ Q45 regarding driving behavior that respondents actually tend to adopt in approaching an HRI with an active Xing crossbuck sign, with a train present or absent

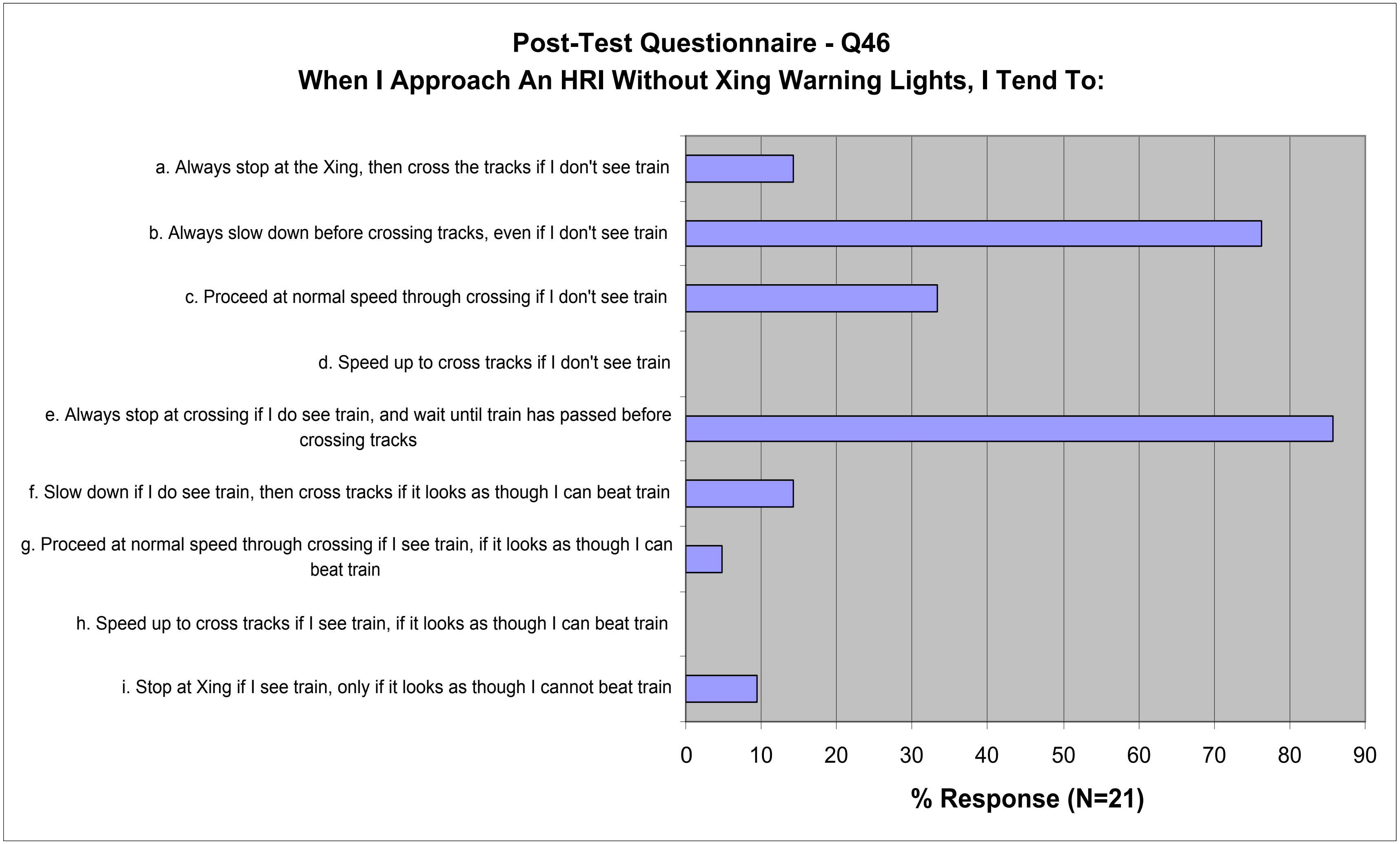


Figure 3-55. Responses to PTQ Q46 regarding driving behavior that respondents actually tend to adopt in approaching an HRI without an active Xing crossbuck sign, with a train present or absent

Table 3-4. Open comments by PTQ respondents regarding their experiences with study

Number	Comment
1	Very well set up. Comfortable environment for subjects.
2	I realize that the [PTQ] answers might be inconsistent with my driving in the simulator. I did slow down although not every time when conditions were foggy and there were no warning lights. Warning lights did encourage me to proceed at normal speed through the crossing, however this may have been in the interest of controlling time as to be closer to the 60 minute target.
3	Other than a few motion sick seconds, I thought the experiment was interesting and worth my time.
4	I think that having passive signs is helpful, but I rather prefer flashing signs both advanced and crossing. Finally, words are more noticeable than lights.
5	Advanced warning signs (excluding passive) are helpful in various weather conditions for increased safety.
6	I thought it was difficult to drive with my hands at the bottom of the steering wheel as I am used to driving with my hands at the top.
7	The advanced word sign & advanced lights were VERY helpful. I think the sign without warning lights is basically useless because it does not provide any useful information.
8	Some times the engine noise got very loud and shook the car which was kind of annoying.
9	It was a good experience, [but] more random obstacles may have kept the driver on their toes a little more.
10	This was a good experiment. I think it was to predictable at times because you could see the branch in the road or the train coming. But it did help to evaluate how one deals with train signals and if people follow them. I was just wondering though what was the point of the tree branch in the road if you were studying the warning lights and how one reacts to the lights.
11	Because of the curvature of the screen, I felt it was more difficult to see the train than it would be in real life.
12	Practice runs were very helpful in adjusting to the steering wheel of the car/computer and the braking. Are you able to incorporate other weather conditions like rain or snow instead of just the fog and sunny conditions?

Chapter 4
Discussion and Conclusions

4.1. Introduction

This report presents results from a simulated driving study involving a human factors evaluation of driver interaction with a low cost active warning system being developed for potential installation at HRIs currently equipped with passive signage. A distinctive feature of the system is that it features both advance and Xing active warnings—the former currently are not used at HRIs. The major objective of the study is to ascertain if, relative to HRIs with passive signage, drivers interact in a more cautious manner with HRIs equipped with active warning system technology.

The study was conducted using the HFRL wrap-around driving simulator with an Acura car and 3 forward projectors. A simulated driving environment was developed for the study, comprising: (1) a 1.05 km (0.65 mi) roadway with a start and end line; (2) an HRI 635.5 m (2084 ft) from the start line; (3) an advance warning sign 293.3 m (962 ft) from the HRI, on the right shoulder; (4) a Xing crossbuck sign 3.7 m (12 ft) from HRI, on the right shoulder; (5) HRI railroad tracks at a right angle to the roadway ; (6) a simulated TC&W train with engine and 16 cars; (7) train emerging from behind trees to right at 150.9 m (495 ft) from HRI, when vehicle is 206.6 m (677.7 ft) from Xing; (8) 40 mph train speed; (9) 55 mph roadway speed limit; (10) at vehicle speed of 55 mph and train speed of 40 mph, arrival times at HRI after train emerges are same (8.4 sec) for vehicle and train; and (11) clear or limited (91.5 m (300 ft), using simulated fog) visibility.

The experimental design comprised: (1) one trial (start to end line) lasts about 1 min; (2) 120 trails/subject (2 60-trial sessions on 2 different days); (3) simulated train encountered in 13.3% of trials; (4) 25 subjects (15 females, 10 males); (5) independent measures are: 4 control/test conditions; train absent/present; visibility clear/fog; (7) 2 control conditions: Control #1—passive advance warning sign/passive Xing crossbuck sign; Control #2—passive advance warning sign/active Xing flashing red lights crossbuck sign; and (8) 2 Test Conditions: Test #1—active advance flashing yellow lights warning sign/active Xing flashing red lights crossbuck sign; Test #2—active advance flashing VMS/active Xing flashing red lights crossbuck sign.

For the experimental protocol, subjects were told: (1) nothing about purpose of study; (2) that they would encounter 'occasional road hazards' (e.g., train or tree); (3) that completion of a session close to target time of 60 min earned monetary bonus (all subjects earned bonus); and (4) the time that had elapsed from the start of the session, every 10 min during the session.

Three approaches were used to collect dependent measures for the study. Visual observations of simulated driving performance documented unsafe driving behavior during driver interaction with the HRI, for trials with a train present. Three objective dependent measures of simulated driving performance---vehicle speed, braking pressure, and vehicle accel/decel—were collected and recorded continuously for each trial, and averaged for following roadway intervals—IntSL-HRI; IntWS-HRI; IntWS-200; Int200-100; and Int100-HRI. A PTQ was used to assess the degree of respondent agreement or disagreement about the usability and conspicuity of different types and configurations of HRI warning signs.

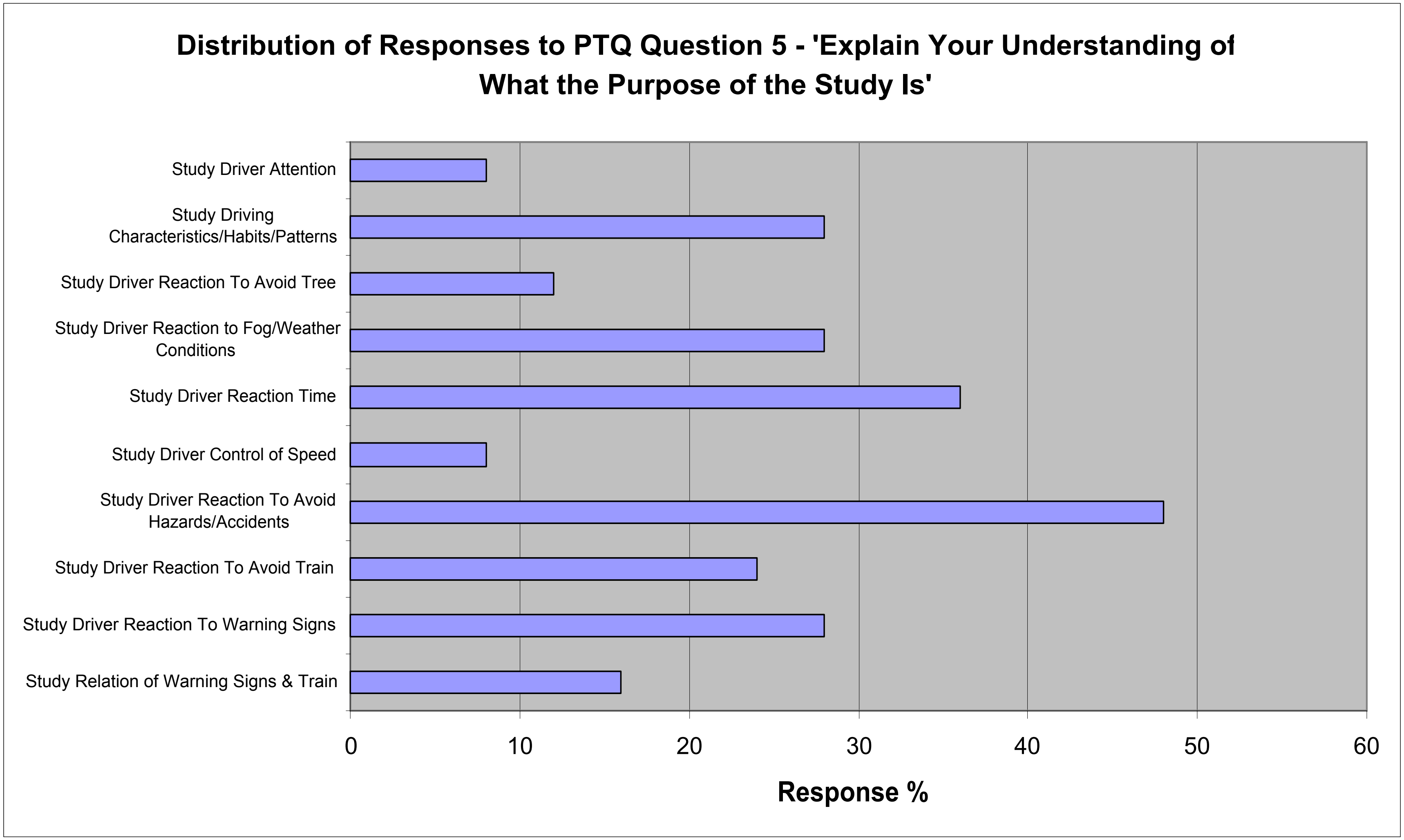


Figure 4-1. Distribution of responses to PTQ Q5 (N=25)—'Explain Your Understanding of What the Purpose of the Study Is'—categorized by type of answer (total percentages exceed 100% because some respondents identified more than one purpose)

One major finding of this study is that, based on visual observations as well as objective dependent measures of simulated driving performance, compared with passive warning signs active warning signs promote safer driver behavior during driver interaction with HRIs. The latter type of signage also is preferred by PTQ respondents. A further major finding is that active advance HRI warning signs are more beneficial to safe driving behavior than active Xing crossbuck signs. Following a discussion of the ecological validity and limitations of the study (next subsection), a series of conclusions that elaborate upon these major findings are presented, following by recommendations supported by these conclusions.

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 major objective of the study is to ascertain if, relative to HRIs with passive signage, drivers interact in a more cautious manner with HRIs equipped with active warning system technology. 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 HRIs 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 simulated driving performance 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. Q5 on the PTQ (Appendix C) asked respondents to explain their understanding of the purpose of the study. They were instructed to complete this question before proceeding to the remaining questions in the questionnaire. Answers registered to this question by each PTQ respondent are listed in Appendix I.

   Figure 4-1 summarizes the distribution of respondent responses to PTQ Q5, categorized by type of answer. Results in the figure indicate a broad range of responses. The most prevalent response specifies that the purpose of the study pertains to avoidance of hazards and accidents. From the perspective of ecological validity, the 2 key observations are that only 16% of respondents identified the relation of warning signs and trains as the focus of the study, and 28% identified driver reaction to warning signs as the purpose of the study. These results suggest that the preponderance of subjects were not aware of the true purpose of the study, and that the results therefore are not likely to have been systematically biased by *a priori* sensitivity by subjects regarding what driving behavior was being evaluated.
2. Under unlimited visibility conditions with passive advance warning signs, during driver interaction with HRIs for train present trials, fewer incidents of unsafe driving behavior are

observed for trials with an active Xing crossbuck signs, compared with trials with a passive Xing crossbuck signs (Fig. 3-3). These findings are aligned with results from previous research [11], summarized in Section 1.2.2, that fewer vehicle-train accidents are observed at HRIs with active Xing flashing red lights crossbuck signs, relative to those with passive Xing crossbuck signs.

3. Ss completed experimental sessions with a mean time close to the target time of 60 min (Figure 3-1). This finding suggests that, on average, subjects attempted to control vehicle speed during simulated driving in compliance with instructions provided (Appendix G).
4. Average vehicle speeds observed under limited visibility (fog) conditions are lower than those observed for unlimited visibility conditions (Fig. 3-4). This finding is in line with expectation and observation that, compared with clear conditions, real world drivers tend to drive more slowly in foggy conditions.
5. During train present trials, average vehicle speeds observed during trials with an active advance flashing yellow lights warning sign are lower than those observed during trials with a passive advance warning sign. This finding is aligned with previous research on active advance warnings at signalized intersections showing that, relative to intersections without such signage, active advance warning of a pending signal change is associated with slower driver speeds approaching the intersection [7].

A number of limitations of the study should be addressed. First, as noted above, observations of driver interaction with HRIs under real-world driving conditions were not made during the study. Therefore, conclusions derived from study results pertaining to how different HRI warning sign types and configurations may influence simulated driving 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.

There are a number of additional limitations to the experimental design based on simulation testing employed for the study. Older subjects were not included in the sample cohort. The small number of subjects evaluated (N=25) limits the generalizability of the results. The experimental design has the primary objective of assessing the main effect of different types and configurations of HRI warning signs on driver interaction with trains at HRIs. Nevertheless, other confounding factors may have contributed to observed variability in the results obtained. For example, subject unfamiliarity and lack of skill with simulated driving, and/or subject anxiety associated with trying to traverse a simulated driving task environment with a 60-min session target time and specified time windows for earning a bonus, also may have contributed to observed individual differences in dependent measures. 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 subjects 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. Pilot training sessions prior to the first (and for some subjects, the second) experimental session were designed to help subjects acclimate to the simulated driving task before actual testing was initiated. The steering delay factor was present for all trials, and the order of task conditions was varied randomly from subject to subject. This design suggests that the delay factor should not have systematically biased any observed main or interactive effect of the independent measures. Nevertheless, the possible confounding influence of delay in visual feedback of steering wheel movements on study results cannot be ruled out.

4.3. Conclusions

Major conclusions supported by findings from the study are summarized below, in relation to visual observations of simulated driving performance, objective measures of simulated driving performance, and the PTQ results.

<u>Conclusions From Visual Observations of Simulated Driving Performance</u>

1. Relative to passive advance warning signs, the presence of active advance warning signs at HRIs (either flashing yellow light or VMS) resulted in fewer vehicle-train accidents and of incidents of 'beating' the train, under both unlimited and limited visibility conditions, and therefore encouraged safer simulated driving behavior among subjects participating in this study during train present trials (Fig. 3-3).
2. With a passive advance warning sign, the presence of an active Xing flashing red lights crossbuck sign resulted in fewer incidents of unsafe simulated driving behavior under unlimited visibility conditions, compared with levels observed with a passive Xing crossbuck sign (Fig. 3-3), during train present trials. The same effect is not observed for limited visibility conditions. This finding suggests that an active Xing crossbuck sign may have limited efficacy in promoting safe driving behavior at HRIs under limited visibility conditions.
3. No differences between active advance flashing yellow lights and active advance VMS warning sign trials are evident, in relation to incidents of unsafe driving behavior observed at HRIs during train present trials, under unlimited or limited visibility conditions (Fig. 3-3).

<u>Conclusions From Objective Measures of Simulated Driving Performance</u>

4. Under unlimited visibility conditions for train present trials, relative to trials with a passive advance warning sign, the following changes are observed in objective dependent measures of simulated driving performance for trials with an active advance flashing yellow lights warning sign: (1) average speeds are lower for all roadway intervals(Fig. 3-5)—these results are recapitulated in post hoc analysis (Table 3-2) and are profiled in Fig. 3-10 for the 3 roadway intervals beyond the advance warning sign; (2) average braking pressure levels are slightly lower for all roadway intervals except the Int200-100 interval (Fig. 3-7); and (3) mixed results for different roadway intervals are observed for average accel/decel levels (Fig. 3-9). With clear visibility therefore, relative to interaction with a passive advance warning sign, interaction with an active advance flashing yellow lights warning sign tends to encourage more cautious driving behavior by subjects approaching an HRI, pending arrival of a train.

5. Across the 3 roadway intervals beyond the advance warning sign, with unlimited visibility, average vehicle braking pressure levels are comparable for all trials with an active Xing flashing red lights crossbuck sign (Fig. 3-12). In contrast, for trials with all passive signage, average vehicle braking pressure levels are substantially higher for the IntWS-200 and the Int100-HRI roadway intervals. The interpretation of these findings offered here is that even with unlimited visibility, the presence of an active HRI warning, either in advance of the HRI or at the Xing or both, encouraged more predictive and therefore more prudent braking behavior on the part of the driver just after the advance warning sign and near the HRI in anticipating that a train would be encountered at the Xing.
6. Across the 3 roadway intervals beyond the advance warning sign, with unlimited visibility, comparable average levels of vehicle deceleration for all 4 warning sign configurations for the IntWS-200 roadway interval are observed (Fig. 3-14). For the next 2 roadway intervals however, contrasting patterns of change in mean vehicle deceleration are observed for trials with a passive advance warning sign, relative to those with an active advance warning sign. With the former configurations, mean vehicle deceleration remains about the same for the IntWS-200 and Int200-100 roadway intervals, and then increases markedly for the Int100-HRI interval. In contrast, for trials with active advance warning signs, mean vehicle deceleration increases markedly for the Int200-100 interval, and then moderates for the Int100-HRI interval. The interpretation of these findings offered here is that the presence of an active advance warning sign enabled more anticipatory deceleration of the vehicle further from the Xing in preparation for arrival of the train, allowing more moderate deceleration behavior when the vehicle approached closer to the Xing.
7. Relative to effects observed for unlimited visibility conditions, comparable differential effects of active versus passive advance warning signs on driving behavior in approaching an HRI, for train present trials, are not observed for limited visibility conditions. Specifically, across all roadway intervals during fog present trials, no consistent effects of active versus passive advance warning signs are observed on mean vehicle speeds and braking pressures (Figs. 3-5 and 3-7), and mixed results are observed for mean vehicle accel/decel (Fig. 3-9). For average speed levels, results in Fig. 3-11 profile these results for the 3 roadway intervals beyond the advance warning sign.
8. For the first 2 roadway intervals beyond the advance warning sign, average braking pressure levels under limited visibility are comparable for all 4 warning sign configurations (Fig. 3-13). For the Int100-HRI interval however, average braking pressure levels for trials with a passive advance warning sign are notably higher than those for trials with an active advance warning sign. The interpretation of these findings offered here is that in the fog, the presence of an active advance HRI warning enabled more predictive, and therefore more prudent, braking behavior by the driver in anticipating that a train would be encountered at the Xing.
9. Across all 4 warning sign configurations, mean vehicle deceleration levels are highest and almost identical for the IntWS-200 roadway interval just beyond the advance warning sign. They then decrease for the Int200-100 interval, with a larger decrease observed for trials with an active advance warning sign, relative to that observed for trials with a passive advance warning sign. For Int100-HRI interval, across all 4 warning sign configurations, mean deceleration levels show little further change relative to levels observed for the Int200-100

interval. The interpretation of these findings offered here is that under limited visibility conditions, the presence of an active advance warning sign enabled anticipatory vehicle deceleration behavior by the driver further from the HRI, in preparation for arrival of the train, whereas higher levels of vehicle deceleration were sustained throughout the Int200-100 and Int100-HRI roadway intervals when advance notice of arrival of the train was not provided.

10. Relative to unlimited visibility conditions for train present trials, with one exception, higher average speeds (Fig. 3-5) and lower average braking pressures (Fig. 3-7) are observed for limited visibility conditions, across all warning sign configurations and roadway intervals. Mixed results for unlimited versus limited visibility conditions are observed for mean accel/decel levels (Fig. 3-9).
11. Why should more aggressive driving behavior occur in the fog during train present trials (Conclusion 10), even with active advance warning of the pending arrival of a train? The interpretation offered here is that in clear conditions, visible emergence of the train with the vehicle just beyond the advance warning sign (Fig. 2-1) enabled subjects to slow well before the Xing, a behavior that was amplified with an active advance flashing yellow lights warning sign. In contrast, in foggy conditions, subjects could not see the train emerge and had no firm idea of the location of the HRI, until they entered the Int100-HRI roadway interval. An appreciable number of subjects either beat or hit the train in foggy conditions, incidents that showed little effect of an active advance flashing yellow lights warning sign (Fig. 3-3). With either type of incident, average speeds would have been sustained throughout all roadway intervals beyond the advance warning sign, contributing in part to results summarized in Conclusions 4-10. The implication of these findings for real world driving conditions is that active advance flashing yellow lights warning signs may have less pronounced effects in limited compared with unlimited visibility conditions, in terms of encouraging cautious driver behavior in interacting with an HRI with an approaching train.
12. Based on pooled results from both train conditions, both visibility conditions, and both Xing crossbuck sign conditions, ANOVA results indicate that the effects of train presence or absence, visibility condition, and Xing crossbuck sign condition all are statistically significant at the $p<.05$ level (Table 3-1). The main effect of the advance warning sign condition is not statistically significant.
13. ANOVA results for interactive effects indicate that the effects of all 3 interactions indicated—train x visibility, visibility x advance warning sign, and visibility x Xing crossbuck sign—are statistically significant at the $p<.05$ level (Table 3-1). All 3 of these significant interactions are explained by the contrasting findings for the 2 visibility conditions with the train absent versus the train present trials, as delineated by the top set of histograms in Figures 3-4 through 3-9.

14. Post hoc analysis of effects on average vehicle speed of different types of advance warning signs, from pooled results for both visibility conditions with the train present trials, indicates that for all 5 roadway intervals, average vehicle speeds for passive advance warning sign trials exceed those for active advance warning sign trials, when the active advance warning sign is either a flashing yellow light or a flashing VMS, and that in every case the difference is statistically significant (Table 3-2). As noted in Conclusion 4, this effect is attributable entirely to lower mean vehicle speeds observed with active relative to passive advance warning sign trials under unlimited visibility conditions, for all 5 roadway intervals (Fig. 3-5).
15. Post hoc analysis of effects of different types of advance warning signs, from pooled results for both visibility conditions with the train present trials, indicates no effects on mean braking pressure, and mixed effects on mean vehicle accel/decel, across the 5 roadway intervals (Table 3-2).
16. Post hoc analysis of effects on average vehicle speed of passive versus active Xing crossbuck signs, from pooled results for both visibility conditions with the train present trials, indicates that for all 5 roadway intervals, average vehicle speeds for passive Xing crossbuck sign trials exceed those for active Xing crossbuck sign trials, and that in every case the difference is statistically significant (Table 3-3). As noted in Conclusion 4, this effect is attributable entirely to lower mean vehicle speeds observed with active relative to passive advance warning sign trials under unlimited visibility conditions, for all 5 roadway intervals (Fig. 3-5).
17. Post hoc analysis of effects of passive versus active Xing crossbuck signs, from pooled results for both visibility conditions with the train present trials, indicates mixed effects on mean vehicle braking pressure and accel/decel, across the 5 roadway intervals (Table 3-3).
18. Collective findings supporting Conclusions 4 through 17 support a series of broad conclusions, in relation to driver interaction with an HRI as a train approaches: (1) at either the Xing or in advance of the HRI, active signage is more effective than passive signage in promoting cautious driving behavior; (2) active advance warning signs are more effective than active Xing crossbuck signs in promoting cautious driving behavior; (3) however, these effects are more pronounced in unlimited relative to limited visibility conditions; and (4) no significant differential effects of active advance flashing yellow lights warning signs versus active advance VMS warning signs on objective measures of simulated driving performance are observed.

<u>Conclusions From PTQ Results</u>

19. Responses to PTQ questions dealing with the usability of different types and configurations of HRI warning signs (Section 3.4.1) indicate that active advance warning signs and active Xing crossbuck signs are perceived by respondents to be more usable than passive advance warning signs and passive Xing crossbuck signs in relation to: (1) serving as aids to warning of and stopping for a train (Figs 3-16 through 3-23); (2) being the preferred design for HRI signage (Figs. 3-24 through 3-29, and 3-34 through 3-39); (3) aiding vehicle speed control and stopping behavior in approaching an HRI (Figs. 3-30 through 3-33); and (4) having an inherently obvious warning meaning (Figs. 3-40 and 3-41).

20. In relation to an artifact or system, Norman [28] equates usability with qualities of: (1) provision of readily interpretable sensory feedback; (2) support of interactive mapping between stimulus and response; and (3) support of a conceptual model regarding function. The usability preferences cited in Conclusion 19 point to the following usability advantages of active relative to passive HRI warning signs: (1) better feedback in warning of a train and aiding vehicle speed control; (2) better interactive mapping in supporting stopping for a train; (3) better conceptual model, in terms of being the preferred HRI warning sign design; and (4) appropriate feedback and support of a conceptual model, in terms of having an inherently obvious meaning.
21. Responses to PTQ questions dealing with the conspicuity of different types and configurations of HRI warning signs (Section 3.4.2, Figs. 3-42 through 3-49) indicate that active HRI warning signs are perceived to be more noticeable, and to attract more attention, than passive HRI warning signs at either the Xing or in advance of the HRI. The conspicuity of active advance HRI warning signs attracts the strongest positive responses.
22. Responses to PTQ Q28 and Q37 (Figs. 3-50, 3-51) indicate that flashing words are considered more conspicuous than flashing yellow lights on an active advance HRI warning sign.
23. Responses to PTQ Q43 through Q46 indicate that the most appropriate driving behaviors that should be adopted, and that would tend to be adopted, in approaching an HRI are cited by the highest percentage of respondents. However, lower percentages of respondents favor both higher risk and more risk aversive behaviors in responses to these questions, with regard to interacting with an HRI.

<u>Summary Conclusion</u>

24. Conclusions 1 through 22 support the summary conclusion that installation of active warning systems at passive railroad crossings, with both active advance warning signs and active Xing crossbuck signs, will benefit driving safety during vehicle-train interactions at HRIs. The findings of the study thereby tend to validate the decision by Mn/DOT to support development of a low-cost active warning system, targeted for installation at currently passive HRIs.

4.4. Recommendations

Conclusions in the preceding section support the following recommendations.

R1. Continue support for development of a low-cost active warning system, targeted for installation at currently passive HRIs.

R2. Include an active advance warning sign as part of this system.

R3. Consider adopting a VMS for the active advance warning sign.

Although no significant differential effects of active advance flashing yellow light warning signs versus active advance VMS warning signs on objective measures of simulated driving performance are observed (Conclusion 18), this recommendation is supported by the observation that PTQ respondents report advance warning signs with flashing words to be more noticeable than advance warning signs with flashing yellow lights (Conclusion 22).

R4. Carry out further research involving collection of field observations in order to validate findings of this study.

References

1. National Transportation Safety Board, *Safety Study. Safety at Passive Grade Crossings. Volume 1: Analysis*, Report NTSB/SS-98/02, PB98-917004, National Transportation Safety Board Washington, D.C., 1998.
2. Caird, J.K., Creaser, J.I., Edwards, C.J., and Dewar, R.E., *A Human Factors Analysis of Highway-Railway Grade Crossing Accidents in Canada*, Report TP 13938E, Transport Development Centre, Transport Canada, Montreal, Canada, 2002.
3. Lerner, N.D., Llaneras, R.E., McGee, H.W., and Stephens, D.E., *Traffic-Control Devices for Passive Railroad-Highway Grade Crossings*, NCHRP Report 470, National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C., 2002.
4. Bahler, S., *Highway-Rail Intersections*, Presentation to North Central Section of the Institute of Transportation Engineers, Saint Paul, MN, May 25, 2001.
5. Melby, G., *Minnesota Low Cost Highway Rail Intersection Program*, Presentation to 8th World Congress on Intelligent Transportation Systems, Sydney, Australia, October, 2001.
6. Taavola, D., *Operational Test of Low-Cost Active Warning System for Low-Volume Highway-Rail Intersections in Minnesota*, Presentation to University of Minnesota Center for Transportation Studies Fourteenth Annual Transportation Research Conference, Saint Paul, MN, April 29, 2003.
7. Smith, T.J., Hammond, C., and Wade, M., *Investigating the Effect on Driver Performance of Advanced Warning Flashers at Signalized Intersections, Final Report*, Report MN/RC - 2002-05, State of Minnesota Department of Transportation, Saint Paul, MN, 2001.
8. Mortimer, R.G., ‘Human factors in highway-railroad grade crossing accidents,’ In G. A. Peters and B.J. Peters, Eds., *Automotive Engineering and Litigation*, vol. 2, New York, Garland Law Publishing, 1988, pp. 35-69.
9. Lerner, N., Ratte, D., and Walker, J., *Driver Behavior At Rail-Highway Crossings*, FHWA Project No. DTFH61-88-Z-00145, COMSIS Corporation, Silver Spring, MD, 1989.
10. Dewar, R.E., ‘Railroad grade crossing accidents,’ In R.E. Dewar and P.L. Olson, Eds., *Human Factors in Traffic Safety*, Tucson, AZ, Lawyers & Judges Publishing, 2002, pp. 507-523.
11. Federal Railroad Administration, *Railroad Safety Statistics, Annual Report 1998*, U.S. Department of Transportation Federal Railroad Administration, Washington, D.C., July, 1999.
12. Morrissey, J., *The Effectiveness of Flashing Lights and Flashing Lights with Gates in Reducing Accident Frequency at Public Rail-Highway Crossings*, FRA Report No. FRA-RRS-80-005, Input Output Services, Waltham, MA, 1980.
13. Schulte, W.R., ‘Effectiveness of automatic warning devices in reducing accidents at grade crossings,’ *Transportation Research Record*, vol. 611, 1975, pp. 49-57.
14. Donovan, L., Rise in rail-crossing deaths a concern, St. Paul Pioneer Press, Saint Paul, MN, July 23, 2002, p. 2B.
15. 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.

16. 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.
17. 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.
18. 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.
19. Ries, G.L., *Evaluation of Dynamic Signing Used to Alert Motorists to Traffic Signal Change Intervals*, Technical Memorandum No. 07043-185, State of Minnesota Department of Transportation, Saint Paul, MN, 1985.
20. 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.
21. 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.
22. Ruden, R.J., Burg, A., and McGuire, J.P., *Activated Advance Warning for Railroad Grade Crossings*, FHWA Report No. FHWA/RD-80/003, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1982.
23. Bahler, S., Personal Communication, Excerpts from Traffic Engineering Manual pertaining to HRI layout and warning sign placement, 2000.
24. Gergen, S., Personal Communication, Specifications for grade crossing active warning device, 2000.
25. Federal Highway Administration, *MUTCD 2000. Manual on Uniform Traffic Control Devices,* Millennium Edition, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 2000 (http://mutcd.fhwa.dot.gov/kno-millennium.htm).
26. Federal Highway Administration, *Standard Highway Signs (2002 Edition) (Metric)*, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 2002, (http://mutcd.fhwa.dot.gov/ser-shs_millennium_met.htm).
27. Smith, T.J., Wade, M.G., and Hammond, C., *Human Factors Evaluation of GAINS, a Prototype In-Vehicle Navigation System. Final Report*, State of Minnesota Department of Transportation, Saint Paul, MN, 1999.
28. Norman, D.A., *The Design of Everyday Things*, New York, Currency Doubleday, 1988.

Appendix A

Traffic Engineering Specifications for HRI Layout and Warning Sign Placement

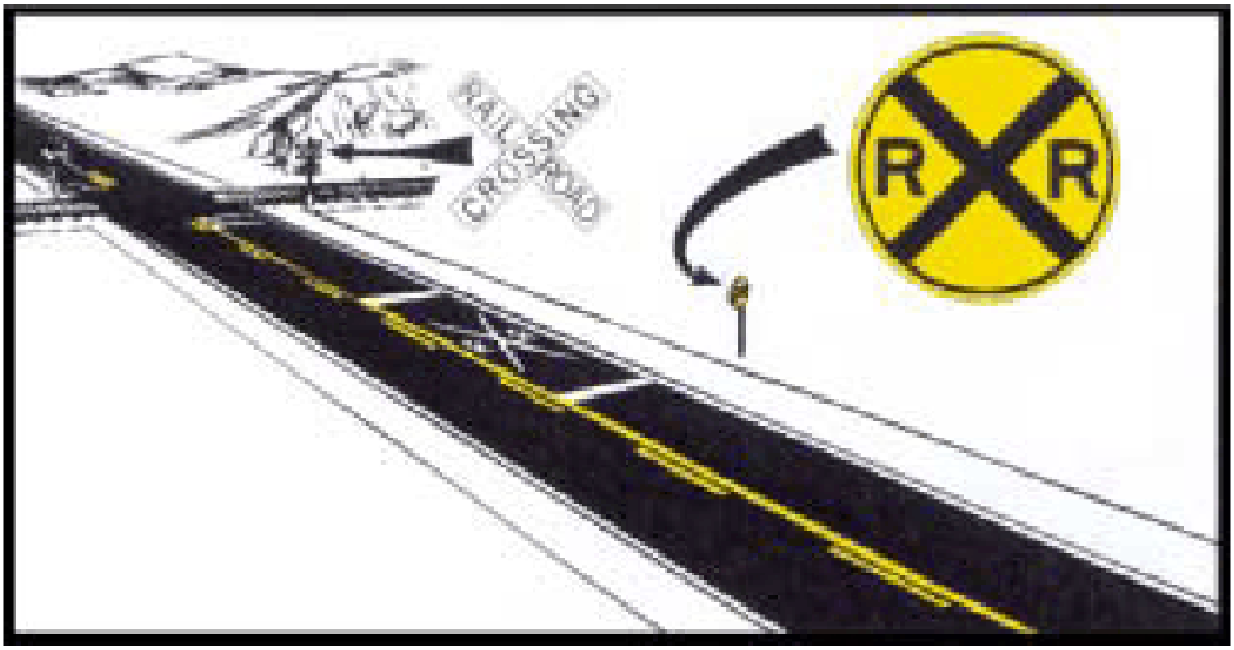


Figure A-1. Schematic illustration of placement of HRI advance warning sign and Xing crossbuck sign [25, Chap. 2A, p. 2A-18, Fig. 2A-7].

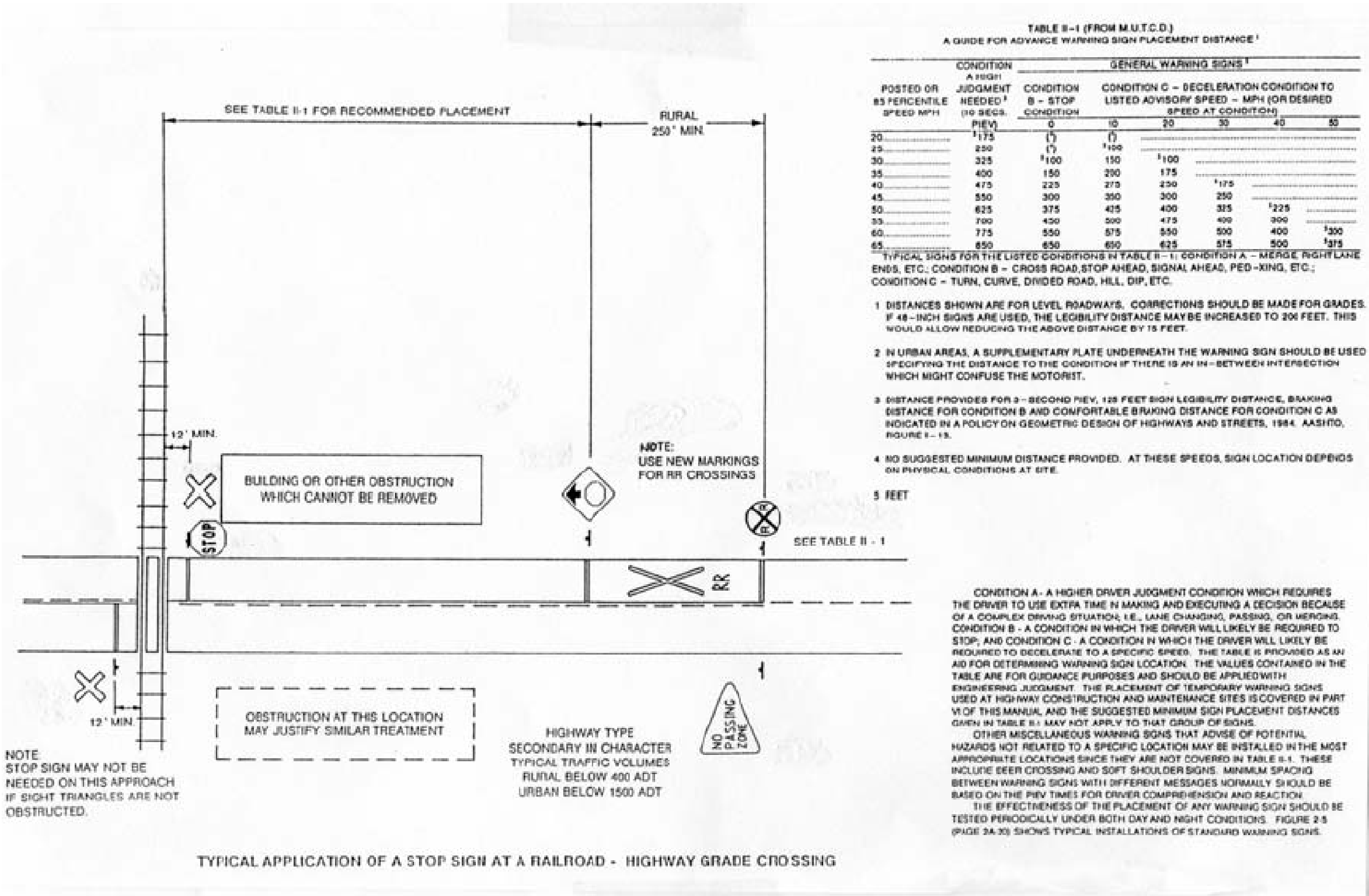


TABLE II-1 (FROM M.U.T.C.D.)
A GUIDE FOR ADVANCE WARNING SIGN PLACEMENT DISTANCE [1]

POSTED OR 85 PERCENTILE SPEED MPH	CONDITION A HIGH JUDGMENT NEEDED [2] (10 SECS. PIEV)	GENERAL WARNING SIGNS [3] CONDITION B - STOP CONDITION	CONDITION C - DECELERATION CONDITION TO LISTED ADVISORY SPEED - MPH (OR DESIRED SPEED AT CONDITION)				
		0	10	20	30	40	50
20	[5]175	[4]	[4]	----	----	----	----
25	250	[4]	[5]100	----	----	----	----
30	325	[5]100	150	[5]100	----	----	----
35	400	150	200	175	----	----	----
40	475	225	275	250	[5]175	----	----
45	550	300	350	300	250	----	----
50	625	375	425	400	325	[5]225	----
55	700	450	500	475	400	300	----
60	775	550	575	550	500	400	[5]300
65	850	650	650	625	575	500	[5]375

TYPICAL SIGNS FOR THE LISTED CONDITIONS IN TABLE II - 1; CONDITION A - MERGE, RIGHT LANE ENDS, ETC.; CONDITION B - CROSS ROAD, STOP AHEAD, SIGNAL AHEAD, PED-XING, ETC.; CONDITION C - TURN, CURVE, DIVIDED ROAD, HILL, DIP, ETC.

1 DISTANCES SHOWN ARE FOR LEVEL ROADWAYS. CORRECTIONS SHOULD BE MADE FOR GRADES. IF 48-INCH SIGNS ARE USED, THE LEGIBILITY DISTANCE MAY BE INCREASED TO 200 FEET. THIS WOULD ALLOW REDUCING THE ABOVE DISTANCE BY 75 FEET.

2 IN URBAN AREAS, A SUPPLEMENTARY PLATE UNDERNEATH THE WARNING SIGN SHOULD BE USED SPECIFYING THE DISTANCE TO THE CONDITION IF THERE IS AN IN-BETWEEN INTERSECTION WHICH MIGHT CONFUSE THE MOTORIST.

3 DISTANCE PROVIDES FOR 3-SECOND PIEV, 125 FEET SIGN LEGIBILITY DISTANCE, BRAKING DISTANCE FOR CONDITION B AND COMFORTABLE BRAKING DISTANCE FOR CONDITION C AS INDICATED IN A POLICY ON GEOMETRIC DESIGN OF HIGHWAYS AND STREETS, 1984. AASHTO, FIGURE II-15.

4 NO SUGGESTED MINIMUM DISTANCE PROVIDED. AT THESE SPEEDS, SIGN LOCATION DEPENDS ON PHYSICAL CONDITIONS AT SITE.

5 FEET

CONDITION A - A HIGHER DRIVER JUDGMENT CONDITION WHICH REQUIRES THE DRIVER TO USE EXTRA TIME IN MAKING AND EXECUTING A DECISION BECAUSE OF A COMPLEX DRIVING SITUATION, I.E., LANE CHANGING, PASSING, OR MERGING. CONDITION B - A CONDITION IN WHICH THE DRIVER WILL LIKELY BE REQUIRED TO STOP; AND CONDITION C - A CONDITION IN WHICH THE DRIVER WILL LIKELY BE REQUIRED TO DECELERATE TO A SPECIFIC SPEED. THE TABLE IS PROVIDED AS AN AID FOR DETERMINING WARNING SIGN LOCATION. THE VALUES CONTAINED IN THE TABLE ARE FOR GUIDANCE PURPOSES AND SHOULD BE APPLIED WITH ENGINEERING JUDGMENT. THE PLACEMENT OF TEMPORARY WARNING SIGNS USED AT HIGHWAY CONSTRUCTION AND MAINTENANCE SITES IS COVERED IN PART VI OF THIS MANUAL AND THE SUGGESTED MINIMUM SIGN PLACEMENT DISTANCES GIVEN IN TABLE II-1 MAY NOT APPLY TO THAT GROUP OF SIGNS.

OTHER MISCELLANEOUS WARNING SIGNS THAT ADVISE OF POTENTIAL HAZARDS NOT RELATED TO A SPECIFIC LOCATION MAY BE INSTALLED IN THE MOST APPROPRIATE LOCATIONS SINCE THEY ARE NOT COVERED IN TABLE II-1. THESE INCLUDE DEER CROSSING AND SOFT SHOULDER SIGNS. MINIMUM SPACING BETWEEN WARNING SIGNS WITH DIFFERENT MESSAGES NORMALLY SHOULD BE BASED ON THE PIEV TIMES FOR DRIVER COMPREHENSION AND REACTION.

THE EFFECTIVENESS OF THE PLACEMENT OF ANY WARNING SIGN SHOULD BE TESTED PERIODICALLY UNDER BOTH DAY AND NIGHT CONDITIONS. FIGURE 2-5 (PAGE 2A-30) SHOWS TYPICAL INSTALLATIONS OF STANDARD WARNING SIGNS.

Figure A-2. Traffic engineering specifications for HRI layout and sign placement [23].
(State Project no. 8809-107 & 8809-108, Sheet No. 79)

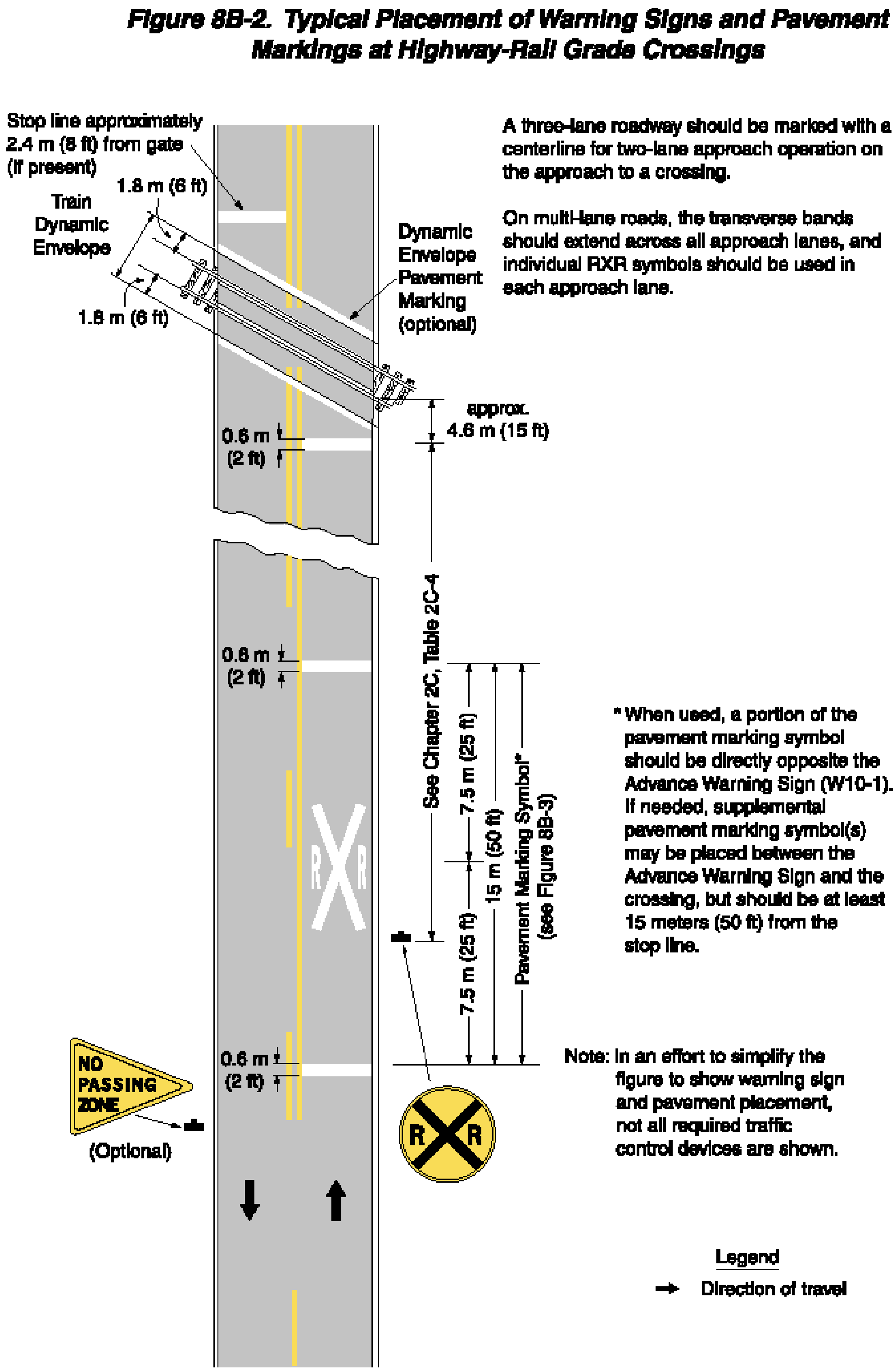
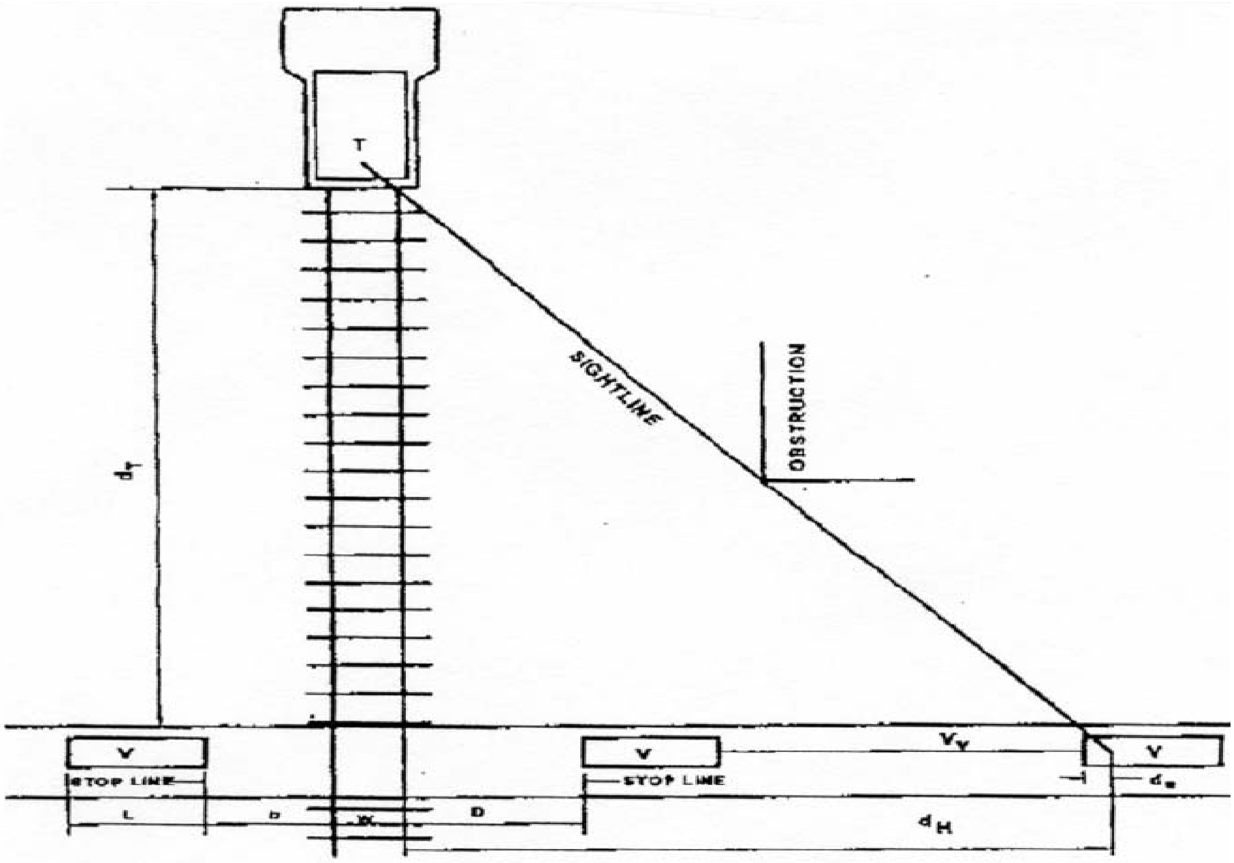


Figure A-3. Typical placement of Xing crossbuck sign and advance warning sign, and pavement markings, for HRIs [25, Chap. 8, p. 8B-13].



$$d_H = 0.28V_v t + \frac{V_v^2}{254f} + D + d_e$$

$$d_T = \frac{V_T}{V_v}\left[(0.28)\, V_v t + \frac{V_v^2}{254f} + 2D + L + W \right]$$

d_H = sight distance along the highway
d_T = sight distance along the railroad tracks
V_v = velocity of the vehicle (km/h)
V_T = velocity of the train (km/h)
t = perception/reaction time (assumed to be 2.5 s)
f = coefficient of friction (see Table III-1)
D = distance from stop line to near rail (assumed to be 4.5 m)
W = distance between outer rails (single track W=1.5 m)
L = length of vehicle (assumed to be 20 m)
d_e = distance from driver to front of vehicle (assumed to be 3.0 m)

Figure A-4. Vehicle-train sight line computation for moving vehicle approaching HRI [23].
(Minnesota Traffic Engineering Manual, Figure 13.7A, Jan. 1, 1996)

DESIGN SIGHT FOR HIGHWAY SPEED OF:

Train Speed (MPH)	0 MPH	10 MPH	15 MPH	20 MPH	25 MPH	30 MPH	35 MPH	40 MPH	45 MPH	50 MPH	55 MPH	60 MPH	65 MPH	70 MPH	75 MPH
	Distance Along Railroad from Crossing (Feet)														
10	162	126	104	94	91	94	96	99	101	107	113	118	125	129	138
15	242	189	156	141	137	141	143	147	152	161	169	176	187	194	207
20	323	252	208	188	182	188	191	197	203	214	226	235	250	258	276
25	404	315	260	235	227	235	238	246	253	267	282	293	312	322	344
30	484	378	312	281	273	281	286	296	303	321	339	352	374	387	414
35	565	441	364	328	318	328	333	342	354	375	395	411	436	452	483
40	645	504	416	376	364	376	382	394	406	428	452	470	500	516	552
45	725	567	468	422	409	422	429	442	455	482	508	528	561	580	620
50	807	630	520	470	454	470	476	492	506	534	564	586	624	644	688
55	886	694	573	516	500	516	524	540	556	588	621	645	685	710	758
60	967	756	624	562	546	562	572	590	606	642	678	704	748	774	828
65	1049	819	676	610	591	610	619	638	657	695	734	762	810	837	895
70	1129	882	728	656	636	656	666	684	708	750	790	822	872	904	986
75	1210	945	780	681	681	704	714	737	758	803	847	879	935	967	1036
80	1290	1008	832	752	728	752	764	788	812	856	904	940	1000	1032	1104
85	1370	1070	885	799	774	779	812	835	861	910	960	998	1059	1097	1172
90	1450	1134	936	844	818	844	858	884	910	964	1016	1056	1122	1160	1240
95	1535	1200	990	890	865	890	910	935	960	1020	1070	1115	1190	1225	1310
	Distance on Highway from Crossing (Feet)*														
	20	65	95	125	166	215	270	330	395	470	560	640	745	840	965

For one track and level gradient.

Figure A-5. Table of computed (Fig. A-2) vehicle-train sight line distances for different vehicle and train speeds [23].
(Minnesota Traffic Engineering Manual, Figure 13.4, July 1, 1992)

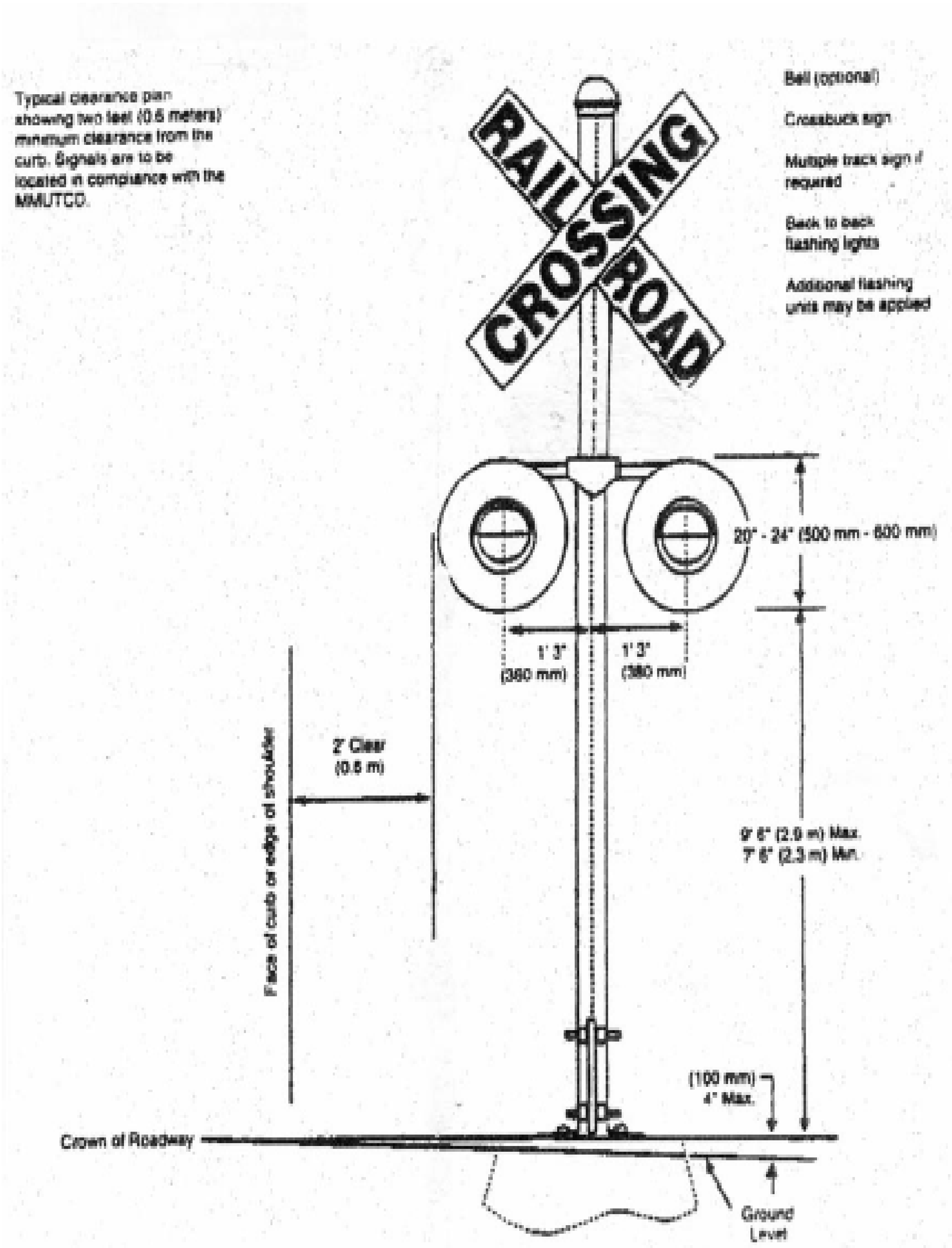


Figure A-6. Design specifications for active Xing flashing red lights crossbuck sign [24].

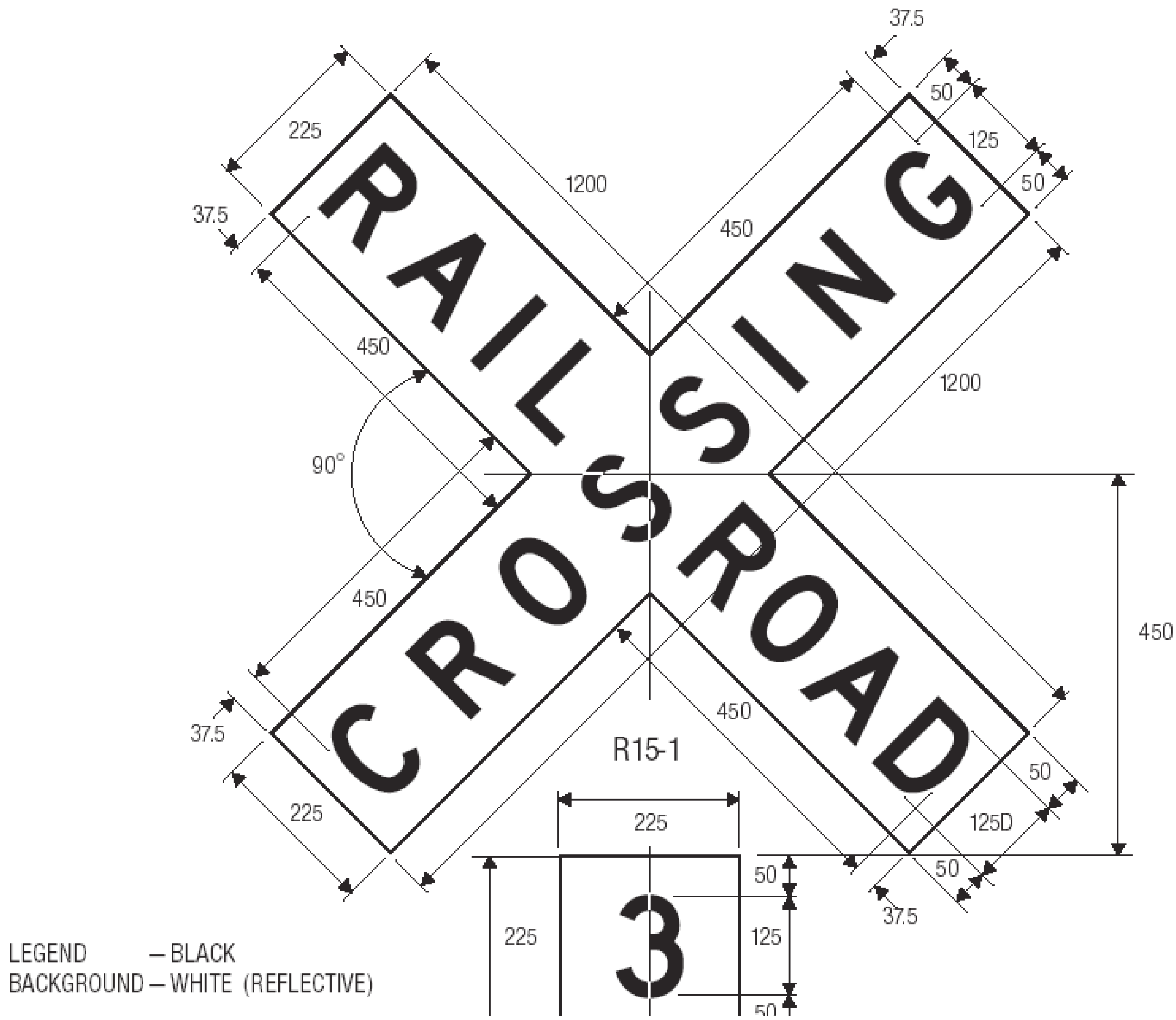
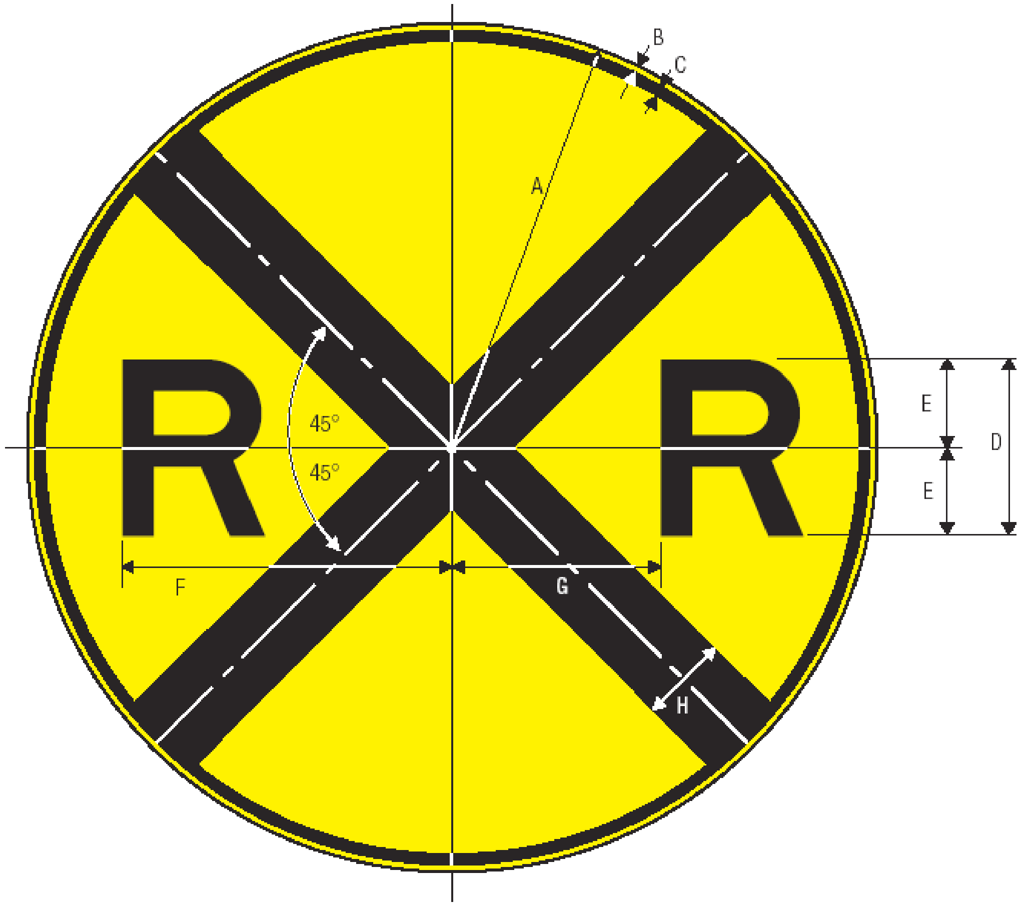


Figure A-7. Design specifications (metric) for passive Xing crossbuck sign (dimensions in mm) (MUTCD Type R15-1) [26, Chap. 1 (Regulatory Signs), p. 1-146].



W10-1

A	B	C	D	E	F	G	H
375	10	15	175 E	87.5	304	172	75
450	10	15	200 E	100	365	212	100
600	10	15	250 E	125	466	295	125
750	13	20	300 E	150	566	362	150
900	15	25	350 E	175	688	433	175

COLORS: LEGEND — BLACK
BACKGROUND — YELLOW (RETROREFLECTIVE)

Figure A-8. Design specifications (metric) for HRI passive AWS (dimensions in table in mm) (MUTCD Type W10-1) [26, Chap. 3 (Warning Signs), p. 2-99].

Appendix B

Observation Form for Recording Visual Observations of Simulated Driving Performance

RAILROAD CROSSING STUDY - REGULAR TESTING VISUAL OBSERVATIONS

Subject No ______ Name ________________________ Age ______ Gender _____ Date ____________ Session Number ___________

Session Start Time ________ Session Stop Time _______________ Session Elapsed Time_____________ Seed Number _______ File Name ______________

Trial	Fog?		Advance Warning		Xing Warning		Train?		Stop at Xing?		Tree?		Accident?		Comments
	No	Yes	Passive	Active	Passive	Active	No	Yes	No	Yes	No	Yes	Train?	Tree?	
1/61															
2/62															
3/63															
4/64															
5/65															
6/66															
7/67															
8/68															
9/69															
10/70															10 Trial ET:
11/71															
12/72															
13/73															
14/74															
15/75															
16/76															
17/77															
18/78															
19/79															

Trial	Fog?		Advance Warning		Xing Warning		Train?		Stop at Xing?		Tree?		Accident?		Comments
	No	Yes	Passive	Active	Passive	Active	No	Yes	No	Yes	No	Yes	Train?	Tree?	
20/80															10 Trial ET:
21/81															
22/82															
23/83															
24/84															
25/85															
26/86															
27/87															
28/88															
29/89															
30/90															10 Trial ET:
31/91															
32/92															
33/93															
34/94															
35/95															
36/96															
37/97															
38/98															
39/99															

Trial	Fog?		Advance Warning		Xing Warning		Train?		Stop at Xing?		Tree?		Accident?		Comments
	No	Yes	Passive	Active	Passive	Active	No	Yes	No	Yes	No	Yes	Train?	Tree?	
40/100															10 Trial ET:
41/101															
42/102															
43/103															
44/104															
45/105															
46/106															
47/107															
48/108															
49/109															
50/110															10 Trial ET:
51/111															
52/112															
53/113															
54/114															
55/115															
56/116															
57/117															
58/118															
59/119															
60/120															10 Trial ET:

Appendix C

Post-Test Questionnaire

SIMULATED DRIVING 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 7-42, please circle the preferred number to indicate how much you agree or disagree with the statement.

After you have answered a question, please do not go back and change your answer.

Please return your completed questionnaire to Thomas Smith or Randy Harney.

Name ____________________________

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

5. PLEASE EXPLAIN YOUR UNDERSTANDING OF WHAT THE PURPOSE OF THIS STUDY IS.

____
____
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____

THANK YOU FOR YOUR HELP IN COMPLETING THIS QUESTIONNAIRE.

While you were driving, you may have noticed warning signs in front of the railroad crossing. The sign before the crossing is the <u>Advanced Warning</u>. The sign right at the crossing is the <u>Crossing Warning</u>. In some trials, standard warning signs, without flashing lights, were used. These are termed <u>Passive Warnings</u>. In some trials however, warning signs with flashing lights or flashing words were used. These are termed <u>Railroad Flashers</u>. The flashing sign before the crossing is the <u>Advanced Flasher</u>. The flashing sign right at the crossing is the <u>Crossing Flasher</u>. The following questions pertain to these different warning signs.

6. HAVE YOU EVER ENCOUNTERED RAILROAD FLASHERS WHILE DRIVING BEFORE?
___ NO ___ RARELY ___ FAIRLY REGULARLY ___ EVERY DAY

7. I NOTICED THE CROSSING FLASHER WHILE DRIVING	Strongly Disagree	1	2	3	4	5	Strongly Agree
8. THE ADVANCED FLASHER HELPED ME STOP FOR THE TRAIN	Strongly Disagree	1	2	3	4	5	Strongly Agree
9. TO WARN OF A TRAIN, PASSIVE WARNING SIGNS ARE MORE HELPFUL THAN FLASHING WARNING SIGNS	Strongly Disagree	1	2	3	4	5	Strongly Agree
10. I DIDN'T PAY MUCH ATTENTION TO THE CROSSING FLASHER	Strongly Disagree	1	2	3	4	5	Strongly Agree
11. MOST RAILROAD CROSSINGS SHOULD BE PRECEDED BY BOTH ADVANCED AND CROSSING PASSIVE WARNING SIGNS	Strongly Disagree	1	2	3	4	5	Strongly Agree
12. I LIKE PASSIVE CROSSING WARNING SIGNS	Strongly Disagree	1	2	3	4	5	Strongly Agree
13. I TEND TO SPEED UP WHILE APPROACHING RAILROAD CROSSINGS WITH FLASHING WARNING SIGNS (to get across before the train comes)	Strongly Disagree	1	2	3	4	5	Strongly Agree
14. A RAILROAD FLASHER HELPS ME TO STOP AT RAILROAD CROSSINGS WHEN I AM DRIVING FAST	Strongly Disagree	1	2	3	4	5	Strongly Agree
15. I TEND TO SLOW DOWN WHILE APPROACHING RAILROAD CROSSINGS WITH FLASHING WARNING SIGNS (to prepare to stop for the train)	Strongly Disagree	1	2	3	4	5	Strongly Agree
16. I NOTICED THE ADVANCED FLASHER WHILE DRIVING	Strongly Disagree	1	2	3	4	5	Strongly Agree
17. A RAILROAD FLASHER HELPS ME TO STOP AT RAILROAD CROSSINGS WHEN I AM DRIVING SLOW	Strongly Disagree	1	2	3	4	5	Strongly Agree

18. I NOTICED THE <u>PASSIVE ADVANCED WARNING</u> SIGN WHILE DRIVING	Strongly Disagree	1	2	3	4	5	Strongly Agree
19. THE <u>PASSIVE CROSSING WARNING</u> SIGN HELPED ME STOP FOR THE TRAIN	Strongly Disagree	1	2	3	4	5	Strongly Agree
20. TO WARN OF A TRAIN, ADVANCED FLASHERs ARE MORE HELPFUL THAN CROSSING FLASHERs	Strongly Disagree	1	2	3	4	5	Strongly Agree
21. IT IS INHERENTLY OBVIOUS WHAT THE PURPOSE OF AN <u>ADVANCED FLASHER</u> IS	Strongly Disagree	1	2	3	4	5	Strongly Agree
22. I NOTICED THE <u>PASSIVE CROSSING WARNING</u> SIGN WHILE DRIVING	Strongly Disagree	1	2	3	4	5	Strongly Agree
23. I DIDN'T PAY MUCH ATTENTION TO THE <u>PASSIVE ADVANCED WARNING</u> SIGN	Strongly Disagree	1	2	3	4	5	Strongly Agree
24. I PREFER THE <u>ADVANCED FLASHER</u> WITH FLASHING <u>WORDS</u> (rather than flashing lights)	Strongly Disagree	1	2	3	4	5	Strongly Agree
25. THE <u>PASSIVE ADVANCED WARNING</u> SIGN HELPED ME STOP FOR THE TRAIN	Strongly Disagree	1	2	3	4	5	Strongly Agree
26. THE <u>CROSSING FLASHER</u> HELPED ME STOP FOR THE TRAIN	Strongly Disagree	1	2	3	4	5	Strongly Agree
27. I LIKE <u>ADVANCED FLASHERs</u>.	Strongly Disagree	1	2	3	4	5	Strongly Agree
28. ON THE <u>ADVANCED FLASHER</u>, FLASHING <u>WORDS</u> WERE MORE NOTICEABLE THAN FLASHING <u>LIGHTS</u>	Strongly Disagree	1	2	3	4	5	Strongly Agree

29. MOST RAILROAD CROSSINGS SHOULD BE PRECEDED BY <u>CROSSING FLASHERs</u>	Strongly Disagree	1	2	3	4	5	Strongly Agree
30. MOST RAILROAD CROSSINGS SHOULD BE PRECEDED BY <u>PASSIVE CROSSING WARNING</u> SIGNS	Strongly Disagree	1	2	3	4	5	Strongly Agree
31. I LIKE <u>PASSIVE ADVANCED WARNING</u> SIGNS	Strongly Disagree	1	2	3	4	5	Strongly Agree
32. I DIDN'T PAY MUCH ATTENTION TO THE <u>ADVANCED FLASHER</u>	Strongly Disagree	1	2	3	4	5	Strongly Agree
33. TO WARN OF A TRAIN, FLASHING WARNING SIGNS ARE MORE HELPFUL THAN PASSIVE WARNING SIGNS	Strongly Disagree	1	2	3	4	5	Strongly Agree
34. I PREFER THE <u>ADVANCED FLASHER</u> WITH FLASHING <u>LIGHTS</u> (rather than flashing words)	Strongly Disagree	1	2	3	4	5	Strongly Agree
35. I DIDN'T PAY MUCH ATTENTION TO THE <u>PASSIVE CROSSING WARNING</u> SIGN	Strongly Disagree	1	2	3	4	5	Strongly Agree
36. MOST RAILROAD CROSSINGS SHOULD BE PRECEDED BY <u>PASSIVE ADVANCED WARNING</u> SIGNS	Strongly Disagree	1	2	3	4	5	Strongly Agree
37. ON THE <u>ADVANCED FLASHER</u>, FLASHING <u>LIGHTS</u> WERE MORE NOTICEABLE THAN FLASHING <u>WORDS</u>	Strongly Disagree	1	2	3	4	5	Strongly Agree
38. TO WARN OF A TRAIN, CROSSING FLASHERs ARE MORE HELPFUL THAN ADVANCED FLASHERs	Strongly Disagree	1	2	3	4	5	Strongly Agree
39. MOST RAILROAD CROSSINGS SHOULD BE PRECEDED BY <u>ADVANCED FLASHERs</u>	Strongly Disagree	1	2	3	4	5	Strongly Agree
40. I LIKE <u>CROSSING FLASHERs</u>	Strongly Disagree	1	2	3	4	5	Strongly Agree

41. IT IS INHERENTLY OBVIOUS WHAT THE PURPOSE OF A CROSSING FLASHER IS

Strongly Disagree 1 2 3 4 5 Strongly Agree

42. MOST RAILROAD CROSSINGS SHOULD BE PRECEDED BY BOTH ADVANCED AND CROSSING FLASHERs

Strongly Disagree 1 2 3 4 5 Strongly Agree

43. When you approach a railroad crossing WITH warning lights at the crossing, you are supposed to (check all that apply):

43a. ___ Always stop at the crossing, whether or not the warning lights are flashing

43b. ___ Always slow down before crossing the railroad tracks, whether or not the warning lights are flashing

43c. ___ Proceed at normal speed through the crossing if the warning lights are not flashing

43d. ___ Speed up to cross the railroad tracks if the warning lights are not flashing

43e. ___ Stop at the crossing if the warning lights are flashing, and wait until a train has passed before crossing the railroad tracks

43f. ___ Stop at the crossing if the warning lights are flashing, and then cross the railroad tracks if you don't see a train coming

43g. ___ Slow down if the warning lights are flashing, and then cross the railroad tracks if you don't see a train coming

43h. ___ Proceed at normal speed through the crossing if the warning lights are flashing, unless you see a train coming

43i. ___ Speed up to make it across the railroad tracks before a train arrives, if the warning lights are flashing and you DON'T see a train

43j. ___ Speed up to make it across the railroad tracks if it looks as though you can 'beat the train,' if the warning lights are flashing and you DO see a train

43k. ___ If the warning lights are flashing and you DO see a train, stop at the crossing only if it looks as though you cannot 'beat the train'

44. When you approach a railroad crossing WITHOUT warning lights at the crossing, you are supposed to (check all that apply):

44a. ___ Always stop at the crossing, and then cross the railroad tracks if you don't see a train

44b. ___ Always slow down before crossing the railroad tracks, even if you don't see a train

44c. ___ Proceed at normal speed through the crossing if you don't see a train

44d. ___ Speed up to cross the railroad tracks if you don't see a train

44e. ___ Always stop at the crossing and wait until the train has passed before crossing the railroad tracks, if you do see a train

44f. ___ Slow down and then cross the railroad tracks if it looks as though you can 'beat the train,' if you do see a train

44g. ___ Proceed at normal speed across the railroad tracks if it looks as though you can 'beat the train,' if you do see a train

44h. ___ Speed up to make it across the railroad tracks if it looks as though you can 'beat the train,' if you do see a train

44i. ___ Stop at the crossing only if it looks as though you cannot 'beat the train,' if you do see a train

45. When I approach a railroad crossing WITH warning lights at the crossing, I tend to (check all that apply):

45a. ___ Always stop at the crossing, whether or not the warning lights are flashing

45b. ___ Always slow down before crossing the railroad tracks, whether or not the warning lights are flashing

45c. ___ Proceed at normal speed through the crossing if the warning lights are not flashing

45d. ___ Speed up to cross the railroad tracks if the warning lights are not flashing

45e. ___ Stop at the crossing if the warning lights are flashing, and wait until a train has passed before crossing the railroad tracks

45f. ___ Stop at the crossing if the warning lights are flashing, and then cross the railroad tracks if I don't see a train coming

45g. ___ Slow down if the warning lights are flashing, and then cross the railroad tracks if I don't see a train coming

45h. ___ Proceed at normal speed through the crossing if the warning lights are flashing, if I don't see a train

45i. ___ Speed up to make it across the railroad tracks if the warning lights are flashing, if I don't see a train

45j. ___ Speed up to make it across the railroad tracks even if the warning lights are flashing and I see a train, if it looks as though I can 'beat the train'

45k. ___ Stop at the crossing if the warning lights are flashing and I see a train, only if it looks as though I cannot 'beat the train'

46. When I approach a railroad crossing WITHOUT warning lights at the crossing, I tend to (check all that apply):

46a. ___ Always stop at the crossing and then cross the railroad tracks, even if I don't see a train

46b. ___ Always slow down before crossing the railroad tracks, even if I don't see a train

46c. ___ Proceed at normal speed through the crossing if I don't see a train

46d. ___ Speed up to cross the railroad tracks if I don't see a train

46e. ___ Always stop at the crossing and wait until the train has passed before crossing the railroad tracks, if I do see a train

46f. ___ Slow down and then cross the railroad tracks if it looks as though I can 'beat the train,' if I do see a train

46g. ___ Proceed at normal speed across the railroad tracks if it looks as though I can 'beat the train,' if I do see a train

46h. ___ Speed up to make it across the railroad tracks if it looks as though I can 'beat the train,' if I do see a train

46i. ___ Stop at the crossing only if it looks as though I cannot 'beat the train,' if I do see a train

47 PLEASE WRITE BELOW ANY COMMENTS OR QUESTIONS YOU MAY HAVE ABOUT YOUR EXPERIENCES WITH THIS STUDY.

THANK YOU FOR YOUR HELP IN COMPLETING THIS QUESTIONNAIRE

Appendix D

Informed Consent Form

CONSENT FORM
SIMULATED DRIVING STUDY

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 Randy Harney and Heron Shiu.

Background Information:
The purpose of the study is to assess your performance during simulated driving, when occasional road hazards are suddenly encountered..

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

You will be asked to participate two experimental sessions that will involve driving in a driving simulator. Each session will last about 1 hour. You will be paid $20 for completing the two sessions. Each session will consist of 60 trials. During each trial, you will drive through a simulated driving environment. During some trials, you may encounter a road hazard. We will ask you to obey all traffic laws during each trial. If your driving performance is acceptable for each session, you will receive a $20 bonus (the definition of 'acceptable' will be explained to you). Before and after the 2 simulated driving sessions, you will be asked to complete a questionnaire.

Risks and Benefits of Being in the Study:
There are no risks associated with the study.

There are no direct benefits to you for participation in the research project.

You will receive payment of $20, plus possibly a $20 bonus, for participating in the study.

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 researchers 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. If you do withdraw prior to completing a session, you will receive partial payment for your participation.

Contacts and Questions:
The researchers conducting this study are Thomas J. Smith and Randy Harney. You may ask any questions you have now. If you have questions later, you may contact Dr. Smith at the Human Factors Research Laboratory, Mariucci Arena, 1901 4th Street SE, Minneapolis, MN 55414, Phone: (612) 625-2044 or (651) 688-7444, Fax: (612) 626-7700, Email: smith293@umn.edu.. You may contact Mr. Harney at Room 204 Cooke Hall, 1900 University Ave. SE, Minneapolis, MN 55414, Phone: (612) 625-8396, Fax: (612) 626-7700, Email: harn0014@umn.edu. You may contact Heron Shiu at the Human Factors Research Laboratory, Phone: 612-626-7521 or 612-987-3255, Email: heronshiu@hotmail.com.

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher, contact the Research Subjects' Advocate line, D528 Mayo, 420 Delaware Street Southeast, Minneapolis, Minnesota 55455; telephone (612) 625-1650.

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 E

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

Q9. 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 F

Simulation Testing Instructions and Check List

GENERAL INSTRUCTIONS

1. 4 computers are used for the project
   - KELLY (a PC) is on the desk just to the right of the simulator door (used as test manager)
   - HAWK (a PC) is on the desk across the aisle from Kelly (stores programs & data)
   - SGI Onyx (an SGI computer) is the purple monster to the left of the simulator door (generates simulation model)
   - SELMA (a PC) is in the cubicle behind Hawk

2. Login and Password
   - Login: HFRL
   - Password: ktb!dktb

   (these apply to Kelly, Hawk, and Selma)

3. Rebooting Kelly and Hawk
   - hit CTRL-ALT-DEL keys together
   - enter Login and Password

4. Simulation management panels on KELLY
   - SimControl panel (controls starting & stopping simulation)
   - SelectProject panel (specifies simulation project choices)
   - SelectFile panel (specifies data storage folders & supplementary projects)
   - Seed panel (specifies seed number for Sessions 1 & 2)

5. To bring up SimControl panel after rebooting Kelly
   - enter Login & Password
   - click on Debian icon (lower lefthand corner of display)
   - click on HostGUI - this will bring up SimControl panel

6. The box to the left of Hawk contains form and subject folders, plus disks to back up data.

7. Emergency help: Peter Easterlund, 6-9130; Curt Olson, 4-6071.

SIMULATION MANAGEMENT CHECKLIST

POWER UP PROJECTORS & ENGINE NOISE AMPS

1. ___Turn on interior lights in wraparound simulator (switch to right of SGI Onyx)
2. ___Turn on 3 projectors using remote

   (NOTE: if projector is on but no scene is displayed, hit ‘Computer’ button on left top corner of remote until scene is displayed)
3. ___Turn OFF interior lights in wraparound simulator
4. ___Turn on engine noise amps (amps are to the left of SGI Onyx---hit power button on top left corner of top amp to turn on both amps)

INITIAL SUBJECT PREPARATION (Session 1 only)

5. ___Assign ID number to subject and prepare folder for subject.

   (start regular subjects at 100R).
6. ___Have subject read and sign consent form.
7. ___Sign consent form, write subject ID number on front of consent form, and place consent form in subject folder.

SELECTING THE TRIAL RUN PROJECT ON KELLY (Session 1 only)

8. ___Click 'Select Project' on SimControl panel
9. ___Click 'Choose from List' on SelectProject panel
10. ___Scroll down SelectFile panel to 'ivnsctrl.adf' and click this project
11. ___Click 'Startup Sim' on SimControl panel
12. ___Put car in 'Neutral' on SimControl panel

TRIAL RUN PROCEDURES (Session 1 only)

13. ___Ask subject to enter car and adjust seat
14. ___Explain car and driving environment to subject. Explain that only the steering wheel, accelerator, brake, and speedometer work.
15. ___Put car in 'Drive'
16. ___Have subject perform series of maneuvers more than once during trial run, such as: (1) speeding up to 55 mph; (2) slowing down; (3) stopping at stop sign; (4) turning; and (5) stopping suddenly in middle of roadway. Ask subject repeatedly how he/she is feeling---listen for reports of upset stomach/nausea. Look for signs of distress---unhappy look, sweating, redness, visible agitation. Watch driving performance. Explain delay problem to subject. Ask them to position hands at base of wheel and position wheel in small increments, rather than big swings, to avoid overshoot.
17. ___Continue Trial Run for 5-10 minutes. If trial run performance is deemed acceptable, click on 'Shutdown Sim' on simulation control window, and have subject exit car and come back outside.
18. ___If trial run performance is NOT deemed acceptable (subject declines to continue; poor driving performance), pay subject $5 and terminate session.
19. ___Do NOT administer trial run for Session 2 subjects.

TEST RUN PROCEDURES

20. ___Have subject complete Pre-Test Questionnaire.
21. ___On Kelly:
    - Click 'Select Project' on SimControl panel. Select 'RRXING' project on SelectProject panel. This will bring up the Seed panel.
    - Use Subject ID as seed number. Enter seed number for Session 1 (Trials 1-60) or Session 2 (Trials 61-120) as appropriate.
22. ___Prepare visual observation recording sheet for session by entering requisite information at top of sheet.
23. ___When subject finishes Pre-Test Questionnaire, write Subject ID number on first page of Pre-Test Questionnaire and place in subject folder.
24. ___Hand copy of Instructions for Subjects to subject, and read thru instructions with subject. Ask subject if instructions are understood, and if there are any questions. Make sure subject understands conditions for earning bonus.
25. ___Ask subject if they would like treat before session starts. Ask subject if they would like music played during session.
26. ___Ask subject to re-enter simulator and car.

27. ___On Kelly:

S Enter ‘seed’ number for session (controls randomization of task condition assigned to each trial for the session). Use the Subject ID number as the seed number

S Click ‘Record’ on SimControl panel. This brings up the SelectFile panel.

S SET SAMPLING FREQUENCY TO 1 HZ on SimControl panel.

S On SelectFile panel, scroll down and select ‘rrxing’ folder.

S Enter file name on top of SelectFile panel using the following convention: ‘rr<subject ID number><R><1 or 2>’, where R stands for ‘Regular Subject’, and 1 or 2 stand for Session 1 or 2. Thus, for a Session 2 test for regular Subject 110, the file name would be ‘rr110R2'.

S Click ‘Startup Sim’ on SimControl panel.
NOTE: DO NOT START RECORDING AFTER STARTUP SIM---it won’t work.
Put car in ‘Neutral’ on SimControl panel.

PROCEDURES DURING TESTING SESSION

28. ___Start music, unless subject declines.
29. ___When your watch/timer nears a minute mark, put car in ‘Drive’ on SimControl panel.
30. ___Start timing at a minute mark on watch/timer.
31. ___Sit in chair in wraparound simulator next to car. Record visual observations for each trial on visual observation recording sheet. If the advance warning is a VMS sign, enter ‘VMS’ in the advance warning column for that trial.
32. ___Record collisions with trains or trees as accidents on visual observation recording sheet.
33. ___At the end of each 10 trials, inform subject of total elapsed time for session (target is 1 min/trial, or 10 min for each 10 trials).
34. ___NOTE - SUBTRACT 1 MINUTE FROM THE ACTUAL ELAPSED TIME PER 10 TRIALS (to account for the delay between trials). Therefore:

    -At 10 trials subtract 1 minute
    -At 20 trials subtract 2 minutes
    -At 30 trials subtract 3 minutes
    -At 40 trials subtract 4 minutes
    -At 50 trials subtract 5 minutes
    -At 60 trials subtract 6 minutes

    Inform the subject of the corrected time (not the actual time).
35. ___At any given 10-trial mark, fudge the time as follows if necessary:

    ___If subject has 2 accidents, tell them that their time is within 52-68 minutes.
    ___If subject has 3 accidents, tell them that their time is within 56-64 minutes.
    ___At 60 trials, fudge time to within 52-68 minutes if necessary.
36. ___Session terminates automatically at end of Trial 60 for Session 1, or Trial 120 for Session 2. Record end time and elapsed time on visual observation recording sheet.

TERMINATING SESSION 1

37. ___Write Subject ID on first page of visual observation recording form. Place form in subject folder.
38. ___Inform subject about their bonus fee for session. Because of time fudging (Step 34 above), the only way they lose bonus dollars is having more than three accidents. For every accident over 3 accidents, they lose $4.
39. ___Subject can leave at this point.

40. ___On SIM Control Panel on Kelly

___Turn off recording (click on ‘Record’ to turn it off)

___Click on ‘Shutoff Sim’

41. ___Turn off projectors in wraparound simulator using remote.
42. ___Turn off fan, music, and engine noise amps.
43. ___Go to Selma:
    - _ Enter login name and password if needed.
    - _ Right click on ‘Network Neighborhood’ on desktop.
    - _ Select ‘map network drive’.
    - _ Select drive ‘H’.
    - _ Enter ‘//hawk/hfrl’ as path.
44. ___Backing up subject data file on Selma:
    - _ Click ‘Windows Explorer’ on desktop.
    - _ Subject data file will be in ‘rrxing’ folder on Drive H (Hawk).
    - _ Copy subject data file to ‘rrxingdata’ folder on Drive C.
    - _ Insert zip disk.

S Copy subject data file (from ‘rrxingdata’ folder on Drive C) to zip disk (Drive E) containing backed up RR Xing project data.

45. ___Backing up task sequence data file on Selma:

S Look for file named ‘rrtrialfile’ on Drive H (Hawk). This file contains the task sequence for the session just completed.

S Copy this file to ‘rrxingdata’ folder on Drive C.

S Rename the copied file ‘rr<subject ID>R<1 or 2>tasks’, where 1 or 2 refers to the Session Number.

S Transfer the renamed file (from ‘rrxingdata’ folder on Driver C) to zip disk (Drive E) containing backed up RR Xing project data.

TERMINATING SESSION 2 (regular subjects only)

46. ___Repeat Steps 37, 40-45 above.
47. ___Have subject complete Post-Test Questionnaire. Write Subject ID number on front page of questionnaire and place in subject folder.
48. ___Ask subject if they have any questions, and respond appropriately.
49. ___Paying subjects:

___Pay subject $20 plus bonus fee. Full bonus fee is $20. For every accident over 3 for each session, subtract $4 from bonus fee.

___Have subject fill out receipt (ignore ISBN line). BE SURE THAT SUBJECT ENTERS THEIR SOCIAL SECURITY NUMBER on receipt.

___Place receipt in subject folder.

Appendix G

Instructions to Subjects

SIMULATED DRIVING STUDY - INSTRUCTIONS TO SUBJECTS

1. **The purpose of the study is to assess your performance during simulated driving, when occasional road hazards are suddenly encountered.**

2. **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 about 0.65 miles.**

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

4. **There will be 2 experimental sessions. During each session, you will complete a total of 60 trials. Each trial will last about 1 minute. After each trial there will be a short delay. Then the next trial will start automatically.**

5. **The posted speed limit is 55 mph.**

6. **Please obey normal traffic laws:**
   - **Try to observe the speed limit (Point 5)**
   - **Try to drive on the roadway**
   - **Do not pull over and stop during task**

7. **The target time for completing an experimental session (60 trials) is 1 hour, or 1 minute per trial.**

8. **After each 10 trials, you will be informed of the time that has elapsed for the session. If you are on target, your elapsed times during a session should be as follows: 10 minutes for 10 trials; 20 minutes for 20 trials; 30 minutes for 30 trials; 40 minutes for 40 trials; 50 minutes for 50 trials; and 60 minutes for 60 trials.**

9. **Your elapsed driving time for the trial will depend, in part, on the speed you maintain during the trial. To meet the target time, you can't drive too fast or too slow during any given trial.**

10. **The time delay between each trial is NOT counted as part of your elapsed time.**

11. **During some trials you may encounter a road hazard.**

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 driving performance is acceptable for each session. 'Acceptable' refers to both meeting the session target time, and avoiding accidents, as follows:**
    - **An accident is defined as a collision with a road hazard.**
    - **One accident per session is acceptable.**
    - **For each additional accident per session, $4 will be subtracted from your bonus fee.**
    - **Coming within 8 minutes of the target time of 60 minutes (i.e., 52-68 minutes total elapsed time) per session cancels out 1 accident per session.**
    - **Coming within 4 minutes of the target time of 60 minutes (i.e., 56-64 minutes total elapsed time) per session cancels out 2 accidents per session.**
    - **If your total elapsed time for a session is outside of 8 minutes of the target time (i.e., outside of 52-68 minutes), $10 will be subtracted from your bonus fee.**

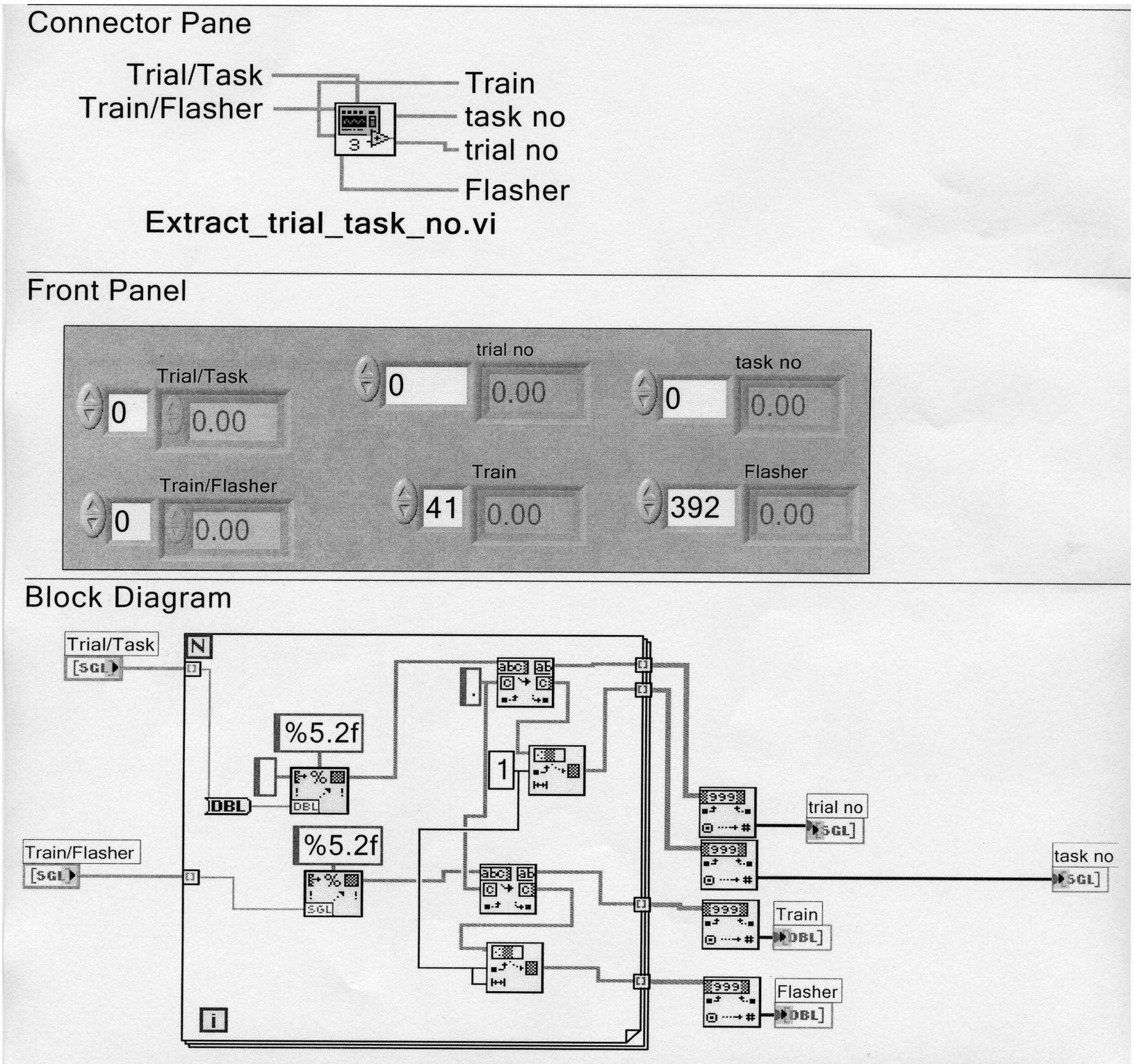
14. **All timing and accident occurrences will be monitored automatically by the computer.**

15. **You are free to terminate a session at any time, if you feel as if you cannot continue.**

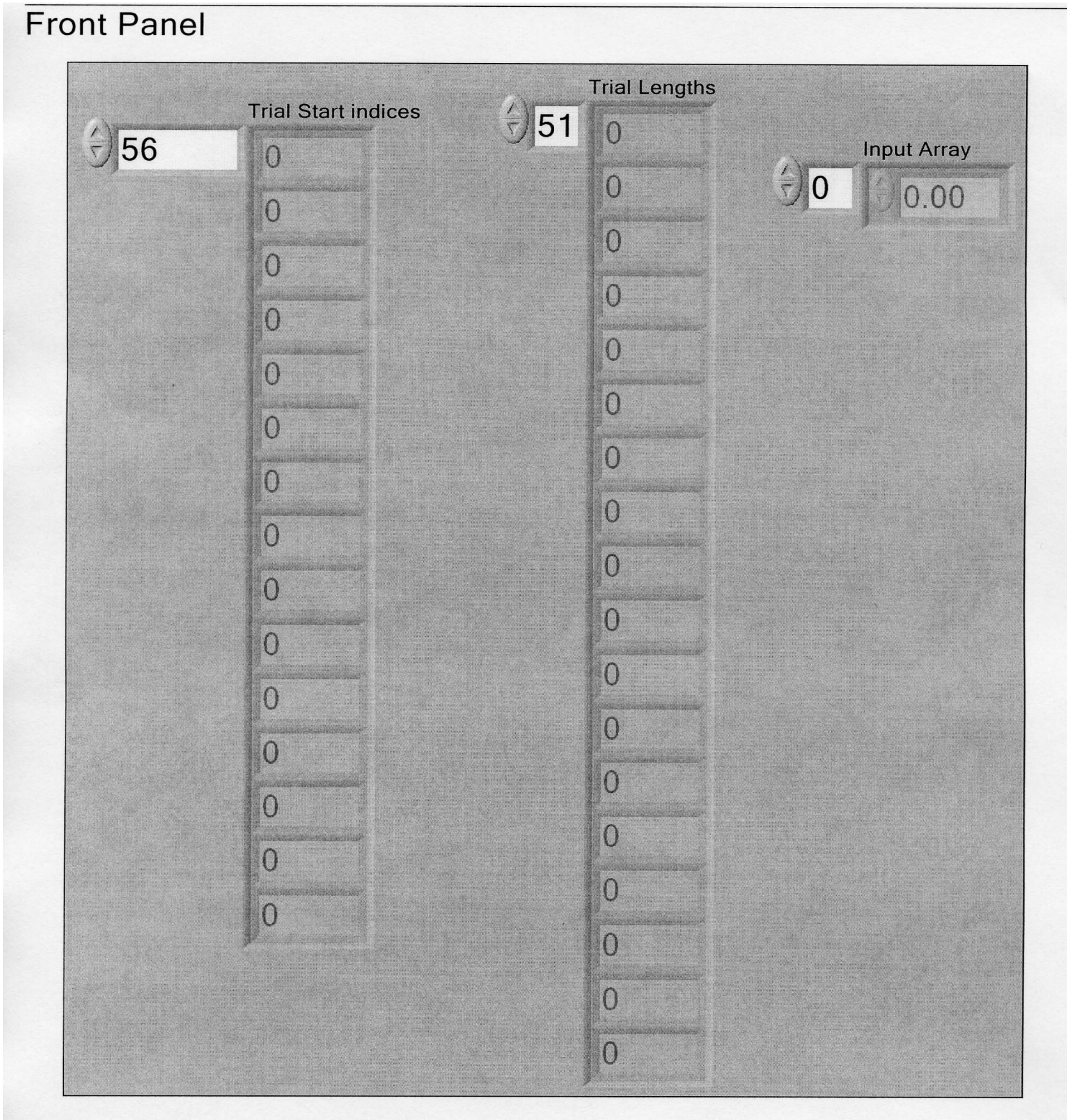
Appendix H

Data Reduction LabVIEW Programs

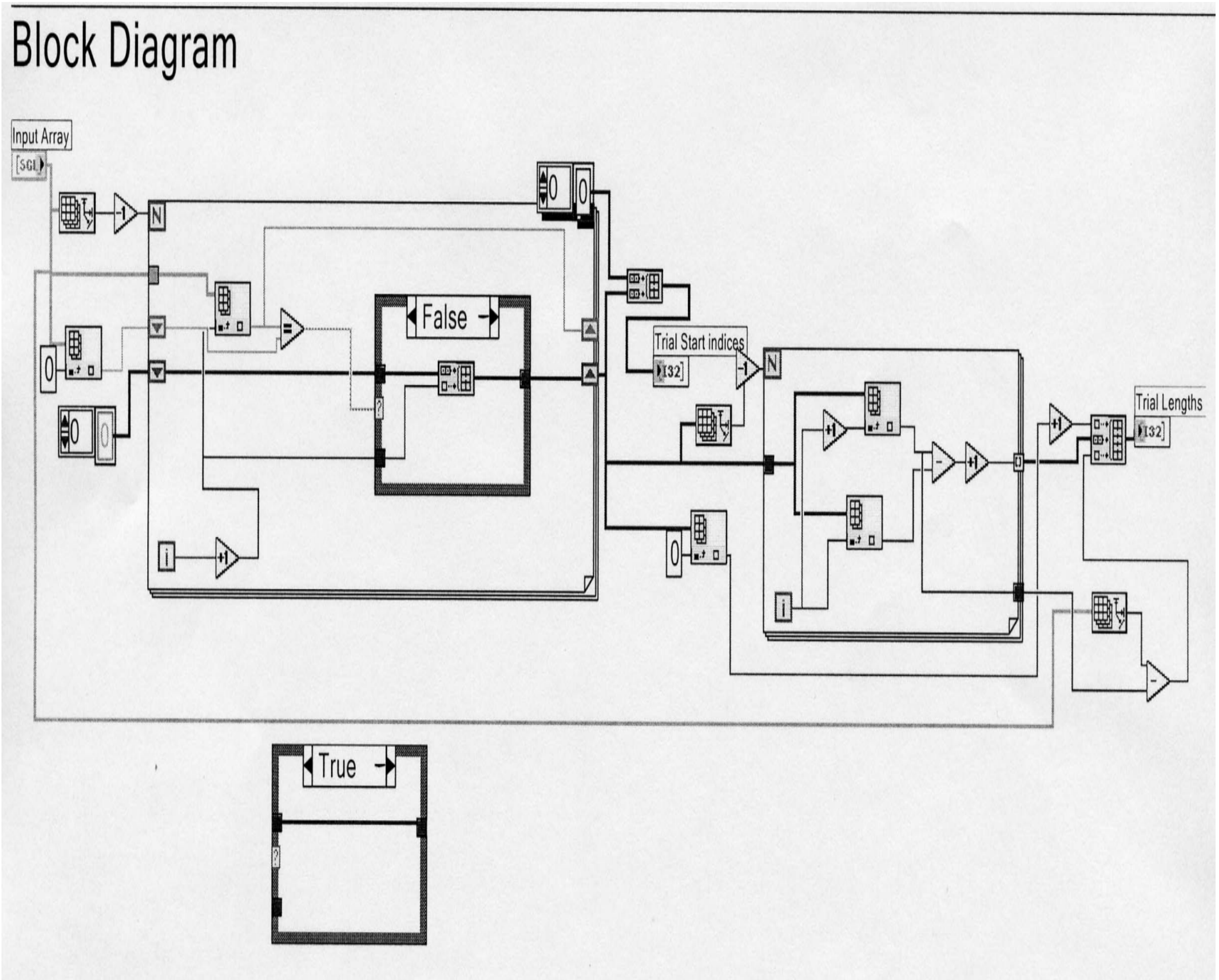
TRIAL SORTING BY TASK CONDITION - LabVIEW PROGRAM FRONT PANEL AND VIRTUAL INSTRUMENT (VI) DIAGRAM



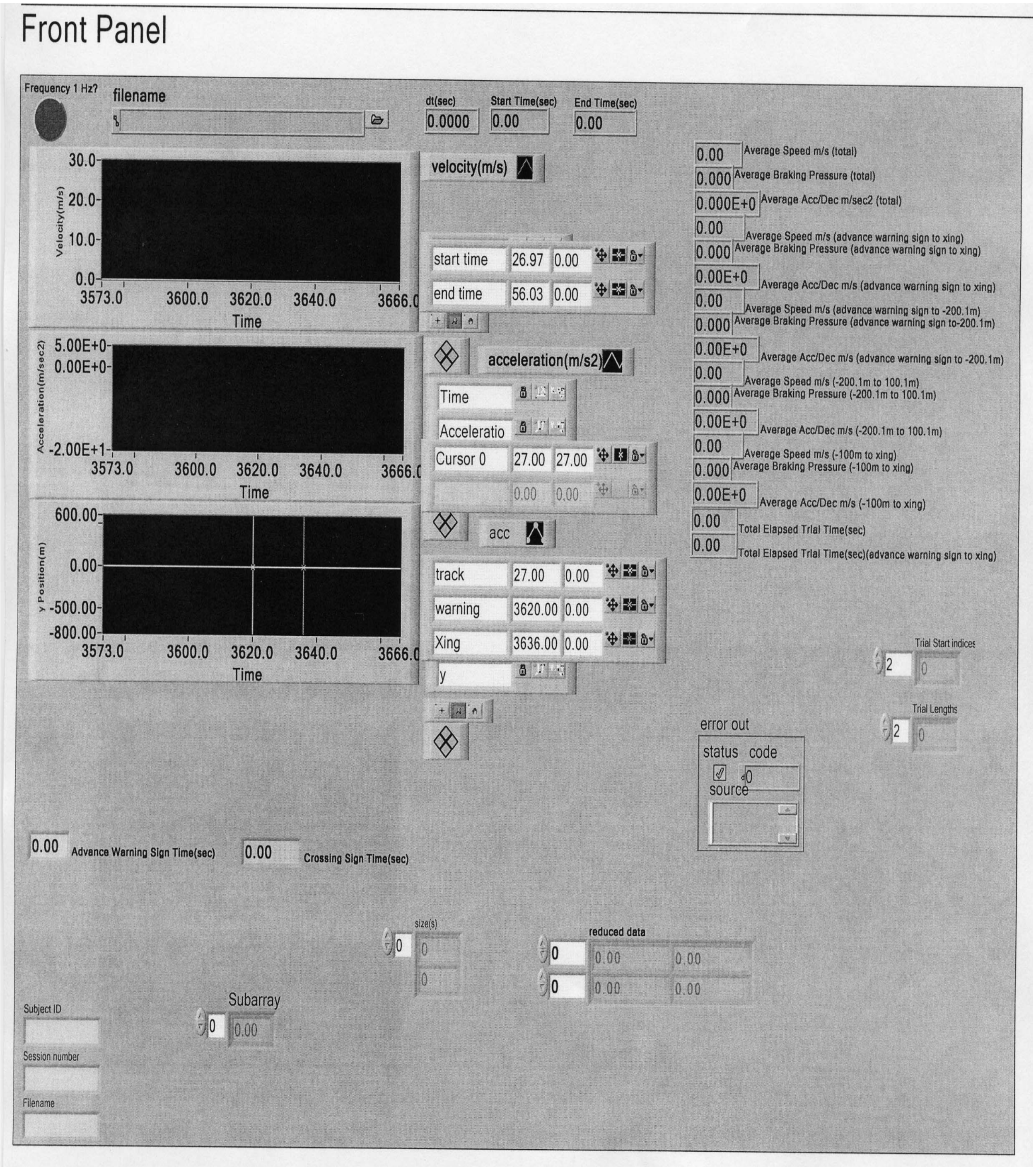
TRIAL DATA EXTRACTION - LabVIEW PROGRAM FRONT PANEL



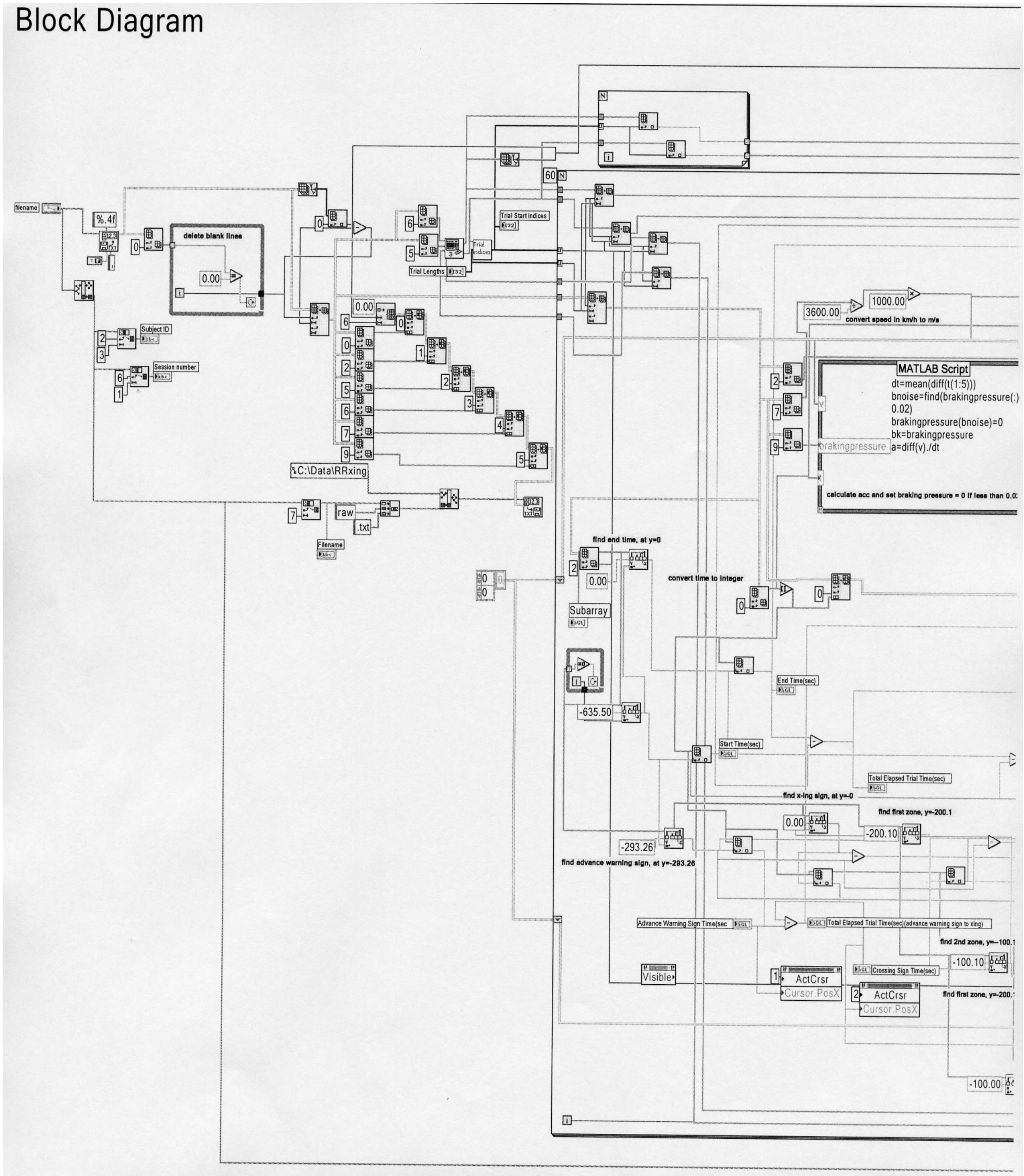
TRIAL DATA EXTRACTION - LabVIEW VI DIAGRAM



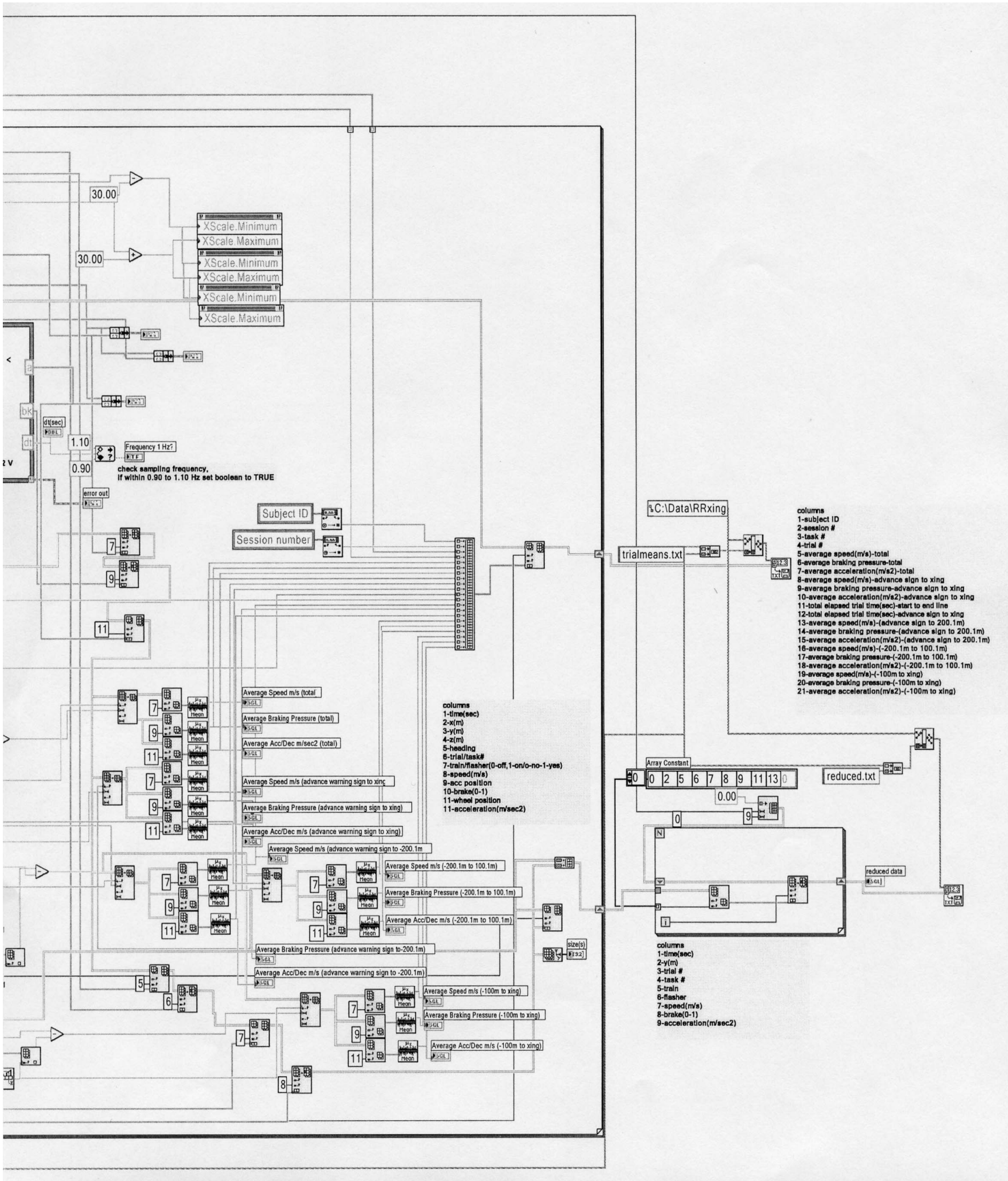
WITHIN SUBJECT DATA AVERAGING - LabVIEW PROGRAM FRONT PANEL



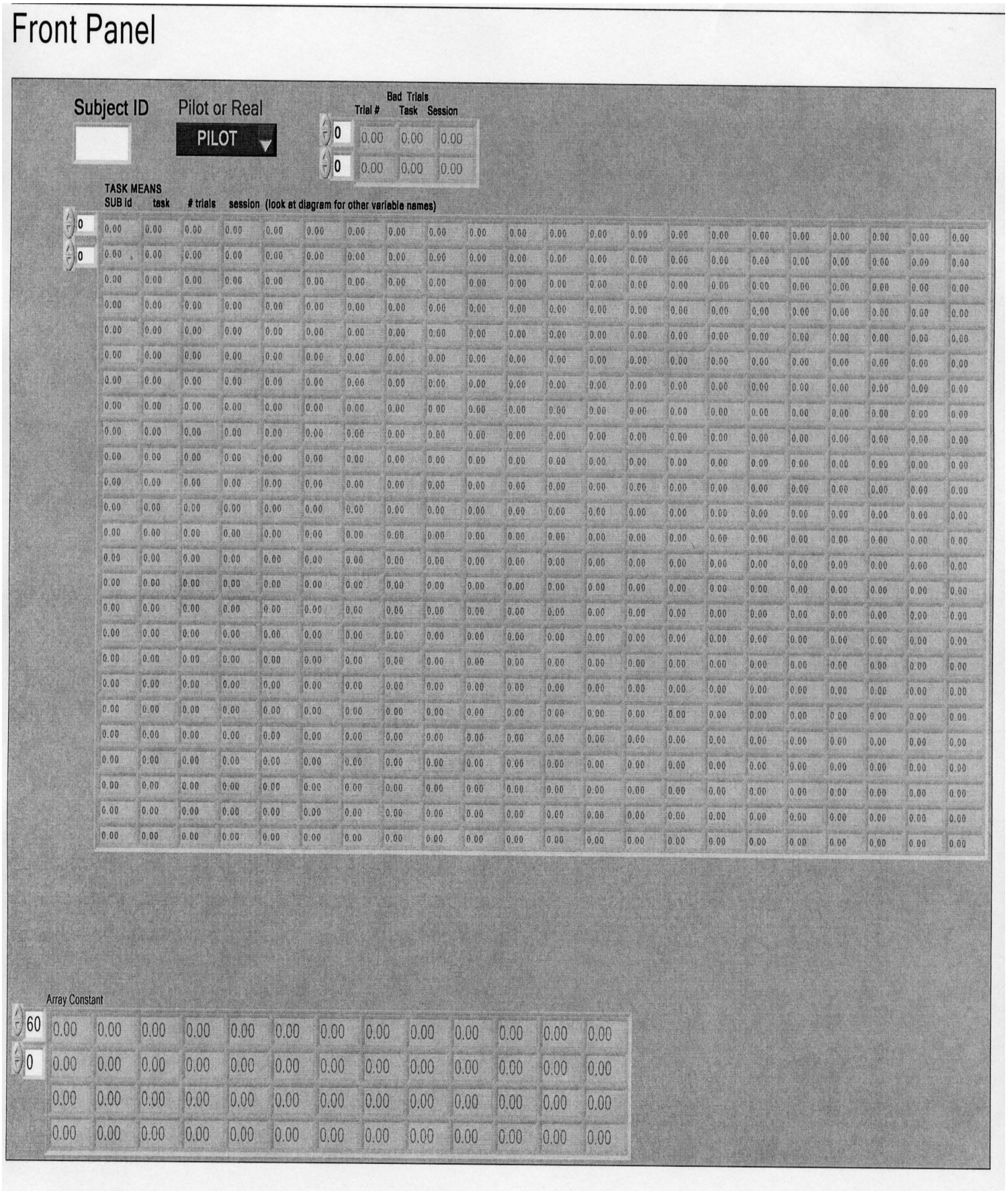
WITHIN SUBJECT DATA AVERAGING - LabVIEW PROGRAM VI DIAGRAM - PART 1



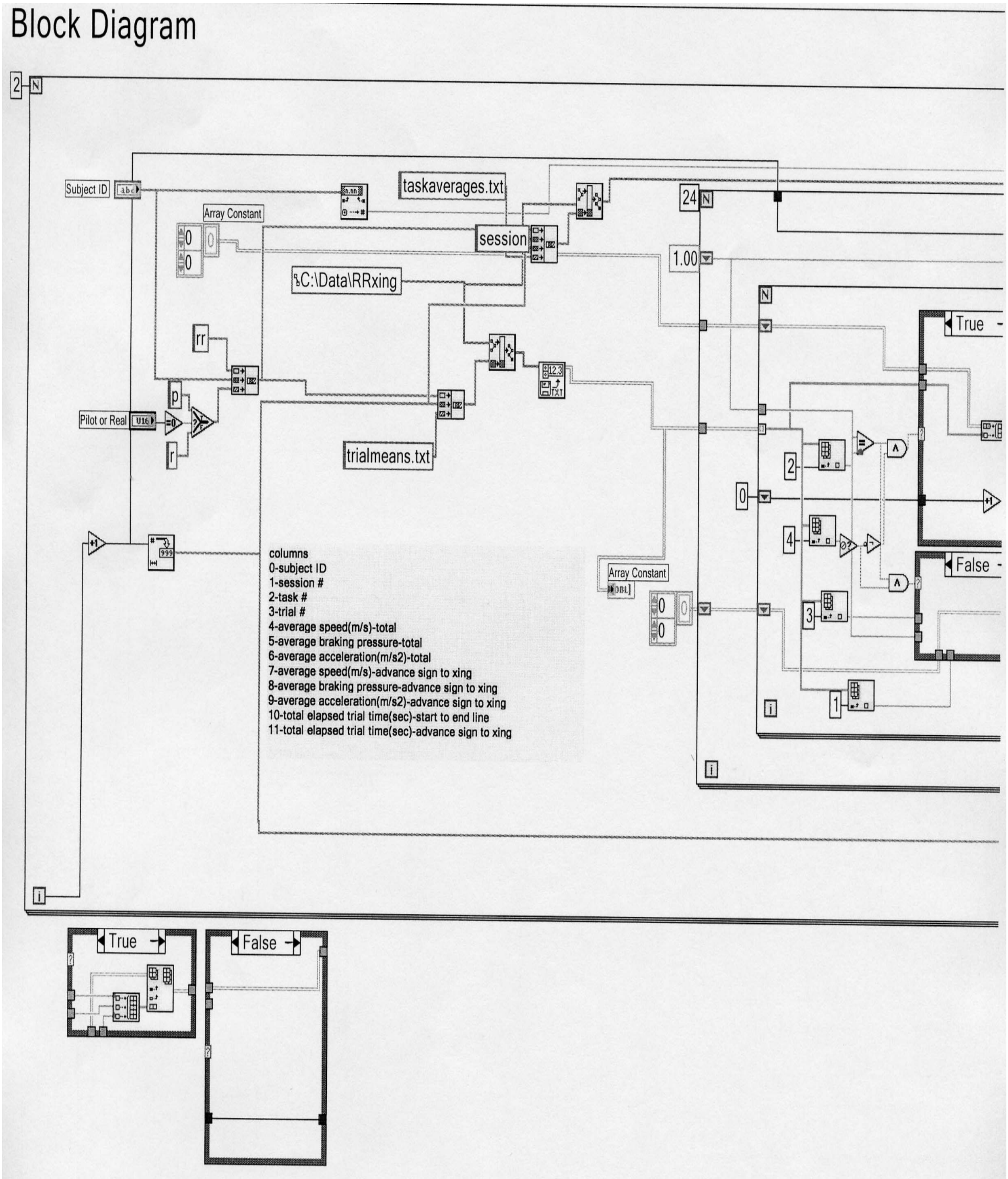
WITHIN SUBJECT DATA AVERAGING - LabVIEW PROGRAM VI DIAGRAM - PART 2



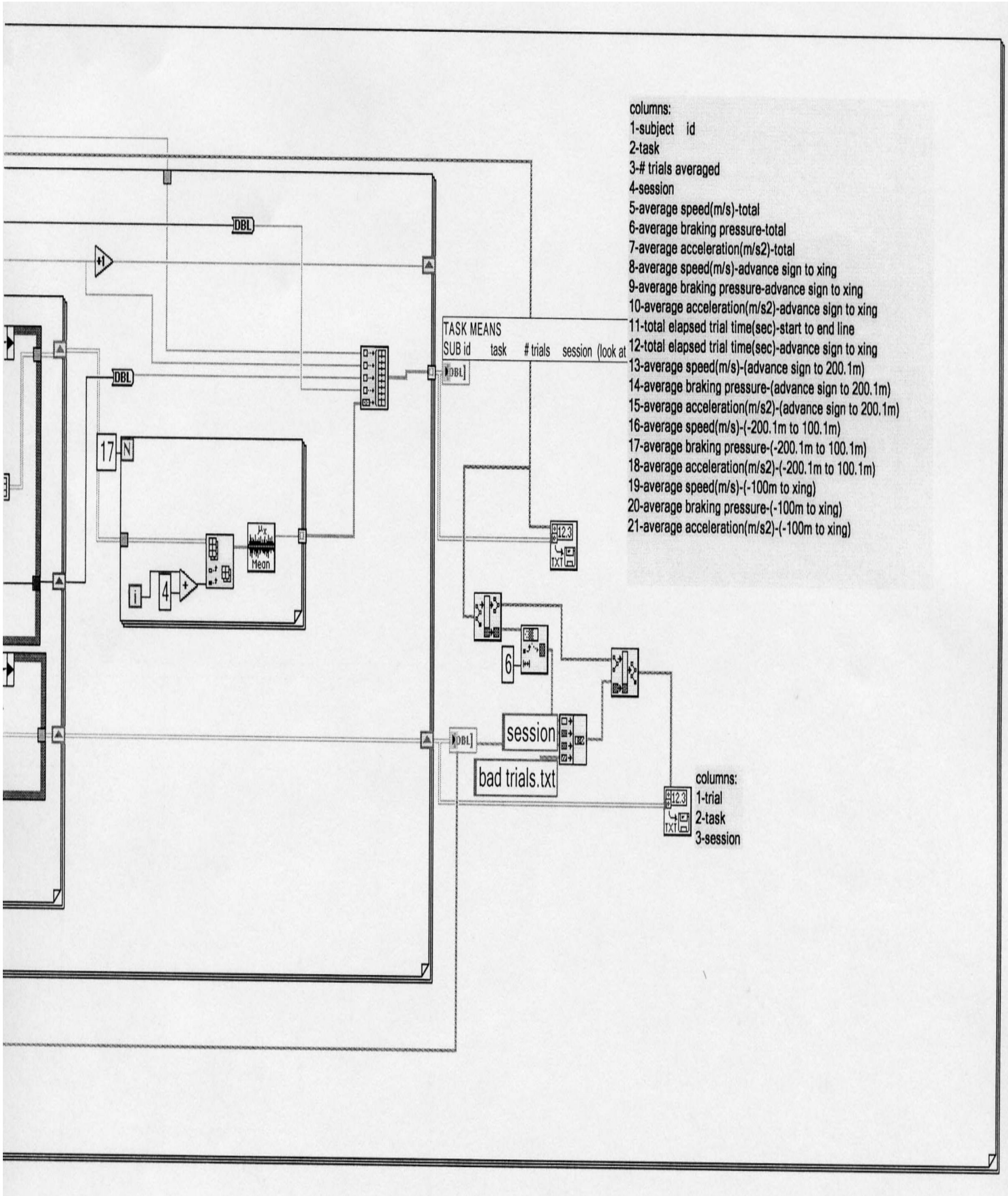
BETWEEN-SUBJECT DATA AVERAGING - LabVIEW PROGRAM FRONT PANEL



BETWEEN-SUBJECT DATA AVERAGING - LabVIEW PROGRAM VI DIAGRAM - PART 1



BETWEEN-SUBJECT DATA AVERAGING - LabVIEW PROGRAM VI DIAGRAM - PART 2



Appendix I

Post-Test Questionnaire Responses Regarding Purpose of Study

Subject ID	Post-Test Questionnaire Response to Q5: 'Please Explain Your Understanding of What the Purpose of This Study Is'
1	Basically I thought that the main part of the study was to see how I could correlate railroad warning signs to when a train would come. Granted, in the beginning I was skeptical as to if the signs were always telling me the truth, but after the first day, I found that they did. The fallen tree I did not understand as much but I figure it's because you wanted to see how I react to corners. I'm sure it was more complex than that, but that's what I took from it.
2	Drive following traffic laws & avoid accidents. Different hazards will appear randomly throughout session. Measure reaction ability to avoid hazards, not to crash, control speed, etc. Ability to avoid hazards.
3	I thought that this study may have something to do with either reaction times when encountering road hazards, or a combination of reaction time and driving characteristics when presented with varying road signs or signals indicating a train or railroad crossing. Also, the results that fog may alter.
4	I think the purpose was to determine reaction times, understand different weather conditions, fair and foggy, and to figure out if the type of rail road sign influenced reaction time.
5	I think the purpose was to see how people react when different hazards are in their way. The hazards were the train & the tree.
6	To observe people's response to driving conditions within a short duration. It seems to me that most accidents occur close to home, so that is why the length of each segment is short as well as somewhat predictable.
7	I noticed if [it was a] flashing warning, I would drive through or slow down. When [it was a] passive warning [it] did not help at all. I had fun.
8	To determine how drivers react to weather conditions and obstacles (road) [i.e., train, tree] by their speed and timing.
9	I don't know.
10	To test an individual's reactions to given stimuli (i.e., road hazards) while in a driving simulator; to explain driving habits.
11	Looking at different warning signals & their effectiveness as to how they warn drivers of possible hazards.
12	I would say reaction time, anticipatory skills, & safe driving distances in varied conditions as well as visual & spatial relationships.
13	To see how well people deal with road hazards in different types of weather. Can they stop in time and avoid accidents.

Subject ID	Post-Test Questionnaire Response to Q5: 'Please Explain Your Understanding of What the Purpose of This Study Is'
14	To observe the reaction time of drivers when confronted with obstacles in the road, and reactions under certain weather conditions.
15	From my understanding, the purpose of this study is to observe driving habits and reactions that are formed by repeated simulations of varying yet repetitive road conditions. Perhaps this is for the purpose of measuring degrees of unattentiveness when the driver becomes used to and expects the varying hazards and conditions.
16	To evaluate response and reaction times in different driving conditions.
17	To determine the effect of visual hazards on driving performance and your health.
18	I believe the purpose of the study was to test the effectiveness of different RR crossing warnings, with foggy weather conditions, a different more visible warning system seemed necessary with the limited distance you could see.
19	The purpose of this study to me was to study how people react to different hazards in the road and also to study how people drive differently according to different environments.
20	To understand the side effects of certain proprioceptors being used and others not. To also see if boredom and frustration play a role in the way people drive.
21	To see how people react to certain road hazards.
22	To study the driving patterns of adults and their reactions to stimuli. To see how people drive normally and how they react to a changing environment. I also think they wanted to see how I react to signs of a train or tree ahead and which 'signs' I recognized earlier and which signs I did not notice.
23	To test people's reaction/reaction time to various driving conditions.
24	To measure reaction times of drivers in various weather and hazardous conditions.
25	My guess is since the simulation repeated with only a few variations several times, it was to test tendencies with familiar settings. I knew certain areas that were more dangerous than others and become more cautious. The one accident I had was because I was not as familiar with the surroundings.