Crosswalk Marking Field Visibility Study

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FOREWORD

The Federal Highway Administration (FHWA) Pedestrian and Bicycle Safety Research Program's overall goal is to increase pedestrian and bicycle safety and mobility. From better and safer crosswalks, sidewalks, and pedestrian technologies to growing educational and safety programs, the program strives to make it safer and easier for pedestrians, bicyclists, and drivers to share roadways in the future.

This study was part of a larger FHWA study to quantify the effectiveness of engineering countermeasures in improving safety and operations for pedestrians and bicyclists. The project focused on existing and new engineering countermeasures for pedestrians and bicyclists that have not yet been comprehensively evaluated in terms of effectiveness. This effort involved data collection and analysis to determine whether the countermeasures reduced fatalities and injuries or increased appropriate driving behaviors. In this study, the detection distances to different crosswalk marking patterns were evaluated using field tests.

This report will interest engineers, planners, and other practitioners who have an interest in implementing pedestrian and bicycle treatments as well as city, State, and local authorities who have a shared responsibility for public safety.

Monique R. Evans
Director, Office of Safety
Research and Development

TECHNICAL REPORT DOCUMENTATION PAGE

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16. Abstract
The objective of this study was to investigate the relative daytime and nighttime visibility of three crosswalk marking patterns: transverse lines, continental, and bar pairs. In general, this study collected information on the distance from the crosswalk at which the participant verbally indicated its presence. The 78 participants were about evenly divided between groups of male and female participants and between groups of younger (younger than 55 years old) and older (55 years old or older) participants. The study was conducted in November 2009 using instrumented vehicles on an open road route on the Texas A&M University campus. Data were collected during two periods: daytime (sunny and clear or partly cloudy) and nighttime (street lighting on). Existing markings (six intersection and two midblock locations) and new markings installed for this study (nine midblock locations) were tested.

For the sites where markings were newly installed for this study, the detection distances to bar pairs and continental markings were similar, and they were statistically different from the detection distance to transverse markings both during the day and at night. For the existing midblock locations, a general observation was that the continental markings were detected at about twice the distance upstream as the transverse markings during daytime conditions. This increase in distance reflects 8 s of increased awareness of the presence of the crossing at 30-mi/h operating speeds.

Participants also rated the appearance of markings on a scale of A to F. These results mirrored the findings from the detection distance evaluation. Overall, participants preferred the continental and bar pairs markings over the transverse markings.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ACRONYMS AND ABBREVIATIONS

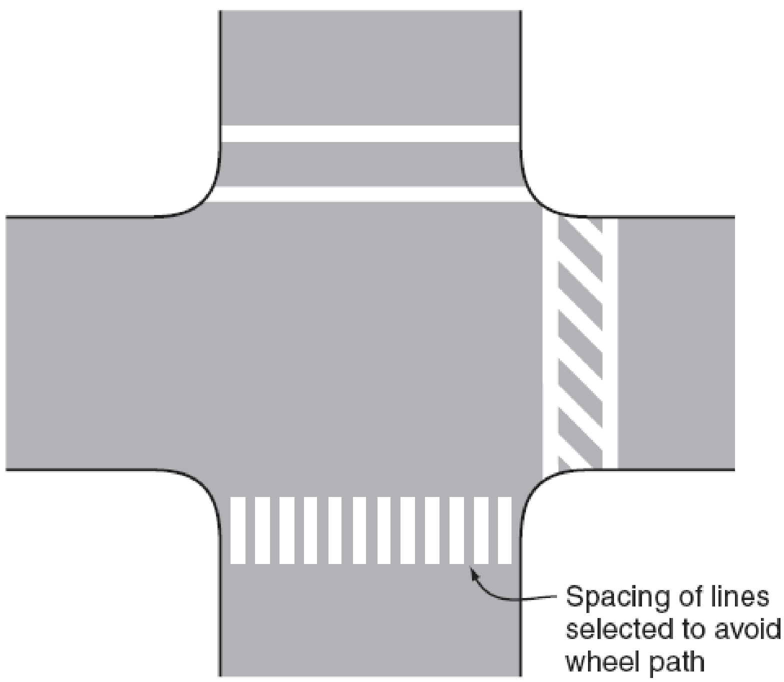
Adj	Adjusted
ANACOVA	Analysis of covariance
ATSSA	American Traffic Safety Services Association
BAR	Bar pairs crosswalk markings
CON	Continental crosswalk markings
DAS	Data acquisition system
DF	Degrees of freedom
DFDen	Denominator degrees of freedom
Driver_Sp	Driver speed
Ei	Crosswalk at existing intersection
Em	Crosswalk at existing midblock
FHWA	Federal Highway Administration
GPS	Global positioning system
ITE	Institute of Transportation Engineers
Loc	Location
LS	Least square
Mark_Type	Marking type
MUTCD	Manual on Uniform Traffic Control Devices
NA	Not applicable
NParm	Number of parameters
Ped/Bike_Pres	Pedestrian or bicycle presence
Prob	Probability
Reg Eqn	Regression Equation
R_L	Retroreflected luminance

S	Crosswalk at study sites
Std Error	Standard error
SS	Statistically significant
Sum Wgts	Sum of all weight values in a column
TAMU	Texas A&M University
TENC	Traffic Engineering Council
TRA	Transverse crosswalk markings
Traf_Pres	Traffic presence
TTI	Texas Transportation Institute
TWLTL	Two-way left-turn lane

CHAPTER 1. INTRODUCTION

BACKGROUND

The *Manual on Uniform Traffic Control Devices* (MUTCD) contains the basic principles that govern the design and use of traffic control devices for all streets and highways open to public travel.[1] Basic information about crosswalk markings is included in part 3 of the MUTCD. Crosswalk markings provide guidance for pedestrians crossing roadways by defining and delineating paths on approaches. These markings are to be used in conjunction with signs and other measures to alert road users of a designated pedestrian crossing point. Figure 1 shows examples of crosswalk markings as presented in the 2009 MUTCD. Because some States adopt their own supplement or manual on traffic control devices and some develop policies and practices for subjects not discussed in the MUTCD, differences in crosswalk markings occur among States, cities, and other jurisdictions.



Source: *Manual on Uniform Traffic Control Devices*, Figure 3B-19[1]

Figure 1. Graphic. Examples of crosswalk markings.

While emphasis has been placed on researching pedestrian treatments, there is insufficient research to identify the relative visibility and driver behavior effects of the many different styles and patterns of crosswalk markings used in the United States and abroad. Previous research has included a laboratory study using projected 35-mm slides of alternative crosswalk markings to determine which markings were the most visible.[2] Other studies have used speed measurements or yielding behavior recorded before and after the markings' installation.[3,4] These studies focused on whether the presence of the markings (rather than a specific pattern) was effective. The lack of knowledge of the relative visibility of different marking patterns has inhibited the development of a consensus on whether more uniformity is needed in the form of tighter MUTCD standards or more comprehensive guidance on crosswalk markings.

STUDY OBJECTIVE

The objective of this study was to investigate the relative visibility of three crosswalk marking patterns: transverse lines, continental, and bar pairs.

STUDY APPROACH

In this study, participants drove an instrumented vehicle on a route through the Texas A&M University (TAMU) campus in College Station, TX. Advantages of the study location included being a college campus associated with heavy pedestrian activity along with an open road environment that avoided the driver being in an artificial setting while participating in the study. The route also included roads through the agricultural area of the campus, where roadways are more rural in feel. The study vehicle was equipped with instrumentation that allowed researchers to measure and record various driving performance data. However, the vehicle operated and drove like a normal vehicle.

Prior to the drive, participants were instructed to indicate when crosswalk markings were first detected by saying “crosswalk.” They were also asked to identify speed-limit signs and two-way left-turn lane (TWLTL) arrows. In general, this study collected information on the distance from the crosswalk at which the participant verbally indicated its presence.

CHAPTER 2. LITERATURE REVIEW

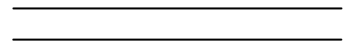
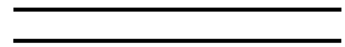
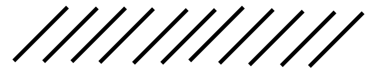
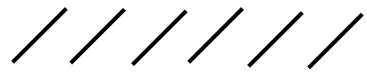
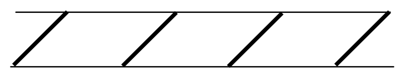
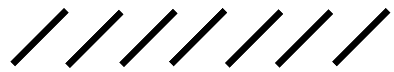
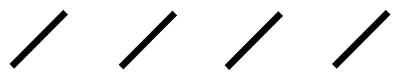
LABORATORY EVALUATION

Knoblauch et al. conducted a laboratory evaluation of alternative crosswalk markings in the late 1980s.[(2)] Researchers projected 35-mm slides of pictures that represented crosswalk markings located at 300, 400, or 500 ft. Preliminary tests included markings at shorter and longer distances, but they were eliminated because they were either always correctly identified (shorter distances) or were almost indiscernible (longer distances). The 59 subjects were told that the slides might show a crosswalk, lettering, or even nothing. The subjects were asked to indicate on an answer sheet, to the best of their ability, what they could see: nothing, something (unsure if it was a crosswalk or lettering), lettering, or a crosswalk. A score of 3 was assigned to the pattern if the subject correctly identified the marking at all three distances (300, 400, and 500 ft), a 2 was assigned if the markings were correctly identified at two of the three distances, and so on. The crosswalk marking patterns tested are shown in table 1.

The authors concluded that one class of pattern emerged consistently as the best—the ladder crossings. Within the ladder group, there was minimal difference between three different patterns that had spacing of 12 or 24 inches between the stripes. The pattern that used the greatest spacing, 48 inches, did not test as well (2.2) as the other ladder patterns (2.8, 2.7, and 2.8).

Using the provided scores, an estimate of where the ladder markings were detectable was calculated to be about 400–500 ft. The authors did not provide the scores for the other markings, so a comparison with the viewing distance to a transverse marking or to word markings cannot be made.

Table 1. Patterns tested by Knoblauch et al.[2]

Test	Description	Sketch (not to scale; but approximate proportions)
1	6-inch wide edgelines	
2	12-inch wide edgelines	
3	24-inch wide edgelines	
4	12-inch diagonal stripe with 12-inch space	
5	12-inch diagonal stripe with 24-inch space	
6	12-inch diagonal stripe with 48-inch space	
7	12-inch diagonal stripe with 48-inch space with 8-inch edgelines	
8	24-inch diagonal stripe with 24-inch space	
9	24-inch diagonal stripe with 48-inch space	
10	12-inch ladder stripe with 12-inch space	
11	12-inch ladder stripe with 24-inch space	
12	12-inch ladder stripe with 48-inch space	
13	24-inch ladder stripe with 24-inch space	
14	24-by-12- inch box with 24-inch spaced edgelines	
15	24-by-12-inch box with 36-inch spaced edgelines	
16	24-by-12-inch box with 48-inch spaced edgelines	
17	Transverse word marking STOP	STOP
18	Transverse word marking ONLY	ONLY

SPEED EVALUATIONS

Speed has also been used as a measure of effectiveness for crosswalk markings. In August 2000, Knoblauch and Raymond reported on the effects of crosswalk markings on vehicle speeds at six sites located in three States.[(3)] All sites were at uncontrolled intersections that had been recently resurfaced and had a speed limit of 35 mi/h. Before speed data were collected after the centerline and edgeline delineation was installed but before the crosswalk was installed. After data were collected after the crosswalk markings were installed for three conditions: no pedestrian present, staged pedestrian looking, and staged pedestrian not looking. The results indicated a slight reduction in speed at most, but not all, of the sites (typically on the order of 1–3 mi/h). Overall, there was a significant reduction in speed under both the no pedestrian and the pedestrian not looking conditions. The authors noted that "any speed reduction in response to the crosswalk marking alone (e.g., with no pedestrians present) is somewhat surprising. The crosswalk markings are intended merely to inform drivers to slow and prepare to yield to a pedestrian if one (or more) is present. It is technically not necessary to slow down unless a pedestrian(s) is present." The authors concluded, "it appears that drivers are aware of—and respond to—crosswalk markings by slowing down slightly. It also appears that drivers react differently to the different pedestrian scenarios that were staged. They are more careful (e.g., they slowed more) when the pedestrian does not appear to be paying attention to approaching traffic, and this is the situation where they, as drivers, need to be especially careful."

In August 2001, Knoblauch et al. reported on research that determined the effect of crosswalk markings on driver and pedestrian behavior at unsignalized intersections.[(4)] A before/after evaluation of crosswalk markings was conducted at 11 locations in 4 U.S. cities. It was found that drivers approach a pedestrian in a crosswalk somewhat slower. No change was found in driver yielding. The vehicle speed and staged pedestrian study involved a comparison of vehicle speeds before and after crosswalk markings were installed. Vehicle speeds were measured at two locations (approach speed and crosswalk speed) under three separate pedestrian conditions (no pedestrian present, staged pedestrian standing in crosswalk looking in the direction of oncoming traffic, and staged pedestrian in crosswalk making a stepping motion as if he/she were about to step into the roadway). For the "Ped Looks" condition, speed reductions were found at all locations. The magnitude of the speed reductions varied from 0.2 to 2 mi/h. For the "Ped Steps" condition, the approach speeds in Sacramento and Buffalo decreased significantly (between 0.4 and 2.1 mi/h) and the approach speeds in Richmond increased significantly, which was not expected. The authors found that there was no difference in approach speed when no pedestrian was present. They noted the following:

> "This was expected since there is no need for a driver to slow down when approaching a crosswalk unless a pedestrian is present. The purpose of the crosswalk marking is to produce a change in driver awareness. The markings should be telling the driver that pedestrians may be present and, if they are present, they may cross the road at that location. Basically, the desired driver response to a marked crosswalk is: 'There may be a pedestrian here; I need to be careful' or 'If I see a pedestrian here, they may cross; I need to be careful.' It is not essential that the driver slow down. Unfortunately, there is no way to observe or measure driver awareness, so vehicle speed is used as a kind of surrogate measure."

While decreases in speed on the approach to a crosswalk may indicate that drivers are more alert to their surroundings, the preference is to use more direct measures. Knoblauch et al. stated that there is no way to observe or measure driver awareness.[(4)] However, there may be methods available in certain situations, such as laboratory or instrumented vehicle settings. For example, an eye tracker or dashboard camera can be used to measure if drivers increase their search of the roadside for potential pedestrians when they detect and recognize crosswalk markings. These settings could also provide information on the distances that drivers can detect and recognize crosswalk markings with or without signs.

CHAPTER 3. MARKING PATTERN SELECTION

CROSSWALK MARKING PATTERNS BEING USED

In spring 2009, the Institute of Transportation Engineers (ITE) Traffic Engineering Council (TENC) Committee 109-01 was formed. The objective of the committee was to document the crossing types and patterns being used at uncontrolled pedestrian crossings.[5] The focus of the committee was on the crosswalk marking patterns at a location rather than whether a marked crosswalk should be present. A recent Transit Cooperative Research Program/National Cooperative Highway Research Program project provided a summary of pedestrian crossing installation guidelines.[6,7] Examples of crosswalk markings along with the common name the ITE TENC committee used to describe them are shown in the following figures:

- Figure 2: two transverse lines crosswalk marking pattern.
- Figure 3: ladder crosswalk marking pattern.
- Figure 4: transverse with diagonal lines crosswalk marking pattern.
- Figure 5: continental crosswalk marking pattern.
- Figure 6: bar pairs crosswalk marking pattern.
- Figure 7: double continental crosswalk marking pattern.

Source: Texas Transportation Institute

Figure 2. Photo. Typical two transverse lines crosswalk marking pattern at a raised crosswalk (Bryan, TX).

Source: Texas Transportation Institute

Figure 3. Photo. Typical ladder crosswalk marking pattern (Boston, MA).

Source: www.pedbikeimages.org/Dan Burden

Figure 4. Photo. Typical transverse with diagonal lines crosswalk marking pattern (Aspen, CO).

Source: Texas Transportation Institute

Figure 5. Photo. Typical continental crosswalk marking pattern (Chicago, IL).

Source: Scott Wainwright

Figure 6. Photo. Typical bar pairs crosswalk marking pattern (Seattle, WA).

Source: Dan Bergenthal

Figure 7. Photo. Typical double continental crosswalk marking pattern (Salt Lake City, UT).

The committee's activity started with an email listserv survey on crosswalk markings. The simple survey provided general insight into the marking patterns being used and identified potential members for the committee. While the survey was conducted informally, it did provide a general indication of preferences for patterns currently used. Summing the number of times a pattern was selected by a respondent generated the following distribution:

- Transverse lines = 8.
- Ladder = 8.
- Continental = 12.
- Diagonal = 2.
- Other = 2.

The comments from the respondents gave insight into the reasons different marking patterns are selected. Areas of concern included the following:

- Spacing the ladder or continental longitudinal lines to avoid the wheel path.
- Providing a portion of crosswalk without markings so pedestrians or stopped motorcyclists can find bare pavement to obtain traction.

OBSERVATIONS FROM ITE TECHNICAL COMMITTEE

While gathering information, the ITE TENC committee members had the opportunity to talk to those making decisions regarding crosswalk marking installations. Following is a summary of observations made by members of the committee:[5]

- In some regions, the type of markings used is a function of the engineer's judgment. The cost of reapplying markings also influences decisions (e.g., diagonal markings wear more quickly because more of the markings are in the wheel path).
- There is a concern regarding the minimal attention given to selecting a style of crosswalk markings in certain regions. This issue could become more critical with staff turnover.
- Information regarding crosswalk markings needs to be distributed, especially better information on when to select a particular marking type.
- A one- or two-sided "tech sheet" with key findings distributed through Local Technical Assistance Program centers could be a resource and a method to distribute information to local agencies responsible for applying crosswalk markings. The sheet could be used in pedestrian safety classes, pavement markings classes, and traffic control devices classes, as well as on any field technical assistance visits related to crosswalks. The ITE TENC committee has developed such a tech sheet.
- The MUTCD allows numerous options for crosswalks in order to give flexibility to highway agencies. Perhaps there is a need for more tightly prescribed allowable options in the MUTCD to provide clearer direction on which types of markings are best suited for certain conditions. However, in the absence of definitive research showing specific safety benefits of one crosswalk style versus others, highway agencies would likely oppose reduction in the flexibility currently afforded to them.

CROSSWALK MARKINGS PATTERNS SELECTED FOR THIS STUDY

During the development of the study approach, routes that included existing crosswalks in Bryan, TX; College Station, TX; and the TAMU campus were considered. During a conference call including the research team and representatives of the Federal Highway Administration (FHWA), the decision was made to focus on evaluations of a smaller number of crosswalk marking patterns and to repeat the patterns at several locations. The conditions at a site, such as presence of lighting or posted speed, can have a significant influence on driver behavior. Therefore, repeating the patterns at several locations helps to isolate driver behavior differences to the markings rather than to another site characteristic. At the meeting between FHWA and the research team, the following patterns were selected for study:

- Transverse lines.
- Continental.
- Bar pairs.

Transverse and continental markings were selected because they are the most common markings, according to the findings from the recent ITE TENC committee survey and in the judgment of the engineers present on the conference call. The bar pair markings were selected because they are being considered and, in several cases, installed by a number of communities. They may also represent a lower-cost alternative to continental markings because they use approximately two-thirds the marking material that would be present in a similar continental marking application.

CHAPTER 4. DATA COLLECTION

CANDIDATE ROADWAY SELECTION

Initial efforts for this study began with identifying potential candidate roads or areas within the community. Potential study sites within TAMU west campus were determined. The main campus was eliminated due to challenges with developing a logical route as several roads have been closed to discourage vehicle traffic. TAMU west campus includes several miles of roadways, so a reasonable study route was possible. Another benefit to restricting the study location to the TAMU campus is that coordination regarding marking installation would be with only one agency.

PRELIMINARY SITE SELECTION

The goal was to identify study sites with similar characteristics such as posted speed limit, cross section width, cross section type, presence of crosswalks, etc. Each study site had to be greater than 600 ft from another site, from a signal or all-way stop-controlled intersection, and from the turn onto the road. The 600-ft dimension was selected based on the review of the findings from the Knoblauch et al. study that found crosswalks were detected at about 400–500 ft.(2)

The potential sites could easily be divided into the following three groups:

- Sites on F&B Road.
- Sites on Agronomy Road.
- All remaining sites.

Each group had at least three feasible sites. The sites on F&B and Agronomy had similar characteristics such as pavement width, number of lanes, and presence of TWLTL. For the third group, sites had to be selected along several different roads. Divided roads were eliminated from the candidate list of sites, which resulted in the third group having potential sites on two roads. These sites had the same posted speed limits (30 mi/h) but with greater differences in cross section width (43–50 ft) than desired.

PHOTOMETRIC READINGS

Photometric readings were taken as part of the site selection process. Once the streets were determined, illuminance readings were taken at potential sites using a T-10 M Illuminance meter. The plan was to have half of the participants drive in a clockwise direction and the other half drive in a counterclockwise direction. Therefore, the readings were taken on both sides of the street during nighttime conditions for each of the potential sites.

The receptors were arranged such that there was one receptor facing each direction of travel and one straight up. Each receptor head was given an identification number, and the three receptor head adapters were connected in series to the main body adapter to record readings simultaneously. An in-house portable setup was built to hold the equipment arrangement for convenience and safety in the field. The sensors were placed such that they did not interfere with each other, were within inches of the pavement surface, and were approximately 4 ft from the curb. Two technicians were involved in the reading. One person operated the instrument and called out the readings while the other watched traffic and recorded the readings. The readings were taken when there was no traffic on the street. The readings from the sensor facing straight up were considered in site selection.

For each of the three groups or roads being considered, the research team identified those sites with similar crosswalk width and illuminance readings. Three sites that had the most similar nighttime light level and that would result in the greatest distance between the study sites were then selected within each group. Table 2 summarizes the characteristics of the sites selected within the three groups. While the characteristics are not the same, they are the most similar of the sites available for this study.

Table 2. Site characteristics.

Group (Road Names)	Speed Limit (mi/h)	Cross Section		Nighttime Light Level (lx)	
		Lanes	Width (ft)	Clockwise	Counterclockwise
Agronomy	30	2 lanes with TWLTL	42	0.11–5.97	0.19–12.89
F&B	45	2 lanes with TWLTL	40	7.81–9.90	57.5–68.20
Discovery	30	4 lanes undivided	50	12.60–23.88	1.08–1.62
Penberthy	30	2 lanes w/ bike lanes	43	36.80	10.55

1 lx = 0.0929 fc

STUDY SITES AND CROSSWALK MARKINGS

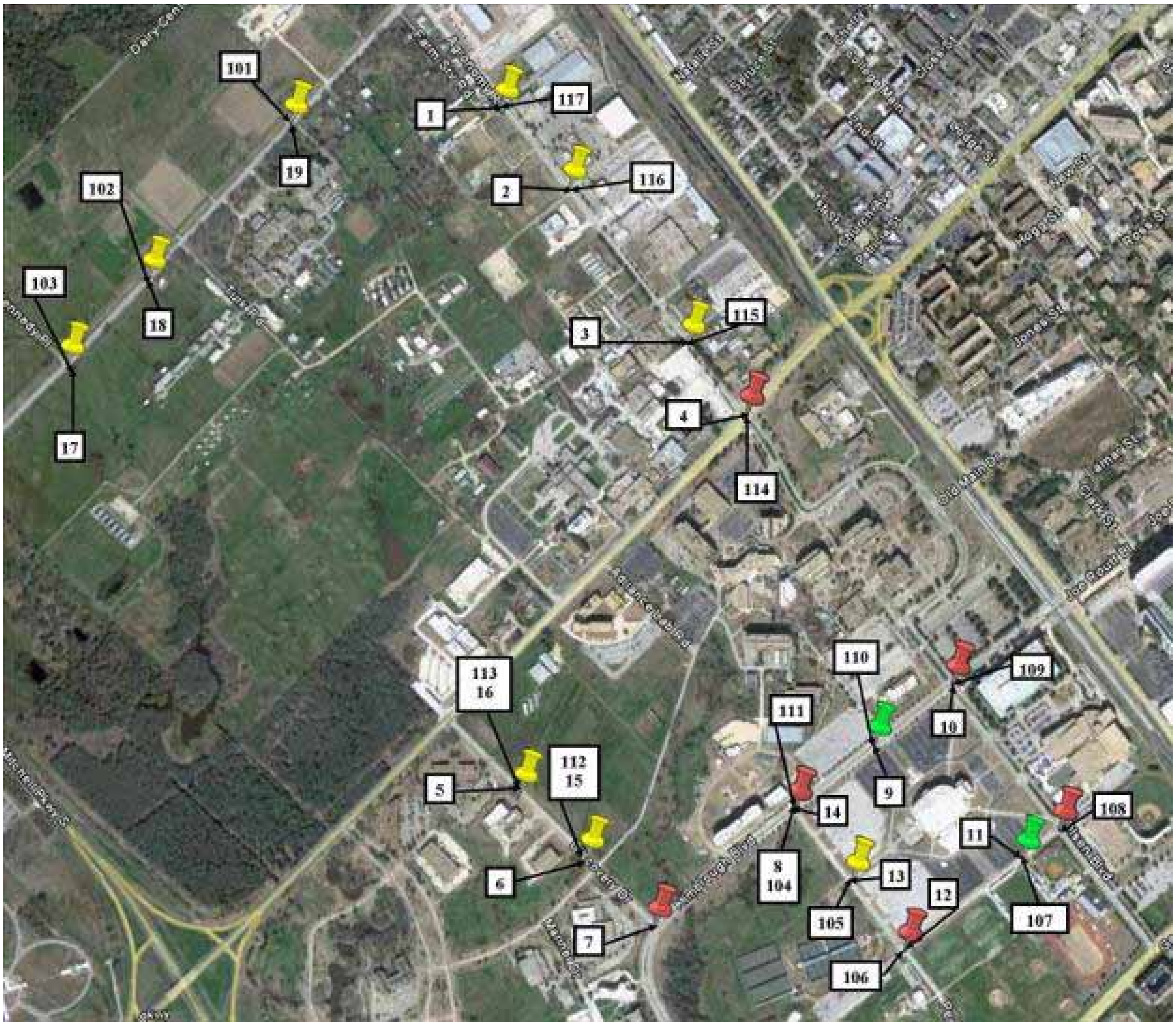
The route taken through the TAMU west campus included a number of intersections and midblock locations with crosswalks. Some of the locations had pre-existing crosswalks while others had experimental crosswalk markings added as part of this study. Figure 8 shows the location of the study sites along with the number assigned to the crosswalk for each direction. The distances between the sites are shown in figure 9. Within each group, the test marking patterns were installed so that a participant did not encounter the marking pattern in the same order across roadway segments. In figure 8 and figure 9, the sites are depicted as follows:

- Yellow pushpins (sites 1, 2, 3, 5, 6, 13, 15, 16, 17, 18, 19, 101, 102, 103, 105, 110, 112, 113, 115, 116, and 117) represent sites with markings newly installed or existing sites with markings repainted.

- Red pushpins (sites 4, 7, 8, 10, 12, 14, 104, 106, 108, 109, 111, and 114) represent all-way stop-controlled, two-way stop-controlled, and signal-controlled intersections.

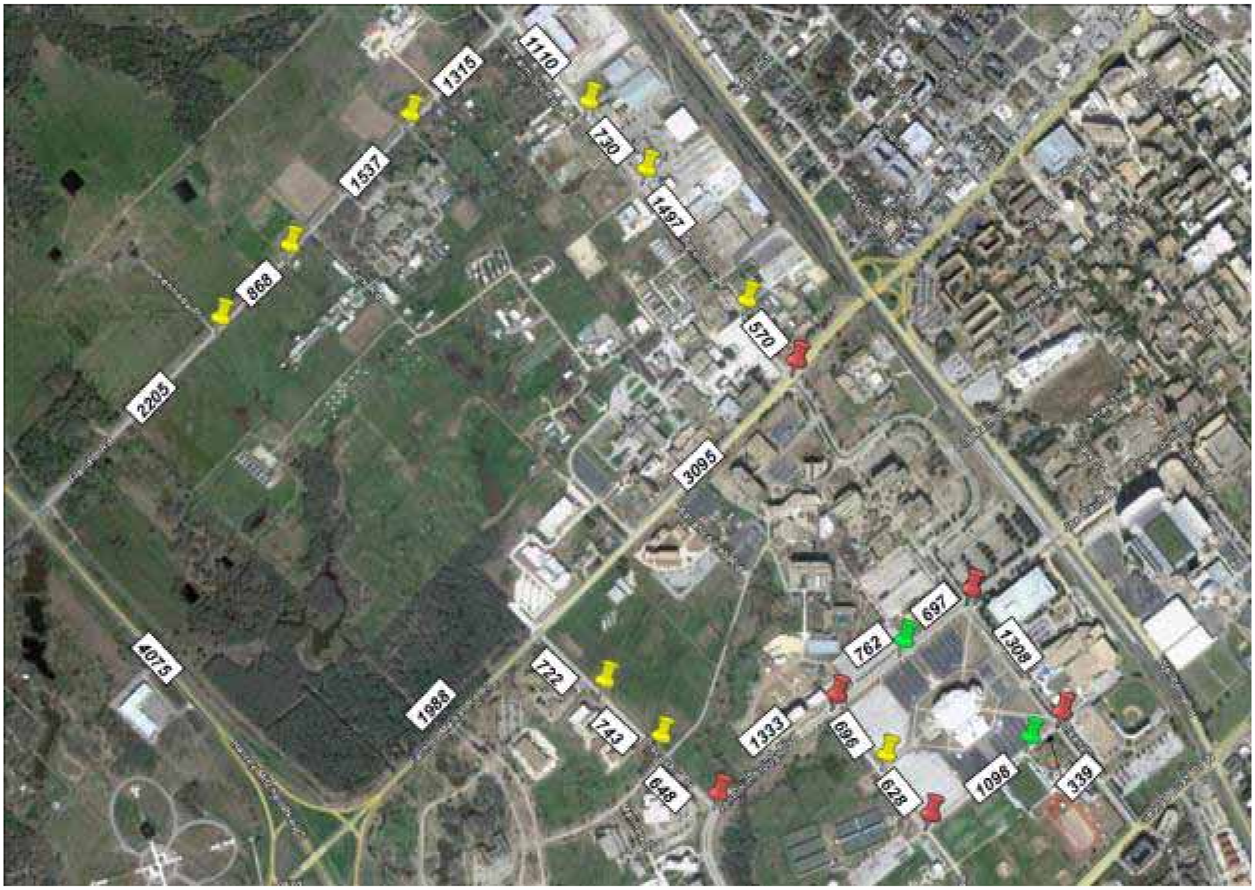
- Green pushpins (sites 9, 11, 107, and 110) represent sites with existing crosswalk markings.

Table 3 lists the sites included in the driving route in the order the participant would encounter them when driving the clockwise route. The site characteristics for the counterclockwise route are listed in table 4. The tables also include the nighttime light level along with the retroreflective measurement of the newly installed markings.



Source: Google Earth™ mapping service

Figure 8. Map. Location of crosswalk study sites.



Source: Google Earth™ mapping service

Figure 9. Map. Distances between crosswalk study sites.

Table 3. Crosswalk number and characteristics for clockwise route.

Crosswalk Number	Road	Marking type	Location	Speed Limit (mi/h)	Width (ft)	Illum[a] (lx)	Retro[b] (mcd/ m^2/lx)
1	Agronomy	Bar pairs	Study	30	42	0.11	787
2	Agronomy	Transverse	Study	30	42	5.97	784
3	Agronomy	Continental	Study	30	42	2.02	702
4	Agronomy	Transverse	E-intersection	30	42	NR	NR
5	Discovery	Transverse	Study	30	50	12.6	734
6	Discovery	Continental	Study	30	50	23.88	652
7	Discovery	Transverse	E-intersection	30	50	NR	NR
8[c]	Kimbrough	Transverse	E-intersection	30	76	NR	12
9	Kimbrough	Transverse	E-midblock	30	76	NR	309
10	Kimbrough	Continental	E-intersection	30	76	NR	524
11	Chandler	Continental	E-midblock	30	40	NR	121
12	Chandler	Transverse	E-intersection	30	40	NR	25
13	Penberthy	Bar pairs	Study	30	43	36.8	900
14	Penberthy	Transverse	E-intersection	30	43	NR	38
15[c]	Discovery	Continental	Study	30	50	1.62	649
16[c]	Discovery	Transverse	Study	30	50	1.08	602
17	F&B	Continental	Study	45	40	9.9	695
18	F&B	Bar pairs	Study	45	40	7.81	856
19	F&B	Transverse	Study	45	40	8.38	799

[a] Illuminance readings taken at nighttime with the sensor aimed up, measured in lux.
[b] Coefficient of retroreflected luminance, measured in mcd/m^2/lx. The American Traffic Safety Services Association (ATSSA) recommended minimum R_L value is 100 mcd/m^2/lx.[(8)]
[c] A few sites were repeated due to the driving route. (See table 4.) Number 104 is the same site as 8, 112 is same site as 15, and 113 is same site as 16.
1 lx = 0.0929 fc
Study = Installed for this study at a midblock location.
E-intersection = Existing crosswalk at a stop-controlled or signalized intersection.
E-midblock = Existing crosswalk at a midblock; location has pedestrian crossing signs.
NR = No reading made (illuminance measurements were only done at proposed sites for marking installation to aid in identifying study locations; some markings were too worn to obtain a reading).

Table 4. Crosswalk number and characteristics for counterclockwise route.

Crosswalk Number	Road	Marking type	Location	Speed Limit (mi/h)	Width (ft)	Illum[a] (lx)	Retro[b] (mcd/ m^2/lx)
101	F&B	Transverse	Study	45	40	57.5	684
102	F&B	Bar pairs	Study	45	40	65.5	619
103	F&B	Continental	Study	45	40	68.2	686
104[c]	Kimbrough	Transverse	E-intersection	30	70	NR	12
105	Penberthy	Bar pairs	Study	30	43	10.55	823
106	Penberthy	Transverse	E-intersection	30	43	NR	32
107	Chandler	Continental	E-midblock	30	40	NR	81
108	Chandler	Transverse	E-intersection	30	40	NR	NR
109	Olsen	Continental	E-intersection	30	92	NR	570
110	Kimbrough	Transverse	E-midblock	30	76	NR	331
111	Kimbrough	Transverse	E-intersection	30	76	NR	30
112[c]	Discovery	Continental	Study	30	50	1.62	649
113[c]	Discovery	Transverse	Study	30	50	1.08	602
114	University	Transverse	E-intersection	40	75	NR	NR
115	Agronomy	Continental	Study	30	42	12.89	696
116	Agronomy	Transverse	Study	30	42	4.91	643
117	Agronomy	Bar pairs	Study	30	42	0.19	801

[a] Illuminance readings taken at nighttime with the sensor aimed up, measured in lux.
[b] Coefficient of retroreflected luminance, measured in mcd/m^2/lx. The ATSSA recommended minimum R_L value is 100 mcd/m^2/lx.[8]
[c] A few sites were repeated due to the driving route, those sites with duplicate numbers. (See table 3). Number 104 is same site as 8, 112 is same site as 15, and 113 is same site as 16.
1 lx = 0.0929 fc
Study = Installed for this study at a midblock location.
E-intersection = Existing crosswalk at a stop-controlled or signalized intersection.
E-midblock = Existing crosswalk at a midblock; location has pedestrian crossing signs.
NR = No reading made (illuminance measurements were only done at proposed sites for marking installation to aid in identifying study locations; some markings were too worn to obtain a reading).

The sites at study locations (see table 3 and table 4) were the sites of primary interest in this research. Markings were newly installed at each of these sites. Each of the sites is located on non-stop-controlled approaches. The following figures show the nine study sites:

- Figure 10: bar pairs on F&B.
- Figure 11: continental on F&B.
- Figure 12: transverse on F&B.
- Figure 13: bar pairs on Agronomy.
- Figure 14: continental on Agronomy.
- Figure 15: transverse on Agronomy.

- Figure 16: bar pairs on Penberthy.
- Figure 17: continental on Discovery.
- Figure 18: transverse on Discovery.

Source: Texas Transportation Institute

Figure 10. Photo. Installed bar pairs on F&B.

Source: Texas Transportation Institute

Figure 11. Photo. Installed continental on F&B.

Source: Texas Transportation Institute

Figure 12. Photo. Installed transverse on F&B.

Source: Texas Transportation Institute

Figure 13. Photo. Installed bar pairs on Agronomy.

Source: Texas Transportation Institute

Figure 14. Photo. Installed continental on Agronomy.

Source: Texas Transportation Institute

Figure 15. Photo. Installed transverse on Agronomy.

Source: Texas Transportation Institute

Figure 16. Photo. Installed bar pairs on Penberthy.

Source: Texas Transportation Institute

Figure 17. Photo. Installed continental on Discovery.

Source: Texas Transportation Institute

Figure 18. Photo. Installed transverse on Discovery.

The markings are 10 ft long. This length was selected to reflect the typical length used for a midblock crossing. The continental and bar pairs stripes were spaced to avoid the wheel path of the vehicles. Figure 19 shows a schematic of the marking dimensions for bar pairs. Figure 20 shows a schematic of the marking dimensions for continental, and figure 21 shows a schematic of the marking dimensions for transverse markings. Each of the three marking patterns was installed at three locations along the driving route for a total of nine study sites.

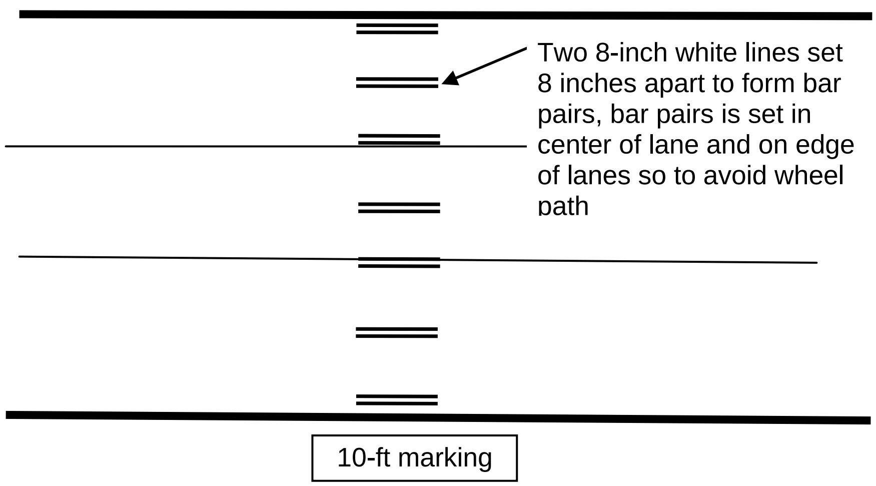


Figure 19. Graphic. Dimensions used for installed bar pair markings.

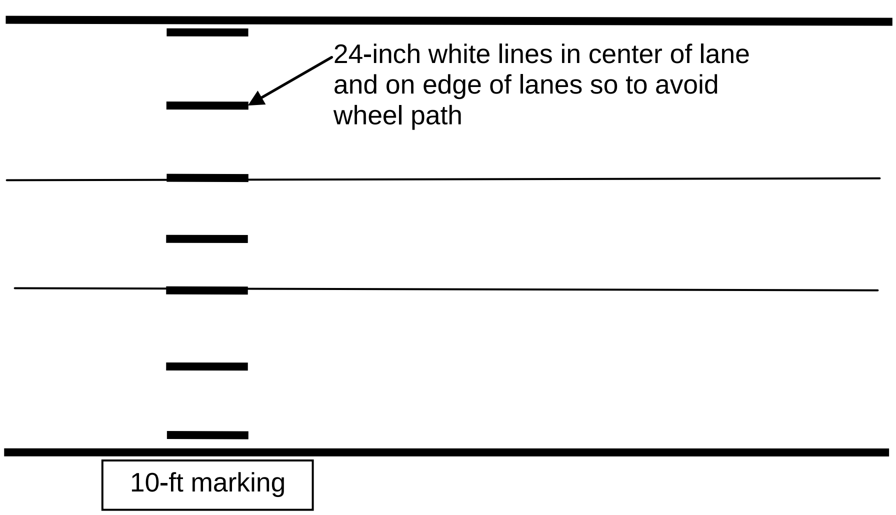


Figure 20. Graphic. Dimensions used for installed continental markings.

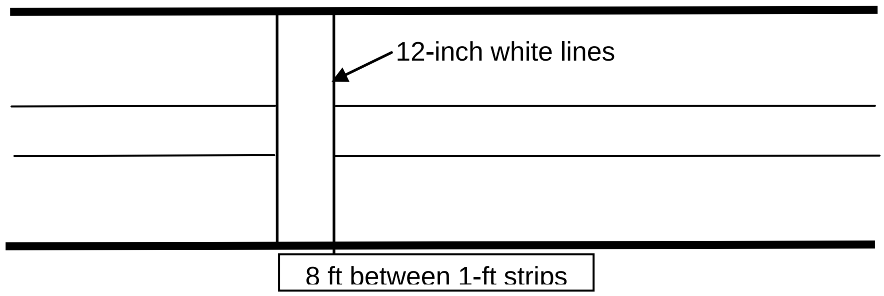


Figure 21. Graphic. Dimensions used for installed transverse markings.

ADDITIONAL CROSSWALKS ENCOUNTERED DURING DRIVE

Along the proposed driving routes, the participants crossed several existing crosswalks located at intersections or at midblock. The sites with existing crosswalk markings located at stop-controlled intersections or at signals are identified in table 3 and table 4 as E-intersection. These crosswalks were included in the study because they were along the driving route. The driving routes also included two existing midblock locations, identified as E-midblock in table 3 and table 4. Figure 22 shows a photo of the midblock location with a continental pattern, and figure 23 shows the midblock location with transverse markings. The site with continental markings was located approximately 300 ft from an intersection. A pedestrian warning sign (W11-2) was not present on this approach but was present on the opposite approach. Because the available viewing distance following the turn was only 300 ft, data for the approach to the existing continental site were removed during data analysis.

The transverse marking site had pedestrian warning signs (W11-2) in advance of the crossing on both approaches. Because the midblock transverse marking site was worn, those markings were repainted at the same time the new markings were installed at the nine study sites. The existing midblock markings were painted rather than being made with marking tape and had warning signs on their approaches. Therefore, comparison between these existing sites and the sites where markings were installed for this study is limited.

Source: Texas Transportation Institute

Figure 22. Photo. Existing midblock site with continental markings (closeup of markings; pedestrian warning sign on approach not visible in this photo).

Source: Texas Transportation Institute

Figure 23. Photo. Existing midblock site with transverse marking (distance view before repainting to show pedestrian crossing warning sign).

MARKING INSTALLATION

New crosswalk markings were installed at each of nine study sites using temporary marking tape (see figure 24 for example). The marking material used was Brite-Line® Series 100 white removable pavement marking tape. At a few of the sites during the study, parts of the markings peeled away from the pavement, usually because of standing water from a rainstorm. Markings were replaced as soon as the issue was identified. For one day, the transverse markings on

Agronomy were not present, and viewing distances were not available for that site for that day. Additional participants were added to the study to offset this situation.

Source: Texas Transportation Institute

Figure 24. Photo. Example of marking installation.

RETROREFLECTIVITY READINGS

Once sites were selected and pavement markings installed, retroreflectivity readings were taken at all sites. The retroreflected luminance (R_L) readings were taken using an LTL 2000S Retroreflectometer. The instrument uses an illumination angle of 1.24 degrees and an observation angle of 2.29 degrees to simulate a driver's viewing distance of 98 ft and an eye height of 47 inches. Readings were recorded at a number of positions along the marking, and the average of these readings was used. Table 3 and table 4 list the average reading for each site. The ATSSA recommended minimum R_L value is 100 mcd/m^2/lx.[(8)] As expected, the new markings greatly exceeded the recommended minimum, and no noticeable difference was observed among the markings at the study sites.

STUDY PERIODS

The study was conducted under both daytime and nighttime conditions over two weeks in November 2009. The actual dates for the study were as follows:

- Monday, November 9, 2009.
- Wednesday, November 11–Friday, November 13, 2009.
- Sunday, November 15–Wednesday, November 18, 2009.

For November 2009, the sunset occurred about 5:25 p.m. The study took approximately 1 h from meeting the participant to the close of debriefing (see table 5). Half of the participants drove during daylight hours and half during nighttime conditions. The following time blocks were used:

- 12–1 p.m.
- 1:15–2:15 p.m.
- 2:30–3:30 p.m.
- 6–7 p.m.
- 7:15–8:15 p.m.
- 8:30–9:30 p.m.

The study was not conducted when it rained on Sunday evening, November 15.

Table 5. Participant time in study.

Activity	**Time**
Initial processing and pretest	10 min
Practice driving and drive to start of route	5 min
Route, detection distance	15 min
Explain second part	2 min
Route, grading brightness	15 min
Drive back to origin	5 min
Final processing and payment	5 min
Total	**57 min**

PARTICIPANTS

The initial intent was to recruit a group of participants composed of one-quarter males over 55 years, one-quarter females over 55 years, one-quarter males under 55 years, and one-quarter females under 55 years. Within each of those demographic groups, the goal was to have an even distribution between those who drove at day and those who drove at night; those who drove the clockwise route and those who drove the counterclockwise route; and those who drove the SUV and those who drove the sedan. Therefore, the following divisions were used in structuring participant recruitment:

- Light level: day or night.
- Age group: young (younger than 55 years) and old (55 years or older).
- Gender: male or female.
- Instrumented vehicle driven: SUV or sedan.
- Route driven: clockwise or counterclockwise.

The research goal was to have 2 participants in each category for a total of 64 participants. A total of 78 participants were included in the study. Participants were added to: (1) replace a participant who did not take the study seriously and provided questionable results and (2) add additional data to offset the study site that had missing markings for a selection of participants. Also, if a time group (e.g., daytime or nighttime) was opened, the goal was to fill the entire group. Six participants could run within a time group (three 1-h blocks with two vehicles). The final participant pool is shown in table 6.

Table 6. Distribution of participants.

Vehicle	Age	Gender	Day Clock	Day Counter	Night Clock	Night Counter	Total
Sedan	Younger than 55	Female	2	5	4	2	13
		Male	4	2	1	2	9
	55 or older	Female	3	4	2	2	11
		Male	1	2	2	3	8
SUV	Younger than 55	Female	3	1	2	3	9
		Male	2	3	3	3	12
	55 or older	Female	3	2	1	2	8
		Male	2	2	2	3	9
		Total	**20**	**21**	**17**	**20**	**78**

Participants were at least 18 years old and possessed a valid driver's license with no restrictions.

Participants were recruited by word of mouth, flyer distribution, and communication with people who participated in past studies and indicated an interest in future studies. Flyers with information about the study, location, contact information, dates, and compensation were distributed among friends and acquaintances and were posted in public places.

After the driving portion of the study, participants returned to the meeting location and were debriefed regarding their experience. Upon completion of the debriefing, participants received monetary compensation of $40.

TASKS

The main task for the participants was to indicate when a crosswalk was detected. Detection distance was measured on the first lap of the route and was the primary measure of effectiveness of the marking patterns. In order to encourage normal driving and eye glance patterns, additional detection tasks were imposed on the participants. These distracter tasks were selected carefully to include items that participants would normally be looking for both on the roadway surface and alongside the road. The two items selected were pavement marking TWLTL arrows and speed-limit signs.

The second measure of effectiveness of the marking patterns was a subjective rating of appearance given by the participants on the second lap of the route. Each of these tasks is described in more detail in the Procedure section of this chapter.

A final task asked participants to rank photographs of selected marking patterns on the basis of overall appearance and preference.

PARTICIPANT TRAINING

To ensure consistency, the research team used checklists and slide shows to aid in providing instructions to each participant. The slide show was advanced with a space bar so that the participant could proceed at any pace. The slide show opened with the following instructions:

> "Welcome to the driving study. Today while you drive we're going to ask you to be looking for some particular items along the route and then saying out loud when you notice these items. The items are:
>
> - Crosswalks.
> - Speed-limit signs.
> - Double turn arrows."

Following the introduction slide was a series of slides that provided example pictures of the crosswalks, speed-limit signs, and TWLTL arrows the participant would see. Figure 25 shows an example of a slide used in the show. The slide show also included examples of situations that would not require a response by the participant (see figure 26).

Figure 25. Graphic. Example of a crosswalk photograph included in training slide show.

Figure 26. Graphic. Example of a situation not requiring action included in training slide show.

RESPONSE TIME

As part of the intake, the participant's and experimenter's response times were measured using a computer test to develop a correction factor for each participant. In the vehicle, the experimenter had to press a button when the participant said "crosswalk." There is a small lag between the participant speaking the word "crosswalk" and the experimenter pressing the button. The lag could vary between the experimenters collecting the data. To address this concern, a pretest was developed to measure the lag time between when the participant sees a symbol on the computer screen and speaks the symbol's name and when the experimenter presses the button. Figure 27 shows the instruction page for the start of the response time test. The following four images were used in the exercise: down arrow, up arrow, plus sign, and black circle (or dot). Each symbol was repeated five times for a total of 20 random images. The task required the participant to identify which stimulus was present and say the correct word, a task analogous to the in-vehicle task of saying "crosswalk" or "arrow." For the experimenters, the task was a simple reaction time test. They pressed a single button regardless of what the participant said, again analogous to the in-vehicle task.

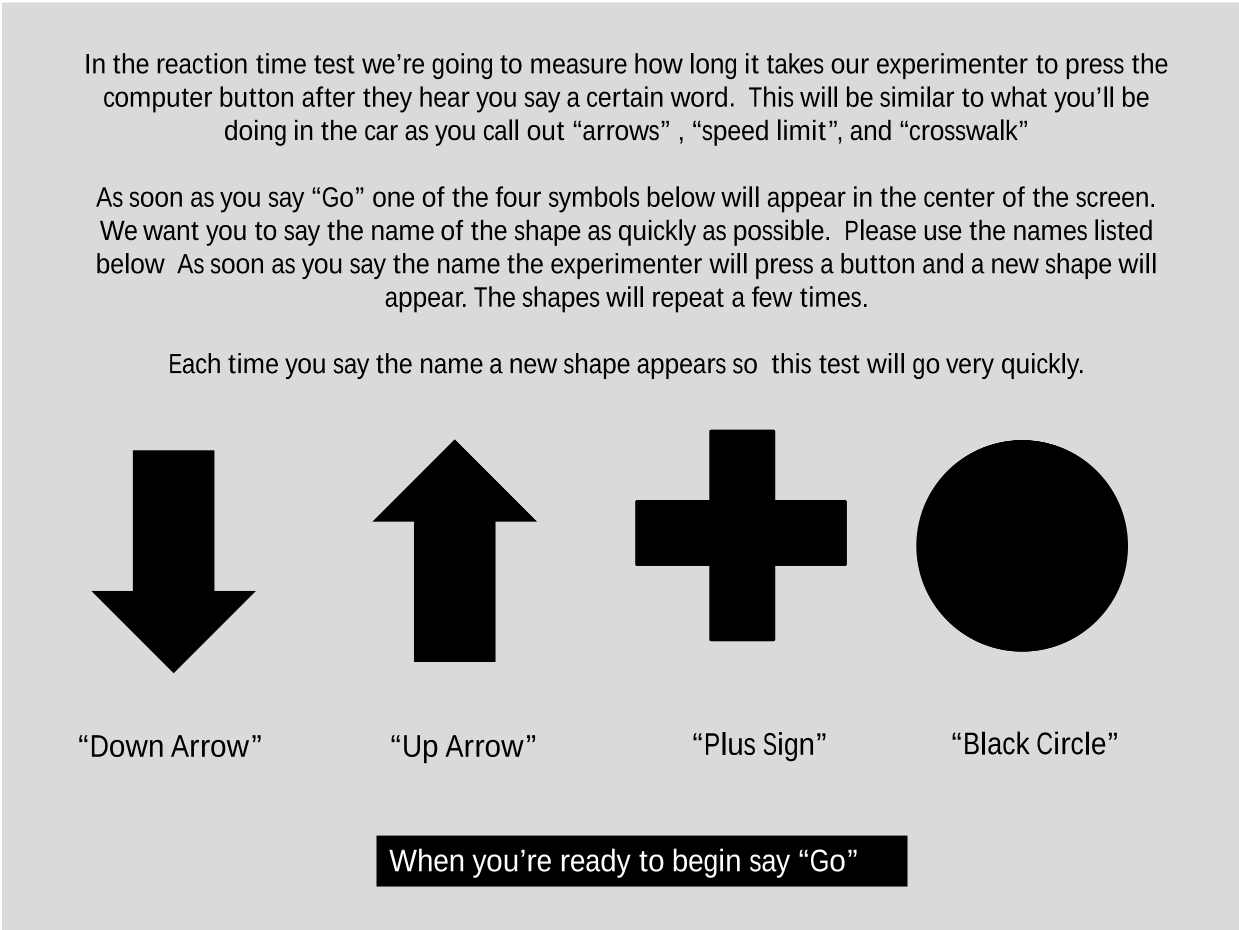


Figure 27. Graphic. Instruction page for response time test.

The participant was instructed to say the name of the shape as quickly as possible once the image appeared on the computer screen. The experimenter had a button that would be pressed upon hearing the participant say the shape name. The software recorded the time difference between the shape appearing on the screen and when the button was pushed. The participant faced the computer screen, and the experimenter's back was to the participant to avoid any anticipation on the part of the experimenter.

An average of the pretest reaction time was used along with the vehicle's speed to estimate actual detection distance.

INSTRUMENTED VEHICLES

The following instrumented vehicles were used as subject cars for this experiment:

- 2006 Toyota Highlander.
- 2003 Ford Taurus.

The Toyota Highlander was called the SUV in the study, and the Ford Taurus was called the sedan.

2006 Toyota Highlander (SUV)

One of the instrumented vehicles used for this experiment was a 2006 Toyota Highlander. The instrumented vehicle has a larger alternator, radiator, and fan coupling than a normal vehicle and has a greater alternator capacity to power instruments in the vehicle. The vehicle also has an eight-way power seat in order to best accommodate test participants. The SUV headlamp is 33 inches high and 28 inches offset from center.

The principal system within the instrumented vehicle was the Dewetron DEWE-5000. Essentially a large portable computer, the DEWE-5000 serves as the data acquisition device for all the peripheral systems in the vehicle. The DEWE-5000 is capable of sampling at 5000 Hz. For this experiment, data were collected at 100 Hz. The DEWE-5000 is mounted in a wooden equipment cabinet, which is located in the place of the driver's-side rear seat.

A Trimble® DSM 232 global positioning system (GPS) receiver was used to track the position of the subject vehicle during a study. It employs a differential GPS antenna, which is mounted on the roof of the vehicle directly over the driver's seat. The GPS samples data at 10 Hz, and the receiver is mounted inside the equipment cabinet. The accuracy of the GPS unit is ±3.28 ft.

Video data of the experiment were collected by several black-and-white cameras. Two of the cameras recorded the forward roadway scene, with one filming a telephoto view and the other filming a wide angle. The other two cameras were used to expand the side views.

Figure 28 shows an example of the camera placement.

Source: Texas Transportation Institute

Figure 28. Photo. Interior of Toyota Highlander.

2003 Ford Taurus (Sedan)

A similar portable onboard data acquisition system (DAS), DEWE-3100, was installed in the 2003 Ford Taurus. For this experiment, data were collected at 100 Hz. The DEWE-3100 was placed in the driver's-side rear seat. A portable inverter using the car battery was used to provide power for the system. The sedan headlamp was 27 inches high and 24 inches offset from center.

An off-the-shelf BU-353 GPS receiver was used to track the position of the subject vehicle during the study. The GPS receiver samples data at 1 Hz and can be directly connected to the DAS. It employs an active patch antenna, which was mounted on the roof of the vehicle directly over the DAS set up.

Video data of the experiment was collected by three black-and-white cameras and one color camera fitted with fisheye lens. Two of the cameras recorded the forward roadway scene, with one filming a telephoto view and the other filming a wide angle. The other two cameras were used to expand the side views.

The software of the DAS can merge different data streams so that the information is visible at the same time. The DAS synchronized the vehicle speed and location coordinates (GPS data) along with video feed from all the cameras. The software can time-stamp any keyboard event onto the video frame so that when the experimenter marked a verbal response with a keystroke, it was time-stamped in the data file.

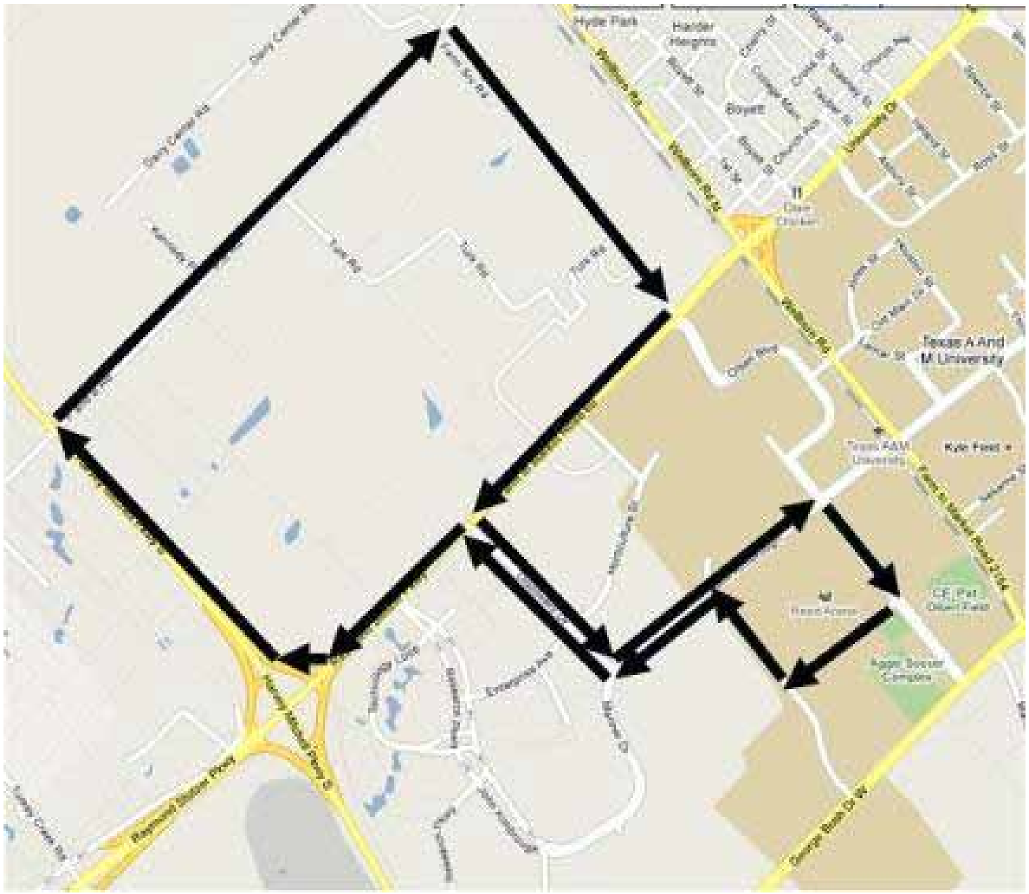
STUDY ROUTE

The driving route consisted of three parts, as follows:

- The first part consisted of driving on neighborhood streets and provided the participant the opportunity to acclimate to the vehicle.
- The second part took place on the TAMU west campus, where the participant indicated when he or she saw a crosswalk, TWLTL arrows, or a speed-limit sign.
- The third part was a repeat of the route TAMU west campus route during which the participant indicated a subjective rating of brightness of the crosswalk.

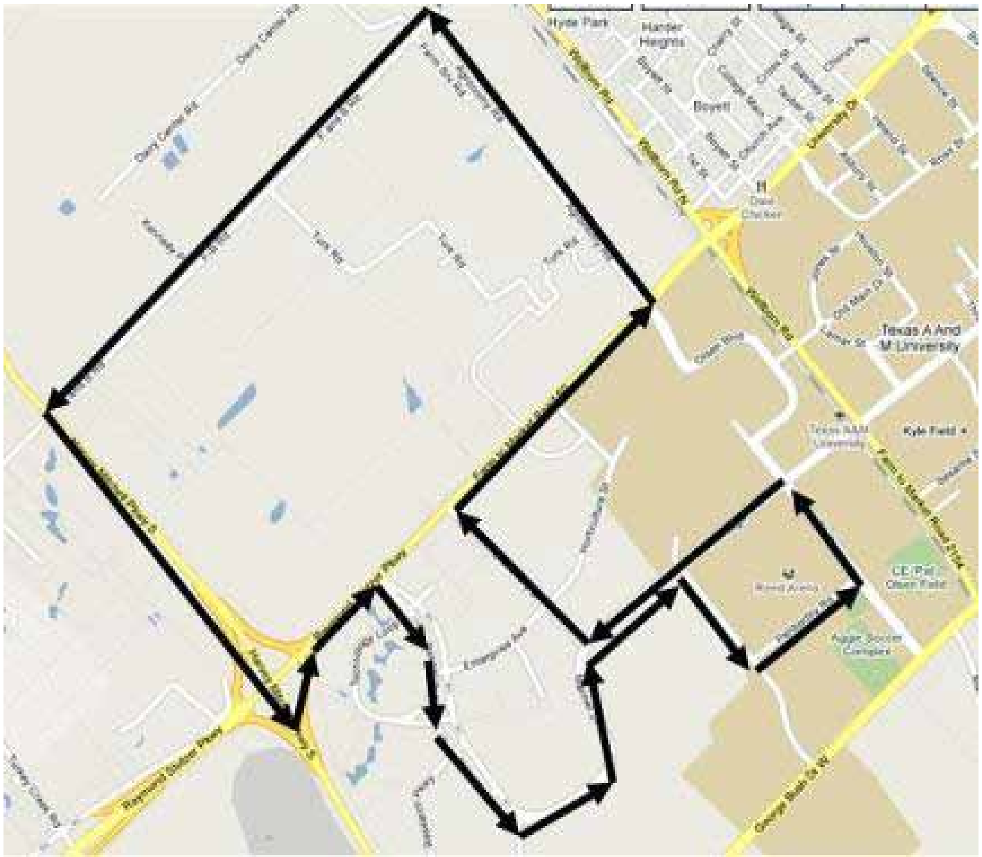
Participant intake was headquartered at the meeting house for a community service group in Bryan, TX, which was rented for the study. This location was chosen so participants should not need to pass any test markings on their way to the meeting location. The location was also selected because it was near the driving route, had public parking available, included restroom facilities, and was available to rent for a reasonable rate.

The route on the TAMU west campus was driven in both clockwise and counterclockwise directions. Figure 29 shows the proposed route when driven in a clockwise direction (5.9 mi), and figure 30 shows the route when driven in a counterclockwise direction (7.2 mi).



Source: Google Earth™ mapping service

Figure 29. Map. Clockwise route (5.9 mi).



Source: Google Earth™ mapping service

Figure 30. Map. Counterclockwise route (7.2 mi).

PROCEDURE

Participant Intake

After meeting with a member of the research team to review the informed consent documentation and complete the demographic questionnaire, participants were given an overview of the study and how the data were to be collected. They were also given a Snellen visual acuity test and the Dvorine color vision test.

The participants then reviewed the instructions for their task using a prepared slide show. After the slide show, the experimenter's and the participant's response times were measured.

The participants were shown a map of the proposed route for the practice and TAMU west campus portions of the study. Participants were informed that they would be driving the Texas Transportation Institute (TTI) instrumented vehicle on public roads and were instructed not to exceed the posted speed limit. They were asked to drive the road system as they normally would and were reminded that they had complete control of the vehicle at all times. Two researchers accompanied the participant: one in the back seat controlling the equipment and the other in the front seat providing direction and acting as a safety observer. Participants were told not to use the radio or cruise control. Conversation between the participant, the experimenter, and the safety observer was permitted; however, the intention was to keep conversation light and at a pace implicitly determined by the participant.

Vehicle Review

The participant was escorted to the instrumented vehicle and given a walk-through of the vehicle's features. The participant was shown the video camera on the dash but was not told specifically what data were being collected. The participant was provided the opportunity to adjust the seat and mirrors and to become accustomed to the controls of the vehicle. A member of the research team then measured driver eye height. The participant held a piece of cord with a string level attached to the bridge of his or her nose while the experimenter held the other end of the cord to a measurement stick. The experimenter adjusted the string until it was being held level. Figure 31 shows an example of measuring a driver's eye height.

Source: Texas Transportation Institute

Figure 31. Photo. Measuring driver eye height.

Lap 1: Crosswalk Detection Task

The participant drove the initial portion of the route to become familiar with the vehicle. Once the participant was comfortable in the instrumented vehicle and had arrived in the parking lot of the TAMU General Services Building, the participant was reminded to indicate when he or she passed one of the following items:

- Crosswalk markings.
- TWLTL arrows.
- Speed-limit sign.

The participant was instructed to say a preselected word to indicate detection of a crosswalk, TWLTL arrows, or a speed-limit sign. The experimenter recorded the response on the DAS computer. The following instructions were given to the participants:

> When you see crosswalk markings, I'd like you to indicate so by saying "crosswalk." When you see double turn arrows, I'd like you to indicate so by saying "arrows" or "turn arrows." When you see a speed-limit sign, I'd like you to indicate so by saying "speed limit."

As soon as the participant said "crosswalk," the rear seat experimenter pressed the appropriate button on the DAS, which placed a mark in the file to indicate detection. When the participant said "turn arrows" or "speed limit," the rear seat experimenter checked the item on a checklist of all crosswalks, TWLTL arrows, and speed-limit signs present along the route. The locations of these other targets were not marked in the computer file in order to keep the data files clean so crosswalk detection could be clearly determined.

Lap 2: Appearance Ratings

After completing the initial route, the participant was told to pull into one of the parking spaces in front of the TAMU General Services Building. In the parking lot, the participant was given additional instructions and asked to drive the same route again to rate each crosswalk marking on how easy it was to see. The instructions given to the participant were as follows:

> "For the next part of the study, we'll be driving the same route. This time, when you approach a crosswalk, please rate it on how easy it was to see, according to the following scale (show the card):
>
> > A: Excellent: Very easy to see.
> >
> > B: Very Good: Easy to see.
> >
> > C: Acceptable: Okay.
> >
> > D: Not Acceptable: Not easy to see.
> >
> > F: Completely unacceptable: I would have missed it, if I wasn't looking for it.
>
> I'll be telling you when we're approaching one of the crosswalks I'd like you to grade."

The participant was then shown the scale illustrated in figure 32. The participant's answers were recorded by the experimenter on a predeveloped checklist of all crosswalks along the route. When provided, participant comments were recorded for explanation of the response.

A	**Excellent**: *Very easy to see*
B	**Very Good**: *Easy to see*
C	**Acceptable**: *Okay*
D	**Not Acceptable**: *Not easy to see*
F	**Completely Unacceptable**: *I would have missed it if I wasn't looking for it*

Figure 32. Graphic. Crosswalk rating scale.

Postdrive Preference Ratings

After completion of the driving tasks, participants drove back to the starting location and were asked to complete a final task before receiving payment. The participant was shown pictures of five of the crosswalk markings located along the route and asked to rank order them from 1 to 5, where 1 was the favorite in terms of ability to see as a driver. These pictures are shown in figure 33 through figure 37.

Source: Texas Transportation Institute

Figure 33. Photo. Postdriving ranking task, image I.

Source: Texas Transportation Institute

Figure 34. Photo. Postdriving ranking task, image II.

Source: Texas Transportation Institute

Figure 35. Photo. Postdriving ranking task, image III.

Source: Texas Transportation Institute

Figure 36. Photo. Postdriving ranking task, image IV.

Source: Texas Transportation Institute

Figure 37. Photo. Postdriving ranking task, image V.

CHAPTER 5. DATA REDUCTION

PARTICIPANT DEMOGRAPHICS

Table 7 lists the demographic information for the 78 participants. The original goal was to have 32 participants age 55 or older. That goal was exceeded, with 35 older participants in the study. The large number that selected retired for employment (33 percent) is a reflection of the emphasis on having half of the participants over 55 years of age.

Table 7. Demographic information for 78 participants.

Characteristics		Number (Percent)	Characteristics		Number (Percent)
Age	< 24	7 (9)	Eye Height	40–45 inch	26 (33)
	24–33	10 (13)		45–50 inch	14 (18)
	34–43	10 (13)		50–55 inch	33 (42)
	44–53	16 (21)		> 55 inch	5 (6)
	54–63	14 (18)	Gender	Female	41 (53)
	64–73	15 (19)		Male	37 (47)
	74–83	6 (8)	Education	Some high school	3 (4)
Age groups	< 55	43 (55)		High school graduate	8 (10)
	≥ 55	35 (45)		Some college/vocational	29 (37)
Race	African American	2 (3)		College graduate	11 (14)
	Asian	3 (4)		Some graduate school	1 (1)
	Hispanic	3 (4)		Graduate degree	26 (33)
	Other	2 (3)	Number of miles driven per year	Less than 12,000	17 (22)
	White	68 (87)		12,000–15,000	35 (45)
Employment	Full time	33 (42)		More than 15,000	26 (33)
	Part time	5 (6)	Normal driving conditions	All	12 (15)
	Student	7 (9)		Freeways	3 (5)
	Homemaker	4 (5)		City streets	51 (65)
	Retired	26 (33)		Rural roads	12 (15)

RESPONSE TIME

The response lag times were determined for each subject. Two experimenters collected all the data, with one experimenter always in the SUV and the other experimenter always in the sedan. Initial effort determined the average response time by experimenter for all the participants. A review of the data revealed several outliers, such as when the response was more the 3 s. To eliminate these outliers, responses of more than 3 s or less than 0.4 s were removed from the data set. The long response times were deemed to be caused by some distraction on the part of the participant or the experimenter, which happened occasionally in the intake room. The very short response times were eliminated because they were cases in which the experimenter accidentally pressed the button before the participant spoke. In addition, data were eliminated if the response time was greater than two standard deviations of the subject's average. These steps removed 177 responses (about 10 percent). Table 8 lists the average response time by experimenter before and after removing data. In general, the response time was about 1 s for either experimenter.

Table 8. Response time by experimenter.

Condition	Experimenter/ Vehicle	Number of Responses	Average Response Time (s)	Standard Deviation (s)
All data	Sedan	860	1.184	1.398
	SUV	760	1.059	0.641
Remove errors and data greater than two standard deviations of subject's average	Sedan	783	0.985	0.218
	SUV	686	0.908	0.206

A more detailed review of the response time data indicated that adjusting the detection distance should occur uniquely for each participant rather than using a per-experimenter average response time. Figure 38 shows the plot of the responses measured for each participant before eliminating the outliers. Figure 39 shows the plot of the responses measured after eliminating the outliers. As can be seen in the plots, some participants had average response times below 0.8 s while other participants' response times averaged above 1.2 s. Therefore, the average response time by participant rather than by experimenter was used to adjust the detection distance.

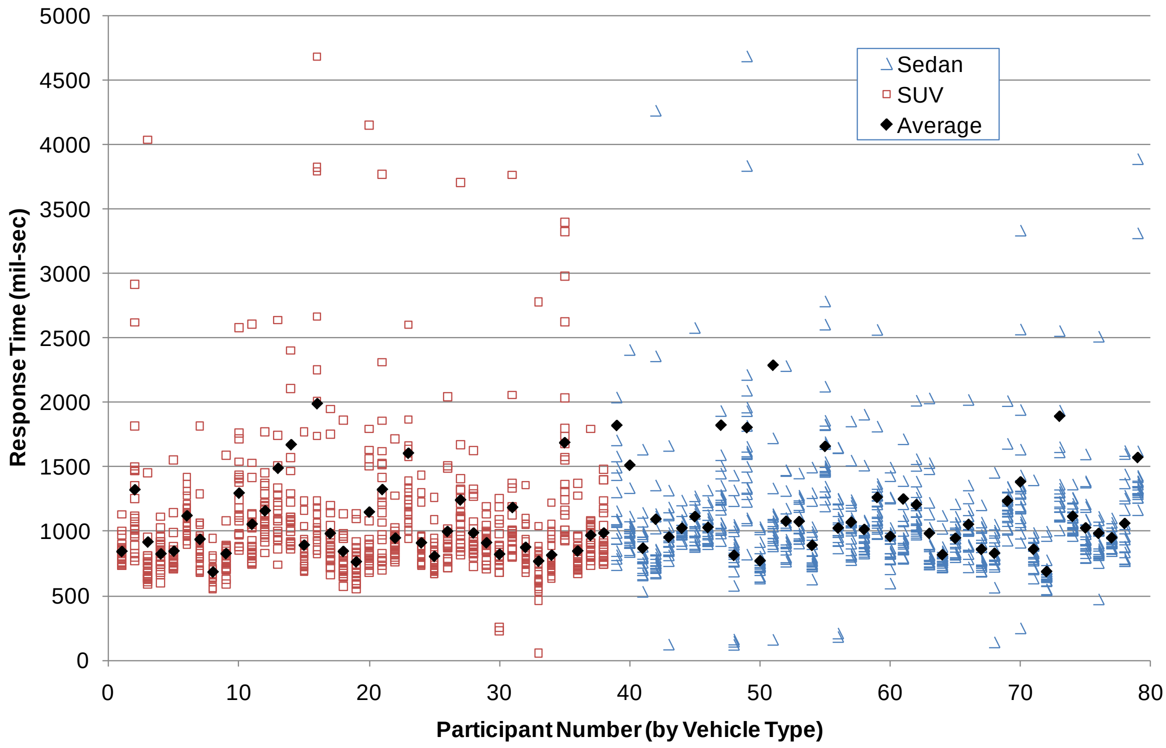


Figure 38. Graph. Measured response times by vehicle/experimenter and participant.

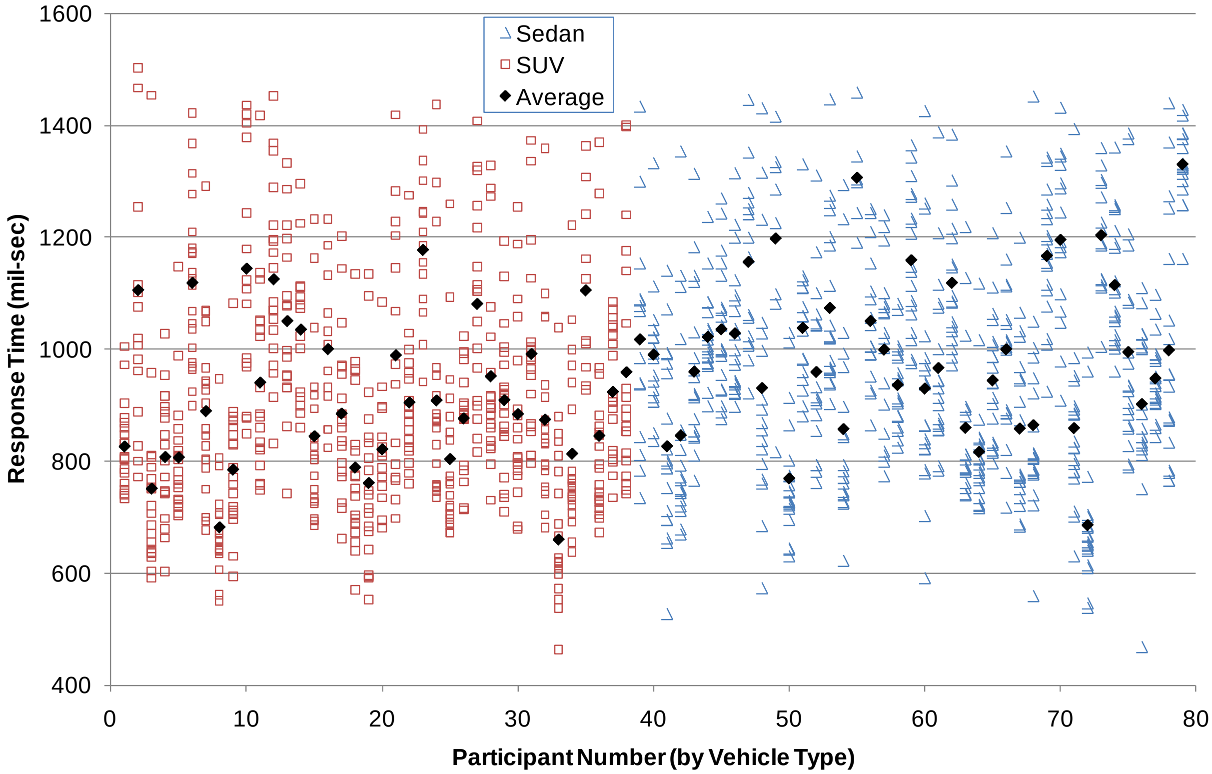


Figure 39. Graph. Response times by vehicle/experimenter and participant after removing outliers.

The measured detection distance was adjusted using the average response time for the participant and the speed of the vehicle at the point when the participant said "crosswalk." The resulting adjustments ranged from 0 to 41 ft. Figure 40 illustrates the adjustments by participant number. The very low adjustments were for the crosswalks at stop-controlled intersections. To illustrate the type of adjustments used at the subject intersections, the minimum and maximum adjustments used for the higher speed F&B crosswalks are shown in figure 41. As shown, the minimum adjustment for the F&B crosswalks was 15 ft and the maximum was 41 ft. For the nine crosswalks installed for this study, the adjustments ranged from 8 to 41 ft on detection distances that averaged 318 ft.

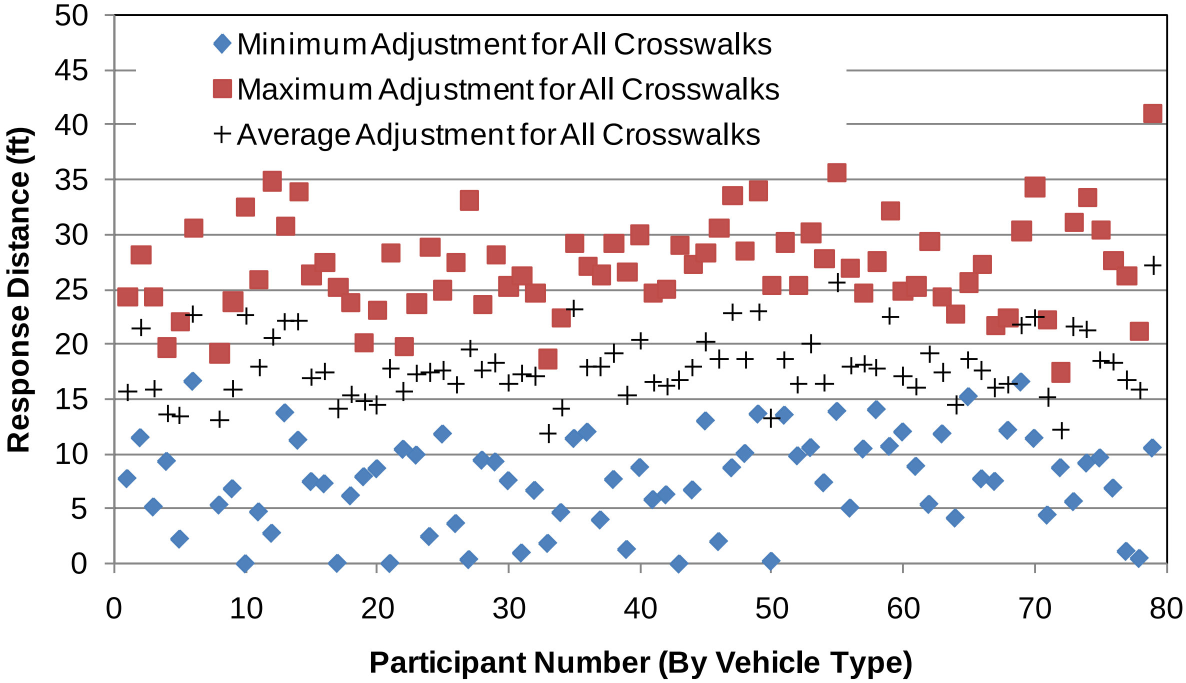


Figure 40. Graph. Response distance for all crosswalks.

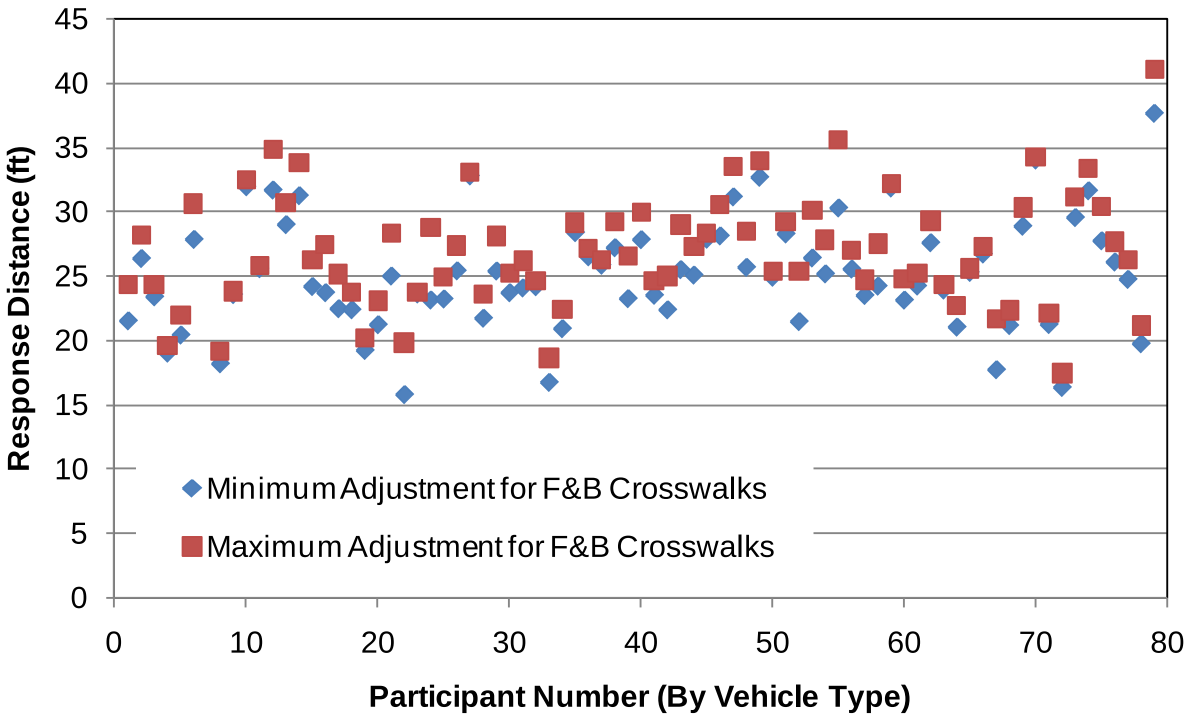


Figure 41. Graph. Response distance for F&B crosswalks.

DETECTION DISTANCE

The Dewesoft software package synchronizes the GPS and video data stream records. The synchronized data were used to determine several items of interest such as the number of pedestrians and bicyclists in the participant's view and the velocity and GPS coordinates when he or she identified crosswalks. The response time determined for each participant was used along with the DAS data to obtain the detection distances. Data reduction included several steps.

Dewesoft Exports

The GPS data from the Dewesoft program were exported into spreadsheets. The time and GPS coordinates when the participant said "crosswalk" were identified within the data streams. The GPS location of each crosswalk was recorded before the study began. The detection distance was determined by subtracting this distance from the location marked by the experimenter in the vehicle. This calculated distance was then adjusted to account for the response time of the experimenter and participant. Average response time of the experimenter for that subject was multiplied by the velocity at the time of crosswalk identification to obtain the response distance. The response distance was added to the detection distance to obtain the adjusted detection distance.

Pedestrian, Bicyclist, and Influencing Vehicular Traffic Presence

The number of pedestrians and bicyclists in the participant's view when approaching a crosswalk was determined using the video data. The number of pedestrians was subdivided into whether the pedestrian was moving toward the crosswalk or away from the crosswalk and if the pedestrian was in between the crosswalk and the vehicle. The view for recording the number of pedestrians was subdivided into the following three areas:

- Roadway driving surface (both directions).
- Right of the driving surface (sidewalk area or approximately 10 ft).
- Left of the driving surface (sidewalk area or approximately 10 ft).

During data reduction, the experimenter also judged whether surrounding vehicular traffic was affecting the participant's ability to see the crosswalk.

Table 9 shows the basic format for the data reduction sheet.

Table 9. Sample data reduction sheet for number of pedestrians.

		Number of Pedestrians						
		Left of Driving Surface		Roadway Driving Surface		Right of Driving Surface		
Crosswalk Number	Traffic?	Toward	Away	Within Crosswalk	Between Driver and Crosswalk	Toward	Away	Number of Bikes
#	y/n	x	x	x	x	x	x	x
#	y/n	x	x	x	x	x	x	x
#	y/n	x	x	x	x	x	x	x

= Crosswalk number.
Traffic? = Traffic affecting the participant's view of the crosswalk (e.g., lead vehicle is within approximately 300 ft).
y/n = Yes or no.
x = Count.

APPEARANCE AND PREFERENCE RATINGS

The appearance rating given for each crosswalk site was recorded on the participant's data sheet. Participant comments were also recorded (when provided) to aid in understanding the reason for a participant's response.

POSTDRIVE RANKINGS

The order of the photographs as indicated in the postdrive ranking task was also recorded on the participant's data sheet. These rankings were transferred from the data sheets into spreadsheets to facilitate evaluations during data reduction. Because the number of participants within a group (e.g., day versus night or sedan versus SUV) was not exact, the frequencies were converted into proportions.

CHAPTER 6. DATA ANALYSIS

OVERVIEW

During data collection in the vehicle, the rear-seat experimenter recorded when crosswalks were identified by the participant. During a second lap, the participant's appearance rating for each crosswalk was recorded. Following the driving portion of the study, the participant rank-ordered photographs of crosswalks to reflect his or her preferences.

CROSSWALK MARKINGS

The prime objectives of this study were to determine the relative visibility of three crosswalk patterns through the use of detection distance and to identify the variables that affect this distance. The differences in detection distances were evaluated with consideration of variables grouped into the following classes:

- Light (day or night).
- Site characteristics (static conditions at the site, always the same for each participant).
- Traffic characteristics (conditions at the site when the crosswalk was identified; conditions could be different for each participant and at each crosswalk).
- Vehicle characteristics.
- Driver characteristics.

Table 10 lists the variables that were originally considered. All variables were considered in the nighttime evaluations. The variable for retroreflectivity of pavement markings was not included in the daytime analysis. For some variables, using groups (categories) as well as continuous values was explored. For example, the eye height values were examined as a continuous value in some models and grouped into four ranges in others. Including a variable as a categorical variable after grouping, rather than as a continuous variable, can sometimes be advantageous in that the nonlinear relationship between the variable and detection distance can be detected (when the actual relationship is not linear).

Table 10. Original list of potential variables for analysis of crosswalk detection distance.

Class	Variable
Light	Day or night
Site	Location of markings (study or new sites, existing intersections, and existing midblock)
	Marking type · Study sites (No. of sites): transverse (3), continental (3), bar pairs (3). · Existing sites (No. of sites): midblock transverse (1), midblock continental (1), all-way stop transverse (4 or 5 depending on route), all-way stop continental (1), signal (1).
	Cross section of roadway (two lanes with TWLTL, four lanes undivided, two lanes with bike lanes)
	Width of roadway (40, 42, or 50 ft)
	Posted speed limit (30 or 45 mi/h)
	Retroreflectivity of markings (only used for nighttime evaluations)
Traffic conditions	Presence of traffic conditions that may have affected visibility, for example, distance to lead vehicle, opposing traffic, etc. (yes or no)
	Driver speed (mi/h)
	Number of pedestrians · moving toward crossing on left side of roadway. · moving away from crossing on left side of roadway. · in crosswalk. · in roadway between driver and crosswalk. · moving toward crossing on right side of roadway. · moving away from crossing on right side of roadway.
Vehicle	Vehicle driven (SUV or sedan)
Driver	Eye height (inches)
	Gender (male or female)
	Age group (younger than 55 years old or 55 years old and older)

The presence of a pedestrian or bicycle in the participant's view was found to be not significant in several preliminary models. The researchers expect this is more of a reflection of the low number of events with the pedestrian/bicycle variable rather than the presence of pedestrians or bicyclists not having an influence. Less than 4 percent of all events for both study sites and existing sites included a pedestrian or bicycle. For study sites, less than 1 percent of the detection distances occurred when a pedestrian was in the participant's field of view. Therefore, this variable was removed from the study site evaluations.

Original investigations tried to uniquely use the variables listed in table 10. The limited range in some of the values (maximum crossing width difference of only 10 ft between sites) and the overlap between values (e.g., the 45 mi/h sites always had no sidewalks) created concerns about the modeling process. Therefore, a new variable—street group—was developed. The street group variable accounted for the following roadway characteristics:

- Posted speed limit (45 or 30 mi/h).
- Roadway cross-section width (40 ft, 42 ft, or 40–50 ft).

- Presence of sidewalks (no sidewalks, sidewalks on only one side, or sidewalks on both sides).
- Number of lanes (two lanes with TWLTL, wide two lanes with bike lanes, or four lanes undivided).
- General characteristics (rural in feel, urban in feel, or mixed feel).

Table 11 shows the characteristics for each street group. The vehicle type overlapped with the driver eye height groups, so those variables were combined in the models that included driver eye heights in groups. Table 12 lists the revised list of potential variables.

Table 11. Street group characteristics.

Street Group	Posted Speed Limit (mi/h)	Roadway Cross-Section Width (ft)	Presence of Sidewalk	Number of Lanes	Feel
Street Group 1	45	40	None	Two lanes + TWLTL	Rural
Street Group 2	30	40–50	One side	Wide two lanes with bike lanes or 4 lanes undivided	Mixed
Street Group 3	30	42	Both sides	Two lanes + TWLTL	Urban
Street Group 4	30	70–92	Both sides	Four lanes	Urban
Street Group 5	40	75	Both sides	Six lanes	Urban

Table 12. Revised list of potential variables for analysis of crosswalk detection distance.

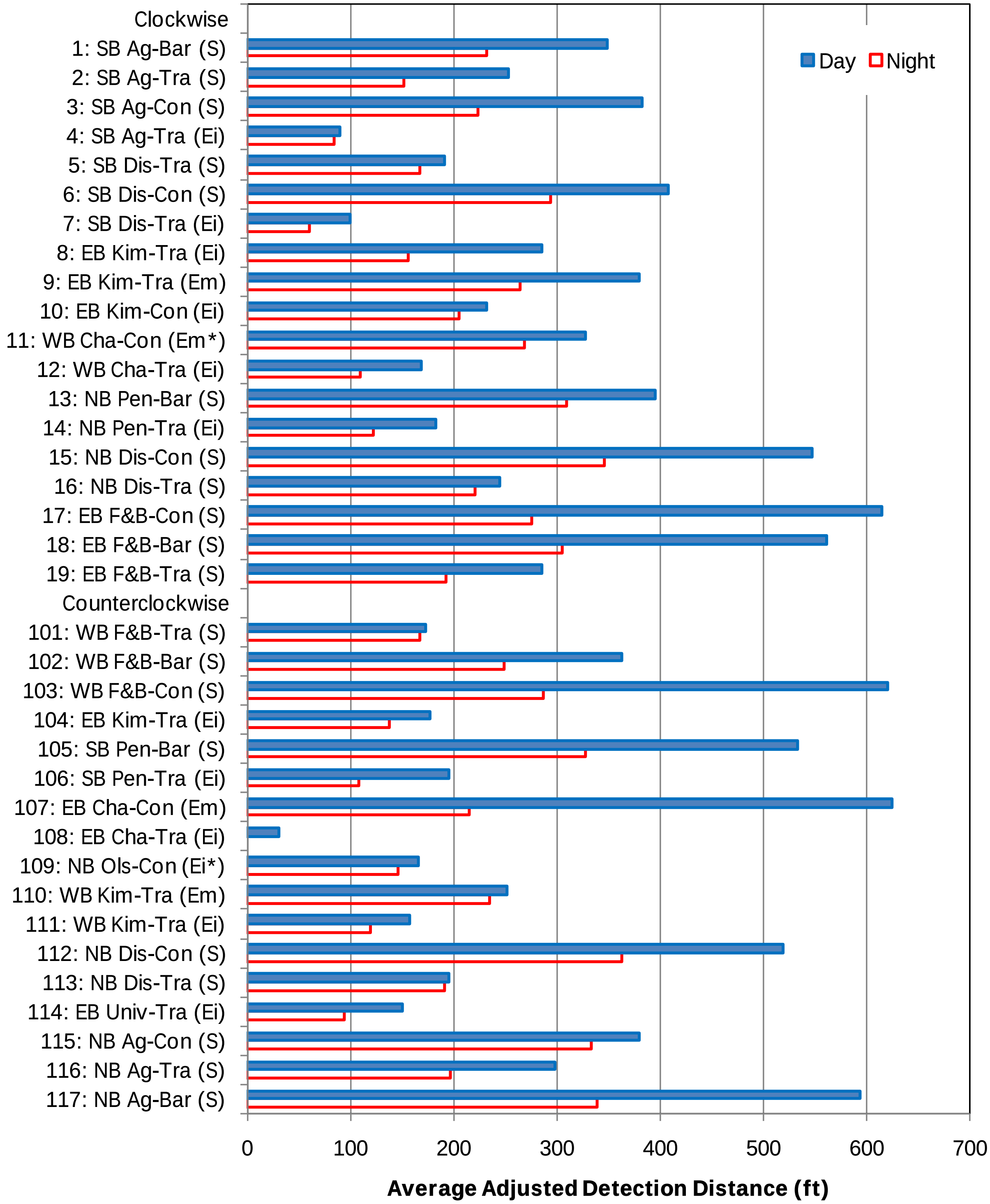
Class	Variable	Name	Description
Light	Separate analysis was conducted for daytime and nighttime data		
Site	Marking type	Mark_Type	Type of marking (transverse, continental, bar pairs)
	Location	Loc	Location · Study: study sites with new marking. · Ei: existing markings at intersections. · Em: existing markings at midblock. Analyses were conducted separately for the markings located at study sites and the existing markings located at intersections (Ei) or midblock (Em).
	Street group	Street Group	Streets assigned to five groups using the following characteristics: posted speed limit, cross section width, sidewalk presence, rural or urban feel. See table 11.
	Retro-reflectivity values or groups	Retro Values	Retroreflectivity of markings (only used for nighttime evaluations)
		Retro Groups	Retroreflectivity (only used for nighttime evaluations) grouped initially into the following: · Low: less than 200 mcd/m^2/lx. · S-300: retroreflectivity readings of 309 or 331. · S-500: retroreflectivity readings of 524 or 570. · New: retroreflectivity readings greater than 600. Later grouped into the following for the existing site evaluation because all S-300 were at midblock and all S-500 were at intersections: · Low: less than 200 mcd/m^2/lx. · Service: retroreflectivity readings above 200 mcd/m^2/lx.
Traffic conditions	Traffic presence	Traf_Pres	Presence of traffic that may have affected visibility (yes or no)
	Driver speed	Driver_Sp	Speed (mi/h) when participant said "crosswalk"
	Pedestrian or bicycle presence	Ped/ Bike_Pres	Number of pedestrians or bicyclist in driver's view
Vehicle	Vehicle type	Vehicle	Vehicle being driven (SUV or Sedan)
Driver	Eye height	Eye_Height	Driver's eye height (continuous) (42.0–47.0 inches for sedan drivers and 50.0–55.5 inches for SUV drivers)
	Gender	Gender	Gender (male or female)
	Age group	Age_Group	Age group ($<$ 55 years old or $\geq$ 55 years old)

While the preference was to identify if retroreflectivity affects detection distance, the existing sites available for this study did not permit such an evaluation. Most existing sites had retroreflectivity readings less than 38 mcd/m^2/lx. Those existing sites with higher retroreflectivity values had continental markings located at intersections or had transverse markings located at midblock crossings, which created confounding issues. Both continuous readings and groups of similar readings were explored. However, the retroreflectivity variable had to be dropped in the evaluations of the existing sites. An evaluation of retroreflectivity was not considered for the study sites because similar marking material was used at all the study sites to ensure that retroreflectivity would not be a factor. The focus of this study was on different marking patterns. The evaluation of retroreflectivity would have been a side benefit that, unfortunately, was not possible.

Figure 42 shows the average detection distance for each crosswalk subdivided by daytime and nighttime conditions, and figure 43 shows the data grouped by location type. As expected, the average adjusted detection distance was always longer during the day than at night. For several locations, such as transverse markings at an intersection, the detection distance was similar in both the daytime and the nighttime, with some being different by only a few feet. Initial statistical evaluations support the observation that effects of several variables on detection distances are different in the daytime as compared to the nighttime. Therefore, the evaluations were subdivided into daytime and nighttime conditions. Initial evaluations also revealed the need to evaluate the study sites separately from the markings at existing locations.

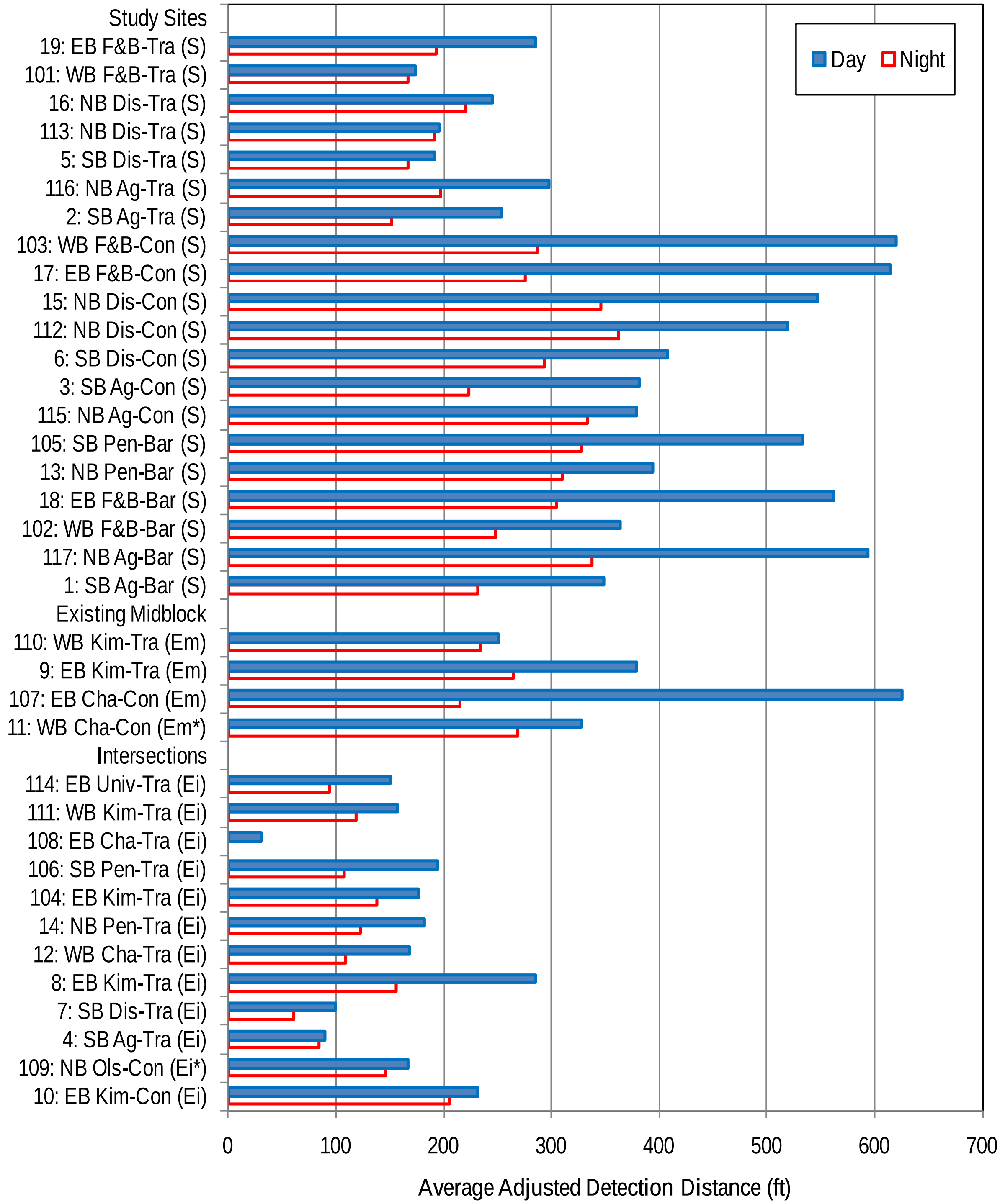
Of particular interest is the detection distance to the markings installed for this study. Figure 44 shows the average detection distance for the three test markings: transverse, continental, and bar pairs. Again, there was a difference between the average adjusted detection distance for daytime and nighttime conditions, with a minimal difference for the transverse marking sites.

The analyses of the adjusted detection distance data were conducted using Analysis of Covariance (ANACOVA) mixed models treating the variables in table 12 as fixed factors/covariates and drivers and crosswalks as random factors. Models were estimated by the restricted maximum likelihood method implemented in the JMP® statistical package (a SAS® product). Several models were explored to determine the best models to describe the variables that influence detection distance. In addition to the main effects, models with two-way interactions were examined. The analysis began with a model that included all main effects variables and logical two-way interaction variables called the "extended" model. Several of the interactions were not significant and were dropped from the models when the *p*-value was less than 0.05. This revised model was called the "reduced" model.



S = Crosswalk at study site.
Ei = Crosswalk at existing intersection.
Em = Crosswalk at existing midblock site.
* = Site with short available viewing distance or with a dip in road prior to intersection.

Figure 42. Graph. Average adjusted detection distance at each crosswalk in order of appearance.



S = Crosswalk at study site.
Ei = Crosswalk at existing intersection.
Em = Crosswalk at existing midblock site.
* = Site with short available viewing distance or with a dip in road prior to intersection.

Figure 43. Graph. Average adjusted detection distance at each crosswalk grouped by location type.

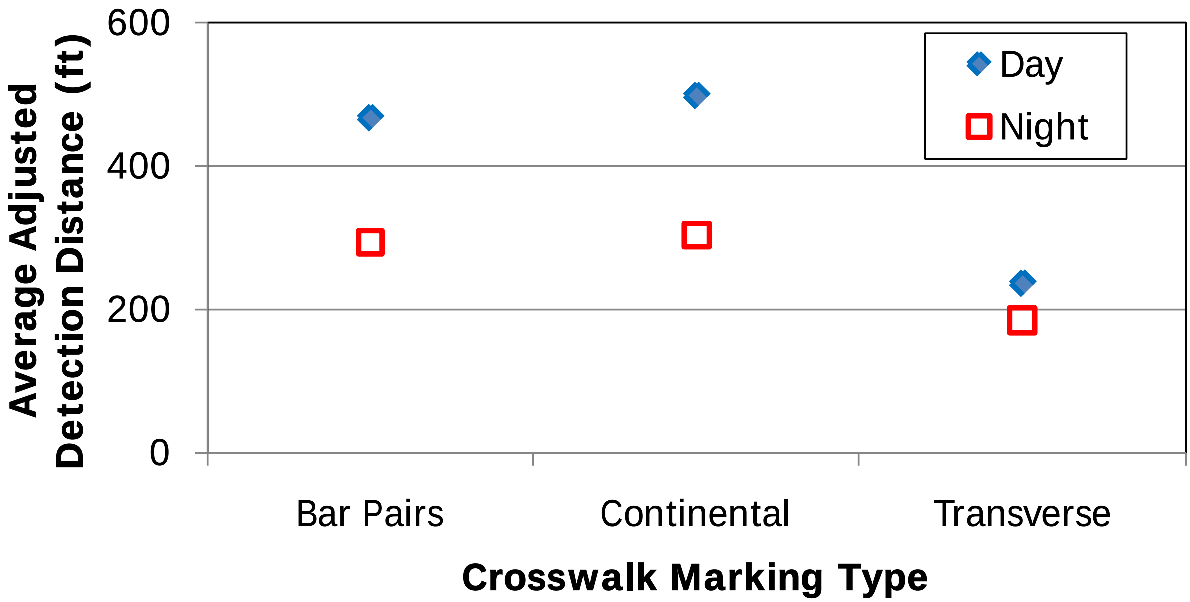


Figure 44. Graph. Average adjusted detection distance for crosswalk markings at study sites.

Daytime Detection—Study Sites

Evaluations began with examining which variables affected daytime detection distance at the nine sites where the markings were installed for this study. Data for both approaches were included for a total of 18 crosswalks. Table 13 lists the results for the model that includes all potential main effect variables along with two-way interactions (the analysis output for random effects is suppressed and not shown in the table for space). The variables that were statistically significant at the 0.05 level include the following:

- Marking type.
- Street group.
- Interaction of marking type and traffic presence.
- Interaction of driver speed and street group.

While there were several significant variables, the model also contained several variables that were not significant. The next step in model development was to remove insignificant two-way interaction variables until an acceptable model was reached. As variables were eliminated or other variables tried, the significant variables changed. The reduced model that the researchers think provides good information on which two-way interaction variables influence the adjusted daytime detection distance at the study sites is shown in table 14.

Table 13. ANACOVA findings for daytime adjusted detection distance for extended model (includes potential variables and two-way interactions) for study sites.

Response Adjusted Detection Distance

Summary of Fit

RSquare	0.785541
RSquare Adj	0.745412
Root Mean Square Error	103.78
Mean of Response	400.7076
Observations (or Sum Wgts)	388

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Age_Group	1	1	36.51	0.0921	0.7633
Driver_Sp	1	1	317.4	0.0522	0.8195
Eye_Height[Vehicle]	2	2	98.51	2.8941	0.0601
Gender	1	1	31	0.2336	0.6323
Mark_Type	2	2	76.15	3.9613	0.0231*
Street Group	2	2	145.5	3.2332	0.0423*
Traf_Pres	1	1	305.5	3.3649	0.0676
Vehicle	1	1	102	2.6035	0.1097
Age_Group*Gender	1	1	27.24	0.0101	0.9208
Age_Group*Street Group	2	2	300.3	2.0055	0.1364
Age_Group*Vehicle	1	1	27.87	0.1398	0.7113
Driver_Sp*Age_Group	1	1	310.8	0.1653	0.6846
Driver_Sp*Gender	1	1	311.7	0.0014	0.9700
Driver_Sp*Street Group	2	2	305.2	8.3582	0.0003*
Driver_Sp*Traf_Pres	1	1	301.1	0.8945	0.3450
Driver_Sp*Vehicle	1	1	309.1	0.4684	0.4943
Eye_Height*Age_Group[Vehicle]	2	2	28.23	0.0698	0.9327
Eye_HeightDriver_Sp[Vehicle]	2	2	310.8	0.4202	0.6573
Eye_HeightGender[Vehicle]	2	2	27.98	0.1313	0.8775
Eye_HeightMark_Type[Vehicle]	4	4	292.6	1.9733	0.0986
Eye_HeightStreet Group[Vehicle]	4	4	301.3	0.9380	0.4422
Eye_Height*Traf_Pres[Vehicle]	2	2	305.3	2.4345	0.0893
Gender*Street Group	2	2	304	1.3179	0.2692
Gender*Vehicle	1	1	28.18	0.1237	0.7277
Mark_Type*Age_Group	2	2	289.3	0.9164	0.4011
Mark_Type*Driver_Sp	2	2	295.9	1.1047	0.3327
Mark_Type*Gender	2	2	291.8	2.7458	0.0659
Mark_Type*Street Group	4	4	14.31	1.6267	0.2215
Mark_Type*Traf_Pres	2	2	292.4	4.0622	0.0182*
Mark_Type*Vehicle	2	2	291.2	2.4786	0.0856
Traf_Pres*Age_Group	1	1	303.8	1.2749	0.2597
Traf_Pres*Gender	1	1	307.8	0.1585	0.6908
Traf_Pres*Street Group	2	2	304.9	1.4474	0.2368
Traf_Pres*Vehicle	1	1	304.8	0.1713	0.6793
Vehicle*Street Group	2	2	299.2	1.5668	0.2104

Note: Abbreviation list provided in front section of report. The horizontal rule separates the main effect variables from the two-way interactions. Asterisks (*) in the Prob > F column represent effects that are statistically significant at the 0.05 level.

Table 14. ANACOVA findings for daytime adjusted detection distance for reduced model for study sites.

Response Adjusted Detection Distance

Summary of Fit

RSquare	0.751547
RSquare Adj	0.740131
Root Mean Square Error	105.557
Mean of Response	400.7076
Observations (or Sum Wgts)	388

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob > |t|
Intercept	502.61731	79.79161	163.9	6.30	< 0.0001*
Mark_Type[BAR]	35.693741	30.40154	20.14	1.17	0.2541
Mark_Type[CON]	61.548665	29.77275	21.91	2.07	0.0507
Driver_Sp	-3.270855	1.890211	369.6	-1.73	0.0844
Traf_Pres[NO]	13.584216	11.70817	347.8	1.16	0.2467
Age_Group[<55]	4.876435	12.78203	34.35	0.38	0.7052
Gender[FEMALE]	27.593795	14.39381	34.51	1.92	0.0635
Vehicle[SEDAN]	70.859695	50.0485	34.54	1.42	0.1658
Street Group[Group 1]	65.32718	35.84712	37.59	1.82	0.0764
Street Group[Group 2]	-62.13144	29.60266	23.15	-2.10	0.0469*
Vehicle[SEDAN]:(Eye_Height-48.6611)	21.086442	17.13312	35.44	1.23	0.2265
Vehicle[SUV]:(Eye_Height-48.6611)	12.079989	13.44581	34.89	0.90	0.3751
Mark_Type[BAR]*Traf_Pres[NO]	17.828553	14.23658	334.3	1.25	0.2113
Mark_Type[CON]*Traf_Pres[NO]	33.633254	15.01947	331.2	2.24	0.0258*
(Driver_Sp-31.3311)*Street Group[Group 1]	0.3886957	2.441723	350.7	0.16	0.8736
(Driver_Sp-31.3311)*Street Group[Group 2]	-8.125032	2.113117	351.9	-3.85	0.0001*
Gender[FEMALE]*Street Group[Group 1]	25.475109	7.957429	322.6	3.20	0.0015*
Gender[FEMALE]*Street Group[Group 2]	-15.1095	7.407964	323.7	-2.04	0.0422*

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Age_Group	1	1	34.35	0.1455	0.7052
Driver_Sp	1	1	369.6	2.9943	0.0844
Eye_Height[Vehicle]	2	2	35.19	1.1164	0.3388
Gender	1	1	34.51	3.6751	0.0635
Mark_Type	2	2	21.35	5.4494	0.0122*
Street Group	2	2	24.93	2.5070	0.1018
Traf_Pres	1	1	347.8	1.3461	0.2467
Vehicle	1	1	34.54	2.0045	0.1658
Driver_Sp*Street Group	2	2	351.2	8.5846	0.0002*
Gender*Street Group	2	2	323.5	5.3384	0.0052*
Mark_Type*Traf_Pres	2	2	333.8	5.9120	0.0030*

Note: Abbreviation list provided in front section of report. The horizontal rule separates the main effect variables from the two-way interactions. Asterisks (*) in the Prob > F and Prob > |t| columns represent effects that are statistically significant at the 0.05 level.

The two-way interaction variables that influenced daytime detection distance are as follows:

- Driver speed and street group.
- Gender and street group.
- Marking type and presence of traffic.

None of the main effect driver variables, which included driver eye height, gender, and age group, were significant at the 0.05 level. While gender was not surprising, a difference due to age group was expected. The selection of participants was designed to ensure adequate representation of the 55 years old and older group by having half of the participants in that age group. Figure 45 shows the average adjusted detection distance subdivided by age group and light. The graph supports the finding that age group was not a significant variable for this particular study. In each marking type and light combination, the average adjusted detection distance was similar for younger and older participants.

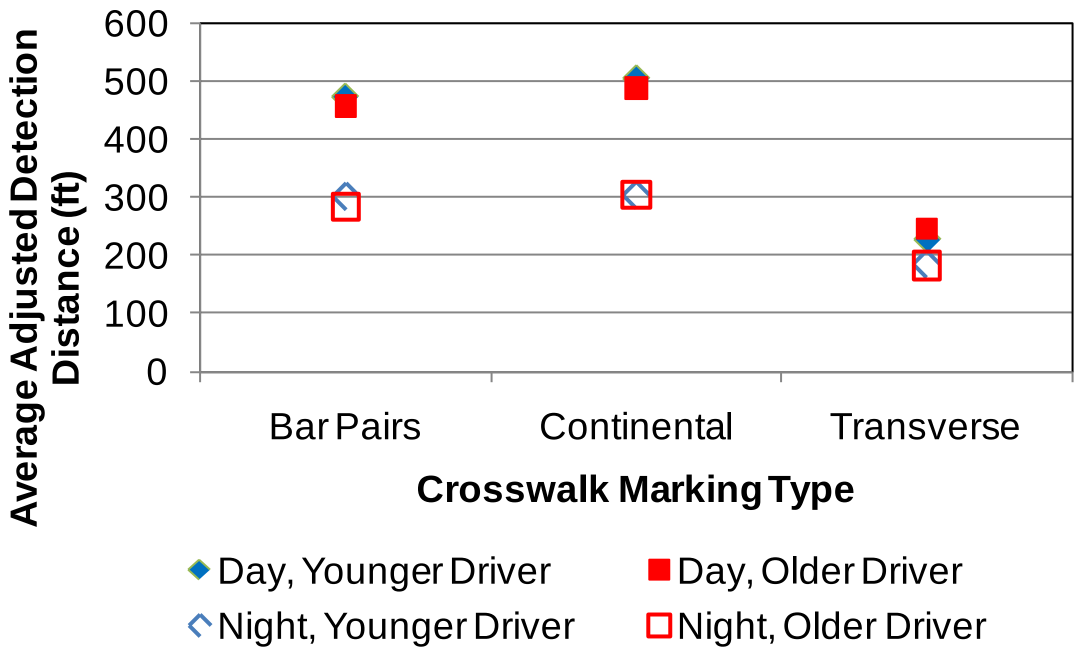


Figure 45. Graph. Average adjusted detection distance by age group and light at study sites.

Vehicle type and driver eye height were also not significant for the daytime condition. Figure 46 shows the average adjusted detection distance subdivided by light and vehicle type. For bar pairs, there were no differences between sedan and SUV in the average values. A small difference occurred in daytime for continental markings. Transverse markings had the most variation in detection distance by vehicle type.

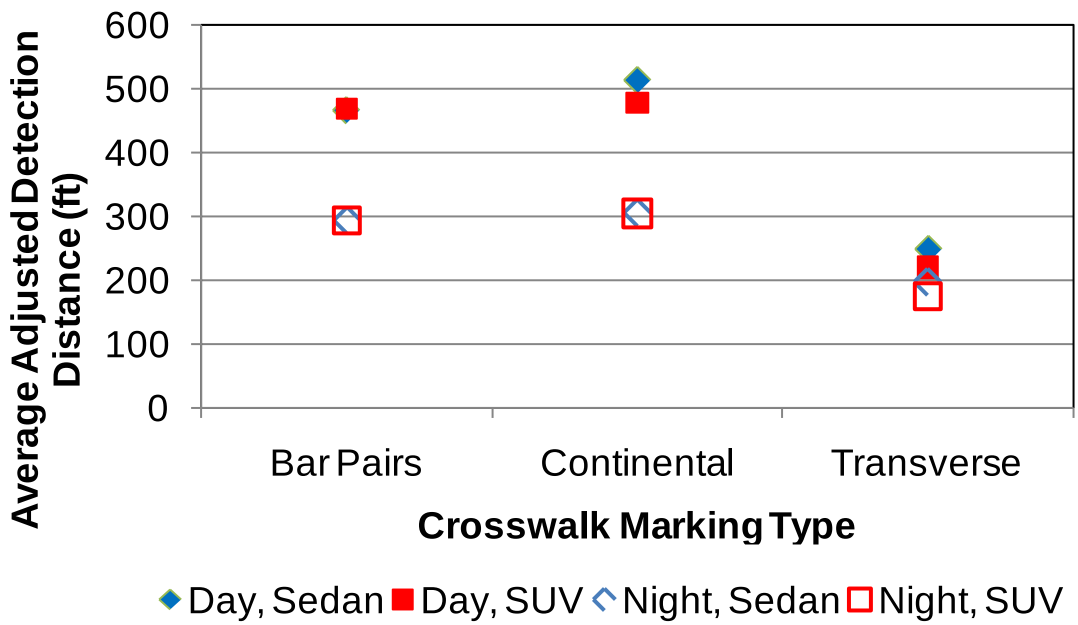


Figure 46. Graph. Average adjusted detection distance by vehicle type and light at study sites.

Marking Type and Traffic Presence Interaction

A significant interaction between marking type and traffic presence was identified for the daytime adjusted detection distances. This significant interaction indicates that the effect of one factor (e.g., marking type) may be different for each level of the other factor (e.g., traffic presence) and may need to be assessed conditionally on each level of the other factor. Table 15 provides the results for the least square means table and the Tukey test.

Table 15. Effect details of traffic presence and marking type interaction on daytime detection distance at study sites.

Mark_Type*Traf_Pres

Least Squares Means Table

Level	Least Sq Mean	Std Error
BAR, NO	467.24424	60.124129
BAR, YES	404.41870	68.013657
CON, NO	508.90386	58.490411
CON, YES	414.46893	70.472726
TRA, NO	265.01773	58.071455
TRA, YES	340.77291	69.539467

LSMeans Differences Tukey HSD

α=0.050

Level			Least Sq Mean
CON, NO	A		508.90386
BAR, NO	A		467.24424
CON, YES	A	B	414.46893
BAR, YES	A	B	404.41870
TRA, YES	A	B	340.77291
TRA, NO		B	265.01773

Note: Abbreviation list provided in front section of report. Levels not connected by the same letter are significantly different.

The interaction plot indicating the effect of marking type on detection distance conditional on the levels of traffic present is shown in figure 47. It can be observed that the least square mean detection distances for bar pairs and continental are longer than that for transverse markings, and the difference is larger when traffic is not present compared to when traffic is present. The Tukey's test (see table 15) shows that when traffic is not present, the detection distances for continental and bar pairs are similar (508 and 467 ft, respectively) but significantly different from transverse markings (265 ft), whereas there is no significant difference among the three marking types when traffic is present.

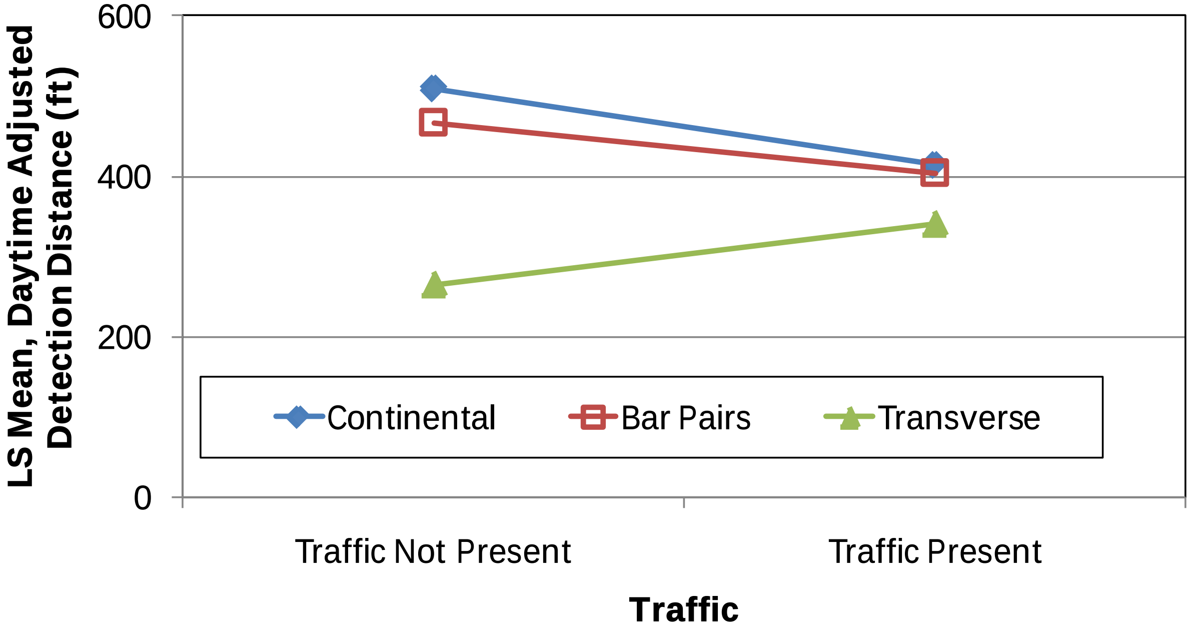


Figure 47. Graph. Least square mean daytime adjusted detection distance by marking type and traffic presence at study sites.

Driver Speed and Street Group Interaction

The driver speed and street group interaction was statistically significant for daytime detection distance. As an initial examination, plots of adjusted detection distance and driver speed by light level and posted speed limit were generated. Figure 48 shows the plot for daytime, and figure 49 shows the plot for nighttime. As can be seen in figure 48, the driver speeds on the 45-mi/h road were higher than the driver speeds at the 30-mi/h sites. Another pattern revealed is that around adjusted detection distances of 600 to 700 ft, several drivers were at speeds less than 20 mi/h. A closer investigation of those data points revealed that those drivers were still accelerating after completing a turn.

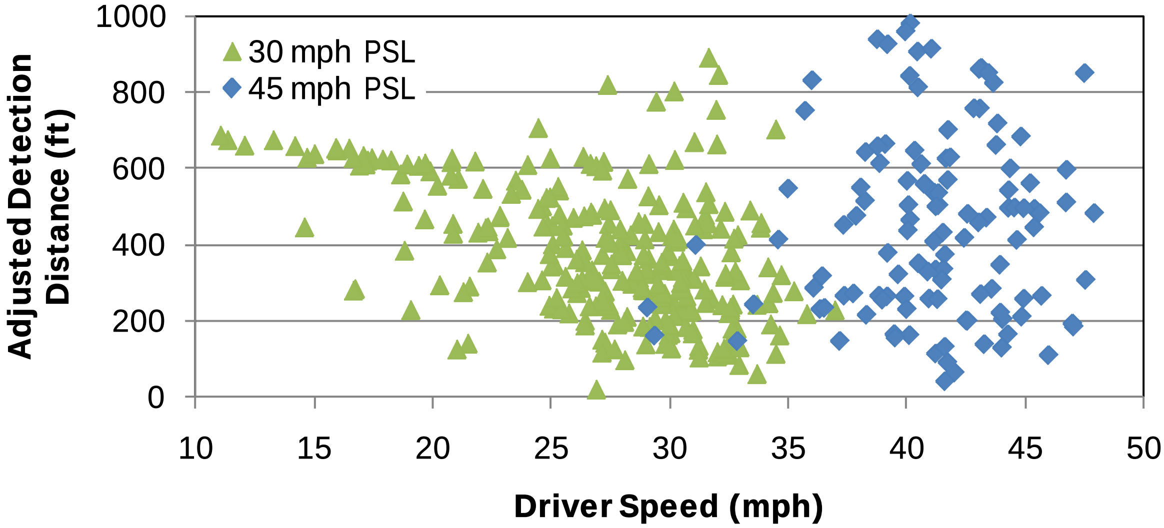


Figure 48. Graph. Adjusted detection distance by driver speed, posted speed limit, and daytime at study sites.

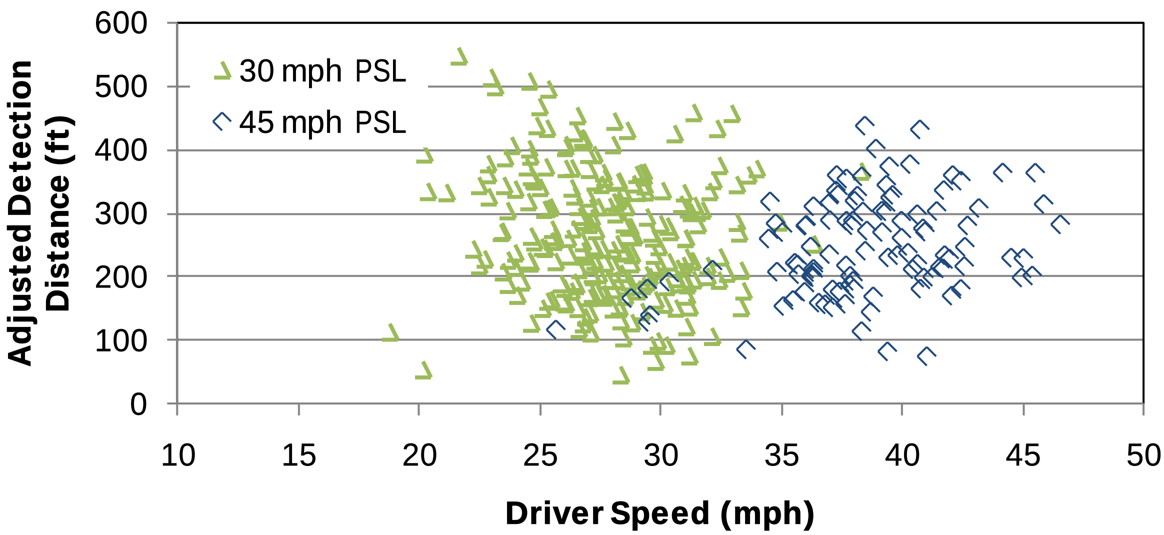


Figure 49. Graph. Adjusted detection distance by driver speed, posted speed limit, and nighttime at study sites.

Because the model indicated that the driver speed and street group interaction was significant, plots were generated of adjusted detection distance by driver speed for each of the street groups. Figure 50 shows the relationship between driver speed and detection distance for street group 1. Street group 2 is shown in figure 51, and street group 3 is shown in figure 52. The figures also show a plot of the regression equation line that would be generated using the coefficients from the reduced model. The following conditions were assumed when generating the plots of regression lines:

- Transverse pavement markings.
- Traffic present.

- SUV.
- 48.66-inch eye height.
- Older age group.
- Male drivers.

The plots for street group 2 show the relationship between low speed and long detection distances; although, closer evaluation of the data revealed that the observation should be that when drivers are at low speed because of turning or accelerating after a turn, they detect crosswalks at a longer distance. A visual review of these graphs shows that higher speeds are associated with shorter detection distances (for street group 3, only slightly shorter detection distances).

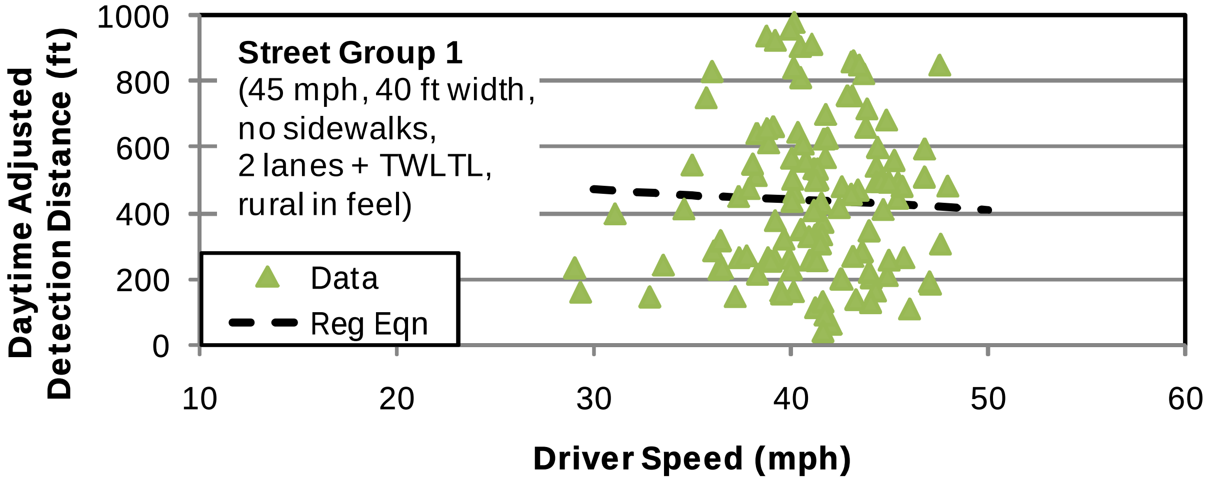


Figure 50. Graph. Daytime adjusted detection distance by driver speed for street group 1 at study sites.

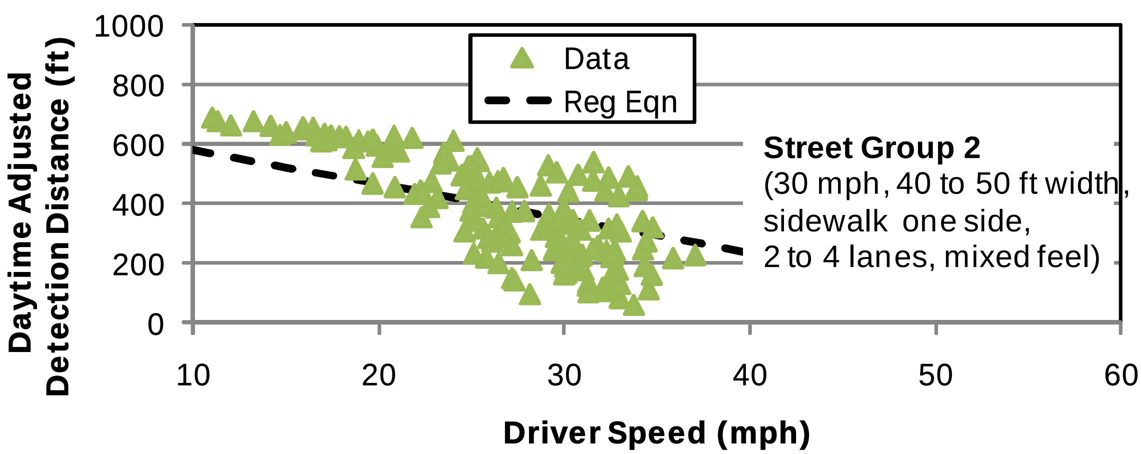


Figure 51. Graph. Daytime adjusted detection distance by driver speed for street group 2 at study sites.

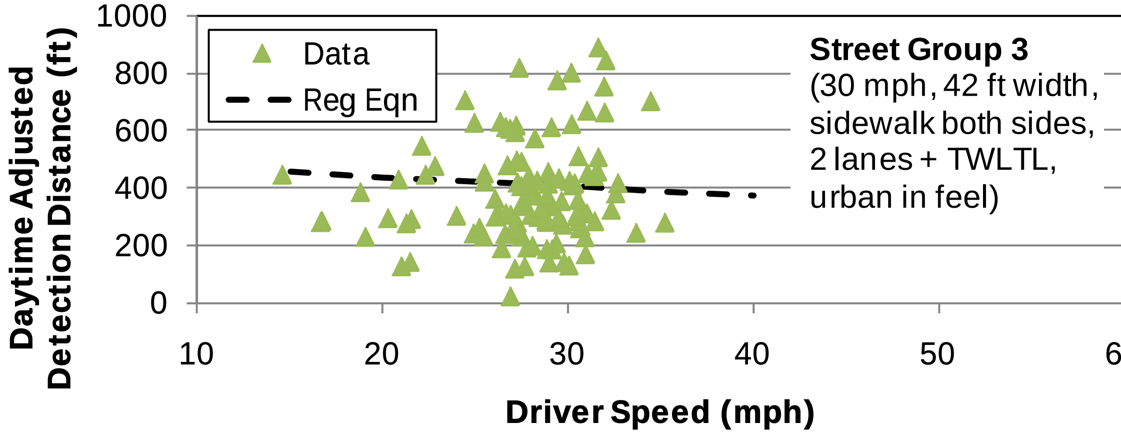


Figure 52. Graph. Daytime adjusted detection distance by driver speed for street group 3 at study sites.

Gender and Street Group Interaction

The interaction between street group and gender was statistically significant in the reduced model (see table 14). The interaction plot indicating the effect of street group on detection distance conditional on gender is shown in figure 53. The least square mean detection distance for street group 1 is longer for female than for male while differences between female and male for the other street group levels is minimal. The least square means along with two difference tests (Tukey HSD and Student's *t*) are provided in table 16, which supports the above observation. There is no reason to believe that women have better eyesight than men (especially for only one street group and not other street groups), and the researchers attribute the gender difference to attention differences or response bias in that women were more willing to "guess" early to identify the marking.

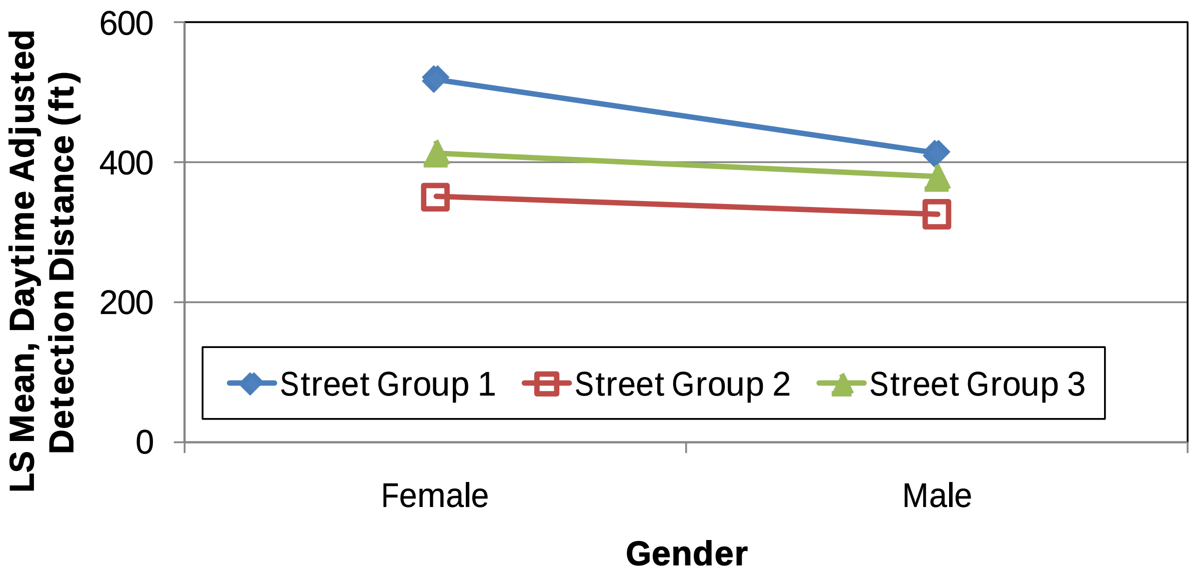


Figure 53. Graph. Least square mean daytime adjusted detection distance by gender and street group at study sites.

Table 16. Effect details of street group and gender interaction variable on daytime detection distance at study sites.

Least Squares Means Table

Level	Least Sq Mean	Std Error
Group 1, FEMALE	518.53381	71.339583
Group 1, MALE	412.39601	67.803389
Group 2, FEMALE	350.49059	63.193574
Group 2, MALE	325.52200	58.453838
Group 3, FEMALE	414.17017	65.700710
Group 3, MALE	379.71380	61.347242

LSMeans Differences, Tukey HSD

α=0.050

Level			Least Sq Mean
Group 1, FEMALE	A		518.53381
Group 3, FEMALE	A	B	414.17017
Group 1, MALE		B	412.39601
Group 3, MALE	A	B	379.71380
Group 2, FEMALE	A	B	350.49059
Group 2, MALE		B	325.52200

LSMeans Differences, Student's t

α=0.050

Level			Least Sq Mean
Group 1, FEMALE	A		518.53381
Group 3, FEMALE	A	B	414.17017
Group 1, MALE		B	412.39601
Group 3, MALE		B	379.71380
Group 2, FEMALE		B	350.49059
Group 2, MALE		B	325.52200

Note: Abbreviation list provided in front section of report. Levels not connected by the same letter are significantly different.

Nighttime Detection–Study Sites

This section presents the findings on nighttime detection at the study sites. Table 17 shows the results when potential main effect variables and two-way interactions are included in the model for nighttime detection (i.e., extended model). Table 18 shows the effect details. Most of the variables were not significant; only the following variables had a *p*-value less than 0.05:

- Interaction of vehicle and street group.
- Interaction of eye height and street group.
- Marking type.

Table 17. ANACOVA Findings for nighttime adjusted detection distance for extended model (includes potential variables and two-way interactions) for study sites.

Response Adjusted Detection Distance

Summary of Fit

RSquare	0.726408
RSquare Adj	0.677254
Root Mean Square Error	54.73319
Mean of Response	261.4497
Observations (or Sum Wgts)	349

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Age_Group	1	1	65.78	0.0323	0.8580
Driver_Sp	1	1	281.8	0.3457	0.5570
Eye_Height[Vehicle]	2	2	23.57	0.4550	0.6399
Gender	1	1	26.11	0.0408	0.8415
Mark_Type	2	2	41.76	8.0342	0.0011*
Street Group	2	2	83.62	1.0485	0.3550
Traf_Pres	1	1	272.5	0.1405	0.7081
Vehicle	1	1	23.18	0.2385	0.6298
Age_Group*Gender	1	1	24	0.0001	0.9921
Age_Group*Street Group	2	2	275.8	0.6185	0.5395
Age_Group*Vehicle	1	1	23.12	0.0441	0.8355
Driver_Sp*Age_Group	1	1	286.1	0.0003	0.9872
Driver_Sp*Gender	1	1	281.7	2.4676	0.1173
Driver_Sp*Street Group	2	2	278.4	2.9832	0.0522
Driver_Sp*Traf_Pres	1	1	264.5	0.0509	0.8216
Driver_Sp*Vehicle	1	1	285.2	0.0138	0.9066
Eye_Height[Vehicle]*Age_Group[Vehicle]	2	2	24.2	0.0633	0.9389
Eye_Height[Vehicle]*Driver_Sp[Vehicle]	2	2	285	0.3753	0.6874
Eye_Height[Vehicle]*Gender[Vehicle]	2	2	24.4	0.2007	0.8195
Eye_Height[Vehicle]*Mark_Type[Vehicle]	4	4	268.8	0.5281	0.7152
Eye_Height[Vehicle]*Street Group[Vehicle]	4	4	277	2.7455	0.0288*
Gender*Street Group	2	2	270.5	2.9509	0.0540
Gender*Vehicle	1	1	22.89	0.2524	0.6202
Mark_Type*Age_Group	2	2	263.9	0.7341	0.4809
Mark_Type*Driver_Sp	2	2	269.2	0.9436	0.3905
Mark_Type*Gender	2	2	263.5	0.0725	0.9301
Mark_Type*Street Group	4	4	12.49	0.6039	0.6670
Mark_Type*Vehicle	2	2	267.1	0.5994	0.5499
Traf_Pres*Age_Group	1	1	271	0.5789	0.4474
Vehicle*Street Group	2	2	277.1	3.5033	0.0314*

Note: Abbreviation list provided in front section of report. The horizontal rule separates the main effect variables from the two-way interactions. Asterisks (*) in the Prob > F column represent effects that are statistically significant at the 0.05 level.

Table 18. Effect details for variables in table 17.

Mark_Type

Least Squares Means Table

Level	Least Sq Mean	Std Error
BAR	314.94222	45.047031
CON	339.39226	44.181831
TRA	209.62588	46.026183

LSMeans Differences Tukey HSD

α=0.050

Level			Least Sq Mean
CON	A		339.39226
BAR	A		314.94222
TRA		B	209.62588

Vehicle*Street Group

Least Squares Means Table

Level	Least Sq Mean	Std Error
SEDAN, Group 1	291.38321	78.116675
SEDAN, Group 2	298.62097	68.575350
SEDAN, Group 3	324.20488	68.539445
SUV, Group 1	235.88453	67.749519
SUV, Group 2	345.19379	50.663010
SUV, Group 3	232.63335	55.367679

LSMeans Differences Tukey HSD

α=0.050

Level		Least Sq Mean
SUV, Group 2	A	345.19379
SEDAN, Group 3	A	324.20488
SEDAN, Group 2	A	298.62097
SEDAN, Group 1	A	291.38321
SUV, Group 1	A	235.88453
SUV, Group 3	A	232.63335

Note: Abbreviation list provided in front section of report. Levels not connected by the same letter are significantly different.

Several additional combinations of main effects and two-way interactions were explored in the modeling efforts. Again, the elimination of non-significant variables changed the *p*-value of other variables, resulting in some variables becoming significant. Removing non-significant two-way interaction variables for the nighttime detection data resulted in the eye height and street group interaction term becoming not significant. In addition, some two-way interaction variables that were not significant became significant (e.g., driver speed and gender as well as driver speed and street group). Table 19 shows the resulting model, and table 20 shows the effect details.

Table 19. ANACOVA findings for nighttime adjusted detection distance for reduced model for study sites.

Response Adjusted Detection Distance

Summary of Fit

RSquare	0.687944
RSquare Adj	0.674864
Root Mean Square Error	55.30777
Mean of Response	261.4497
Observations (or Sum Wgts)	349

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob > |t|
Intercept	298.35687	54.72263	223.5	5.45	< 0.0001*
Mark_Type[BAR]	33.485489	11.68135	14.48	2.87	0.0121*
Mark_Type[CON]	40.649419	11.13278	14.16	3.65	0.0026*
Driver_Sp	-0.12983	1.391714	306.4	-0.09	0.9257
Traf_Pres[NO]	-8.706513	17.78169	307.7	-0.49	0.6247
Age_Group[<55]	6.2600997	6.765981	30.15	0.93	0.3622
Gender[FEMALE]	-0.944633	8.0266	30.08	-0.12	0.9071
Vehicle[SEDAN]	11.979836	22.82694	30.84	0.52	0.6035
Street Group[Group 1]	-24.59589	15.50594	40.65	-1.59	0.1204
Street Group[Group 2]	22.915578	12.96046	27.33	1.77	0.0882
Vehicle[SEDAN]:(Eye_Height-48.265)	10.51826	7.517456	30.38	1.40	0.1719
Vehicle[SUV]:(Eye_Height-48.265)	-7.229076	7.063262	31.9	-1.02	0.3138
(Driver_Sp-31.029)*Gender[FEMALE]	-1.30988	0.537722	302.2	-2.44	0.0154*
(Driver_Sp-31.029)*Street Group[Group 1]	3.179567	1.497779	322.9	2.12	0.0345*
(Driver_Sp-31.029)*Street Group[Group 2]	-3.626649	1.613191	312.8	-2.25	0.0253*

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Age_Group	1	1	30.15	0.8561	0.3622
Driver_Sp	1	1	306.4	0.0087	0.9257
Eye_Height[Vehicle]	2	2	31.13	1.5595	0.2262
Gender	1	1	30.08	0.0139	0.9071
Mark_Type	2	2	14.4	22.1189	< 0.0001*
Street Group	2	2	28.28	1.8156	0.1812
Traf_Pres	1	1	307.7	0.2397	0.6247
Vehicle	1	1	30.84	0.2754	0.6035
Driver_Sp*Gender	1	1	302.2	5.9340	0.0154*
Driver_Sp*Street Group	2	2	316.9	3.2324	0.0408*

Note: Abbreviation list provided in front section of report. The horizontal rule separates the main effect variables from the two-way interactions. Asterisks (*) in the Prob > F and Prob > |t| columns represent effects that are statistically significant at the 0.05 level.

Table 20. Effect details for variables in table 19.

Mark_Type

Least Squares Means Table

Level	Least Sq Mean	Std Error
BAR	327.81389	33.016531
CON	334.97782	32.526158
TRA	220.19349	32.389847

LSMeans Differences Tukey HSD

α=0.050

Level			Least Sq Mean
CON	A		334.97782
BAR	A		327.81389
TRA		B	220.19349

Traf_Pres

Least Squares Means Table

Level	Least Sq Mean	Std Error
NO	285.62188	24.379877
YES	303.03491	43.726314

LSMeans Differences Student's t

α=0.050

Level		Least Sq Mean
YES	A	303.03491
NO	A	285.62188

Age_Group

Least Squares Means Table

Level	Least Sq Mean	Std Error
< 55	300.58850	31.849965
≥ 55	288.06830	30.840379

LSMeans Differences Student's t

α=0.050

Level		Least Sq Mea
< 55	A	300.58850
≥ 55	A	288.06830

Gender

Least Squares Means Table

Level	Least Sq Mean	Std Error
FEMALE	293.38376	33.671583
MALE	295.27303	29.479982

LSMeans Differences Student's t

α=0.050

Level		Least Sq Mean
MALE	A	295.27303
FEMALE	A	293.38376

Vehicle

Least Squares Means Table

Level	Least Sq Mean	Std Error
SEDAN	306.30823	39.834548
SUV	282.34856	36.460101

LSMeans Differences Student's t

α=0.050

Level		Least Sq Mean
SEDAN	A	306.30823
SUV	A	282.34856

Street Group

Least Squares Means Table

Level	Least Sq Mean	Std Error
Group 1	269.73251	35.991041
Group 2	317.24397	32.058958
Group 3	296.00871	32.832548

LSMeans Differences Tukey HSD

α=0.050

Level		Least Sq Mean
Group 2	A	317.24397
Group 3	A	296.00871
Group 1	A	269.73251

Note: Abbreviation list provided in front section of report. Levels not connected by the same letter are significantly different.

Driver Speed and Street Group

Similar to the daytime analysis, the driver speed and street group interaction term was statistically significant. The plots showing the nighttime detection data along with a plot of the line that would be generated using the regression coefficients are shown in figure 54 for street group 1, figure 55 for street group 2, and figure 56 for street group 3. The following conditions were assumed when generating the plots of regression lines:

- Transverse pavement markings.
- Traffic present.
- SUV.
- 48.3-inch eye height.

- Older age group.
- Male drivers.

The plots show that the relationship between driver speed and nighttime adjusted detection distance is different for the different street groups. For street group 3, the influence of driver speed on detection distance was nominal. For street group 2, the influence of driver speed was similar to the influence seen for the daytime data—longer detection distances are associated with lower speeds. The relationship for street group 1, however, was the opposite. Detection distances were longer at higher speeds.

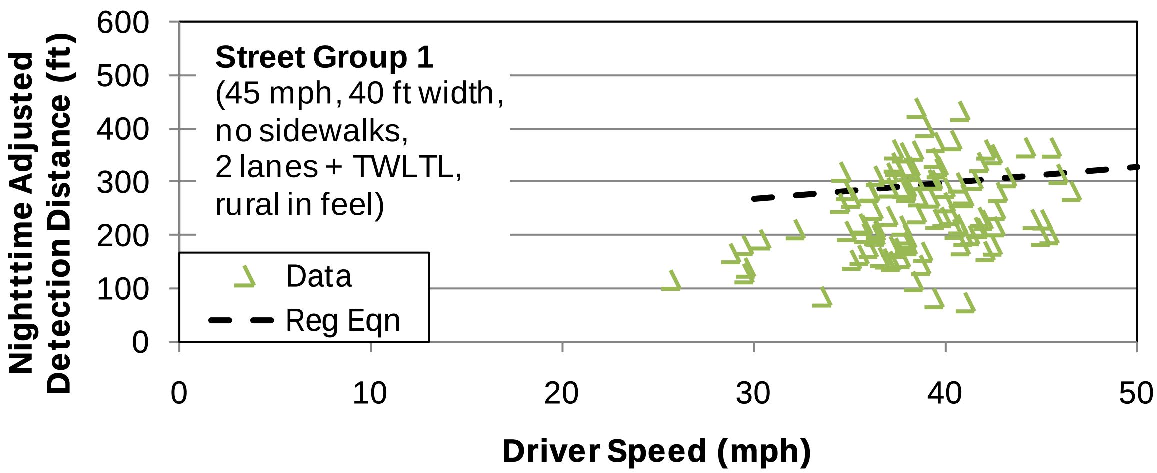


Figure 54. Graph. Nighttime adjusted detection distance by driver speed for street group 1 at study sites.

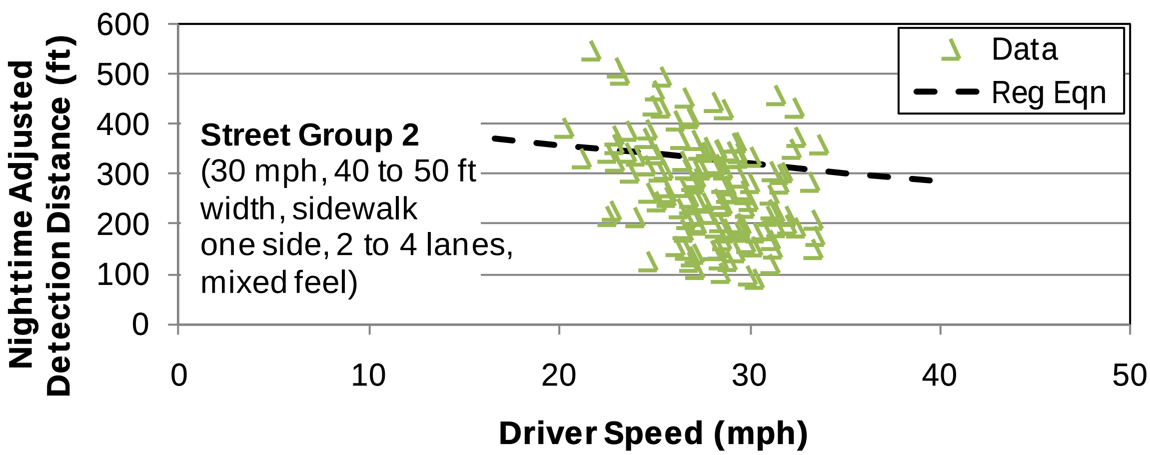


Figure 55. Graph. Nighttime adjusted detection distance by driver speed for street group 2 at study sites.

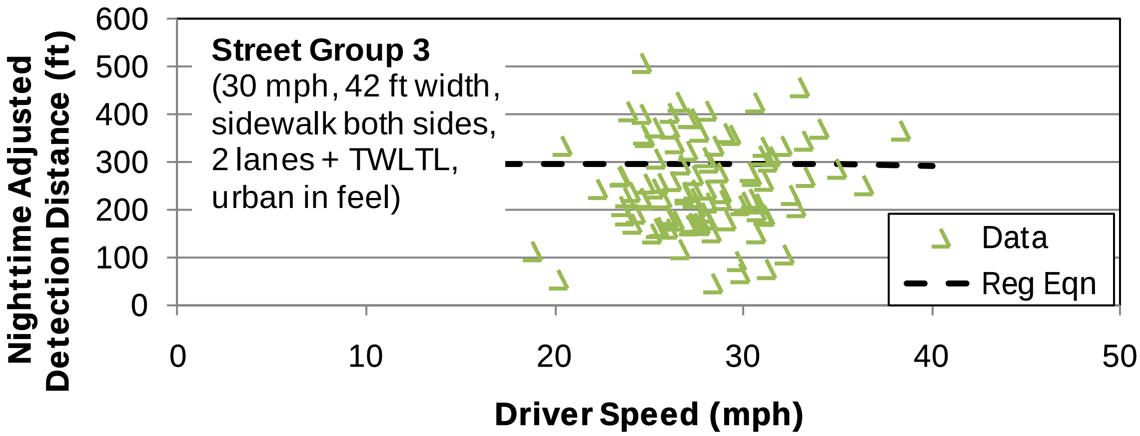


Figure 56. Graph. Nighttime adjusted detection distance by driver speed for street group 3 at study sites.

Driver Speed and Gender

The gender and driver speed interaction was statistically significant. Figure 57 shows the original data along with the estimated regression lines for male and female using the parameter estimates. The plots of the regression lines for male and female are not parallel, and they cross at about 30 mi/h, which would contribute to the finding that there is an interaction between gender and speed. Given that the difference in predictions is 14 ft at 20 mi/h and -19 ft at 45 mi/h, the finding may be statistically significant but probably not of practical difference.

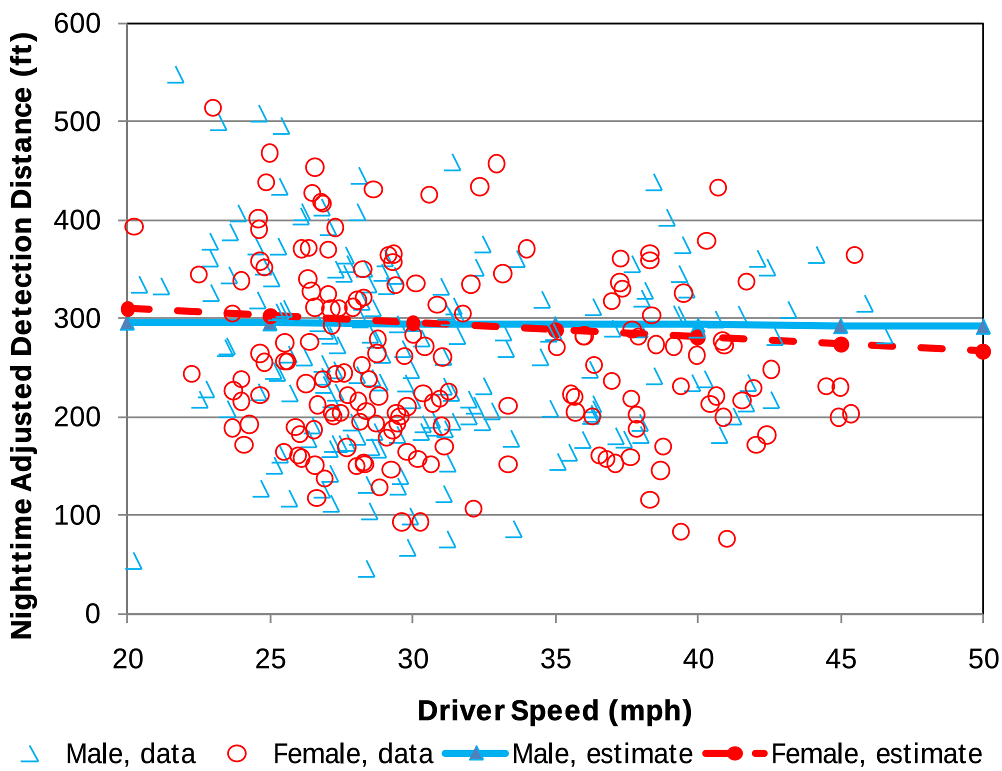


Figure 57. Graph. Nighttime adjusted detection distance by gender and driver speed at study sites.

Eye Height and Street Group along with Vehicle and Street Group

Within the extended model, the interaction term driver eye height and street group was statistically significant along with the interaction term of vehicle and street group. The nighttime adjusted detection distance data by driver eye height and street group are shown for street group 1 in figure 58, street group 2 in figure 59, and street group 3 in figure 60. The following conditions were assumed when generating plots of regression lines:

- Transverse pavement markings.
- Speed is 31 mi/h.
- Older age group.
- Male drivers.

Because all driver eye heights below 48 inches were in the sedan and all driver eye heights of 50 inches and greater were in the SUV (i.e., driver eye height is nested within vehicle type), the plots also show the detection data by vehicle. As unique main effect variables, driver eye height, vehicle type, and street group were not significant. This could indicate that the effect of driver eye height or vehicle type changes depending upon the street group, which would be surprising because the expectation is that driver eye height or vehicle type would have the same effect regardless of the characteristics of the roads.

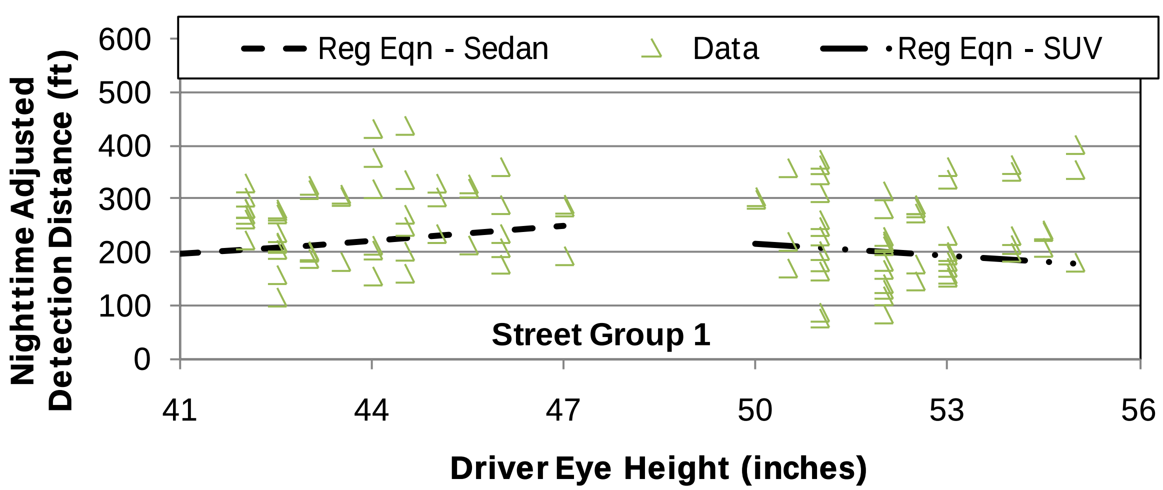


Figure 58. Graph. Nighttime adjusted detection distance by vehicle type and driver eye height for street group 1 at study sites.

Figure 59. Graph. Nighttime adjusted detection distance by vehicle type and driver eye height for street group 2 at study sites.

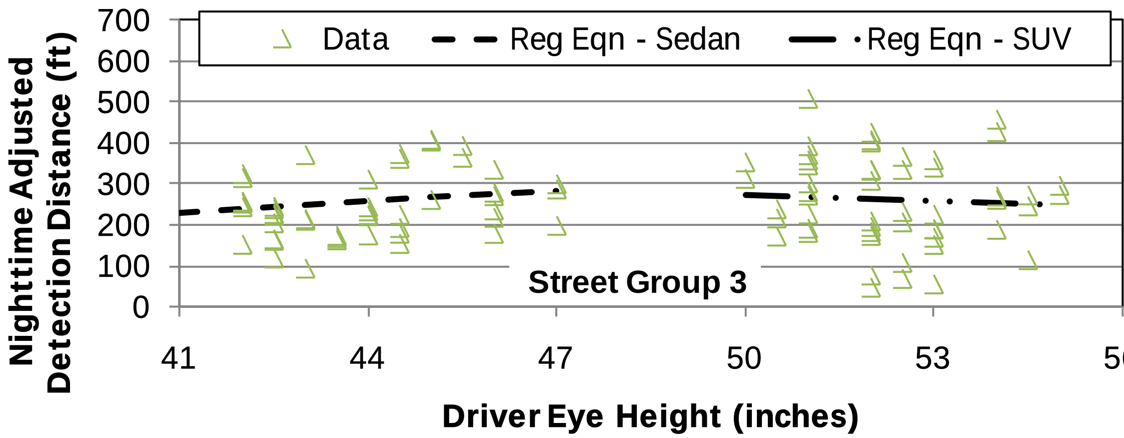


Figure 60. Graph. Nighttime adjusted detection distance by vehicle type and driver eye height for street group 3 at study sites.

The overall expectation for driver eye height was that as driver eye height increases, the nighttime adjusted detection distance would be longer. Taller drivers should be able to see farther. For vehicle type, the relationship between detection distance and vehicle type is not known because of the different headlamps. To account for the potential effects of headlamps, vehicle type was kept as a separate variable from driver eye height.

The two-way interaction of vehicle type and street group was statistically significant in the extended model. The headlamps on the different vehicles along with the street lighting available on a street could affect the detection distances along the different streets. The Tukey test for vehicle and street group interaction (see table 20) showed that the least square means for the different combinations of vehicle type and street group were not significantly different. Even though the initial statistical evaluation, *F*-test, found these terms significant, the multiple comparison procedure, Tukey test, did not find a difference. While a difference due to vehicle type would not be unexpected, having the impact of vehicle type change because the vehicle was on a different street would not be expected.

The relationship found for the sedan drivers showed longer nighttime adjusted detection distances for drivers sitting higher. An opposite relationship was found for the SUV drivers. As eye height increased, the adjusted detection distance decreased. Regression lines were generated using the coefficients from the extended model as shown in figure 58, figure 59, and figure 60. The regression lines show general patterns rather than specific values, since the plot of the line includes several assumptions, such as marking type and speed. In most combinations (e.g., SUV drivers on street group 2) the predicted differences between the lowest and highest eye height drivers would be considered practically different, so driver eye height may be a variable of interest. A better understanding of why increasing eye height improves detection distance in the sedan but decreases detection distance in the SUV is needed. This question is beyond the scope of the study, especially given that the interaction terms of marking type with vehicle type or eye height were not statistically significant. The interaction with marking type would be of greater interest. The interaction terms of vehicle and street group and eye height and street group were not significant in the reduced model, which is an additional reason to set aside this finding.

Marking Type

Marking type is the only main effect significant variable in the models (see table 17 and table 19). None of the interaction terms that included marking type were statistically significant for nighttime adjusted detection distance at the study sites. As shown in table 20, the detection distance is similar for the continental and bar pairs markings (about 328–335 ft), and the detection distance to the continental and bar pairs markings is different from the detection distance to the transverse markings (about 220 ft).

Daytime Detection—Existing Sites

Issues arose in the analysis of the data at the existing sites due to potential confounding between marking type and street group. The limited number of sites was a major obstacle in the evaluation. There was only one set of midblock continental crossing data because the data for the opposite approach (with an available viewing distance of only 339 ft) were removed from the data set. There was also only one midblock transverse marking crossing with data available for both approaches. Because of this limited number of sites, the midblock sites always had the same street groups (only street group 2 for the continental site and street group 4 for the transverse site). Only continental and transverse markings were used at the existing sites; there were no bar pair markings.

Reviewing patterns of the data also indicated that a square root transformation of detection distance was needed to satisfy an underlying assumption for ANACOVA. The data were transformed back to original form (i.e., the results were squared) in the graphs developed to illustrate findings.

Table 21 and table 22 show the summary of fit findings and fixed effect results for the daytime detection of existing markings when using all main effect variables along with reasonable two-way interaction variables. The response variable was transformed using a square root. The significant variables for daytime adjusted detection distance at existing sites include the following:

- Interaction of marking type and location.
- Interaction of driver speed and location.
- Marking type.
- Location.

Table 21. ANACOVA summary of fit findings for daytime adjusted detection distance for extended model (includes potential variables and two-way interactions) for existing sites.

Response Square Root Adjusted Detection Distance

Summary of Fit

RSquare	0.903852
RSquare Adj	0.862806
Root Mean Square Error	2.234199
Mean of Response	14.33578
Observations (or Sum Wgts)	245

Note: Abbreviation list provided in front section of report. A square-root transformation was applied to the data.

Table 22. ANACOVA fixed effects findings for daytime adjusted detection distance for extended model (includes potential variables and two-way interactions) for existing sites.

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Age_Group	1	1	43.72	0.0005	0.9825
Driver_Sp	1	1	162.9	0.3737	0.5418
Eye_Height[Vehicle]	2	2	142.5	1.7863	0.1713
Gender	1	1	40.3	1.3573	0.2509
Loc	1	1	117.7	8.5329	0.0042*
Mark_Type	1	1	109.2	4.2945	0.0406*
Ped/Bike_Pres	1	1	155.2	0.0067	0.9348
Street Group	3	3	89.03	1.2662	0.2909
Traf_Pres	1	1	158.3	0.1002	0.7519
Vehicle	1	1	143.4	0.7320	0.3937
Age_Group*Gender	1	1	25.17	0.5552	0.4631
Age_Group*Loc	1	1	146.6	3.0087	0.0849
Age_Group*Street Group	3	3	149.3	1.7658	0.1562
Age_Group*Vehicle	1	1	25.82	2.7776	0.1077
Driver_Sp*Age_Group	1	1	166.2	1.2538	0.2644
Driver_Sp*Gender	1	1	166.3	3.6359	0.0583
Driver_Sp*Loc	1	1	161.2	49.6153	<.0001*
Driver_Sp*Ped/Bike_Pres	1	1	161.7	0.1781	0.6736
Driver_Sp*Street Group	3	3	151.5	0.3501	0.7891
Driver_Sp*Traf_Pres	1	1	158.1	0.0332	0.8557
Driver_Sp*Vehicle	1	1	162.9	2.7089	0.1017
Eye_Height*Age_Group[Vehicle]	2	2	27.82	1.2638	0.2983
Eye_Height*Driver_Sp[Vehicle]	2	2	157.9	0.9817	0.3770
Eye_Height*Gender[Vehicle]	2	2	29.68	1.1480	0.3310
Eye_Height*Loc[Vehicle]	2	2	147.2	2.3291	0.1010
Eye_Height*Mark_Type[Vehicle]	2	2	146.9	2.1699	0.1178
Eye_Height*Ped/Bike_Pres[Vehicle]	2	2	154.9	0.0312	0.9693
Eye_Height*Street Group[Vehicle]	6	6	150.1	0.7802	0.5867
Eye_Height*Traf_Pres[Vehicle]	2	2	156	0.3270	0.7216
Gender*Loc	1	1	149.5	0.2338	0.6294
Gender*Street Group	3	3	150.2	0.2601	0.8541
Gender*Vehicle	1	1	28.34	2.1389	0.1546
Mark_Type*Age_Group	1	1	143.8	2.5675	0.1113
Mark_Type*Driver_Sp	1	1	147.2	0.0190	0.8905
Mark_Type*Gender	1	1	150.9	2.2527	0.1355
Mark_Type*Loc	1	1	8.059	13.3022	0.0064*
Mark_Type*Ped/Bike_Pres	1	1	151.9	0.2005	0.6550
Mark_Type*Traf_Pres	1	1	151.7	1.5928	0.2089
Mark_Type*Vehicle	1	1	145.9	2.9372	0.0887
Ped/Bike_Pres*Age_Group	1	1	163.7	0.2310	0.6315
Ped/Bike_Pres*Gender	1	1	158.9	0.1145	0.7355
Ped/Bike_Pres*Loc	1	1	148.4	0.0006	0.9799
Ped/Bike_Pres*Vehicle	1	1	153.8	0.0072	0.9327
Traf_Pres*Age_Group	1	1	153.5	0.3345	0.5639
Traf_Pres*Gender	1	1	157.2	1.4259	0.2342
Traf_Pres*Loc	1	1	155.6	0.1321	0.7167
Traf_Pres*Ped/Bike_Pres	1	1	154.2	1.2313	0.2689
Traf_Pres*Vehicle	1	1	158.2	0.0613	0.8048
Vehicle*Loc	1	1	148.9	3.5603	0.0611
Vehicle*Street Group	3	3	149.6	0.2391	0.8690

Note: Abbreviation list provided in front section of report. The horizontal rule separates the main effect variables from the two-way interactions. Asterisks (*) in the Prob > F column represent effects that are statistically significant at the 0.05 level.

Table 23 provides the model that reflects only significant interaction terms and main effect variables that are part of a statistically significant two-way interaction term. Table 24 provides the effects details for this model. Statistically significant interaction terms are as follows:

- Location and marking type.
- Location and driver speed.
- Location and age group.

Table 23. ANACOVA findings for daytime adjusted detection distance for reduced model for existing sites.

Response Square Root Adjusted Detection Distance

Summary of Fit

RSquare	0.866385
RSquare Adj	0.862438
Root Mean Square Error	2.237075
Mean of Response	14.33578
Observations (or Sum Wgts)	245

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob > |t|
Intercept	19.236047	1.564591	223.1	12.29	< 0.0001*
Mark_Type[CON]	2.3179499	0.427766	9.118	5.42	0.0004*
Driver_Sp	-0.029766	0.054706	225.3	-0.54	0.5869
Loc[Ei]	-4.898095	0.497594	16.33	-9.84	< 0.0001*
Age_Group[< 55]	0.1409495	0.247201	43.87	0.57	0.5715
Loc[Ei]*Mark_Type[CON]	-1.56501	0.427635	9.102	-3.66	0.0051*
Loc[Ei]*(Driver_Sp-22.9289)	0.5004652	0.055108	227.1	9.08	< 0.0001*
Loc[Ei]*Age_Group[< 55]	-0.398108	0.167933	196.1	-2.37	0.0187*

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Mark_Type	1	1	9.118	29.3626	0.0004*
Driver_Sp	1	1	225.3	0.2960	0.5869
Loc	1	1	16.33	96.8957	< 0.0001*
Age_Group	1	1	43.87	0.3251	0.5715
Loc*Mark_Type	1	1	9.102	13.3933	0.0051*
Loc*Driver_Sp	1	1	227.1	82.4737	< 0.0001*
Loc*Age_Group	1	1	196.1	5.6199	0.0187*

Note: Abbreviation list provided in front section of report. A square-root transformation was applied to the data. The horizontal rule separates the main effect variables from the two-way interactions.

Table 24. Effects details for variables in table 23.

Mark_Type

Least Squares Means Table

Level	Least Sq Mean	Std Error
CON	20.871501	0.79140242
TRA	16.235601	0.54885479

LSMeans Differences Student's t

α=0.050

Level			Least Sq Mean
CON	A		20.871501
TRA		B	16.235601

Loc

Least Squares Means Table

Level	Least Sq Mean	Std Error
Ei	13.655456	0.50117427
Em	23.451646	0.89756016

LSMeans Differences Student's t

α=0.050

Level			Least Sq Mean
Em	A		23.451646
Ei		B	13.655456

Age_Group

Least Squares Means Table

Level	Least Sq Mean	Std Error
< 55	18.694501	0.57909702
≥ 55	18.412602	0.59030037

LSMeans Differences Student's t

α=0.050

Level		Least Sq Mean
< 55	A	18.694501
≥ 55	A	18.412602

Loc*Mark_Type

Least Squares Means Table

Level	Least Sq Mean	Std Error
Ei, CON	14.408397	0.8561985
Ei, TRA	12.902516	0.4401467
Em, CON	27.334605	1.3058417
Em, TRA	19.568686	0.9720994

LSMeans Differences Tukey HSD

α=0.050

Level				Least Sq Mean
Em, CON	A			27.334605
Em, TRA		B		19.568686
Ei, CON			C	14.408397
Ei, TRA			C	12.902516

Loc*Age_Group

Least Squares Means Table

Level	Least Sq Mean	Std Error
Ei,< 55	13.398298	0.54764873
Ei, ≥ 55	13.912615	0.57341631
Em,< 55	23.990703	0.96036704
Em, ≥ 55	22.912589	0.95905659

LSMeans Differences Tukey HSD

α=0.050

Level			Least Sq Mean
Em,< 55	A		23.990703
Em, ≥ 55	A		22.912589
Ei, ≥ 55		B	13.912615
Ei,< 55		B	13.398298

Note: Abbreviation list provided in front section of report. A square-root transformation was applied to the data. Levels not connected by same letter are significantly different.

Marking Type and Location

The interaction between marking type and location was significant (see figure 61). The continental markings were always detected at a greater distance as compared to the transverse markings. The Tukey results (see table 24) show that the detection distances to the continental or transverse markings at intersections are not significantly different. The detection distance to midblock continental is statistically different from the detection distance to midblock transverse markings.

The difference between the continental and the transverse markings is more apparent at the midblock locations, as illustrated in figure 61. Both transverse and continental marking midblock sites had pedestrian warning signs (W11-2). These sites are located on either side of a basketball arena near large parking lots used by TAMU students. Therefore, both sites have heavy pedestrian traffic associated with students going to classes during the day. One site was a two-lane street with bike lanes, and the other was a four-lane divided roadway, so the roadway width may be a factor. If one assumes that the roadway width is not a factor, a general observation could be that at a midblock location the continental markings were detected at about twice the distance upstream as the transverse markings. Another interpretation of the finding is that the additional 350 ft of detection distance between transverse and continental markings reflects 8 s of increased awareness of the presence of the markings at 30-mi/h operating speeds.

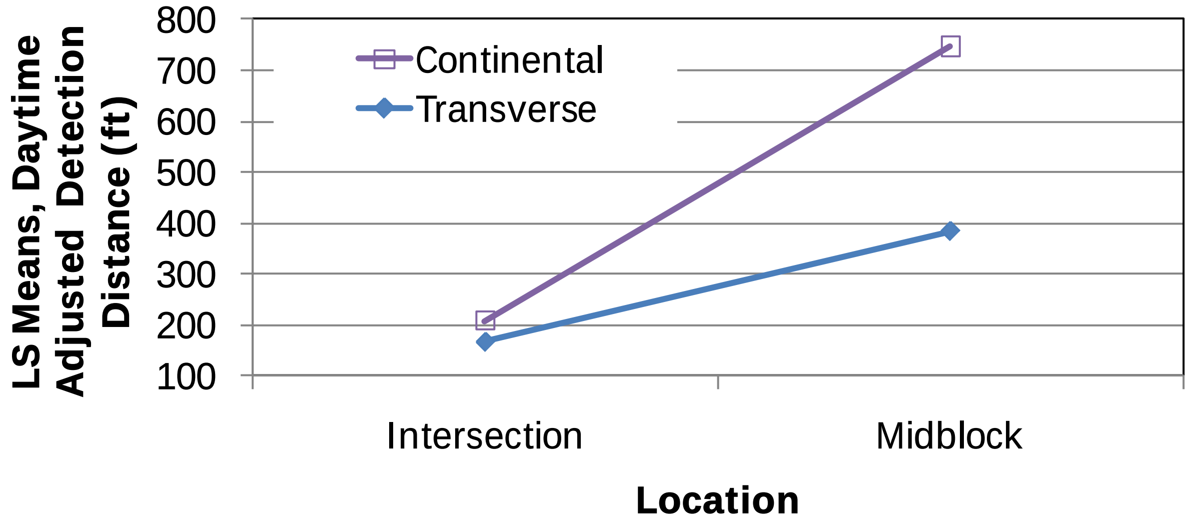


Figure 61. Graph. Least square mean daytime adjusted detection distance by marking type and location at existing sites.

Location and Driver Speed

Driver speed was not significant. However, the interaction between driver speed and location was significant. Figure 62 shows the individual data points along with the regression line that would be generated using the coefficients from the reduced model (see table 23). The lower speeds on the approaches to the stop- or signal-controlled intersections can easily be seen. The effects of driver speed are statistically different for the midblock locations and the intersection locations. At the intersection locations, shorter adjusted detection distances were associated with lower speeds while the opposite occurred at the midblock locations. Faster drivers at the midblock locations had slightly shorter detection distances. The low detection distance and low speed at the intersections is related to the drivers coming to a complete stop at the intersection. Several drivers focused more on the stopping maneuver than on the task of identifying the crosswalk. They would make comments such as “oh yes, crosswalk,” indicating that they only recalled the crosswalk identification task after initiating the stopping maneuver.

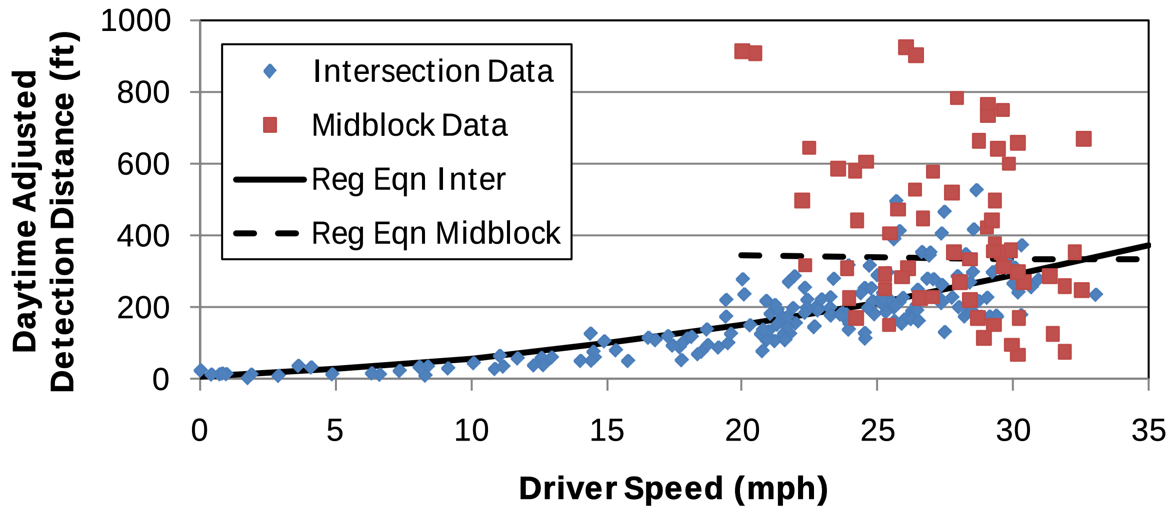


Figure 62. Graph. Daytime adjusted detection distance by driver speed and location at existing sites.

Age Group and Location

Age group was not significant. However, the interaction between age group and location was significant. As shown in figure 63, younger drivers had slightly shorter detection distances than older drivers at the intersections (180 ft compared to 194 ft). For the midblock sites, the pattern was reversed; younger drivers had greater detection distances (576 ft compared to 525 ft). The Tukey results shown in table 24 reveal that detection distances are not statistically different for the two age groups at the midblock locations or at the intersections. Stated in another manner, the detection distance is different for midblock and intersection locations. Detection distance is not different for older and younger drivers at the midblock locations or at the intersections.

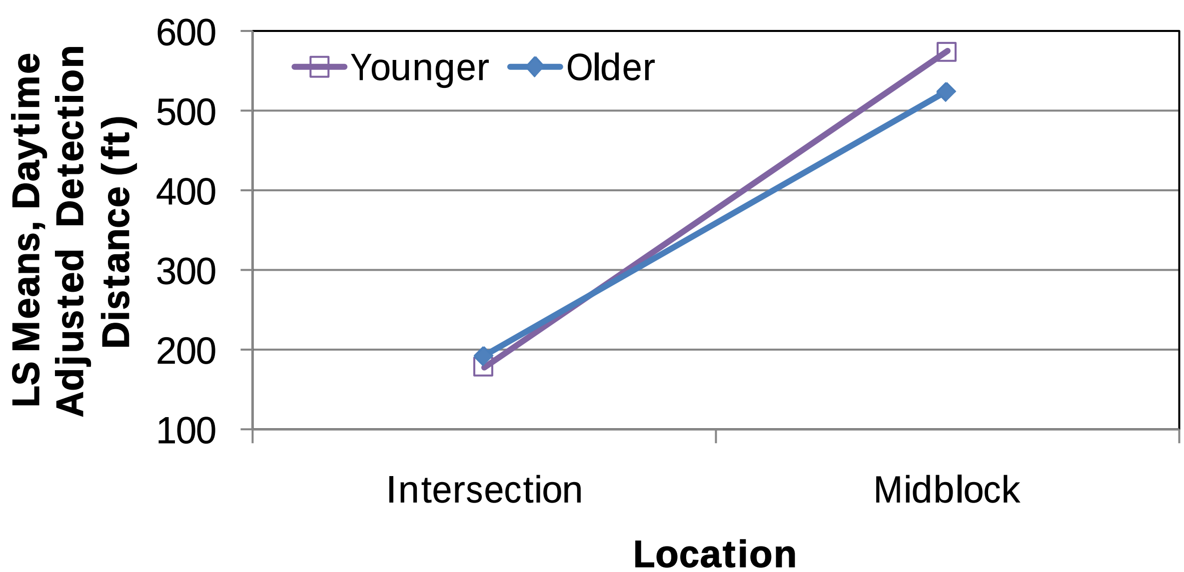


Figure 63. Graph. Least square mean daytime adjusted detection distance by driver age and location at existing sites.

Nighttime Detection—Existing Sites

Similar to the analysis of the existing site daytime data, the analysis of the existing site nighttime data had potential confounding issues. In addition to the overlaps between marking type and street group was an overlap between marking type and retroreflectivity group. At the stop-controlled intersections, all of the transverse markings had retroreflectivity readings less than 38 mcd/m^2/lx and the continental markings had readings in the 500s (524 or 570 mcd/m^2/lx). On the other hand, at the midblock locations, all of the continental markings had retroreflectivity readings of 81 mcd/m^2/lx and the continental markings had readings in the 300s (309 or 331 mcd/m^2/lx). Therefore, retroreflectivity was not included in the model.

Similar to the daytime analysis, the nighttime data indicated that a square root transformation of detection distance was needed to satisfy an underlying assumption for ANACOVA. The data were transformed back to original form (i.e., the results were squared) in the graphs developed to illustrate findings. Table 25 (summary of fit) and table 26 (fixed effect tests) show the results for the nighttime detection of existing markings when using all main effect variables along with reasonable two-way interaction variables. The response variable was transformed using a square root. The significant two-way interaction variables for nighttime adjusted detection distance at existing sites include the following:

- Driver speed and location.
- Gender and location.

Table 25. ANACOVA summary of fit findings for nighttime adjusted detection distance for extended model (includes potential variables and two-way interactions) for existing sites.

Response Square Root Adjusted Detection Distance

Summary of Fit

RSquare	0.839382
RSquare Adj	0.763414
Root Mean Square Error	1.674317
Mean of Response	11.67063
Observations (or Sum Wgts)	219

Note: Abbreviation list provided in front section of report.

Table 26. ANACOVA fixed effect tests findings for nighttime adjusted detection distance for extended model (includes potential variables and two-way interactions) for existing sites.

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Age_Group	1	1	147.6	0.4825	0.4884
Driver_Sp	1	1	142.9	4.2601	0.0408*
Eye_Height[Vehicle]	2	2	146.5	0.2699	0.7638
Gender	1	1	147.9	2.4619	0.1188
Loc	1	1	148	1.5435	0.2161
Mark_Type	1	1	139.6	0.1174	0.7324
Ped/Bike_Pres	1	1	147.8	0.1832	0.6693
Street Group	3	3	130.9	0.1993	0.8967
Traf_Pres	1	1	147.2	0.0793	0.7786
Vehicle	1	1	146.3	0.0180	0.8936
Age_Group*Gender	1	1	144.2	0.0029	0.9572
Age_Group*Loc	1	1	144.3	2.0896	0.1505
Age_Group*Street Group	3	3	143.4	0.8255	0.4819
Age_Group*Vehicle	1	1	142.7	0.3809	0.5381
Driver_Sp*Age_Group	1	1	147.6	3.1912	0.0761
Driver_Sp*Loc	1	1	147.2	24.6120	< 0.0001*
Driver_Sp*Ped/Bike_Pres	1	1	142	1.1750	0.2802
Driver_Sp*Street Group	3	3	145.3	0.2328	0.8734
Driver_Sp*Traf_Pres	1	1	147.3	0.0090	0.9247
Driver_Sp*Vehicle	1	1	144.9	0.9253	0.3377
Eye_Height*Age_Group[Vehicle]	2	2	146.1	0.8108	0.4465
Eye_Height*Driver_Sp[Vehicle]	2	2	145.4	0.1828	0.8331
Eye_Height*Gender[Vehicle]	2	2	143.8	0.1963	0.8220
Eye_Height*Loc[Vehicle]	2	2	145.1	2.7651	0.0663
Eye_Height*Mark_Type[Vehicle]	2	2	145.8	1.0681	0.3463
Eye_Height*Ped/Bike_Pres[Vehicle]	2	2	145.7	2.2295	0.1112
Eye_Height*Street Group[Vehicle]	6	6	143.7	0.9592	0.4551
Eye_Height*Traf_Pres[Vehicle]	2	2	147.3	0.1932	0.8245
Gender*Loc	1	1	143.3	34.3619	< 0.0001*
Gender*Street Group	3	3	142.6	0.6398	0.5906
Gender*Vehicle	1	1	148	0.0607	0.8057
Mark_Type*Age_Group	1	1	143.7	0.4522	0.5024
Mark_Type*Driver_Sp	1	1	147.4	3.1338	0.0788
Mark_Type*Gender	1	1	143.1	0.0170	0.8963
Mark_Type*Loc	1	1	10.6	2.6708	0.1315
Mark_Type*Ped/Bike_Pres	1	1	147.5	0.1602	0.6896
Mark_Type*Traf_Pres	1	1	146.6	0.0022	0.9630
Mark_Type*Vehicle	1	1	144.1	0.4123	0.5218
Ped/Bike_Pres*Age_Group	1	1	145.9	0.6445	0.4234
Ped/Bike_Pres*Gender	1	1	147.4	0.0674	0.7955
Ped/Bike_Pres*Loc	1	1	148	0.1634	0.6866
Ped/Bike_Pres*Vehicle	1	1	142.1	2.7309	0.1006
Traf_Pres*Age_Group	1	1	145.4	0.0074	0.9316
Traf_Pres*Loc	1	1	145.1	2.6451	0.1060
Traf_Pres*Vehicle	1	1	146.9	0.0645	0.7998
Vehicle*Loc	1	1	146.7	0.2459	0.6207
Vehicle*Street Group	3	3	144.1	1.6618	0.1779

Notes: Abbreviation list provided in front section of report. The horizontal rule separates the main effect variables from the two-way interactions. Asterisks (*) in the Prob > F column represent effects that are statistically significant at the 0.05 level.

The reduced model that only includes significant two-way interaction terms along with main effects variables is shown in table 27. The least square means and Student's *t* test results are provided in table 28.

Although marking type was not significant either as a main effect or part of a two-way interaction in the extended model, it was significant under the reduced model for the nighttime existing site data.

Table 27. ANACOVA findings for nighttime adjusted detection distance for reduced model for existing sites.

Response Square Root Adjusted Detection Distance

Summary of Fit

RSquare	0.784536
RSquare Adj	0.778438
Root Mean Square Error	1.67663
Mean of Response	11.67063
Observations (or Sum Wgts)	219

Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob > |t|
Intercept	8.5579982	1.147526	201.8	7.46	< 0.0001*
Mark_Type[CON]	0.5071214	0.214537	8.673	2.36	0.0433*
Driver_Sp	0.217536	0.042904	210.5	5.07	< 0.0001*
Gender[FEMALE]	0.7442613	0.159262	44.75	4.67	< 0.0001*
Loc[Ei]	-1.336532	0.320496	36.25	-4.17	0.0002*
Loc[Ei]*(Driver_Sp-21.0628)	0.1857927	0.042542	211.9	4.37	< 0.0001*
Loc[Ei]*Gender[FEMALE]	-0.733821	0.134929	183.1	-5.44	< 0.0001*

Fixed Effect Tests

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Mark_Type	1	1	8.673	5.5875	0.0433*
Driver_Sp	1	1	210.5	25.7078	< 0.0001*
Gender	1	1	44.75	21.8387	< 0.0001*
Loc	1	1	36.25	17.3906	0.0002*
Loc*Driver_Sp	1	1	211.9	19.0727	< 0.0001*
Loc*Gender	1	1	183.1	29.5781	< 0.0001*

Note: Abbreviation list provided in front section of report. A square-root transformation was applied to the data. The horizontal rule separates the main effect variables from the two-way interactions. Asterisks (*) in the Prob > F and Prob > |t| columns represent effects that are statistically significant at the 0.05 level.

Table 28. Effects details for variables in table 27.

Mark_Type

Least Squares Means Table

Level	Least Sq Mean	Std Error
CON	13.647036	0.44162265
TRA	12.632794	0.35248148

LSMeans Differences Student's t

α=0.050

Level			Least Sq Mean
CON	A		13.647036
TRA		B	12.632794

Gender

Least Squares Means Table

Level	Least Sq Mean	Std Error
FEMALE	13.884176	0.38485597
MAL	12.395654	0.36032780

LSMeans Differences Student's t

α=0.050

Level			Least Sq Mean
FEMALE	A		13.884176
MALE		B	12.395654

Loc

Least Squares Means Table

Level	Least Sq Mean	Std Error
Ei	11.803383	0.25872210
Em	14.476447	0.60474724

LSMeans Differences Student's t

α=0.050

Level			Least Sq Mean
Em	A		14.476447
Ei		B	11.803383

Loc*Gender

Least Squares Means Table

Level	Least Sq Mean	Std Error
Ei, FEMALE	11.813823	0.30883108
Ei, MALE	11.792943	0.29868711
Em, FEMALE	15.954529	0.67715160
Em, MALE	12.998365	0.62965734

LSMeans Differences Tukey HSD

α=0.050

Level			Least Sq Mean
Em, FEMALE	A		15.954529
Em, MALE		B	12.998365
Ei, FEMALE		B	11.813823
Ei, MALE		B	11.792943

Note: Abbreviation list provided in front section of report. A square-root transformation was applied to the data. Levels not connected by the same letter are significantly different.

Driver Speed and Location

Similar to the findings for the daytime, driver speed was significant along with the interaction term of driver speed and location. Figure 64 illustrates the findings for driver speed and location. For existing crosswalks at stop- or signal-controlled intersections, lower speeds are associated with shorter detection distances. The statistical evaluation found a similar trend for midblock locations; longer detection distances are associated with higher speeds (see plot of regression equation).

Gender and Location

The interaction between gender and location was significant, with women seeing the crosswalk markings at a greater distance upstream for the midblock locations. A similar difference between male and female detection distance was found for the study sites. As previously noted, there is no reason to believe that women have better eyesight than men. This gender difference might be attributable to attention differences or response bias in that women were more willing to "guess" early to identify the marking. Figure 65 illustrates the trend. The difference for gender was over 136 ft at the midblock locations, which was statistically significant based on Tukey's test (see table 28). The difference was minimal for the intersections and was not statistically significant.

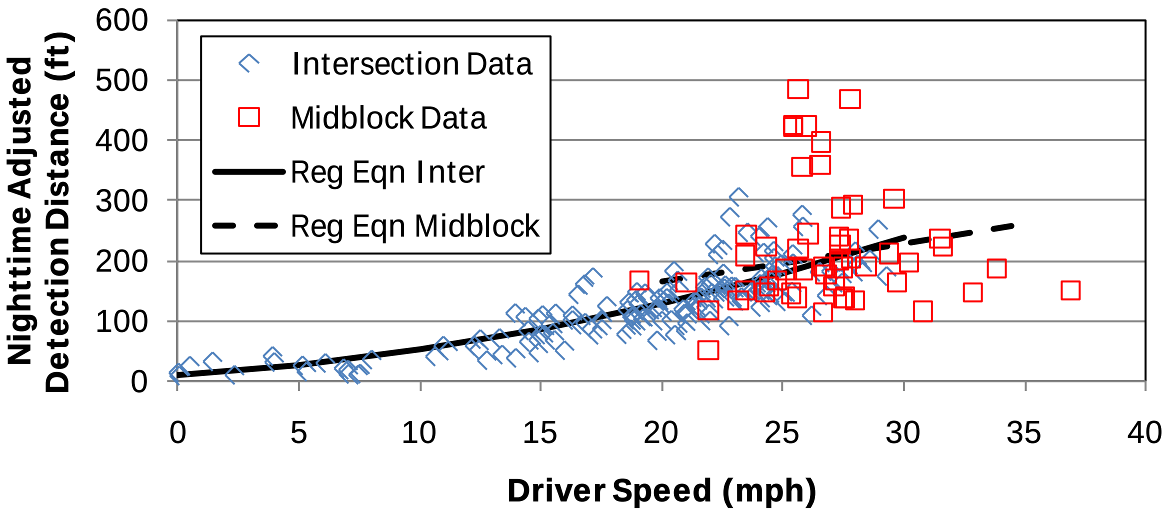


Figure 64. Graph. Nighttime adjusted detection distance by driver speed and location at existing sites.

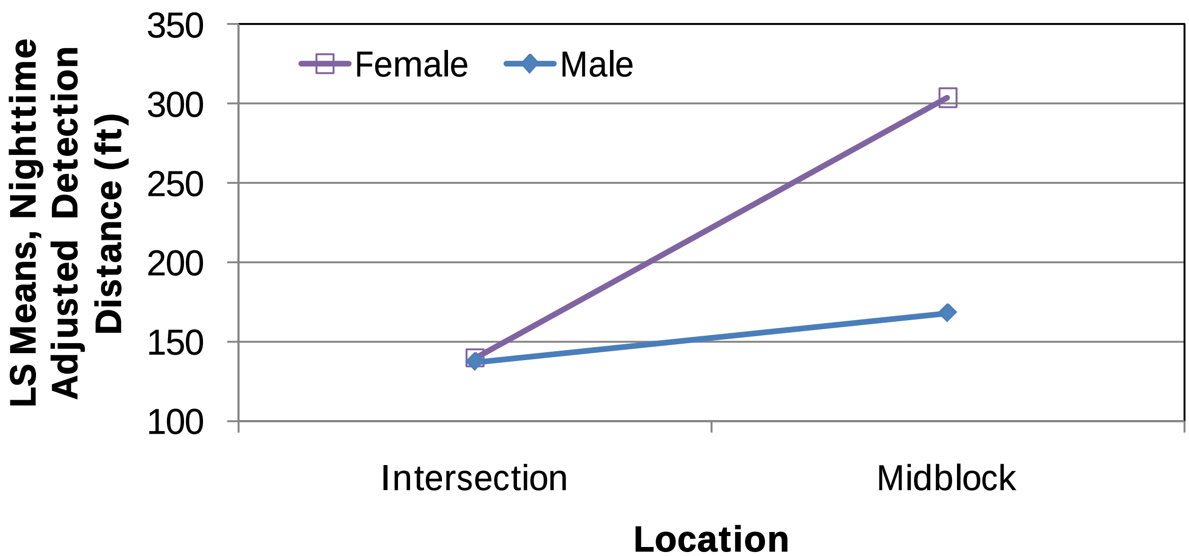


Figure 65. Graph. Least square mean nighttime adjusted detection distance by gender and location at existing sites.

Marking Type

Marking type was statistically significant in the reduced model (see table 27 and table 28). Similar to the study site evaluation, none of the interaction terms that included marking type were statistically significant for nighttime adjusted detection distance at the existing sites. The least square mean detection distance to the continental markings was 186 ft (after applying a squaring transformation) as compared to 160 ft to the transverse markings. The Tukey test (see table 28) did identify these distances as being significantly different.

Comparison of Findings

Table 29 summarizes the findings from the statistical evaluations of the adjusted detection distances. The results are subdivided by the site type (study or existing) and light (day or night). Preliminary evaluations demonstrated that evaluations needed to be conducted separately for the study sites (where the markings were installed at midblock locations) and the existing sites (where the markings were already present at midblock locations with pedestrian warning signs or at intersections). The preliminary evaluations also clearly showed a difference in detection distance for day and night. Since the nighttime condition had an additional variable, retroreflectivity, to consider and some of the variables were believed to have different effects during the night (such as vehicle type and driver eye height), separate analyses were done for daytime and nighttime conditions. The average detection distances by location, day or night, and marking type is shown in table 30. In all combinations, daytime detection distances are longer than nighttime detection distances.

As shown in table 29, the marking type (bar pair, continental, or transverse) for the study sites was statistically significant. The detection distances to bar pairs and continental markings were similar, and they were statistically different from the detection distance to the transverse markings.

For the study sites, the presence of traffic had an impact on detection distance, in most cases limiting the ability to see the markings farther upstream, as expected. The impact of traffic on the transverse markings was minimal as the detection distance to these markings was already small compared to the detection distances for bar pairs or continental. Overall, shorter detection distances were associated with higher speeds. However, in most cases, it was only slightly shorter detection distances. The characteristics of the streets also influenced the detection of the crosswalk markings. An unexpected result was that the street group with 45-mi/h posted speed limit had longer nighttime adjusted detection distances for the higher speeds. This was opposite the finding for daytime conditions; daytime adjusted detection distances were (slightly) shorter for the higher speeds. Variables that included gender, driver eye height, and vehicle type as part of an interaction term were found to be statistically significant; however, closer examination found them to not be of practical significance.

For the existing sites, marking type had a significant effect on detection distance. During the day, the detection distances to the continental or transverse markings at intersections were not significantly different. The detection distance to midblock continental was statistically different (longer) from the detection distance to midblock transverse markings. During nighttime conditions, variables in addition to marking type, such as location (midblock or intersection) and driver speed, had an effect on detection distances at the existing sites. Driver speeds had mixed effects on detection distance depending upon location (intersection or midblock) and light level (day or night). For intersections, an increase in driver speed was associated with longer detection distances for both the daytime and nighttime conditions. All of the intersections included in this project were either stop-controlled or signal–controlled. Several drivers appeared to be more focused on the stop maneuver than the detection task and would not call out the recognition of a crosswalk until close to the stop bar. For midblock (or uncontrolled approaches), the finding was dependent on light level. Nighttime detection distance at midblock was similar to intersections; longer detection distances were associated with the higher speeds. For daytime, the opposite occurred; higher driver speeds were associated with shorter detection distances to the midblock crosswalk.

While the higher driver speeds were associated with shorter detection distances, the differences were small and would not be considered of practical difference.

Table 29. Summary of adjusted detection distance findings.

Variable	Study Sites (Bar, Con, Tra at Midblock Locations)		Existing Sites (Con, Tra at Intersections and Midblock Locations)	
	Day	Night	Day	Night
Driver speed				SS(R)
Gender				SS(R)
Location	NA	NA	SS(E), SS(R)	SS(R)
Marking type	SS(E), SS(R)	SS(E), SS(R)	SS(E), SS(R)	SS(R)
Street group	SS(E)			
Age group X location	NA	NA	SS(R)	
Driver speed X gender		SS(R)		
Driver speed X location	NA	NA	SS(E), SS(R)	SS(E), SS(R)
Driver speed X street group	SS(E), SS(R)	SS(R)		
Eye height X street group		SS(E)		
Gender X location	NA	NA		SS(E), SS(R)
Gender X street group	SS(R)			
Marking type X location	NA	NA	SS(E), SS(R)	
Marking type X traffic presence	SS(E), SS(R)			
Street group X vehicle		SS(E)		
Traffic presence X location	NA	NA		SS(E)

Blank cell = Variable not significant in either the extended or reduced variable models.
SS(R) = Statistically significant (at 0.05 level) in the reduced variable model.
SS(E) = Statistically significant (at 0.05 level) in the extended variable model.
NA = Not applicable, location was not a variable for the study sites since all were at midblock.

Table 30. Average adjusted detection distances.

Location	Light	Average Adjusted Detection Distance (ft)		
		Bar Pair	Continental	Transverse
Existing intersection	Day	NA	195	170
	Night	NA	161	115
Existing midblock	Day	NA	625	313
	Night	NA	215	221
New study sites	Day	466	497	235
	Night	293	304	185

NA = Not applicable.

CROSSWALK RATING

The participants rated each crosswalk on how easy it was to see. The ratings given were A through F (with no E), with A being excellent or very easy to see and F being completely unacceptable or very hard to see, as shown in figure 32. These ratings were recorded along with participant comments and explanations of the response, when available. The ratings were summarized to make the following comparisons:

- Marking types (bar pairs, continental, transverse) among the study sites.
- Study site with the existing sites markings (continental and transverse).

In addition, the average scores were compared to the illuminance present at the sites and the retroreflectivity of the markings.

Comparison Among Study Site Markings

Figure 66 summarizes the average crosswalk ratings by marking type. The graph suggests that continental and bar pairs received similar ratings, with slightly more A ratings for continental than for bar pairs. Transverse markings were observed to receive more C ratings than continental and bar pairs. Transverse markings were the only marking type to receive D and F ratings.

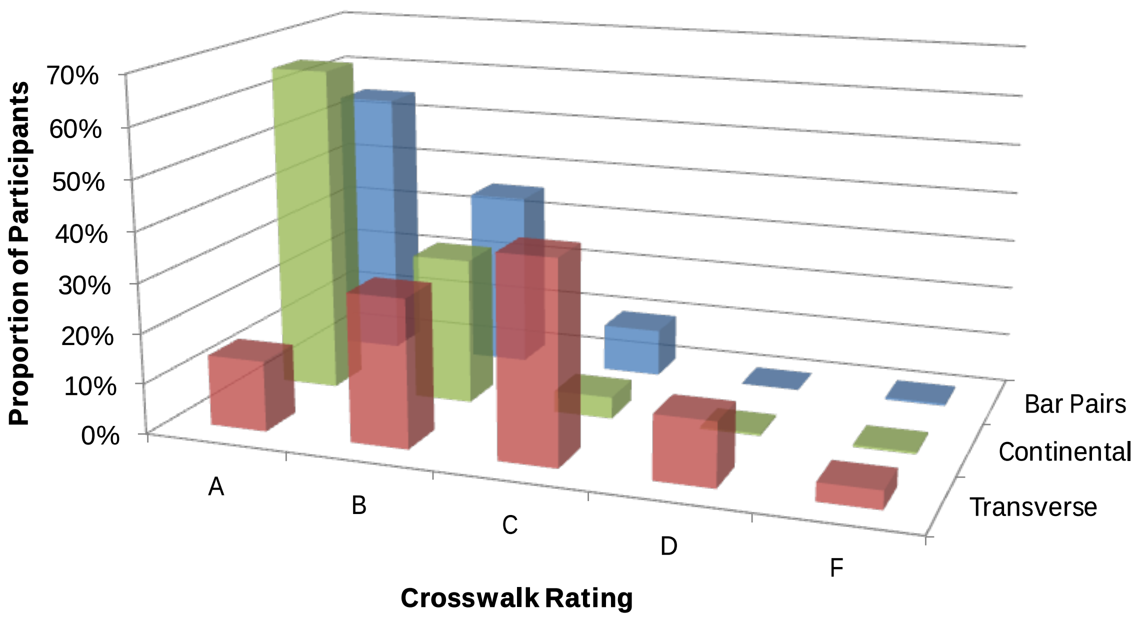


Figure 66. Graph. Rating by marking type for study sites.

Figure 67 through figure 69 summarize crosswalk ratings for the three marking types subdivided by the time of the day (day or night). As illustrated in figure 67 and figure 68, similar ratings were given to the bar pairs and continental markings during both daytime and nighttime conditions. For example, the bar pairs had about 55 percent A ratings in both day and night (see figure 67). A variation in day and night ratings, however, is observed for transverse markings (see figure 69). The transverse markings received better ratings in the night than in the day. Several participants commented about sun glare or shadow issues during the daytime at the study sites.

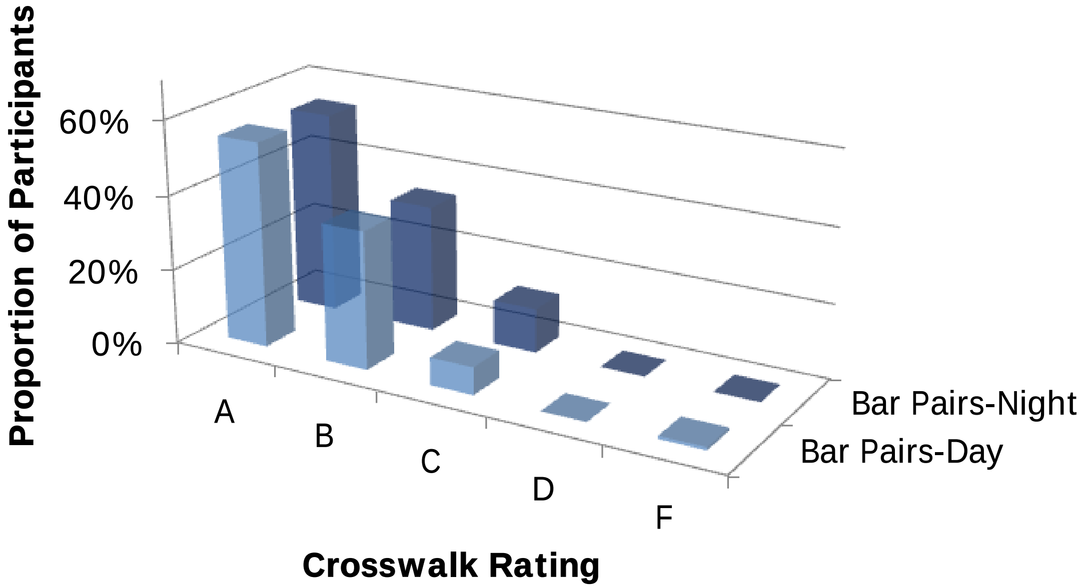


Figure 67. Graph. Rating by light level for study sites bar pairs marking.

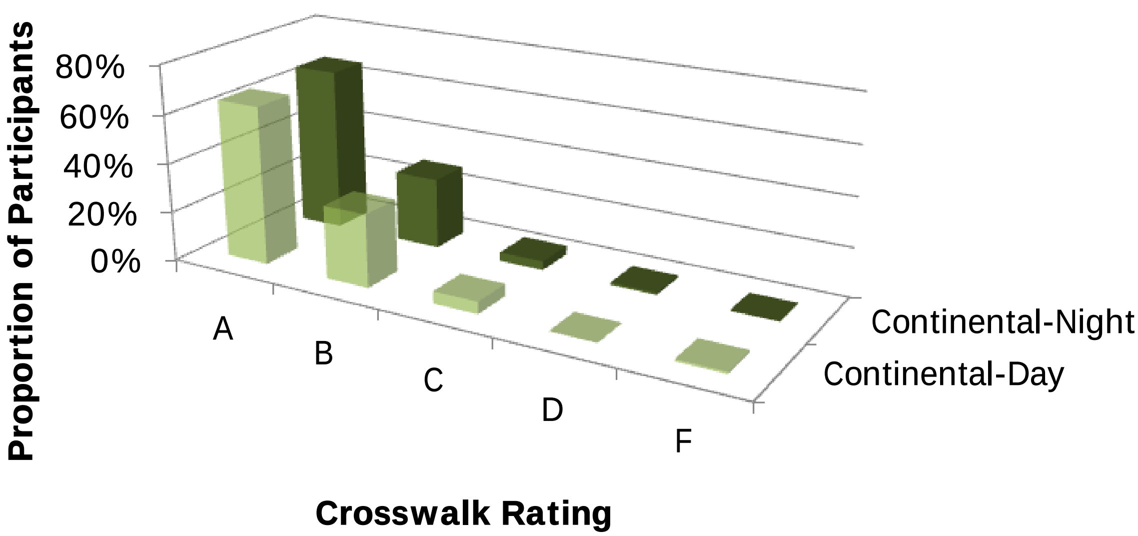


Figure 68. Graph. Rating by light level for study sites continental marking.

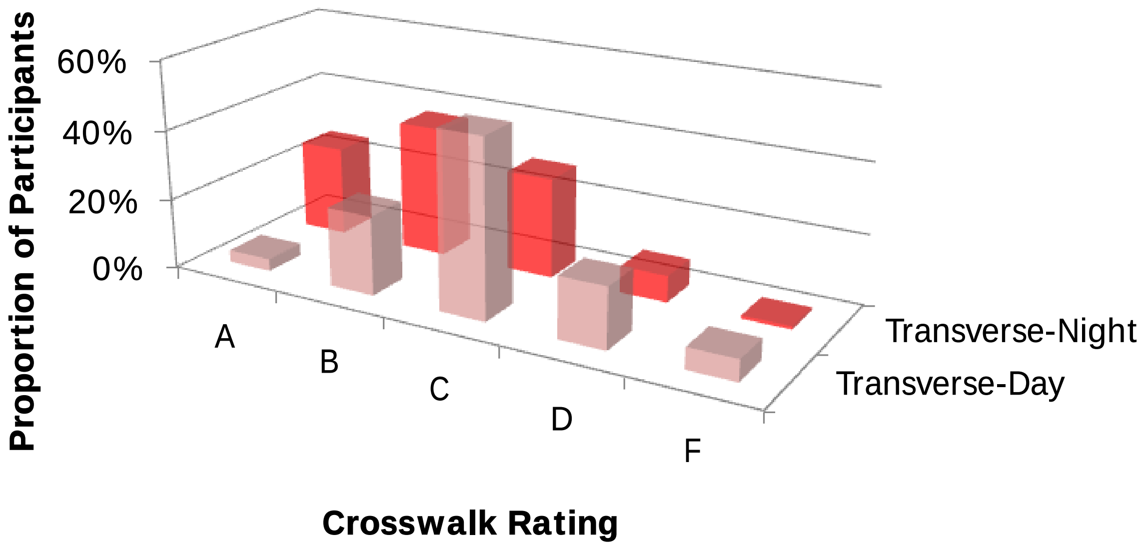


Figure 69. Graph. Rating by light level for study sites transverse marking.

To compare among marking patterns, table 31 was generated to summarize the crosswalk ratings for the three marking types. It contains the same information shown in figure 67 through figure 69. Within both daytime and nighttime conditions, continental and bar pairs were given better ratings than transverse markings. For example, 54 percent of the participants gave the bar pairs an A rating and 67 percent gave the continental markings an A rating; however, only 26 percent gave an A rating for transverse markings during the nighttime. The subdivision of ratings by light level does reveal that transverse markings received different ratings during the day than at night. Bar pairs and continental markings however, received similar ratings in both the daytime and nighttime.

Table 31. Rating by light level.

Marking Type (Number of Sites)	Age Group	Proportion of Participants (Percent)									
		Day					Night				
		A	B	C	D	F	A	B	C	D	F
Bar pairs (6)	Both	55	37	7	0	1	54	34	12	0	0
Continental (6)	Both	64	30	5	0	1	67	29	4	1	0
Transverse (6)	Both	3	23	50	17	6	26	37	29	8	1

Table 32 summarizes crosswalk ratings for the three marking types subdivided by light level (day or night) and age group. Age groups did not influence the type of ratings given to the different marking patterns; continental and bar pairs were given better ratings than transverse markings by both young (younger than 55) and old (55 or older) participants. Table 31 illustrates that transverse markings received better ratings during nighttime. Table 32 illustrates that the finding does not vary for young or old participants. In both cases, transverse markings had better ratings during nighttime conditions than during daytime conditions.

Table 32. Rating by age group and light level.

Marking Type (Number of Sites)	Age Group	Proportion of Participants (Percent)									
		Day					Night				
		A	B	C	D	F	A	B	C	D	F
Bar pairs (6)	< 55	54	42	5	0	0	57	33	10	0	0
Continental (6)	< 55	61	31	8	0	0	73	25	2	0	0
Transverse (6)	< 55	5	21	48	18	8	26	33	33	9	0
Bar pairs (6)	≥ 55	56	32	11	0	2	51	35	14	0	0
Continental (6)	≥ 55	68	28	2	0	2	59	33	6	2	0
Transverse (6)	≥ 55	2	24	54	17	4	26	43	23	6	2

A chi-square test for homogeneity was conducted to compare the proportion of participants giving A, B, or C ratings for each marking type. In some combinations, the proportion of participants was subdivided by marking type and light (day or night). The test hypothesis was that the proportions of ratings received by each marking type for the given runs were same. This hypothesis was rejected when the calculated *p*-value for the test statistic (calculated chi square) was lower than the test significance level (0.05). The test results were the same as the observations made in figure 66 through figure 69 and table 31 and found the following:

- Transverse marking daytime ratings were different from nighttime ratings.
- Daytime ratings for continental and bar pairs markings were similar.
- Nighttime ratings for continental and bar pairs markings were different (with continental receiving slightly better ratings).
- When daytime and nighttime data were combined, ratings for bar pairs and continental markings were not different.

The odds ratio for continental and bar pairs were estimated for nighttime ratings to further understand their association. The odds ratio shows whether the probability of an event is the same for two groups. An odds ratio of 1 implies that the event is equally likely in both groups.

For nighttime ratings for continental markings when compared to the bar pairs, the estimated odds of getting a rating of A is 45 percent higher and that of getting a rating of C is 64 percent lower. This implies that continental markings have a higher likelihood of receiving a better rating when compared to the bar pairs markings. This result is same as the observation made for table 31.

Comparison Among Existing Markings

There were no existing sites with bar pairs markings, hence only continental and transverse markings at the study sites were compared to the existing intersection and midblock sites. All the midblock crosswalks had warning signs, which participants said helped them detect the crosswalks. Transverse markings at the intersection of Kimbrough at Penberthy and those at the midblock on Kimbrough were used for this comparison. Continental markings at the intersection of Kimbrough and Olsen and those at the midblock on Tom Chandler were also used.

The ratings for continental markings on Olsen are thought to be affected by a dip in the pavement, based on participants' comments. Also, the ratings for continental midblock markings on the clockwise route on Tom Chandler are thought to be affected by the smaller available viewing distance from the turn onto the street. Therefore, the data for these sites are not included in the evaluations.

Marking Type, Light Level, and Location

Table 33 summarizes the ratings given to the existing markings at intersection and midblock sites by light level (day or night). As shown in the table, continental markings received better ratings than transverse markings at existing intersection and midblock crosswalks during both daytime and nighttime. During daytime, both the continental and transverse midblock markings received better ratings than the continental and transverse intersection markings. The advance pedestrian warning signs associated with the midblock locations could have contributed to the better ratings for the midblock locations as compared to the intersections. During nighttime, transverse markings were also found to have better ratings at the midblock location compared to the intersection location. Nighttime ratings of existing continental markings, however, were slightly better for the intersection site than for the midblock site. Near the continental midblock crossing are intramural soccer fields with bright lights that may have influenced the driver's ratings.

Table 33. Existing marking ratings by location and light level.

Marking Type (Number of Sites)	Location	Proportion of Participants (Percent)									
		Day					Night				
		A	B	C	D	F	A	B	C	D	F
Continental (1)	Intersection	15	60	25	0	0	50	44	6	0	0
Continental (1)	Midblock	100	0	0	0	0	33	28	28	6	6
Transverse (2)	Intersection	8	18	58	18	0	3	8	42	33	14
Transverse (2)	Midblock	15	30	40	10	5	14	28	42	14	3

Marking Type, Age Group, Light Level, and Location

Table 34 summarizes the ratings given to continental and transverse existing markings subdivided by age group, location of the marking (intersection or midblock), and light level (day or night). The table illustrates that at intersection and midblock existing sites, young (younger than 55 years) and old (55 years or older) participants gave higher ratings to continental markings than transverse markings during both daytime and nighttime. Overall, younger participants gave better ratings to both existing marking types than older participants.

Table 34. Existing marking rating by light level, age group, and location.

Marking Type (Number of Sites)	Age Group	Location	Proportion of Participants (Percent)									
			Day					Night				
			A	B	C	D	F	A	B	C	D	F
Continental (1)	< 55	Intersection	18	64	18	0	0	67	22	11	0	0
Transverse (2)	< 55	Intersection	5	19	62	14	0	5	11	47	26	11
Continental (1)	< 55	Midblock	100	0	0	0	0	38	38	13	0	13
Transverse (2)	< 55	Midblock	19	33	38	10	0	16	26	47	11	0
Continental (1)	≥ 55	Intersection	11	56	33	0	0	29	71	0	0	0
Transverse (2)	≥ 55	Intersection	11	16	53	21	0	0	6	35	41	18
Continental (1)	≥ 55	Midblock	100	0	0	0	0	30	20	40	10	0
Transverse (2)	≥ 55	Midblock	11	26	42	11	11	12	29	35	18	6

Comparison Between New and Existing Markings

The ratings given to the continental and transverse study sites were compared with those given to sites with existing markings. Bar pairs were not included since there were no existing sites with bar pairs markings. Table 35 summarizes the ratings given to the transverse and continental markings by location (intersection or midblock) and light level (day or night). The summary supports all the findings previously discussed, with emphasis on the following:

- Overall, continental markings received better ratings than transverse markings at both new and existing sites.
- For transverse markings, daytime ratings are slightly better at intersections than at the study crosswalks (i.e., the newly installed markings), perhaps due to sun glare or shadow issues mentioned by participants.

Table 35. Comparison of existing marking ratings with new marking (study sites) ratings by light level.

Marking Type	Location	Proportion of Participants (Percent)									
		Day					Night				
		A	B	C	D	F	A	B	C	D	F
Continental	Intersection	15	60	25	0	0	50	44	6	0	0
Continental	Midblock	100	0	0	0	0	33	28	28	6	6
Continental	Study	64	30	5	0	1	67	29	4	1	0
Transverse	Intersection	8	18	58	18	0	3	8	42	33	14
Transverse	Midblock	15	30	40	10	5	14	28	42	14	3
Transverse	Study	3	23	50	17	6	26	37	29	8	1

Comparison of Rating to Illuminance and Retroreflectivity

An average score was calculated for each study site based on the nighttime ratings received. The score assigned to each rating is shown in table 36.

Table 36. Score assigned to each rating.

Rating	Score
A	5
B	4
C	3
D	2
F	1

The score for each rating was multiplied with the nighttime proportion of participants giving that rating for a site to calculate the average score of the site. The illuminance readings at the site were compared to this average score. Figure 70 shows the log of illuminance along with the average score for each study site on the clockwise route. Figure 71 shows the log of illuminance along with the average score for each study site on the counterclockwise route. The sites were grouped by the type of marking such that the initial three columns are the bar pairs sites, the middle three columns are the continental sites, and the final three columns are the transverse sites. For the clockwise route shown in figure 70, all but the southbound Agronomy bar pairs crosswalk had a log of illuminance value of nearly 1 or greater. The counterclockwise route had two sites with very low illuminance values—northbound Agronomy at the bar pairs site and northbound Discovery at the transverse site. For each of these locations, a decrease in the average nighttime score is not seen. The graphs show that the average score curve does not follow the same trend as log illuminance. This implies that there is no noticeable effect of illuminance on the nighttime ratings of the study sites.

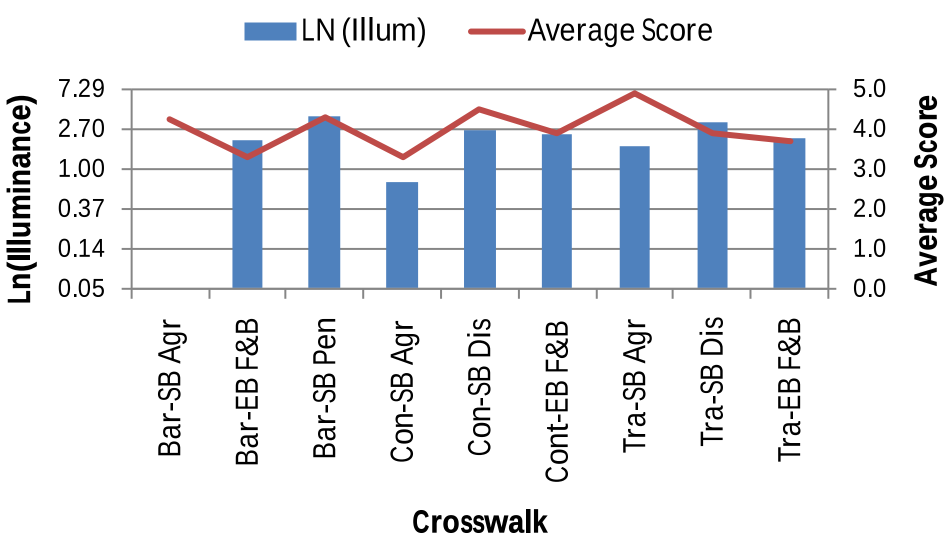


Figure 70. Graph. Average crosswalk score with illuminance level at the site (clockwise route).

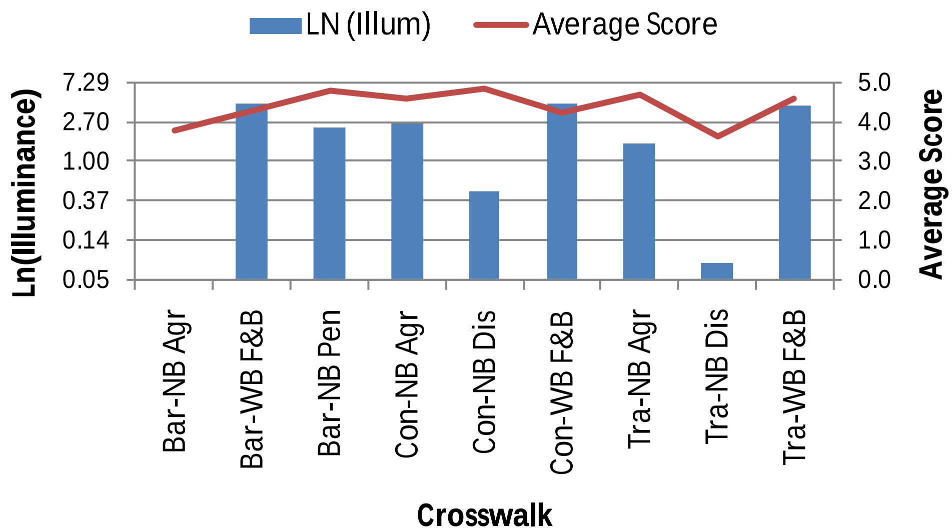


Figure 71. Graph. Average crosswalk score with illuminance level at the site (counterclockwise route).

The retroreflected luminance (R_L) values were much higher than the minimum required, as shown in figure 72 and figure 73. So, the R_L values of all the sites are believed to be practically the same. Figure 72 shows the average R_L along with the average score for each study site on the clockwise route, and figure 73 shows the counterclockwise route. The graphs show that the average score curve does not follow the same trend as the average R_L. This implies that there is no noticeable effect of retroreflectivity on the nighttime rating given at a study site.

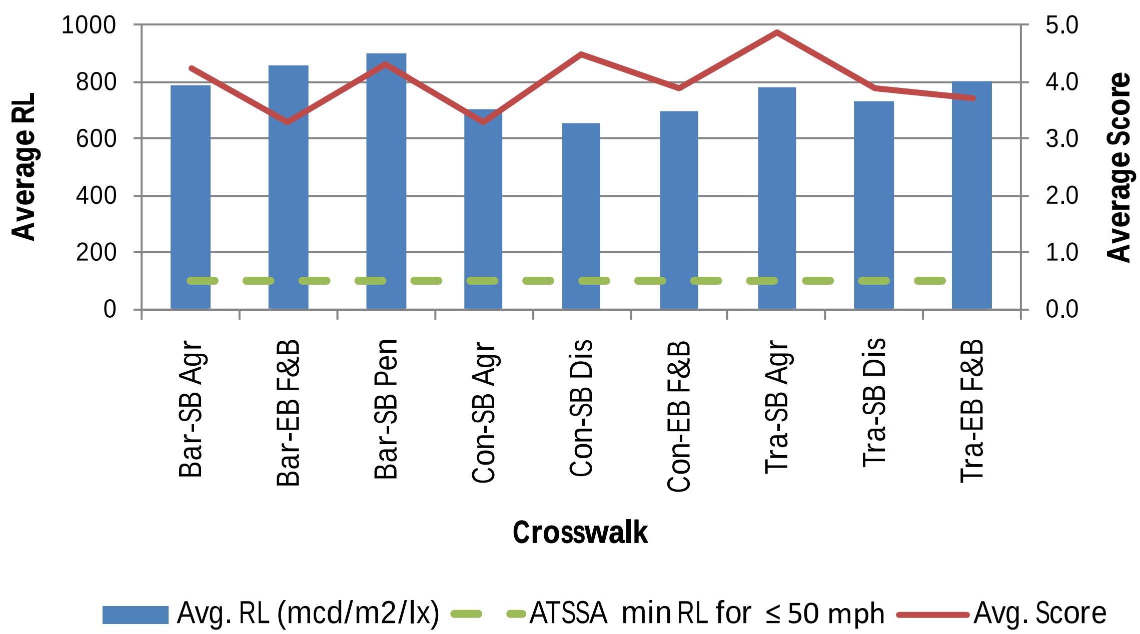


Figure 72. Graph. Average crosswalk score with retroreflectivity level at the site (clockwise route).

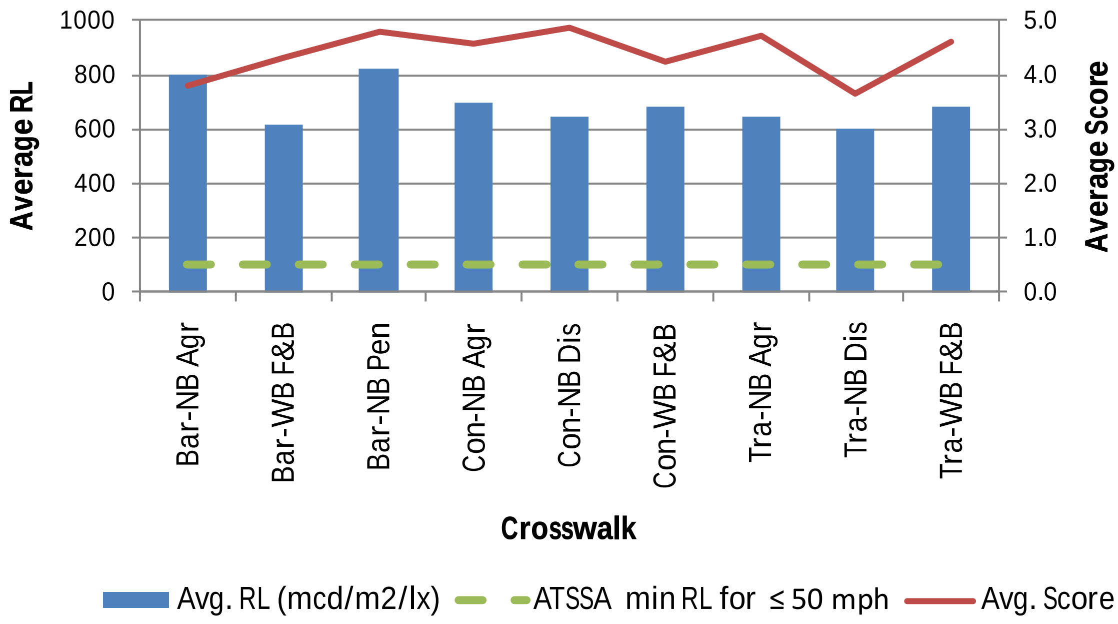


Figure 73. Graph. Average crosswalk score with retroreflectivity level at the site (counterclockwise route).

Summary of Crosswalk Ratings

In summary, the observations show that the ratings for continental and bar pairs are consistent over various comparison groups, with better ratings for bar pairs and continental markings than for transverse markings.

POSTDRIVE TASK—MARKING PREFERENCE

Table 37 shows the results from the postdrive task of marking preference. Drivers' preference for the continental or bar pairs markings was supported by the results of the postdrive task. The photo of the continental markings was selected as the favorite by 54 percent of the participants. The second photo of continental markings showed the markings at a greater distance and was selected as the favorite by 22 percent of the participants. The bar pairs markings photo was the favorite for 23 percent of the participants. The photos of the transverse markings were almost always selected as either fourth or fifth out of the five photos, representing 97–100 percent of the participants.

Table 37. Results from postdrive task—marking preference.

Photograph	1	2	3	4	5	Photo Number
	**42 (54%)**	26 (22%)	9 (12%)	1 (1%)	0 (0%)	IV
	18 (23%)	**38 (49%)**	21 (27%)	1 (1%)	0 (0%)	I
	17 (22%)	13 (17%)	**47 (60%)**	0 (0%)	1 (1%)	II
	1 (1%)	1 (1%)	1 (1%)	**40 (52%)**	**35 (45%)**	III
	0 (0%)	0 (0%)	0 (0%)	**36 (46%)**	**42 (54%)**	V

Note: Participants were instructed to physically order the photographs from 1 to 5 where 1 was their favorite in terms of ability to see as a driver. Bold text and shading indicate greater than 40 percent of participants selected response.

CHAPTER 7. CONCLUDING REMARKS

SUMMARY

Basic information about crosswalk markings is included in part 3 of the MUTCD. Crosswalk markings are to provide guidance for pedestrians crossing roadways by defining and delineating paths on approaches. The amount of research into the effectiveness of pedestrian treatments has increased in recent years, but there had been insufficient research to identify the relative visibility and driver behavior effects of the many different styles and patterns of crosswalk markings used in the United States and abroad. The lack of knowledge of the relative visibility of different marking patterns has inhibited the development of a consensus on whether more uniformity is needed in the form of tighter MUTCD standards or more comprehensive guidance on crosswalk markings.

The objective of this study was to investigate the relative visibility of three crosswalk marking patterns. These patterns were transverse lines, continental, and bar pairs. In general, this study collected information on the distance from the crosswalk when the participant verbally indicated its presence.

In this study, participants drove an instrumented vehicle on a route through the TAMU west campus. The study vehicles were equipped with instrumentation that allowed the researcher to measure and record various driving performance data. However, the vehicle operated and drove like a normal vehicle. The instrumented vehicle recorded the forward view, and experimenters postprocessed the number of pedestrians and bicyclists in the driver’s view at the time when the crosswalk was detected. The route included existing midblock and intersection crosswalk markings along with nine locations where crosswalk markings were installed for this project. Street lighting was present at or near all crosswalk sites, and the new sites were selected to have similar street light levels. The crosswalk markings were installed using white removable retroreflective pavement marking tape. Each of the study sites was located at midblock. The markings were 10 ft in length, selected to reflect a typical length used for midblock crossings. The continental and bar pairs stripes were spaced to avoid the wheel paths of vehicles.

The study was conducted under both daytime (sunny and clear or partly cloudy) and nighttime (with street lights on) conditions over two weeks in November 2009. The following divisions were used in structuring participant recruitment:

- Light level: day or night.
- Age group: young (younger than 55 years old) and old (55 years old or older).
- Gender: male or female.
- Instrumented vehicle driven: SUV or sedan.
- Route driven: clockwise or counterclockwise.

A total of 78 participants were included in the study, which exceeded the goal of 64 participants. The original goal was to have 32 participants that were age 55 or older. That goal was exceeded with 35 older participants in the study.

The participant drove the initial portion to become familiar with the vehicle. Once the participant was comfortable in the instrumented vehicle and had arrived in a parking lot near the start of the route, the participant was reminded to indicate when he or she saw one of the following items: crosswalk markings, TWLTL arrows, or a speed-limit sign. The arrows and signs were included to ensure that the driver utilized a normal eye glance pattern and was not exclusively searching for crosswalks. As soon as the driver said “crosswalk,” the rear seat experimenter pressed the appropriate button to place a mark in the computer file to indicate detection.

To ensure consistency, the research team used checklists and slide shows to aid in providing instructions to each participant. As part of the in-processing, the participant’s and experimenter’s response times were measured using a computer test, and a correction factor was developed for each driver to account for the lag between the time the driver verbally responded and the time the experimenter pressed the data recorder button. A more detailed review of the response time data indicated that adjusting the detection distance should occur uniquely for each participant rather than using a per experimenter’s average response time. For the nine crosswalks installed for this study, the adjustments to the participant’s detection distance ranged between 3 and 13 percent.

After completing the initial route, the participant was given additional instructions and asked to drive the same route again to rate each crosswalk marking on how easy it was to see using a scale of A (excellent) to F (completely unacceptable).

The primary objective of this study was to determine the detection distance of a crosswalk and to identify the variables that affect this distance. The differences in detection distances were evaluated with consideration of the following:

- Light (day or night).
- Site characteristics.
    - Marking type (transverse, continental, and bar pairs).
    - Location (study, existing intersection, existing midblock).
    - Street characteristics (crossing width, posted speed limit, sidewalk presence, rural or urban feel).
    - Retroreflectivity.
- Traffic characteristics.
    - Traffic presence that could affect detection distance.
    - Pedestrian or bicyclist presence.
    - Driver speed.

- Vehicle characteristics (sedan or SUV).
- Driver characteristics.
    - Driver eye height.
    - Gender
    - Age group (younger than 55 years old or 55 years old and older).

Initially, a statistical model was examined that contained main effects and reasonable two-way interactions (termed the “extended” model). Not all variables could be included in the extended model due to exact linear dependency issues (i.e., a linear combination of one or more factors can exactly duplicate another factor’s values). Next, several models were explored to determine the best model to describe the variables that influence detection distance (termed the “reduced” model). Interactions were dropped from the models when the *p*-value was less than 0.05 (i.e., they were not statistically significant).

Preliminary evaluations demonstrated that the analyses needed to be conducted separately for the study sites (where the markings were installed new at midblock locations) and the existing sites (where the markings were already present at an intersection or midblock with pedestrian warning signs). The preliminary evaluations also clearly showed a difference in detection distance for day and night. Since the nighttime condition had an additional variable (retroreflectivity) to consider and some of the variables were believed to have different effects during the night (such as marking type, vehicle type, and driver eye height), separate analyses were done for daytime and nighttime conditions. In all combinations, daytime detection distances were longer than nighttime detection distances.

For the study sites, the marking type (bar pair, continental, or transverse) was statistically significant. The detection distances to bar pairs and continental markings were similar, and they were statistically different from the detection distance to the transverse markings both during the day and at night.

For the study sites, the presence of traffic had an impact on detection distance, in most cases limiting the ability to see the markings farther upstream, as expected. The impact of traffic on the transverse markings was minimal, as the detection distance to these markings was already small compared to the detection distances for bar pairs or continental. Overall, shorter detection distances were associated with higher operating speeds. However, in most cases it was only slightly shorter detection distances. The characteristics of the streets also influenced the detection of the crosswalk markings. An unexpected result was that the street group with a posted speed limit of 45 mi/h had longer nighttime adjusted detection distances for the higher speeds. This was opposite the finding for daytime conditions; daytime adjusted detection distances were (slightly) shorter for the higher speeds. Variables that included gender, driver eye height, and vehicle type as part of an interaction term were found to be statistically significant; however, closer examination found them to not be of practical significance.

Age (younger versus older) was only a significant factor during the day for the existing sites; however, the size of this difference was quite small and was not considered to be of practical significance. Variables that included gender, driver eye height, and vehicle type as part of an interaction term were found to be statistically significant; however, closer examination found them to not be of practical significance.

For the existing sites, marking type had a significant effect on detection distance during the daytime and the nighttime. There were no existing sites with bar pairs markings, hence only continental and transverse types of markings were compared. During the day, the detection distances to the continental or transverse markings at intersections were not significantly different. The detection distance to midblock continental was statistically different (longer) from the detection distance to midblock transverse markings.

During nighttime conditions at existing sites, variables in addition to marking type had an effect on detection distances, such as location (midblock or intersection) and driver speed. Driver speeds had mixed effects on detection distance depending on location (intersection or midblock) and light level (day or night). For intersections, an increase in driver speed was associated with longer detection distances for both daytime and nighttime conditions. All of the intersections included in this project were either stop-controlled or signal-controlled. Several drivers appeared to be more focused on the stop maneuver than the detection task and would not call out the recognition of a crosswalk until close to the stop bar.

For midblock (or uncontrolled approaches) the finding was dependent on light level. Nighttime detection distance at midblock was similar to intersections; longer detection distances were associated with the higher speeds. For daytime the opposite occurred; higher driver speeds were associated with shorter detection distances at the midblock crosswalks. While the higher driver speeds were associated with shorter detection distances, the differences were small and would not be considered of practical difference.

CONCLUSIONS

The conclusions from this project are as follows:

- The detection distances to continental and bar pairs markings are statistically similar. The detection distances to continental and bar pairs are statistically different from transverse markings.

- For the existing midblock locations, a general observation is that the continental markings were detected at about twice the distance upstream as the transverse markings during daytime conditions. This increase in distance reflects 8 s of increased awareness of the presence of the crossing at a 30-mi/h operating speed.

- The results of the appearance ratings of the markings on a scale of A to F mirrored the findings from the detection distance evaluation. Participants preferred the continental and bar pairs markings over the transverse markings.

- Participants gave the continental and bar pairs markings similar ratings during both the day and night; however, the transverse markings ratings differed based on the light level. The participants gave slightly better (although still worse than continental or bar pairs markings) ratings for transverse markings during the nighttime than during daytime. The lower ratings during daylight conditions may be due to sun glare or shadow issues mentioned by the participants.

RECOMMENDATIONS

Based on the findings from this research, the researchers recommend revising the MUTCD in the following ways:

- Add bar pairs as a usable crosswalk pattern.
- Provide typical dimensions for the marking patterns, including spacing that will assist in avoiding wheel paths.
- Consider making bar pairs or continental the “default” for all crosswalks across uncontrolled approaches (i.e., not controlled by signals or stop signs), with exceptions allowing transverse lines where engineering judgment determines that such markings would be adequate, such as a location with low-speed residential streets.

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