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TRAFFIC CONTROL IMPROVEMENTS FOR URBAN ARTERIAL WORK ZONES

Alexei Tsyganov, Randy Machemehl, Katherine Liapi, and Dinesh Natarajan Mohan

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16. Abstract

Numerous improvement projects on urban arterial streets cause significant changes in traffic operation and safety. A review of the design standard documents shows that the majority of guidelines related to work zone design do not adequately reflect the specifics of urban arterial streets. In turn, the traffic control plan developments are greatly affected by the designers' background and experience. Therefore, the conducted study was focused on identifying current traffic control problems on urban arterial street work zones, developing countermeasures for improvements, and developing recommendations for changes to the Texas Manual on Uniform Traffic Control Devices, and for supplemental guidelines on traffic control plan development. Accident statistics analysis, field observations of work zones on urban arterial streets and the questionnaire survey of Texas Department of Transportation personnel identified existing traffic control problems. Based on the joint analysis of the identified problems and principles of human perception, the guidelines for traffic control plans on urban arterial street work zones were developed. The development includes recommendations for urban street work zone signing and traffic control device location, better suited to human abilities and behavior. The effectiveness of the developed recommendations was tested in computer experiments and field studies.

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1. Urban Arterial Street Work Zones Traffic Control Problems and Improvement Solutions

1.1 Identification of Traffic Control Problems

One primary research task was to identify current traffic control improvement opportunities on urban arterial street work zones. This effort was performed through field observations and a survey of TxDOT personnel involved in work zone design and inspection.

In total, twenty-three work zones in the Austin, Houston, and San Antonio metropolitan areas were investigated in detail. Work zone location and design, traffic control strategy, types and location of control devices, as well as traffic operation and the observed improvement opportunities were analyzed. In addition, the TxDOT Traffic Control Review Team provided several reports of work zone inspections in seven districts. These reports, which contain review and discussion of the implemented traffic control plans and traffic control device inspection forms, represent around 100 ongoing construction projects.

For the TxDOT personnel survey a special questionnaire was developed in two formats, one for traffic control plan designers and the other for work zone inspectors, and was distributed in the Austin, Houston, and San Antonio TxDOT districts. Traffic control plan (TCP) designers were asked to rate different problems experienced in TCP design by their significance for traffic operation and safety on urban arterial work zones. The questionnaire for inspectors was focused on estimation of frequencies of specific problems. A total of 208 responses were received, 71 from TCP designers and 137 from work zone inspectors.

These studies and the results were described in detail in Research Report 4266-1 (Ref. 1)

Based on analysis of the collected data, many traffic control problems were identified and classified. Some of them reflected TCP implementation problems and others related to design standards. Two groups of problems with the potential for traffic control design standards improvement were identified.

The first group is related to driver information. The field observations and the majority of respondents indicated problems resulting from information insufficiency caused by typically urban characteristics, such as frequent intersections and visual noise produced by commercial displays.

The second group reflects the significant operational and safety effects of numerous access roadways (driveways) to local businesses.

1.2 Accident Statistics for Urban Arterial Street Work Zones in Texas

For a better understanding of work zone traffic control problems, analysis of accident statistics is of great importance. In addition to the accident statistics reviewed in Research Report 1, which reflected national data as well as data from some other countries, statistics of traffic crashes that occurred during the presence of roadwork on urban arterial streets in Texas were collected and analyzed.

Three arterial streets of Houston – namely, Richmond Avenue, Westheimer Avenue, and San Felipe Road – were selected for the analysis because of the heavy roadwork conducted on those streets during the past two years. In order to perform the analysis, the following information was needed:

- Locations, dates, and times of roadwork
- Accidents during roadwork on the selected streets

This information was obtained from the databases provided by the City of Houston (COH) and the Houston Police Department (HPD).

The database from COH contained information about the permits issued by the COH to contractors to conduct roadwork. It included the dates, times, locations, and duration of all roadwork permitted on the selected arterial streets in Houston. A total of 146 permits were issued between 2000 and 2002 for the selected streets.

The HPD database contains information regarding incident-reporting telephone calls, including dates, times, and locations from where calls were made. Each call was assigned a code based on the type of incident. The database was reviewed to extract the police calls related to traffic accidents, and a corresponding database for the selected streets was prepared.

The times and locations of traffic accident calls and roadwork were compared, and the calls that matched with roadwork were selected for further analysis.

Finally, detailed police reports for each traffic accident that occurred on the selected streets during roadwork were obtained from the Houston Police Department. Reports were obtained for 151 accidents (96 on Richmond Avenue, 41 on Westheimer Avenue, and 14 on San Felipe Road).

It is important to highlight that the COH database contained information about permits issued for special construction activities, which sometimes overlap in time and space. Further, overlapping of sections limited the ability to relate accidents to particular roadwork permits. However, the collected data provided the basis to analyze accident statistics from the perspective of general impacts of roadwork. Therefore, accident statistics for the investigated streets were combined, and the performed analysis is presented in this chapter.

Taking into consideration identified traffic control problems on urban work zones, the objectives of the analyses were to determine major accident types, contributing factors, times when accidents are more frequent, as well as other characteristics that can suggest traffic control improvement solutions.

First, accidents were classified based on the day of the week on which they occurred, and the frequencies of accidents on different days are tabulated in Table 1.1.

Table 1.1 Accident Distribution by Day of the Week

Day of Week	Streets						Overall	
	Richmond		Westheimer		San Felipe			
	Accidents							
	#	%	#	%	#	%	#	%
Sunday	12	12.50	3	7.32	0	0.00	15	9.93
Monday	15	15.63	11	26.83	2	14.29	28	18.54
Tuesday	16	16.67	4	9.76	3	21.43	23	15.23
Wednesday	17	17.71	6	14.63	2	14.29	25	16.56
Thursday	17	17.71	5	12.20	2	14.29	24	15.89
Friday	10	10.42	8	19.51	4	28.57	22	14.57
Saturday	9	9.38	4	9.76	1	7.14	14	9.27
Total	96	100.00	41	100.00	14	100.00	151	100.00

It was evident from the data that the frequency of accidents during weekdays was higher that during weekends, which might be explained by the difference in traffic volumes.

The following method was adopted to determine whether any particular day of the week is significantly different from the other days with respect to accident frequency. The 95 percent confidence interval for the mean daily accident rate was calculated, and any rate outside the interval was considered significantly different from the average daily rate.

Because of significant differences in traffic volumes between weekdays and weekend days, the analysis of accident frequencies was conducted for weekdays alone.

From the sample data available, a confidence interval for the mean daily percentage of accidents during weekdays can be constructed as shown in Equation 1.1.

$$\bar{x} - t_{\alpha/2,n-1} \frac{s}{\sqrt{n}} \leq \mu \leq \bar{x} + t_{\alpha/2,n-1} \frac{s}{\sqrt{n}} \tag{1.1}$$

where:

μ	- Population mean
$\bar{x}$	- Sample mean (16.16)
α	- Level of significance (0.05)
s	- Sample standard deviation (1.525)
n	- Number of observations (5)
$t_{\alpha/2,n-1}$	- Student t value for α/2 and n-1 degrees of freedom (2.776)

After computation, it was concluded with 95% confidence that the mean percentage of accidents occurring daily during weekdays varies between 14.27 and 18.05. Accident frequencies and the confidence interval for the mean are shown graphically in Figure 1.1.

Since only the Monday percentage of accidents (18.54) lies outside the confidence interval, it can be concluded that accident frequency on Monday significantly exceeds that of other weekdays.

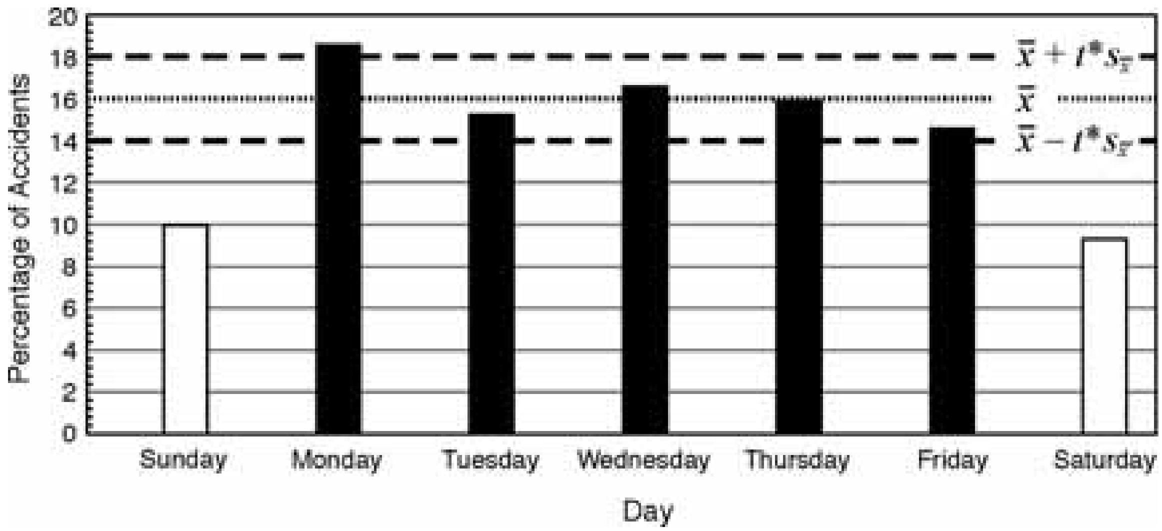

Figure 1.1 Weekday accident percentages and 95 percent confidence interval for the mean

In the next stage, the day was split into 24 one-hour slots, and the frequency of accidents in each time slot was determined. The result is shown in Table1.2.

The data indicated increased accident frequency at peak hours as well as at lunchtime and reduced frequency during nighttime. To determine the hours with significantly higher accident frequency an analysis similar to the above-mentioned was conducted. Considering the difference in traffic volumes during day and night, daytime accident frequency was analyzed separately. The confidence interval for the mean percentage of accidents during the time slots between 7 a.m. and 8 p.m. was found to be from 4.65 to 7.07. The accident frequencies and confidence interval are shown in Figure 1.2.

Accident frequencies in two time slots (7:00 – 8:00 and 8:00 – 9:00) during the morning peak hours and two (17:00 – 18:00 and 18:00 – 19:00) during the evening peak hours exceeded the upper limit of the confidence interval. This fact suggested that significantly more than the average number of accidents occurred from 7 a.m. to 9 a.m. (15%) and from 5 p.m. to 7 p.m. (18%). These four hours accounted for 33% of the daily observed accidents.

Table 1.2 Accident Distribution by Hour of the Day

Time	Streets						Overall	
	Richmond		Westheimer		San Felipe			
	Accidents							
	#	%	#	%	#	%	#	%
0:00 to 1:00	1	1	1	2	0	0	2	1
1:01 to 2:00	3	3	1	2	0	0	4	3
2:01 to 3:00	6	6	0	0	0	0	6	4
3:01 to 4:00	0	0	1	2	0	0	1	1
4:01 to 5:00	1	1	0	0	0	0	1	1
5:01 to 6:00	1	1	1	2	0	0	2	1
6:01 to 7:00	1	1	0	0	1	7	2	1
7:01 to 8:00	11	11	1	2	0	0	12	8
8:01 to 9:00	10	10	1	2	0	0	11	7
9:01 to 10:00	7	7	1	2	1	7	9	6
10:01 to 11:00	5	5	1	2	3	21	9	6
11:01 to 12:00	1	1	3	7	0	0	4	3
12:01 to 13:00	7	7	1	2	0	0	8	5
13:01 to 14:00	2	2	4	10	1	7	7	5
14:01 to 15:00	2	2	2	5	1	7	5	3
15:01 to 16:00	1	1	7	17	0	0	8	5
16:01 to 17:00	3	3	3	7	1	7	7	5
17:01 to 18:00	10	10	4	10	1	7	15	10
18:01 to 19:00	11	11	1	2	0	0	12	8
19:01 to 20:00	3	3	3	7	2	14	8	5
20:01 to 21:00	2	2	2	5	0	0	4	3
21:01 to 22:00	0	0	0	0	1	7	1	1
22:01 to 23:00	5	5	1	2	0	0	6	4
23:01 to 24:00	3	3	2	5	2	14	7	5

The next accident classification targets prevailing conditions when accidents happened, including weather and the road surface. The description of conditions is based on the classification utilized in the police reports.

The weather conditions and corresponding accident frequencies are shown in Table 1.3. The data showed that a majority of the accidents, overall 85%, happened during clear or cloudy conditions and that only around 10% occurred during rain.

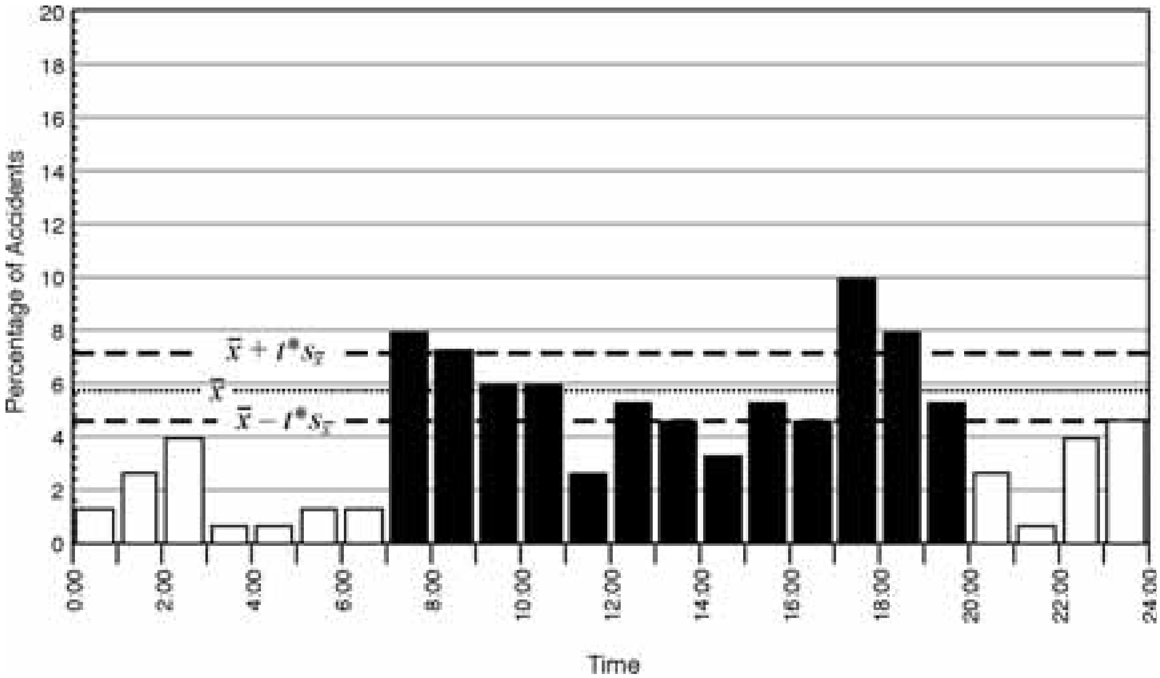

Figure 1.2 Hourly accident percentages and 95 percent confidence interval for the mean

Table 1.3 Accident Distribution by Weather Conditions

Weather Conditions	Streets						Overall	
	Richmond		Westheimer		San Felipe			
	Accidents							
	#	%	#	%	#	%	#	%
Clear/Cloudy	80	83.33	37	90.24	12	85.71	129	85.43
Raining	11	11.46	3	7.32	1	7.14	15	9.93
Snowing	0	0.00	0	0.00	0	0.00	0	0.00
Fog	0	0.00	0	0.00	0	0.00	0	0.00
Slowing Dust	0	0.00	0	0.00	0	0.00	0	0.00
Smoke	0	0.00	0	0.00	0	0.00	0	0.00
Sleeting	0	0.00	0	0.00	0	0.00	0	0.00
High Winds	0	0.00	0	0.00	0	0.00	0	0.00
Other	2	2.08	0	0.00	0	0.00	2	1.32
Unknown	3	3.13	1	2.44	1	7.14	5	3.31
Total	96	100.00	41	100.00	14	100.00	151	100.00

Accidents were also classified based on the condition of the roadway surface, and the corresponding frequencies are represented in Table 1.4.

Table 1.4 Accident Distribution by Roadway Surface Conditions

Surface Conditions	Streets						Overall	
	Richmond		Westheimer		San Felipe			
	Accidents							
	#	%	#	%	#	%	#	%
Dry	73	76.04	36	87.80	13	92.86	122	80.79
Wet	22	22.92	5	12.20	1	7.14	28	18.54
Muddy	0	0.00	0	0.00	0	0.00	0	0.00
Snowy / Icy	0	0.00	0	0.00	0	0.00	0	0.00
Other	1	1.04	0	0.00	0	0.00	1	0.66
Total	96	100.00	41	100.00	14	100.00	151	100.00

In this case wet pavement accidents included those during rain as well as afterward when the pavement was still wet. Overall 81% of the accidents occurred on dry surfaces versus 19 % on wet pavement.

Data of Table 1.3 indicate that the ratio of accidents during clear weather to those during rain is 9 to 1, but the ratio is 4 to 1 if the aftereffects of rain are taken into account.

To evaluate the impact of weather conditions more accurately, the number of clear or cloudy and rainy days was considered. During the period of observation the city of Houston experience 413 clear or cloudy days and 164 rainy days. The ratio of number of accidents to the number of days was calculated for clear or cloudy and rainy conditions separately. The corresponding ratios are 0.3 and 0.1 accidents per day for the investigated work zones. Similar comparisons of accidents occurring on dry and wet road surfaces show even less variation. Accidents on dry surfaces averaged 0.3 per day versus 0.2 per day on wet pavement.

Though the comparison of absolute accident frequencies showed that the majority of accidents occur during good weather conditions, the analysis of relative frequencies proved that the difference in accidents experience during good and bad weather is much smaller. The smaller accident rate during bad weather might be explained by lower traffic flow speed and greater driver awareness.

The next stage of study was focused on analyzing accident statistics with respect to the number of vehicles involved, accident type, accident severity, and major contributing factors. The classification criteria for accident types, severity, and contributing factors were adopted as defined in the police reports.

Table 1.5 represents frequencies of accidents involving different numbers of vehicles. The data indicate the predominance of two-vehicle collisions (80% of the observed accidents), and the second most common type was three-vehicle collision (11%).

Table 1.5 Accident Distribution by Number of Vehicles Involved

Number of Vehicles Involved	Streets						Overall	
	Richmond		Westheimer		San Felipe			
	Accidents							
	#	%	#	%	#	%	#	%
1	7	7.29	2	4.88	1	7.14	10	6.62
2	73	76.04	35	85.37	13	92.86	121	80.13
3	13	13.54	3	7.32	0	0.00	16	10.60
4	3	3.13	1	2.44	0	0.00	4	2.65
Total	96	100.00	41	100.00	14	100.00	151	100.00

The observed accident types and their frequencies are shown in Table 1.6. The most common types of accidents were identified as side (54%) and rear (34%) collisions.

Table 1.6 Accident Types and Frequencies

Type of Accident	Streets						Overall	
	Richmond		Westheimer		San Felipe			
	Accidents							
	#	%	#	%	#	%	#	%
Auto-Pedestrian Collision	2	2.08	1	2.44	0	0.00	3	1.99
Auto-Pedal Cyclist Collision	0	0.00	0	0.00	1	7.14	1	0.66
Fixed Object Collision	5	5.21	1	2.44	0	0.00	6	3.97
Head-On Collision	4	4.17	0	0.00	0	0.00	4	2.65
Rear-End Collision	25	26.04	22	53.66	3	21.43	50	33.11
Side Collision	57	59.38	17	41.46	8	57.14	82	54.30
Unknown	3	3.13	0	0.00	2	14.29	5	3.31
Total	96	100.0	41	100.0	14	100.0	151	100.0

The distribution of accidents by location showed that 53% of all accidents occurred at streets intersections and 47% between intersections.

Analysis of the details of accident reports showed that between intersections local access roads have a significant impact. Overall, 27% of all side collisions occurred when drivers tried to enter local driveways or exit from them to the main street. The corresponding percentage for rear-end collisions was 8%.

Accidents were also classified based on their severity, and the data are represented in Table 1.7.

Table 1.7 Frequencies of Accident Severities

Accident Severity	**Streets**						**Overall**	
	Richmond		**Westheimer**		**San Felipe**			
	Accidents							
	#	**%**	**#**	**%**	**#**	**%**	**#**	**%**
Fatal	0	0.00	0	0.00	0	0.00	0	0.00
Injury	51	53.13	16	39.02	5	35.71	72	47.68
Property Damage	45	46.88	25	60.98	9	64.29	79	52.32
Total	96	100.00	41	100.00	14	100.00	151	100.00

Overall, 52% of all accidents resulted in property damage only, while 48% caused injuries. No fatality was observed. A total of 398 people, 304 drivers and 94 passengers, were involved in the investigated accidents. In relation to the total number of accidents, this figure amounts to an average of 2.7 people involved per accident.

Considering different levels of injuries, 40% of all accidents caused minor injuries, 6% medium injuries, and 2% severe injuries. These levels are based on the definitions in the police reports as possible (minor), non-incapacitating (medium), and incapacitating (severe), injuries. Of the 104 people who were injured in the observed accidents, 89 suffered minor injuries, 12 medium, and 3 severe injuries. Injury ratios, defined as the number of injured people to the total number of accidents were found to be 0.02, 0.08, and 0.59 injures per accident respectively for the minor, medium, and severe classifications.

The overall injury ratio for the investigated accidents was 0.69 injured people per accident. The accident statistics of the Texas Department of Public Safety (DPS) for 1999 indicated that 45,228 accidents occurred in the Houston metropolitan area, resulting in 55,358 injured people, which can be translated to an injury ratio of 1.22 (Ref. 2). Lower speed on urban arterial streets, especially during work zone presence, can be assumed to be the major reason for such a significant difference in this ratio.

Factors contributing to the accidents, as identified in the police reports, were classified, and the frequencies of different groups of factors are represented in Table 1.8.

Table 1.8 Frequencies of Factors Contributing to Accidents

Contributing Factors Groups	Streets						Overall	
	Richmond		Westheimer		San Felipe			
	Accidents							
	#	%	#	%	#	%	#	%
I. Driving While Intoxicated	3	3.13	1	2.44	1	7.14	5	3.31
II. Speeding	27	28.13	17	41.46	3	21.43	47	31.13
III. Failure to Yield Right-of-Way	40	41.67	9	21.95	6	42.86	55	36.42
IV. Unsafe Driving	27	28.13	11	26.83	4	28.57	42	27.81
V. Driver Inattention	6	6.25	2	4.88	0	0.00	8	5.30
VI. Other	2	2.08	1	2.44	1	7.14	4	2.65
Total	105	109.38	41	100.00	15	107.14	161	106.62

The average number of factors noted by the police officers in the reports as contributing to accidents was 1.2. Since multiple factors contributed to some accidents, the total number of accidents in Table 1.8 does not match the actual number of observed cases.

The first and second groups of contributing factors reflect a driver's conscious violation of traffic law, such as intoxicated driving, under the influence of both alcohol and drugs (group I), and speeding (group II). Overall, such violations contributed to 34 percent of the investigated accidents.

The third and fourth groups comprise cases in which accidents can be caused by the drivers' conscious violation of traffic regulations as well as by inadequate perception of traffic situations. The third group, which accounts for more than 36% of the cases, includes driver failure to yield right-of-way (ROW) and to observe signs and signals at intersections. Driving behaviors, such as unsafe lane changing, following too close, failure to drive in a single lane, and improper turning, were included in the fourth group. The factors of this group were mostly identified in situations in which vehicles improperly entered or exited driveways between intersections. Overall, in 28% of all investigated cases these factors were noted.

The next group of factors, which includes use of cellular phones, handling stereos, and other activities not related to driving tasks, was identified in 5% of all cases.

The last group, noted in 3% of all cases, combined factors such as driver illness, unsecured load, and road rage.

From the perspective of traffic control improvements the third and fourth groups of factors are of major interest. The high frequencies of these factors indicate that traffic control at intersections in urban arterial street work zones require special attention. Also, the data highlight the potential for safety improvements by better consideration of local access driveways in traffic control plan designs.

The next analysis is related to identifying categories of drivers overrepresented in the investigated accidents in the urban arterial street work zones. For this purpose, drivers were classified based on gender and age.

The data in Table 1.9, which shows the number of male and female drivers involved in the observed accidents, indicate that males (52%) and females (48%) are represented almost equally.

Table 1.9 Gender Distribution of Drivers Involved in Accidents

Gender	Streets						Overall	
	Richmond		Westheimer		San Felipe			
	Drivers Involved in Accidents							
	#	%	#	%	#	%	#	%
Male	104	52.53	41	50.62	13	52.00	158	51.97
Female	94	47.47	40	49.38	12	48.00	146	48.03
Total	198	100	81	100	25	100	304	100

The drivers were classified by their ages, and the data are represented in Table 1.10 and graphically shown in Figure 1.3.

Table 1.10 Distribution of Drivers' Ages

Age of Driver	Driver			
	Male		Female	
	#	%	#	%
Under 21	16	10.39	7	4.90
21 to 30	58	37.66	58	40.56
31 to 40	38	24.68	25	17.48
41 to 50	19	12.34	23	16.08
51 to 60	11	7.14	18	12.59
61 to 70	10	6.49	6	4.20
Over 70	2	1.30	6	4.20
Total	154	100.00	143	100.00

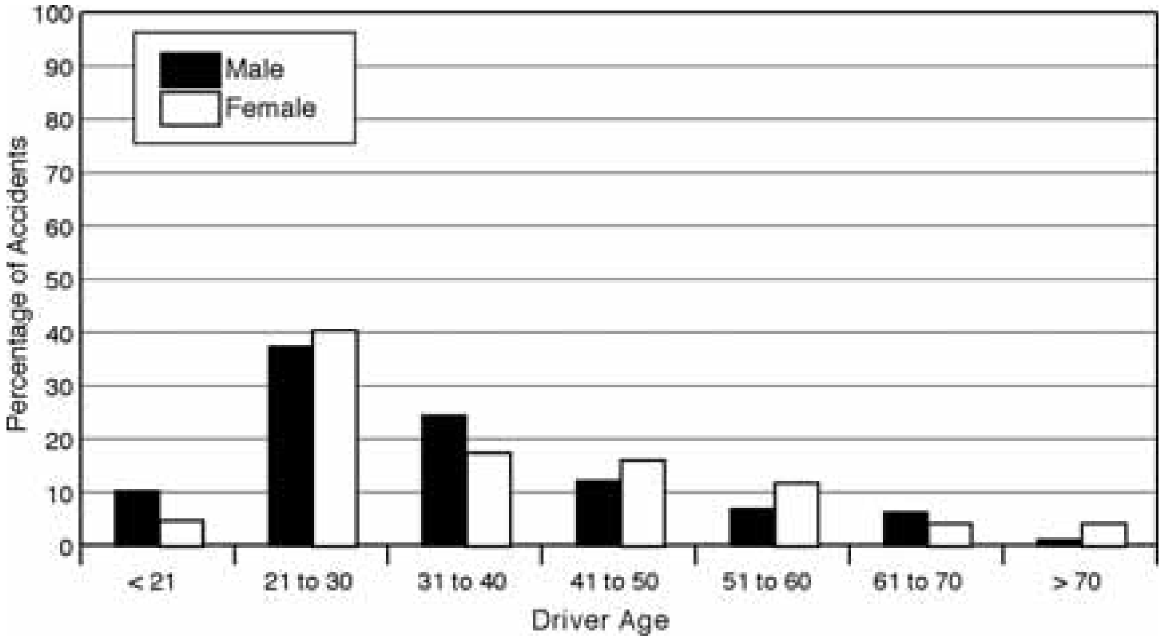

Figure 1.3 Frequencies of male and female drivers of different age groups

In both groups, male and female, the drivers most frequently involved in the observed accidents belonged to the age groups of 21 to 30 and 31 to 40.

The obtained data showed some differences in frequencies between male and female drivers in all age groups. To determine the significance of this difference the Wilcoxion Test was performed. This test was chosen because the population distribution was unknown and the sample size was small. The null hypothesis was that the two samples came from identical populations. The test showed that, at a level of significance 0.05, the null hypothesis could not be rejected, and therefore the difference between male and female drivers is not statistically significant.

The above data represent the number of male and female drivers involved in the observed accidents and do not take into account who was responsible for the accident. The detail scheme of each individual accident was analyzed to determine which driver was responsible for the accident. The results showed that the male drivers were responsible in 52% of all investigated accidents and the female drivers in 48%. The ratio of the number of male-female drivers responsible for the accidents to the number of male-female drivers involved in accidents was exactly 50% in both cases.

Similar ratios were calculated for each age group, and the results are represented in Table 1.11 and graphically shown in Figure 1.4.

Table 1.11 Drivers Responsible for Accidents Out of Drivers Involved, for Different Age Groups

Age of Driver	Drivers Responsible for the Accidents					
	Male		Female		Overall	
	#	%	#	%	#	%
Under 21	10	62.50	4	57.14	14	60.87
21 to 30	31	53.45	29	50.00	60	51.72
31 to 40	15	39.47	13	52.00	28	44.44
41 to 50	9	47.37	10	43.48	19	45.24
51 to 60	3	27.27	6	33.33	9	31.03
61 to 70	7	70.00	4	66.67	11	68.75
Over 70	2	100.00	4	66.67	6	75.00

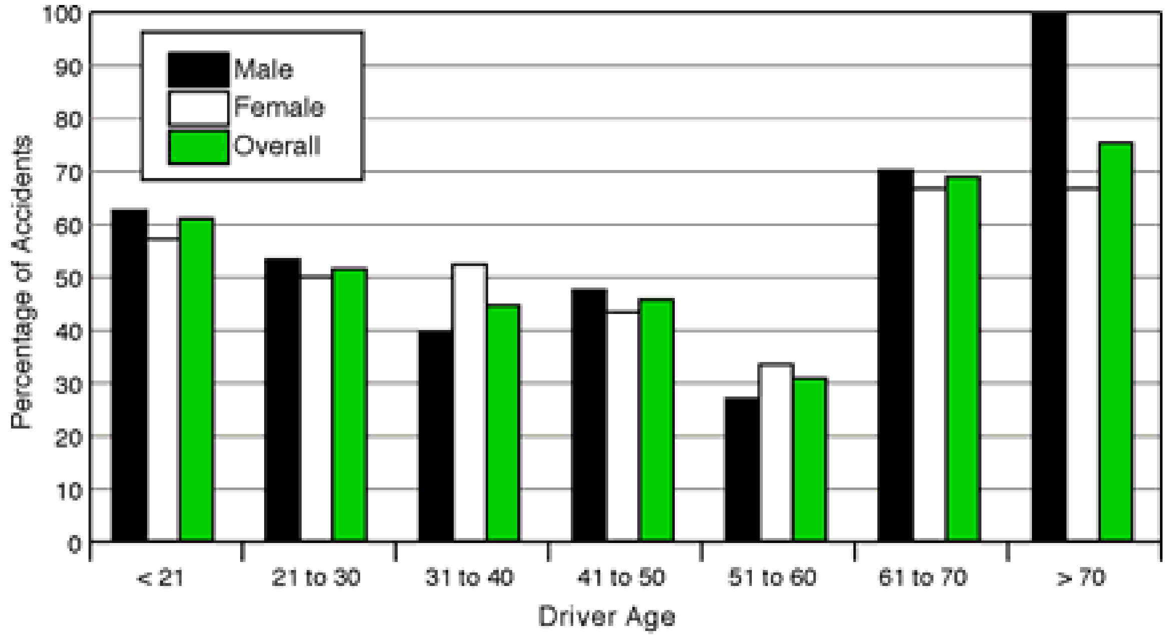

Figure 1.4 Percentage of Drivers Responsible for Accidents Out of Drivers Involved, for Different Age Groups

As expected, for both males and females, the youngest (under 21) and the oldest (over 60) drivers were more often than not responsible for the accidents they were involved in. Overall, more than 60% of the youngest and around 70% of the oldest drivers were responsible for the accidents, versus only 31% for the safest group of observed drivers (51 to 60).

Further analysis of the accident types and contributing factors did not indicate any relation between them and the driver's gender and age. This analysis showed that, for all age groups as well as for males and females, the most common types of accidents were side and rear collisions and the distribution of contributing factors was similar to one shown in Table 1.8.

From the analysis of the accident statistics, the following major conclusions can be drawn.

Accident frequency on Monday significantly exceeds that on other weekdays. This finding suggests that drivers are less familiar with work zone activity on the first business day of the week, but may adapt to the traffic conditions over the week.

The probability of accidents during bad weather is slightly lower than that during normal conditions. This might be explained by the lower traffic flow speed and greater driver awareness.

The data indicate the predominance of two-vehicle collisions, with the most common types of accidents being side and rear collisions.

Around half of the accidents resulted in property damage only, and the other half caused mostly minor injuries. The injury ratio of the accidents on arterial street work zones was observed to be significantly lower than the average for the investigated area, which can probably be explained by reduced speed in work zones.

Driver failure to yield ROW and to observe signs and signals were the major factors contributing to accidents in arterial street work zones. Disregarding signs and signals may be done consciously by the drivers, while failure to yield ROW can be a result of inadequate perception of traffic situations. Therefore, both traffic control countermeasures, which better consider human perception, and enforcement solutions should be taken into account when developing work zone safety improvement strategies.

During work zone presence on streets, access to local businesses or private driveways can be hidden by construction equipment or channelizing devices, causing last-minute maneuvering. The large numbers of accidents associated with driveway entry or exit operations clearly indicate the need for better consideration of local access roadways in designing work zone traffic control plans.

For males and females, the drivers younger than 21 and older than 60 were more often than not responsible for the accidents they were involved in, with the safest observed drivers being the ones between 51 and 60 years old.

1.3 Development of Recommendations for Traffic Control Improvements

This section summarizes the identification of countermeasures and the development of the improvement solutions described in detail in Research Report 4266-1 (Ref. 1).

For identification of countermeasures, the common schemas of urban arterial work zones were analyzed and the principal design sections were identified. Joint analysis of those sections and the observed traffic control problems led to determination of special requirements for TCP design on each design section. Then, based on analysis of human visual perception, a set of principles that apply to work zone traffic control was formulated.

Taking into consideration all the above-mentioned findings, the recommendations for improvements of traffic control planning on urban arterial street work zones were developed. Figure 1.5 represents the general proposed traffic control concept. Recommendations include several improvement solutions that can be classified into three major groups: advance information, active roadwork zone design, and road sign dominance.

1.3.1 Advance Information

For motorists' advance information, a new sign was developed that provides advance information by indicating road intersections between which construction takes place – in other words, information that helps a driver, approaching a work zone area, decide what route to follow to avoid traffic delays (Figure 1.6).

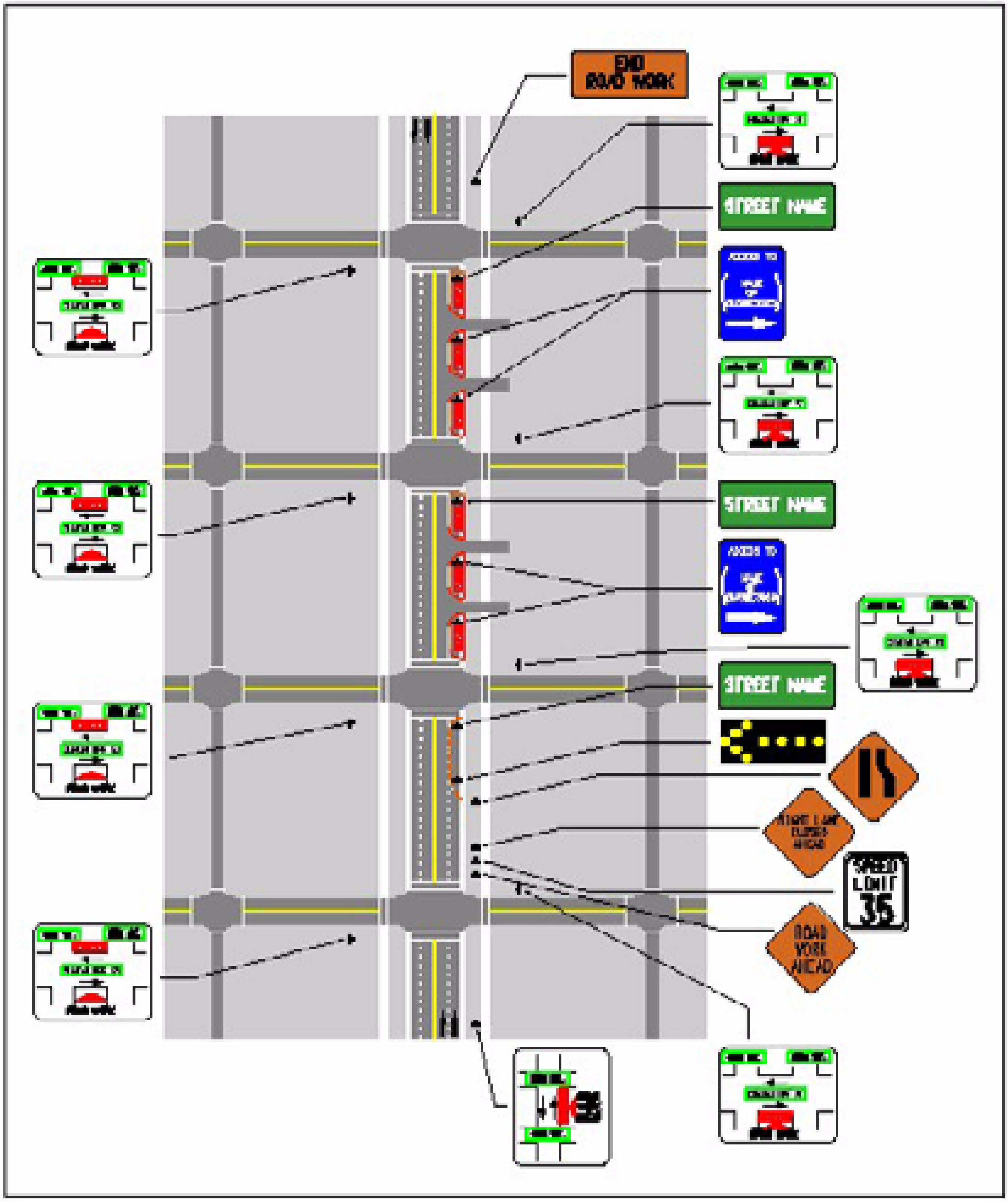

Figure 1.5 General guidelines for traffic control in urban arterial streets work zones

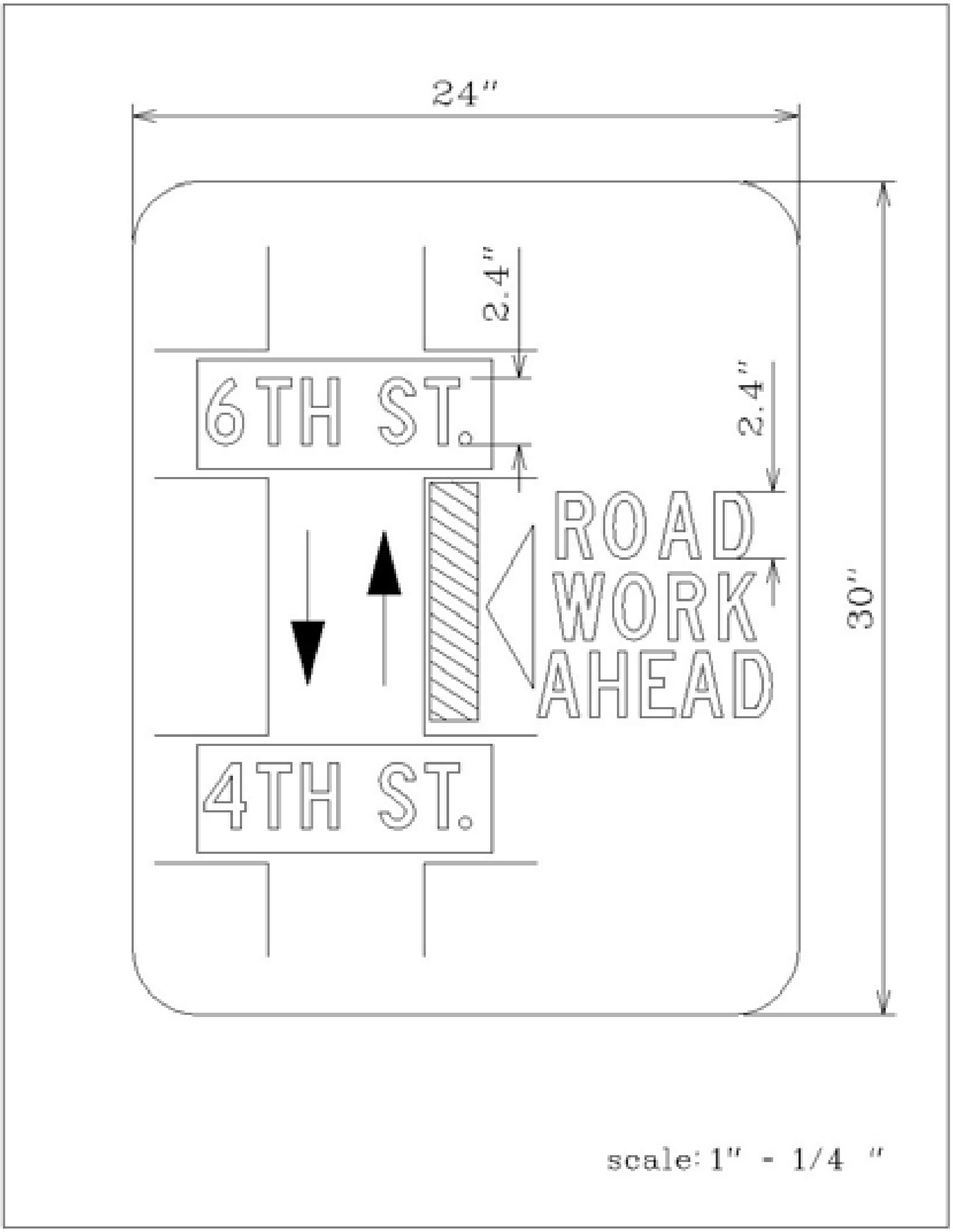

Figure 1.6 Advance information sign dimensions

Use of this sign is suggested in instances in which a driver's early decision to choose an alternative route to avoid traffic delays caused by a work zone is of critical importance. This sign has been developed to help drivers on the main road as well as those on crossing streets. The alignment of the schematic plan, representing the location of the work zone between intersections, with drivers' direction will facilitate the drivers' spatial orientation in relation to the upcoming road closure and reduce the time required for decision making.

The last part of the advance information design should include an area where traffic flow redistributes from the permanent to the temporary roadway. Beginning lane closure a block upstream of the actual roadwork location will reduce interaction of traffic flow approaching the work zone from the main and crossing streets. Figures 1.7 and 1.8 show this part of the design for two cases: (1) an arterial street intersecting with a street of lower significance (Figure 1.7) and (2) an arterial street intersecting with a similar arterial street (Figure 1.8).

1.3.2 Active Roadwork Zone Design

The recommended traffic control plan for the "Active Roadwork Zone" is represented in Figure 1.9. The major recommendations are related to sign placement and to minimizing the effects of local access driveways.

The presence of a work zone may cause a situation in which street-name signs left at their permanent locations will be out of the driver's cone of clear vision because the sign is now farther from the temporary roadway. So enlargement of street-name signs with relocation is recommended.

Taking into consideration the complexity of the work zone environment, stop sign placement on all non-signalized minor streets or driveway approaches adjacent to an active roadwork area can help to increase general driver awareness.

To address the common problem of local access, a new sign providing commercial zone information is intended to assist drivers in sorting out the information they need by grouping all business names on one sign. Figure 1.10 shows the dimensions of this sign. Such a sign will help drivers better orient themselves to the environment and in turn minimize last-minute maneuvering.

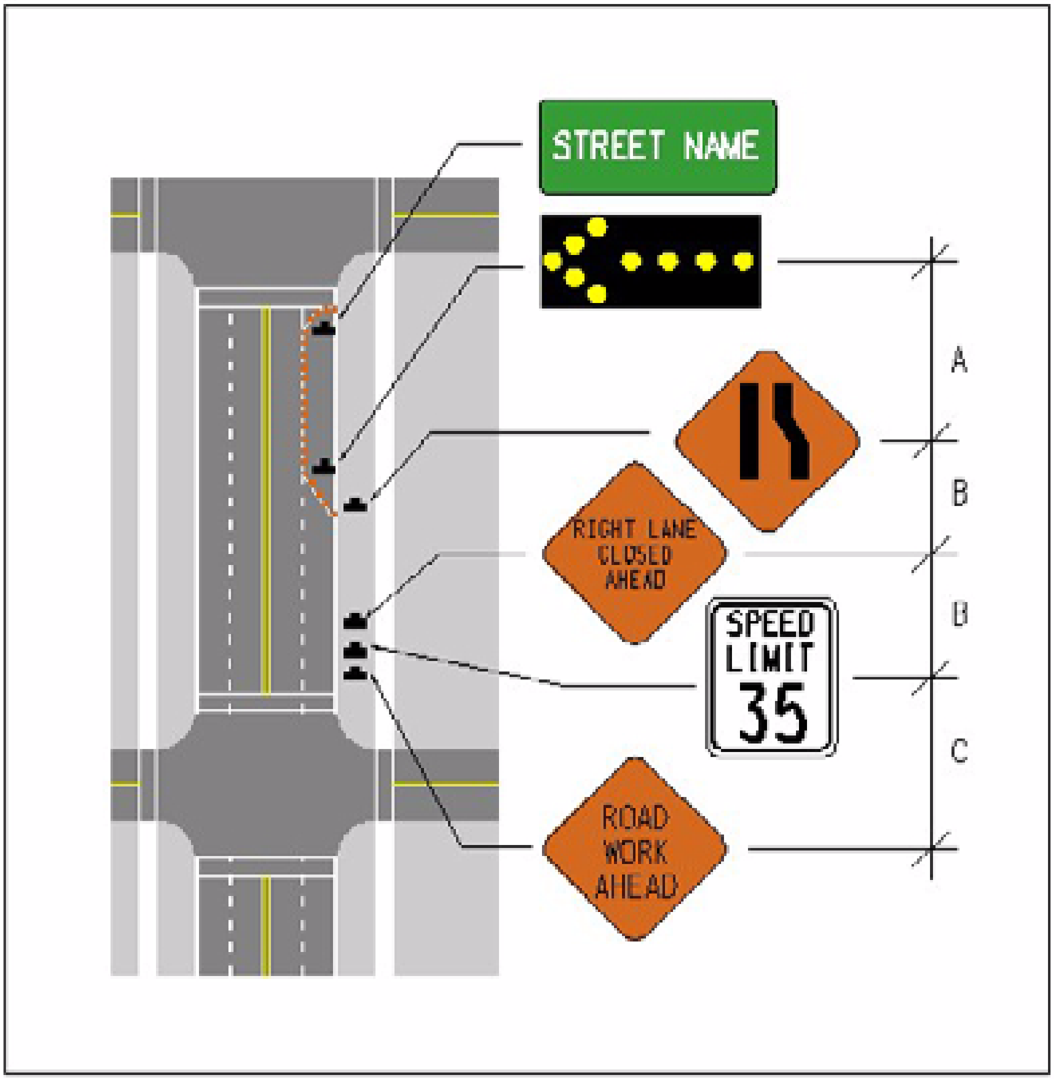

Figure 1.7 Recommended transition zone design in the case of an intersection with a street of less significance

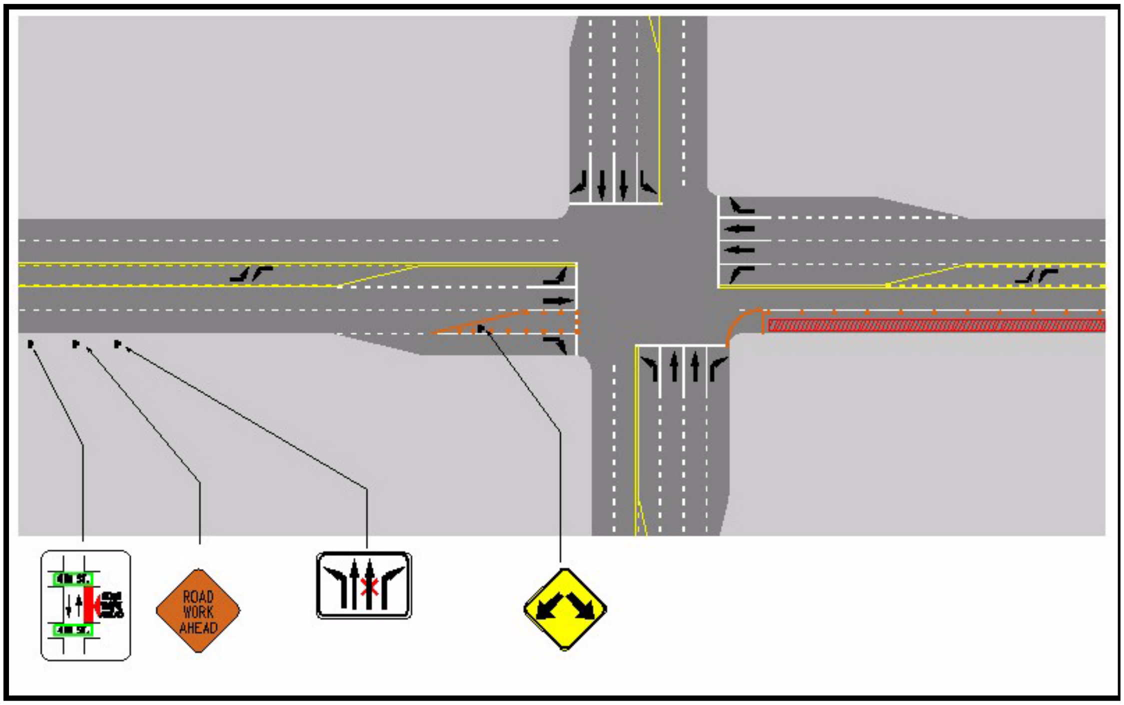

Figure 1.8 Recommended transition zone design in the case of an intersection with an arterial street

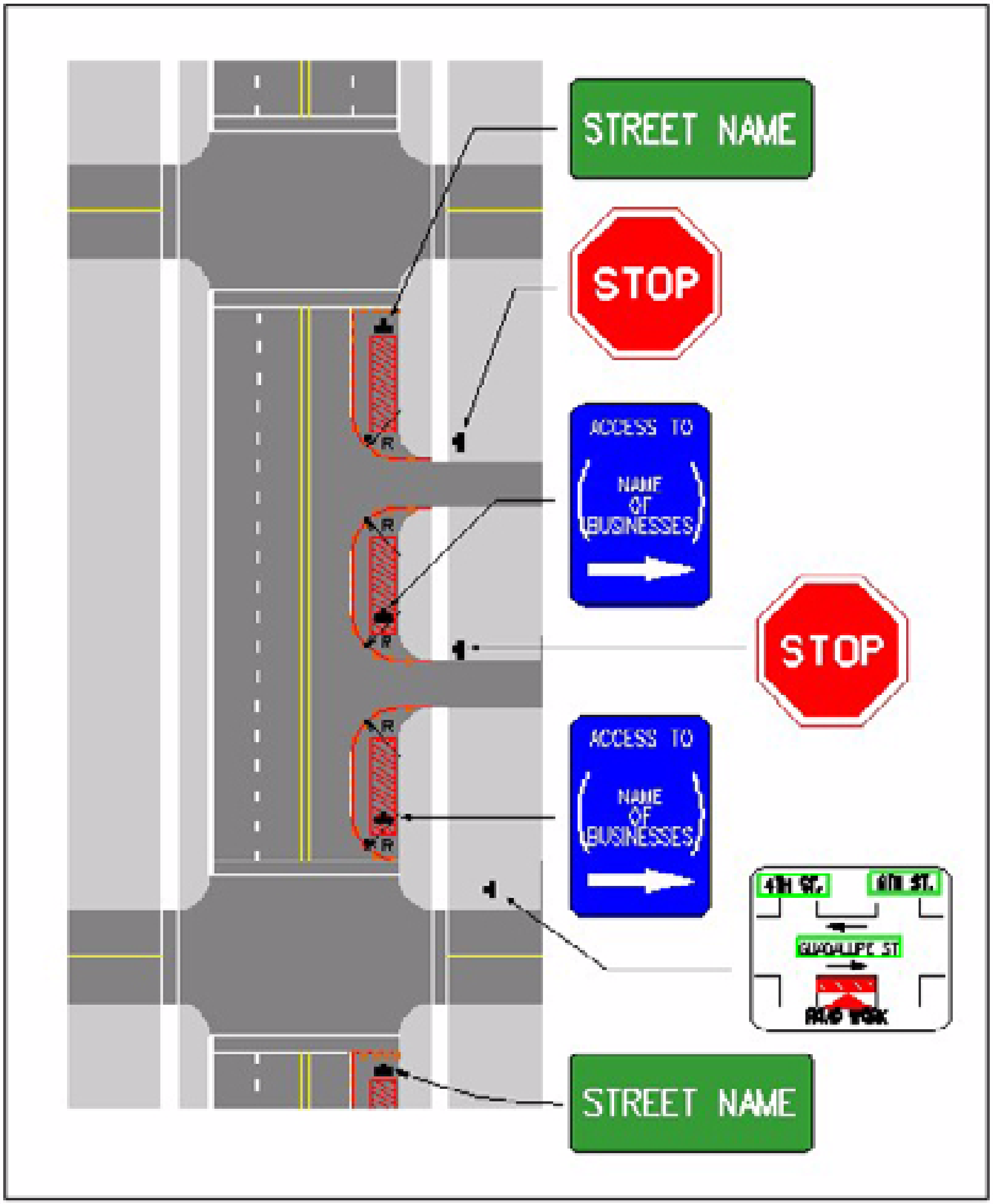

Figure 1.9 Recommended active roadwork zone design

Figure 1.10 Business access sign dimensions

The major problem of local access is related to human optical illusions. Traffic control devices such as drums on the edge of a roadway create a confusing visual image of discontinuities in the horizontal alignment. In the proposed schema, the placement of currently used devices (cones) in close proximity to each other, as indicated in Figure 1.11, is intended to assist drivers in easily perceiving work zone boundaries.

Driving in close proximity to construction equipment may cause accidents, even if adequate clearance is provided for construction operations, because of reduced or distorted depth perception. Figure 1.12 shows the recommended placement of a see-through device, like a net, that provides the perception of a spatial barrier between construction equipment and drivers.

1.3.3 Road Sign Dominance

The existence of numerous commercial displays, typical for urban arterial streets, creates a high level of visual noise and complicates the perception of work zone signs. Certain characteristics of visual acuity are of special interest for understanding the interaction of signs: dynamic visual acuity, peripheral vision, and depth perception (Ref. 3). Dynamic visual acuity is the ability to see and perceive stimuli in a moving field. The most acute vision is within a narrow cone (cone of clear vision) of 3 to 5 degrees, although the limit of fairly clear sight is within 10 to 12 degrees. In view of this fact, it is necessary to place signs or other important informative devices within this 10- to 12- degree cone of vision, and certainly within 20 degrees (Ref. 4). This characteristic is a major consideration for providing drivers with information regarding roadway parameters, traffic control devices, and behavior of other traffic participants. As speed increases, the point of visual concentration extends farther ahead. In other words, the eyes feel their way ahead of the vehicle and try to allow the driver sufficient time for emergencies. At speeds less than 50 mph (80 km/h) the driver is focusing from 240 to 360 feet (80 to 120 meters) ahead, while at 62 mph (100 km/h) it is 1800 feet (600 meters) ahead.

Based on the above-mentioned characteristics, guidelines for identifying interacting signs and redistributing them to ensure work zone sign dominance in the driver's visual field were developed.

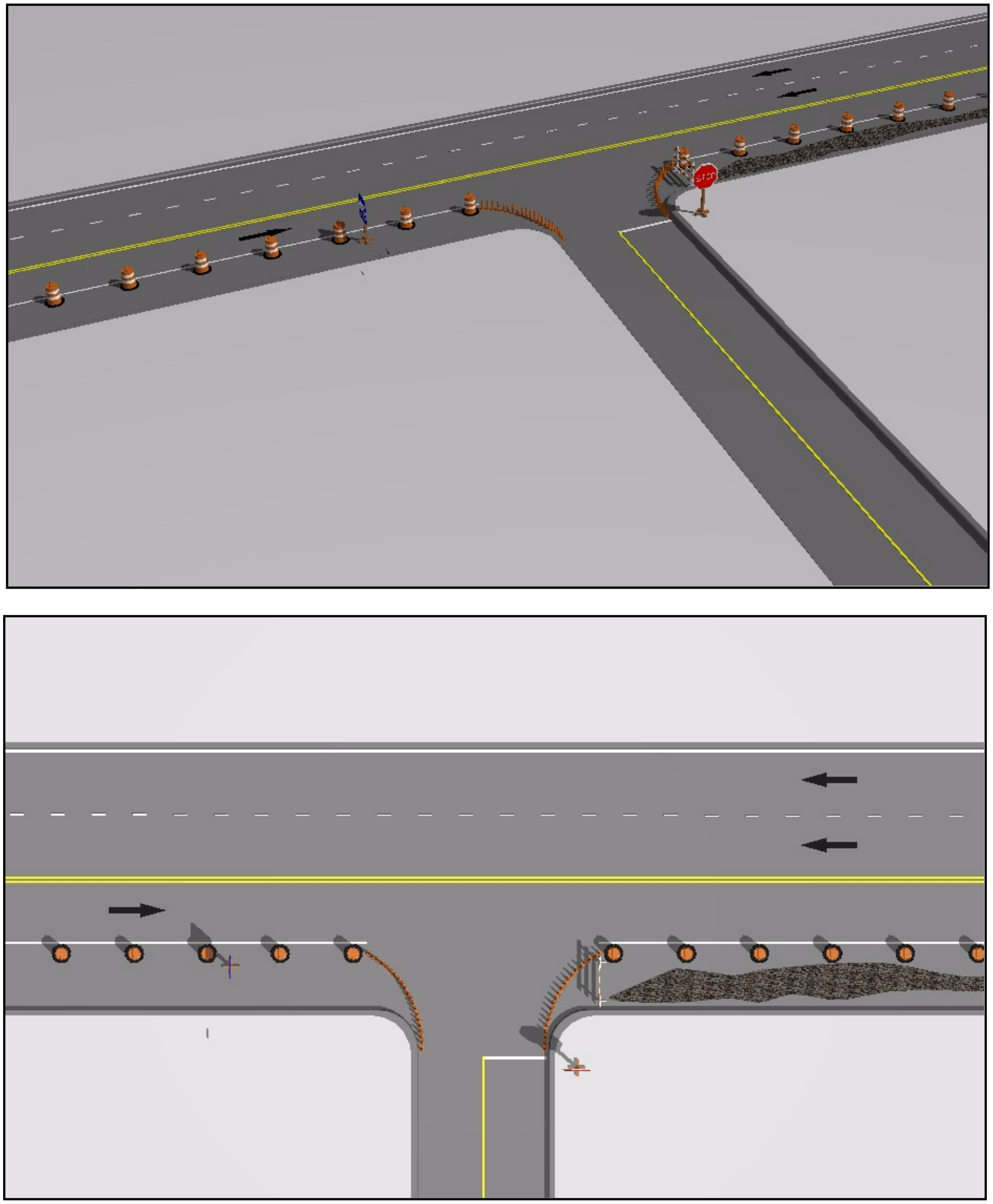

Figure 1.11Recommended placement of blocking devices on local access roads

Figure 1.12Recommended protection of traffic in close proximity to construction equipment

Figure 1.13 graphically represents the driver's visual fields. First the lateral distance (L) from the roadway covered by the driver's visual concentration zone was calculated based on the dimensions of the cone of clear vision at speeds of 35-45 mph (56-72 km/h). For the given speed such distance is 30 feet (10 meters). So if commercial signs or billboards exist in the lateral clear zone, they may interfere with work zone signs. To determine longitudinal distance between signs in the lateral clear zone causing sign interaction, the visual concentration zone fluctuation was taken into consideration. For speeds of 35-45 mph (56-72 km/h) such fluctuation is from 240 feet (80 meters) to 360 feet (120 meters) ahead.

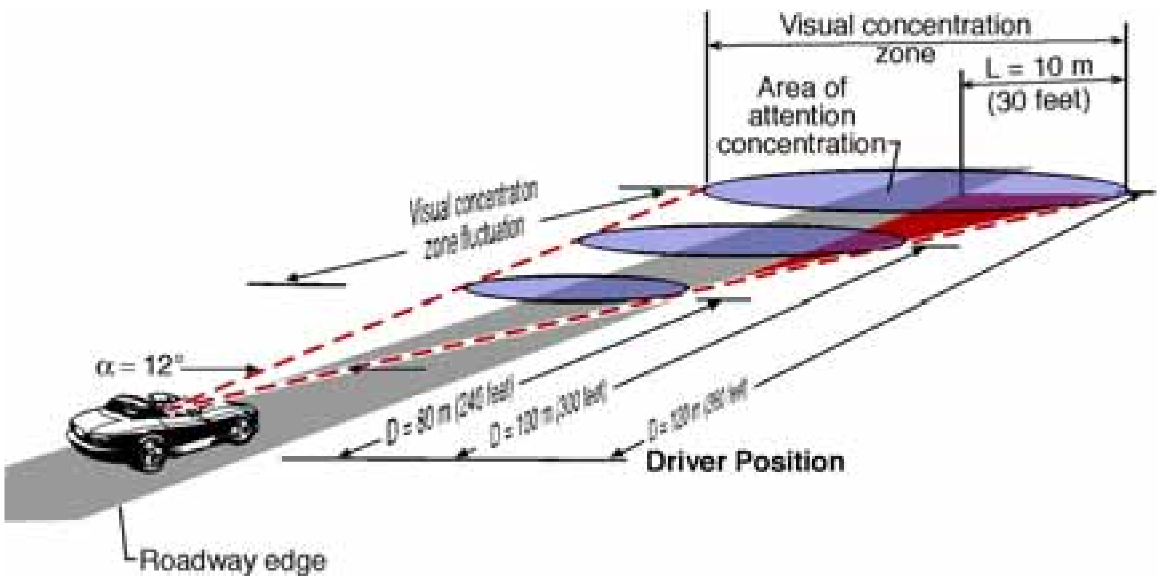

Figure 1.13 Driver visual perception characteristics at speeds of 35-45 mph

Taking into account visual perception characteristics, work zone signs should be placed where no other types of signs exist in the lateral zone 30 feet (10 meters) from the roadway edge or where existing signs or commercial billboards are located more than 60 feet (20 meters) upstream and downstream from the work zone sign. If no such location is available, all commercial signs should be relocated to ensure the above-mentioned clear zone around the work zone sign.

2. Evaluation of the Recommendations for Traffic Control Improvements

2.1 Identification of Countermeasures Requiring Testing

The recommendations for traffic control improvements on urban arterial street work zones were reviewed from the perspective of their compliance with the Manual on Uniform Traffic Control Devices (MUTCD) (Ref. 5) and countermeasures, which require evaluation, were identified.

As described in Section 1.3, all recommendations were classified into three groups and are summarized below from the perspective of necessary evaluation procedures.

The group named “Advance Information” includes two recommendations. The first is a new sign, shown in Figure 1.6, which provides advance information on road work by indicating road intersections between which construction takes place. Before such a sign can be implemented in practice, it requires tests to determine visibility, readability, and driver understanding. Corresponding with MUTCD, blue and white color designs were selected for testing.

The other recommendation of this group is to begin lane closure one block upstream of the actual roadwork, illustrated in Figures 1.7 and 1.8. Because this recommendation does not conflict with current standards, it was not selected for testing.

The “Active Roadwork Zone” group of recommendations, represented in Figure 1.9, is related to sign placement and minimizing the effects of local access.

The newly developed “Business Sign,” intended to assist drivers in sorting out the information they need by grouping all business names in one sign, requires tests of visibility, readability, and driver understanding.

The recommended enlargement and relocation of street-name signs during work zone presence does not conflict with current standards, but this recommendation still should be tested to determine the effect on traffic.

The recommendation to install stop signs on all non signalized intersections with minor streets and driveways in the active roadwork area, targeting increased driver awareness, does not conflict with MUTCD and was not selected for testing.

Recommended placement of cones in close proximity to each other to assist drivers in easily perceiving work zone boundaries on adjacent roads, shown in Figure 1.11, requires a test of driver perception.

Recommended placement of a see-through device, like a net, that provides the assurance of a spatial barrier between construction equipment and drivers is based on well-investigated human depth perception and does not require any additional study. The major problem is developing a net support that will be stable enough and also easily movable to follow the construction equipment. Such a task is not a subject of the present research and can be identified as a potential problem statement.

To ensure road sign dominance in the driver's field of view, a methodology for identifying interacting signs was developed and described in Section 1.3.3. The proposed concept is based on well-known principles of human visual perception and does not conflict with current standards. During development, the calculated dimensions of the sign clear zone were modeled on some existing work zones and showed definite dominance of work zone signs. A sample model is represented in Figure 2.1. No additional tests were necessary.

Figure 2.1 Relocation of commercial signs to ensure speed limit sign's dominance in the driver field of view (left, before relocating and right after relocating)

For the purpose of investigating driver perception of and reactions to the selected countermeasures, two sets of experiments were conducted: (1) computer animation and (2) field studies.

2.2 Computer Experiment

As a first step in evaluating the recommendations, computer experiments were conducted.

2.2.1 3D Digital Model Development

A 3D digital model of a typical urban work zone was developed. A general view of the animation is shown in Figures 2.2 and 2.3. The setting for the model is based on a compilation of typical urban work zone features. Specifically, the urban work zone model included the following features:

- A 3D digital model of a typical four lane urban arterial road. Lane width and pavement markings are based on existing standards.
- 3D digital models of:

1.Work zone signs based on MUTCD specifications

2. Proposed signs based on MUTCD specifications (letter type, placement, etc.)

3. Temporary work zone devices (barrels, barricades, etc.) based on MUTCD specifications

4. Permanent road elements (light poles, power lines, barriers, etc.)

Placement of these elements, including distance from edges of street and distance between elements, was also based on MUTCD specifications.

- 3D models of buildings and other structures typically adjacent to urban roads,
- 3D models of commercial signage.

To simulate a traffic condition of average complexity, the following steps were taken:

1. The animation camera was placed on the right (outside) traffic lane.

Figure 2.2 Snapshot of the animation developed from the 3D work zone model

Figure 2.3 Commercial signage and logos used in the development of the digital model (left, snapshots of the animation; right, photographs of commercial signage and logos)

2. Camera settings were based on the driver's perspective (distance from road surface, cone of vision, focal direction).

3. At least four cars were animated.

4. Speed was set to 35 mph.

5. Light and atmospheric conditions were set to daylight and clear sky.

The software MicroStation (Version 8) was used to develop the animation. The total duration of the animation was 30 seconds.

Figure 2.4 indicates the similarity in the perspective view of the road between an animation snapshot and a picture taken from the driver's position.

2.2.2 The Experimental Procedure

The computer experiment was focused on investigating the impacts on the driver of the following three improvement concepts:

1. Advance Information Sign
2. Business Sign
3. Placement of Cones on Adjacent Roadways

The following three tasks were given to each participant:

Task 1. Advance information perception. The purpose of this task was to investigate driver recognition and understanding of the proposed "Advance Information Sign," to determine what information provided by this sign was appreciated by drivers and to identify possible misconceptions.

Task 2. Destination identification. The purpose of this task was to investigate driver perception of the proposed "Business Sign."

Task 3. Adjacent roadways perception. This task investigated driver visual recognition of the adjacent roadways with and without the proposed treatment.

A special questionnaire (Appendix A) was developed to gather participant feedback for each task, and the following procedure was implemented:

Step 1. Participant was asked to find some destination while watching the computer animation (Task 2). The Figure 2.5 shows the laboratory environment during step 1.

Step 2. Participant was asked to examine the photo shown on the computer screen and identify as much traffic-related information as possible (Task 1).

Figure 2.4 Similarity in the perspective view of the road between an animation snapshot (above) and a photo taken from the driver's position (below)

The photo represented a driver's visual field and was made from a moving vehicle on an existing street with a work zone starting one block downstream from the vehicle position. The proposed "Advance Information Sign" was digitally added to the actual photograph (Figure 2.6). Based on human visual perception requirements and considering the difference between static and dynamic information processing, the photo was presented to the participant for 5 seconds. Then the participant was given a questionnaire to determine whether he or she recognized the proposed sign.

Step 3. Participant was asked to watch the animation and pause the picture when he or she recognized an adjacent roadway ahead, and the observer recorded the corresponding time code (Task 3).

Step 4. Observer showed the picture of "Advance Information Sign" for 5 seconds and then asked the participant about his or her understanding of the provided information (Task 1).

2.2.3 Results of Computer Experiment

A total of 99 people (61 males and 38 females) participated in the computer experiment. Table 2.1 shows the composition of different groups in the sample and the average age (full years) and driving experience (full years) for each group.

Table 2.1 Computer Experiment Participants

Participants	Participant Groups				
	UT Students	CTR Staff	TxDOT Staff	Other	Overall
Total Number	45	20	20	14	99
Number of Males	27	12	15	7	61
Number of Females	18	8	5	7	38
Average Age	24	44	34	45	37
Average Driving Experience	6.6	27.5	18.2	13.1	16.3

All participants were classified into two groups based on age and driving experience: (1) younger and (2) older. Table 2.2 represents the number of people in each group with corresponding average age and driving experience.

Figure 2.5 View of the laboratory environment during computer experiment

Figure 2.6 Photo of driver visual field with modeled "Advance Information Sign"

Table 2.2 Classification of Computer Experiment Participants

Participants	Participant Groups	
	Younger	Older
Total Number	45	54
Number of Males	27	34
Number of Females	18	20
Average Age	24	41
Average Driving Experience	6.6	19.6

The computer experiment showed the following results.

Driver perception of the proposed "Advance Information Sign"

In designing the "Advance Information Sign" the researchers had the following targets:

- Inform drivers that they are approaching a work zone
- Indicate streets between which construction activity is taking place so that drivers can select an alternative route
- Indicate the side of the road with construction activity so that drivers can better prepare for complex traffic conditions.

The first objective of the experiment was to determine how many drivers recognized the new sign and adequately perceived the provided information while viewing the photo of the street with the modeled sign for 5 seconds (Step 2). Table 2.3 represents the number of participants who recognized the proposed sign and correctly understood all information provided. The data indicated that on average only a small percentage of people recognized the new sign and adequately perceived the provided information. The experienced drivers (older group) recognized the sign in 9.3% of the cases, while in the younger group this value was around 4.4%. The comparison between signs with white and blue backgrounds showed that 16% of the experienced drivers (older group) recognized and correctly understood the white sign where as this percentage dropped to only 3% for the blue background. Such a difference was not observed in the younger group, for which the corresponding values were 4% and 5%.

Table 2.3 Percentage of Participants Who Recognized Sign and All Provided Information

Participants	Both Groups	Younger	Older
	Sign with White Background		
All	10	4	16
Male	13.3	7.1	18.8
Female	5	0	11.1
	Sign with Blue Background		
All	4.1	5	3.4
Male	3.2	7.7	0
Female	5.6	0	9.1
	Average for Both Signs		
All	7.1	4.4	9.3
Male	8.2	7.4	8.8
Female	5.3	0	10

The next target was to identify what information the drivers obtained from the new sign. The majority of participants, overall 70% in the older group and 51% in the younger group, recognized the "Advance Information Sign" as providing only information that some roadwork existed ahead without details (Table 2.4).

Table 2.4 Percentage of Participants Who Recognized Sign in General

Participants	Both Groups	Younger	Older
	Sign with White Background		
All	62	52	72
Male	66.7	57.1	75
Female	55	45.5	66.7
	Sign with Blue Background		
All	53.1	50	55.2
Male	45.2	46.2	44.4
Female	66.7	57.1	72.7
	Average for Both Signs		
All	61.6	51.1	70.4
Male	57.4	51.8	61.8
Female	68.4	50	85

Tables 2.5 and 2.6 show percentages of participants who recognized the sign as identifying streets between which the work zone was located (Table 2.5), or the side of the roadway where the work zone was located (Table 2.6).

Table 2.5 Percentage of Participants Who Recognized Sign As Identifying Streets between Which Work Zone Was Located

Participants	Both Groups	Younger	Older
	Sign with White Background		
All	12	4	20
Male	16.7	7.1	25
Female	5	0	11.1
	Sign with Blue Background		
All	12.2	10	13.8
Male	6.5	7.7	5.6
Female	22.2	14.3	27.3
	Average for Both Signs		
All	12.1	6.7	16.7
Male	11.5	7.4	14.7
Female	13.2	5.6	20

Table 2.6 Percentage of Participants Who Recognized Sign As Identifying the Side of the Road with Work Zone

Participants	Both Groups	Younger	Older
	Sign with White Background		
All	28	16	40
Male	30	21.4	37.5
Female	25	9.1	44.4
	Sign with Blue Background		
All	12.2	5	17.2
Male	9.7	7.7	11.1
Female	16.7	0	27.3
	Average for Both Signs		
All	20.2	11.1	27.8
Male	19.7	14.8	23.5
Female	21.1	5.6	35

About 17% and 7% of respondents in the older and younger groups, respectively, recognized the existence of roadwork ahead and identified streets between which the work zone was located. The location of the work zone (right or left road side) was identified by 28% (older group) and 11% (younger group) of the subjects.

For both the participant groups, the sign with white background produced better participant performance than blue.

Overall, the data clearly indicated that the proposed "Advance Information Sign" was not very effective. It can be concluded that in real traffic conditions, the majority of drivers will perceive only that they are approaching a work zone and will miss other information. In other words, this sign functions as a standard "Road Work Ahead" sign.

The test for determining driver understanding of the "Advance Information Sign" (Step 4) yielded the following results.

Roughly, 13% (6% of males and 25% of females) of the participants from the older driver group did not understand this sign at all, while 100% of the younger group had partial understanding. At the same time, practically all drivers who generally understood the sign had different misconceptions. Table 2.7 represents observed problems and misunderstandings and their frequency.

Table 2.7 Percentage of Participants Who Experienced Problems with "Advance Information Sign" Comprehension

Problems and Confusions	**Both Groups**	**Younger**	**Older**
	Male		
Did not identify road side	15.7	23.5	11.8
Road work on right shoulder	66.7	58.8	70.6
One lane in each direction	33.3	23.5	38.2
Did not identify streets	3.9	5.9	2.9
Road narrows ahead	7.8	5.9	8.8
Right lane closed ahead	7.8	0	11.8
Road closed ahead	7.8	0	11.8
	Female		
Did not identify road side	21.4	12.5	25
Road work on right shoulder	71.4	75	70
One lane in each direction	25	12.5	30
Did not identify streets	7.1	25	0
Road narrows ahead	14.3	0	20
Right lane closed ahead	7.1	0	10
Road closed ahead	17.9	0	25
	Average for Both Genders		
Did not identify road side	17.7	20	16.7
Road work on right shoulder	68.4	64	70.4
One lane in each direction	29.1	20	33.3
Did not identify streets	5.1	12	1.9
Road narrows ahead	10.1	4	13
Right lane closed ahead	7.6	0	11.1
Road closed ahead	11.4	0	16.7

Generally, the analysis of participant responses indicated that the proposed sign allows multiple interpretations and therefore does not provide drivers with exact information regarding traffic conditions ahead. At the same time, practically all participants appreciated the attempt to inform the driver about the work zone length and felt that it would help to make a decision about route selection.

Driver perception of the proposed "Business Sign"

The proposed new sign for commercial zone information is intended to assist drivers by grouping all business names in one sign, minimizing the frequency of last-minute maneuvering. Considering these targets, the main goal of the experiment (Step 1) was to determine the impact of the proposed sign on the driver way-finding process. The results of the experiment (Table 2.8) showed that the majority of drivers, 94% in the older group and 91% in the younger, easily perceived the proposed sign and noted it as a basis for their destination identification.

Table 2.8 Percentage of Participants Who Recognized Destination

Participants	Both Groups	Younger	Older
All	93.6	90.5	94.4
Male	93.4	96.3	91.2
Female	93.9	84.6	100

Adjacent Roadway Perception by Drivers

The test purpose was to investigate driver recognition of the adjacent roadways with and without the proposed cone placement. Several adjacent roadways were modeled in the computer animation, one of which simulated proposed continuous cone placement. During the test (Step 3), the time when the driver recognized an adjacent roadway was recorded and compared with the actual time of roadway passing. The difference in the time measurements permitted estimation of the vehicle position relative to the adjacent roadway. Table 2.9 shows the average advance detection time of the adjacent roadways. A very uniform distribution of detection times for all investigated groups was observed. The average values were 5.6 seconds for current traffic control conditions and around 7.5 seconds with the proposed delineation features. Therefore, the proposed cone delineation feature provided drivers with almost 50% more time to prepare for turning into a driveway or a crossing roadway. The other positive effect of the cone placement was the reduction in frequency with which drivers missed a desired turning roadway. In 2% and 15% of the cases in the older and younger groups, respectively, the participant missed the desired adjacent roadway in the standard conditions, but the proposed delineation feature completely excluded such a problem.

When a participant detected an adjacent roadway, he or she was asked whether this roadway was open or closed. Table 2.10 shows the percentage of participants who missed adjacent roadways with standard traffic control. For intersections with current traffic control, participants usually identified the roadway as closed and recognized it as open only at an intersection. When the proposed cone placement was implemented, 89% of the respondents correctly identified the roadway as open at the time of first roadway recognition.

Table 2.9 Average Advance Detection Time of Adjacent Roadways

Participants	Both Groups	Younger	Older
	Average Time for Standard Accesses, seconds		
All	5.6	5.7	5.6
Male	5.8	5.9	5.8
Female	5.3	5.4	5.2
	Average Time for Proposed Developments, seconds		
All	7.5	7.4	7.3
Male	7.8	7.3	7.8
Female	7	7.5	6.6

Table 2.10 Percentage of Participants Who Missed Adjacent Roadways

Participants	Both Groups	Younger	Older
	Average for Standard Accesses		
Total	7.4	15	1.9
Male	7.1	18.2	0
Female	7.9	11.1	5

Conclusions

The computer experiments resulted in the following conclusions:

- Due to numerous insufficiencies, the "Advance Information Sign" should not be implemented. Significant improvements could be made only with a significant increase of sign complexity. At the same time, the experiment indicated a potential positive impact of work zone length information. Therefore, portable changeable message signs (CMS) could be used to provide this information.
- The proposed "Business Sign" produced good participant performance and can be recommended for implementation.
- The proposed adjacent roadway delineation feature, using traffic cones, had a positive impact on both roadway detection and open/closed recognition and can be implemented.

2.3 Field Experiment

2.3.1 Test Sites Selection

For the field experiment, the work zone on 1st Street in Austin was selected and test driving was conducted. During the experiment, the effectiveness of the developed business sign (Figure 2.7), recommended enlargement and relocation of the street-name sign (Figure 2.8), and the recommended placement of cones (Figure 2.9) on the local access roadways were investigated.

Two marketplaces with limited visibility from the roadway were selected to test the business sign. The business sign was placed at one of the locations and the access was treated by the cones, as shown in Figure 2.10 (Test Section 1). The corresponding control section (Control Section 1c) represented local access with current traffic control (Figure 2.11). In both cases, test and control, the destination businesses or their logos were not directly visible from the roadway until the last moment.

Figure 2.7 Recommended sign for local businesses access

Figure 2.8 Recommended relocation and enlargement of street-name sign

Figure 2.9 Recommended placement of cones on adjacent road

Figure 2.10 View of Test Section 1 before (above) and after (below) treatment

Figure 2.11 View of Control Section 1c

Two intersections were selected to test the effectiveness of the recommended street-name sign relocation and enlargement. The new street-name sign was placed on the street, and the cones were implemented as well. Views of the test section (Test Section 2) before and after treatment are shown in Figure 2.12. The control section (Section 2c) was an intersection with standard street-name sign location and dimensions (Figure 2.13).

2.3.2 Methodology of Field Observations

Based on the tasks of the field observations, the following characteristics were selected for quantitative description of driver behavior and reactions:

- Advance recognition time of the adjacent roadway
- Duration of turning maneuver and speed history during approach to the destination point and reentering the main street
- Driver electrocardiogram

The experimental vehicle was equipped with a digital camcorder for recording the driver’s field of view, a portable device for the driver’s electrocardiogram (wave form) registration, and a special device connected to the vehicle’s on-board diagnostic system for recording speed, acceleration, and deceleration history.

To allow for differences in driver psycho-physiological states at the time of observations, their basic or pre-test electrocardiograms were recorded before each test drive under non driving conditions. For further analysis, relative characteristics, such as drivers’ pulse rates under the investigated conditions as a percentage of basic value, were used.

A total of 8 drivers from TxDOT Austin District volunteered for the field experiment. Ages of test drivers ranged from 22 to 52 years, and their driving experience ranged from 6 to 35 years.

Each driver was directed to drive to some destination point on the given route, which included all test and control sections, as well as other city streets. Test drivers were informed that the purpose of the observations was general investigation of traffic conditions in Austin. They had no other instructions and did not know about the locations of the investigated street sections.

Figure 2.12 View of Test Section 2 before (above) and after (below) treatment

Figure 2.13 View of Control Section 2c

During the test, the investigator asked drivers to find businesses (test and control) and approach them, or to find the streets (test and control) and approach them.

Field observations were made in similar weather conditions and with adequate traffic volume.

2.3.3 Results of Field Test

The collected data are summarized in Table 2.11.

Table 2.11 Characteristics of Drivers' Reactions during Field Test

Investigated Parameter	Test 1 -Business Sign				Test 2 - Street Sign			
	Driver							
	1	2	3	4	5	6	7	8
Destination Recognition								
Test	yes	yes	yes	yes	yes	yes	yes	yes
Control	no	yes	no	yes	no	yes	yes	yes
Advance Recognition Time, sec								
Test	9.1	6.2	0.5	4.3	5.5	11.4	7.7	9.4
Control	n/a	n/a	n/a	0.5	n/a	10.3	4.1	5.6
Duration of Turning In, sec								
Test	6	n/a	n/a	10	n/a	9	9	7
Control	n/a	7	n/a	6	n/a	9	n/a	9
Duration of Turning Out, sec								
Test	6	n/a	n/a	8	n/a	9	7	7
Control	n/a	7	n/a	7	n/a	8	n/a	8
Average Turning In Speed, kph								
Test	10	n/a	n/a	4.5	n/a	8.9	4.4	5.9
Control	n/a	4.8	n/a	6.3	n/a	5.7	n/a	8.2
Average Turning Out Speed, kph								
Test	13.2	n/a	n/a	5.4	n/a	7.2	9.5	7.9
Control	n/a	7.9	n/a	10.1	n/a	6.3	n/a	6.9
Average Deceleration, m/sec^2								
Test	0.51	n/a	n/a	0.92	n/a	0.57	0.91	n/a
Control	n/a	0.65	n/a	1.41	n/a	1.01	n/a	1.25
Average Heart Rate, % to basic								
Test	105	111	108	n/a	105	103	92	106
Control	n/a	115	106	n/a	n/a	101	95	105

On the control sections representing current traffic control, 3 of the 8 drivers were unable to find their destination. This problem was observed more frequently when drivers were asked to find a business (2 of 4 subjects), than when asked to find a street (1 of 4 subjects). The implementation of the developed countermeasures completely excluded such a problem.

Advance recognition times were different in test and control sections. On average, drivers recognized their destination 1.6 seconds earlier with the recommended treatments. In turn, early recognition of the destination point caused the drivers to reduce speed further upstream to access the roadway. Therefore, the deceleration values on test sections were observed to average 33% less than the control.

It was hypothesized that the recommended cone installation, in addition to assisting drivers to easily perceive work zone boundaries on adjacent roads, may have helped to make the turn from and to the main roadway more comfortable and faster. However, the obtained data did not show any significant differences in the turning time and speed with and without cone placement. But some significant safety advantages were observed. Due to construction activity, the experimental street sections contained one traffic lane of narrow width in each direction. The lane width constraint forced drivers, who were turning right onto the main street from local driveways, to approach in the opposite direction lane while performing the right turn. Such a situation was observed for all test drivers with standard placement of traffic barricades. With the recommended cone placement, all test drivers were able to make a turn within the borders of their own traffic lane.

From the results of the field studies it can be concluded that tested countermeasures showed good performance and can be implemented in practice.

At the same time it is necessary to recognize that extensive placement of cones or the recommended “Business Sign” can be costly due to numerous local access roadways typical for an urban environment. For identification of traffic conditions for which such treatments can be recommended, field observations were conducted on 1st Street in Austin. The experimental site represents a street section with construction activity, one lane in each traffic direction, and several adjacent driveways to local businesses. The researchers recorded the number of vehicles that had visually identifiable changes in speed or travel path due to a vehicle approaching a driveway from either traffic direction. The observations were conducted at low, medium, and heavy traffic volumes. A total of 136 cases were observed, and the results are summarized in Table 2.12.

Table 2.12 Number of Vehicles Affected by a Single Vehicle Approaching Local Access Roadway

Traffic Volume, vphpl	Number of Observations	Number of Affected Vehicles	
		Mean	Std.Dev.
260	38	1.63	1.15
430	58	2.26	2.16
972	40	4.78	5.06

As expected, data indicated an increased number of affected vehicles with traffic volume growth, from an average of 1.6 vehicles at low volume to 4.8 vehicles in average to heavy traffic.

The criterion for assessment of local access roadway (driveway) significance was formulated as the percentage of the main roadway traffic volume affected. Corresponding to the basic concept of designing for the 85th percentile, 15% of the main street traffic being negatively affected by driveway activity could represent a threshold value. Therefore, for the observed samples, 15% of traffic volumes were divided by the corresponding mean value of affected vehicles, producing traffic volumes from low to high of 24.4, 27.7, and 30.5 approaching vehicles per hour, or 28 approaching vehicles per hour on average. Because local access roadways typically lead to roadside businesses and each vehicle entering will be exiting back to the street, the frequency should be divided by 2. So it can be assumed that 14 or 15 approaching vehicles per hour or greater indicate that the local access roadway (driveway) has a significant impact on main street traffic and special treatments to minimize potential conflicts should be included in traffic control plan design.

3. Summary of Findings and Recommendations

As described in the previous chapters, the candidate traffic control improvement solutions were classified into the following three groups:

- Advance Information
- Active Roadwork Area
- Road Sign Dominance

Each group includes several countermeasures. The countermeasures requiring evaluation were identified, and their effectiveness was tested using computer experiments and field studies. Based on the test results, the necessary corrections were made and guidelines for traffic control plan design were developed and are presented below. All the references in the following are made to the Texas MUTCD, 1998 edition (Ref. 6).

Driver advance information.

Target: Provide drivers with advance information regarding work zone location and length and give them opportunity to select an alternative route to avoid possible traffic delays.

Solution: Road sign indicating street intersections between which construction is taking place. The developed sign is represented in Figure 1.6.

Test result: During the evaluation procedure, the developed sign showed numerous insufficiencies and was not recommended for implementation. At the same time, practically all participants of the experiment indicated a potential positive impact of work zone length information. Therefore, portable changeable message signs (CMS) or static message boards (SMB) could be used to provide this information.

Texas MUTCD addition: The following paragraph should be included into Chapter 6C “Temporary Traffic Control Elements,” Section 6C-1a(1):

On urban arterial streets to provide drivers with the opportunity to select an alternative route avoiding possible traffic delays through the work zone, advance information regarding work zone location should be provided using CMS or SMB. The board indicating street intersections, between which construction takes place, should be *placed upstream of the last intersection with street of arterial system on a distance corresponding to Table VI-3.*

Advance lane closure.

Target: Reduce congestion emanating from work zone lane drops.

Solution: Move lane drop transition upstream to the block preceding the work zone, allowing traffic to merge before the work zone.

Test result: No test required.

Texas MUTCD addition: Section 6C-1b should have the following supplement:

On an urban arterial street the transition area should be located on the block before the last intersection preceding the active roadwork and designed corresponding to guidelines of Section 6G-8. A sample of advance lane closure is represented in Figure TA-x.

The proposed typical application draft TA-x, shown in Figure 3.1, can follow the current typical application of TA-21.

Active roadwork area.

In the Texas MUTCD, the typical application draft traffic control plan for the "Active Roadwork Zone," represented in Figure 3.2, could precede the current typical application of TA-21 and should be referenced in Chapter 6G-6 "Work Within Traveled Way-Urban Streets or Arterials."

The four countermeasures proposed under this group consider the impact of intersections and local access on traffic operation and safety.

Street-name sign.

Target: To provide drivers with information regarding intersecting streets, taking into consideration possible driver perception constraints due to work zone presence.

Solution: Relocate the street-name sign so that drivers can clearly see it.

Test result: Experiments showed that the proposed sign relocation increased the probability of street identification. All test drivers indicated easy way-finding due to sign presence in the visual concentration zone.

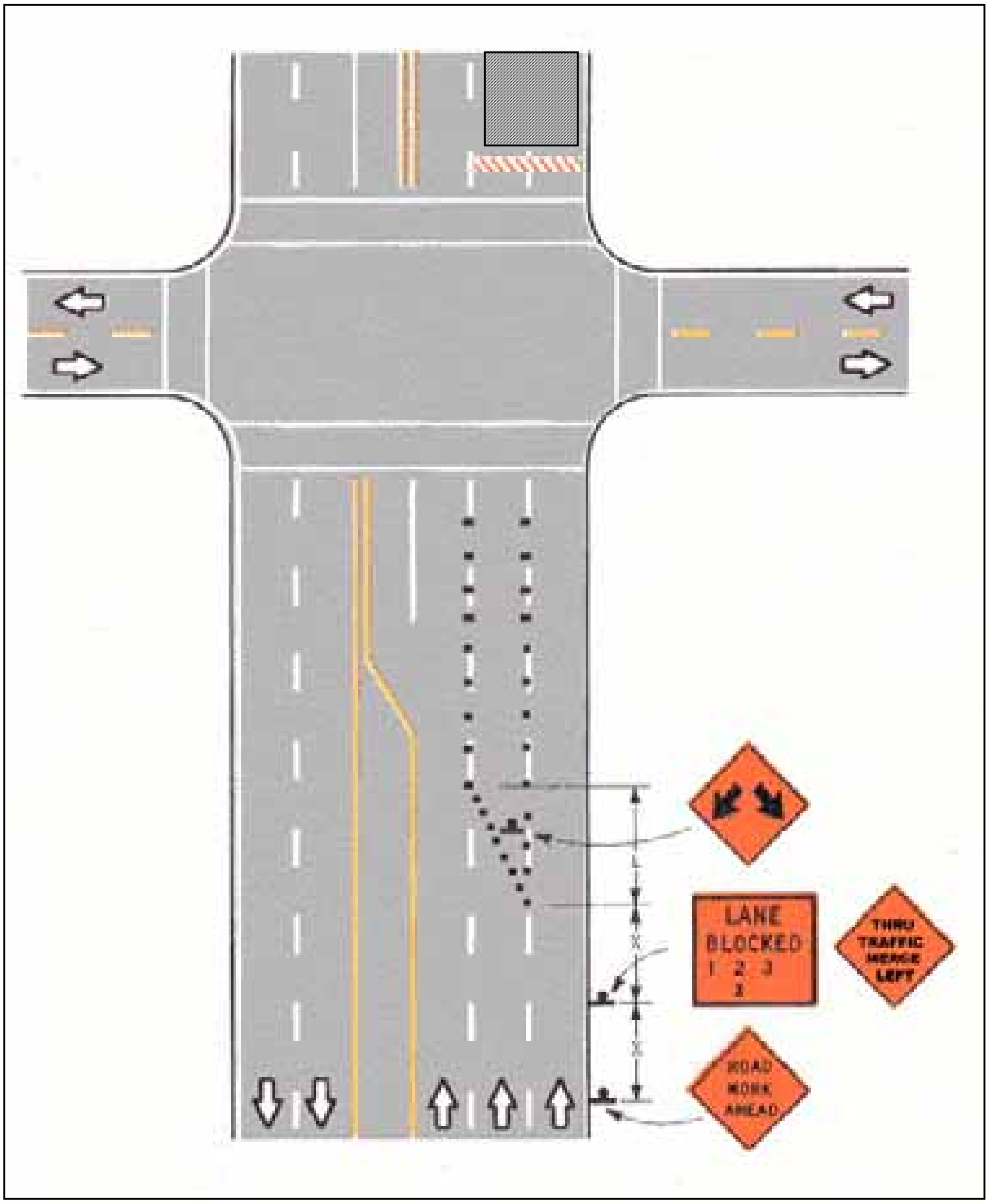

Figure 3.1 Advance lane closure at intersection

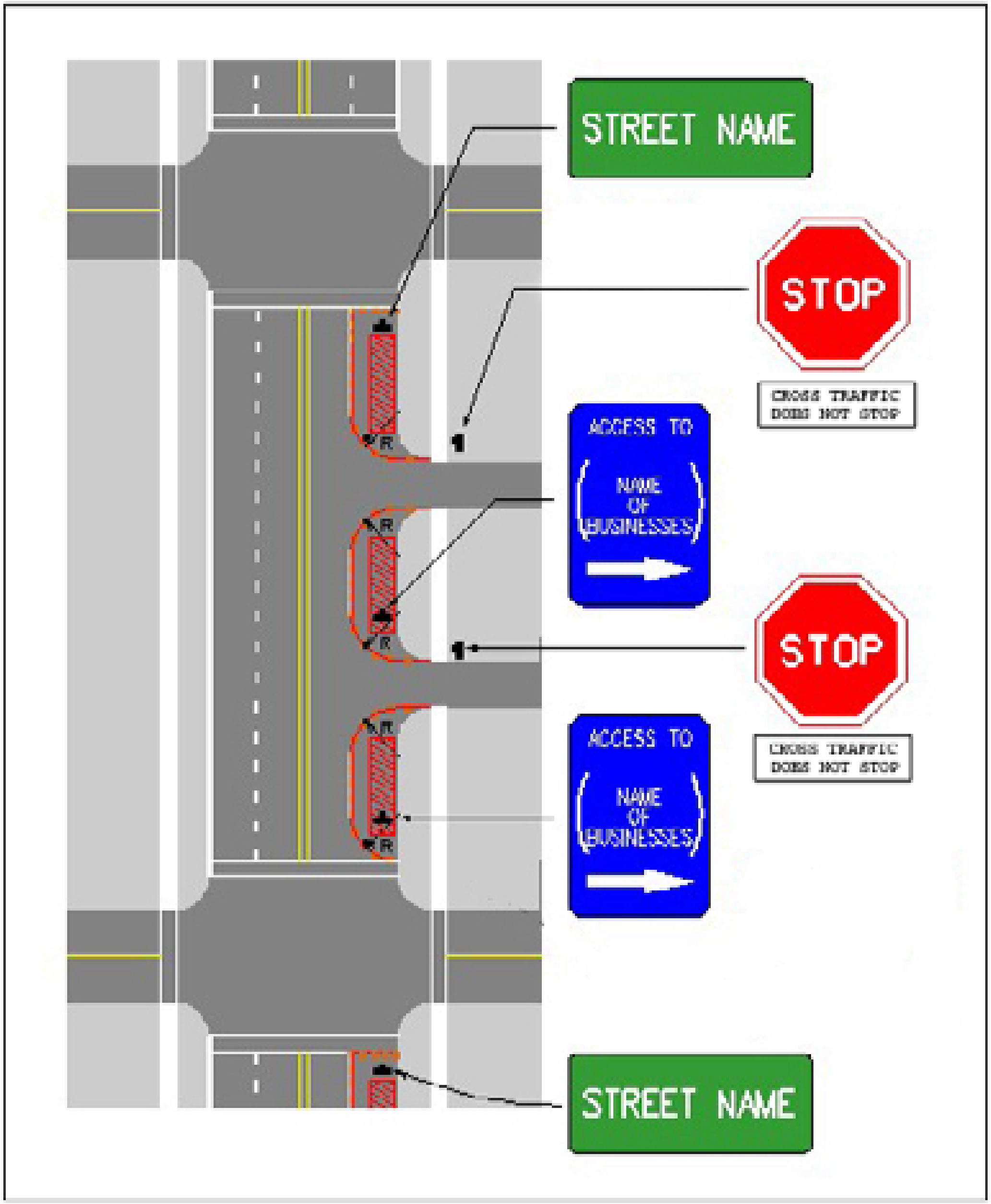

Figure 3.2 Traffic control in work zone activity area on urban street

Texas MUTCD addition: The following references can be included in Section 6G-6:

A work zone on an urban street may cause a street-name sign to be out of the driver visual concentration zone. In such cases the street-name sign should be duplicated and located, as shown in the Figure TA-xx, to ensure normal driver perception.

Stop sign.

Target: To increase driver awareness of access roads or driveway when entering an arterial work zone from a driveway.

Solution: Place stop sign and supplementary plate indicating which movements must stop on access road or driveway approaches inside the work zone.

Test result: No test required.

Texas MUTCD addition: Add the following to Section 6G-6:

To increase awareness of drivers approaching the work zone from a driveway, stop signs (R1-1) should be added to driveways within the work zone. A supplemental plaque reading "Cross Traffic Does Not Stop" shall be mounted below each stop sign.

Business Sign.

Target: To provide drivers with information regarding location and access to the local businesses to help drivers easily identify potential destinations and in turn minimize frequency of last-moment maneuvering.

Solution: Place a Business Sign, grouping business names or logos to ensure destination identification within driver zone of clear vision.

Test result: The experiments showed that the majority of participants easily perceived the proposed sign and noted it as a basis for their destination identification.

Texas MUTCD addition: The following paragraphs should be included in Section 6G-6:

The Business Sign is intended to help drivers identify potential destinations and therefore to reduce last-moment maneuvering in situations in which construction equipment or work zone traffic control devices limit visibility of roadside businesses. The sign should be placed at local access roadways where 15 or more entering vehicles per *hour can be expected at any time. At lower-volume access roadways, the sign placement may be based on engineering judgment.*

In the active roadwork area, local access roadways can be blocked if an alternative approach to the affected business exists. In case of adjacent roadway blocking, the Business Sign indicating the businesses and the temporary access to them should be placed within the driver zone of clear vision.

The dimensions of the Business Sign, represented in Figure 1.10, should be included in Chapter 6F-1c "Guide Signs."

Adjacent roadways.

Target: To avoid optical illusions of discontinuities in the work zone boundaries and assist drivers in easily recognizing and safely entering adjacent roadways (driveways).

Solution: Ensuring curvature (corner radius) on intersection and placement of cones close to each other.

Test result: The proposed treatments of intersections with adjacent roadways (driveways) had a positive impact on both roadway detection and open/closed recognition. The advance recognition time increased by 1.6 seconds, which in turn, caused smooth speed reductions.

Texas MUTCD addition: The following additions to Chapter 6G-6 are proposed:

Work space boundaries at intersections with other streets should ensure a roadway curb return radius of 3 to 4.5 meters corresponding to the AASHTO "A Policy on Geometric Design of Highways and Streets," Chapter IX "At-Grade Intersections," Section "Curvature for Turning Movements, Urban Streets." The same requirements apply to major local access roadways (driveways) where 15 and more approaching vehicles per hour can be expected at any time. To help drivers recognize adjacent roadways, cones placed on 2- to 3- foot centers should delineate edges of the curves, as shown in Figure TA-xxx.

The recommended figure is represented in Figure 1.11.

Road sign dominance.

Target: To ensure the driver's clear perception of road signs in a visually noisy environment.

Solution: Place road signs in locations where they do not interact with other objects.

Test results: The modeled placement of work zone signs based on the proposed concept ensured their dominance in the driver's field of view.

Texas MUTCD addition: The following can be included in the introductory section of Chapter 6F-1 "Signs":

To ensure dominance in the driver's field of vision, the distance between work zone signs and the nearest other road signs or commercial boards should be at least 10 meters (30 feet) laterally and 20 meters (60 feet) longitudinally.

Important notice: When selecting appropriate locations ensuring the clear zone, the designer should not violate minimal sign placement requirements.

Placement of work zone signs with large commercial billboards in close proximity, even when the clear zone is ensured, should be avoided wherever possible.

To provide a better visual environment for drivers in work zones, all small commercial boards, which can be easily moved, should be relocated to at least 10 meters from the roadway edge.

References

1. Tsyganov, A., Machemehl, R., and Liapi, K. "Identification of Traffic Control Problems on Urban Arterial Work Zones," Research Report 4266-1, Center for Transportation Research, The University of Texas at Austin, (unpublished).

2. http://www.txdps.state.tx.us/administration/driver_licensing_control/accident_records/mvta1999/tablecontents99.htm

3. Wickens, C. D., and Hollands, J. G. *Engineering Psychology and Human Performance,* New Jersey, Prentice Hall; 1999.

4. Klebelsberg, D. *Verkehrspsychologie*, Springler-Verlag, Berlin-Heidelberg-New York; 1982.

5. Manual on Uniform Traffic Control Devices, Millennium Edition, FHWA, U.S. Department of Transportation, 2001.

6. Texas Manual on Uniform Traffic Control Devices for Streets and Highways, Texas Department of Transportation, 1998.

Appendix A

Questionnaire for Computer Experiment

Step 1.

Task. You are looking for the "______________________".

On the provided video your destination may be:

- directly visible,
- you may see its logo on the roadside or some commercial board with its name or logo,
- road sign informing about business location and access.

Your destination may not exist at all.

Question 1. Did you find your destination?

A - yes

B – no

Question 2. How did you obtain information about your destination location?

A - business logo on the roadside

B - actually seeing the business

C - road sign informing about business location and access.

Your personal information.

You are:	UT Student	UT Staff
	TxDOT employer	Other _________

Age: _____________ full years

Gender: Male Female

Driving experience:_________________ full years

Step 2.

Task. From the provided photograph you need to identify information related to the work zone downstream to your driving direction.

Question 1. Did you recognize that you are approaching a work zone?

A - yes

B – no

Question 2. If yes, how did you obtain this information?

A - road signs (even if you could not read the sign but recognized shape or color)

B - actually see the work zone ahead.

C - Other ____

Question 3. Could you identify the exact location of the work zone?

A - yes

B - no

If you answered YES, please explain where it is :

on the (circle one) right left or both sides to your driving direction

between streets: _______________________

Your personal information.

You are:	UT Student	UT Staff
	TxDOT employer	Other _________

Age: _____________ full years

Gender: Male Female

Driving experience:_________________ full years

Step 3.

Task. You need to find all roads, crossing or adjacent to the road where you are driving.

At the first moment when you recognize that a crossing or adjacent road appears ahead, press the PAUSE button and record the time code located in the upper-right corner of the video. Write each obtained time in the spaces below:

1. ____
2. ____
3. ____
4. ____
5. ____
6. ____
7. ____
8. ____
9. ____
10. ____

Your personal information.

You are:	UT Student	UT Staff
	TxDOT employer	Other _________

Age: _____________ full years

Gender: Male Female

Driving experience:_________________ full years

Step 4.

How did you understand this sign? (mark all that apply)

a. road closed ahead
b. right lane closed ahead
c. road work ahead on right shoulder
d. road closed between 4th and 6th streets, prepare to detour on 4th street
e. one lane in each direction ahead, due to road work
f. road narrows ahead
g. road work ahead
h. road work ahead on the right side
i. road work ahead between 4th and 6th streets
j. road closed ahead, prepare for detour
k. other _______________
l. did not understand

How would you act in response to this sign? (mark all that apply)

a. no change of behavior
b. drive to another street to avoid work zone
c. continue driving, with increased awareness
d. follow detour
e. merge due to lane closure
f. stop
g. other__________________