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16. Abstract

Popular opinion has it that “road rage” is increasingly prevalent in the urban driving environment. Whether or not this opinion is true, driver frustration in congested conditions may lead to an increase in aggressive driving, a less malignant and more common subset of road rage. The potential for significant safety benefits might be realized if engineers had a better understanding of roadway factors and characteristics of the driving environment that induce irritation and contribute to aggressive driving. This report documents major activities: literature review, focus groups, telephone survey, and evaluation of three mitigation measures aimed at reducing driver stress that can lead to aggressive driving.

Researchers evaluated the benefits of improvements at freeway bottlenecks. Feedback from commuters revealed that a majority realized reduced aggressive behaviors (e.g., preventing merge, cutting across solid lines, tailgating, etc.) and commute time after improvements were made at a bottleneck location in Dallas. Almost 50 percent also indicated an improvement in their personal stress level after the implementation of improvements. Operational data collected at this site such as increased volumes, speeds, and decreased queue lengths supported the feedback from commuter surveys.

Secondly, researchers assessed the ability of photogrammetry to expedite clearance of incidents. Data from several police agencies suggested that photogrammetry could effectively reduce overall incident clearance time. Other data showed that photogrammetry compares very favorably in measurement accuracy to traditional investigation techniques.

Finally, researchers tested the Late Merge concept developed in Pennsylvania at a work zone on Interstate 30 in Dallas. Merging at lane closures is the subject of considerable debate by drivers, the media, and even traffic engineers. The Late Merge concept is designed to encourage drivers to use all lanes approaching a lane closure and then take turns near the merge point by using several static signs in addition to normal work zone traffic control. The simulation laboratory and field tests revealed that the Late Merge concept is feasible on an urban freeway where three lanes are reduced to two. Further testing of this concept and other innovative merge strategies such as Early and Zip Merging is needed to determine the most efficient, safe, and least stressful method of encouraging merging at lane closures.

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UNDERSTANDING ROAD RAGE:
EVALUATION OF PROMISING MITIGATION MEASURES

by

Carol H. Walters, P.E.
Senior Research Engineer
Texas Transportation Institute

and

Scott A. Cooner, P.E.
Assistant Research Engineer
Texas Transportation Institute

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TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

DISCLAIMER

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LIST OF ABBREVIATIONS

3-D	three dimensional
AAA	American Automobile Association
AASHTO	American Association of State Highway and Transportation Officials
CAD	computer aided dispatch
CBD	central business district
CHP	California Highway Patrol
CPD	Chattanooga Police Department
DCS	DeChant Consulting Services
DCSD	Dallas County Sheriff Department
DESi	driving environment simulator
DLM	Dynamic Late Merge
DMN	Dallas Morning News
DMS	dynamic message sign
DNT	Dallas North Tollway
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
GPS	Global Positioning System
HA	Highways Agency
HPMS	highway performance monitoring data
HOV	high occupancy vehicle
IH	interstate highway
IMS	innovative merge strategy
ITS	intelligent transportation system
LMTCS	lane merge traffic control system
MDOT	Michigan Department of Transportation
ME	merge environment
MIT	Massachusetts Institute of Technology
Mn/DOT	Minnesota Department of Transportation
MOE	measure of effectiveness
MUTCD	Manual on Uniform Traffic Control Devices
NDOR	Nebraska Department of Roads
NSC	National Safety Council
PPRI	Public Policy Research Institute
PSA	public service announcement
SH	state highway
TDOT	Tennessee Department of Transportation
TEE	traffic emotions education
TMT	traffic management team
TRB	Transportation Research Board
TRL	Transport Research Laboratory
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
UDOT	Utah Department of Transportation

LIST OF ABBREVIATIONS (continued)

UK	United Kingdom
UHP	Utah Highway Patrol
WSU	Wayne State University

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND AND SIGNIFICANCE OF RESEARCH

Popular opinion has it that "road rage" is increasingly prevalent and dangerous in the urban driving environment. Whether or not this opinion is based on fact, driver frustration in congested conditions may lead to an increase in aggressive driving, a less intentionally malignant and more common subset of road rage. The research staff believes the potential for significant safety benefits might be realized if transportation professionals had a better understanding of some roadway factors and characteristics of the congested driving environment that induce stress and perhaps contribute to aggressive driving. For instance, some geometric features may allow (or even invite) aggressive drivers to exacerbate an already difficult congested driving environment by driving on shoulders, cutting in line, weaving unsafely through traffic, or performing other erratic driving maneuvers. Likewise, drivers may perceive some recurrent congestion problems to be unnecessary, requiring only slight geometric or signing/striping modifications to resolve. Frustration that the condition is not getting fixed may also contribute to driver impatience. Non-recurrent congestion, unexpected by definition, may be an even greater contributor to driver stress, especially if advance information about construction zones comes too late to allow drivers to choose an alternate route or if there seems to be slow progress in clearing freeway incidents.

The subjects of road rage and aggressive driving have received a great deal of attention and coverage from constituencies such as the media, research organizations (primarily human factors and psychology professionals), and the law enforcement community. One of the initial difficulties for the research team was clearly defining the objectives and overall scope for the study. In particular, the researchers had difficulty creating definitions for road rage and aggressive driving. A comprehensive literature review throughout the two-year duration revealed a myriad of definitions for the terms road rage and aggressive driving. Based on the results of the literature review, documented in the first-year research report published in November of 2000 *(1)*, and discussions between the researchers and project advisory panel, the researchers developed the following definitions:

- *Road rage*: active hostility directed toward a specific driver [e.g., running another driver off the road, using the vehicle as a weapon, verbal threats, etc.]; and

- *Aggressive driving*: selfish, "me-first" attitude that is intentionally inconsiderate of other drivers [e.g., weaving and cutting, passing on the shoulder, tailgating, etc.].

While the title of the research project is "Understanding Road Rage," this project concentrated on addressing factors contributing to aggressive driving because it is much more common than road rage and because some factors may be amenable to engineering-related mitigation measures.

1.2 RESEARCH OBJECTIVES

The research staff developed the following three objectives to provide guidance to this project:

1. Define and characterize the elements of aggressive driving that relate to driver irritation due to the roadway environment under congested conditions.

2. Identify and prioritize the contributory factors for possible mitigation.

3. Develop practical mitigation measures that might be implemented at minimal cost to TxDOT.

1.3 WORK PLAN

The research staff devised a work plan for this project to accomplish the research objectives listed in the previous section. The following subsections provide descriptions of the work tasks contained in the second year of this research as outlined in the original proposed scope of work.

<u>Task 6. Conduct Field Tests of Selected Mitigation Measures.</u> Where feasible and practical, the study team will conduct field tests of selected mitigation measures.

<u>Task 7. Conduct Simulator Tests of Mitigation Measures.</u> The study team will conduct simulator tests of selected mitigation measures, including those being tested in the field, using the TTI Human Factors driving environment simulator (DESi) located in the Gibb Gilchrist Building on the Texas A&M west campus. The DESi, operational in September of 1999, performs research on human factors and safety issues associated with human-environment interactions. The DESi uses a PC-based driving environment simulator consisting of a vehicle cab, one signal capture computer, three image generation computers, one laptop computer, three liquid crystal display projectors, and proprietary third-party software to produce a simulated driving experience interactive with high-resolution high-fidelity driving environment scenarios. The driving environment scenarios can be customized to replicate any real world driving scenario or roadway configuration.

The driving simulator allows drivers to navigate through a computer-generated driving environment while controlling steering, braking, and acceleration exactly like they would in a real driving environment. Drivers' behaviors, reactions, and ability to 'drive' the vehicle are all recorded for objective and subjective analyses that allow investigators to examine human perception, cognition, and behavior in realistic driving scenarios.

<u>Task 8. Prepare Research Report, Research Summary Report, and Implementation Plan</u>. Following review by the Project Advisory Committee, the research staff will develop a research report, a research summary report, and an implementation plan for submittal to TxDOT at the end of the project.

1.4 REPORT ORGANIZATION

This report is divided into five chapters. Chapter 1, "Introduction," contains the background and significance of this research, the research objectives, and the work plan utilized to accomplish the stated objectives.

Chapter 2, "Background Information on the Mitigation Measures Selected for Evaluation," provides a brief summary of the three mitigation measures selected for evaluation during the second year of the project.

Chapter 3, "Evaluation of Improvements at Freeway Bottlenecks," presents the findings of whether improvements at bottleneck locations produce operational and psychological (i.e., reduced driver stress/frustration) benefits.

Chapter 4, "Evaluation of Using Photogrammetry for Incident Clearance," documents the results from several law enforcement agencies' evaluations of using photogrammetry for investigation of traffic-related incidents.

Chapter 5, "Evaluation of Innovative Merging Strategies at Lane Closures," describes innovative traffic control concepts at freeway lane closures and the results of the testing of the Late Merge traffic control concept in the DESi and on an urban freeway in Dallas.

Chapter 6, "Study Conclusions and Recommendations," summarizes the conclusions and recommendations of this research and outlines the suggested implementation plan for TxDOT.

CHAPTER 2

BACKGROUND INFORMATION ON THE MITIGATION MEASURES SELECTED FOR EVALUATION

The primary objective of the first-year activities was to identify and select mitigation measures believed to have potential for improving the problem of road rage and aggressive driving *(1)*. The research team developed and considered mitigation measures in the three basic categories—education, enforcement, and engineering. The primary focus was on engineering mitigation measures because those have the most potential for implementation by TxDOT. Table 1 provides a listing of these mitigation measures by category.

Table 1. Listing of Mitigation Measures *(1)*.

Education-Related Mitigation Measures
Dynamic message sign (DMS) usage
Traffic emotions education (TEE) cards
Curriculum for road rage/aggressive driving for driver's education/defensive driving courses
Media exposure of road rage and aggressive driving research results
Public service announcements (PSAs) on radio and television programs promoting safe driving
Enforcement-Related Mitigation Measures
Stronger legal penalties for aggressive driving related offenses
Cellular hotlines for reporting acts of road rage and aggressive driving to enforcement officials
Selective enforcement techniques targeted at citing motorists for aggressive driving offenses
Expediting the clearance of traffic incidents from the roadway
Engineering-Related Mitigation Measures
Signing, marking, and traffic control measures intended for aggressive drivers
Deployment of speed trailers in strategic locations to deter motorists from excessive speed
Entrance ramp improvements meant to make merging easier and smoother
Improved construction scheduling to prevent motorist frustration
Provision of traveler information via intelligent transportation system (ITS) devices
Geometric and operational improvements at bottleneck locations
Implementation of innovative merge strategies (IMSs)

Researchers developed all of the mitigation measures listed in Table 1 based on the results of the literature review, focus groups, and telephone survey results. The literature review was conducted throughout the duration of the project. The research team conducted the focus group and telephone survey activities during the first year of the study. The following sections briefly summarize the literature review, focus group, and telephone survey results.

2.1 SUMMARY OF LITERATURE REVIEW RESULTS

The research team performed a critical review of literature on the subjects of road rage, aggressive driving, and driver stress. Researchers divided the literature review into five major categories: definitions, driver stress and aggression, reduction of driver stress and aggression, focus group and survey research, and aggressive driving behavior on freeways.

2.1.1 Definitions

A major problem in assessing the extent to which either road rage or aggressive driving occurs and in resolving if they are becoming increasingly prevalent lies in the definitions of the terms.

The usefulness of the terms themselves, especially "road rage," in any scientific or technical sense is suspect, in part because of the inconsistent usage. Researchers found that confusion and discrepancies in how the term is used are by no means restricted to the popular press. Much of the highway safety technical and practitioner literature also reveals significant inconsistencies and, often, confusion in the definition and application of "road rage," "aggressive driving," and related constructs. Like "obscenity," they seem to defy a widely agreed-upon definition while, at the same time, most people are certain they "know it when they see it." The research team used the definitions from various literature sources to reach the definitions for road rage and aggressive driving presented in Chapter 1 of this report.

2.1.2 Driver Stress and Aggression

Researchers directed the second major effort at providing an overview of some of the theoretical and empirical issues and findings that may assist in moving toward the ultimate goals of the present project. These goals are to identify the pertinent factors that increase driver impatience, irritation, and stress in the congested urban environment that may be precursors to aggressive behaviors on the road and to identify, develop, and test mitigation measures, especially traffic engineering measures that TxDOT can implement without major infrastructure changes. In order to develop measures that have the potential to influence driver behavior, it is useful to understand some of the behavioral mechanisms and psychological characteristics that contribute to driver stress and aggression.

Researchers examined a number of studies and theories regarding sensation/thrill-seeking and risky driving. Like road rage and aggressive driving, the literature review revealed that driver stress is subject to multiple definitions and interpretations. Most of the stress definitions included something related to driver workload, cognitive skills, and personality. Increase in workload can directly influence the driver's performance, but can also serve to increase driving stress, which may in turn impact driving performance, usually negatively. The driver's cognitive skills (or deficits), personality variables, and, Cox *(2)* would add, the social support received by the driver, will affect the degree of stress experienced by the driver. It is also possible that the driver may reduce the stress experienced by changing his perception of the stressor or of himself.

In addition to the theoretical implications arising from competing definitions of stress, there is also the practical matter of how to measure stress in relation to the driving environment. The literature concentrated on physiological (heart rate, blood pressure, etc.), psychological (arousal checklist, self-reports, etc.), and behavioral (body posture, grip strength, etc.) measures of stress.

The research team also investigated the relationship of traffic congestion to driver stress and behavior. Much of the work in this area is very speculative and appears to support particular political or social agendas. From an intuitive standpoint, it seems logical that the presence of traffic congestion would contribute to increased driver stress. Some studies *(3,4)* have shown that congestion during a commute contributes to increased blood pressure, lower frustration tolerance, and increased negative mood (irritability, impatience, tension, etc.).

2.1.3 Reducing Driver Stress and Aggression

Despite difficulties in defining exactly what constitutes road rage, aggressive driving, and driver stress, and in ascertaining either their frequencies or rates of occurrence, there has been no lack of effort to develop countermeasures aimed at their reduction. Based on their underlying orientation, most of these efforts can be classified as:

- social, behavioral (including psychological and psychiatric interventions), and educational programs;
- enforcement and legislative activities; or
- traffic engineering/road design approaches.

Social, behavioral, and educational programs have concentrated on providing advice on how to recognize and deal with aggressive driving or road rage in others or oneself. This advice is promulgated through books, newspaper and magazine articles, pamphlets and other public information and education materials, and entire web sites.

Enforcement and legislative activities related to aggressive driving have dramatically increased during the last five years. The literature revealed that many state legislatures have adopted statutes that specify violations and penalties for aggressive driving. The enforcement community has increasingly used technologies and other innovative strategies to combat aggressive drivers.

Broad-based public education, individual therapeutic interventions, and targeted enforcement all have received a great deal of attention as potential means for reducing aggressive driving, while engineering and technology-based approaches have generally received less emphasis. This may be because aggressive driving is often viewed only in terms of the specific behaviors identified as being aggressive without consideration of the antecedents to such behaviors. It is those antecedents that may be most amenable to traffic engineering, road design, and other technological countermeasures. The literature review investigated traffic-engineering measures such as innovative merge strategies at work zone lane closures and automated highway systems that are designed to reduce the overall stress experienced by drivers.

2.1.4 Focus Group and Survey Research

The research team devoted a significant part of the effort in the present project to the development, planning, and execution of a series of focus groups and a telephone survey of

Dallas-area commuters. Researchers reviewed a number of related efforts addressing similar issues as part of the planning for the work undertaken in this project.

The research community has conducted many focus groups addressing a broad spectrum of issues related to road rage and aggressive driving in recent years. Participants in such groups, varying as a function of the groups' goals, have ranged from people with specific professional interests in the topic, e.g., law enforcement personnel, insurance executives, driver training teachers, etc., to members of the general driving public. Most pertinent work to the present project is a series of focus groups conducted among drivers of the Capital Beltway in the metropolitan Washington, D.C., area in 1994, 1995, and 1997 *(5,6)*. These groups have particular relevance because they focus on the attitudes, beliefs, and perceptions of drivers, many who are regular commuters that drive on a high-volume freeway in a large metropolitan area.

2.1.5 Aggressive Driving Behavior on Freeways

Researchers reviewed two major efforts aimed at examining aggressive driving behavior on freeway facilities. The research report documenting the first-year activities included information on a study of aggressive driving behavior on freeways in the San Diego metropolitan area *(7)*. Aggressive driving behaviors were collected via motorist cell phone reports to the California Highway Patrol (CHP). There were a total of 1987 reported incidents in the study database for the three-month time period. The study offered a spatial analysis (by major freeways) of aggressive driving behavior patterns that drivers/callers reported to CHP dispatchers. Significant findings included that: (1) aggressive driving, speeding, and road rage were more prevalent during the afternoon peak period (i.e., 3:00 to 6:00 pm); (2) the number of calls reporting aggressive behaviors on Fridays was significantly greater than other days; and (3) both volume (average daily traffic) and length of the freeway section were robustly correlated with the number of phone reports per freeway.

The second major effort examined during the literature review was a 1997 study that TTI performed entitled *Freeway Operations Under Congested Conditions (8)*. TTI researchers observed congested traffic operations at 12 sites on freeways in the Dallas metropolitan area. The analysis attempted to identify patterns in driver behavior that may create inefficiencies or hazards in the flow of traffic that are correctable or avoidable through design changes or by different signing, markings, or other traffic control devices.

Generally, the data revealed that aberrant driving behavior occurred wherever there was enough clear pavement available to do so and seemingly whenever drivers felt it was to their advantage to do so. Most likely, drivers perceived a time-savings significant enough to warrant their behavior. The negative aspects of the aberrant driving behavior, such as possible collisions with other vehicles or roadside structures, delaying other vehicles, or possible citations from law enforcement, were likely either not perceived or were viewed as such a low risk that they could be ignored.

There appeared to be a full range of driving behaviors, from aggressive to apprehensive, with most drivers falling somewhere in between. The videos of the 12 sites revealed that as congestion increased, drivers appeared to become more aggressive. Furthermore, some drivers appeared to imitate aggressive behaviors of other drivers. At most of the sites for much of the time, the researchers observed no aberrant driving maneuvers; however, when a single driver behaved aggressively, several following drivers were likely to repeat the behavior. The researchers concluded that this imitative behavior seemed to occur most often at sites where driving on the shoulder occurred, but it was also observed with gore crossings. Obviously, many drivers were either unaware of the possible maneuver until they saw other drivers complete the maneuver to their apparent advantage, or they were unwilling to violate traffic laws unless someone else did so first.

The conclusions of the portion of the study on driving behavior in congestion are as follows:

- Sites where long-distance queue jumping was prevalent had a negative impact on overall throughput and should be actively discouraged through design or operational means such as signal timing on frontage roads, ramp metering, rumble strips, etc.
- Unavoidable lane closures should be signed to delay the vacating of the closing lane until the last moment, to maximize throughput.
- Weaving in congestion appeared to be easier and had higher capacity than high-speed weaves.
- Shoulder driving is aggressive driving behavior and should be actively discouraged both by occasional enforcement and by installing rumble strips or raised traffic bumps along shoulders.

2.2 SUMMARY OF FOCUS GROUP RESULTS

The research staff conducted a series of five focus groups designed to explore issues related to driving in stressful environments as experienced by Dallas-area commuters between March 21 and May 9, 2000 *(1)*. Researchers used the focus group approach to provide information that they could use in developing a telephone survey about driving in the Dallas area, and to provide a mechanism for obtaining driver input to the identification of candidate measures that may mitigate some of the stresses associated with driving in congested urban environments.

The group discussion emphasized those aspects of driving in the Dallas area that individuals experience as particularly irritating, frustrating, and stress-producing. Participants discussed the stresses of driving under all conditions, but placed primary emphasis on those stresses associated with regular commuting, especially on Dallas-area freeways. The moderator asked participants in each group to write down five things that irritate or aggravate them about driving in Dallas. Following this exercise, which took about five to 10 minutes, the moderator asked the groups to discuss the items they listed. The listed items seemed to fall into six broad categories:

- *Category 1*: behaviors of other drivers that are identified as irritating;
- *Category 2*: irritating features/aspects of Dallas area road infrastructure, design, and general traffic conditions;
- *Category 3*: construction zone and maintenance area specific problems;
- *Category 4*: enforcement and emergency response-related concerns;
- *Category 5*: high occupancy vehicle (HOV) lane-related items; and
- *Category 6*: tollway-specific issues.

Group discussion of the "irritating" aspects of driving prompted new issues that none of the participants had noted in their written responses. Clearly, the subject of stressful driving struck a nerve, at least among the volunteers comprising these groups.

In each group, the moderator also posed the question of what would help reduce the stresses of driving in Dallas. As evident from the suggestions, participants generated a substantial range of ideas that would require:

- behavioral changes among drivers;
- improved roadway information;
- changes in enforcement practices;
- modifications to the physical infrastructure of Dallas roadways;
- stricter driver licensing and training procedures; and
- changes in area transportation policy, particularly as related to construction and mass transit.

The information provided by 40 focus group participants, along with review of previous studies, proved useful to the project team in developing the survey instrument used in the telephone survey, in concentrating the team's attention on potential public response to some of the mitigating measures that they could test in future phases of the project, and in providing greater insight into the perceptions and opinions of the driving public.

2.3 SUMMARY OF TELEPHONE SURVEY RESULTS

The Public Policy Research Institute (PPRI) at Texas A&M University conducted a telephone survey of drivers in 431 households in Dallas from May 29 to June 7, 2000 *(1)*. The purpose of the survey was to assess the prevalence and driver definition of stressful conditions that may lead to aggressive driving behaviors. Additionally, the 33-question survey was intended to assess the perceived effectiveness of a set of proposed countermeasures for reducing the stress of driving.

PPRI selected the survey sample from among blocks of current telephone exchanges in Dallas County using a random sampling procedure in which telephone numbers were computer generated. After the interviewer reached a residential household, randomization within the household was enhanced using the "last birthday" method. With this method, the interviewer asked to speak to the person 18 years of age or older who had the most recent birthday. PPRI used this technique to reduce the bias introduced into telephone surveys by the propensity of certain household members to answer the phone most often or the varying willingness within households to respond to surveys.

Interviewers made at least four attempts to reach a respondent at each telephone number. The refusal rate was very low—8.31 percent. Additionally, once respondents agreed to participate in the survey, their cooperation throughout the survey was phenomenally high. There were only 14 terminated interviews. This percentage is an extraordinarily low number of terminates relative to telephone surveys in general and indicates an interest in and willingness to discuss this topic.

The sample size of 431 represented a reasonable approximation of the driving population of Dallas. The sample size was large enough to provide a confidence interval of 95 percent and a sampling error of 6 percent. In other words, in 95 of 100 such samples, statistics show that the results should differ by no more than three percentage points in either direction from what was obtained through this survey. Furthermore, PPRI's use of the random sampling technique allows the results to be generalized to the driving population of Dallas County.

Interviewers asked respondents to describe the one driving behavior that is most likely to raise their stress level when driving on the freeways in Dallas. The results showed that the most prevalent answer was related to some type of lane change or merging behavior. Almost 25 percent of the respondents specifically stated that "cutting people off or people cutting in" aggravated them the most. When researchers considered all of the responses that describe a lane change, merge, or related activity, the proportion added up to 50.4 percent. In other words, the research staff determined that half of the driving behaviors volunteered as the most likely to raise stress were directly related to changes in lane positioning or queuing.

The survey included a series of questions designed to measure the degree of stress associated with eight driving behaviors, as well as the frequency of occurrence of these behaviors. Specifically, interviewers asked commuters to rate how stressful a list of driving situations was, on a scale from 1 to 5, where 1 was "doesn't add to the stress of driving at all" and 5 was "adds very much to the stress of driving." Table 2 provides the outside marginal and the frequency of occurrence for each of the driving situations that the interviewers presented.

Table 2. Driving Behaviors That Raise Stress Levels *(1)*.

Behavior	Does Not Add to Stress Level (%)	Adds Very Much to Stress Level (%)	Encountered Daily	Encountered Weekly (%)
Weaving in and out of traffic	5.1	52.7	65.2	75.3
Drivers prevent merge	4.9	50.8	27.6	40.1
Inattentive driving	5.1	47.6	59.6	58.6
Tailgating	9.7	44.8	46.6	60.2
Passing on freeway shoulder	14.2	44.3	18.8	24.9
Staying in a closing lane	8.8	39.7	53.1	67.3
Drivers block move from closing lane	8.4	37.1	36.7	50.7
Excessive speeding	15.3	31.6	73.5	74.6

Following the inquiry regarding stress-producing behaviors and perceptions of aggressive driving in Dallas, a concluding segment of the interview dealt with potential countermeasure approaches. The interviewer then provided respondents with a list of 14 possibilities and asked them to give each a rating as to how effective they might be in reducing the stress of driving. Table 3 summarizes the results of the countermeasure evaluation.

Table 3. Rating of Potential Countermeasure Approaches (*1*).

Countermeasure Approach	Limited or No Effectiveness (%)	Effective (%)	More or Highly Effective (%)
Clear accidents and other incidents faster	6.9	15.5	76.8
Build more freeway lanes where needed to handle traffic better	9.5	13.0	76.3
Add more freeway lanes at bottleneck locations	12.7	14.8	71.0
Increase the length of acceleration lanes at freeway entrances to make merging easier	15.3	17.2	67.3
Encourage employer-provided flexible work hours and telecommuting	17.4	16.0	66.1
Improve public information about lane closures due to crashes or breakdowns	13.7	23.2	62.8
Improve the signs or pavement markings that advise of lane closures	14.1	23.4	62.1
Have hotlines to report aggressive driving to the police	23.2	17.4	57.7
Improve public information for scheduled freeway lane closures	17.9	24.4	57.6
Increase enforcement targeted at aggressive driving	17.0	24.6	56.3
Encourage more use of public transportation	23.9	23.7	51.8
Focus on aggressive driving in driver education and defensive driving classes	21.4	26.9	51.3
Build more non-freeway major streets	20.5	26.5	50.8
Run campaigns in the media that promote more courteous driving	44.1	24.6	30.0

The top three countermeasure approaches, that is, those countermeasures that received the highest percentage of "more effective" and "very effective" ratings, were those solutions that would most directly impact congestion. First, clear accident and incident obstructions faster. Closely at second, build more freeway lanes where needed. Third, and akin to building more lanes in general, add more freeway lanes at bottleneck locations.

2.4 MITIGATION MEASURES SELECTED FOR FURTHER TESTING

The final process undertaken by the research team during the first year was the selection of the most promising mitigation measures for inclusion in second-year evaluation and testing. Because of the limited budget and scope, the research team decided that they would select only three mitigation measures for further evaluation. After considering all of the educational-, enforcement-, and traffic engineering-related mitigation measures listed in Table 1, the research team selected the following mitigation measures.

2.4.1 Mitigation Measure #1—Using Photogrammetry to Expedite Incident Clearance

The first mitigation measure the research team selected for inclusion in the second year was the use of photogrammetry for expediting incident clearance. Telephone survey participants indicated that clearing accidents and other incidents faster was the most effective countermeasure.

2.4.2 Mitigation Measure #2—Bottleneck Improvements

Second, the research team felt that evaluating the benefits of bottleneck improvements for mitigating aggressive driving had merits for further evaluation. The telephone survey confirmed that this countermeasure approach was one of the most effective in the eyes of motorists who regularly commute (see Table 3).

2.4.3 Mitigation Measure #3—Innovative Merge Strategies

Finally, merging difficulties accounted for over half of the number one volunteered stress-producers, and a majority (62.1 percent) of telephone survey respondents rated improving signs and pavement markings in advance of lane closures as a highly effective countermeasure. These results prompted the research team to select the evaluation of an innovative merge strategy in an urban location as a mitigation measure for further testing. Researchers decided to evaluate the Late Merge traffic control concept in the driving environment simulator (DESi) and at one field site in the Dallas area. The DESi is comprised of four components: a full-size 1995 Saturn SL automobile, four computers, three projection units, and a projection screen *(9)*. Figure 1 shows a rendering of the simulator. The DESi is designed to allow participants to "drive" a real vehicle through realistic computer-generated driving environments while controlling acceleration, braking, and steering—exactly like they would in the real world. In this case, researchers used the DESi to gather feedback and monitor driver behavior in a freeway "world" replicating a lane closure with the Late Merge signing.

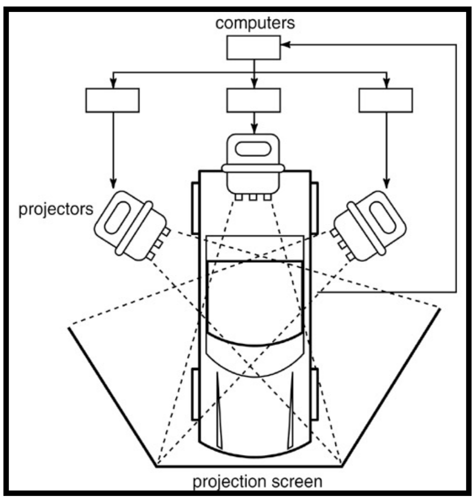

Figure 1. TTI Driving Environment Simulation Laboratory *(9)*.

CHAPTER 3

EVALUATION OF IMPROVEMENTS AT FREEWAY BOTTLENECKS

A kink in a hose restricts the flow of water, regardless of the capacity of the hose. Similarly, a "kink" in a freeway system (referred to as a bottleneck), usually occurring at a ramp junction, causes the available capacity to be underutilized, with congestion (stored demand) upstream and free flow conditions at a volume reflecting the bottleneck capacity downstream. The bottleneck may limit flow downstream to less than the available freeway capacity. In this era of maximizing the efficiency of our existing traffic systems, we need to understand bottlenecks, and where appropriate, eliminate them. Often the constriction is removable through a relatively low-cost improvement to a short section of freeway within existing right-of-way. Often this improvement requires only conversion of a shoulder to a driving lane with slight narrowing of main lanes from 12 feet to 11 feet *(10)*.

This chapter presents the results of the evaluation of improvements at freeway bottleneck locations for mitigating the occurrence of driver stress and subsequent aggressive driving. The first section provides some background information on the evaluation of freeway bottleneck locations. The second section expands on the discussion of correlating driver stress to freeway congestion. The final section provides the results of the assessment of two bottleneck improvements to freeways in the Dallas metropolitan area.

3.1 BACKGROUND INFORMATION ON EVALUATION OF FREEWAY BOTTLENECK LOCATIONS

Bottlenecks on freeway facilities create traffic congestion. In recent years studies have brought significant attention to problems created by freeway bottlenecks throughout the United States.

3.1.1 American Highway Users Alliance Bottleneck Report

In November of 1999, the American Highway Users Alliance released a report entitled *Unclogging America's Arteries: Prescriptions for Healthier Highways (11)*. This report received widespread media attention (54 print, 69 network TV/radio, and 511 local TV/radio stories) with an estimated 122 million viewers. The study, conducted by veteran transportation research organization Cambridge Systematics, examined 167 freeway bottleneck locations throughout the United States and identified the 18 worst in a separate list (Table 4). To identify, rank, and assess the nation's worst freeway bottlenecks, Cambridge analysts relied on information provided by local transportation planning agencies and state transportation departments, coupled with recently developed analytic methods for assessing the impacts of transportation decisions. Briefly described, the methodology involved a survey of transportation officials in the 30 most congested cities in the nation, as identified by the 1998 report on area-wide congestion by the Texas Transportation Institute. Transportation officials in those cities nominated candidate bottlenecks from their area, which Cambridge analysts then examined and ranked using the QSIM, a macroscopic queuing model developed specifically for studying the effects of varying traffic conditions on overall delay. Cambridge supplemented the nominated bottlenecks with data from an American Automobile Association (AAA) report *(12)* and Highway Performance Monitoring Data (HPMS) data from the FHWA.

Cambridge researchers not only identified the worst bottlenecks, they also estimated the benefits to travelers and the environment by removing the bottlenecks. The report calculated the combined benefits of improving bottlenecks nationwide. Collectively, improvements to these 167 serious bottlenecks would prevent 287,200 crashes (including 1150 fatalities and 141,000 injuries). Carbon dioxide (CO_2) emissions would drop by an impressive 71 percent at these bottlenecks. Emissions of smog-causing volatile organic compounds would drop by 44 percent, while carbon monoxide would be reduced by 45 percent. Finally, rush hour delays would decline by 71 percent, saving commuters an average of almost 40 minutes each day.

Table 4. 18 Worst Bottlenecks in America List *(11)*.

Rank	City	Freeway	Location	Vehicles per Day	Annual Hours of Delay (000)
1	Los Angeles	IH 405	IH 10 jct.	296,400	22,284
2	Houston	US 59	IH 610 jct.	321,000	22,085
3	Seattle	IH 5	IH 90 jct.	283,226	21,884
4	Boston	IH 93 (C. Artery)	US 1 jct.	223,300	20,264
5	Washington, D.C.	IH 495	IH 270 jct.	255,500	20,145
6	Washington, D.C.	IH 95	IH 495 jct.	267,000	19,629
7	Los Angeles	US 101 (Ventura)	IH 405 jct.	278,000	18,787
8	Los Angeles	SR 55 (Newport)	SR 22 jct.	221,500	18,049
9	Los Angeles	IH 10 (S. Monica)	IH 5 jct.	308,787	16,364
10	Albuquerque	IH 40	IH 25 jct.	209,900	16,029
11	Atlanta	IH 285	IH 85 jct.	256,400	14,013
12	Atlanta	IH 75	IH 85 jct.	234,700	13,496
13	Chicago	IH 290	IH 88/IH 294 jct.	220,635	12,268
14	Denver	IH 25	IH 225 jct.	192,000	11,296
15	Houston	IH 610	IH 10 jct.	251,540	10,877
16	Washington, D.C.	IH 66	IH 495 jct.	196,000	10,220
17	Washington, D.C.	IH 95/IH 495	US 1/IH 95 jct.	168,025	10,115
18	Atlanta	IH 285	IH 75 jct.	220,400	9,585

* In reviewing the list of bottleneck locations identified by this report, readers will note that none of the worst bottlenecks are in the New York City area. As most travelers know, congestion in and around the boroughs of New York can be significant. However, a very large share of the delay in the New York area is related to bridge and tunnel crossings into Manhattan, most of which are toll facilities. Early in the study, Cambridge Systematics personnel decided to exclude toll facilities from the ranking of the worst bottlenecks in the United States. The reason for this exclusion is that toll facilities are fundamentally different from other physical bottlenecks (such as freeway-to-freeway interchanges) that are prevalent around the country. Delay comparisons between toll facilities and other types of bottlenecks might not be consistent since different modeling techniques would be used. If objective field measurements of delay could be made at all locations around the country, several river crossings into Manhattan would no doubt be included in a list of the nation's worst bottlenecks.

3.1.2 AAA Bottleneck Study

In the summer of 2000, the American Automobile Association released a report entitled *Ten Most Notorious Traffic Bottlenecks (12)*. This report also received a large amount of national and local media attention, indicating a high level of interest in the subject of traffic bottlenecks. AAA identified the bottleneck locations through a survey of AAA members throughout the United States. Table 5 provides the AAA list of the 10 most notorious traffic bottlenecks in the United States.

Table 5. AAA List of the 10 Most Notorious Traffic Bottlenecks *(12)*.

Rank	City	Location Description
1	Boston	IH 93 north and south. The city's central artery cuts an elevated pass through downtown.
2	Chicago	IH 88 (Eisenhower Expressway). Traffic merges from two highways on a road that goes down to a single lane for 1½ blocks.
3	Dallas	IH 35E at IH 30. The highways merge and carry downtown traffic through "the Canyon".
4	Houston	US 59 (Southwest Freeway) at IH 610 Loop. Only one lane exits US 59 to IH 610 Loop.
5	Los Angeles	IH 5, IH 10, SR 60, and SR 101 interchange. An estimated 566,000 vehicles per day travel this location, overwhelming its capacity.
6	Milwaukee	IH 94 (East-West Freeway). Stretches of the road carry twice the intended traffic.
7	Minneapolis	NB IH 35W at Minnehaha Creek. Only three lanes are on this major route into downtown.
8	New Orleans	IH 10 at IH 610. Lanes are reduced from three to two and visibility is restricted as drivers move from an elevated section to a surface level road.
9	New York	IH 278 (Gowanus Expressway). Primary bottleneck is a 3.8 mile stretch between the Brooklyn Battery Tunnel and the Belt Parkway.
10	Washington, D.C.	Woodrow Wilson Bridge. A six-lane bridge that is fed by the eight-lane IH 95 (Capital Beltway).

3.1.3 TTI Bottleneck Studies

Urban Mobility Study

For approximately 10 years researchers at the Texas Transportation Institute have produced the Urban Mobility Study report that uses a variety of measures to illustrate the nation's growing traffic problem *(13)*. The annual study documents the growth of congestion on the major road systems of 68 urban areas in the United States. The most recent report, released in May 2001, provides data from 1999 and includes the following significant findings:

- The cost of traffic congestion nationwide totaled $78 billion, representing the cost of 4.5 billion hours of extra travel time and 6.8 billion gallons of fuel wasted while sitting in traffic.
- The average delay is 36 hours per person per year.
- The average rush hour trip takes 32 percent more time than the same trip taken during non-rush hour conditions.

TTI researchers based the costs on both recurrent (congestion where traffic demand exceeds available capacity) and non-recurrent (congestion caused by unexpected incidents—accidents, debris, stalled vehicles, etc.) congestion estimates. A portion of the estimated recurrent congestion is thought to be due to the presence of bottlenecks on freeway facilities.

TTI Bottleneck Case Study Examples

TTI has been involved in several research projects related to the evaluation of bottlenecks on freeway facilities. A 1992 study, *Methodology for Assessing the Feasibility of Bottleneck Removal*, discussed methodologies for identifying and determining the cause(s) of a bottleneck, suggested appropriate ways to alter geometrics to diminish the impacts of a bottleneck, and provided guidance on estimating the benefits transportation agencies could expect from implementing a bottleneck improvement *(10)*. Also included in this report were several case study examples that demonstrate the benefits of successful bottleneck removal projects. The following subsections briefly document the IH 635/US 75 and northbound IH 35E Stemmons Freeway bottleneck case studies.

IH 635/US 75 Interchange

The IH 635/US 75 interchange in north Dallas was the site of recurrent congestion. Demand for the eastbound IH 635 to northbound US 75 movement was clearly underserved, with eastbound queues during much of the day, particularly the evening peak. The bottleneck improvement at this location involved converting the inside shoulder on IH 635 into a travel lane for a distance of 2000 feet; this new lane became an exit-only to the US 75 northbound ramp, which TxDOT rebuilt to two lanes. The former inside lane on IH 635 then became an option lane. Figure 2 shows the site before and after the bottleneck improvements. Downstream on the US 75 northbound exit ramp, TxDOT eliminated the yield to US 75 main lane traffic, allowing free flow for the new two-lane exit.

Traffic volumes immediately increased to take advantage of the new capacity, both for the ramps and through lanes. Figure 3 shows the before and after volumes for the evening peak hour for the study location. TTI determined that the overall volume during the evening peak hour increased by almost 30 percent. Even with the increased volume, speeds after the bottleneck improvement increased by over 50 percent during the peak period.

Researchers assessed benefits based only on the travel time savings of the original traffic volumes, and found them to be $3.6 million per year during the morning and evening peak periods combined. The cost of the project was approximately $1.2 million, yielding a benefit/cost ratio of 24 (with a 4 percent discount rate and 10-year project life).

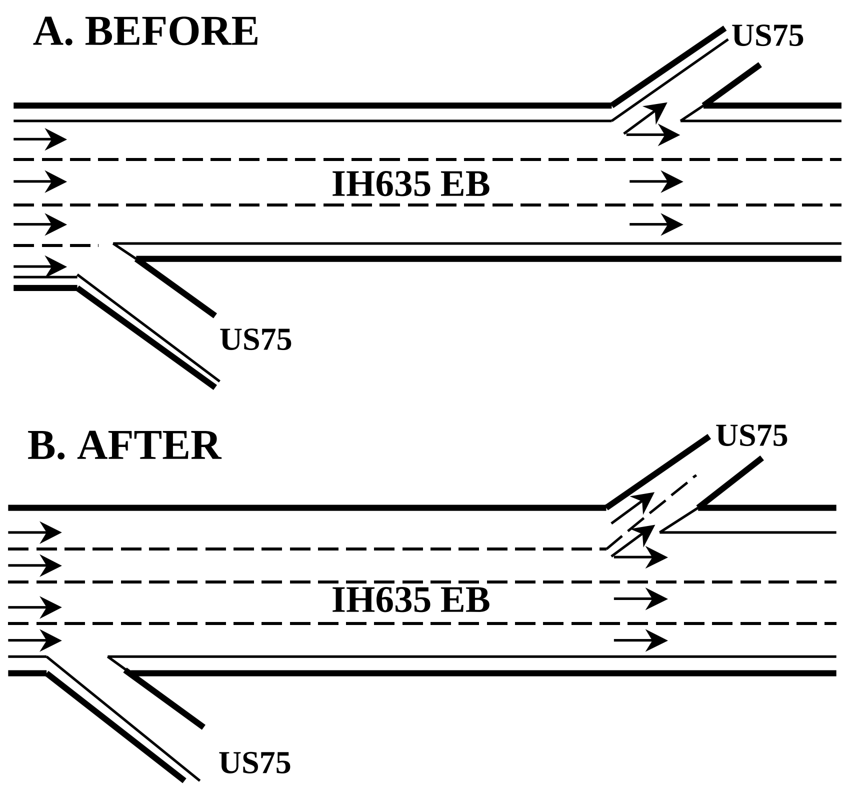

Figure 2. IH 635/US 75 Bottleneck Case Study Before and After Improvements *(10)*.

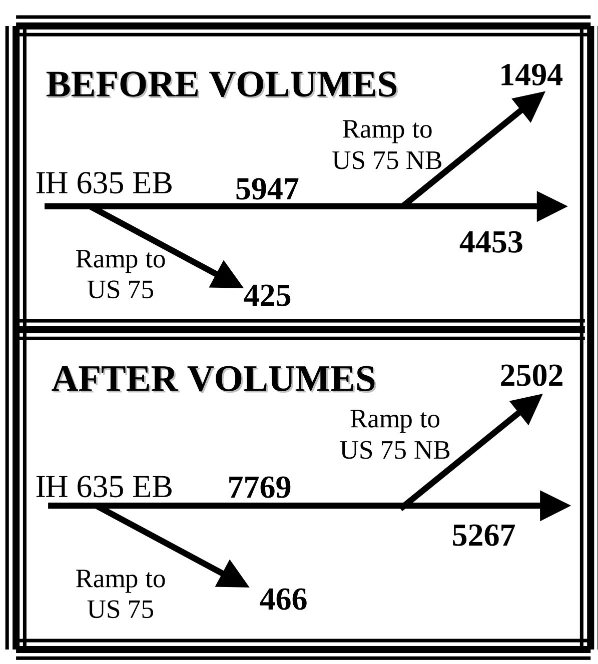

Figure 3. IH 635/US 75 Bottleneck Case Study Before and After Volumes *(10)*.

Northbound IH 35E Bottleneck Case Study

The second case study was a more complex bottleneck located along northbound IH 35E Stemmons Freeway near the Dallas central business district (CBD) (see Figure 4). The bottleneck location is located in the middle of the junction of northbound Stemmons, eastbound IH 30, westbound Woodall Rodgers, and northbound Dallas North Tollway (DNT), all major links in the CBD loop. The main problem with this section of freeway is that all of these movements are made up of a significant number of through commuters, meaning they are just traveling through this area on their way to and from work. This through traffic creates a large demand on the system at this one junction point. Further, at the downstream end of the bottleneck section, there is a heavy exit to the DNT. In summary, there are three high-volume approaches to the bottleneck with multiple heavy points of egress, creating a saturated freeway section with multiple points of conflict and vehicle interaction.

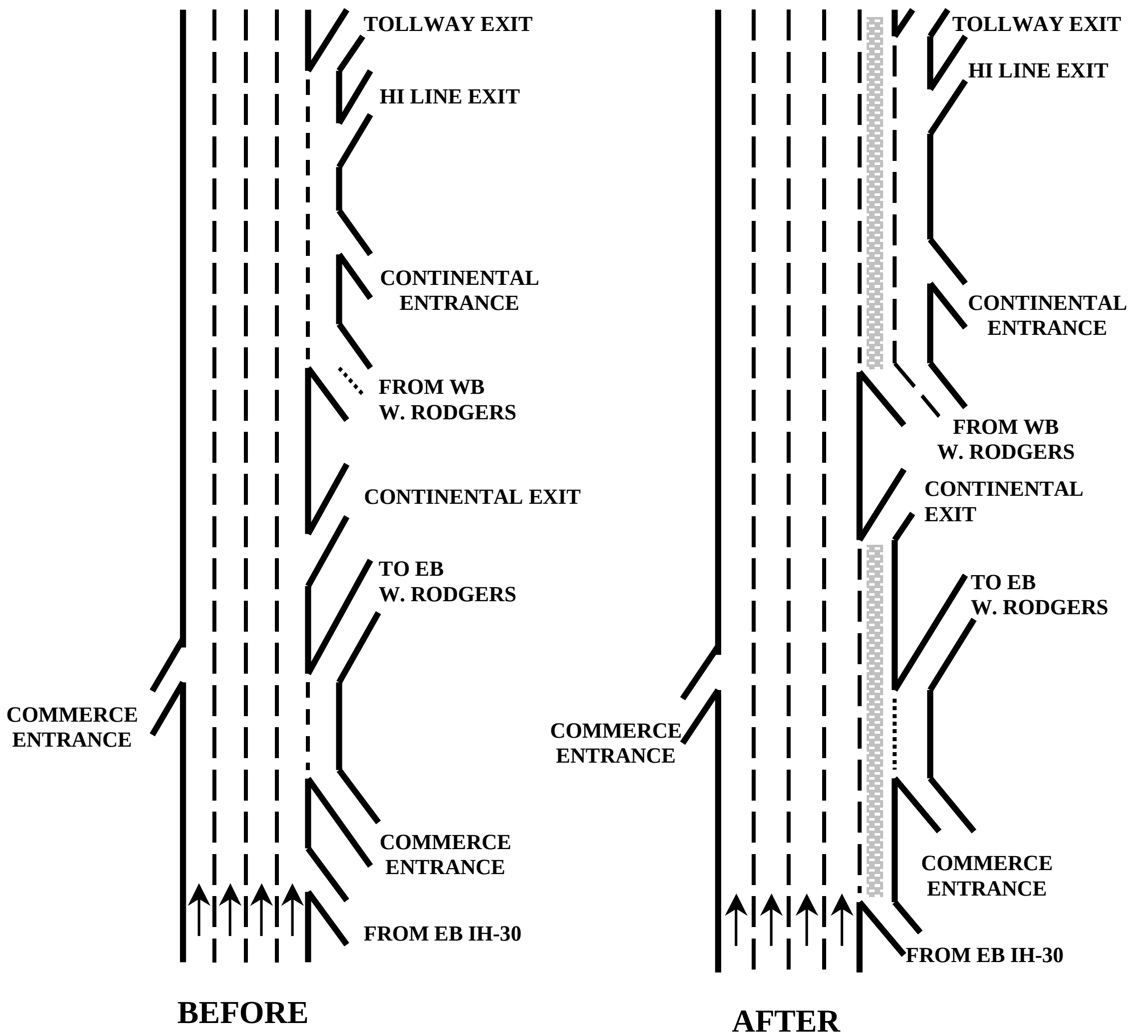

Figure 4. Northbound IH 35E Stemmons Freeway Bottleneck Improvement *(10)*.

Planners intended to remove the bottleneck by adding a lane from the eastbound IH 30 entrance ramp to the Continental exit ramp, and then adding another lane from the westbound Woodall Rodgers entrance ramp to the DNT exit ramp. The primary benefits of these additions were improvements in operation from eastbound IH 30 and westbound Woodall Rodgers. Where the eastbound IH 30 entrance was forced to merge before, it would be given its own lane, and the same improvement was made to the Woodall Rodgers entrance ramp. This type of improvement basically served merging and diverging operations but did not create new capacity for through volume. So, the improvement made operations from IH 30 to downtown, from Woodall Rodgers, and to the DNT smoother and safer but did not significantly increase the overall through volume.

The methodology used for determining benefits for this bottleneck improvement was to look at speeds and volumes for the before and after cases. In most cases, the speeds changed very little, but volumes increased in almost every case. This result can be explained by the nature of the improvement (adding auxiliary lanes or short sections in strategic places) and by the fact that there was sufficient latent demand to "fill in the gaps" created by the new capacity. The problem with determining appropriate benefits was that the latent demand increased the volume that in turn kept speeds from increasing. There was obviously some benefit being provided to those drivers that either were using a different facility before the improvement or were waiting in queues on the freeway. A methodology for assigning some monetary value to that benefit, or to determine whether or not this is possible, was the focus of this particular bottleneck case study.

Table 6, which represents each of the four freeway approaches, contains the before and after measures of effectiveness (MOEs) for the IH 35E bottleneck project. Again, it is important to note that this improvement was primarily intended to improve operations on the eastbound IH 30 and Woodall Rodgers approaches. Most importantly in the table are the values indicated for before and after speeds and volumes for each approach. Traditionally, TTI researchers measure before speed and estimate the after speed. The changes in these speeds would then be used for each section to estimate the benefit and to compare the benefit to the estimated cost. TTI researchers expected that all approaches and IH 35E would be improved. The actual result was that volumes went up on all segments, but speeds only went up on two of the approaches. Therefore, it is more appropriate to assign benefits based on the increased volumes.

The real problem is that speed, or travel time, can be used to determine delay savings, which can be converted to a monetary benefit. In cases where there is sufficient latent demand that speeds do not increase through the bottleneck (but the motorists who could not get through before the improvement are deriving some benefit), the problem is how to assess the level of benefit.

One option is to assume some before speed (be it sitting in queue or on an arterial) for the motorists who were able to use the facility after the improvement was made. If you assume that the motorists were sitting still, then a benefit can be assessed based on the after-improvement average speed and the additional volume.

Another option would be to use a different MOE that accounts for both speed and volume. One MOE that is available is "throughput", which is simply the product of speed and volume. The problem with using this MOE is that it is not easily converted to monetary benefits.

Table 6. Northbound IH 35E Before and After Evaluation: Morning Peak Period (*10*).

Roadway	Measure of Effectiveness	Before (1/96)	After (3/97)	Percent Change	Monetary Benefit
NB IH 35E to Stemmons	Average Speed (mph)	22	22	0.0%	-$621,335
	Volume (vehicles)	9,266	10,101	9.0%	
	Throughput (veh-mph)	203,850	222,200	9.0%	
EB IH 30 to Stemmons	Average Speed (mph)	41	39	-4.9%	$1,378,065
	Volume (vehicles)	5,429	6,902	27.1%	
	Throughput (veh-mph)	222,600	269,200	20.9%	
WB IH 30 to Stemmons	Average Speed (mph)	25	28	12.0%	$2,029,555
	Volume (vehicles)	8,335	8,393	0.7%	
	Throughput (veh-mph)	208,375	235,000	12.8%	
W. Rodgers to Stemmons	Average Speed (mph)	32	42	31.3%	$3,504,085
	Volume (vehicles)	8,367	9,249	10.5%	
	Throughput (veh-mph)	267,700	388,450	45.1%	

For examples of the merits of using an aggregate MOE, Table 6 reports throughput in vehicle distance per hour. Throughput captures any improvement in speed but also includes the new latent demand. Throughput may capture the capacity benefits; however, it is difficult to determine a monetary value. In order to calculate a monetary benefit, researchers estimated the improvement in speed for the traffic diverted from the arterial system to the adjoining freeway system.

The far right column of Table 6 provides the monetary benefits, estimated for both existing and diverted traffic, which resulted from bottleneck improvement project. To arrive at a monetary benefit, researchers used a value of $14.97 per hour of vehicle delay, 250 weekdays per year, a discount rate of 4 percent, and a project life of 10 years. Each of the freeways entering the bottleneck experienced a net positive benefit with the exception of northbound IH 35E to Stemmons, which had a disbenefit of $621,335. Overall, the estimated benefits were $6,290,370 and, with a construction cost of $130,000, the calculated benefit-to-cost ratio was 48 to 1.

3.2 CORRELATING DRIVER STRESS AND TRAFFIC CONGESTION

Analysts typically evaluate improvements at freeway bottlenecks based on operational, environmental, and safety benefits such as reduced travel time, greater throughput, less fuel consumption, lowered emissions, and decreased crash rates. These variables can then be translated into a monetary benefit by assigning cost values to time, fuel, and crashes (i.e., property damage only, injury, and fatal). A number of organizations, including the National Safety Council (NSC), produce yearly cost values for these parameters accounting for variables such as inflation.

The correlation between driver stress and traffic congestion has not received as much attention and has been difficult to quantify. Stress effects vary widely between people and are difficult to measure. The following subsections provide some additional information augmenting that presented in Chapter 2 regarding the relationship between driver stress and traffic congestion. Specifically, the information will attempt to validate the focus groups' contention and researchers' belief that the presence of congestion contributes to higher stress levels in most individuals.

3.2.1 Minnesota Department of Transportation Statewide Congestion Survey

The Minnesota Department of Transportation (Mn/DOT) released a report entitled *Congestion 2000* in February of 2001 *(14)*. The report presents the findings from an effort to understand the Minnesota citizens' attitudes toward congestion. Mn/DOT conducted focus groups throughout the state in both urban and rural locations. The information gleaned from the focus groups was valuable, but not statistically valid, and therefore Mn/DOT planned a quantitative telephone survey. The focus group information was the basis for question development in this follow-up telephone survey. This approach was similar to the one TTI researchers used in this project.

A total of 800 interviews (50 percent urban / 50 percent rural) were completed with a random household sample. A sample size of 800 provided for a sampling error of +/- 3.5 percent at 95 percent confidence level. A few of the key findings related to the relationship between driver stress and traffic congestion were the following:

- Respondents rated "managing traffic and removing bottlenecks" as the number one short-term transportation priority.
- Sixty-six percent of respondents indicated that added stress associated with traffic congestion was more difficult to deal with than the added time of a commute.

3.2.2 Cornell Study of Bus Driver Job Stress

During the early 1990s researchers at the Cornell and Stockholm (Sweden) Universities performed studies evaluating the stress implications of urban bus drivers *(15)*. Epidemiological, psychophysiological, and survey data all converged on the conclusion that driving a bus in an urban area was highly stressful and posed serious health risks. The study pointed to the toxic combination of high-pressure workload demands that include physical and psychosocial stressors, a low sense of control over factors affecting the job, and a high degree of social isolation on the job for producing a powerful multiplicative and negative effect on health.

Cornell researchers found that physical stressors included traffic congestion, long periods of sitting, heat, overcrowding, and noise. The psychosocial stressors included pressure to be timely, which were frustrated by the need to drive safely and provide accurate passenger information.

Having identified major stressors on bus drivers' health, Stockholm researchers designed an intervention study to determine whether stress could be reduced. The study used a multifaceted approach, including questionnaires, objective observations, interviews, and psychosocial protocols of 47 drivers to assess health before and after the intervention. The intervention reduced traffic congestion, driving impediments, and time pressures by regulating that private vehicles give way to buses, broadening roads in problem areas, and changing routes to avoid sharp turns and "bottlenecks," extending separate bus lanes, reducing the number of bus stops, automating some traffic lights to turn green for oncoming buses, and improving routes.

Drivers who participated in the study reported reduced stress and lighter workload. Furthermore, drivers used significantly fewer medications to cope with stress, showed fewer psychosomatic symptoms, and had lower blood pressure and heart rates than before the intervention.

3.2.3 Massachusetts Institute of Technology Driver Stress Study

The Massachusetts Institute of Technology (MIT) recently conducted a study to demonstrate how pattern recognition techniques can detect driver stress *(16)*. MIT utilized a car equipped with four physiological sensors—electromyogram, electrocardiogram, galvanic skin response, and respiration through chest cavity expansion—to measure stress during natural driving situations. MIT designed the route to simulate a work commute. The situations on the route included:

1. beginning stationary period,
2. parking garage exit,
3. city road 1,
4. toll booth 1,
5. highway driving period 1,
6. toll booth 2,
7. exit ramp turnaround,
8. toll booth 3,
9. highway driving period 2,
10. two lane merge,
11. toll booth 4,
12. bridge crossing,
13. city road 2,
14. parking garage entry, and
15. end stationary period.

MIT analyzed the data from the physiological sensors and it revealed the following stress ratings:

- VERY HIGH: exit ramp turnaround and two lane merge;
- HIGH: city road (1 and 2) and bridge crossing;
- NEUTRAL: toll booth (1 to 4), highway driving period (1 and 2); and
- LOW: beginning and end stationary periods and parking garage exit and entry.

All three of the studies cited previously in this section seem to support the relationship that traffic congestion contributes to higher driver stress levels. It is important to establish this finding in order to support the hypothesis that improvements at freeway bottleneck locations that lead to a reduction in traffic congestion in turn contribute to relief in driver stress and frustration.

3.3 RESULTS OF BOTTLENECK ASSESSMENTS

This section summarizes the results of the assessment of two bottleneck improvement projects in the Dallas area. The first subsection outlines a bottleneck project at the interchange of Spur 345 with US 75. The second subsection discusses a bottleneck project proposed near the interchange of Loop 12 and IH 30 and a survey of driver stress for the "before" case. Researchers attempted to utilize two methods to assess the effectiveness of the improvements at these locations:

1. collection of traditional before and after operational data (i.e., volumes, speed/travel times, and queue lengths; and
2. use of the *Dallas Morning News* (DMN) web site (http://www.dallasnews.com) to obtain commuter feedback.

3.3.1 Spur 345/US 75 Bottleneck Improvement Results

This subsection outlines the assessment of the bottleneck improvement project at the interchange of Spur 345 (Woodall Rodgers) with US 75 on the northeast corner of the Dallas CBD.

Description of Bottleneck Improvement

The TxDOT Dallas District made improvements to the ramp connection from eastbound Woodall Rodgers to northbound US 75, striping it from a one-lane to a two-lane connection. Prior to the improvement and during the reconstruction of US 75, severe congestion was occurring much of the day due to the one-lane connection to northbound US 75; congestion and queue jumping were heaviest during the evening peak period. Eastbound Woodall Rodgers consists of four main lanes approaching the connections to US 75 and IH 45. The two outside lanes connect to southbound IH 45. Before the improvement, the middle inside lane connected to the northbound frontage road of US 75 and Hall Street, and the inside main lane connected to US 75 (prior to US 75 reconstruction both inside lanes had connected to the northbound main lanes of US 75). Part of the construction project had added a new ramp from Routh Street that provided a connection to northbound US 75 from the CBD. Before the recent improvement, this ramp became the inside main lane of northbound US 75, but this ramp originally had been designed to be a merge. The top portion of Figure 5, labeled "BEFORE," shows the general layout of the lanes before the improvements.

To eliminate the severe congestion, TxDOT again configured the connection to northbound US 75 for two-lane operation. In the improvement case, the inside lane on Woodall Rodgers fed the inside northbound main lane, and the inside middle lane on Woodall Rodgers became an option lane to US 75 or the frontage road to Hall Street. TxDOT changed the ramp from Routh Street to northbound US 75 to a left side merge from a lane addition. The bottom portion of Figure 5, labeled "AFTER," shows the general layout of the lanes after the improvements. The evening peak hour (4:30 to 5:30 pm) volumes collected both before and after are also shown in Figure 5.

Operational Benefits

Table 7 shows the morning peak hour, evening peak hour, and daily volumes collected by TTI before and after the improvement to the northbound connection to US 75. TTI used automatic tube counters to collect the before data in February 2000, shortly after TxDOT completed the reconstruction of US 75 and opened the new ramp from Routh. TTI collected the after data at the same locations in June 2001 a few weeks after TxDOT implemented the bottleneck improvement.

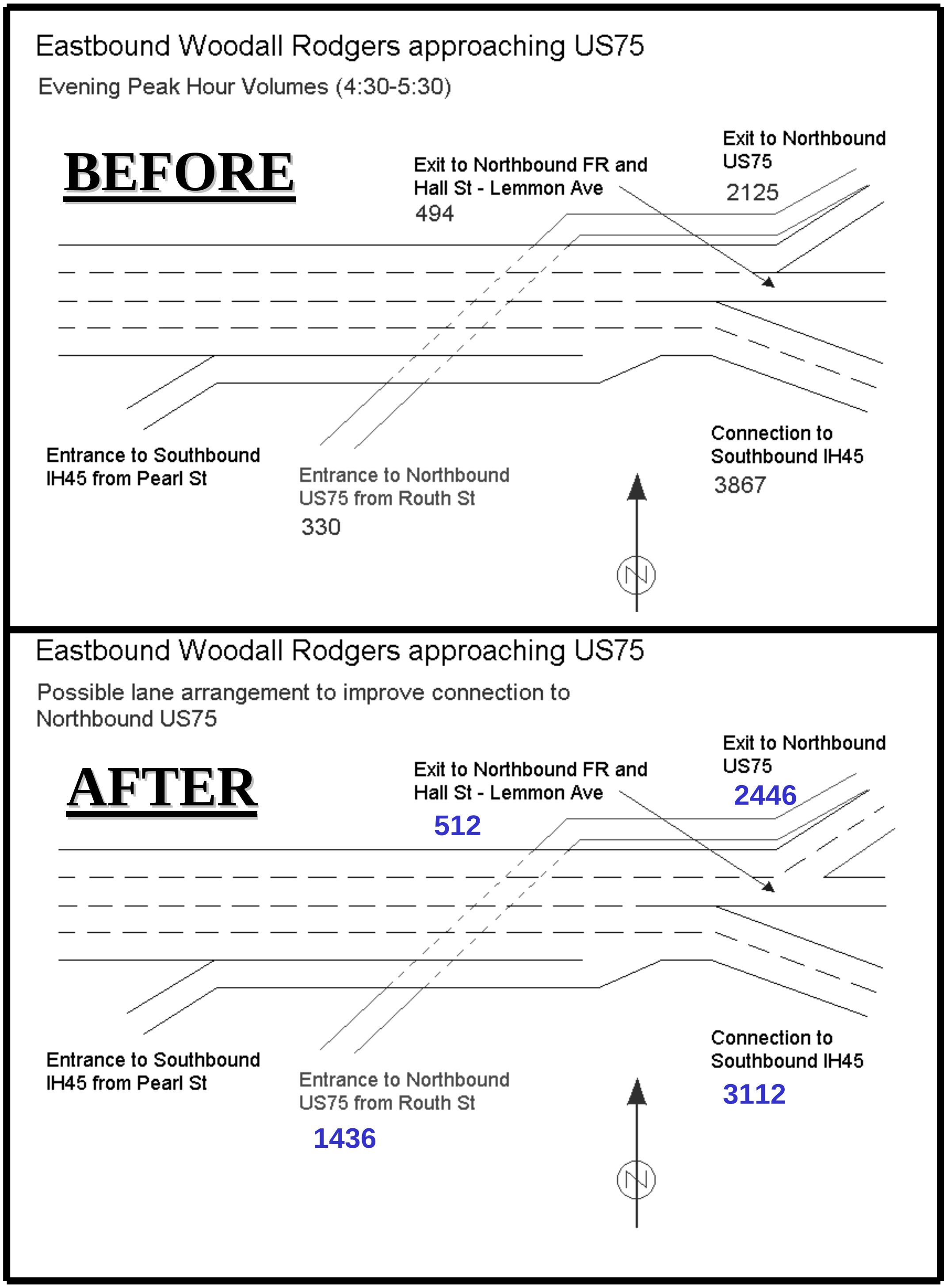

Figure 5. Before and After Spur 345/US 75 Bottleneck Improvement.

Table 7. Eastbound Woodall Rodgers at US 75 Volumes Before and After Improvements.

Count Location		Morning Peak Hour	Evening Peak Hour	Daily Volume
A. Woodall Rodgers Connection to Northbound US 75	Before	1998	2125	35,368
	After	2218	2446	40,307
B. Woodall Rodgers Exit to Hall Street	Before	782	494	7807
	After	686	512	7042
C. Woodall Rodgers Connection to Southbound IH 45	Before	1228	3867	37,550
	After	1346	3112	37,559
D. Routh Entrance to Northbound US 75	Before	59	330	2644
	After	156	1436	7688

The volume on the northbound connection increased as expected throughout the day. The after peak hour volumes are greater than the capacity of a single lane, which shows that the two-lane connection was needed. The increase in the daily volume to northbound US 75 is larger than expected. TTI may have collected the before data too soon after the reconstruction of US 75, and the large increase in daily traffic may be due to traffic changing route to US 75 and not just growth in traffic. The volume of vehicles exiting to Hall Street decreased as expected. TTI did not expect the volume to southbound IH 45 to change, and the decrease in the evening peak hour is likely due to an increase in volume from southbound US 75 and congestion in the weaving area on IH 45 between Woodall Rodgers and IH 30. The Routh Street entrance had a large increase in traffic. When TTI collected the before data the ramp had only recently been opened. However, the high evening peak hour volume does indicate that the on ramp is not having operational problems due to being changed from a lane addition to a left side merge.

The volume alone does not indicate an operational improvement for traffic on the connection to US 75. During the before condition the traffic operated in a stop-and-go behavior throughout the morning and evening peak periods. The average speed in the evening peak hour was about 15 mph with queues in the inside lanes extending to about Field Street (0.75 mile). Queue jumping was also a chronic problem with vehicles disrupting traffic in both the adjacent outer lane and the exit-only lane to Hall Street by merging into the inside lane at the last possible point. After TxDOT restriped the connection there were no longer any traffic queues in the inside lanes, and vehicles maintained a free flow speed of 55 mph throughout the peak periods.

Stress-Related Benefits

Researchers designed a survey instrument to gather feedback from drivers regarding the Woodall Rodgers/US 75 bottleneck improvement. The DMN web site also hosted this survey for a one-month period beginning on July 30, 2001. This was about a two-month lag between the implementation of the bottleneck improvement. The survey is shown below:

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1. Do you regularly travel eastbound on Woodall Rogers to northbound US 75 Central Expressway during the peak hours?

YES NO

If YES, please continue to Question 2 and complete the rest of the survey.

The Texas Department of Transportation recently (May 2001) implemented improvements at this location and is requesting driver feedback as part of an ongoing research project.

2. Have you observed aggressive (rude, discourteous) driving while driving on this section of roadway?

Never Occasionally Often Very Often

3. Check all of the behaviors that you have witnessed at this location:

- ❑ Drivers preventing others from merging
- ❑ Cutting across solid white lines
- ❑ Speeding past the traffic backup and cutting in at the last possible second
- ❑ Using the shoulder to pass
- ❑ Tailgating
- ❑ Horn-honking
- ❑ Rude gestures
- ❑ Others: ____

4. Have the improvements at this location reduced the frequency and seriousness of these behaviors?

Not at All Somewhat Noticeably Very Noticeably

5. Have the improvements at this location reduced your personal stress level?

Not at All Somewhat Noticeably Very Noticeably

6. Have you saved time on your commute traveling through this location since the improvement was implemented?

Not at All Somewhat Noticeably Very Noticeably

Researchers received a total of 225 responses. Researchers eliminated respondents who answered "NO" to the initial survey question "Do you regularly travel eastbound on Woodall Rogers to northbound US 75 Central Expressway during the peak hours?" from further consideration. This reduced the total responses included in the analysis to 154. The following subsections present the results for each of the individual questions, excluding Question 1.

<u>Question 2: Have you observed aggressive (rude, discourteous) driving while driving on this section of roadway?</u>

Response	Frequency (%)
Never	4.5
Occasionally	22.1
Often	26.6
Very Often	46.8

The results of this question revealed that almost all (95.5 percent) participants have observed aggressive driving on eastbound Woodall Rodgers near US 75. Furthermore, almost three in every four respondents indicated they observed these behaviors on a regular basis (often or very often).

<u>Question 3: Check all of the behaviors that you have witnessed at this location?</u>

Behavior	% Yes
Drivers preventing others from merging	86.4
Cutting across solid white lines	90.9
Speeding past the traffic backup and cutting in at the last possible second	89.6
Using the shoulder to pass	52.6
Tailgating	70.1
Horn-honking	49.4
Rude Gestures	58.4

A majority of respondents witnesses all of the aggressive behaviors listed in the survey except horn-honking (49.4 percent). This seems to mirror the Question 2 results that showed that a significant percentage of drivers have frequently witnessed aggressive driving.

<u>Questions 4, 5, and 6: Have the improvements at this location reduced the frequency and seriousness of the behaviors witnessed, your personal stress level, and your commute time</u>?

Response	Behavior	Stress Level	Commute Time
Not at All	40.9	56.5	47.4
Somewhat	45.5	32.5	37.0
Noticeably	11.1	10.4	13.0
Very Noticeably	2.5	0.6	2.6

A majority of respondents perceived that the bottleneck improvements reduced the frequency and seriousness of aggressive driving and helped decrease their travel time. Only 43.5 percent of motorists sensed a reduced personal stress level as a result of the bottleneck improvement.

The following list provides a summary of the key findings from this survey.

- Almost three in four respondents observed aggressive behavior at this site often or very often.
- Close to 90 percent of respondents witnessed drivers preventing others from merging, cutting across solid white lines, and cutting in at the last second—all behaviors related to queue jumping.
- The improvements reduced the frequency and seriousness of aggressive behaviors (59.1 percent) more so than personal stress level (43.5 percent) or commute time (52.6 percent).

These survey findings correlate closely with the observed behaviors on the videotapes used to gather the before and after operational data. It should be noted that people from anywhere in the world could respond to this survey and no scientifically valid conclusions can be drawn. Due to the two-month lag time between the bottleneck improvement and the DMN online survey, many drivers may have forgotten the improvement referred to in the questions. Still, more than 50 percent acknowledged improved commute times, which in fact, have been achieved.

3.3.2 Northbound Loop 12/Interstate 30 Bottleneck Improvement Results

This subsection outlines the assessment of the northbound Loop 12 bottleneck improvement project in the vicinity of the IH 30 interchange in Dallas.

Description of Bottleneck Improvement

TxDOT converted an inside shoulder into a fourth lane in each direction on Loop 12 north of IH 30, for a distance of approximately two miles in the northbound direction and three miles in the southbound direction. However, field crews striped the new lane with an inside lane "pop-out" rather than a lane addition at a heavy entrance ramp (Singleton Boulevard) as intended. Researchers anticipated that TxDOT would implement the proposed striping during the time period of the research project. The research team proposed to test driver stress levels before the striping was corrected and again afterward. The restriping was not accomplished during the project schedule, so only "before" information is available from driver surveys. Although TTI has not collected the after operational data, it is obvious that traffic conditions have improved with the addition of the fourth lane on Loop 12.

Stress-Related Benefits

Researchers designed a survey instrument to gather feedback from drivers regarding the northbound portion of the Loop 12 bottleneck improvement project. The survey instrument was posted on the *Dallas Morning News* web site beginning on November 30, 2000, and ending on January 11, 2001. Again, the survey data collected during this effort represents the before case because the correct striping of the northbound Loop 12 main lanes has not yet been completed.

TTI received a total of 258 responses from drivers who regularly traveled along Loop 12 near IH 30 during the peak periods. The following subsections present the results for each of the individual questions, excluding question one.

Question 2: How would you rate the stress level you experience while driving this section of roadway, on a scale of 1 to 10, with 10 being the worst stress?

Stress Ratings	
Response Category	Frequency (%)
Low (1 to 3)	7.8
Medium (4 to 7)	27.1
High (8 to 10)	65.1

Average stress rating = 7.7

The results of this question showed that over 90 percent of respondents rated their stress level at either medium or high level. Almost two in every three participants indicated a high stress level, with the average stress rating being calculated as 7.7 on the 10-point scale.

Question 3 (essay answer): What is the problem you experience, if there is one?

Not every participant answered this question; however, the range of responses seemed to fall into several broad categories including:

1. *Design*: the majority of responses related to the outdated and inefficient design of the Loop 12/Interstate 30 interchange;
2. *Congestion/Capacity*: a number of individuals expressed the idea that there are too many cars and not enough pavement to accommodate the travel demand during peak periods;
3. *Driver Behavior*: numerous respondents indicated that other drivers' aggressive and rude behavior, particularly use of left and right shoulders for passing, was a problem;
4. *Enforcement*: several participants cited a lack of enforcement by police as contributing to the overall problems; and
5. *Trucks*: several persons mentioned that a high presence of trucks (i.e., "eighteen wheelers") was a recurring problem in this area.

Question 4: Have you **experienced** rage or aggression of other motorists while driving on this section of roadway?

Response	Frequency (%)
Never	2.7
Occasionally	23.3
Often	32.2
Very Often	41.9

The results of this question revealed that almost all (97.3 percent) motorists surveyed experienced an act of rage or aggression while driving on northbound Loop 12 near IH 30. Furthermore, almost three in every four respondents indicated they experienced these behaviors on a regular basis (often or very often).

Question 5: Have you **expressed** rage or aggression while driving on Loop 12 near Interstate 30?

Response	Frequency (%)
Never	8.5
Occasionally	46.9
Often	22.5
Very Often	22.1

Over 90 percent of the survey participants admitted to expressing rage or aggression while driving on Loop 12 near IH 30. Almost 45 percent acknowledged that they expressed these behaviors on a regular basis (often or very often).

CHAPTER 4

EVALUATION OF USING PHOTOGRAMMETRY FOR INCIDENT CLEARANCE

4.1 USING PHOTOGRAMMETRY FOR INCIDENT INVESTIGATION

The benefits of rapid clearance of traffic incidents have been widely reported. For every minute saved in clearing the incident, an estimated four to five minutes of associated motorist delay are also saved *(17)*. Nationally, studies have estimated that 60 percent of congestion is caused by incidents that range from stalled vehicles to major crashes. Many transportation agencies have focused their incident management programs on reducing the impacts of incidents through quicker and more reliable detection techniques.

One area of incident management that traditionally has not received as much attention is the time required by response agencies, notably law enforcement, to complete on-scene investigations. Currently, law enforcement officers spend a considerable amount of time during an investigation of a traffic incident documenting evidence and measuring important scene characteristics. This component of the incident management process is starting to receive more consideration as both transportation and law enforcement agencies realize the significant motorist delays and safety problems created by major incidents. In several recent cases, transportation and law enforcement agencies have created partnerships to test innovative techniques for obtaining scene measurements that are designed to minimize the impact on traffic and the time it takes for roadways to re-open after an incident occurs. Over the last 10 years a number of studies have tested innovative techniques including Total Stations, Global Positioning System (GPS) mapping devices, laser measuring devices, and most recently close-range photogrammetry *(18,19,20,21)*.

Researchers, in cooperation with the project advisory committee, decided to evaluate photogrammetry for its potential in reducing the clearance time associated with traffic incidents. While studies have shown the benefits of some of the other techniques, notably Total Stations, it appears that photogrammetry has greater potential for reducing the time that roadways are closed or restricted due to investigations. To comprehend why photogrammetry has greater potential than some of the other techniques, several items must be understood:

- Total Stations, GPS mapping devices, and laser measuring devices must all be brought to the scene and set up to take the measurements while on the roadway. This process often involves an officer being dispatched to the scene, arriving, determining the incident requires a detailed investigation, and then notifying a trained officer (accident reconstructionist) to bring the equipment to the scene and perform the investigation. This process typically takes anywhere from 1.5 to more than 3 hours, depending on the travel time and complexity of the incident scene. The time for these devices also depends on the number and availability for use.
- Photogrammetry requires only one scale measurement at the scene (object of known scale is normally placed in the scene); all other measurements are performed back in the office.

- Advancements in computer processing speed, along with using consumer grade film or digital cameras for photography, have made photogrammetry feasible and affordable.
- Photographs are typically taken of all major crashes and, with some additional training, officers can take photographs that are compatible with the photogrammetry software.

4.1.1 Overview of Photogrammetry Basics

Photogrammetry is the technology of obtaining information (whether it be three-dimensional data or qualitative data) through the process of analyzing and interpreting photographs. Photogrammetry records objects with non-contact methods and calculates the real dimensions of objects within the image through photographic triangulation. Photogrammetric investigation of traffic incidents involves the responding officer(s) taking pictures of the scene in the field. Officers or technicians can then perform the measurement of vital incident data (i.e., skid marks, vehicle deformations, object locations, etc.) back in the office at a later time using a personal computer equipped with specialized software designed to make measurements from the imported photographs. An officer back in the office imports two or more photographs (scanned analog photographs or digital camera images) into the software program for measurement.

This subsection provides some of the basic information on the measurement theory behind photogrammetry, with an emphasis on crash investigation. Photogrammetry is not limited to traditional film cameras. Officers can use video cameras, still video cameras, digital cameras, and normal consumer 35-millimeter cameras to perform three-dimensional (3-D) measurement using photogrammetric techniques. The use of video or photography also allows one to document other traits of the object such as surface color, texture, and general condition. A high-speed camera can be used to capture an object in motion and hence photogrammetry can be used for vibrating and moving objects unlike most other 3-D measurement technologies.

Using photographs of the object being measured, one can make as many or as few measurements as necessary. At a later date, if more extensive measurements are needed, officers can reuse the photographs to get measurements without revisiting the site or object. There are three central tenets for obtaining measurements from photographic images *(22)*:

1. a ray of light that comes from some point through the focal node of the lens of a camera and hits the film can be described by a perfectly straight line;
2. knowing the camera position at the time of exposure so that where the ray of light hit the film can be used to calculate the equation of that ray of light in 3-D; and
3. each point that is to be measured needs to be visible in at least two photographs, and preferably in three or more. These points are used to compute light ray positions and their intersections for determining positions in 3-D space.

There are a number of factors that can cause the above tenets to be false or partially incorrect:

1. *Air effects*: particles and turbulence in the air between the object and the camera bend the light ray.
2. *Lens distortion*: an imperfect camera lens distorts the path of the light ray. There are two major types of distortion—radial and tangential. Variations in angular magnification with

angle of incidence are interpreted as radial lens distortion. Tangential lens distortion is the displacement of a point in the image caused by the misalignment of lens components.

3. *Imperfect imaging*: the film or imaging sensor (a charged couple device in a video camera, perhaps) does not image the light ray perfectly (it blurs or shifts it).
4. *Imperfect point location*: the precise location of the imaging surface (film or charged couple device) relative to the camera at the time of the exposure is not known.
5. *Equipment changes*: the camera characteristics, such as focal length and lens distortion, change from photograph to photograph thereby interfering with the repeatability of the light ray measurement.

In most cases, the effects of these factors are negligible in the investigation of an incident scene. The factors are negligible because: (1) the photos are taken at close range, and (2) the camera equipment used is calibrated, maintained well, and has high-quality resolution.

At this time photogrammetry has not been widely validated for its effectiveness as an incident management tool. This research attempts to document the results of several law enforcement agencies in the United States that have used photogrammetry for investigation of incidents. Figure 6 shows an example of an officer using photogrammetry at an incident scene.

4.2 INCIDENT TERMINOLOGY AND TIMELINE

The research team contacted a number of different law enforcement agencies throughout the country about providing data for the evaluation of photogrammetry. Researchers included the incident timeline (Figure 7) and the associated definitions for the terms comprising the incident timeline with the initial correspondence. The research team included this information so that law enforcement personnel had a common understanding up front about the types of data being requested.

Figure 6. Using Photogrammetry for Incident Investigation *(23)*.

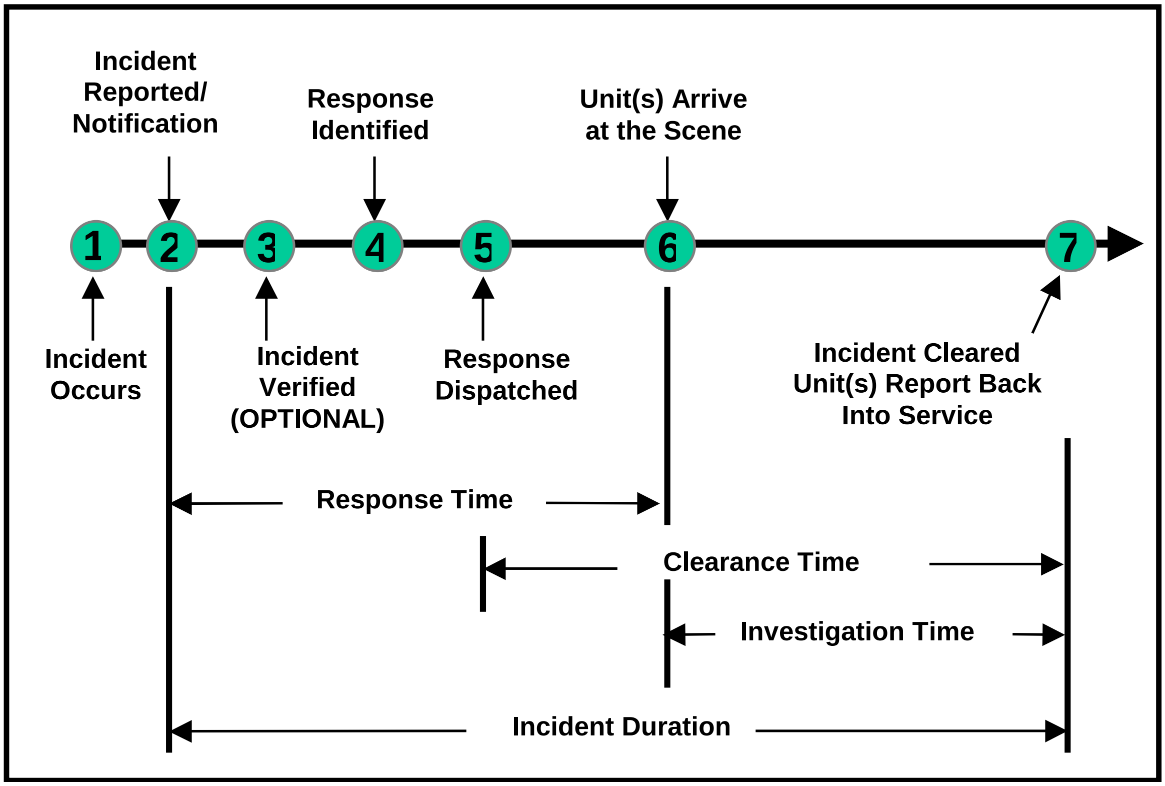

Figure 7. Incident Timeline.

1. *Incident Occurs*: traffic-related incident (crash, debris in road, stalled vehicle, etc.) occurs.
2. *Incident Reported*: authorities notified of incident mostly via 911 calls from wireless phones.
3. *Incident Verification*: response authorities confirm the existence of the incident (optional).
4. *Response Identified*: dispatcher assigns the priority, personnel, equipment, and other necessary resources for the incident response.
5. *Response Dispatched*: dispatcher notifies, via radio, mobile data terminal, etc., appropriate response personnel of the incident.
6. *Unit(s) Arrival on Scene*: response vehicles and personnel arrive at the incident location.
7. *Incident Cleared*: the incident scene is cleared (i.e., no lanes are blocked)—this may or may not correspond to the responding unit(s) reporting back into service.

- *Response Time* = the difference between the time the unit(s) arrive on scene and time the incident was reported.

- *Clearance Time* = the difference between the time the incident is cleared and time the response was dispatched.

- *Investigation Time* = the difference between the time the incident is cleared and time the unit(s) arrived on scene.

- *Incident Duration* = the difference between the time the incident is cleared and time the incident was first reported.

4.3 RESULTS FROM AGENCIES USING PHOTOGRAMMETRY

TTI researchers contacted law enforcement agencies throughout the country that are currently using photogrammetry to expedite their incident clearance activities. The research team received information and incident clearance data from four agencies regarding their experiences using photogrammetry. The following subsections present the results for the Dallas Country Sheriff Department, Chattanooga Police Department, and Utah Highway Patrol.

4.3.1 Dallas County Sheriff Department

Dallas County is located in the north-central portion of the state of Texas and encompasses the city of Dallas and several major suburbs such as Garland, Grand Prairie, Irving, and Mesquite. According to the 2000 Census, Dallas County had a population over 2.2 million *(24)*.

The Dallas Country Sheriff Department (DCSD) is currently responsible for patrolling approximately 33 miles of freeways in the southern portion of Dallas County under a program initiated in October of 2000. Specifically, DCSD Traffic Division deputies are responsible for patrolling parts of IH 20, IH 35E, IH 45, and US 67 in the cities of DeSoto, Cedar Hill, Duncanville, Glenn Heights, Hutchins, Lancaster, and Wilmer. The DCSD designed the program, which began as a series of rush-hour patrols, to move patrol officers in these seven cities from the freeways back to the local neighborhoods. An article in the June 22, 2001, edition of the *Dallas Morning News* provided some details about the use of photogrammetry by the DCSD *(25)*. The research team received additional information from the DCSD through telephone interviews, dialogue at a Dallas Traffic Management Team (TMT) meeting, and via exchange of incident clearance data files from their computer aided dispatch (CAD) system.

Evaluation of Photogrammetry in Dallas

Beginning in November of 2000, DCSD started to use photogrammetry for investigation of traffic incidents in addition to the traditional roller-tape measurement technique. The DCSD implemented the photogrammetry program in order to reduce the average incident clearance time. Researchers conducted a telephone conversation with Captain Gary Lindsey, Traffic Division Supervisor, which revealed the following important information about the DCSD photogrammetry program:

- DCSD deputies received a week-long training course on photogrammetry from DeChant Consulting Services (DCS).
- DCSD deputies use PhotoModeler Pro Software (http://www.photomeasure.com) to get measurements from incident scene photographs.
- DCSD has a goal of an overall average of 20 minutes for the clearance of all incidents to which they respond.
- DCSD deputies estimate that it takes 15 minutes to take the necessary scene photographs. Deputies also take a reference point so that they can return to the scene if necessary at a later time to make additional measurements.
- One difficulty with using photogrammetry has been transferring the data from the PhotoModeler software to a drafting software package to produce a scale drawing.

- DCSD has policies and target clearance times for all types of accidents and does a debriefing to discuss what happened if a target clearance time is not met.
- DCSD is using photogrammetry primarily on minor accident investigations.
- DCSD stores the pictures taken from the incident scene on a CD-ROM. Capt. Lindsey estimated that approximately 80 percent of the incidents are archived and the other 20 percent are processed using PhotoModeler and then a scale drawing with the drafting software.
- DCSD's overall philosophy is to reduce the clearance time, even if it means a lot more work back in the office. This philosophy has led to dramatic reduction in secondary accidents.

TTI researchers requested that the DCSD extract data from their CAD system in order to evaluate the effectiveness of using photogrammetry for incident clearance. The research team received CAD data for 34 incidents the DCSD responded to during the February to May 2001 time period. Table 8 lists these incidents including the following data:

- call date,
- time call received,
- time call dispatched,
- time deputy arrived,
- response time,
- freeway clearance time,
- freeway blockage time,
- deputy clear time,
- total time, and
- average time per call.

The text notes at the bottom of Table 8 provide important information including definitions of some of the DCSD terminology such as response, clearance, blockage, and clear times. The DCSD classified approximately half (18) of the 34 incidents as major, and the remainder as minor. The basic distinction between a major and minor incident is whether or not any of the parties involved sustain injuries. Of the incidents in Table 8, 53 percent occurred on IH 35E, 24 percent on IH 45, 20 percent on IH 20, and 3 percent on US 67.

Figure 8 illustrates the clearance times for each of the incidents. DCSD defines clearance time as the difference in time from when the deputy arrived on scene until there are no freeway lanes blocked. Researchers calculated the average clearance time for the 34 incidents to be 17 minutes 39 seconds, well below the goal of 20 minutes. In every incident, DCSD was able to open all freeway lanes in less than one hour. Figure 9 provides the blockage times for each of the incidents. DCSD defines blockage time as the total time there was any lane blockage on the freeway. This time is calculated from the time the call was received until the deputy advised there were no lanes blocked. Researchers calculated the average blockage time for the 34 incidents to be 22 minutes 38 seconds. Figure 10 shows the deputy clear times (a.k.a. incident duration) for each of the incidents. DCSD defines deputy clear time as the total time spent on the incident. Researchers calculated the average deputy clear time for the 34 incidents to be 26 minutes 31 seconds.

Table 8. Dallas County Sheriff Department Incident Clearance Data.

Call Date	Time Call Received[1]	Time Call Dispatched[1]	Time Deputy Arrived[1]	Response Time[2]	Response Time[3]	Freeway Clearance[4]	Freeway Blockage Time[5]	Deputy Clear Time[6]
02/10/01	15:26:00	15:35:00	15:54:00	0:28:36	0:19:03	0:07:39	0:26:42	0:36:15
02/13/01	7:59:00	8:01:00	8:16:00	0:16:59	0:15:06	0:00:37	0:15:43	0:17:36
02/15/01	10:37:00	10:42:00	10:42:00	0:05:33	0:00:10	0:13:57	0:14:07	0:19:30
02/18/01	17:22:00	17:25:00	17:37:00	0:14:56	0:11:50	0:33:52	0:45:42	0:48:48
02/23/01	12:13:00	12:13:00	12:19:00	0:05:55	0:06:40	0:34:25	0:41:05	0:40:20
03/01/01	6:39:00	6:39:00	6:39:00	0:00:00	0:00:00	0:26:38	0:26:38	0:26:38
03/02/01	7:28:00	7:30:00	7:32:00	0:03:50	0:02:09	0:54:35	0:56:44	0:58:25
03/05/01	11:48:00	11:47:00	12:09:00	0:21:22	0:22:11	0:06:12	0:28:23	0:27:34
03/06/01	12:32:00	12:36:00	12:41:00	0:09:36	0:05:50	0:00:15	0:06:05	0:09:51
03/08/01	18:28:00	18:34:00	18:46:00	0:17:52	0:12:42	0:23:56	0:36:38	0:41:48
03/08/01	19:13:00	19:13:00	19:13:00	0:00:00	0:00:00	0:47:42	0:47:42	0:47:42
03/11/01	10:55:00	10:57:00	11:01:00	0:06:25	0:04:29	0:02:21	0:06:50	0:08:46
03/14/01	13:09:00	13:09:00	13:09:00	0:00:00	0:00:00	0:00:19	0:00:19	0:00:19
03/17/01	16:10:00	16:10:00	16:10:00	0:00:00	0:00:00	0:07:29	0:07:29	0:07:29
03/19/01	15:53:00	15:55:00	16:03:00	0:10:31	0:08:23	0:04:34	0:12:57	0:15:05
03/22/01	14:26:00	14:28:00	14:35:00	0:08:59	0:06:34	0:50:53	0:57:27	0:59:52
04/04/01	7:18:00	7:20:00	7:21:00	0:02:56	0:00:58	0:30:19	0:31:17	0:33:15
04/11/01	5:46:00	5:46:00	5:46:00	0:00:00	0:00:00	0:43:06	0:43:06	0:43:06
04/11/01	5:48:00	5:48:00	5:48:00	0:00:00	0:00:00	0:55:46	0:55:46	0:55:46
04/15/01	16:26:00	16:27:00	16:49:00	0:23:17	0:22:11	0:00:56	0:23:07	0:24:13
04/17/01	15:32:00	15:32:00	15:32:00	0:00:03	0:00:00	0:39:50	0:39:50	0:39:53
04/23/01	8:12:00	8:15:00	8:27:00	0:15:23	0:12:32	0:15:41	0:28:13	0:31:04
04/23/01	13:11:00	13:15:00	13:27:00	0:16:06	0:11:49	0:01:43	0:13:32	0:17:49
04/26/01	7:49:00	7:53:00	8:00:00	0:11:05	0:06:51	0:00:27	0:07:18	0:11:32
05/01/01	10:13:00	10:13:00	10:13:00	0:00:00	0:00:00	0:02:00	0:02:00	0:02:00
05/15/01	12:01:00	12:04:00	12:13:00	0:12:22	0:00:00	0:02:40	0:02:40	0:15:02
05/17/01	15:15:00	15:15:00	15:29:00	0:13:52	0:00:00	0:07:02	0:07:02	0:20:54
05/17/01	20:10:00	20:15:00	20:18	0:08:13	0:00:00	0:26:47	0:26:47	0:35:00
05/19/01	15:08:00	15:09:00	15:14	0:05:50	0:00:00	0:00:29	0:00:29	0:06:19
05/19/01	16:41:00	16:42:00	16:50	0:08:45	0:00:00	0:02:23	0:02:23	0:11:08
05/21/01	11:05:00	11:09:00	11:15	0:10:33	0:00:00	0:03:02	0:03:02	0:13:35
05/21/01	19:51:00	19:54:00	19:54	0:03:19	0:00:00	0:26:28	0:26:28	0:29:47
05/24/01	12:39:00	12:40:00	12:44	0:04:13	0:00:00	0:01:31	0:01:31	0:05:44
05/24/01	15:01:00	15:05	15:16	0:14:54	0:00:00	0:24:31	0:24:31	0:39:25
TOTAL TIME				5:01:25	2:49:28	10:00:05	12:49:33	15:01:30
AVERAGE TIME PER CALL				0:08:52	0:04:59	0:17:39	0:22:38	0:26:31

Notes

1 Time Call Received, Time Call Dispatched, and Time Deputy Arrived are listed in 24 Hour Military Time.

2 Response Time is the difference in time from when the call was received by dispatch until the deputy arrived on scene.

3 Response Time is the difference in time from when the call was received by the deputy until the deputy arrived on scene.

4 Freeway Clearance is the difference in time from when the deputy arrived on scene until there are no freeway lanes blocked.

5 Freeway Blockage Time is the total time there was any lane blockage. This is calculated from the time the call was received until the deputy advised there were no lanes blocked.

6 Deputy Clear Time is the total time spent on the incident.

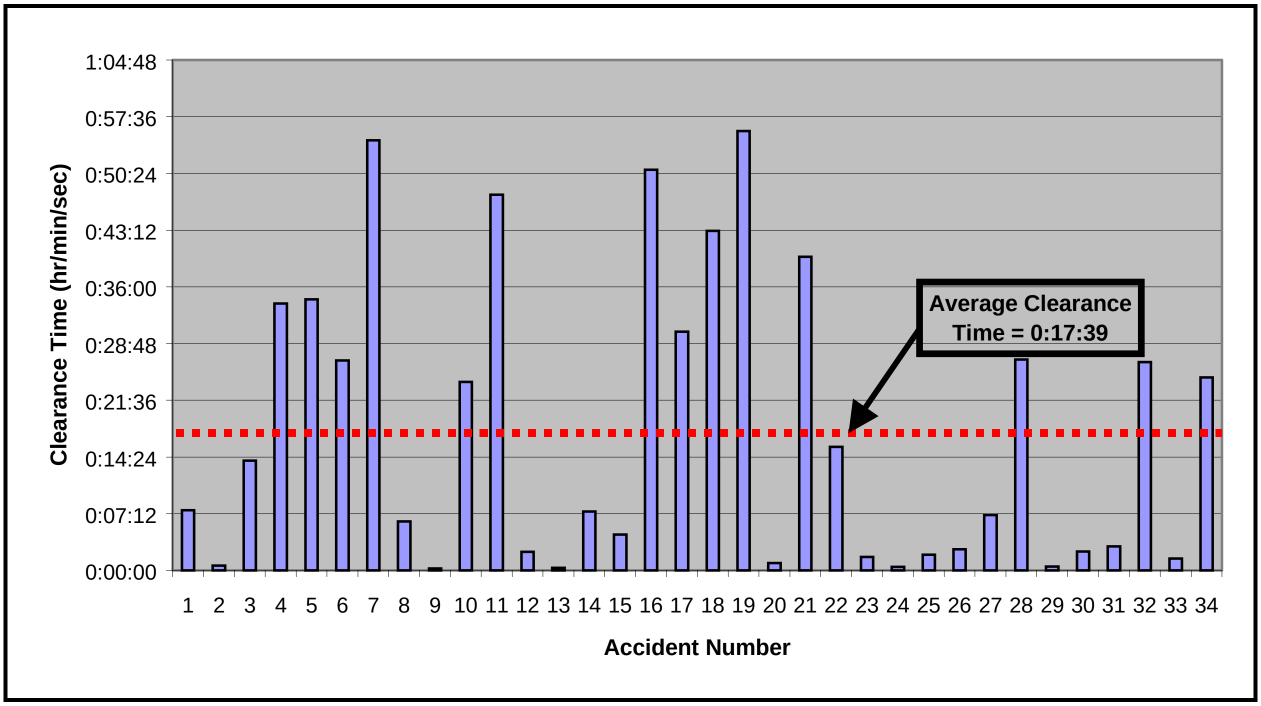

Figure 8. Dallas County Sheriff Department Incident Clearance Times.

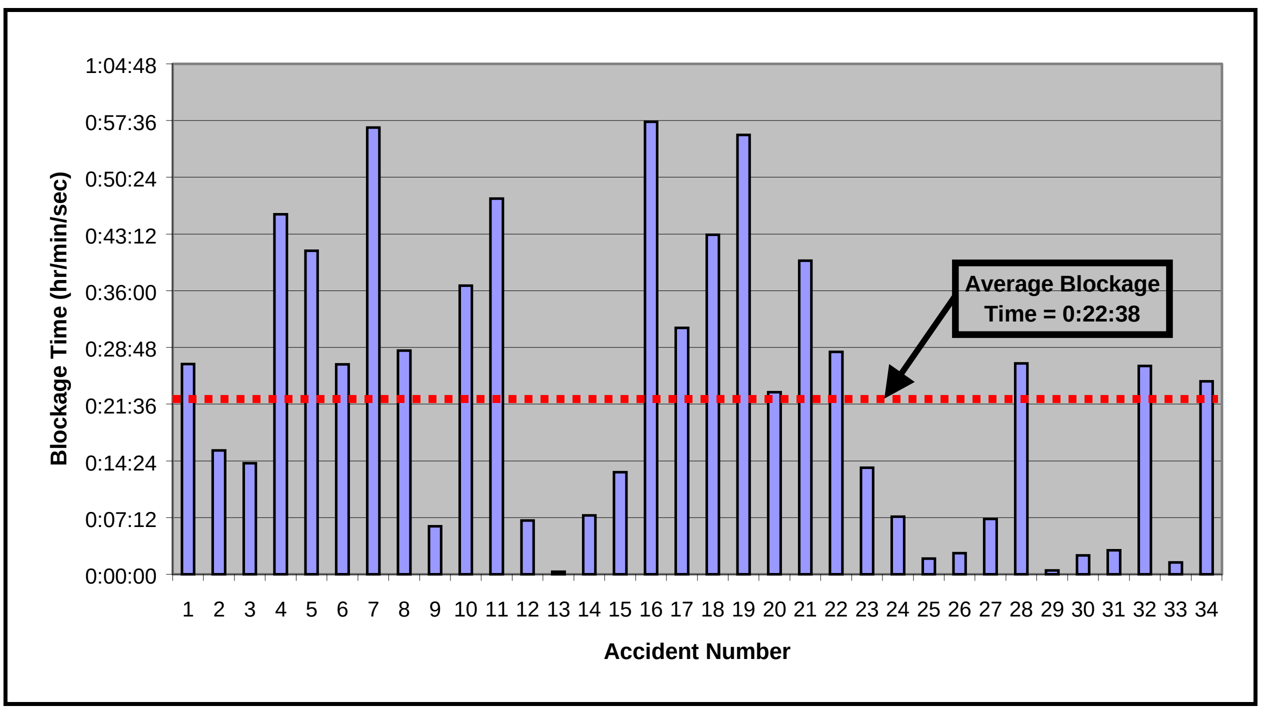

Figure 9. Dallas County Sheriff Department Incident Blockage Times.

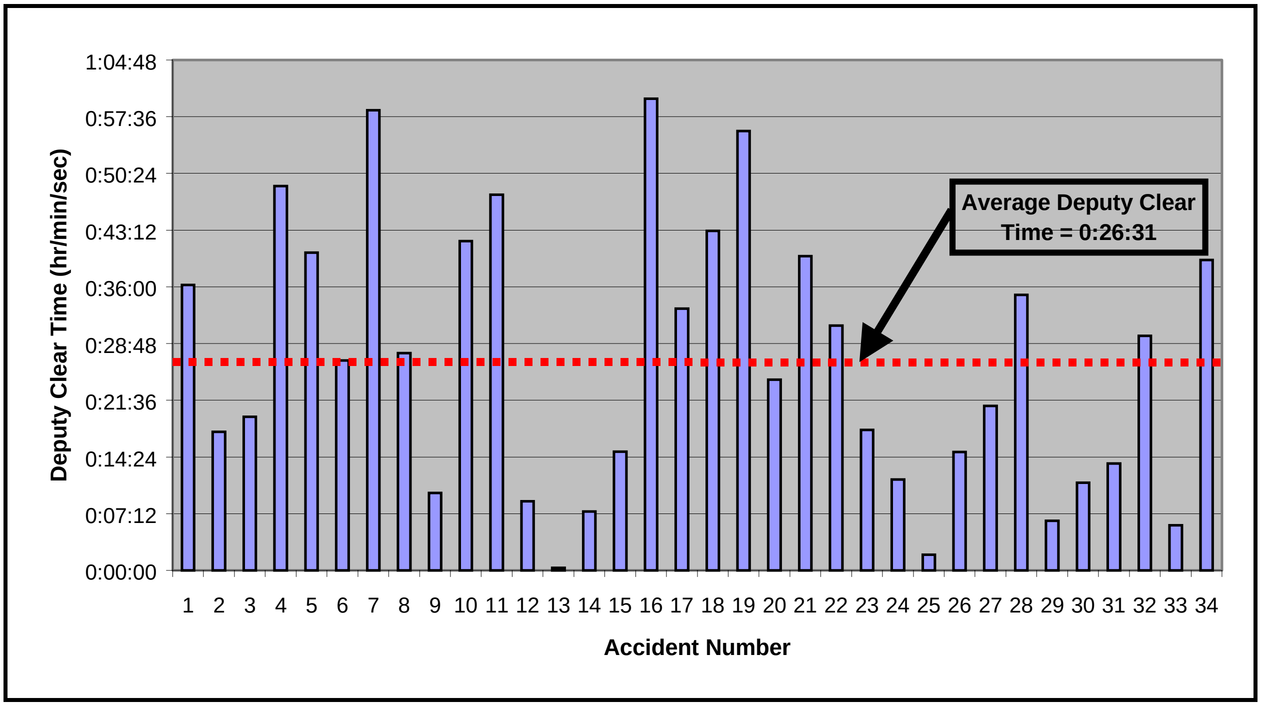

Figure 10. Dallas County Sheriff Department Incident Deputy Clear Times.

4.3.2 Chattanooga Police Department

The city of Chattanooga is located in the south central portion of the state of Tennessee and is served by IH 24 and IH 75. The Chattanooga Police Department (CPD) began using photogrammetry to investigate traffic incidents in November of 2000. The CPD started using photogrammetry based on the recommendation of the local area's highway incident management team. An article in the December 4, 2000, edition of the *Chattanooga Times & Free Press* gave some details regarding the photogrammetry program shortly after the CPD used it in the first field investigation *(26)*. The article cited several anticipated benefits of using photogrammetry:

- reduces the time needed to get traffic flowing smoothly following an incident,
- increases the accuracy of critical measurements that are sometimes referred to in court,
- reduces motorist frustration by clearing the accident scene in a timely way,
- reduces the occurrence of secondary collisions due to stopped traffic, and
- easily archives data to use in trials in which charges are not brought immediately.

A combination of federal, state, and local grants totaling $21,000 paid for the equipment for the CPD photogrammetry program. This money purchased the following items:

- PhotoModeler software;
- cameras: Nikon N60 35mm;
- scanner: Hewlett Packard 6300c;
- reflective evidence markers;

- training: three-day course for six CPD officers taught by DCS officials; and
- technical support: one year of technical support for the PhotoModeler software.

One final interesting item in the article was that the CPD had an agreement with a local radio/television traffic reporting service to share aerial photographs taken from a helicopter of major incident scenes free of charge. These aerial photographs help the CPD supplement photographs taken on the ground for their measurements.

Evaluation of Photogrammetry in Chattanooga

As a stipulation of receiving the grant money for the photogrammetry program, the CPD was responsible for submitting a quarterly report to the Tennessee Department of Transportation (TDOT) documenting the use of the photogrammetry-related equipment. The research team requested and received copies of the three quarterly reports (Oct.-Dec. 2000, Jan.-Mar. 2001, and Apr.-Jun. 2001) from Lieutenant Fred Layne, supervisor of the CPD traffic division *(27)*.

Table 9 provides incident clearance data taken from the quarterly reports submitted by the CPD for the photogrammetry project. CPD officers investigated 11 crashes during the nine-month period between October of 2000 and June of 2001. The CPD used both traditional measurements (i.e., laser and roller tape) and photogrammetry measurements on most investigations because using photogrammetry was a new technique they were testing for both timeliness and measurement accuracy. The data reported in Table 9 reflect the total time to investigate, remove the vehicles, and restore the incident scene to normal conditions. The CPD normally performed traditional measurements with three investigators using a laser measurement device and a conventional roller tape. The CPD typically made photogrammetry measurements with one officer placing the evidence markers and taking the required scene photographs.

Table 9. Chattanooga Police Department Clearance Times Using Photogrammetry *(27)*.

Crash Number	Traditional Measurement (min) [1]	Photogrammetry Measurement (min) [2]	Time Savings [3]	Fatalities
1	120	45	75	0
2	135	70	65	0
3	240 [4]	75	165	0
4	150	70	80	0
5	45	30	15	0
6	90	30	60	1
7	85	20	65	1
8	60	35	25	2
9	60	15	45	1
10	35	15	20	2
11	N/A [5]	20	N/A	0

[1] Traditional measurements were normally taken by three investigators using laser and roller tape.
[2] Measurements using photogrammetry were normally taken by one investigator.
[3] Time savings is the number of minutes that would have been saved by using photogrammetry.
[4] Traditional time was estimated due to the size of scene and the fact that the vehicle was in a wooded ravine.
[5] Traditional measurements could not be performed at this crash due to the terrain (no permanent fixed objects to reference for scale measurements).

Comparison of the data in Table 9 reveals an average 58 percent reduction in clearance time if photogrammetry had been the only investigative technique used. The column labeled Time Savings in Table 9 also shows that the average clearance time reduction was approximately 61 minutes per incident. The CPD noted that only one officer was necessary for an investigation using photogrammetry while three officers were typically used for the traditional measurement technique. The CPD were able to use photogrammetry to get scene measurements for crashes 3 and 11 but were not able to obtain traditional measurements because of difficult terrain.

The CPD also performed a comparison of the measurement accuracy of photogrammetry versus the traditional techniques. Table 10 summarizes the comparison of techniques for seven cases where the CPD took incident measurements in the field with roller tape and laser and back in the office using photogrammetry. The evaluation compared 69 measurements and found the average percent difference between photogrammetry and traditional measurements to be only 2.3 percent. Almost half (44 percent) of the measurements compared were less than 1 percent in difference.

Table 10. Chattanooga Police Department Evaluation of Measurement Accuracy *(27)*.

Case Number	Number of Measurements	Average Percent Difference
1	6	2.5
2	11	1.2
3	5	3.2
4	11	0.8
5	18	3.1
6	9	3.3
7	9	1.9
Totals	**69**	**2.3**

While the CPD evaluation of photogrammetry has indicated considerable benefits in terms of reduced scene clearance time and less personnel required for the investigation, there have been some drawbacks. CPD personnel have spent more office time calculating the measurements and producing the scale diagram than using traditional methods. The office time for photogrammetry has been reduced since the program's inception because CPD officers have become more familiar with the software programs that obtain measurements and produce the scale drawings of the scene.

4.3.3 Utah Highway Patrol

The Utah Department of Transportation (UDOT) and the Utah Highway Patrol (UHP) have performed a comparison of Total Station and photogrammetry systems to determine the most effective means of obtaining measurements of traffic crashes. TTI researchers interviewed UDOT and UHP personnel regarding their joint activities *(21)*. The UDOT personnel revealed that fatal and major accidents in the Salt Lake City area were taking approximately three to four hours to be cleared from the roadway using Total Stations. Only 15 percent of that time was spent on the response portion of the incident management process with the balance of the time on investigation of the incident scene. UDOT officials decided that an investment in equipment and training for the UHP to evaluate the use of photogrammetry was warranted in order to help reduce the time spent during the incident investigations. Congestion Mitigation and Air Quality funds in the amount of approximately $40,000 were used to purchase the training (three one-day sessions) and equipment (digital cameras, accessories, and PhotoModeler software) necessary for using photogrammetry.

4.4 OTHER POLICE AGENCIES USING PHOTOGRAMMETRY

This final section provides some information on law enforcement agencies using photogrammetry for crash investigation that did not provide the detailed data the agencies in Section 4.3 supplied. Most of this information is taken from the TTI research report 4907-2 *(21)*. Table 11 lists some additional police agencies with photogrammetry experience and their stage of implementation.

Table 11. Listing of Police Agencies with Photogrammetry Experience.

Type	Name	Stage of Implementation
State Police Agencies	Arizona Highway Patrol	Have been using photogrammetry for 10 years
	California Highway Patrol	3 patrol divisions use photogrammetry in the field
	Maryland State Patrol	Unknown
	Minnesota State Patrol	Received training in June 2001
	New Jersey State Police	Unknown
	New York State Police	Field testing as part of IH 95 corridor coalition project
	Oregon State Police	Testing and comparing with Total Stations usage
	Washington State Patrol	Testing phase with 5 trained investigators
Local Police Agencies	Bergen County (NJ) Police	Unknown
	DeSoto (TX) Police	Unknown
	Duncanville (TX) Police	Unknown
	Harris County (TX) Sheriff	Less than a year of field experience
	Honolulu Police	Used several years in Honolulu
	Houston (TX) Police	Less than a year of field experience
	Houston (TX) Metro Police	Less than a year of field experience
	Peoria (Illinois) Sheriff	Only used on major crashes as a supplement
	San Diego (CA) Police	Unknown
	San Diego (CA) Sheriff	Unknown
Foreign Police Agencies	Hanamaki Police (Japan)	Used in field for hit-and-run and other difficult crashes
	Manheim Police (Germany)	Stereo photogrammetry used for many years
	Nordrhein Police (Germany)	Stereo photogrammetry used for many years
	New South Wales (Australia)	Stereo photogrammetry for many years around Sydney

Researchers found that the use of photogrammetry for investigation of traffic incident scenes is still a relatively new practice in the United States. At this point, many police departments are still in the initial stages of using photogrammetry and therefore do not have a large amount of evaluation data to substantiate its effectiveness. The evaluation data contained in this report is limited; however, the results seem to indicate that the use of photogrammetry has produced a positive impact on getting incidents cleared more quickly from the roadway travel lanes. The research team believes that a more thorough and widespread evaluation of photogrammetry should be conducted to determine whether the benefits experienced by the DCSD and CPD are true for the many other agencies that are implementing photogrammetry.

CHAPTER 5

EVALUATION OF INNOVATIVE MERGING STRATEGIES AT LANE CLOSURES

This chapter documents the evaluation of innovative merge strategies at lane closures. The focus group and telephone survey results both indicated that merging, whether at lane closures, entrance ramps, or other situations, was one of the highest stressors in the driving environment.

Merging at lane closures created by construction or maintenance activities was the focus of this study. Motorists are confronted with many different types of traffic control plans approaching a lane closure, and the rules in this situation do not seem to be as well understood as those in other traffic situations (e.g., four-way stop controlled intersection). In fact, the high-stress environment of a lane closure coupled with the lessened understanding of rules often creates a situation where drivers experience frustration that can lead to aggression and/or rage. The cartoon below (Figure 11) provides a humorous way of looking at the dilemma motorists face when trying to make decisions about where, how, and when to merge on the approach to a lane closure.

Figure 11. Merging Behavior Cartoon *(28)*.

Typical traffic control signing on the approach to a freeway lane closure tells the driver well in advance the closing lane(s) and the distance to the beginning of the merge point. This information seems to create two distinct camps of motorists: one group that vacates the closing lane as soon as possible and the other group that stays in the closing lane as long as possible.

These distinct groups exhibit vastly different behaviors, but both groups seem to perceive their way of driving to be the right way. Cartoons, like in Figure 11, are normally funny because they hit on a topic that rings true to a large audience. The topic of merging behavior has received a lot of attention, even in the popular press. A columnist in the *Washington Post* referred to as Dr. Gridlock wrote a series of articles entitled "Last-Minute Merges: Rude or Efficient?" *(29,30,31)*. A recent article in the DMN by a feature columnist was about the subject of the precarious freeway entrance ramp merge (*32*). The article chronicled a situation that the columnist had been involved in while trying to enter eastbound Woodall Rodgers Freeway on the Pearl Street entrance ramp. In summary, the columnist accelerated to merge in front of another driver already on the freeway, then was followed by this driver with lights flashing, and after pulling over together got in an argument about who had the right-of-way. This situation was resolved with only a few words exchanged, but it is a typical example of how merging creates a competition that can escalate quickly into aggressive and even violent actions.

Transportation authorities in the United States and throughout the world have taken notice of this problem and have developed a number of innovative merge strategies (IMSs) designed to provide better understanding of expectations and reduce the stress and aggression for drivers approaching work zone lane closures. It is interesting to note that even transportation professionals appear divided on the optimal method to merge on the approach to a lane closure. This chapter will present an overview of some of the IMSs identified during the literature review and document the testing and evaluation of an IMS in the driving simulator and at a Dallas freeway site.

5.1 DESCRIPTIONS OF INNOVATIVE MERGE STRATEGIES

The literature review yielded a wealth of information about different IMSs including the Late Merge, Early Merge, and Zip Merge. Each of the following subsections provides descriptions of these IMSs including results of previous evaluations of their effectiveness.

5.1.1 Late Merge Strategies

The static Late Merge is a traffic control concept developed by the Pennsylvania Department of Transportation for use in work zones, typically on four-lane rural interstate highways *(33)*. The Late Merge is designed to encourage drivers to use both lanes to the merge point and then take turns merging. Figure 12 shows a photograph of the 'USE BOTH LANES TO MERGE POINT' sign. Figure 13 is a picture of the 'MERGE HERE TAKE YOUR TURN' sign drivers see just prior to the beginning of the taper for the lane closure.

Typical traffic control plans work well during most hours of the day; however, when traffic demand exceeds capacity of the work zone, problems occur, which is what prompted the development of the Late Merge strategy. The objectives of the Late Merge concept are to reduce the queue length by 50 percent, decrease potential for accidents at the tail of the queue, and lessen driver anxiety and frustration. Figure 14 shows a typical layout for the Late Merge traffic control plan on a rural four-lane interstate highway. Researchers from the University of Nebraska *(33)* conducted field studies to evaluate the Late Merge concept. Field personnel collected volume, lane distribution, queue length, vehicle type, and speed data to assess the effectiveness of the strategy. The following list provides some of the major findings of the evaluation:

Figure 12. 'Use Both Lanes to Merge Point' Sign Used in Pennsylvania.

Figure 13. 'Merge Here Take Your Turn' Sign Used in Pennsylvania.

- The concept did not work as effectively as hoped based on the lane distribution data obtained during both free-flow and congested-flow periods.
- Speed profiles showed that both passenger cars and trucks drove faster in the left lane (i.e., the lane being dropped) versus the right lane.
- Researchers observed during the field study that in a breakdown situation where the length of queue exceeded two miles, the lane distribution was close to 50/50 (i.e., vehicles behaved according to the Late Merge concept).
- A large portion of the motorists did not follow the directions given by the traffic signs and truck drivers were especially reluctant to remain in the closed lane.
- A common case observed during congested periods was that of two trucks blocking both lanes by traveling side-by-side at the same, generally very slow, speed.
- Still, an independent study conducted by a consulting firm in Pennsylvania *(34)* determined that the Late Merge strategy increased the capacity of the work zone by as much as 15 percent.

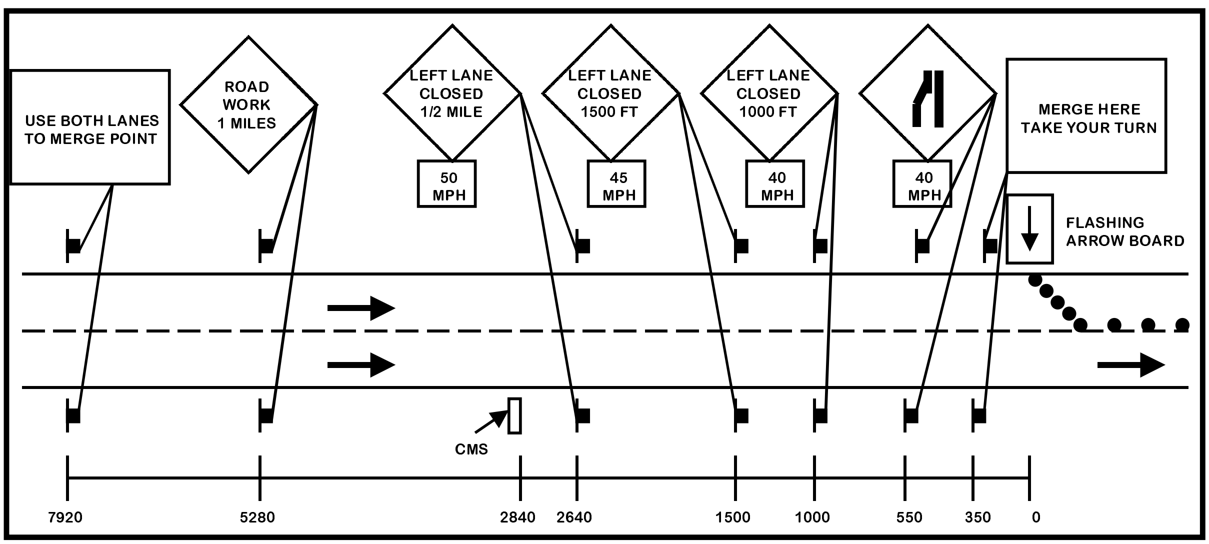

Figure 14. Late Merge Traffic Control Plan *(32)*.

Another component of the evaluation was surveys of drivers who had traversed one of the field sites *(35)*. The surveys revealed that Late Merge detractors (40 percent of vehicles and 73 percent of trucks) said that "drivers don't follow instructions," "does not prevent drivers from cutting in front of them," "signs were confusing," and "having one merge point increases congestion." Late Merge proponents (60 percent of vehicles and 27 percent of trucks) said that "not having to worry about changing lanes" and "being able to use either lane to pass slower vehicles" were benefits. The study results, especially the increased capacity of merging operations, caused this project's research team to select the Late Merge strategy as a mitigation measure for further evaluation.

Dynamic Late Merge Concept

The Nebraska Department of Roads (NDOR) has sponsored several research projects to evaluate and compare the performance of merge strategies such as the Early Merge and Late Merge at freeway work zones. A paper presented at the 2001 Transportation Research Board (TRB) meeting in Washington, D.C., by McCoy and Pesti summarized the results of these research efforts *(36)*.

The results of a NDOR study showed that both the Early and Late Merge provided safer merging operations than the NDOR Merge *(37)*. McCoy and Pesti observed that both systems had lower merging conflict rates than the NDOR Merge. They used traffic conflicts as measures of the safety effectiveness of different merge control strategies. They observed three main types of conflicts:

1. *Forced merges*: a vehicle in the closed lane attempted to merge into the open lane when the available gap was not sufficient for performing a safe lane-changing maneuver. This led to evasive actions that had to be taken by either the merging vehicle or the vehicles in the open lane to avoid a collision;
2. *Lane straddles*: a vehicle straddled the lane line occupying both lanes to prevent other vehicles from passing it in the merge area; and
3. *Lane blocking*: two vehicles, typically trucks, moving slowly, traveling side-by-side, blocked both lanes, and prevented other vehicles from passing them in the open lane.

McCoy and Pesti cited a concern about the potential for driver confusion at the merge point of the Late Merge, especially under high-speed, low-volume conditions, which could adversely affect safety. On the other hand, they found the Late Merge to have a higher capacity than the NDOR Merge and the Early Merge *(37)*. The Late Merge's higher capacity and larger queue storage area reduce the probability of congestion extending back beyond the advance warning signs; thus, reducing the potential of rear-end collisions on the approach to the work zone.

The higher capacity also reduced the duration of congestion, which in turn reduces the exposure to rear-end collisions. In addition, because of its higher capacity, the Late Merge reduces congestion delay; whereas, the studies have found that the Early Merge increases travel times, especially under high traffic volumes *(38,39)*. Based on these findings, McCoy and Pesti concluded that the best system of merge control during peak periods was the Late Merge. However, because of the safety concerns regarding its operation under high-speed, low-volume conditions, the Late Merge may not be the best system during off-peak periods. Therefore, in order to maintain optimum merging operations at all times, it would be necessary to convert from the NDOR Merge or Early Merge during periods of uncongested flow to the Late Merge during periods of congested flow. In other words, a Dynamic Late Merge (DLM) would be needed. Forms of the Early Merge, which utilize pavement markings, rumble strips, or no-passing zones to discourage use of the closed lane, would not be conducive to a real-time conversion to the Late Merge, which uses the closed as well as the open lane. Therefore, a merge control similar to the NDOR Merge would be used during the uncongested periods in the DLM system.

McCoy and Pesti created the concept of the DLM to resolve the aforementioned dilemma. The goal of the DLM is to provide the safest and most efficient merging operations at all times in advance of the lane closure by switching between the NDOR Merge, or conventional lane closure merge operation, and the Late Merge, based on real-time measurements of traffic. It would operate as the NDOR Merge, or a conventional lane closure merge operation, during periods of uncongested flow, and as the Late Merge during congested flow conditions.

McCoy and Pesti envision that the DLM would consist of a series of advance signs that would activate to advise drivers to 'use both lanes to the merge point' when congestion was detected in the open lane adjacent to the signs. A sign would also be placed at the merge point advising drivers to 'take turns merging'. When the congestion clears, the DLM signs would deactivate, or change, to advise drivers of the lane closure and to effect the NDOR Merge, or conventional lane closure merge operation. The signs could be DMSs equipped with traffic detectors. Or, perhaps, the signs could be static signs equipped with traffic detectors and flashing strobes. McCoy and Pesti will be conducting research during 2001 and 2002 to determine the most effective sign message, type, and spacing. This research will also address the operations issue regarding the lane distribution between the open and closed lane prior to the switch to the DLM. Under the conventional mode of merge control, drivers are encouraged to merge into the open lane. Therefore, when the traffic volume approaches the capacity of the conventional mode of merge control, the speed of traffic in the open lane may be much lower than the speed of traffic remaining in the closed lane. Consequently, when the system switches to the Late Merge, the accident potential may be high if drivers in the slower open lane attempt to merge into the higher speed closed lane before flow conditions in the two lanes are similar. Speed control and/or messages to advise drivers to stay in their lanes during the transition may be necessary to minimize this accident potential. Future research would determine the need for such measures.

TTI Research on Work Zone Traffic Management

An ongoing research effort at TTI, Project 7-2137 "Improving Work Safety Through Better Work Zone Traffic Management and Enforcement," is evaluating a variety of engineering and enforcement measures designed to improve work zone safety *(40)*. In the fall of 2001, TTI researchers plan to select a site in Houston to evaluate the effectiveness of the DLM strategy.

Preliminary selection of site for the field test of the DLM is a work zone on the IH 45 freeway in Houston. The TTI researchers on this project are working closely with Scientex Corporation representatives. Scientex Corporation is the vendor for the *ADAPTIR*™ system (***A***utomated ***D***ata ***A***cquisition and ***P***rocessing of ***T***raffic ***I***nformation in ***R***eal-time) that TTI plans to use to dynamically activate the Late Merge traffic control plan on portable DMSs spaced throughout the work zone *(41)*. The testing of the DLM traffic control concept will further the state of knowledge regarding how Texas drivers respond to the suggestions to use all lanes to the merge point and then take turns when they get there. The results of the evaluation in Houston will complement the results obtained during this study for the static Late Merge on IH 30.

5.1.2 Early Merge Strategies

The Early Merge traffic control concept was originally developed by engineers at the Indiana Department of Transportation to alleviate aggressive driving behavior at work zones. In contrast to the Late Merge strategy detailed in the previous section, the Early Merge concept encourages drivers to switch into the open lane well in advance of the lane closure. The primary goals of this approach are to: (1) reduce accidents, and (2) improve safety by making motorists move smoothly into one lane when approaching the lane closure, rather than passing long lines of vehicles before swinging into the remaining lane at the last instant. The Early Merge traffic control system uses a series of 'DO NOT PASS' signs placed in advance of the taper area, creating an enforceable no passing zone to encourage motorists to make an early merge. Each state revised their Manual on Uniform Traffic Control Devices (MUTCD) to allow testing of the Early Merge traffic control system.

In May of 2000 when the research team was selecting the mitigation measures, the initial results of a simulation study by the University of Purdue indicated that travel times were longer for the Early Merge concept utilized during the 1997 construction season in Indiana *(42)*. Furthermore, data from 1997 field tests indicated no increase in work zone throughput. These initial results caused this research team to eliminate the Early Merge as a candidate for testing during the second year of the project. Subsequent field test results from both Indiana and Michigan, presented in the following paragraphs, create a more positive picture of the Early Merge strategy.

The literature review revealed that the states of Indiana and Michigan have deployed and evaluated a number of different variations, both static and dynamic, of the Early Merge concept. In Indiana, Tarko, Shamo, and Wasson *(43)* performed a study to evaluate motorist compliance with the signs, travel times, and passing maneuvers on the approach to the lane closure. The preliminary findings on the Early Merge concept in this study, published in late 1999, indicated safer driver behavior and decreased time through the transition area on the approach to the lane closure. Tarko et al. did caution that the long-term capacity and safety effects of the system have not yet been quantified.

The Michigan Department of Transportation (MDOT) began a pilot project in the year 2000 to study the effectiveness of a dynamic lane merge traffic control system (LMTCS). A team of researchers from Wayne State University (WSU) performed the evaluation of the LMTCS deployments at construction sites on the state freeway system *(44)*. WSU tested the LMTCS during two consecutive construction seasons. In Phase I of this study, WSU examined four test sites and four control sites in order to evaluate the effectiveness of the LMTCS in terms of reducing driver delay at the merge point, driver understanding and compliance of the system, and the effects of enforcement. Phase II (Spring/Summer 2001) involved the development of an optimal traffic control system (based on the Phase I results) and field testing to determine its effectiveness. Figure 15 provides schematics of the Phase I and II systems.

The Michigan LMTCS consists of traditional work zone traffic control supplemented with a system of static and/or dynamic 'DO NOT PASS' signs. In the dynamic systems, these signs are mounted on trailers, along with sensors that detect traffic volumes and occupancy. MDOT designed the system to detect traffic slowdowns then activate the flashers on the next upstream 'DO NOT PASS WHEN FLASHING' sign in order to prompt drivers to change lanes in advance of the congestion. The 'DO NOT PASS WHEN FLASHING' sign closest to the taper is always activated and in the flashing mode. In the static system, flashing beacons are mounted on the 'DO NOT PASS' signs. To activate the signs, field crews have to manually turn on or off the beacons depending upon the anticipated times of congestion.

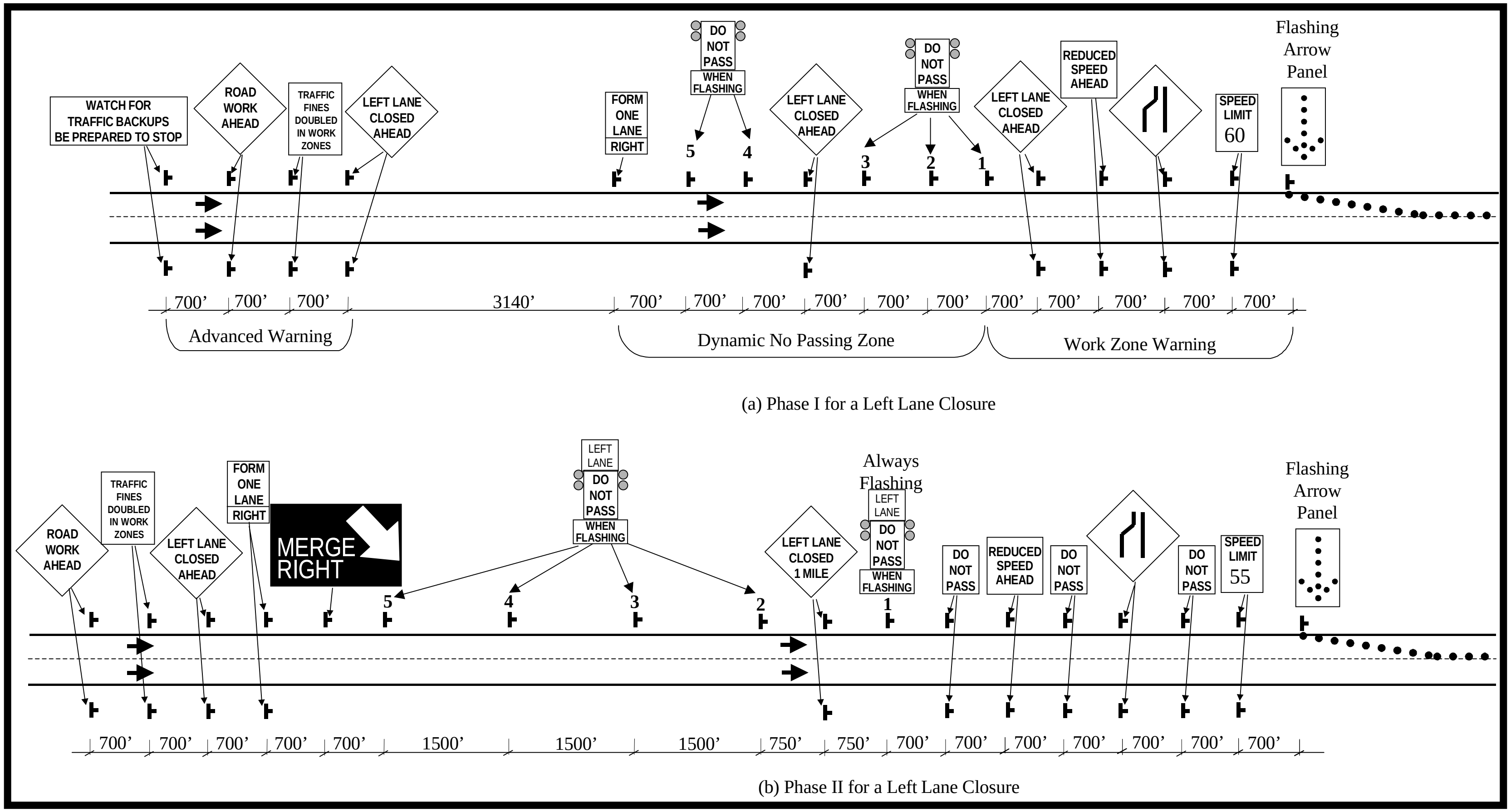

Figure 15. Schematic of the Dynamic Lane Merge System Used in Michigan (44).

As mentioned previously, WSU researchers made several modifications to the Phase I layout based on field test results and by applying a human factors and "Positive Guidance" analysis. The following list summarizes these major modifications.

- WSU revised the sequence of signs placed after the dynamic sign trailers to incorporate static 'DO NOT PASS' signs placed in between the standard lane closure warning signs and dynamic 'DO NOT PASS WHEN FLASHING' signs.
- WSU increased the spacing between the dynamic signs to 1500 feet from 700 feet to allow drivers the time to respond properly.
- WSU added a DMS with the message 'MERGE RIGHT' and an arrow symbol pointing down upstream of the dynamic signing to provide an additional cue to motorists to respond appropriately.
- Because WSU tested the system for both right and left lane closures, WSU added sign panels with text 'RIGHT LANE'/'LEFT'LANE' to the top of the dynamic 'DO NOT PASS WHEN FLASHING' signs.
- WSU modified the detector settings (i.e., detection time and occupancy threshold) to improve system operation.

Preliminary Evaluation Results

In the first phase of this project the data collection and analysis did not reveal any significant findings with respect to travel time and delay. The WSU team concluded that this finding was probably due to non-optimal sensor settings. Other findings for Phase I included:

- WSU researchers observed more aggressive driving behavior at the static LMTCS than the dynamic LMTCS for similar flow rates.
- Police enforcement had a positive impact on reducing the amount of aggressive driving behavior in work zones.
- Drivers were confused by the dynamic LMTCS due to non-optimal system layout and the frequently arbitrary sensor settings.

During Phase II, a comparison of the before and after data indicated that for similar flows the average operating speeds increased in the after period due to a smoother traffic flow created by the dynamic LMTCS. Additionally, WSU researchers concluded that the average delay (peak period) and aggressive driving maneuvers (peak hour) were reduced due to the dynamic LMTCS.

The research team realizes that the WSU study results appear promising; however, they were not available during the time period when mitigation measures were being selected for testing. Even with the promising results, it is unlikely that the research team would have selected the Early Merge strategy over the Late Merge strategy because of the reliance on enforcement and need for revision of the Texas MUTCD to allow an Early Merge-type system to be deployed. A recent article in the *Detroit News* examined the Michigan LMTCS. The article seems to question the intentions of the system (traffic benefits vs. citation revenue) and the driver perception. A link on the online story provides a forum for drivers to indicate their approval or disapproval of the Michigan dynamic LMTCS *(45)*.

5.1.3 Zip Merge Strategies

The Zip Merge is a traffic control concept utilized primarily in European countries such as the Netherlands and United Kingdom (UK). The basic premise of the Zip Merge is to encourage drivers to merge smoothly on the approach to lane drops by spacing out to allow gaps sufficient for vehicles to safely enter.

Zipping Strategy in the Netherlands

Researchers at Delft University in the Netherlands developed the zipping strategy *(46)*. Delft researchers conducted focus groups with motorists in Rotterdam, a congested region, to discuss problems with freeway operations. Participants indicated that they often had difficulty at lane drops. The Dutch Department of Transport wanted to influence lane changing at lane drops and therefore requested a study. The basic strategy of zipping is to reduce queue extent, improve queue discharge rate by concentrating lane changes closer to the lane drop, and to increase the frequency of the zipping maneuver. Zipping means that each driver does not change lanes until a fixed distance from the lane drop, immediately behind the follower of their original leader. The research hypothesis was that traffic flow would be more efficient and safer when the prevalence of zipping was high.

Figure 16 is a representation of the four phases in the mandatory lane changing process at a lane drop and the five types of lane changing maneuvers researchers used during the evaluation. Figure 17 shows the signing used to promote zipping at the test site. Field personnel placed a set of signs 1 km upstream of the lane drop to warn the motorist which lane is dropping (phase 1—look for gap). Another sign, positioned 650 m prior to the lane drop adjacent to the closing lane, tells the motorist to begin to ‘Zip in 300 m’ (phase 2—adjusting speed). The final set of signs is placed 300 m before the lane drop (phase 3—merging). The sign adjacent to the lane being dropped includes the instruction to ‘Zip Here.’ Delft researchers designed the sign adjacent to the lane being continued to say ‘Allow Drivers to Zip’ (phase 4—adjusting following distance). The official web site for this strategy, written in the Dutch language, is http://www.ritsen.nl/index.html.

Preliminary Evaluation Results

Preliminary results from the evaluation of sites with the zipping traffic control configuration have indicated that neither objective (i.e., reduced queue length and improved queue discharge rate) was achieved by the promotion of zipping. The University of Delft plans further research on this concept. Feedback from approximately 400 drivers revealed that 50 percent understood the signs and almost everyone (97 percent) expected zipping to improve throughput. This positive feedback caused the Delft research team to view the zipping concept as a mitigation measure to consider for further evaluation.

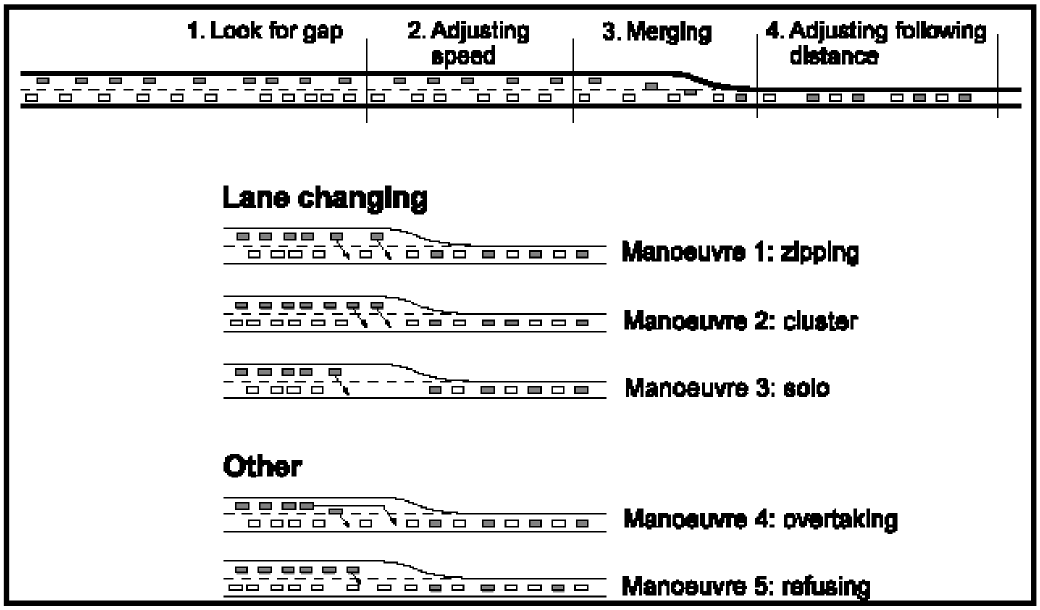

Figure 16. Lane Changing Phases and Maneuvers at a Lane Drop *(46)*.

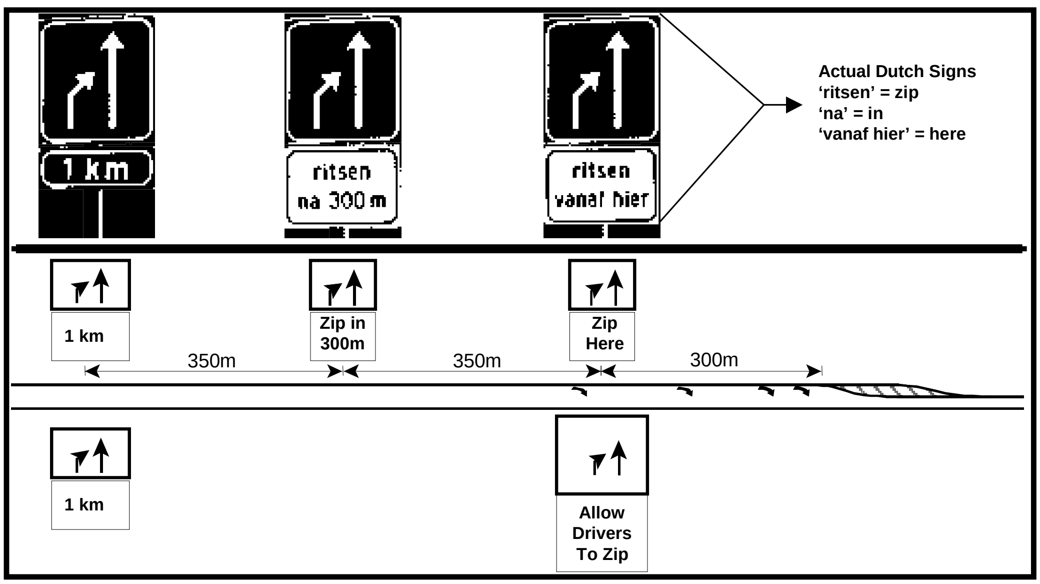

Figure 17. Zipping Traffic Control Plan Used in the Netherlands *(46)*.

Zipping Strategy in the United Kingdom

The Highways Agency (HA) and researchers at the Transport Research Laboratory (TRL) jointly developed a zip signing technique *(47)*. A January 1997 research report summarizes the rationale for the zip signing *(48)*:

> "The system of signing on the approach to road works in the United Kingdom (UK) has evolved over many years from road works practice, and in free flowing traffic conditions is considered to satisfy both the need to facilitate early merging, and the need to ensure efficient usage of the traffic lanes which remain open. Such free flowing traffic conditions exist at most road works sites for most of the time. However at peak times at some works, traffic demand is greater than traffic capacity at the merge point, and queuing begins. In these circumstances the need for early merging diminishes and a need for efficient queue management develops. Zip merging helps with the latter."

Zip merging is facilitated by the deployment of the signs 'WHEN QUEUING USE BOTH LANES' and 'PLEASE MERGE IN TURN' in addition to the standard signing at road works. The HA recommends that the 'WHEN QUEUING USE BOTH LANES' sign should be deployed on both sides of the roadway and located at 600 m (1965 feet) and 1000 m (3275 feet) in advance of the taper. For longer queues, the HA suggests that this sign should be placed beyond the furthest point upstream to which queues are likely to extend. The HA also recommends that the 'PLEASE MERGE IN TURN' sign should be deployed on both sides of the roadway and located 300 m (980 feet) in advance of the taper. Both signs have letter heights of 150 mm (6 inches), and are white on red for trunk roads, and black on yellow for motorways. Figure 18 shows pictures comparing the queuing of vehicle before and after the implementation of zip signing. Figure 19 provides a schematic of the typical zip signing layout on the approach to the lane closure.

Figure 18. Before and After Pictures for Zip Signing Site in the United Kingdom *(47)*.

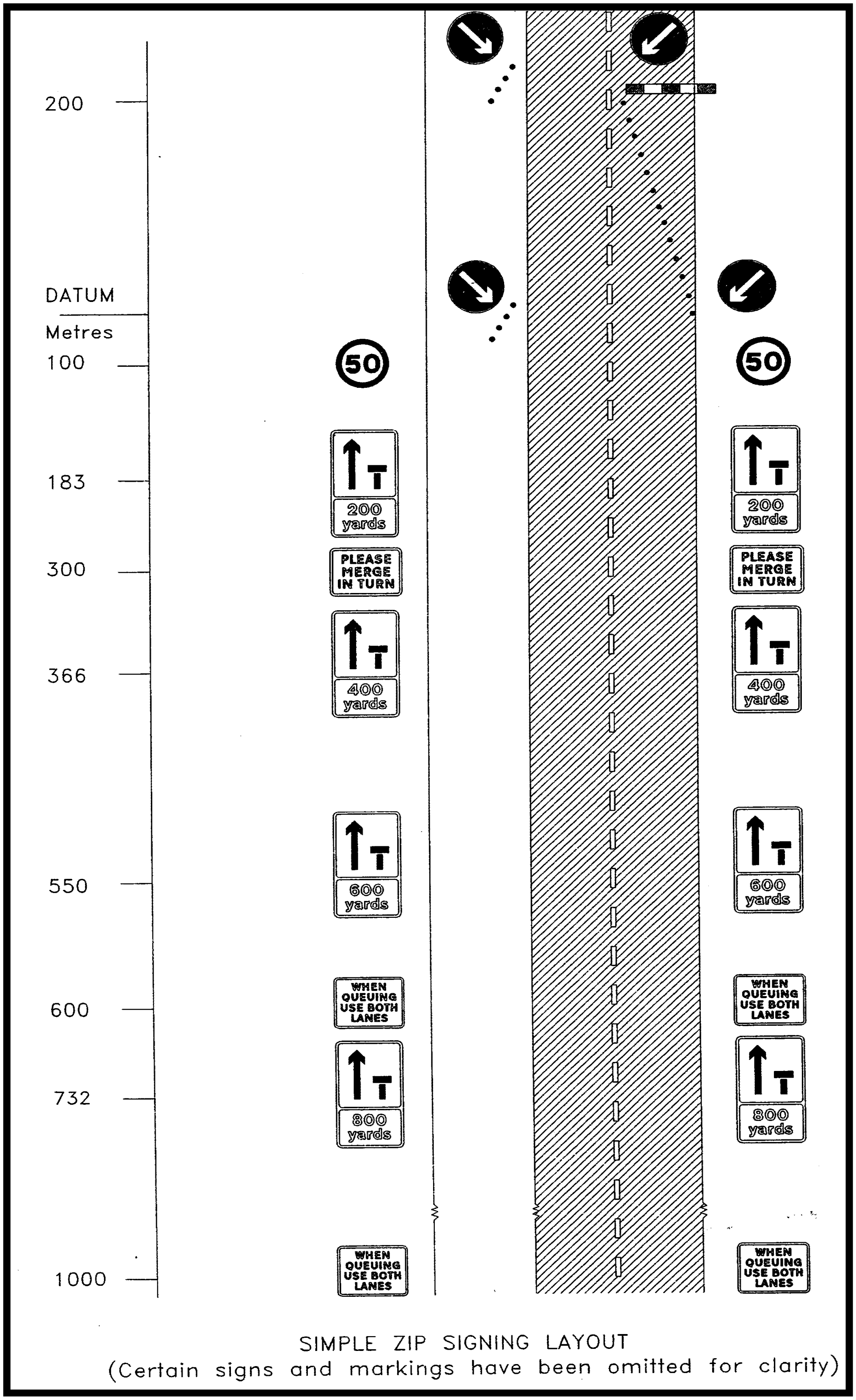

Figure 19. Schematic of the Zip Signing Layout Used in the United Kingdom *(48)*.

Preliminary Evaluation Results

TRL researchers performed trial evaluations of the Zip Merging layout shown in Figure 19. TRL concluded that the zip merging did not produce an increase in traffic capacity at the merge point but did facilitate more efficient queuing and reduce driver frustration. The more equal use of both lanes on the approach for queuing shortened the physical extent of the queues and, in turn, reduced delays arising from interference with upstream ramps.

The TRL research team also contended that it was important to recognize that the quality of service provided encompasses aspects that cannot be measured in quantity and time. The perception of delays at road works is affected by the degree of exasperation and frustration experienced by the driver. By reducing "queue jumping," Zip Merging seemed to reduce such tensions. To date, the use of Zip Merge signing was only found to be effective at merges of two lanes into one. The HA and TRL are in the process of evaluating the utilization of the Zip Merging system at merges of three lanes into two.

Zip Merging in the United States

An Internet search revealed that there is at least one proponent of the Zip Merging strategy in the United States. A commuter in San Francisco/Oakland, California, has undertaken a personal crusade to promote and educate fellow commuters on merging behavior *(49)*. This individual outfitted his personal vehicle with artwork and text designed to promote his cause. Figure 20 shows several different photographs of the vehicle and also includes bumper stickers that are distributed through a personal web site. The following list provides a description of some of the rationale behind the artwork and text on the vehicle:

- *Yellow/black merge sign*: this introduces the concept of merging behavior with an easily recognizable image;
- *Zipper logo*: this is intended to suggest a concept for appropriate merging behavior (i.e., a zipper works because each tooth takes its turn and two sides are united into one—similar cooperation is required for vehicles in traffic to merge together);
- '*ACCELERATE then merge*': people waiting to merge tend to drive too slowly so they are admonished to accelerate before they merge;
- '*TRAFFIC SCHOOLING Drive with Grace*': this text advances the idea that education and courteous are necessary for proper merging to be accomplished;
- '*MOVE OVER! / GET OUT OF THE WAY*': these messages are intended to support the idea that sometimes you have to sacrifice in order to allow others space to merge into;
- '*Competition? Cooperation!*': this text promotes that merging should not be a competition between drivers but should be cooperative; and
- '*Helping Bay Area drivers merge one car at a time*': this message explains the overall objective of the effort, to change individual drivers into more cooperative mergers.

Figure 20. Pictures of the Bay Area Commuter Promoting Zip Merging Behavior *(49)*.

5.2 TESTING OF THE LATE MERGE IN THE DRIVING SIMULATOR

This section documents the testing of the Late Merge in the driving environment simulator (DESi). The first subsection provides basic information on the experimental participants. The second subsection describes the DESi components and capabilities. The third subsection briefly explains the experimental procedures used in the Late Merge evaluation. The final subsection presents some of the results and feedback obtained from test subjects who drove in the DESi.

The initial objective of using the DESi was to gather feedback on how drivers would respond to the Late Merge prior to conducting field tests. Researchers hoped to be able to optimize the placement and messages on the Late Merge signs. These objectives were changed because the scheduling of the DESi had to be concurrent to the field tests. The new objective was to get the DESi to emulate the Late Merge and gather feedback from a limited number of test subjects.

5.2.1 Experimental Participants

Researchers recruited twelve females and twelve males from the staff at the Texas Transportation Institute at Texas A&M University. All participants were between 18 and 60 years of age. Each participant possessed a valid driver's license, had 20/40 vision or corrected to 20/40 vision via contact lenses or glasses, were not considered to be color vision deficient, possessed acceptable sensitivity to contrasts, and had no known physical or cognitive limitations that might affect their performance in this study. Participants received no monetary compensation, class credit, or other benefit for their participation.

5.2.2 Experimental Apparatus

Researchers conducted the study in the DESi, which consists of a semi-circular aluminum structure onto which three white polypropylene screens are affixed. Each screen extended up from the floor and was 2280 mm (90 inches) in height and 2280 mm (90 inches) in width. KQ Corporation software (Hyperdrive 1.2) generated the driving scene presented to participants using three computers that were projected through three liquid crystal display projectors. Researchers aligned the three separate images projected onto the screens so that they appeared as one single image subtending a 150º field of view horizontally and a 50º field of view vertically for the driver.

Participants sat in the driver's seat of a full-sized 1995 Saturn SC2, positioned in the center of the DESi. Researchers collected participants' performance measures via a fourth computer connected to the vehicle's steering column, brake pedal, and accelerator pedal. The recorded data included the lane position, steering input, accelerator input, speed, and brake input, and was sampled at a rate of 10 times per second. Researchers measured the lane position in meters as the distance from the center of the vehicle to the center of the occupied lane. The DESi captures the steering input in radians as the physical movement of the steering wheel. The DESi measures the accelerator input based on the physical movement of the accelerator pedal. Researchers then normalized the measurement to obtain a value between 0 and 1. Similarly, the DESi records the brake input as the physical movement of the brake pedal and researchers normalized these values to obtain a value between 0 and 10. Figure 21 shows photographs of the DESi both while in use and also not in use.

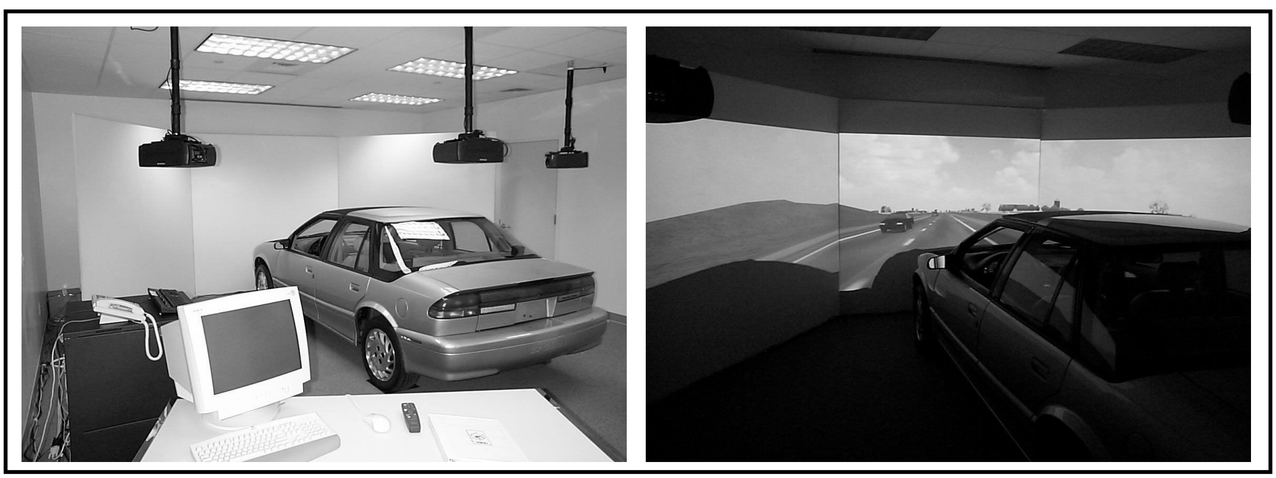

Figure 21. Photos of the Driving Environment Simulator at Texas A&M University.

5.2.3 Experimental Procedure

Upon reading and signing the Human Subjects Consent form (Appendix A), participants performed three visual screening tests, which included a Snellen test to assess visual acuity, a contrast sensitivity test to provide a measure of visual capabilities across a wide range of sizes and contrasts that appear in everyday environments, and a color vision test consisting of Dvorine color plates. Prior to entering the simulator, participants also completed a sickness pre-screening form (Appendix B). Researchers then seated participants in the Saturn and gave them time to adjust the seat, put on the seatbelt, and become familiar with the controls of the vehicle. Once comfortable, participants were given instructions for the practice drive (Appendix C). The purpose of the practice drive was to provide participants with an opportunity to become familiar with the operation and responses of the DESi. When the practice drive began, there was a red vehicle on the right shoulder ahead of the participant's vehicle. The red vehicle moved forward and accelerated to 56 km/h (35 mph) and maintained that speed throughout the practice drive. Participants were instructed to place their vehicle in 'drive' and follow the lead car. The practice drive included both straight and curved roadway sections with traffic and roadside features such as buildings, barns, fields, etc., and lasted approximately seven minutes. At the end of the practice drive the vehicle approached a stop sign. Participants were instructed to stop at the stop sign, put the vehicle transmission in 'park' and turn their attention to the experimenter.

Researchers then gave participants the instructions for the experimental drive of the Late Merge scenario (Appendix D). The drive consisted of a straight, six-mile section of freeway, three lanes wide. At the beginning of the fifth mile test section of roadway, there existed on both side of the roadway signs which read 'ROAD WORK 2 MILES', at the 1.5-mile mark there existed two signs which read 'USE ALL LANES TO MERGE', at the one-mile mark two signs read 'ROAD WORK 1 MILE', at the 0.75-mile mark two signs read 'USE ALL LANES TO MERGE', at the 0.5-mile mark two signs read 'LEFT LANE CLOSED 1/2 MILE', at 1500 feet two signs read 'LEFT LANE CLOSED 1500 FT', at 1000 feet two signs indicated lanes were merging, and at 500 feet two signs read 'MERGE HERE TAKE YOUR TURN'. Figures 22 and 23 show screen captures of the Late Merge signs in the demonstration version of the DESi. Five hundred feet after the last sign, there existed, in the left lane, a series of traffic cones, which reduce traffic to two lanes over a distance of approximately 500 feet. The participants' task was to simply follow the traffic flow and merge at the merge point. Appendix E presents specifications for each road sign.

When the experimental drive began, the participant's vehicle was located off the road to the left of the left lane of traffic. The participant then put the vehicle in 'drive' and joined the roadway within the traffic flow. As the participant approached the merge point, all vehicles in the left lane were forced to merge into the center lane and, as a result, many of the vehicles in front of the participant's vehicle in all three lanes were forced to decelerate to a near stop until they systematically merged. As the participants drove down the roadway, it was their task to attend to the roadway signs and then merge into the center or right lane when they felt it was appropriate. When the participant was 50 m past the merge point the simulation was stopped. Researchers presented the same task to the participant four additional times. Upon completion of the last experiment drive the participant was given one survey to assess potential levels of simulator-induced discomfort (Appendix F) and a second survey to determine general demographics and driver characteristics of the participant (Appendix G).

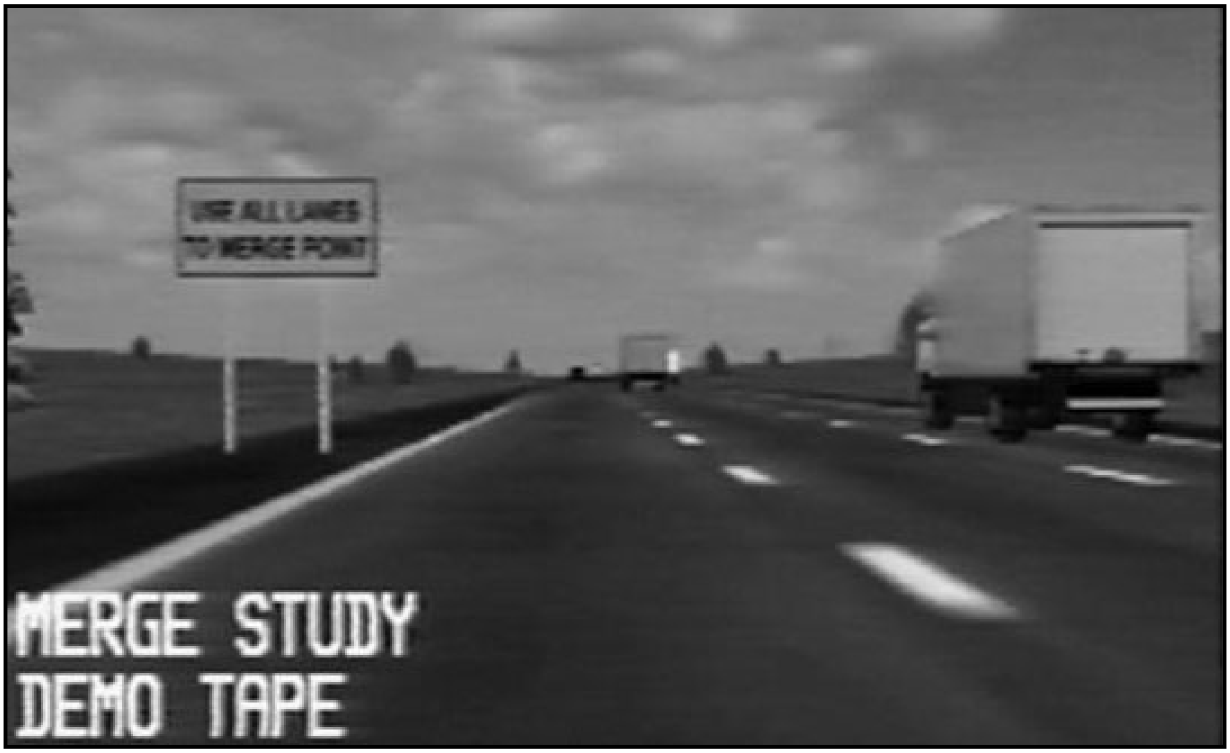

Figure 22. Screen Capture of 'Use All Lanes to Merge Point' Sign in Driving Simulator.

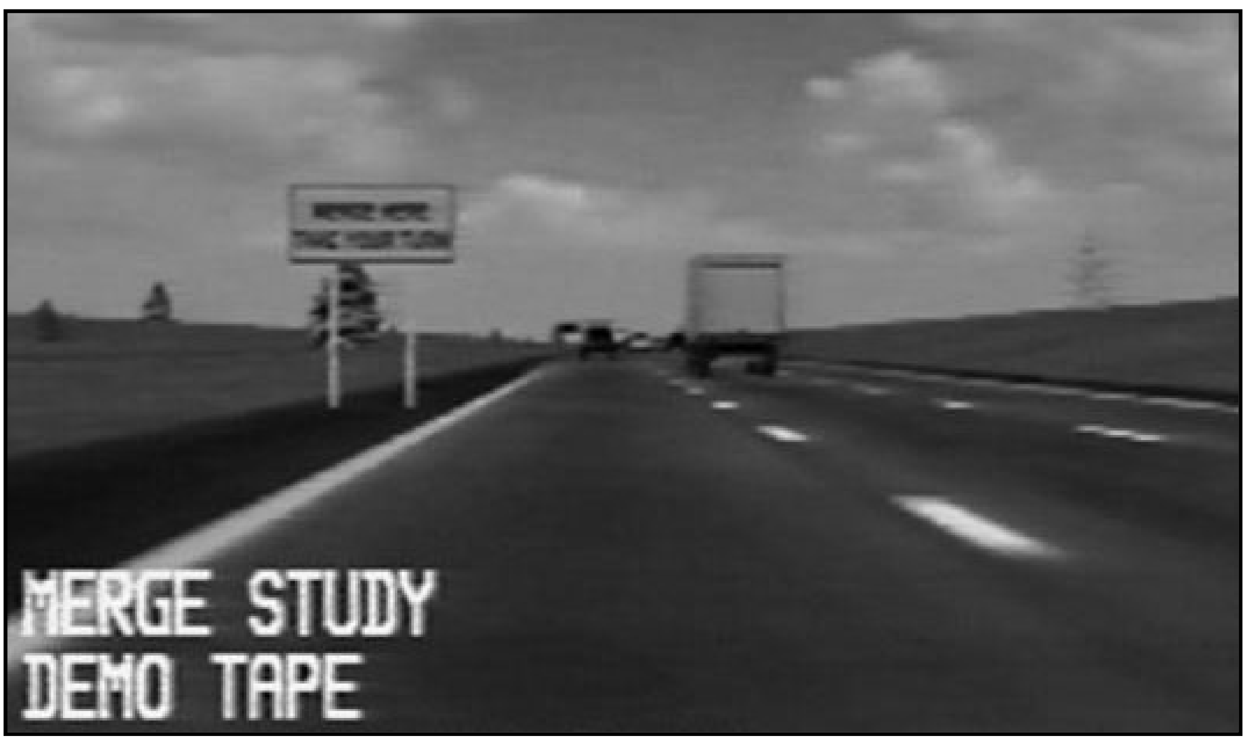

Figure 23. Screen Capture of 'Merge Here Take Your Turn' Sign in Driving Simulator.

5.2.4 Experimental Results

The purpose of the driving environment simulation portion of this project was to determine the nature and extent of the utility of a simulator for late lane merging maneuvers and perceptions. The associated goals were to: (1) design and build a realistic lane merge environment that emulated late lane merge environments employed in previous research efforts, (2) design and build realistic congested traffic behavior within the late lane merge environment, and (3) observe the objective and subjective responses of drivers to a late lane merge situation. The discussion here presents a summary of the research team's actions, the pros and cons associated with each of the aforementioned goals, and also addresses the overall purpose of utilizing the simulator.

Late Lane Merge Environment

The late lane merge environment (ME) was a three-dimensional computer-generated world through which participants drove. It included elements such as the roadway, trees, general landscape features, sky, and terrain. The first step in developing the ME was to identify 'tiles' that typify expressway driving. A tile is a computer generated 200 x 200 m square 3-D computer-generated world, which comes complete with a style of roadway (i.e., rural, urban, expressway, and suburban) and the appropriate elements. For the purpose of the present project, researchers chose tiles that depicted a three-lane expressway, shoulders, a grassy median, and no houses, buildings, or other features typically not found in an expressway environment. These tiles were joined so that the environment through which the participant drove resembled an expressway, was just over two miles in length, and met American Association of State Highway and Transportation Officials (AASHTO) standards. Figures 22 and 23 give a good idea of how the ME looked to the test subjects. Researchers added a series of traffic signs to the ME according to the specifications in the experimental procedure section of this report.

Traffic Behavior

Researchers used two phases to design and build a simulation that emulated real world traffic. Phase 1 consisted of placing the participant's vehicle two miles from the start point and in the far left lane, of placing approximately 40 ambient vehicles in the ME in front of the participant's vehicle, commanding all ambient vehicles to travel down the road in their respective lanes at 55 mph, and then having participants drive the vehicle down the road at a speed they felt comfortable with and one which did not exceed the posted speed limit. Several advantages associated with Phase 1 were immediately evident. These advantages included the fact that researchers required very little design and build time to create fairly realistic traffic behavior, researchers could quickly implement changes to the behavior of the traffic, and participants drove through this world exhibiting normative driving behavior. However, there were also several challenges with Phase 1. The challenges centered around unusual and unexpected ambient vehicle behavior, which included sudden lane changes, sudden drops in the speed of ambient vehicles, and large headway distances that allowed participants to believe they were not in heavy expressway traffic.

The purpose of Phase 2 was to continue to capitalize on the strengths and address the challenges observed during Phase 1. Phase 2 consisted of reducing the potential minimum headway distance between ambient vehicles to 1 m (not all vehicles decreased headway to 1 m). Employing this action allowed ambient traffic to more freely and realistically created a variety of random headways, which resulted in a dramatic improvement in the participants' impression that they were driving in congestion. Next, researchers forced ambient vehicles to stay in the same lane throughout their drive. This action eliminated unnatural lane changes. Researchers fixed the speed of ambient vehicles in each lane so that the right lane traveled at 50 mph, the center lane traveled at 55 mph, and the left lane traveled at 60 mph. This action, combined with reducing the number of vehicles in the left lane and increasing the number of vehicles in the center and right lanes, added dramatically to the realism and, in particular, to the impression that the left lane was traveling faster than other lanes. Other issues addressed included increasing the total number of ambient vehicles, forcing the vehicles to slow gradually (like the real world), and increasing the types of vehicles employed to include cars, vans, commercial trucks, and passenger trucks.

Driver Responses

Researchers provided several participants with five runs through the ME for Phase 1. For the first run, the experimenter instructed participants to drive in the left lane and merge with the ambient traffic at the specified merge point. Instructions for runs two through five were to execute a path of their own choosing that they felt would allow them to traverse the course and through the merge area in the least amount of time. The experimenter collected participants' objective data from the driving simulator, which included lane position, speed, and braking behavior, and subjective data in the form of an interview and questionnaire after the drive. Figure 24 shows lane position data for a typical driver in Phase 1. The typical participant remained in the left lane during Trial 1. However, for the majority of subsequent trials the participant eventually moved to the center lane, and in Trial 4, moved to the far right lane. When asked about their motives, several participants indicated they chose those lanes because they "appeared to move faster than the left lane." Participants also indicated they expected significant challenges in merging at the merge point and, by moving to the other lanes well in advance, they could avoid those problems.

The experimenter gave Phase 2 participants identical instructions as in Phase 1 and also performed the same number of trials. Figure 25 shows lane position data for a "typical" driver in Phase 2. The typical participant remained in the left lane throughout Trial 1. However, for the majority of subsequent trials the participant moved to the center lane and then moved back to the left lane. When asked 'why' they changed lanes, participants usually indicated an affinity to the lane that was moving the fastest. Participants who moved into the center lane indicated they wanted to be in a fast lane but felt approaching the merge would be easier if they were in a lane that did not end.

Utility of Driving Simulation

The primary benefit of employing a driving environment simulator is that researchers can easily, safely, and cost-effectively examine drivers' behaviors, cognitions, and perceptions in response to late lane merging maneuvers. The preliminary indication, based on a limited number of subjects, is that the DESi is a promising tool for applications such as a freeway work-zone environment. As with any simulation model or tool, calibration to real-world conditions and proper experimental procedures are necessary to obtain the best overall results. Phase 2 testing came close to replicating what researchers observed in the field tests. Still, more research is needed to optimize the DESi's effectiveness for modeling congested driving conditions like those for the Late Merge.

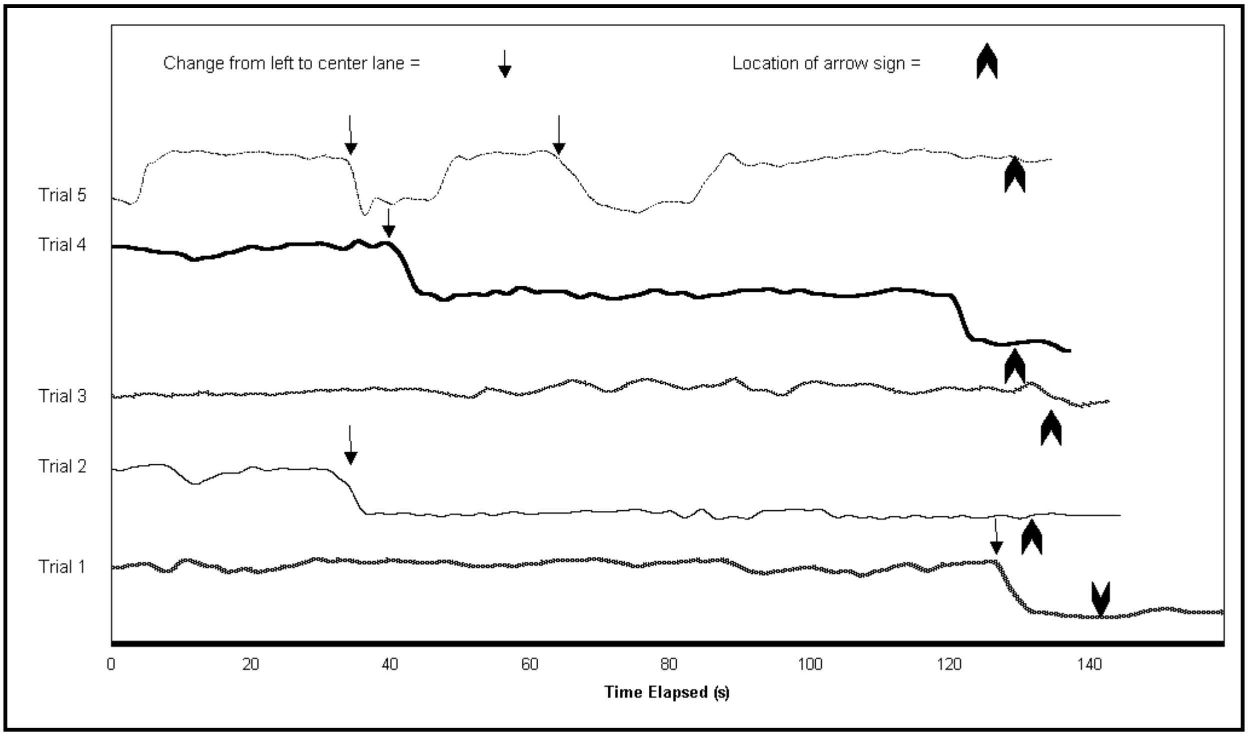

Figure 24. Lane Position Data for a Typical Driver for Phase 1.

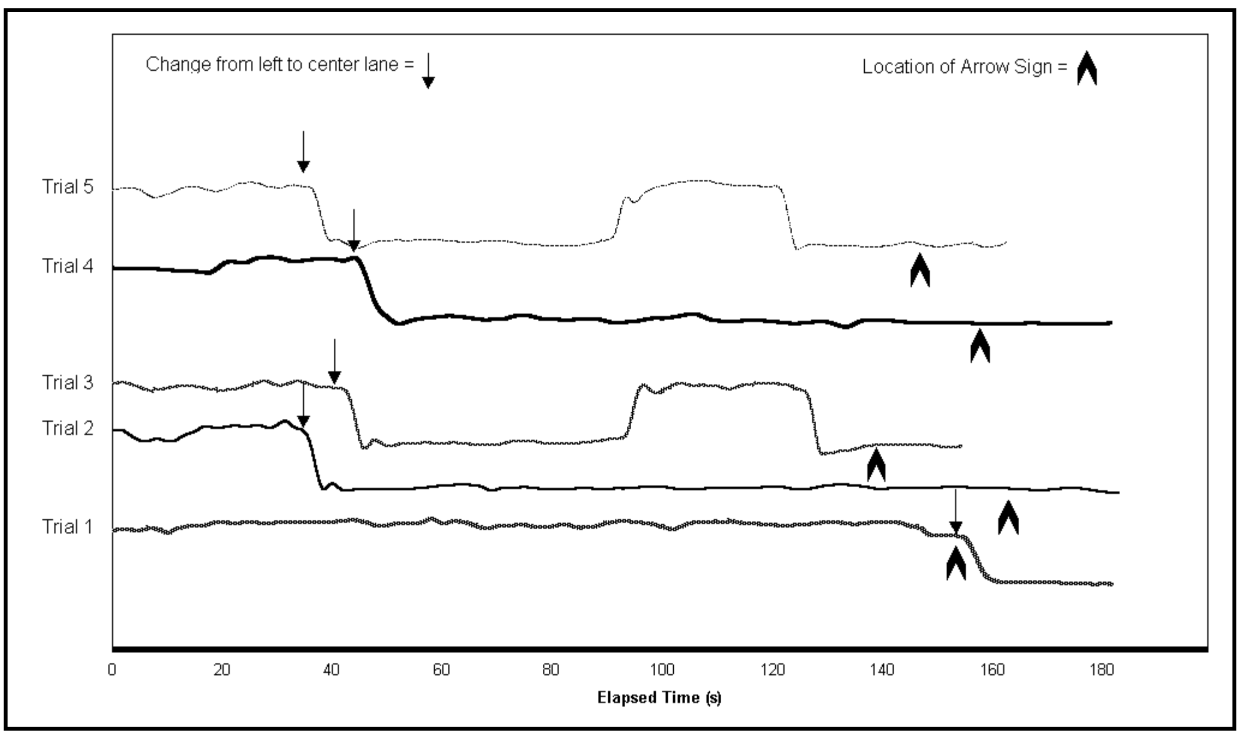

Figure 25. Lane Position Data for a Typical Driver for Phase 2.

5.3 LATE MERGE FIELD TEST

This section documents the testing of the Late Merge traffic control concept at a field site in Dallas. The first subsection provides basic site information. The second subsection describes the data collection and analysis. The final subsection presents the results of the Late Merge field test.

5.3.1 Site Information

After selecting the Late Merge as a mitigation measure for testing, the research team started the process of finding a site in the Dallas urban area. The project director contacted each of the four TxDOT area engineers in the Dallas urban area regarding their interest in participating in a field study of the Late Merge concept. Only one area engineer responded with a willingness to sponsor an evaluation at a site within their jurisdiction. The research team held a meeting with this area engineer was held to discuss candidate sites. One site, IH 35E at SH 190 (President George Bush Turnpike) was considered; however, most of the main lane closures occurred at night and this eliminated it from further consideration. Researchers selected IH 30 near Loop 12 as the site for the field studies. Specifically, researchers chose the westbound direction of IH 30 approaching the construction area between Loop 12 and MacArthur Boulevard.

Figure 26 provides a representation of the location of the IH 30 field site in relation to the entire Dallas area. The site is located approximately six miles west of the Dallas CBD. The westbound direction typically peaks during the afternoon (i.e., 4:00 to 7:00 pm) peak period as motorists commute back from downtown toward Grand Prairie, Arlington, and Fort Worth.

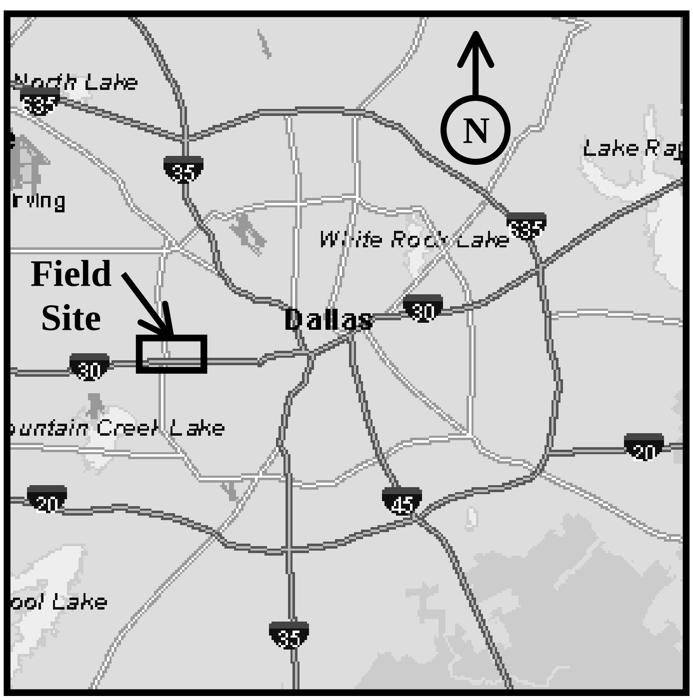

Figure 26. Late Merge Evaluation Field Site in Dallas.

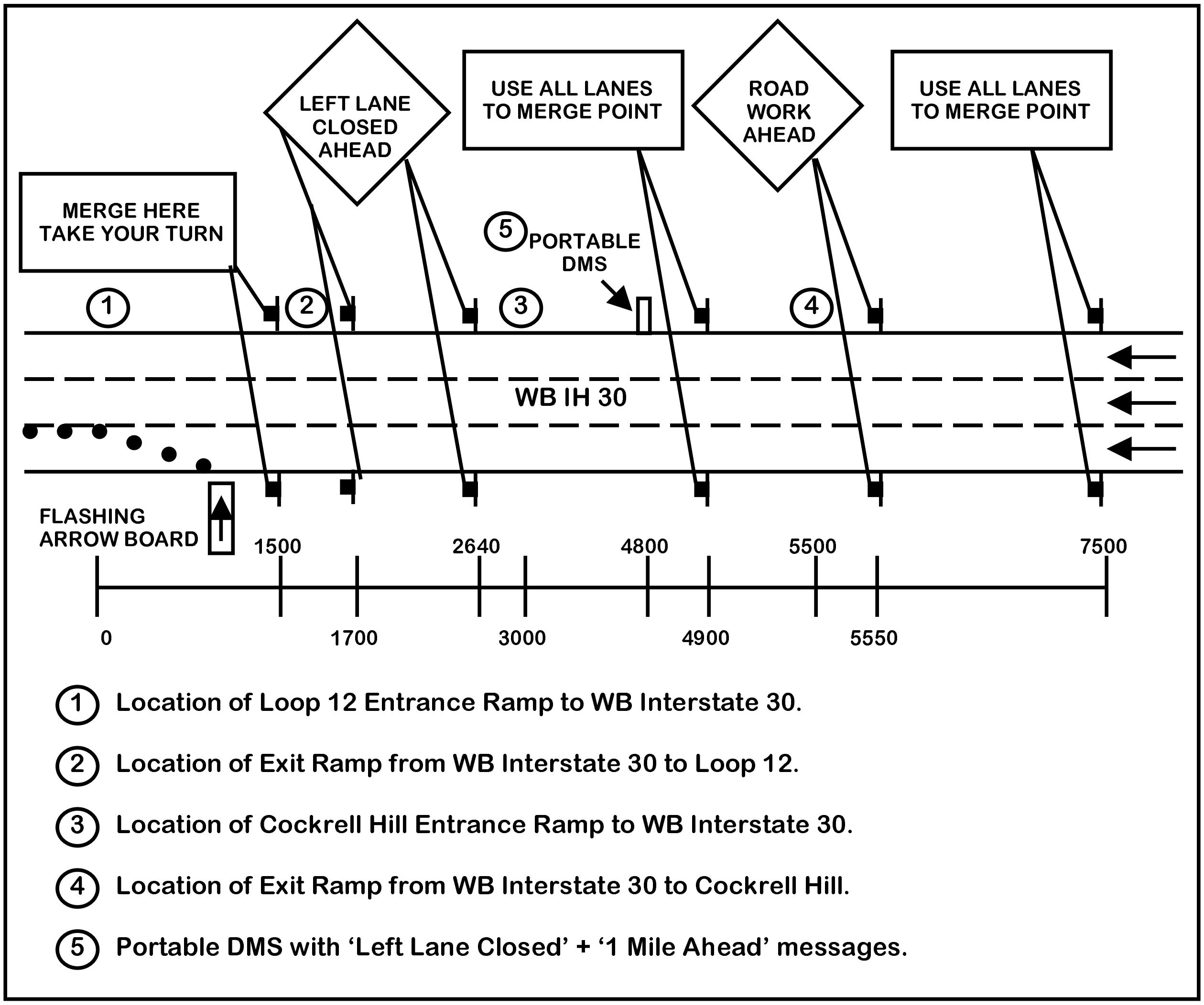

Figure 27. Westbound IH 30 Site for Late Merge Field Test.

Figure 27 shows an illustration of the westbound IH 30 main lanes on the approach to the left lane closure that occurred almost daily just prior to Loop 12. Researchers believe that this site is the first research evaluation of an urban site with a three to two-lane closure scenario. Up until this time, the Late Merge traffic control concept has only been tested on rural interstate highways with two to one-lane closure scenarios. The majority of the construction after the lane closure involved widening toward the median in an area protected by concrete barriers. The purpose of the lane closure was to allow construction vehicles to enter and exit the median construction area safely without having to compete with vehicular traffic in the left westbound IH 30 main lane.

The typical traffic control plan, in place 24 hours a day 7 days a week prior to the Late Merge evaluation, involved the following sequence of signs:

1. '*Road Work Ahead*': initial set of signs placed approximately 5500 feet in advance of the lane closure;

2. *Portable DMS*: this electronic sign, placed approximately 4800 feet in advance of the lane closure on the right side of the freeway, scrolled between the 'Left Lane Closed' and '1 Mile Ahead' messages;
3. '*Left Lane Closed*': two sets of these signs placed approximately 0.5 mile and 1700 feet in advance of the lane closure; and
4. *Flashing Arrow Board*: this device, placed at the beginning of the lane closure taper, signaled to drivers to merge to the right.

To perform the evaluation of the Late Merge concept, the research team added three new sets of signs in addition to the typical traffic control plan described in the previous list. The sign additions included:

1. '*Use All Lanes to Merge Point*': two sets of these signs placed approximately 7500 feet and 4900 feet in advance of the lane closure; and
2. '*Merge Here Take Your Turn*': final set of signs placed approximately 1500 feet in advance of the lane closure.

Researchers did not modify the spacing of the other signs and the messages used on the portable DMS for the Late Merge field study. Also, TxDOT had to modify the wording on the first two sets of Late Merge signs from 'Use <u>Both</u> Lanes to Merge Point' to 'Use <u>All</u> Lanes to Merge Point' to account for the three-lane cross section as opposed to the typical two-lane cross section used in Pennsylvania. Figure 28 shows a photograph of one of the 'Use All Lanes to Merge Point' signs installed by TxDOT for the field study. Figure 29 provides a photograph of one of the 'Merge Here Take Your Turn' signs used during the Late Merge evaluation.

Another important aspect of the site that needs attention is the schedule of lane closure activities. The Environmental Protection Agency (EPA) has classified the Dallas/Fort Worth metropolitan area as a non-attainment area based on air quality considerations. This designation mandates that TxDOT and other transportation agencies adhere to rules regarding the times of day when construction activities are allowable. Typically all construction involving lane closures must occur between 9:00 am and 4:00 pm during weekdays unless the work is for emergency-related maintenance or repairs. This timeframe is in effect in order to maintain the full capacity of freeways during the morning (6:00 to 9:00 am) and evening (4:00 to 7:00 pm) peak traffic periods so that overall system-wide congestion is minimized and air quality preserved. Due to these restrictions, contractor personnel typically initiate the lane closure at the site using traffic cones sometime between 9:00 and 10:30 am each workday. The same personnel typically pick up the cones and reopen the left lane sometime between 2:30 and 3:30 pm depending on their scheduling needs. As mentioned previously, the westbound direction of IH 30 normally peaks between 4:00 and 7:00 pm each weekday. Because contractor personnel typically pick up the lane closure in advance of this peak time, the congestion due to the lane closure is typically of a short duration (1 to 1.5 hours). The traffic conditions in the westbound direction are normally free-flow during other time periods unless there is an incident or special event. These factors made the testing at this site a challenge because the Late Merge concept is designed to work best during congested conditions, which only occur for a short duration at this particular IH 30 location.

Figure 28. 'Use All Lanes to Merge Point' Sign on IH 30 Field Site.

Figure 29. 'Merge Here Take Your Turn' Sign on IH 30 Field Site.

5.3.2 Data Collection Activities

This section describes the considerations and methods for collecting data at the IH 30 field site for the Late Merge evaluation. The research team and panel selected the Late Merge as a promising mitigation measure; however, due to the original project scope and budget the evaluation was intended to be a feasibility-type test instead of a traditional full-scale field test. Stated differently, the researchers wanted to demonstrate the potential usefulness of the Late Merge concept in an urban environment with a three- to two-lane closure scenario. In the ideal situation, the research team desired to collect three days of data before and another three days of data after the addition of the Late Merge signing in order to assess the feasibility of the Late Merge traffic control concept.

The research team formulated a data collection plan in cooperation with the TxDOT supervisor of the construction project. The TxDOT construction supervisor recommended that Fridays were the best day for data collection activities because of the typically higher volumes and congestion experienced during the afternoon time period. Researchers decided that volume distribution by lane (i.e., left, middle, and right) at three locations along the approach to the lane closure needed to be collected before and after the introduction of the Late Merge. Video recording was the method used to obtain the lane volumes. Field crews used two video trailer units and one still camera to capture data while the lane closure was in place. The three locations included:

- *Location 1*: the TxDOT video trailer (pictured in Figure 30) was stationed on the north side of the Cockrell Hill Road overpass and captured traffic at a point approximately 6000 feet away from the lane closure after the first set of 'Use All Lanes to Merge Point' signs prior to the Cockrell Hill exit ramp.
- *Location 2*: a tripod-mounted video camera was stationed on top of an embankment on the north side of the IH 30 westbound main lanes and captured traffic at a point approximately 2500 feet away from the lane closure just past the Cockrell Hill entrance.
- *Location 3*: the TTI video trailer (pictured in Figure 31) was stationed near the Loop 12 overpass on the north side of the IH 30 westbound main lanes and captured traffic approaching the merge point near the 'Merge Here Take Your Turn' signs.

Researchers believe that all three of the cameras were fairly inconspicuous to passing motorists, especially the TxDOT video trailer and the tripod-mounted camera that were both located a substantial distance away from the westbound IH 30 main lanes.

Field crews recorded video at these three locations during the lane closure from approximately 9:30 am to 3:30 pm. Due to logistics problems, including weather, rescheduling of lane closures by the contractor, and equipment availability and malfunction, the field crew only collected one day of reliable before (Friday, July 27) and after (Friday, August 3) data. This data fell short of the desired amount; however, researchers still could assess the feasibility and usefulness of the Late Merge on a more limited basis than originally anticipated.

Field data collection personnel also monitored the tail end of the queue during congested conditions in order to quantify the maximum queue length created by the lane closure. Researchers verified the data collected in the field by looking at the videotapes of the congested time periods and checking the field measurements.

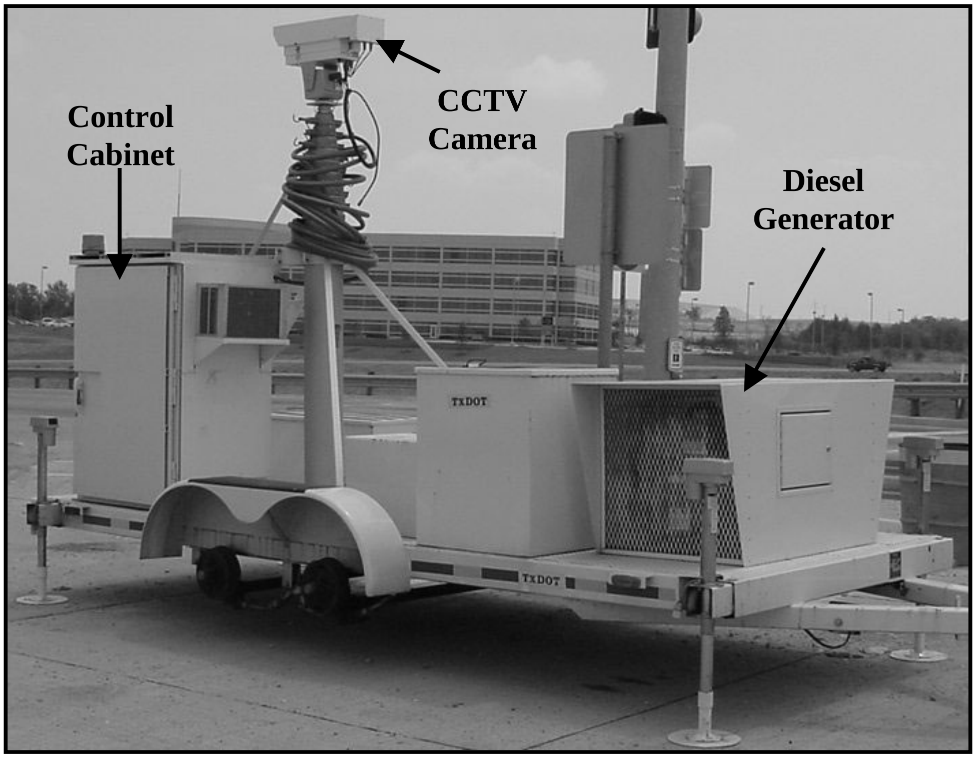

Figure 30. TxDOT Video Trailer Stationed on the Cockrell Hill Overpass.

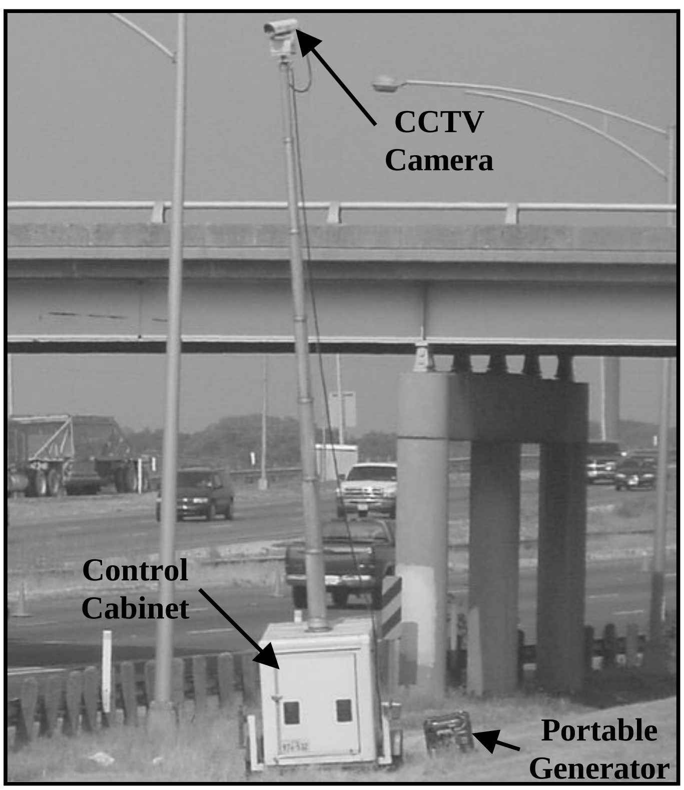

Figure 31. TTI Video Trailer Stationed Near the Loop 12 Overpass.

5.3.3 Evaluation Results

The following subsections describe the evaluation results for the Late Merge test at the IH 30 field site.

Before Data Summary

The research team collected the before data on Friday, July 27, 2001. A timeline of important events during the collection of the before data is provided below:

- The taping began at approximately 10:00 am after the westbound lane closure was already in place.
- At approximately 2:00 pm, the video showed the first sign of congestion as a queue developed near the merge point (camera Location 1).
- At 2:44 pm the tail of the queue reaches back to the Location 2 data collection site (approximately 0.5 mile) for the first time of the day.
- At 2:47 pm the tail of the queue reaches the Cockrell Hill exit ramp (camera Location 3). The queue fluctuates between the Cockrell Hill overpass (0.75 mile) and the Cockrell Hill exit ramp (1 mile) for the next 30 minutes.
- At 3:18 pm the queue begins to grow past the Cockrell Hill exit ramp and extends all the way past the first set of the ‘Use All Lanes to Merge Point” signs. This maximum queue length (estimated as approximately 7800 feet) occurred at 3:29 pm (camera Location 3).
- At 3:30 pm the queue begins to dissipate as all lanes are full but begin to pick up speed in unison (camera Location 3).
- At 3:32 pm the contractor personnel have picked up the last of the traffic cones and the left lane is now fully open for all traffic to use (camera Location 1).
- At 3:41 pm the study section has returned to basically free-flow conditions with no queue present.

After Data Summary

The research team collected the after data on Friday, August 3, 2001. TxDOT installed the Late Merge signs on the afternoon of Wednesday, August 1; therefore, motorists had one day of exposure (August 2) to the signs before data was collected. A timeline of important events during the collection of the after data is provided below:

- The taping began at approximately 9:30 am after the westbound lane closure was already in place.
- At approximately 2:14 pm the first sign of congestion was seen as a queue developed near the merge point (camera Location 1).
- At 2:20 pm three trucks ride abreast on the approach to the merge point with a large gap in front of them, then let the truck in the left lane merge over to the middle lane near the merge point.
- At 2:24 pm the tail of the queue reaches back to the Location 2 data collection site (approximately 0.5 mile) for the first time of the day. The queue fluctuates between this location and the merge point for the next 40 minutes until it begins to grow again.

- At 3:16 pm the tail of the queue reaches the Cockrell Hill exit ramp (approximately 1 mile) for the first time of the day.
- At 3:18 pm the contractor personnel have picked up the last of the traffic cones and the left lane is now fully open for all traffic to use (camera Location 1).
- At 3:22 pm the queue reaches the maximum length approximately 500 feet past the Cockrell Hill exit ramp (6000 feet).
- At 3:24 pm the entire study section is beginning to recover and the congestion is quickly dissipating.

Comparison of Before vs. After Data

The research team performed the comparison of the before versus after data to evaluate the feasibility of the Late Merge traffic control concept in urban conditions. It should be emphasized that with only one day of before and after data, only limited conclusions can be drawn. Researchers did not attempt to perform any statistical evaluation of the data because of the small sample size and overall scope of the study.

The next few subsections break the comparison down into logical pieces. The first subsection presents the results of the comparison of the timeline data, specifically the onset of congestion and queue length data. The final subsection provides the results of the comparison of the lane distribution and volume data.

<u>Queuing and Onset of Congestion</u>

The timeline data presented in the previous section highlights benchmark events such as the onset of congestion, queue lengths reaching data collection checkpoints, and the estimated time and length of the maximum queue. Table 12 presents a comparison of these benchmark events for both the before and after scenarios.

Table 12. Comparison of Before and After Benchmark Event Data.

Benchmark Event Description	Before	After
Onset of congestion (first queue present at the merge point)	2:00 pm	2:14 pm
Tail of queue reaches camera Location #2 for first time	2:44 pm	2:24 pm
Tail of queue reaches camera Location #3 for first time	2:47 pm	3:16 pm
Time of maximum queue length	3:29 pm	3:22 pm
Length of maximum queue length (feet)	7800	6000
Lane closure removed and all lanes are open for traffic	3:32 pm	3:18 pm
Return to free-flow conditions (no queue in the study area)	3:41 pm	3:24 pm
Duration of congestion (total minutes)	101	70

The comparison revealed that the Late Merge scenario delayed the onset of congestion at the merge point by approximately 14 minutes. The queue propagated back from the lane closure to camera Location 2 (2500 feet) 20 minutes faster in the after case; however, the queue reached camera Location 3 (5500 feet) almost 30 minutes faster in the before case. The length of the maximum queue was approximately 7800 feet in the before case versus 6000 feet in the after case. It should be mentioned that the contractor removed the lane closure approximately 15 minutes earlier in the after case meaning that the queue did not have as much time to grow.

In both cases, the conditions returned to normal (i.e., no queue present) very quickly after lane closure was picked up and all three lanes were available for travel. This shows that congestion would not exist at this site without the lane closure. The total duration of congestion, calculated from the onset to normal conditions being restored, was about 0.5 hour longer in the before case.

Lane Distribution and Volume Data

Researchers reduced the 36 hours of videotapes into volume counts by lane at the three locations. Researchers recorded volumes in five-minute time increments and then performed the analysis.

Table 13 provides the before and after comparison of volume and lane proportion data for the entire day. Researchers calculated the proportion data by lane for data collected between 10:00 am and 3:15 pm—the common data set for the two different Fridays. The far right column shows the calculated percent difference between the before and after proportions. It is evident that the before and after proportions are very similar, especially at Location 2 and Location 3, further away from the merge point. The largest percent difference, which is measuring the change in proportion of volume within a lane, occurred at Location 1 near the merge point where 3.3 percent more vehicles used the left lane with the Late Merge signing in place. Another significant finding for the all day data is that the volume level was lower in the after case for Location 3 (3.2 percent) and Location 2 (1.9 percent); however, the volume level was higher for Location 1 (3.6 percent). This data indicates that more vehicles were able to pass the merge point with the Late Merge in effect. The total volume levels between the three locations change because of the presence of ramps (Cockrell Hill exit/entrance and Loop 12 exit) within the data collection area. These ramps also influence motorist lane choice. The volume and lane proportion data for the entire day suggested that the Late Merge concept did influence driver behavior, especially near the merge point.

Table 13. Late Merge Evaluation: Total Volumes and Lane Proportions for the Entire Day (10:00 am to 3:15 pm).

Data Location	Lane Designation	Before Proportion	After Proportion	Percent Difference
Location 3 Furthest	Left Lane	33.8	32.7	-1.1
	Middle Lane	37.3	38.6	+1.3
	Right Lane	28.9	28.7	-0.2
	Total Volume	18,257	17,673	-3.2
Location 2 Midpoint	Left Lane	24.7	23.3	-1.4
	Middle Lane	39.2	38.7	-0.5
	Right Lane	36.1	38.0	+1.9
	Total Volume	18,572	18,211	-1.9
Location 1 Near Merge	Left Lane	7.0	10.3	+3.3
	Middle Lane	61.4	60.5	-0.9
	Right Lane	31.6	29.2	-2.4
	Total Volume	13,328	13,808	+3.6

Table 14 provides the before and after comparison of volume and lane proportion data for the congested conditions. Researchers calculated the proportion data by lane for data collected between 2:00 and 3:15 pm—the data set where a queue was present and the lane closure was still in place. The far right column shows the calculated percent difference between the before and after proportions. The before and after proportions for Location 2 and Location 3 are still somewhat similar during the congested time period; however, there is more disparity than with the data for the entire day. The largest percent difference during the congested time period also occurred at Location 1 near the merge point where more vehicles used the left (2.9 percent) and center (3.5 percent) lanes with the Late Merge signing in place. Following the same trends as the all day data, the congested data showed that:

- the volume level was lower in the after case for Location 3 (4.2 percent) and Location 2 (4.8 percent); however, the volume level was higher for Location 1 (4.4 percent);
- more vehicles were able to pass the merge point with the Late Merge; and
- the volume and lane proportion data for the congested time period suggested that the Late Merge traffic control concept did influence driver behavior, especially near the merge point.

Table 14. Late Merge Evaluation: Total Volumes and Lane Proportions for Congested Conditions (2:00 pm to 3:15 pm).

Data Location	Lane Designation	Before Proportion	After Proportion	Percent Difference
Location 3 Furthest	Left Lane	32.7	33.5	+0.8
	Middle Lane	35.7	37.5	+1.8
	Right Lane	31.6	29.0	-2.6
	Total Volume	4853	4651	-4.2
Location 2 Midpoint	Left Lane	29.4	27.0	-2.4
	Middle Lane	35.0	35.1	+0.1
	Right Lane	35.6	37.8	+2.2
	Total Volume	5201	4954	-4.8
Location 1 Near Merge	Left Lane	11.1	14.0	+2.9
	Middle Lane	45.6	49.1	+3.5
	Right Lane	43.3	36.9	-6.4
	Total Volume	3239	3382	+4.4

CHAPTER 6

STUDY CONCLUSIONS AND RECOMMENDATIONS

This chapter provides the study conclusions and recommendations for the Understanding Road Rage research project.

6.1 STUDY CONCLUSIONS

Bottleneck Improvements

- Bottlenecks on freeway facilities are a significant source of traffic congestion as evidenced by recent national studies conducted by the American Highway Users Alliance, American Association of Automobiles, and the Texas Transportation Institute.
- Several of the focus groups composed of regular freeway commuters emphasized bottlenecks as a significant source of stress and frustration, sometimes even going so far as to name locations within the Dallas/Fort Worth metropolitan area and then to offer suggestions for improvements.
- The telephone survey revealed that building more freeway lanes where needed and building more freeway lanes at bottleneck locations were two of the three highest rated countermeasures for effectively reducing the stress of driving.
- Many bottlenecks only require slight modifications such as striping, shoulder conversion, or decreased lane widths to relieve the traffic congestion.
- Several of the case study bottleneck locations had high benefit-to-cost ratios based on the comparison of construction cost versus the delay savings created by improved operations.
- Survey data collected before the Loop 12 bottleneck improvement showed that a high level of stress existed at this location. In fact, almost two in three respondents indicated a high level of stress with an average stress level of almost 8 on a 10-point scale.
- Survey data collected after the Woodall Rodgers bottleneck improvement revealed that a majority of drivers perceived the benefits of reduced aggressive driving and travel time. Also, almost half (43.5 percent) of the drivers sensed a decrease in their personal stress level. These findings corroborate the operational data that indicated that travel times were reduced.

Using Photogrammetry to Expedite Incident Investigation

- The use of photogrammetry, the practice of obtaining measurements from photographs, is still a relatively new practice for investigation of traffic incidents in the United States.
- Focus group participants mentioned frustration with incident delays and had questions about the effectiveness of all response agencies in opening lanes as quickly as possible.
- The telephone survey revealed that clearing incidents and other obstructions faster was the top-rated countermeasure for effectively reducing the stress of driving.
- Not much evaluation data exists to document the performance of photogrammetry in actual field investigations.

- Initial results, obtained from the Dallas County Sheriff Department and the Chattanooga Police Department, suggest that photogrammetry has produced a positive impact on getting incidents cleared more quickly from the roadway travel lanes. Data from Chattanooga indicated that the average clearance time was reduced by almost 60 percent, equating to over an hour difference per incident.
- Other benefits of using photogrammetry gathered from the Dallas County and Chattanooga case studies were: (1) less personnel required to complete the investigation compared to traditional techniques, (2) reliable measurement accuracy, (3) cost-effectiveness, and (4) scene measurements are only performed on approximately 20 percent of all incident investigations.
- One of the drawbacks of photogrammetry noted by both case study participants was that they spend more time in the office calculating the measurements and producing the scale diagram than using traditional methods.

Late Merge Evaluation

- In several of the focus groups, participants placed special emphasis on traffic merging problems. Participants cited merging in areas with lane drops, mainly in construction areas where queuing situations often arise, as being particularly problematic.
- Merging behavior on the approach to a lane closure is the subject of great debate in the media and within the transportation profession. Typical traffic control signing on the approach to a freeway lane closure tells the driver well in advance the closing lane(s) and the distance to the beginning of the merge point. This information seems to create two distinct camps of motorists: one group that vacates the closing lane as soon as possible and the other group that stays in the closing lane as long as possible. These distinct groups exhibit vastly different behaviors, but both seem to perceive their way of driving to be the right way.
- Transportation authorities in the United States and throughout the world have taken notice of this problem and have developed a number of innovative merge strategies designed to provide better understanding of expectations and reduce the stress and aggression for drivers approaching work zones. It is interesting to note that even transportation professionals appear divided on the optimal method to merge on the approach to a lane closure.
- The telephone survey revealed that merging difficulties accounted for over half of the number one volunteered stress-producers, and a majority (62.1 percent) of telephone survey respondents rated improving signs and pavement markings in advance of lane closures as a highly effective countermeasure.
- The Late Merge, a traffic control concept for work zones that is designed to encourage drivers to use all available lanes to the merge point and then take turn turns near the lane closure, was selected as a strategy for testing in an urban environment.
- The use of the driving environment simulator, DESi, to evaluate the Late Merge allowed researchers to examine driver behavior. The preliminary indication, based on a limited number of subjects, is that the DESi is a promising tool for applications such as a freeway work-zone environment. As with any simulation model or tool, calibration to real-world conditions and proper experimental procedures are necessary to obtain the best overall results. Still, more research is needed to optimize the DESi's effectiveness for modeling congested driving conditions like those for the Late Merge.

- The IH 30 field site was not the optimal site for a Late Merge evaluation because of the small window of congested conditions (approximately 1.5 hours) and possible driver familiarity created by the routine lane closure activities.
- The data collection effort was limited compared to previous evaluations of the Late Merge in Pennsylvania due to project constraints and the overall objective of testing for feasibility instead of proof of concept.
- The comparison revealed that the Late Merge scenario delayed the onset of congestion at the merge point by approximately 14 minutes.
- The length of the maximum queue was shortened from approximately 7800 feet in the before case to 6000 feet in the after case.
- In both before and after cases, the conditions returned to normal (i.e., no queue present) very quickly after lane closure was picked up and all three lanes were available for travel. This finding shows that congestion would not exist at this location without the lane closure.
- The total duration of congestion, calculated from the onset to normal conditions being restored, was about a 0.5 hour longer in the before scenario.
- More vehicles were able to pass the merge point with the Late Merge traffic control in effect.
- The volume and lane proportion data for the entire day and the congested time period suggested that the Late Merge concept did influence driver behavior, especially near the merge point with more vehicles staying in the left lane in accordance with the Late Merge signing.
- Although not enough data (one day of before and one day of after) were collected to support significant conclusions on the operational effectiveness of the Late Merge, researchers believe the concept is feasible for application in Texas based on the successful trial at an urban site with a three- to two-lane closure scenario.

6.2 STUDY RECOMMENDATIONS

- TxDOT should increase efforts to fund and implement bottleneck improvement projects and other early action projects that can have positive impacts on reducing driving stress, aggressive driving behaviors, and travel time.
- TxDOT, in cooperation with the local media outlets such as the *Dallas Morning News*, should continue to gather driver feedback about bottleneck locations and the effectiveness of improvement projects.
- The researchers recommend further implementation of photogrammetry, perhaps via pilot projects with several police agencies in major urban areas throughout the state of Texas, to validate the promising preliminary results exhibited by the Dallas County Sheriff Department and the Chattanooga Police Department. TxDOT should pursue grants for funding through avenues such as the ITS peer-to-peer (money available for training) and Congestion Mitigation and Air Quality (money available for equipment and supplies) programs.
- When the driving environment simulator is used on future research projects similar in scope, researchers suggest further calibration to optimize modeling of congested conditions.
- The researchers recommend further testing of the static Late Merge at sites throughout Texas to more comprehensively investigate the effectiveness of the strategy. This testing should include both three- to two-lane and two- to one-lane scenarios. Researchers believe that shorter-term work zones (e.g., maintenance activities such as pavement overlays, etc.) would make good test sites because drivers would not have preconceived ideas about how to drive approaching the lane closure.

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APPENDIX A

HUMAN SUBJECTS CONSENT FORM

LANE MERGING MANEUVERS IN A DRIVING ENVIRONMENT SIMULATOR

I have been invited to participate in an experiment designed to examine lane-merging maneuvers in a driving environment simulator. I am being asked to drive in a normal fashion obeying all traffic laws. The experiment is to take place in a driving environment simulator in Room 320 of the Gibb Gilchrist Building. I am aware the experiment will last approximately 60 minutes. I am being selected as a possible participant because I have normal or corrected to normal vision, I am at least 18 years of age, I possess a valid driver's license, and I have no apparent limitations impeding my ability to drive. I am aware there will be a total of 24 participants in this study and that data collection will occur from June 20, 2001 until June 30, 2002. I have been instructed to read this form and ask any questions I may have before agreeing to participate in the study.

This experiment is being conducted by Michael P. Manser, of the Texas Transportation Institute (TTI), part of the Texas A&M University System. The Texas Department of Transportation is funding this experiment.

Background Information: The purpose of this study is to examine lane-merging maneuvers in a driving environment simulator.

Procedures: If I agree to be in this study, I am asked to participate in an introductory session, a practice session, an experiment session, and a debriefing session.

If I agree to be in this study, I voluntarily agree to be videotaped during the practice session and the experiment session during my drives. The videotape will include a view of my head and shoulders, my hands as they interact with the steering wheel, my feet as they interact with the accelerator and brake peddles, and the computer generated world in which I am driving. I understand the information added to each tape will include an identification number for me, my age, my sex, the title of the experiment, and that no other personal information will be included. I understand that the tapes will be used only to determine my behavioral responses to driving and for the purposes of documentation (verification the experiments were conducted). The individuals who will have access to these tapes to determine behavior responses will include Michael P. Manser and Jacqueline Jenkins. The tapes will be kept for a period of three years in a locked file cabinet in Room 308 Gibb Gilchrist Building. After all data is collected and the three-year period has elapsed, the tapes will be erased using a magnetic tape eraser. I understand that portions of the video/audio tape may be used for presentation purposes at professional conferences. I understand that if I refuse to be video/audio taped I cannot participate in this study.

______ *Initial*

______ *Date*

Introductory Session: During the introductory session I will read the consent form. I will indicate my willingness to continue with the experiment by signing the form. Before proceeding, I will receive a copy of the form. I will also be asked to complete a simulator-induced discomfort pre-screening questionnaire, a general driving questionnaire, a standard visual acuity test, a standard contrast sensitivity test, and a standard color vision test.

Practice Session: During the practice session I will be provided an information sheet about the simulator and instructions on performing the practice session. This practice session is to provide me the opportunity to become familiar with driving the simulator. This session will last approximately five minutes.

Experiment Session: During the experiment, which will be conducted in the simulator, I will be asked to drive through four computer-generated worlds consisting of expressways.

Debriefing Session: Following the experiment, I will be asked to complete a Post-Experiment Simulator Induced Discomfort Questionnaire. The purpose of the questionnaire is to determine the extent of simulator induced discomfort occurrences exhibited by those who participate in experiments involving the driving environment simulator. In addition, I will be asked questions about my performance in the driving environment simulator. Lastly, before leaving, I will be provided a debriefing packet, which will provide contact information regarding the study.

Possible Discomforts: I understand that the only risk associated with this study is a temporary condition named 'Simulator Induced Discomfort' (SID) which is characterized by feelings of dizziness and increased body temperature. The potential for this discomfort is minimal as it only affects about 3 to 5 persons out of every 100 under the driving conditions to be tested. I understand that I am to indicate to the investigator if I experience any of these symptoms, and that the study will be stopped to prevent any further discomfort to me. I also understand that it is my right to stop the study at any time for any reason without any repercussion.

Confidentiality: I understand the records of this study and the video footage will be kept private. In any sort of report that might be published, no information will be included which may make it possible to identify me. I understand the research records will be kept in a locked file, accessible only to the principal investigator.

Voluntary Nature of the Study: My decision whether or not to participate will not affect my current or future relations with the Texas Transportation Institute, Texas A&M University, or the Texas A&M University System. If I decide to participate, I am free to withdraw at any time without affecting those relationships.

______ *Initial*

______ *Date*

LANE MERGING MANEUVERS
IN A DRIVING ENVIRONMENT SIMILATOR

Payment: I understand that if I accept payment for participating in this study, the fact that I participated in this study may be obtained under the Texas Open Records Act, even though any information that I gave to the investigator is confidential.

As a non-Texas Transportation Institute employee, I understand that upon the completion of the introductory session, the practice session, the experiment session, and the debriefing session, I will receive payment of $10 for participation. However, if after reading the Simulator Induced Discomfort Pre-Screening Questionnaire, I wish not to participate in the experiment I will still receive $10. If any of the three vision tests precludes my participation, I will still receive payment of $10. If I experience Simulator Induced Discomfort during the practice session or any portion of the experiment session, the experiment will be stopped and I will receive $10.

If I decide not to complete all portions of the experiment for other reasons, compensation will not be awarded. If I choose to refuse to be video/audio taped the experiment will be stopped and I will not receive compensation.

I understand that payment will be included with the debriefing packet, which I will receive prior to leaving the test location. I will acknowledge receipt of payment by signing a receipt form.

As an employee of the Texas Transportation Institute I understand that I will not receive any compensation, credit, compensation time, or any other rewards for participating in this study.

Contacts and Questions: The researcher conducting this study is Michael P. Manser. If I have questions now or later, I may contact Michael P. Manser at the Texas Transportation Institute, Texas A&M University, College Station, TX 77843-3135, (979) 862-3311.

I will be given a copy of this form for my records.
A copy of this form will be given to me prior to my proceeding with the experiment.

I understand this research study has been reviewed and approved by the Institutional Review Board - Human Subjects in Research, Texas A&M University. For research-related problems or questions regarding subjects' rights, the Institutional Review Board may be contacted through Dr. Michael W. Buckley, Director of Support Services, Office of the Vice President for Research at (979) 458-4067.

Statement of Consent: I have read and understand the explanation provided me. I have had all my questions answered to my satisfaction, and I voluntarily agree to participate in this study. I have been given a copy of this consent form.

______________________________ ___________
Signature of Research Participant Date

______________________________ ___________
Signature of Principal Investigator Date

APPENDIX B

SIMULATOR SICKNESS PRE-SCREENING QUESTIONNAIRE

LANE MERGING MANEUVERS
IN A DRIVING ENVIRONMENT SIMILATOR

SIMULATOR SICKNESS PRE-SCREENING QUESTIONNAIRE

This study will require you to drive in a simulator. In the past, some participants have felt uneasy after participating in studies using the simulator. To help identify people who might be prone to this feeling, we would like to ask the following questions.

- Do you or have you had a history of migraine headaches? yes no
  If yes, please describe: ____

- Do you or have you had a history of claustrophobia? yes no
  If yes, please describe: ____

- Do you or have you had a history of motion sickness? yes no
  If yes, please describe: ____

APPENDIX C

PRACTICE SESSION INSTRUCTIONS

LANE MERGING MANEUVERS
IN A DRIVING ENVIRONMENT SIMULATOR
PRACTICE SESSION INSTRUCTIONS

Currently, you are seated in the driving environment simulator (DESi). It is an interactive simulator, which means the driving scenes you experience react to your steering and pedal inputs to provide a realistic driving experience. During your drive in the simulator, please drive in a normal fashion and obey all traffic laws.

Your task is to get comfortable with driving in a simulated driving environment. The driving scene that will be presented to you begins with the simulator vehicle stopped at an intersection. You are to start the vehicle, put it into ‘drive’, and when the light turns green, proceed through the driving environment by following the car traveling in front of you. Please continue to follow the lead car at a comfortable distance. After a couple of minutes the lead car will pull off the road. Your task is to continue driving down the road. After a couple more minutes the screens will turn black. At that time please turn your attention to the experimenter. The practice session will take approximately five minutes.

If you have any questions regarding the practice session please consult the experimenter. Otherwise, acknowledge that you are ready by telling the experimenter to begin the driving scene.

APPENDIX D

EXPERIMENTAL INSTRUCTIONS

LANE MERGING MANEUVERS
IN A DRIVING ENVIRONMENT SIMULATOR
EXPERIMENTAL INSTRUCTIONS

You are now asked to complete an experimental driving scene. Your task is to drive through the scene as you normally would drive in the real world at 50 mph. As before, drive through the scenes in a normal fashion obeying all traffic signs and laws. Please do not deviate from the directed course.

Task One

Your task is to drive through the scene, obeying all traffic signs, and traffic laws. Please try to complete the scenarios as you would normally in the real world. Do not drive with undue aggression or undue conservatism.

When the driving scene begins, the simulator vehicle will be stopped on the side of the roadway. Place the vehicle in ‘drive’, drive onto the roadway, and proceed through the driving environment at 50 mph. At some point during your drive you will approach a construction area which will require you to merge. Please obey all traffic signs. The experimenter will indicate to you when the drive has been completed. At that time please bring the vehicle to a complete stop, place it in ‘park’, and direct your attention to the investigator. This experiment session will take approximately 20 - 25 minutes.

If you have any questions regarding your task in the experiment consult the experimenter. Otherwise, acknowledge that you are ready by telling the experimenter to begin the driving scene.

APPENDIX E

SIGN DETAILS AND SPECIFICATIONS FOR LATE MERGE SIMULATION

Purpose

The purpose of this Appendix is to detail the specifications of 12 different signs used in the driving simulator for the Understanding Road Rage project. The title of each sign is presented in larger bold font at the top of each page.

Property Definitions

Sign Height:	The vertical length of a sign.
Sign Width:	The horizontal length of a sign.
BG Color:	The color of a sign's background.
FG Color:	The color of any text or drawings on the sign.
Font Height:	Height of sign's text.
Font Width:	Width of sign's text.
Border:	Does the sign have a border?
Border Width:	Width of border.
Border Color:	Color of the border.
Distance from Ground:	Distance between the ground and the bottom of a sign.
Distance from Road:	Distance between roadway and the sign.
Text on Sign:	The characters that will be on the sign.

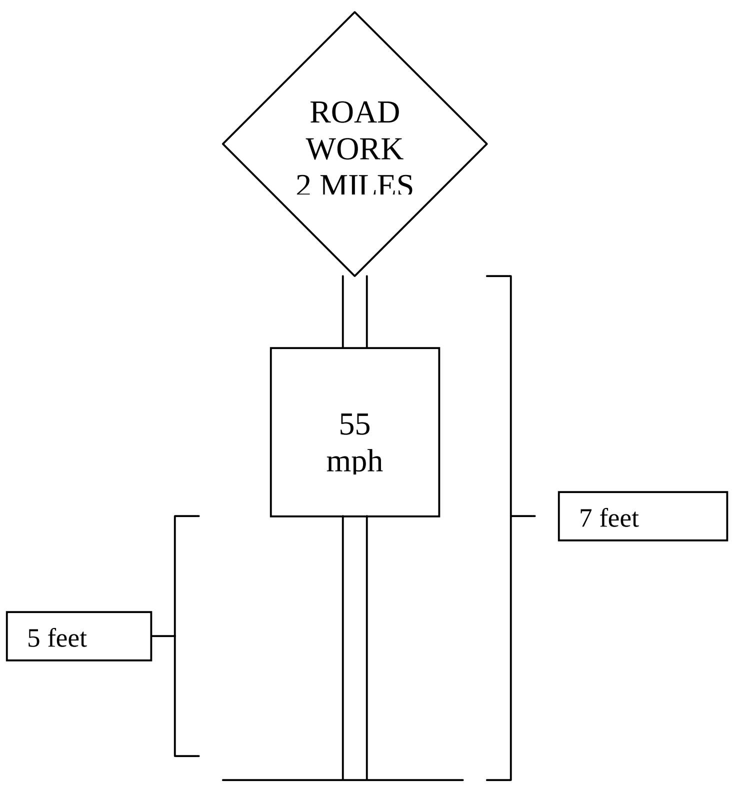
SIGN W20-1-A (ROAD WORK 2 MILES)

Sign Properties

Height:	4 ft.
Width:	4 ft.
BG Color:	Orange
FG Color:	Black
Font Height:	7 inch
Font Width:	Series D (25% of letter height)
Border:	Yes
Border Width:	1.25 inch
Border Color:	Black
Distance from Ground:	7 ft.
Distance from Road:	2 ft.
Text on Sign:	ROAD WORK 2 MILES

Assumptions:

Sign Schematic:



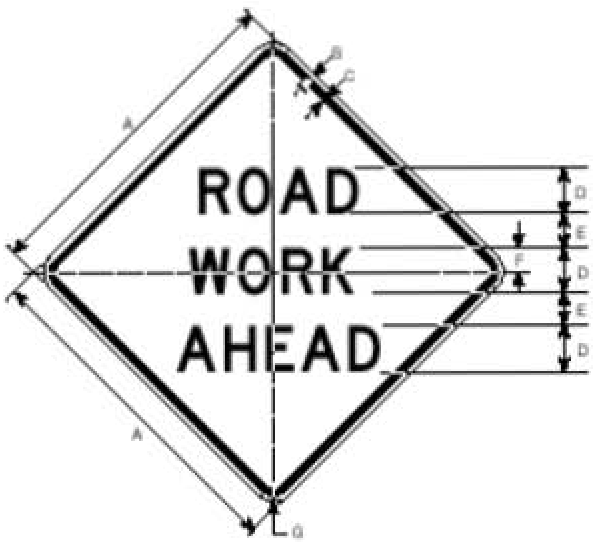
Additional Notes:

This sign has a W13-1 (55 mph speed limit) sign attached to it.

The following diagram illustrates this signs general properties, but it may have differences from the requested model.

W20-1

12/94



DIMENSIONS (MILLIMETERS)						
A	B	C	D	E	F	G
750	13	19	100D	72	66	47
900	16	22	125D	88	81	56
1200	22	31	175D	119	113	75

DIMENSIONS (INCHES)						
A	B	C	D	E	F	G
30	1/2	3/4	4D	2 7/8	2 5/8	1 7/8
36	5/8	7/8	5D	3 1/2	3 1/4	2 1/4
48	3/4	1 1/4	7D	4 3/4	4 1/2	3

COLORS

LEGEND - BLACK (NON-REFL.)
BACKGROUND - ORANGE (REFL.)

W20-1
1200 x 1200 mm
(48 x 48 in)

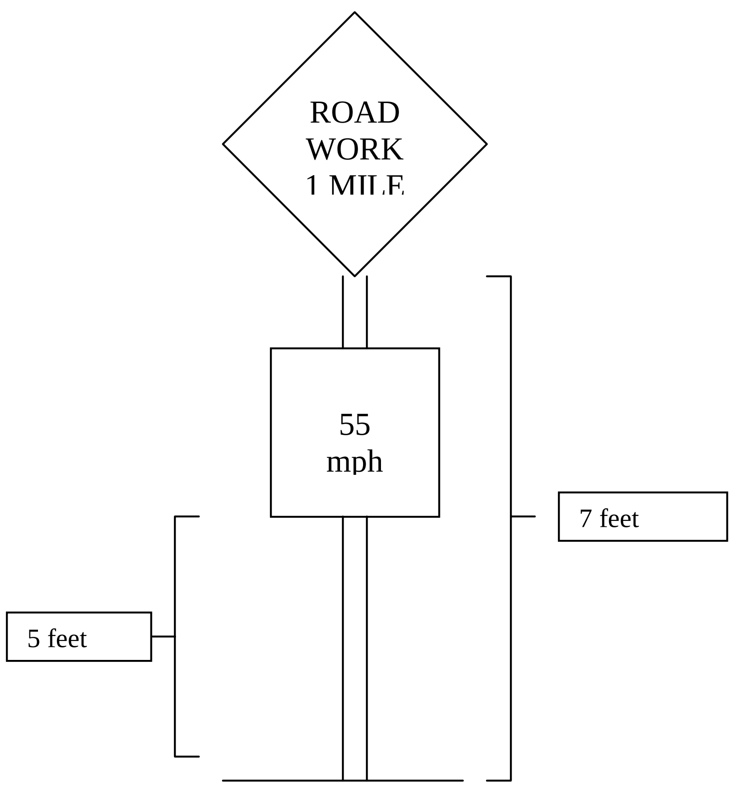
SIGN W20-1-B (ROAD WORK 1 MILE)

Sign Properties

Height:	4 ft.
Width:	4 ft.
BG Color:	Orange
FG Color:	Black
Font Height:	7 inch
Font Width:	Series D (25% of letter height)
Border:	Yes
Border Width:	1.25 inch
Border Color:	Black
Distance from Ground:	7 ft.
Distance from Road:	2 ft.
Text on Sign:	ROAD WORK 1 MILE

Assumptions:

Sign Schematic:



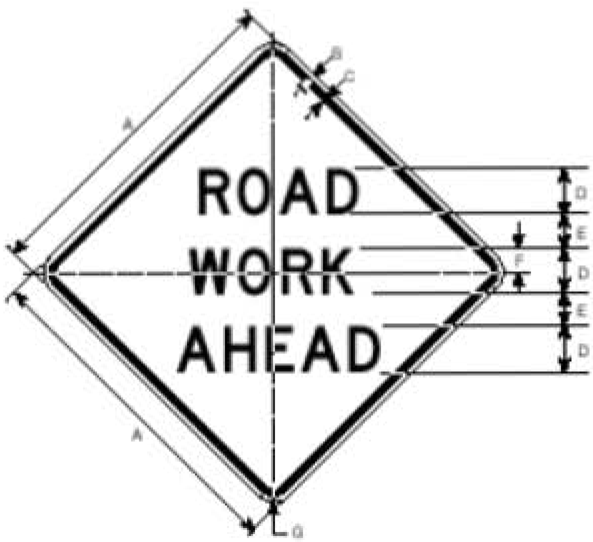
Additional Notes:

This sign has a W13-1 (55 mph speed limit) sign attached to it.

The following diagram illustrates this sign's general properties, but it may have differences from the requested model.

W20-1

12/94



DIMENSIONS (MILLIMETERS)						
A	B	C	D	E	F	G
750	13	19	100D	72	66	47
900	16	22	125D	88	81	56
1200	22	31	175D	119	113	75

DIMENSIONS (INCHES)						
A	B	C	D	E	F	G
30	1/2	3/4	4D	2 7/8	2 5/8	1 7/8
36	5/8	7/8	5D	3 1/2	3 1/4	2 1/4
48	3/4	1 1/4	7D	4 3/4	4 1/2	3

COLORS

LEGEND - BLACK (NON-REFL.)
BACKGROUND - ORANGE (REFL.)

W20-1
1200 x 1200 mm
(48 x 48 in)

SIGN W13-1 (55 MPH)

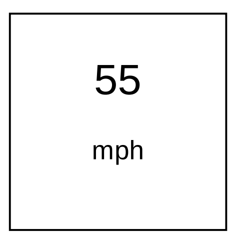
Sign Properties

Height:	2 ft.
Width:	2 ft.
BG Color:	Orange
FG Color:	Black
Font Height:	10 inch for numbers and 4 inch for MPH text
Font Width:	Series E (25% of letter and number height)
Border:	Yes
Border Width:	5/8 inch
Border Color:	Black
Distance from Ground:	5 ft.
Distance from Road:	N/A
Text on Sign:	55 mph

Assumptions:

- Sign will require 5 foot post.

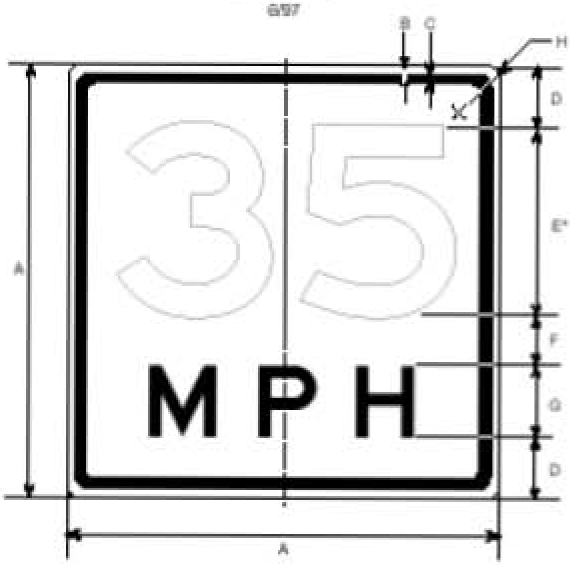
Sign Schematic:



Additional Notes:

The following diagram illustrates this sign's general properties, but it may have differences from the requested model.

W13-1

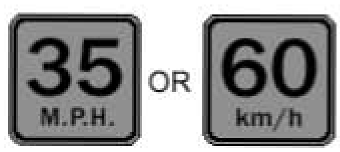


* OPTICALLY SPACE NUMBERS ABOUT VERT. CENTERLINE

DIMENSIONS (MILLIMETERS)							
A	B	C	D	E	F	G	H
450	9	9	56	200E	50	75E	38
600	9	16	91	250E	56	100E	38
900	19	22	113	375E	86	150E	63

DIMENSIONS (INCHES)							
A	B	C	D	E	F	G	H
18	3/8	3/8	2 1/2	8E	2	3E	1 1/2
24	3/8	5/8	3 1/2	10E	2 3/4	4E	1 1/2
36	3/4	7/8	4 1/2	15E	3 1/2	6E	2 1/2

COLORS
LEGEND—BLACK (NON-REFL)
BACKGROUND—YELLOW (REFL)



W13-1
450 x 450 mm (18 x 18 in)
600 x 600 mm (24 x 24 in)

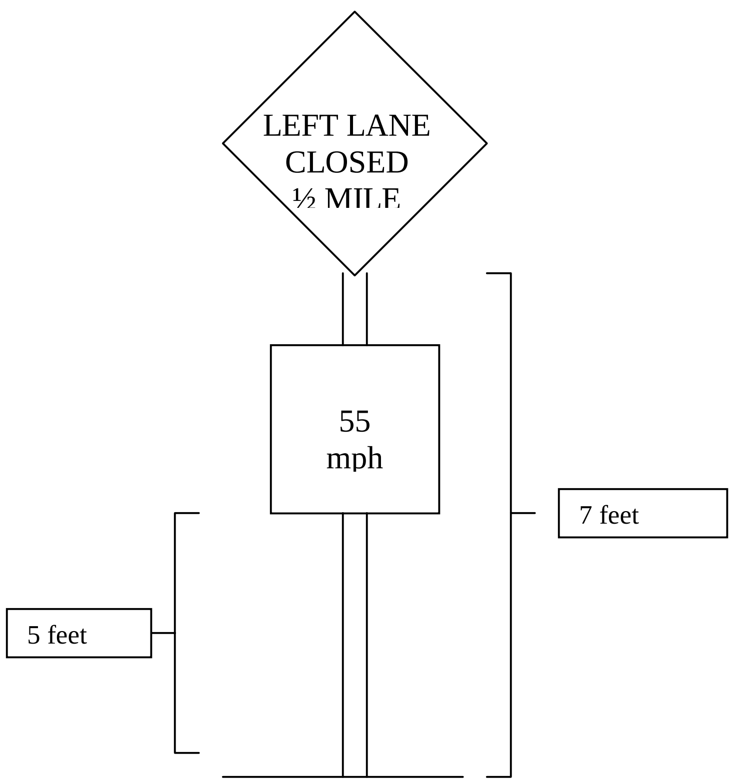
SIGN W20-5-A (LEFT LANE CLOSED ½ MILE)

Sign Properties

Height:	4 ft.
Width:	4 ft.
BG Color:	Orange
FG Color:	Black
Font Height:	6 inch
Font Width:	Series C
Border:	Yes
Border Width	1.25 inch
Border Color:	Black
Distance from Ground:	7 ft.
Distance from Road:	2 ft.
Text on Sign:	LEFT LANE CLOSED ½ MILE

Assumptions:

Sign Schematic:



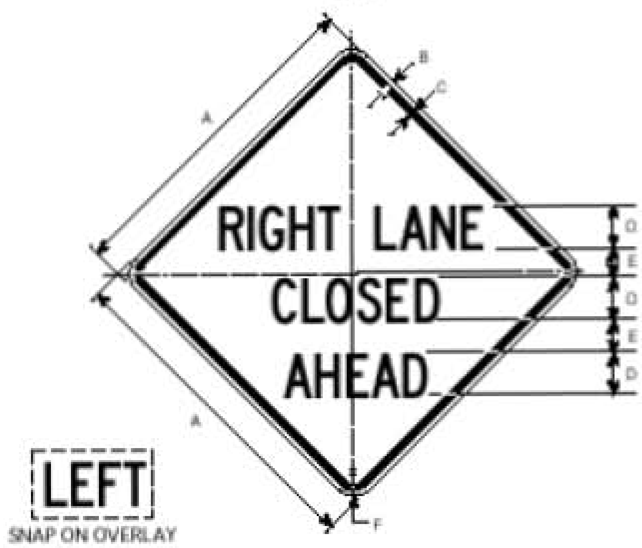
Additional Notes:

This sign has a W13-1 (55 mph) sign attached to it.

The following diagram illustrates this sign's general properties, but it may have differences from the requested model.

W20-5

12/94



LINE 1 ALTERNATIVES

LEFT LANE CENTER LANE

DIMENSIONS (MILLIMETERS)					
A	B	C	D	E	F
900	16	22	125C	69	56
1200	19	31	150C	84	97

DIMENSIONS (INCHES)					
A	B	C	D	E	F
36	5/8	7/8	5C	2 3/4	2 1/4
48	3/4	1 1/4	6C	3 3/8	3

COLORS

LEGEND—BLACK (NON-REFL)
BACKGROUND— ORANGE

W20-5
1200 x 1200 mm
(48 x 48 in)

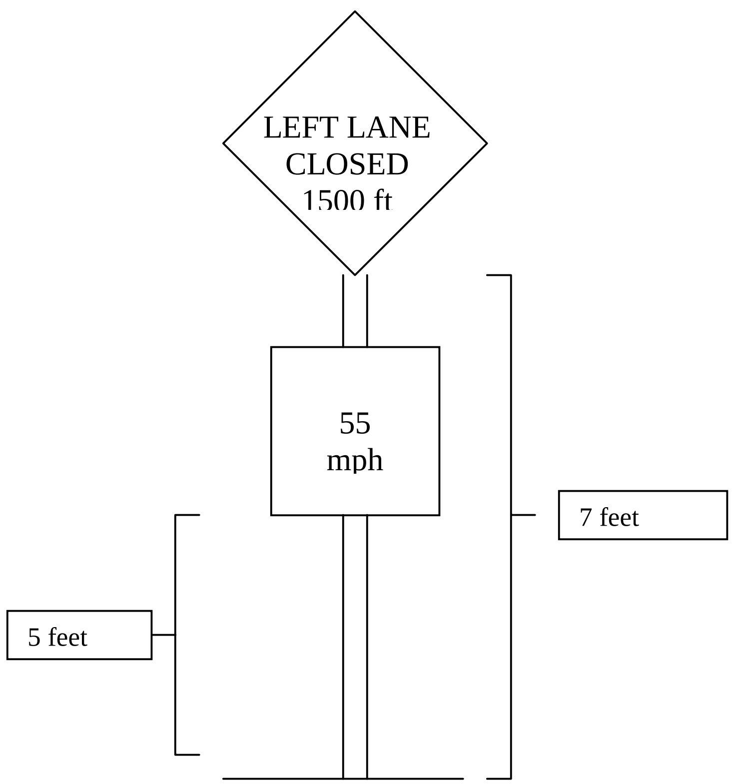
SIGN W20-1-B (LEFT LANE CLOSED 1500 FT)

Sign Properties

Height:	4 ft.
Width:	4 ft.
BG Color:	Orange
FG Color:	Black
Font Height:	6 inch
Font Width:	Series C
Border:	Yes
Border Width:	1.25 inch
Border Color:	Black
Distance from Ground:	7 ft.
Distance from Rroad:	2 ft.
Text on Sign:	LEFT LANE CLOSED 1500 FT

Assumptions:

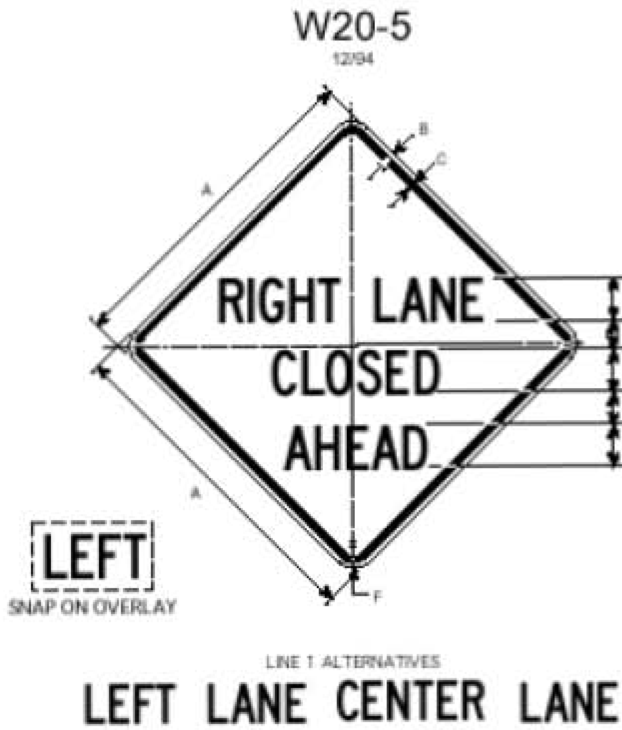
Sign Schematic:



Additional Notes:

This sign has a W13-1 (55 mph) sign attached to it.

The following diagram illustrates this sign' general properties, but it may have differences from the requested model.



DIMENSIONS (MILLIMETERS)					
A	B	C	D	E	F
900	16	22	125C	69	56
1200	19	31	150C	84	97

DIMENSIONS (INCHES)					
A	B	C	D	E	F
36	5/8	7/8	5C	2 3/4	2 1/4
48	3/4	1 1/4	6C	3 3/8	3

COLORS

LEGEND—BLACK (NON-REFL)
BACKGROUND— ORANGE

W20-5
1200 x 1200 mm
(48 x 48 in)

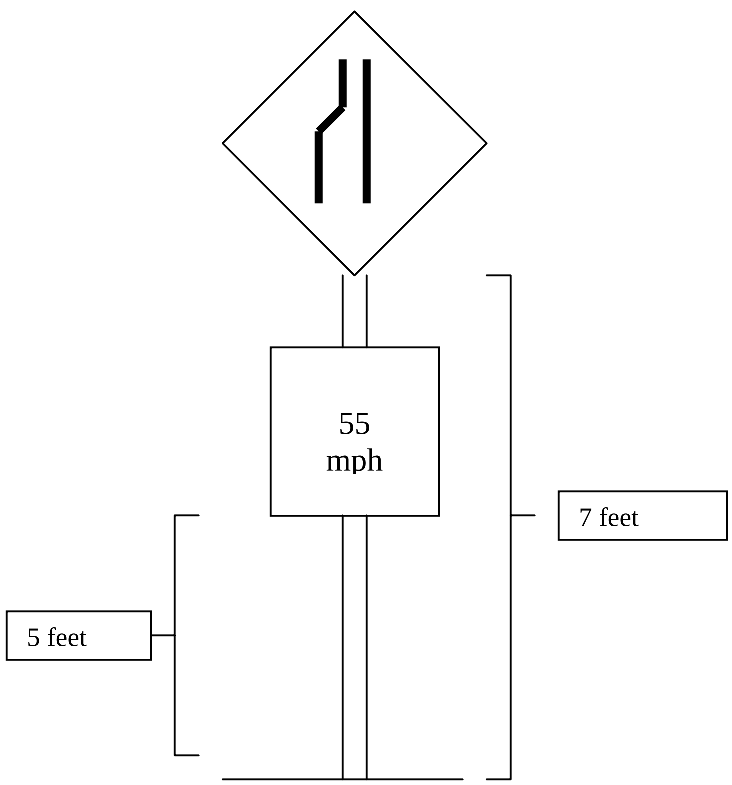
SIGN W4-2R (MERGE RIGHT)

Sign Properties:

Height:	4 ft.
Width:	4 ft.
BG Color:	Orange
FG Color:	Black
Font Height	N/A (Stripe is 24 ¼ inches long)
Font Width	N/A (Stripe is 5 5/16 inches thick)
Border:	Yes
Border Width:	1.25 inch
Border Color:	Black
Distance from Ground:	7 ft.
Distance from Road:	2 ft.
Text on Sign:	N/A

Assumptions:

Sign Schematic:



Additional Notes:

This sign has a W13-1 (55 mph) sign attached to it.

The following diagram illustrates this sign's general properties, but it may have differences from the requested model.

W4-2L & W4-2R

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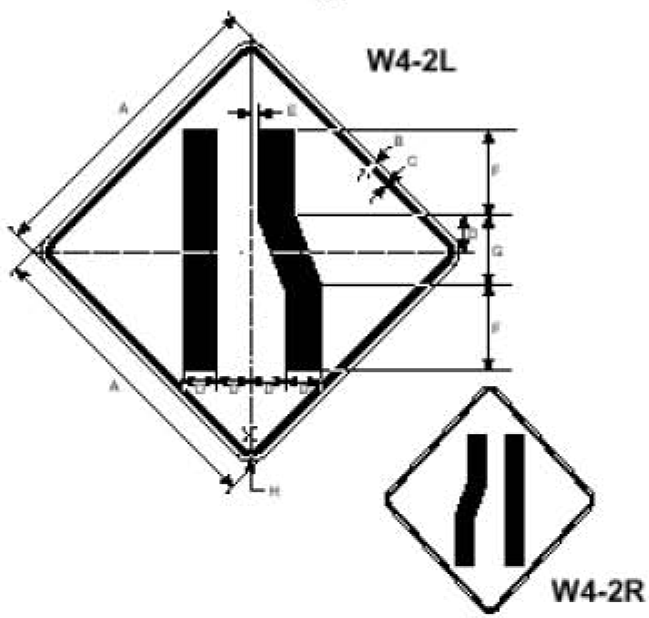


DIMENSIONS (MILLIMETERS)							
A	B	C	D	E	F	G	H
750	13	19	84	21	211	169	47
900	16	22	100	25	250	200	56
1200	19	31	133	34	333	266	75

DIMENSIONS (INCHES)							
A	B	C	D	E	F	G	H
30	1/2	3/4	3 3/8	13/16	8 7/16	6 3/4	1 7/8
36	5/8	7/8	4	1	10	8	2 1/4
48	3/4	1 1/4	5 5/16	1 3/8	13 5/16	10 5/8	3

COLORS

LEGEND — BLACK (NON-REFL)
BACKGROUND — YELLOW (REFL)

W4-2
900 x 900 mm
(36 x 36 in)

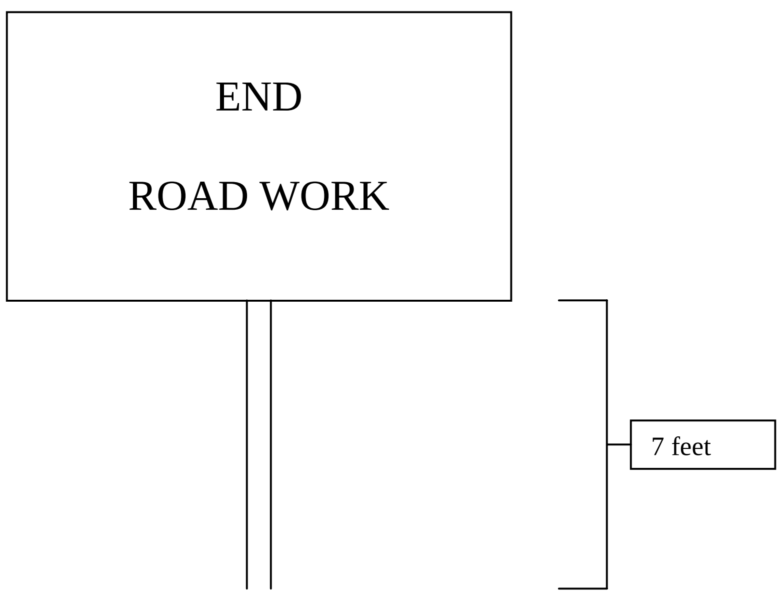
SIGN G20-2 (END ROAD WORK)

Sign Properties

Height:	2 ft.
Width:	5 ft.
BG Color:	Orange
FG Color:	Black
Font Height:	6 inch
Font Width:	Series C
Border:	Yes
Border Width:	5/8 inch
Border Color:	Black
Distance from Ground:	7 ft.
Distance from Road:	2 ft.
Text on Sign:	END ROAD WORK

Assumptions:

Sign Schematic:

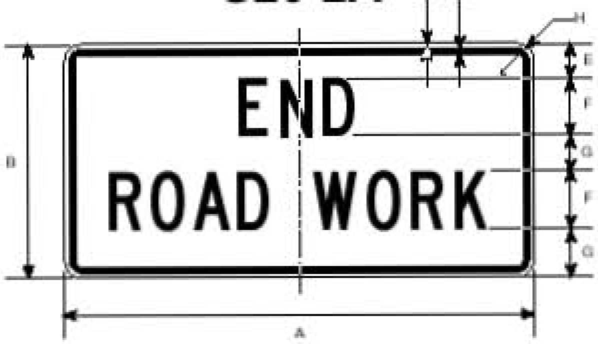


Additional Notes:

G20-2A & G20-4

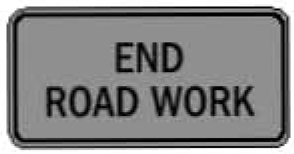
6/95

G20-2A



DIMENSIONS (MILLIMETERS)							
A	B	C	D	E	F	G	H
1200	600	9	16	75	150C	113	38

DIMENSIONS (INCHES)							
A	B	C	D	E	F	G	H
48	24	3/8	5/8	3	6C	4 1/2	1 1/2



G20-2a
900 x 450 mm
(36 x 18 in)

SIGN ARROW

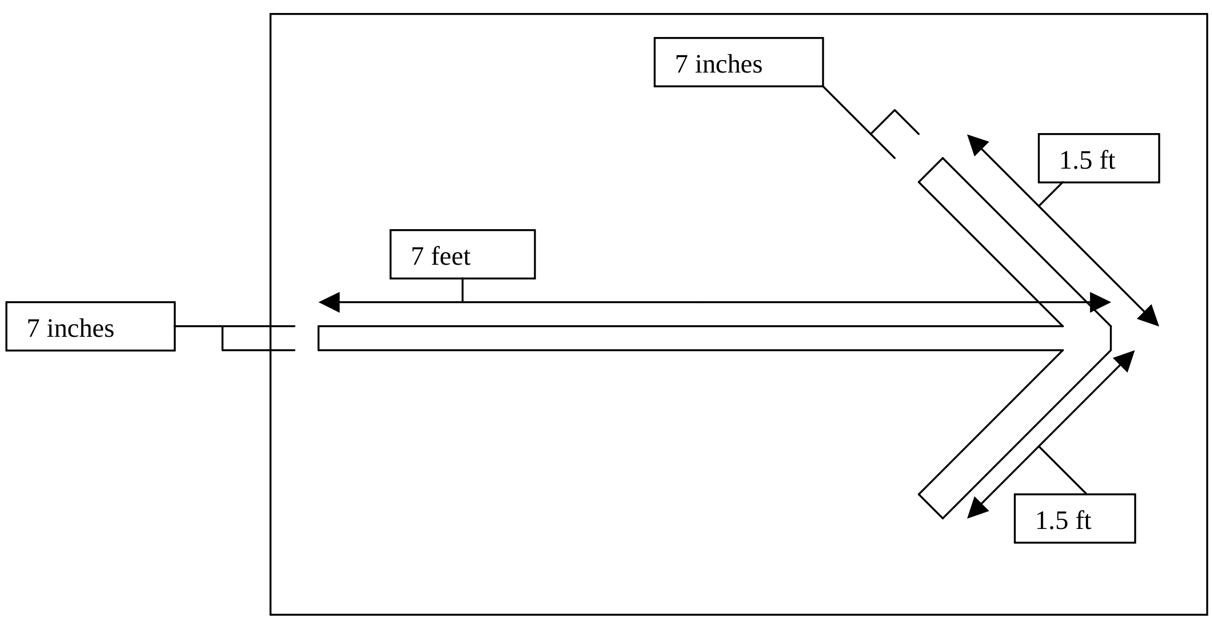
Sign Properties

Height:	4 ft.
Width:	8 ft.
BG Color:	Black
FG Color:	Yellow
Font Height:	N/A
Font Width:	N/A
Border:	No
Border Width:	N/A
Border Color:	N/A
Distance from Ground:	7 ft.
Distance from Road:	2 ft.
Text on Sign:	N/A

Assumptions:

- Sign can be made to flash but be advised that this will require more time and more resources than a non-flashing sign. We recommend a non-flashing sign.
- Due to image resolution, depicting individual bulbs on sign will be extremely difficult. We recommend using solid lines in place of rows of lights.
- Line width of 7 inches. See following image.

Sign Schematic:



SIGN G70-1 (USE ALL LANES TO MERGE POINT)

Sign Properties:

Height:	4 ft.
Width:	8 ft.
BG Color:	Orange
FG Color:	Black
Font Height:	10 inch
Font Width:	Series E (25% of letter height)
Border:	Yes
Border Width:	2 inch
Border Color:	Black
Distance from Ground:	7 ft.
Distance from Road:	2 ft.
Text on Sign:	USE **ALL** LANES TO MERGE POINT

Assumptions:
Replace the word 'BOTH' with 'ALL' so that participants will know that it is o.k. to drive in all 3 lanes approaching the lane closure. Sign Layout: 2 inch border then 8 inches down to top of first line of text (USE ALL LANES – 10 inch) then another 8 inches down from the bottom of this text until the top of the second line of text (TO MERGE POINT – 10 inch) then another 8 inches down until the 2 inch border.

Sign Schematic:

SIGN G70-2 (MERGE HERE TAKE YOUR TURN)

<u>Sign Properties</u>

Height:	4 ft.
Width:	8 ft.
BG Color:	Orange
FG Color:	Black
Font Height:	10 inch
Font Width:	Series E (25% of letter height)
Border:	Yes
Border Width:	2 inch
Border Color:	Black
Distance from Ground:	7 ft.
Distance from Road:	2 ft.
Text on Sign:	MERGE HERE TAKE YOUR TURN

<u>Assumptions:</u>
Sign Layout: 2 inch border then 8 inches down to top of first line of text (MERGE HERE – 10 inch) then another 8 inches down from the bottom of this text until the top of the second line of text (TAKE YOUR TURN – 10 inch) then another 8 inches down until the 2 inch border.

<u>Sign Schematic:</u>

APPENDIX F

POST-EXPERIMENT SIMULATOR INDUCED DISCOMFORT QUESTIONNAIRE

LANE MERGING MANEUVERS
IN A DRIVING ENVIRONMENT SIMULATOR
POST-EXPERIMENT SIMULATOR INDUCED
DISCOMFORT QUESTIONNAIRE

(The questionnaire is computer-based, developed as a web page.)

There is a small risk associated with driving in the driving environment simulator. The driver may experience feelings of dizziness and increased body temperature, which are symptoms of a temporary condition called 'Simulator Induced Discomfort' (SID).

To verify the extent of SID occurrence, we are tracking the occurrence and severity of any discomfort felt by those who drive in the driving environment simulator.

Sex:

- ❑ male
- ❑ female

Age: ______

Are you wearing prescription glasses or contact lenses?

- ❑ no
- ❑ glasses
- ❑ contact lenses

What is your exposure to the driving environment simulator?

- ❑ first time
- ❑ second time
- ❑ more than two times

During this most recent experience in the driving environment simulator did you experience any feelings of discomfort?

Eye Strain:		❑ none	❑ slight	❑ moderate	❑ severe
Temperature increase:		❑ none	❑ slight	❑ moderate	❑ severe
Dizziness:	❑ none	❑ unsteady	❑ slight	❑ moderate	❑ severe
Headache:	❑ none	❑ lightheaded	❑ slight	❑ moderate	❑ severe
Nausea:	❑ none	❑ uneasy	❑ slight	❑ moderate	❑ severe

APPENDIX G

GENERAL QUESTIONNAIRE

LANE MERGING MANEUVERS
IN A DRIVING ENVIRONMENT SIMULATOR
GENERAL QUESTIONNAIRE

The questionnaire is computer-based, developed as a web page.

DEMOGRAPHICS

Sex: Male Female

Age:

Marital Status:
- Single
- Married
- Divorced
- Widowed

Racial Background:
- White
- African-American
- Asian or Pacific Islander
- Hispanic
- Other

Current Employment:
- Full Time
- Part Time
- Retired
- Student
- Homemaker
- Other

Do you live in:
- City
- Suburban
- Rural

DRIVING HISTORY

How many years have you been driving?
- 1-5 yrs
- 6-10 yrs
- 11-15 yrs
- 16-20 yrs
- 21-25 yrs
- 25 + yrs

How often do you drive a motor vehicle?
- A few times a year
- A few times a month
- A few times a week
- Once a day
- Several times a day

How many miles per year do you drive?
- 0 - 5,000
- 5,000 - 10,000
- 10,000 - 15,000
- 15,000 - 20,000
- 21,000+

How often do you drive with other people in your vehicle?
- Almost every day
- Few days a week
- Few days a month
- Few days a year

What times of the day do you typically drive (check all that apply)
- 6:00 - 9:00 am
- 9:00 am - 12:00 pm
- 12:00 - 3:00 pm
- 3:00 - 6:00 pm
- 6:00 - 9:00 pm
- 9:00 pm - 12:00 am
- 12:00 - 6:00 am

The roads you drive on most often are in:
- City
- Suburban
- Rural
- About the same on each

VEHICLE INFORMATION

What kind of vehicle do you drive most often?
- Car
- Van or minivan
- Sport utility vehicle
- Pick-up truck
- Motorcycle

What is the year model of your vehicle that you drive the most?

ISSUES

How often do you wear a seat belt?
- Never
- Rarely
- Some of the time
- Most of the time
- Always

How often do you:
Drive through a light that was already red before you reached it?

Never	Rarely	Sometimes	Most times	Always

Drive 10 mph higher than the speed limit

Never	Rarely	Sometimes	Most times	Always

Drive 20 mph higher than the speed limit

Never	Rarely	Sometimes	Most times	Always

Enter an intersection as the light turns yellow

Never	Rarely	Sometimes	Most times	Always

How often do you:
Come to a rolling stop at a stop sign

Never	Rarely	Sometimes	Most times	Always

Drive when just under the legal alcohol limit

Never	Rarely	Sometimes	Most times	Always

Drive when over the legal alcohol limit

Never	Rarely	Sometimes	Most times	Always

Cross the railroad tracks when the red light is blinking

Never	Rarely	Sometimes	Most times	Always

What is the importance of these issues:
Speeders

None	Little	Some	A lot	No opinion

Drunk Driving

None	Little	Some	A lot	No opinion

Red light runners

None	Little	Some	A lot	No opinion

Aggressive driving

None	Little	Some	A lot	No opinion

What is the importance of these issues:
Poor road signs

None	Little	Some	A lot	No opinion

Older drivers

None	Little	Some	A lot	No opinion

Younger drivers

None	Little	Some	A lot	No opinion

APPENDIX H

MERGE UNDERSTANDING QUESTIONNAIRE

LANE MERGING MANEUVERS
IN A DRIVING ENVIRONMENT SIMULATOR
MERGE UNDERSTANDING QUESTIONNAIRE

On a scale from 1 - 10 with 1 being completely unsatisfied and 10 being very very satisfied:
Did you like merging early?
Did you like merging late?
Why:____
____

When in a merging situation like that in the simulator, how often would you prefer to merge late?
Never Rarely Sometimes Most times Always

When in a merging situation like that in the simulator, how often would you prefer to merge early?
Never Rarely Sometimes Most times Always

On a scale from 1 - 10 with 1 being stopped in the road and 10 being clear flow through the merge area, how fast do you think you could get through the early merge?
Why:____
____

On a scale from 1 - 10 with 1 being stopped in the road and 10 being clear flow through the merge area, how fast do you think you could get through the late merge?
Why:____
____

On a scale from 1 - 10 with 1 being absolutely not and 10 being absolutely yes, how fair do you think it is to merge late?
Why:____
____

On a scale from 1 - 10 with 1 being absolutely not and 10 being absolutely yes, how fair do you think it is to merge early?
Why:____
____

On a scale from 1 - 10 with 1 being absolutely not and 10 being absolutely yes, do you think merging early would prevent drivers from 'skipping' in line?
Why:____
____

On a scale from 1 - 10 with 1 being absolutely not and 10 being absolutely yes, do you think merging late would prevent drivers from 'skipping' in line?
Why:____
____