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16. Abstract

Popular opinion has it that "road rage" is increasingly prevalent in urban areas. 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 and environmental factors that induce irritation and contribute to aggressive driving.

Researchers evaluated the benefits of freeway bottleneck improvements. Feedback from commuters revealed that a majority realized reduced aggressive behaviors and commute time after improvements at a bottleneck. Almost 50 percent indicated an improvement in their stress level. Operational data collected at the bottleneck site (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.

This document provides a simple plan for implementation of the research results. This plan will help provide some additional detail for TxDOT, Metropolitan Planning Organizations (MPOs), law enforcement agencies, and other transportation-related groups responsible for putting the plan into practice.

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UNDERSTANDING ROAD RAGE: IMPLEMENTATION PLAN FOR PROMISING MITIGATION MEASURES

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DISCLAIMER

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LIST OF ABBREVIATIONS

CMAQ	Congestion Mitigation and Air Quality
CMS	congestion management system
DCS	DeChant Consulting Services
DESi	driving environment simulator
DLM	Dynamic Late Merge
FHWA	Federal Highway Administration
GRAI	Gary Robertson Accident Investigation
ITS	intelligent transportation system
LOS	level-of-service
MPO	metropolitan planning organization
NCTCOG	North Central Texas Council of Governments
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation

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 SELECTION OF MITIGATION MEASURES

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 usage
Traffic emotions education 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 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 at work-zone lane closures

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. Full accounts of these activities were documented in several other project-related research reports *(1,2)*.

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 only three mitigation measures would be selected 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.

1.3.1 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.

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 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. Researchers, in cooperation with the project advisory committee, evaluated photogrammetry for its potential in reducing the clearance time associated with traffic incidents compared to other traditional investigation techniques.

1.3.2 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.

A bottleneck in a freeway system usually occurs at a ramp junction or lane drop. A bottleneck 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. Often the constriction can be removed 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 *(3)*. Researchers evaluated whether or not improvements at freeway bottleneck locations could successfully mitigate the occurrence of driver stress and subsequent aggressive driving behaviors.

1.3.3 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 *(4)*. 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.

CHAPTER 2

SUMMARY OF
PROJECT CONCLUSIONS AND RECOMMENDATIONS

2.1 PROJECT CONCLUSIONS

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.

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.

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 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.

2.2 PROJECT 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 and Congestion Mitigation and Air Quality 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.

CHAPTER 3

IMPLEMENTATION PLAN FOR THE PROMISING MITIGATION MEASURES

3.1 IMPLEMENTATION OF PHOTOGRAMMETRY

Law enforcement and potentially some transit police with jurisdiction over incident investigation will be the agencies responsible for implementing the use of photogrammetry. In Section 2.2, the research team recommended further implementation of photogrammetry, perhaps via pilot projects, to validate the promising results exhibited by the Dallas County Sheriff Department and the Chattanooga Police Department. TxDOT and other transportation agencies such as the Federal Highway Administration can support the implementation through education (i.e., messages on the importance of quick incident clearance on public and responder safety) and also through funding opportunities. The key element needed to implement a successful program is a funding source to procure the necessary equipment, training, and possibly even personnel for using photogrammetry to investigate traffic incidents. The following subsections briefly outline the components of a pilot program that could be utilized by TxDOT Districts in cooperation with local law enforcement agencies.

3.1.1 Funding Sources

Photogrammetry is a relatively inexpensive technique to implement. Three law enforcement agencies that participated in this project, the Dallas County Sheriff Department, the Chattanooga Police Department (CPD), and the Utah Highway Patrol, all implemented their programs for under $50,000.

In the case of the Dallas County Sheriff Department, funding from the intelligent transportation system peer-to-peer program was used to cover training costs. The ITS peer-to-peer program is a FHWA, Federal Transit Administration, and Federal Motor Carrier Safety Administration technical assistance program that provides public sector transportation stakeholders with a convenient method to tap into the growing knowledge base of ITS experience in a broad range of categories, including incident management systems and emergency services. The peer-to-peer web site, http://www.its.dot.gov/peer/peer.htm, provides a comprehensive description of the program and what types of activities (generally training) are eligible for grants.

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 DeChant Consulting Services, Inc. (DCS) officials; and
- technical support: one year of technical support for the PhotoModeler software.

The CPD procured the state and federal funds through a grant from the Tennessee Governor's Highway Safety Office administered by the Tennessee Department of Transportation. Some local funds from the City of Chattanooga were put up as a match in order to receive the grant.

In the case of the Utah Highway Patrol, Congestion Mitigation and Air Quality (CMAQ) 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. These funds were requested in partnership with the Utah Department of Transportation in order to perform a comparison of Total Station and photogrammetry systems to determine the most effective means of obtaining measurements of traffic crashes.

3.1.2 Necessary Equipment

Photogrammetry is a relatively simple technique that requires the following equipment for a complete investigation:

1. Cameras – Either digital (preferred) or conventional cameras can be used.
2. Measurement software – A number of inexpensive software programs are available for performing measurements of incident photographs. The most popular, based on surveys of law enforcement agencies in the United States, is the PhotoModeler Pro software ($795), http://www.photomodeler.com/, available for purchase from EOS Systems. Other software programs include ShapeCapture, http://www.shapequest.com/, and CDW available from Rolleimetric, http://www.rolleimetric.com/.
3. Measurement targets – Evidence markers with numbers that can be placed throughout an incident scene to identify and mark important items (i.e., skid marks, point of impact, location of vehicles, etc.) in the scene photographs. Available for purchase from DCS, http://www.photomeasure.com/em.htm, for $325.
4. Personal computer – The type of computer needed is going to be controlled by the measurement software, but most computers with Pentium level processors are sufficient.
5. Scanner – This is necessary only if conventional cameras are used. The photographs need to be scanned into a digital format before loading into the measurement software.
6. Computer aided drafting software package – A software package such as AutoCAD or Microstation is needed to produce the scene diagrams based on the measurements obtained in the photogrammetry software.
7. Storage media – Typically the scene photos, accident forms, and scale scene drawing (if produced) need to be stored on compact discs or other storage media to file for later retrieval and analysis.

3.1.3 Training Program

In order to successfully and accurately use photogrammetry in the field, law enforcement agencies should receive training. DCS offers training workshops that introduce the basic theory and operation of the PhotoModeler Pro software [http://www.photomeasure.com/training.htm]. At this time, DCS offers both basic and advanced training workshops that each last two days. There are two options available for each workshop:

- Option 1: On-site

    1. At your company's facility;
    2. $695 per student (minimum fee of six students per workshop);
    3. Client pays airfare, hotel accommodations, and expenses for the DCS instructor; and
    4. Client is required to furnish computing resources for the workshop exercises.

- Option 2: One on one

    1. At Seattle, Washington, DCS area training facility; and
    2. $950 per student (minimum fee of three students per workshop).

Gary Robertson Accident Investigation (GRAI) Imaging [http://www.grai-imaging.com/] offers full training programs for the ShapeCapture software. GRAI employees have been extensively involved with air accident projects, specifically in the Swiss Air crash investigation in the previous several years.

3.2 IMPLEMENTATION OF BOTTLENECK IMPROVEMENTS

Implementation of bottleneck improvements on freeway facilities will be the responsibility of TxDOT Districts. In Section 2.2, researchers recommended that TxDOT should increase efforts to fund and implement bottleneck improvement projects with high benefit-to-cost ratios and other early action projects in order to have a positive impact on reducing driver stress, aggressive driving behaviors, and travel time. The key elements to implementing a successful and systematic bottleneck improvement program are to:

- identify bottleneck locations;
- collect and evaluate before and after operational data at the bottleneck location;
- develop and implement low-cost improvements to make operations better in the vicinity of the bottleneck; and
- collect and evaluate before and after driver feedback about the bottleneck location.

The following subsections briefly describe these key elements that TxDOT could utilize in cooperation with local transportation planning and engineering agencies.

3.2.1 Identification of Bottleneck Locations

The first step in the implementation of bottleneck improvements is to identify bottleneck locations on the freeway system. The research team will use a case study approach of the North Central Texas region (i.e., the Dallas-Fort Worth metropolitan area) to illustrate a systematic and cost-effective approach to identifying bottleneck locations that could be utilized in other areas throughout the state of Texas.

The North Central Texas Council of Governments (NCTCOG), the Metropolitan Planning Organization (MPO) for the Dallas-Fort Worth metropolitan area, has recognized the importance of freeway bottleneck removal. In fact, the NCTCOG has a designated freeway bottleneck removal program within the larger congestion management system (CMS) program.

The NCTCOG used an innovative method, low-level aerial photography, to survey freeway traffic conditions in the Dallas-Fort Worth metropolitan area. NCTCOG contracted with Skycomp, Inc. [http://www.skycomp.com/] to conduct this study, which consisted of using aerial photography to survey the region's freeways during the peak periods *(5,6)*. NCTCOG conducted the study to identify areas with freeway bottlenecks so that they could be targeted for future improvements. The methodology determined a level-of-service (LOS) and traffic speeds based on traffic density. Skycomp, Inc. used a fixed-wing aircraft to photograph approximately 750 miles of highways during the peak morning and evening periods of commuter travel during the fall of 1999. Skycomp personnel in the aircraft gathered four samples per segment per hour during each peak period and then averaged these samples for each segment in order to determine the LOS. A second effort conducted by Skycomp, Inc., also in the fall of 1999, involved an inventory of the freeway infrastructure. These photographs were taken during weekend off-peak hours and can be used to document the number of lanes, interchange configuration, and adjacent land uses. The cost of the data collection effort was $300,000 due to the extensive aerial photography. The NCTCOG Executive Board plans to redo the LOS portion of the study in the future in order to compare congestion trends and determine the benefits of various transportation improvement strategies, including freeway bottleneck removal.

All of the information, LOS by freeway segment and the infrastructure photolog, was documented on two CD-ROMs. A summary of this information can be found at the following NCTCOG web site: http://www.dfwinfo.com/trans/photo-survey/index.html. The information on the CDs and web site is very valuable and provides an excellent overview of locations of recurrent congestion that might be bottlenecks.

Figure 1 provides an example of the type of information presented on the NCTCOG Commuter CD for a freeway corridor (US 75 Central Expressway between Eldorado Parkway and IH 635 LBJ Freeway) including locations of congestion, bottleneck descriptions, and estimated speeds and queue lengths. The text describing the locations with recurrent congestion also tells the user to refer to photos contained on the CD that provide visual documentation of the traffic conditions. Figure 2 is a diagram showing the estimated LOS for the same freeway corridor for the AM peak period. The photograph in Figure 3 is an example of one of the pictures taken to document the congested conditions at the SH 190 interchange on the same freeway corridor.

The state of Minnesota also has a designated program with funding for bottleneck removal projects. Bottleneck removal is one of the three components of the *Moving Minnesota Investment Strategy (7)*. The state legislature has funded the bottleneck program at $177 million per year.

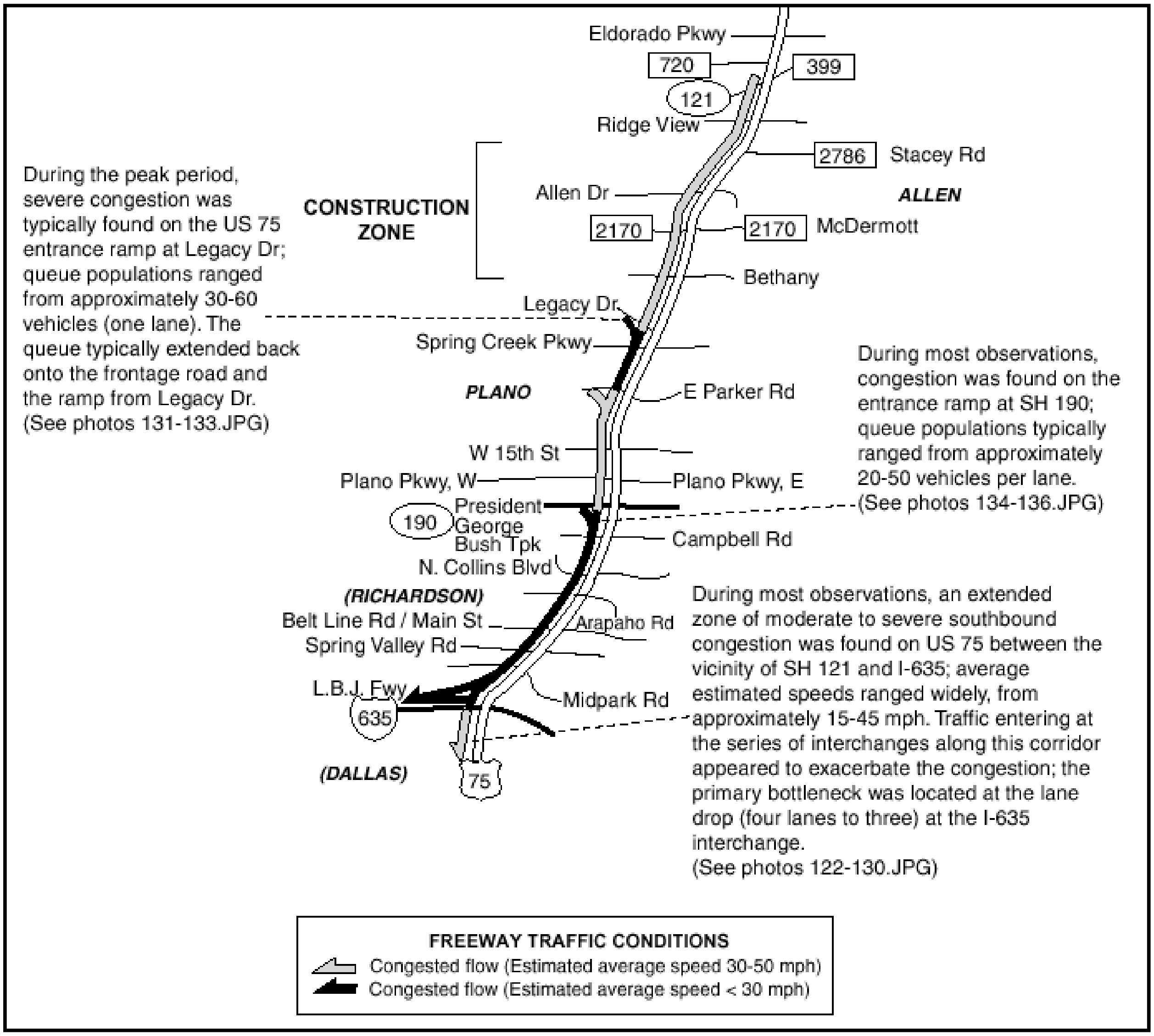

Figure 1. US 75 AM Peak Period Overview from the NCTCOG Commuter CD.

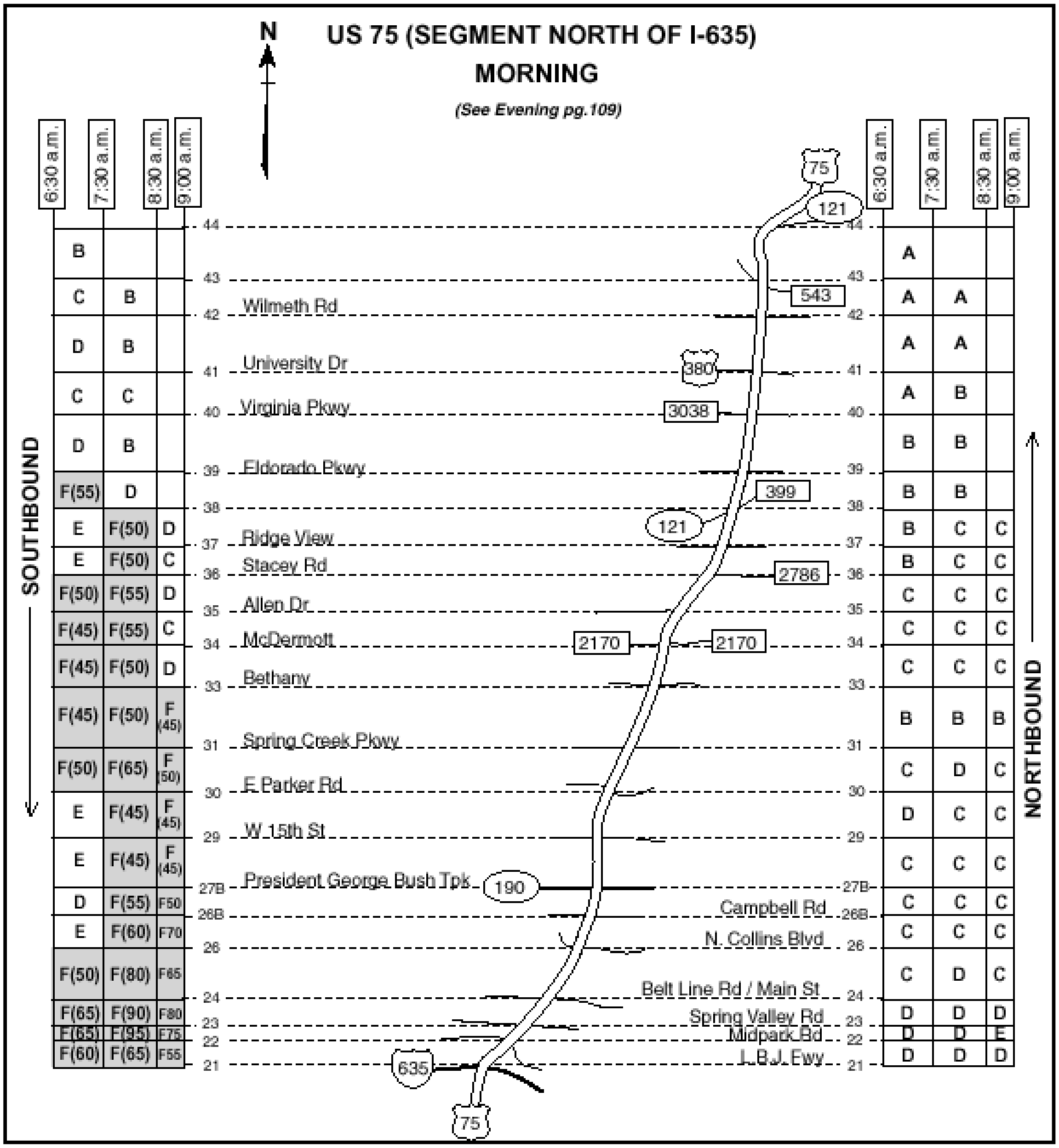

Figure 2. US 75 AM Peak Period LOS Estimates from the NCTCOG Commuter CD.

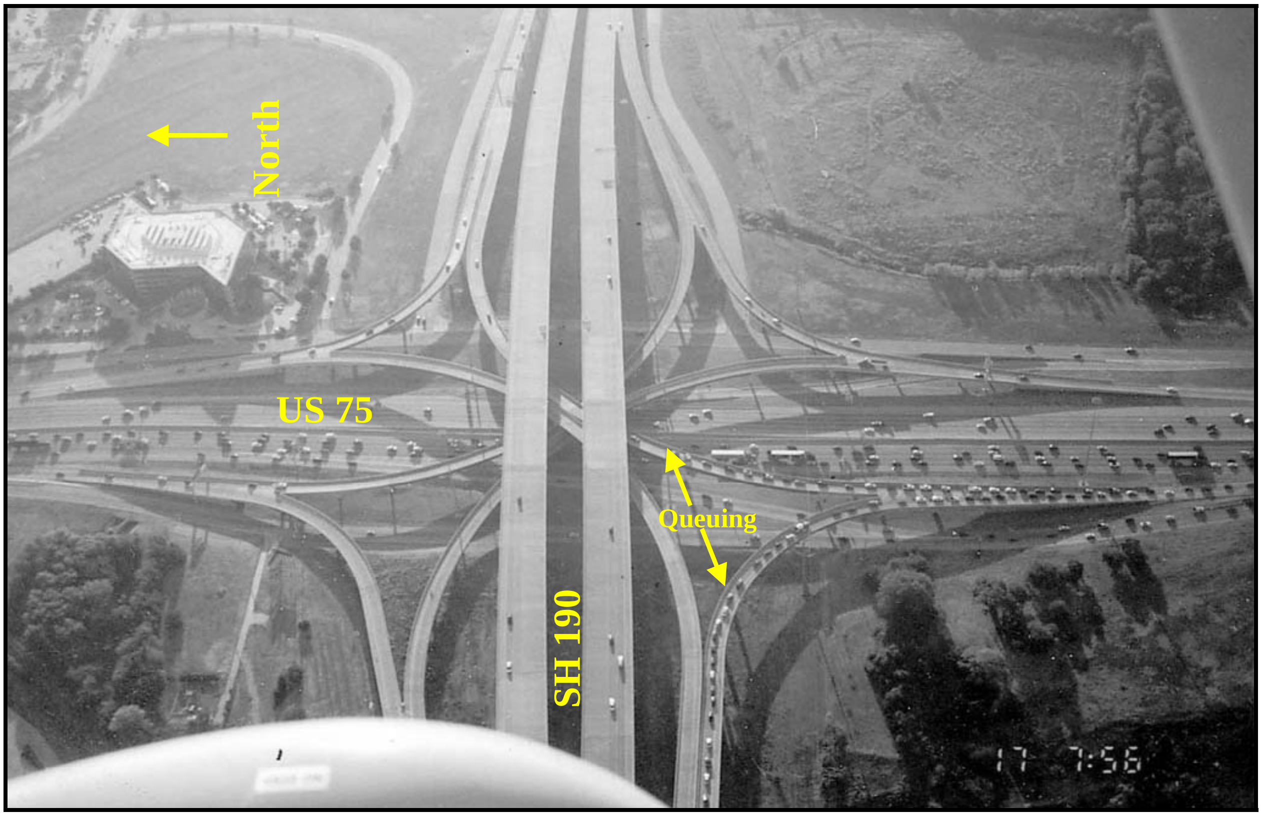

Figure 3. View of Congestion at the SH 190 at US 75 Interchange – CD File #0134.jpg.

3.2.2 Collection and Evaluation of Operational Data

Several previous research projects conducted by the Texas Transportation Institute have good guidelines and information regarding how to perform a bottleneck study *(3,8)*. Collection and evaluation of good before and after operational data are key components to a successful bottleneck removal project. Researchers collect the before operational data to gain an understanding of the problem and to document existing conditions. Researchers collect the after operational data to determine the benefits resulting from the implementation of the bottleneck improvement. The following list presents some general guidelines for the collection of before and after operational data for a bottleneck study.

1. Before data need to be collected beginning outside the region of congestion, both temporal and spatial.
2. Speed and volume data on alternate routes adjacent to the freeway should be collected.
3. After data should be collected the same way as the before data.
4. Original volumes should be assessed benefits based on the measured speed increases or decreases based on the travel times.
5. Increased volumes (i.e., new traffic induced to the facility because of the improvement) should be assessed benefits based on the average speed of the alternate routes.

The analysis portion will often involve the use of some type of traffic simulation model. TTI project number 7-3943 contains recommendations for what type of simulation model works best for analysis of congested freeway sections *(9)*.

3.2.3 Develop and Implement Bottleneck Improvements

Transportation departments can often remove bottlenecks on freeway facilities through a relatively low-cost improvement to a short section of freeway, within existing right-of-way. Typical bottleneck improvements include:

- *Restriping-only*: changing the configuration of freeway lanes by removing existing striping, often by narrowing lanes or using shoulders, and restriping to better serve traffic. This may also involve striping out an under utilized lane in an interchange to better serve traffic on the freeway-to-freeway direct connectors.
- *Shoulder conversion*: strengthening the shoulder pavement to allow traffic to use it as a travel lane, often an auxiliary lane connecting a pair of nearby entrance and exit ramps.
- *Ramp metering*: use of signals on entrance ramps to control the entry rate of traffic on the approach to a bottleneck location.
- *New pavement*: addition of new pavement to provide additional capacity.

Having identified programs like the NCTCOG bottleneck removal program should help in the implementation of improvements at freeway bottleneck locations.

3.2.4 Obtain Driver Feedback on Bottleneck Locations

In Section 2.2, researchers recommended that TxDOT should continue to gather driver feedback about bottleneck locations and the effectiveness of improvement projects. In the *Understanding Road Rage* project, the research team utilized the *Dallas Morning News* web site to obtain driver feedback on two bottleneck improvement projects. This feedback was useful and helped to quantify and corroborate the operational data in terms of improvements in personal stress level, aggressive driving, and commute time.

Most of the newspapers in major urban areas in the state of Texas have a web site that provides an online edition of the daily newspaper. A list of these sites includes:

- Austin American Statesman: http://www.austin360.com/aas/;
- Beaumont Enterprise: http://www.southeasttexaslive.com/site/news.asp?brd=2287;
- Bryan-College Station Eagle: http://www.theeagle.com/;
- Corpus Christi Caller-Times: http://www.caller.com/;
- Dallas Morning News: http://www.dallasnews.com/;
- Denton Record-Chronicle: http://www.dentonrc.com/;
- El Paso Times: http://www.elpasotimes.com/;
- Fort Worth Star-Telegram: http://www.star-telegram.com/
- Houston Chronicle: http://www.chron.com/;
- Laredo Morning Times: http://lmtonline.com/;
- Lubbock Avalanche-Journal: http://www.lubbockonline.com/;

- Midland Reporter-Telegram: http://www.mywesttexas.com/;
- Odessa American: http://www.oaoa.com/;
- Port Arthur News: http://www.panews.com/;
- San Antonio Express-News: http://www.mysanantonio.com/expressnews/;
- San Marcos Daily Record: http://www.sanmarcosrecord.com/;
- Waco Tribune-Herald: http://www.wacotrib.com/; and
- Wichita Falls Times Record News: http://www.trnonline.com/.

Local residents that commute to work tend to use these sites. The Internet provides an excellent and easy source for obtaining driver feedback via electronic mail. There is now even automated survey software that can generate the online survey form and analyze the electronic mail responses that survey respondents submit *(10)*.

3.3 IMPLEMENTATION OF THE LATE MERGE CONCEPT

Implementation of the Late Merge traffic control concept on freeway facilities will be the responsibility of TxDOT Districts. In Section 2.2, researchers recommended that further testing of the static Late Merge should be conducted throughout Texas to more comprehensively investigate the effectiveness of the strategy. The research team suggested that the testing should include both three to two-lane and two to one-lane closure scenarios. Furthermore, researchers offered the belief that shorter-term work zones such as maintenance activities for pavement overlays might make good test sites for the Late Merge because drivers would not have preconceived ideas about how to drive approaching the lane closure.

The implementation of the static Late Merge concept requires the addition of the Late Merge signs to the standard work zone traffic control set up. In the field test conducted on IH 30 in Dallas during this project, TxDOT mounted the Late Merge signs on wooden posts. The preferred method in future tests will be to have the signs mounted on Type III barricades to provide for greater portability and visibility. In the three to two-lane closure scenario, the first two sets of Late Merge signs will need to read 'Use All Lanes to Merge Point' (Figure 4). Whereas in the two to one-lane closure scenario, the first two sets of Late Merge signs would need to read 'Use Both Lanes to Merge Point' (Figure 5). The last set of signs for both cases will read 'Merge Here Take Your Turn' (Figure 6).

Figure 7 provides the typical layout for the two to one-lane closure scenario used in Pennsylvania on a rural Interstate freeway facility *(11)*. The recommended sign sequence and spacing can be adapted to fit TxDOT standard traffic control plans and may omit items such as the portable dynamic message sign (DMS) if one is not available for the project. As shown in Figure 7, the research team recommends the placement of two sets of the 'Use All/Both Lanes to Merge Point' signs in order to give motorists a better chance to get the message on the approach to the lane closure.

Figure 4. 'Use All Lanes to Merge Point' Sign for Three to Two-Lane Closure Scenario.

Figure 5. 'Use Both Lanes to Merge Point' Sign for Two to One-Lane Closure Scenario.

Figure 6. 'Merge Here Take Your Turn' Sign for All Late Merge Scenarios.

The Late Merge signs used in the IH 30 field test had the following specifications:

- 4 feet high and 8 feet wide;
- Orange background;
- 10 inch tall black Series E font;
- 2 inch black border;
- Layout – 2 inch border then 8 inches down to the top of first line of text ('USE ALL LANES' or 'MERGE HERE') then another 8 inches down from the bottom of the first line of text until the top of the second line of text ('TO MERGE POINT' or 'TAKE YOUR TURN') then another 8 inches down until the 2 inch border;
- The bottom edge of the sign was mounted 7 feet above the ground; and
- The left edge of the sign was placed 2 feet from the edge of the pavement.

Figure 4 shows a sign on the IH 30 field site that TxDOT field crews mounted with wooden posts. Figures 5 and 6 show signs from a site in Pennsylvania that are mounted on Type III barricades. The researchers recommend the latter mounting method for future tests to provide portability of the signs (so they can be easily removed from the site when a lane closure is not in effect) and also to enhance their overall visibility.

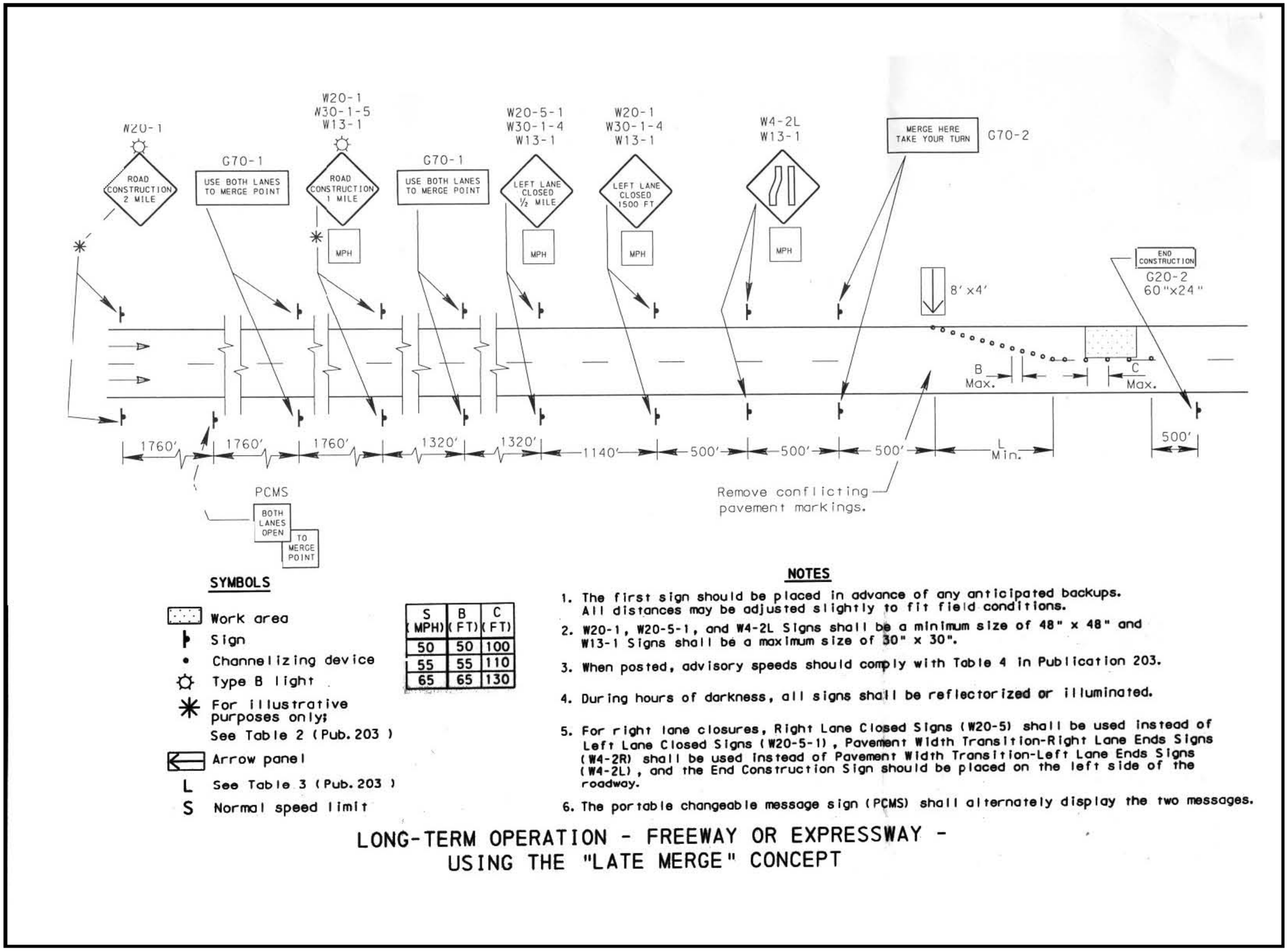

Figure 7. Two to One-Lane Late Merge Scenario Used in Pennsylvania (11).

3.3.1 Dallas District Evaluation

It is anticipated that the static version of the Late Merge concept will continue to be evaluated at different sites in the TxDOT Dallas District. The Dallas District supported the feasibility testing and has indicated a commitment to obtaining more data for a continuing evaluation. These tests will be collaborative efforts between TxDOT and TTI and will be funded using the existing interagency contract.

3.3.2 Evaluation of the Dynamic Late Merge

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 *(12)*. In the fall of 2001, TTI researchers plan to select a site in Houston to evaluate the effectiveness of the Dynamic Late Merge (DLM) strategy.

Preliminary selection of the 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 *(13)*. 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.

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