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16. Abstract

During the past several years, the continuous industrial development in Texas, as well as the North American Free Trade Agreement (NAFTA), led to a population increase and a significant growth of freight movements through Texas. This caused an overload of the existing highway network in many Texas regions and in turn necessitated alterations and improvements to bring the transportation system up to date. Numerous work zones currently cause significant changes in traffic operation and safety. The present research was focused on identifying existing problems and developing recommendations that better address complex work zone traffic control situations as an overall system.

An extended literature review regarding different impacts of complex work zones on traffic operation and safety allowed for determination of the most frequent types of accidents and the major contributing factors. The researchers analyze different work zone designs from safety and operational perspectives, and compare the obtained findings with current design standards. Studies of drivers' behavior and reactions at different workloads were conducted. Improvement solutions were identified, and recommendations for complex work zone traffic control plan designs were developed.

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The University of Texas at Austin

Complex Work Zone Safety

Alexei Tsyganov
Randy Machemehl
Rob Harrison

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Center for Transportation Research
The University of Texas at Austin
3208 Red River
Austin, TX 78705

www.utexas.edu/research/ctr

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Project Engineer: Randy B. Machemehl
Professional Engineer License Number / State: 41921 / Texas
P. E. Designation: Research Supervisor

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1. General Questions of Work Zone Traffic Operation and Safety

1.1 Problem Description

Texas has the most roadway mileage of any state in the nation, and comparable levels of maintenance activity, which in turn result in increased accident frequency. During the past several years, industrial development in Texas, as well as implementation of the North American Free Trade Agreement (NAFTA), have led to population increases and significant growth of freight transportation through Texas. This has caused an overload on the existing highway network in many Texas regions, and created the need for improvements to bring the transportation system up to date. The large number of work zones currently cause significant changes in traffic operation and safety. Identification of solutions to improve work zone design standards and traffic control plans is one of the major priorities of the Texas Department of Transportation (TxDOT).

Much research has been conducted on various work zone problems. Many problems stem from conditions such as the ineffectiveness of assorted traffic control devices, traffic delays, and work zone capacity. Through-traffic in work zones is affected by many factors, such as type of work activity, work zone geometry, and traffic volume. For significant improvements to occur, a thorough investigation of work zone traffic is necessary. Presently, there is little ongoing research for the development of a systematic method for selection of appropriate traffic control strategies. An understanding of road work activities, work zone types, accident statistics, and general principles of traffic through work zones is necessary for the development of a systematic approach to the problem of safety in the work zone.

Work zone traffic control plans define how signs, pavement markings, barricades, channelizing devices, object markers, and flashing warning lights are to be combined to delineate a specific situation, such as a temporary lane closure or pavement drop-off. However, many work zones involve a combination of these "situations," some of which overlap. Often this results in a large number of devices being implemented in order to meet the requirements of each of the applicable traffic control plans. In some cases the combined set of devices can be visually overwhelming and, in actuality, cause confusion and safety problems for drivers trying to navigate through the zone. Research is needed to determine the extent of this type of problem and the conditions under which it typically occurs. Research is also needed to develop guidelines that better address complex work zone traffic control situations as an overall system.

Tasks to be included in this research are as follows:

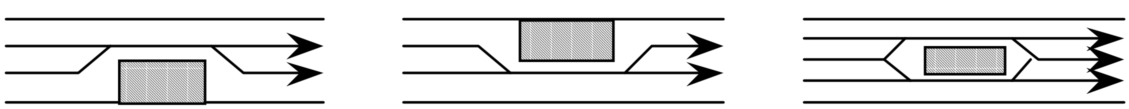
- Determine the extent and key causes of the complex work zone traffic control problem in Texas.
- Identify and evaluate opportunities for improving traffic control systems in complex work zones.

- Develop recommendations for changes to TxDOT's traffic control standard sheets and the Texas Manual on Uniform Traffic Control Devices (MUTCD), and for supplemental guidelines on traffic control plan development.

1.2 Typical Sections of Work Zones

Depending on what sort of activity is taking place, work zone areas fall into three categories: construction, maintenance, and utility zones. Maintenance and road repair are major functions of state departments of transportation (DOTs). Taking into account labor and energy consumption, economic properties, and purpose of work, the activities taking place in work zones can be classified as maintenance; current, partial, or major repair; and utility work. Based on traffic management strategies, work zones can be characterized by lane closures, crossovers, temporary bypasses, and detours. Depending on the effect on traffic conditions, roadwork may be subdivided into two groups. In the first group the work takes place adjacent to the road (road shoulders, earth slopes, medians, etc.) and not on the road itself. These projects present little possibility of danger for motorists or workers and are not considered in this study. In the second group, the work takes place directly on the pavement, with the work zones channeling the traffic flow. The second group may be further divided into three subgroups:

1. There are no lane closures. The traffic lanes are directly adjacent to the work zone, and although lane configuration has changed, work can proceed without impacting the traffic stream.
2. Traffic continues through the work zone with one or more lane closures but with normal directional lane flow. For this particular subgroup, there may be three principal diagrams of traffic flow, depending on where the work zone is located on the roadway. Those major traffic flow schemes are represented in Figure 1.1.
3. Complete permanent roadway closure, with traffic rerouting to the detour.



a) b) c)

a – traffic passes work zone on the left
b – traffic passes work zone on the right
c – traffic passes work zone on both sides

Figure 1.1 Principal Traffic Work Zone Arrangements

The three arrangements affect traffic flow differently and require different traffic control strategies.

The typical work zone consists of the following elements (as depicted in Figure 1.2):

- user information zone
- approach zone, including detour exits
- non-recovery zone
- work zone
- termination zone

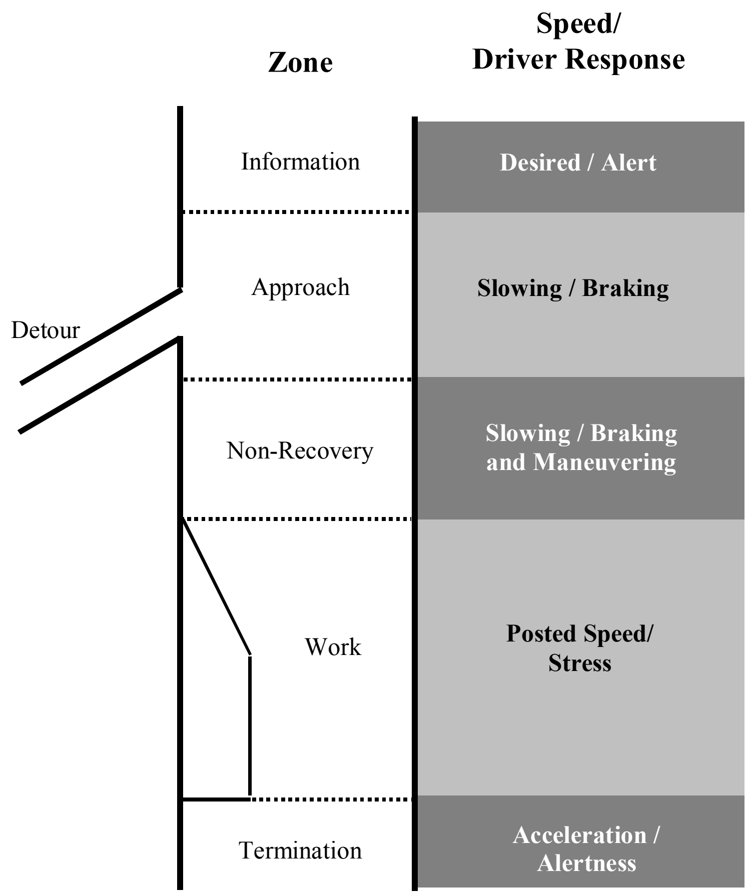


Figure 1.2 Work Zone Elements and Associated Driver Responses

Information via User Information Zone

In this area of the work zone, the user is provided with information that warns about an approaching work zone and given directions with respect to traveling safely through the work zone. Typically, the length of the information zone depends on the type of highway and the geometry of the approach to the work zone. Such lengths can vary significantly, from over one mile on freeways and highways to just a few hundred feet on other roadways.

Approach Zone

The approach zone consists of a variable portion of the work zone where vehicle behavior, particularly speed and direction, may require adjustment. It includes a site distance related to these maneuvers and is related to the distance from which a driver can recognize the emerging hazard and select the appropriate speed, path, and lane choice in a safe and effective manner. The approach zone should be of adequate length to enable users to detect any hazards and thus react safely.

Non-Recovery Zone

This zone comprises the distance required to execute an avoidance maneuver or the point beyond which the motorist cannot avoid the hazard unless erratic maneuvers are undertaken. The distance corresponds to the stopping site distance and the speed of the vehicle. The hazard zone incorporates transitions to the lane configurations over the work zone site and configurations at the work zone activity site itself. In this zone, traffic is channeled from normal traffic lane flow to that required through the work zone itself.

Work Zone

At the work zone activity site itself, there are typically two components. First, a buffer zone is established where there is no work activity or equipment and materials. This allows the recovery of errant vehicles that stray into work zones. Buffer zones are particularly important where semipermanent deflection barriers cannot be implemented, as they act as another safety device for construction workers. Second the heavy equipment required for typical roadwork can be a distraction for many motorists.

Termination Zone

As the name implies, this zone directly follows a work zone where vehicles can accelerate back to their normal cruising speeds. The complex work zones usually related to metropolitan area highway construction or reconstruction projects require complete or partial highway closure and have a major effect on the normal traffic operation. Given heavy traffic volume and high speeds on the urban freeways, adequate advance information to the driver and safe redistribution of traffic flow from the existing roadway to the temporary detour are of great importantance. Of course, such deterioration of traffic conditions has a significant effect on motorists and causes a high probability of accidents.

1.3 Effects of Lane Closure

Many studies (Refs 1, 2, 3, 4, 5) have indicated that lane closures at approaching work zone sites cause motorists to change from an upcoming closed lane to an open lane at a distance of 2,500 to 3,000 feet. Forty percent of motorists change from the approaching closed lane 3,000 ft. (915m) to 2,000 ft. (610m) from the work zone, 30% change at 2,000 ft. (610m) to 1,000 ft. (305m), and 30% wait until 1,000 ft. (305m) to 0 ft. Observations of motorists (Ref 6) indicated that approximately half of drivers (50.7%) change lanes at the first opportunity. Twelve percent attempt to pass vehicles in the adjacent lane prior to changing lanes, and 18% wait until they actually see construction. Analysis of the field data indicated that under low-volume conditions (less than 1,000 vph), drivers wait even longer to merge (Ref 6).

Researchers next investigated the point at which drivers begin to reduce speed in work zones (Ref 6). About half of drivers (46.5%) indicated that they begin to reduce speed when they see signs directing them to do so. Twenty-one percent said that they wait until they actually see construction work, and 17.3% watch the behavior of other drivers for cues. Speed reduction for different road and traffic conditions on work zones with lane closures was from 16% to 50% (Refs 1, 2, 4, 5, 7). Further data revealed that the mean speed reduction for right-lane closures was 16% and for left-lane closures was 21% (Ref 1). Standard deviation for speed distribution on road sections affected by work zones was 4.695 to 9.81 mph (Ref 8). Mean acceleration values ranged from 0.26251 to 1.10840 feet per second squared, and the mean velocity gradient range was 0.00053 to 0.03745 feet per second squared per mile per hour, depending on work zone design and traffic volume (Ref 9).

1.4 Accidents in Work Zones

Data indicates that the number of accidents in work zones is three to ten times greater than that in areas with no roadwork (Refs 10, 11). U.S. data indicates that total accident rates during construction increased from 7.5% to 21.4% above rates experienced before construction (Refs 12, 13, 14). Even higher accident rate increases occur on urban streets. An analysis of traffic accidents in Virginia indicated a 74% increase in accident rates in urban work zone locations (Ref 15).

Accident analyses were conducted for seventy-nine construction projects in seven states (Ref 16). This data indicate that 31% of the projects experienced reduced accident rates during construction, while 24% experienced rate increases of 50% or more. The following data (Ref 16) show how road configuration affects accident rates:

six- or eight- lane interstate reduced to two lanes in each direction	+ 5.3%
six- or eight- lane interstate reduced to one lane in each direction	+ 114.6%
four lane interstate reduced to one lane in each direction	+ 68.6%
four lane interstate reduced to two lanes, two way	+ 147.2%

The data below illustrate changes in mean accident rates by types of construction activities (Ref 13).

bridge work	+ 50 %
reconstruction of existing roadway	+ 33 %
median barrier work	+ 9 %
resurfacing, patching	+ 8 %
pavement widening	+ 3 %

Accidents are not distributed evenly in the areas influenced by a work zone, with 65 to 74% of the accidents occurring at the work zone approach. Most of the accidents occur during daytime (Ref 17). The number of accidents occurring during nighttime increased by 9.4% (Ref 16), but the percentage of night accidents to total accidents remained at 30%, both before and during construction. Between 60 and 65% of the total number of accidents during a typical day and night occur between 9 a.m. and 6 p.m. When comparing daytime and nighttime accidents, it is necessary to take into account traffic volume differences. The index of relative number of accidents (number of accidents per million automobile/kilometer) can be used. In this case the nighttime accident rate will be characterized at a higher level because traffic is more dangerous under insufficient lighting conditions.

Data from the U.S. show the following changes in collision type during construction (Ref 16).

right angle	- 18.8%
rear end	+ 16.6%
sideswipe	- 9.6%
head on	+ 15.2%
turning	+ 15.0%
running off road	- 26.3%
roll	+ 10.3%
fixed object	+ 38.9%

Investigations in three states indicated that an overwhelming percentage of work zone accidents involve rear-end collisions (Ref 18). The main accident types occurring in work zones are distributed as follows (Ref 17):

vehicles running into the road-building materials and equipment	19.5%
vehicles colliding with the road-building machines and mechanisms	4.9%
joint collisions of vehicles	42.7%
running into road workers	8.5%
running into pedestrians	7.3%
getting into the pits and potholes	11.0%
other accidents	6.1%

National research (Ref 16) showed that around 31% of all accidents in work zones are multivehicle collisions, and 38.9% involve vehicles running into immovable objects. Other research indicates that 8.5% of accidents involve road workers and 7.3% involve pedestrians (Ref 17).

In contrast to accidents occurring during usual traffic conditions, accidents occurring in work zones are characterized by heavier consequences. The average number of fatalities in road and street accidents is roughly 10% of all people injured. In terms of the work zones, this index is 16.7% or greater (Ref 19). Approximately 81% of the total number of accidents in work zones result in injuries and 19% in property damage. The increase in the fatal accident rate to 132.4% during construction (Ref 12) is very alarming. The most advanced work zone fatal accident analysis was conducted in Georgia (Ref 20). It showed that during the period between 1995 and 1997, a total of 181 fatal crashes, or about 60 fatal crashes per year, occurred within highway work zones in the state of Georgia. Table 1.1 represents the fatal crashes by manner of collision. Fatal crashes occurred primarily in construction work zones, rather than maintenance work zones. More than half of the fatal crashes occurred in work zones that were idle, compared to about 30% of crashes occurring in work zones in progress. More fatal crashes occurred in work zones where roadway resurfacing and widening were undertaken, compared to work zones with any other type of activity.

Fatal crashes within work zones in Georgia primarily involved passenger vehicles. These vehicles accounted for 80% of vehicles involved in fatal crashes.

Table 1.1 Fatal Crashes by Manner of Collision

Manner of Collision	Percentage of Fatal Crashes	
	Work Zone	Non-Work Zone
Single-vehicle	48.6	56.3
Rear-end	12.1	5.0
Head-on	17.7	16.1
Angle	17.7	20.7
Sideswipe, same direction	2.8	1.1
Sideswipe, opposite direction	1.1	0.8

A significantly higher proportion of fatal crashes occurred during dark conditions in the work zone compared with non-work zones with 42% of fatal crashes occurring in dark conditions in work zones and 32% in non-work zone. Table 1.2 shows the functional classification of roadways on which fatal crashes occurred in work zones and non-work zone locations in Georgia.

Table 1.2 Fatal Crashes by Highway Functional Classification

Functional Classification	Percentage of Fatal Crashes	
	Work Zone	Non-Work Zone
Rural Principal Arterial - Intersate	6	5
Rural principal Arterial - Other	22	10
Urban Principal Arterial - Interstate	18	6
Urban Principal Arterial – Other Freeway	1	2
Urban Principal Arterial - Other	12	10

Supporting Factors for Traffic Accidents

An accident analysis for Kentucky work zones determined the work-zone-related factors that contributed to accidents (Ref 21). The most common factor was congestion, which agrees with the previous findings that rear-end collisions make up the most common type of work zone accidents. Restricted lane width was the second most common factor. Other frequently occurring factors were striking or avoiding construction equipment; material, such as gravel or oil, on the roadway; uneven pavement; pavement (shoulder) drop-off; and late-merging vehicles. The second phase of the study involved evaluation of traffic control and accident analyses at twenty case study locations (Ref 21). Accident analyses included a three-year period before construction and the time period during construction. At 14 of the 19 locations where accident rates were calculated, rates during construction exceeded those in the period before construction. When analyzing the fourteen locations where accident rates during construction exceeded those before construction, ten had rates during construction that exceeded statewide averages for their respective highway types. Analysis by accident type showed that the most frequently occurring types were sideswipes and rear-end collisions. Contributing factors most frequently listed were driver inattention, failure to yield right-of-way, and following too close. Similar results were found by J. W. Hall and V. M. Lorenz in their studies in New Mexico (Ref 22), and by S. Venugopal and A. Tarko for Indiana work zones (Ref 23).

During traffic accident investigations the most common accident causes are usually determined to be driver errors, inattention, or traffic regulation violations. Drivers' full responsibility for accidents was found in 82% of all cases in Germany, 75% in Brazil, 74% in Hungary, 41% in Italy, 96% in Poland, 56% in the United Kingdom, 92% in Spain, 86% in France, 81% in Sweden, and 44% in Japan (Ref 24). Road and traffic conditions were identified as major reasons for accidents in much fewer cases, for example, approximately 7% in the United Kingdom, Spain, and Sweden; 8% in Germany; 10% in France; and 17% in Japan (Ref 24). But only roadway damages, lack of guardrails, slippery pavement, and bad weather were considered to be road conditions. The above-mentioned statistics are based on police records. However, engineering accident investigations identified road and traffic conditions as one of the significant accident supporting factors (Ref 25). The methodologies for traffic safety estimation utilized by practically all developed countries provide evidence of greater significance of road and traffic conditions. For example, “black spot,” “black mile,” and similar methods identified highway sections as dangerous, if during some period of time (usually one year) the number of accidents exceeded some fixed value (usually three). So it is concluded that those road and traffic conditions on such highway sections lead drivers to unsafe behavior.

Each traffic accident is the result of some disturbance in the complex driver-vehicle-road-weather system. Studies conducted in Germany and Sweden concluded that each accident has 1.5 to 1.6 supporting factors (Ref 24). During accident investigations it is very simple to classify the reason as driver error or as violations such as speeding, failure to yield right-of-way, and red-light running. But errors and violations can be caused by drivers' conscious violations of the traffic regulations, as well as by the limited human ability to perceive and analyze information while driving.

Modern traffic conditions are complicated and stressful for drivers. High traffic volumes, high speeds, and people or obstacles near the roadway require a high level of attention from drivers, especially when roadwork is present. Under such conditions it is important to provide drivers with the information they need, with sufficient time for them to respond. A proper traffic control strategy is one of the most important components of safety improvement in work zones. Again, some effect of drivers' limited abilities can be noted. For example, the maximum number of words that can be read and clearly understood by drivers at vehicle speeds of around 60 km/h (37 mph) is three, if the total number of syllables is not greater than fifteen (Refs 26, 27). If the total number of syllables exceeds fifteen, drivers will read only two words. A Canadian investigation of drivers’ perceptions of guide signs indicated that with four or five guides per sign, approximately one in eight subjects reported an incorrect direction for their target destination (Ref 28). The next component of typical work zone conditions is a group of signs in close proximity to each other. Drivers perceive a single sign more easily than a group of signs; with too many signs in one place, individual signs are not easily recognized by drivers. Drivers took

0.42 to 1.25 seconds to recognize and understand single signs, but 1.8 to 2.3 seconds to recognize and understand a group of four signs (Refs 26, 27). More such results on the physiological limitations of human perceptions during vibration, high temperature, high visual noise, personal illness, etc. can be given. Therefore, highway design and traffic control systems should help drivers understand traffic conditions adequately and respond properly.

1.5 Traffic Control on Work Zones

Traffic control strategies and services must operate efficiently to ensure the safety of motorists, their passengers, and road workers. Road workers must be separated and protected from oncoming traffic, and motorists must be adequately informed in order to adapt to the changing road configurations in a timely fashion.

As mentioned above, a work zone includes a user information zone, an approach zone, a non-recovery zone, a work zone, and a termination zone. Typically, the information zone begins at the first warning sign, which identifies the hazard and posts the speed limit, and ends just before the approach zone. Because temporary signs are often difficult to see and do not convey information in a comprehensive way, they can be ineffective in changing driver behavior. Recently, mobile electronic signboards have been used to alert motorists and have been more successful than traditional temporary signing. Some state agencies have been able to use media in order to inform the users of impending work zones. Intelligent transportation systems (ITS) are being developed that have great potential to convey information to the driver in advance.

The next phase is to direct traffic from its normal flow to the detoured route through the placement of tapers in the closing lane(s), thereby shifting travel paths using devices such as cones, barrels, and barriers. There is ample literature on how such devices should be installed and maintained, together with information on the kinds of tapers and arrangements for channeling traffic.

Finally, for protection workers must be shielded from oncoming traffic, and this is accomplished with the aid of a variety of devices such as barriers, cones, and barrels. The Texas Transportation Institute surveyed different traffic control devices being used throughout the U.S. to improve worker safety in order to evaluate their appropriateness in Texas (Ref 29). Based on a detailed analysis of the reviewed devices, two devices were judged to be ready for implementation: opposing traffic lane dividers and drum wraps. Two other devices appear to have potential for implementation but will require some change or modification to TxDOT policy in order to be implemented. The devices are referred to as “direction indicator barriers” and “water-filled barriers” (Ref 29).

It is necessary to note that if traffic flow characteristics do not correspond to given conditions, it is impossible to ensure safety even with strong protective devices. For instance, work zones with lane closures and heavy traffic volumes cannot guarantee motorist safety because there are not enough acceptable gaps for merging from a closed lane to an open one.

The goal of this research is to analyze traffic control and devices, with the focus on determining how to inform motorists about work zone traffic conditions and compel them to adjust their driving behavior accordingly. At work sites various devices are employed to provide motorists with information and warn them about possible detours. Some of these include signs, lights, pavement markings, rumble strips, and noise strips. Each of these devices is utilized based on where and what type of work activity is taking place at a work zone. The literature search provided some solutions for improvement that are discussed below.

Road Signs. Road signs have little effect on the driving behavior of motorists. There are several reasons for this: (1) road signs may be poorly placed, (2) information provided on the sign may not agree with motorists' perception of the situation, and (3) motorists' visual ability may be limited. Often there are numerous warning signs placed at sites approaching the work zones, and research of motorists' psycho-physiology indicates that they cannot adequately read more than two signs at once. One solution is to place signs displaying a multistage speed reduction. For better results signs can be supplemented by other devices. Some agencies use durable orange fluorescent sign sheeting on which the warning signs are mounted, and the literature indicates that such sheeting is more conspicuous than standard nonfluorescent orange sheeting. A comparative investigation showed significant reduction of speed variance and traffic collisions when fluorescent signs were used (Ref 30).

Rumble Strips. Rumble strips are one of the most effective traffic control devices. Transverse or in-line rumble strips are used to alert drivers of an upcoming change or hazard in the roadway. They are used to warn drivers of needed lane changes, the need to slow down or stop, or changes in the roadway alignment. Rumble strips are intended to provide motorists with an audible and tactile warning that their vehicles are approaching a decision point of critical importance. An audible warning to drivers is provided by the noise generated by the vehicle tires passing over the rumble strip. A tactile warning to the driver is provided by the vibration induced in the vehicle by the rumble strip; the driver senses this vibration through contact with the steering wheel and the vehicle seat. Such advanced warning improves drivers' attention, provides extra time to analyze the situation and take appropriate corrective action, and has the potential to improve operation and safety.

A review of the effectiveness of rumble strips in work zone applications prepared by Noel, Sabra, and Dudek indicates that rumble strips in work zones have been studied only under a limited number of applications and that these studies have produced inconsistent findings (Ref 31). As on approaches to intersections, studies indicate that rumble strips have minimal effectiveness for controlling work zone speeds. For example, investigations conducted in Kansas found that the greatest reduction in mean speeds was 1.7 mph for passenger cars and 2.9 mph for trucks (Ref 32). At the same time rumble strips installed in advance on work zones reduce the number of late merges from closed lanes. Pigman and Agent reported that rumble strip installation decreased the percentage of traffic in the closed lane at 0.1 mile in advance of the taper from 11% to 4.1% (Ref 33).

D. W. Harwood's nationwide literature survey suggested that rumble strip installation can reduce by at least 50% the most correctable types of accidents and should be considered at locations where rear-end accidents and other accidents involving an apparent lack of driver attention are prevalent (Ref 34). An Iowa investigation of daytime and nighttime effects of rumble strips found that the nighttime accident rate declined by 51% at lighted locations and by 83% at locations without lights (Ref 35).

Pavement Markings (longitudinal and diametrical). Research has indicated that motorist behavior depends on parameters of pavement marks and that a noise frequency of greater than 5 hertz communicates to them that they are driving too fast. An investigation demonstrated that motorists feel comfortable at a level of noise frequency no greater than 3 hertz (Refs 26, 27). Simultaneously changing the length of pavement marks and gaps will affect motorists' perceptions of speed. The same result can be obtained with diametrical marks on pavement with varying gaps between the marks. Research conducted in the U.S. and Canada further reported that the use of optical speed bars could be an effective tool for the enforcement of speed reduction and could have a positive impact on reducing the accident rate (Ref 36).

A critical problem of the modern traffic control system is how to motivate motorists to comply with traffic regulations, especially speed limits. Controlling speeds through posted speed zones requires a process for simultaneously establishing reasonable speed limits as well as enforcement, sanctions, and public education. It has been mentioned previously that road signs have the least influence on motorists' behavior because of ineffective placement of signs, failure of information to affect motorists' perceptions, and limitations on visual ability. A Center for Transportation Research (CTR) investigation of Texas highways determined that more than 80% of vehicles exceeded speed limits even though all the observed highway sections were well marked with speed limit signs (Ref 37). These results correspond to previous research of road sign effectiveness that also concluded that signs have very little effect on motorists' behavior (Ref 38). A better solution appears to incorporate a multistage speed reduction and to supplement road signs with other devices such as photo radar. Automated speed enforcement (ASE) equipment has been in use for over thirty years, and recent improvements in technology have enhanced its effectiveness. With computer technology advances, sophisticated photographic and video equipment is now available for speed detection purposes.

Other innovative technologies for speed management include: (a) unmanned radar drones that activate in-vehicle radar detectors, (b) unmanned decoy police vehicles with cruiser lights, (c) dynamic message signs with auxiliary radars that identify and warn drivers with excessive speeds, (d) pavement detectors upstream from work zones that detect erratic driver behavior and provide advance warning to workers, and (e) speed cameras that photograph speed limit violators within the work zone and fax the photo to police vehicles downstream from the work area. The last is practiced in Australia, where signs advise drivers of speed cameras ahead, and has been effective in controlling approach speeds to work zones. Although the use of speed cameras to enforce speed limits is controversial in the U.S., no restrictions exist on using such devices for issuing warnings to drivers.

Research in the U.S. and Europe showed that an effective way to encourage drivers to observe speed limits is the use of psychological influences, which stimulate involuntary speed reduction. Possible sources are rumble strips, shaky strips, longitudinal and diametrical pavement markings, and painting or striping to create illusions of narrower roads or increasing speed.

2. Traffic Control Improvements on Complex Work Zones

The analysis of the complex work zones traffic control problems—described in detail in CTR's first-year research report for project 0-4021 (Report 1, unpublished)—helps to formulate four general strategies for improvements:

- Safely redirecting traffic flow from the permanent to the temporary roadway
- Adequate advance information to road users
- Proper traffic control through work zone detour
- Effective inspection of traffic control devices

This chapter presents recommendations for traffic control improvements developed by the Center for Transportation Research (CTR) during its studies of work zone operation and safety.

2.1 Safe Redirecting of Traffic Flow from the Permanent to the Temporary Roadway

The first question is how traffic flow can be redirected from the permanent roadway to the detour safely and with minimal effect on traffic operation. CTR researchers, on the basis of a review of investigations of traffic characteristics around the world and their own research, developed two methodologies for the estimation of traffic safety in work zones not entailing a reduction in lane numbers and in work zones with a reduction in lane numbers (Ref 39).

The first method is based on analysis of lane width, work zone geometry, approach speed, and speed in the work zone. Depending on different combinations of these parameters, the maximum values of deceleration corresponding to normal traffic were determined, and the requirements for an appropriate transition zone design were formulated.

The second method is based on analysis of the redistribution of vehicles from the closed lane to the open one. Vehicle distribution in traffic lanes and headways in the traffic flow at different traffic volumes were investigated. Analysis of traffic safety was made comparing traffic volume in closed lanes, headways available for lane changing, and number of headways of different duration in the flow on the open lane. This research allowed for estimation of traffic conditions on work zones if lane number reduction was selected.

Using knowledge of traffic volume on the open and closed lanes, headways acceptable for lane changing, and the number of headways of different duration in the flow on the open lane, the volumes at which there would be no feasible gaps that allow for safe vehicle merging were estimated. The following estimation procedure was used:

1. For the given total traffic volume in one direction, determine the traffic volume on lanes.
2. For the obtained traffic volume on an open lane, determine the number of headways equal to and greater than the critical value (two seconds).

3. Compare the traffic volume on the closed lane and the number of headways equal to and greater than the critical on the open lane.

If traffic volume on a closed lane is greater than the number of headways acceptable for lane changing on the free lane, traffic will be blocked, or vehicles will have difficulty merging. This takes into consideration that not all drivers change lanes at the same time. As described in the section “Effects of Lane Closure” in Chapter 1, there are three sections where vehicles merge upstream from the lane closure. Therefore, calculations were made using the above-mentioned procedure for those three sections separately, considering traffic volume changes on lanes.

- The first section is 3,000 to 2,000 feet upstream from the lane closure. The number of vehicles trying to merge is 40% of the traffic volume on closed lanes.
- The second section is 2,000 to 1,000 feet upstream from the lane closure. Traffic volume on open lanes increases by the number of vehicles merged in section 1. The number of headways equal to and greater than critical on open lanes must be corrected accordingly. The number of vehicles trying to merge in this section is 30% of the traffic volume on closed lanes, without the influence of the work zone. This number is increased because of vehicles that wanted to, but did not, merge in the first section.
- The third section is up to 1,000 feet upstream from the lane closure. Estimation procedures and the required corrections are similar to those in the second section.

Based on the results of the research (Refs 39, 40) regarding traffic flow distribution by lanes (Figure 2.1) and frequency of headways equal to and greater than two seconds (Figure 2.2), an analysis of traffic conditions at different traffic volumes was conducted. The mathematical description of the relations between total traffic volume in one direction and traffic volume on lanes is graphically represented in Figure 2.1.

Two-Lane, One-Direction Freeways

$N_1 = 86.797 + 0.36035 * N$ $\quad R = 0.96917$

$N_2 = (-86.797) + 0.63965 * N$ $\quad R = 0.98956$

Three-Lane, One-Direction Freeways

$N_1 = (-106.4) + 0.57665 * N + (-0.000051447) * N^2$ $\quad R = 0.97133$

$N_2 = 27.125 + 0.41179 * N + (-0.000013961) * N^2$ $\quad R = 0.98788$

$N_3 = 79.28 + 0.011559 * N + 0.000065408 * N^2$ $\quad R = 0.98628$

Four-Lane, One-Direction Freeways

$N_1 = (-31.976) + 0.18605 * N + (-0.0000057058) * N^2$ $\quad R = 0.73883$

$N_2 = 63.296 + 0.39741 * N + (-0.000025553) * N^2$ $\quad R = 0.95675$

$N_3 = (-41.027) + 0.42193 * N + (-0.000019115) * N^2$ $\quad R = 0.96333$

$N_4 = 9.7075 + (-0.0053915) * N + 0.000050374 * N^2$ $\quad R = 0.97589$

where: N_1, N_2, N_3, and N_4 = traffic volume on lane, vph
Lanes are marked as 1, 2, 3, and 4 starting from the right side (outside) of freeway.
N = total traffic volume in one direction, vph
R = coefficient of regression

Average error of volume estimation varies from -0.08% to 3.87%.

The mathematical description of the relationship between number of headways equal to and greater than two seconds and traffic volume on lane is graphically represented on Figure 2.2.

$H_2 = 93.709 - 0.0332 * N_i$ R = 0.867

where: H_2 = percentage of headways equal to and greater than 2 seconds
N_i = traffic volume on lane, vph
R = coefficient of regression

Average error of headways frequency estimation is -1.61%.

Detailed calculations are presented in Appendix A, and the results are summarized in Table 2.1. For example, 5,000 vph on four-lane divided highways with one lane closed does not provide sufficient merging opportunities.

These calculations show that even at heavy volume traffic flow, there exists a high proportion of gaps between vehicles appropriate for lane changing. In reality it is necessary to take into account the complex effect of lane closure on drivers' perceptions that cause impacts, such as speed reduction when waiting for an appropriate gap and inadequate estimation of gaps, and significantly reduce work zone capacity.

Table 2.1 Threshold Traffic Volumes that Limit Required Merging

Number of Closed Lanes	Number of Traffic Lanes in One Direction		
	2	3	4
	Total Traffic Volume in One Direction (vph)		
1	2,800	3,800 / 4,200 *	5,000
2	n/a	2,800	3,800 / 4,200 *
3	n/a	n/a	2,800

* The first traffic volume is related to the right-side closure and the second to the left-side closure.

The research conducted by the Texas Transportation Institute (TTI) indicated the following values of work zone real capacity depending on lane closure strategy:

2 lanes in one direction with 1 lane closed — 1,340 vph
3 lanes in one direction with 1 lane closed — 2,980 vph
3 lanes in one direction with 2 lanes closed — 1,170 vph
4 lanes in one direction with 2 lanes closed — 2,960 vph
4 lanes in one direction with 1 lane closed — 4,560 vph.

Currently these values are recommended by the Highway Capacity Manual for work zone traffic control plan designs. A comparison of the CTR research findings and MUTCD requirements indicate that current design standards are generally providing drivers with opportunities to safely merge from closed to open lanes.

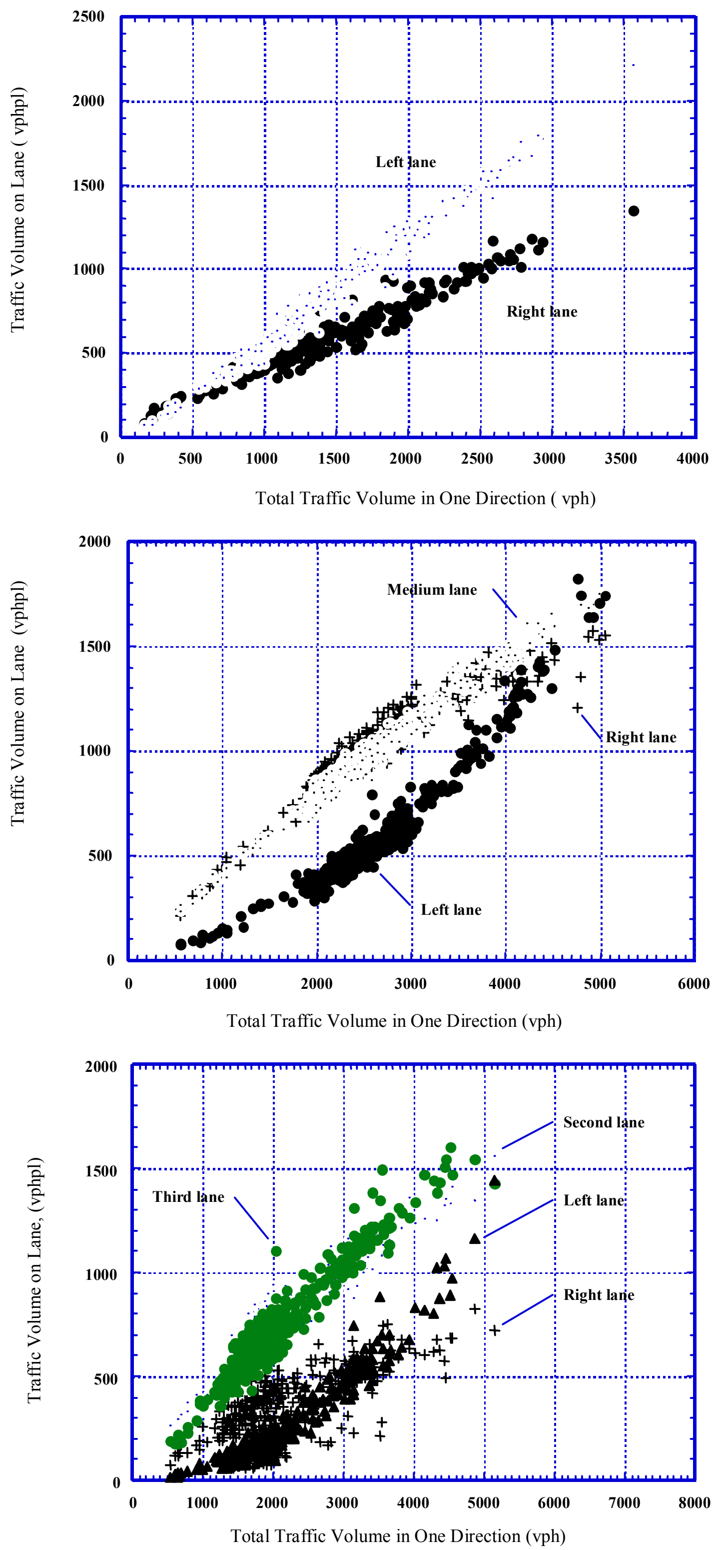


Figure 2.1 Distribution of Traffic Flow by Lanes on Multilane Highways

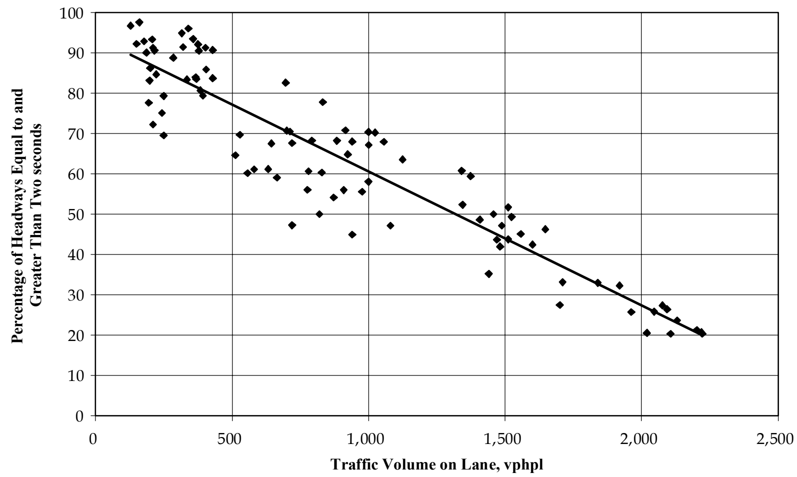


Figure 2.2 Number of Headways Equal to and Greater than Two Seconds at Different Traffic Volumes on Lane

The next question is how to adequately design the transition section. It is necessary to determine a comfortable regime for speed reduction, taking into consideration the difference in speeds in the work zone detour and on the preceding highway section. Many researches have established that in normal traffic conditions (except critical situations that preceded accidents) deceleration varies from 0.5 m/s^2 to 3.5 m/s^2 (1.65 - 11.55 ft/s^2). Based on the "Speed Reduction Coefficient" method (Ref 41), the maximum permissible values of deceleration corresponding to comfortable traffic were determined (Table 2.2) (Ref 39). These values depend on the different combinations of speed in the work zones and the speed on the road section before the work zones.

Table 2.2 Maximal Desirable Deceleration at Different Speed Reduction

Speed before W.Z. km/h / mph	Speed in the Work Zone, km/h / mph							
	110 / 65	100 / 60	90 / 55	80 / 50	70 / 45	60 / 35	50 / 30	40 / 25
	Maximum Desirable Deceleration, m/s^2 / ft/s^2							
120 / 75	2.5/ 8.2	1.5/ 4.9	0.5/ 1.6	u.c.	u.c.	u.c.	u.c.	u.c.
110 / 65		2.5/ 8.2	1.5/ 4.9	0.5/ 1.6	u.c.	u.c.	u.c.	u.c.
100 / 60			2.5/ 8.2	2.5/ 8.2	1.5/ 4.9	0.5/ 1.6	u.c.	u.c.
90 / 55				2.5/ 8.2	2.5/ 8.2	0.5/ 1.6	0.5/ 1.6	u.c.
80 / 50					2.5/ 8.2	2.5/ 8.2	1.5/ 4.9	0.5/ 1.6

• u.c. = undesirable condition, excess driver tension.

Using the knowledge of speed before the work zone, speed on the work zone detour, and maximum permissible deceleration, the minimal desirable length for the transition zone was calculated (Table 2.3) (Ref 39).

Table 2.3 Minimal Length of Transition Section from Desirable Speed Reductions Perspective

Speed before W.Z. km/h / mph	Speed in the Work Zone, km/H / mph							
	110 / 65	100 / 60	90 / 55	80 / 50	70 / 45	60 / 35	50 / 30	40 / 25
	Minimum Length of Transition Zone, m, ft.							
120 / 75	34 / 112	100 /329	430/1412	u.c.	u.c.	u.c.	u.c.	u.c.
110 / 65		29 / 95	91 / 298	309/1012	u.c.	u.c.	u.c.	u.c.
100 / 60			29 / 95	49 / 160	116 / 381	438/1435	u.c.	u.c.
90 / 55				24 / 78	44 / 143	308/1009	384/1257	u.c.
80 / 50					21 / 69	39 / 126	90 / 292	329/1078

• u.c. = undesirable condition, excess driver tension.

From the point of view of movement on the road, the transition zone is perceived by drivers as inverse curves (Fig 2.3).

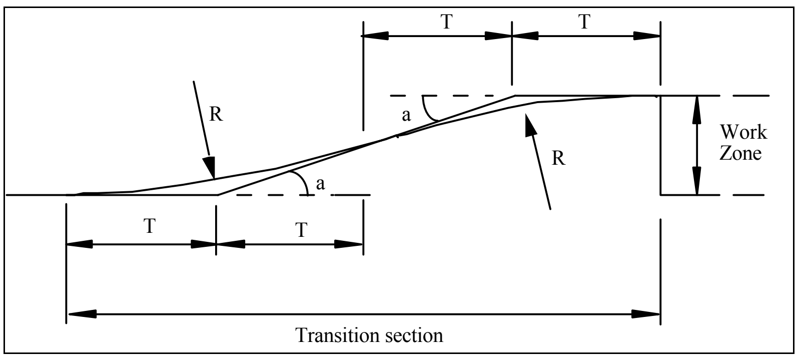


Figure 2.3 The Scheme of Transition Section

The minimum length of a transition zone, determined on the basis of desirable speed reduction, was recalculated according to the minimum recommended radius criteria. Then the comparison of results, determined on the basis of desirable speed reduction and recommended curvature of the transition zone, was made. The higher value of the two transition zone lengths was taken. Finally, the corresponding taper length was calculated (Table 2.4) (Ref 39).

Table 2.5 gives the results of calculations of minimal taper length based on current MUTCD requirements for combinations of posted speed limits on work zones and width of offset similar to those above. For data comparison it is necessary to take into account that the MUTCD requirement restricted speed reductions of more than 16 km/h (10 mph). If necessary, greater speed reduction must be designed in several steps. Comparisons show that current MUTCD requirements of taper length (Table 2.5) exceed minimal values shown in Table 2.4 and therefore, correspond well to both criteria speed reduction and curvature.

Table 2.4 Minimal Taper Length

Speed before W.Z. km/h (mph)	Width of offset, m (ft)	Speed on Work Zone Detour, km/h (mph)				
		110 (70)	100 (60)	90 (55)	80 (50)	70 (45)
		Minimal Taper Length, m (ft)				
120 (75)	7.5 (24.5)	87 (284)	87 (284)	215 (706)	u.c.	u.c.
	3.75 (12.3)	62 (201)	62 (201)	215 (706)	u.c.	u.c.
	3.5 (11.5)	59 (194)	59 (194)	215 (706)	u.c.	u.c.
110 (70)	7.5 (24.5)	n/a	78 (254)	78 (254)	155 (506)	u.c.
	3.75 (12.3)	n/a	55 (180)	55 (180)	155 (506)	u.c.
	3.5 (11.5)	n/a	53 (174)	53 (174)	155 (506)	u.c.
100 (60)	7.5 (24.5)	n/a	n/a	67 (220)	67 (220)	67 (220)
	3.75 (12.3)	n/a	n/a	48 (156)	48 (156)	58 (191)
	3.5 (11.5)	n/a	n/a	46 (151)	46 (151)	58 (191)
90 (55)	7.5 (24.5)	n/a	n/a	n/a	62 (201)	62(201)
	3.75 (12.3)	n/a	n/a	n/a	44 (142)	44 (142)
	3.5 (11.5)	n/a	n/a	n/a	42 (137)	42 (137)

• u.c. = undesirable condition, excess driver tension.

Table 2.5 Minimal Taper Length Based on MUTCD Requirements

Taper Type	Width of Offset, m (ft)	Posted Speed Limit on Work Zone, km/h (mph)				
		110 (70)	100 (60)	90 (55)	80 (50)	70 (45)
		Minimal Taper Length, m (ft)				
Shifting Taper	7.5 (24.5)	258 (864)	234 (767)	211 (692)	188 (616)	164 (538)
	3.75 (12.3)	129 (423)	117 (384)	105 (344)	94 (308)	82 (269)
	3.5 (11.5)	120 (393)	109 (357)	98 (321)	88 (289)	77 (252)
Merging Taper	7.5 (24.5)	516 (1,692)	469 (1,538)	422 (1,384)	375 (1,230)	328 (1,075)
	3.75 (12.3)	258 (846)	234 (767)	211 (692)	188 (616)	164 (538)
	3.5 (11.5)	241 (790)	219 (718)	197 (646)	175 (574)	153 (502)

2.2 Adequate Advance Information to Road Users

As accident statistics show (see Chapter 1), the most crashes occur on the approach section, where driving behavior requires adjustment. Therefore, it is possible to conclude that drivers were not ready for the significant traffic condition changes. Excluding the conscious violation of traffic regulations, the principal driver problem is inadequate perception of advance information.

Part 6, "Temporary Traffic Control," of MUTCD (Ref 42) requires that warning signs should be placed in advance of the temporary traffic control zone at varying distances depending on roadway type, condition, and posted speed. Section 6C.04, "Advance Warning Area," formulates that "Typical distances for placement of advance warning signs on expressways and freeways should be longer because drivers are conditioned to uninterrupted flow. Therefore, the advance warning sign placement should extend on these facilities as far as 800 m (0.5 mi.) or more."

Due to heavy traffic volume on urban freeways, long vehicle queues typically are created upstream from work zones. Many studies show that queue length on urban multilane freeways caused by complex work zones varies from 0.5 to 2 miles or higher (Refs 43, 44, 45). During field observation a situation was identified where the queue covered the advance warning sign locations. Thus TCP designers need more detailed recommendations for advance information placement. For this purpose, the model "Queue and User Cost Evaluation of Work Zones" (QUEWZ-92) developed by the TTI (Ref 46) is recommended as a tool for queue length determination. QUEWZ-92 compares traffic flow through a freeway segment with and without a work zone lane closure and estimates the changes in traffic flow characteristics (average speeds and queue length). This model can be applied to freeway facilities or multilane divided highways with as many as six lanes in each direction and can analyze work zones with any number of lanes closed in either one or both directions. Depending on highway design and lane closure configuration, the model calculates work zone capacity, and the model determines the queue length with an input of hourly traffic volumes approaching the highway section. Using this method, a designer can now develop an adequate advance information placement scheme.

Two solutions for advance information placement take into consideration vehicle queuing. One is to duplicate advance warning signs corresponding to maximum queue length or typical queue dimensions. The other is to implement a dynamic advance information concept. This concept foresees installation of several special changeable message boards on highway sections under possible queue influence. Based on real-time measurements of traffic flow, these special devices determine the queue growth and activate the next upstream sign. For a sample of such devices, see "Dynamic Work Zone Safety System," developed by International Road Dynamics Inc. (Canada).

During traffic control design it is also necessary to take into consideration the limitations of human abilities while driving. Major metropolitan areas, where complex work zones typically exist, are composed of a complex highway network with numerous directional signs. The addition of temporary work zone signs can cause driver information overload and reduce the probability of adequate information perception. Much research on driver perception of road signs summarizes requirements that state that the number of signs displayed at one location should not exceed three. Here it is necessary to clearly understand what "one location" means. A sign's effect on drivers involves processes described as recognition, identification, reading, perception, intellect, evolution, volition, and reaction. The distance through which a vehicle passes when all these processes happen can be defined as a sign's zone of influence. If zones of influence of the neighboring signs overlap, then for the purposes of the current research, these signs can be considered to be at one location. Based on the limit of three signs per location and taking into account other traffic control devices, it is possible that a greater number of signs with overlapping influence zones may cause driver perception difficulty. With the purpose of determining the zone of sign influence, the CTR research team conducted a literature review regarding drivers' perceptions of road signs. A brief summary of the review results is presented below.

Drivers' perceptions of road signs can be divided into three stages:

- Detection, which involves the driver seeing the sign among other objects but not being able to determine sign characteristics exactly
- Identification and understanding, when the driver determines form, color, and other characteristics of the sign and can classify the sign
- Judgment, which involves a decision-making process

Sign identification and understanding start when the size of a sign exceeds the threshold of human visual perception. This process depends on numerous factors, such as sign brightness and color, size ratio between the sign symbol and its background, form of the symbol, and speed of the vehicle. Research conducted in the United States determined the threshold values for sign identification and sign understanding (six to seven angular minutes for sign identification, eight to ten angular minutes for sign understanding). Similar values were obtained in Germany, Holland, Russia, and other countries (Refs 26, 27). These values change significantly as the speed of the vehicle increases (1.3 to 1.6 times the threshold value at speeds greater than 60 km/h). A reduction in the driver's visual concentration zone with an increase in speed has been observed. Most people have clear vision within a conical angle of 3° to 5° and fairly clear vision within a conical angle of 10° to 12°. Vision beyond these ranges is usually blurred. Therefore, to be identified accurately by the driver, signs must fall within a visual cone of 10°. The data obtained allows calculation of the approximate distance from a sign when drivers begin to perceive it. For large overhead signs common on urban freeways, this distance is around 600 meters, and for temporary work zone signs it is around 200 meters.

Other studies of drivers' perceptions of a group of signs indicated that, depending on a sign's dimensions, color, contrast, type of signs in the group, and travel speed, the distance between signs when drivers perceive them separately varied from five to ten seconds of driving time (Refs 26, 27). Taking into consideration the specifics of freeway signs, one might assume a minimum of five seconds of travel time for distance upstream from the sign at the point when drivers start to analyze it. Based on this assumption, it is possible to calculate values of zones of sign influence for the most frequent speeds on freeways and complex work zones (Table 2.6).

Table 2.6 Zone of Road Sign Influence

Units	Posted Speed Limit					
mph	70	65	60	55	50	45
	Zone of Sign Influence					
feet	508	475	443	393	361	328
meter	155	145	135	120	110	100

Figure 2.4 represents a sample of information load estimation based on the above-calculated zones of sign influence. A sample section is interstate freeway with a speed limit of 65 mph at the time of analysis. For the given speed limit, the zone of sign influence will be 145 meters or approximately 0.1 mile. Corresponding to limitation of three signs in one location, all locations (excluding one) provide minimal levels of increased driver information. So, the following changes in placement of signs are recommended:

- Taking into consideration that permanent guide signs on positions 1.3 and 1.4 are perceived by drivers continuously, it is better to relocate signs from 1.3 to another upstream location, for example at 1. 1 miles
- Relocate "Road Work Ahead" sign from the position at 1.4 miles to a position at 1.2 miles
- Relocate "Right Lane Closed" signs from the positions at 2.3 and 2.4 miles to the positions at 2.2 and 2.3 miles, respectively

The proposed concept for information load checking can help TCP designers in the placement of temporary work zone signs to better reflect human abilities.

2.3 Proper Traffic Control through Work Zone Detours

Observations have shown that the principal reasons for frequent weaving were operating on and off ramps, numerous accesses to local businesses, and insufficient information about the directions of traffic lanes. Better traffic control plan design can eliminate such problems.

We recommend that TCP predesign include an analysis of surrounding areas affected by work zones and determine possibilities for redistribution of local traffic to alternative routes to close available on- and off-ramps. Any ramp closure will lead to alterations in the proposed traffic control plan, such as changes in signal cycles at affected intersections, placement of additional signs providing information about ramp closure, and recommended alternative routes.

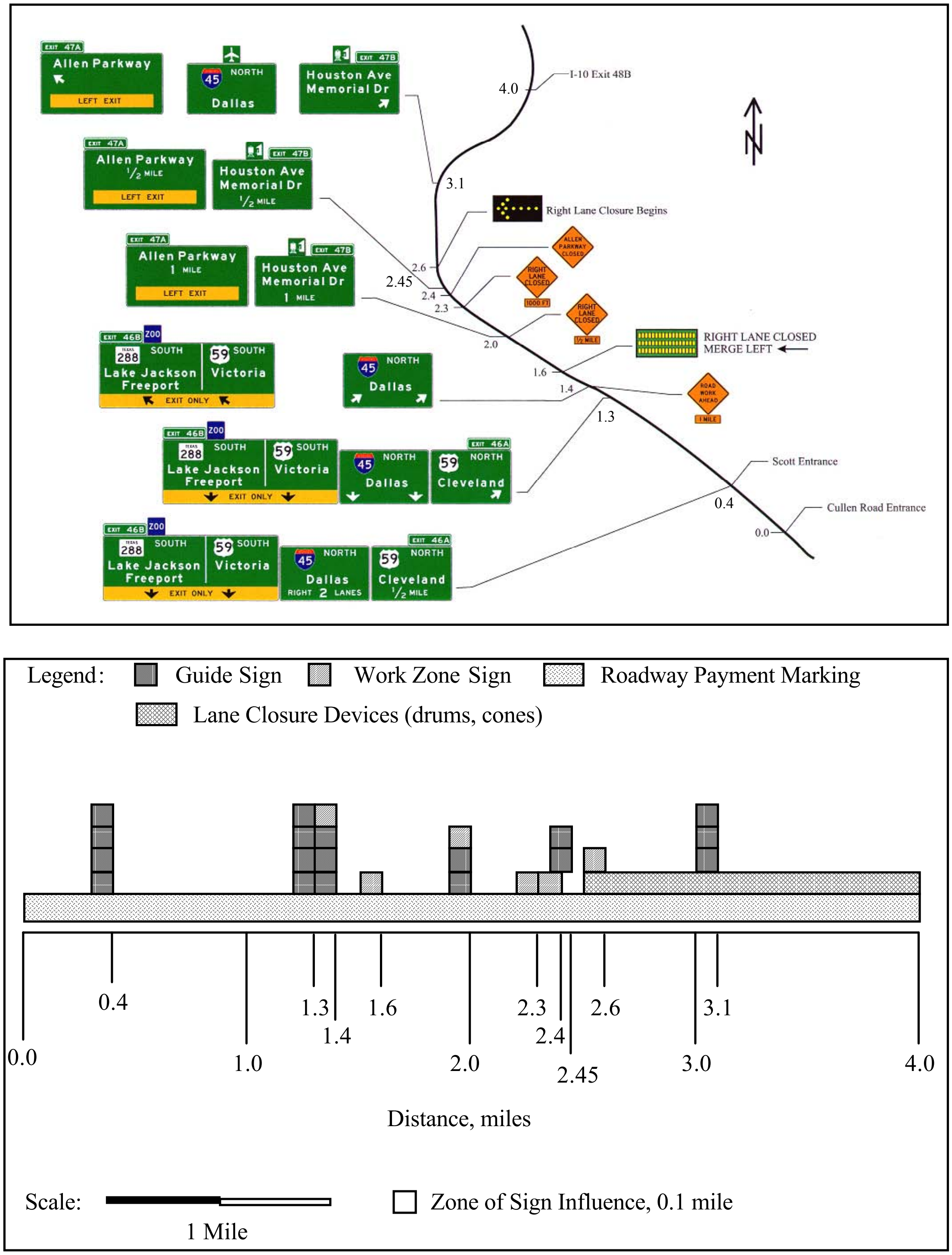


Figure 2.4 Sample of Information Load Estimation

Under normal traffic conditions local accesses have little impact on traffic. During increased traffic flow as a result of work zone, the effect of local accesses increases significantly. Therefore, it is necessary to analyze alternative accesses to the affected businesses, close all accesses whose closure will not affect the businesses, and place special signs informing motorists about the closure and new access.

2.4 Summary of Recommendations

1. Lane Closure Strategy

A comparison of CTR research findings with MUTCD requirements indicates that current standards related to work zone design correspond well to safety criteria. CTR research shows that utilization of work zone capacity depending on the ratio of open lanes to total lanes recommended by MUTCD ensures the presence of adequate frequency of large headways in the traffic flow, allowing motorists to merge from closed to open lanes.

The TTI research determined the maximum delay acceptable by drivers to be twenty minutes. Incorporating this lane closure strategy in TCP design would help minimize the effect of lane closures and aid in the selection of the most appropriate hours of the day for a given number of lanes to be closed without causing excessive queuing.

2. Transition Area Design

Analysis of vehicle movement in the work zone transition area shows that MUTCD requirements of minimal taper length ensure normal speed reduction as well as smooth redirection of traffic flow from normal paths.

3. Traffic Control in Advance Warning Area

It is very important to take into consideration queuing of vehicles when determining locations for advance information signs. We recommend that be used at the TCP predesign phase to estimate the available queue length for the selected work zone design the QUEWZ-92 model or similar model and to determine the queue length for the work zone active time. Following this additional warning device specifications corresponding to the typical queue dimension can be developed.

3. Samples of Drivers' Behavior and Reactions at Different Information Loads

3.1 Introduction

Each traffic accident is a result of some disturbance in the complex driver-vehicle-road-environment system. During accident investigations the most common causes are usually determined to be driver errors, inattention, or violations such as speeding, failure to yield right-of-way, or red-light running (see Chapter 1). Furthermore, errors and violations can be caused by the conscious violation of traffic regulations by drivers, as well as by the limited human ability to perceive and analyze information while driving.

Engineering psychology has formulated the general rule that each type of labor activity has its own corresponding optimal operator's emotional tension. When information is absent, an operator of any system has very low emotional tension and a high probability of errors in performing duties. On the other hand, when an operator has too much information at once, emotional tension significantly escalates, and this causes an increase in the probability of errors as well. Studies have found similar effects on the emotional states of drivers that, in turn, influence the driver's reactions (Figure 3.1) (Refs 26, 27).

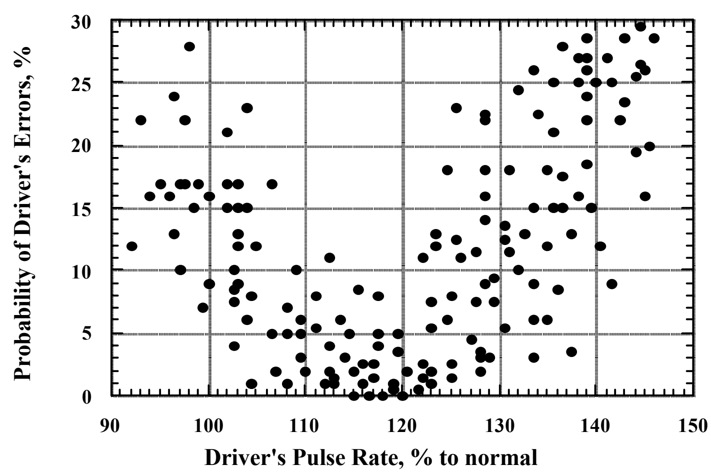


Figure 3.1 Probability of Driver Errors at Different Levels of Emotional Tension

The modern driving environment, especially in urban areas, is very complicated and can be extremely stressful for drivers. Multilane roadways, high traffic volumes and speeds, numerous exits and entrances causing weaving of vehicles, and a visually noisy environment cause information overload, require a high level of driver attention, and provide limited time for decision and behavior correction. Paradoxically, drivers may suffer from insufficient information when signs are not provided or cannot adequately be recognized. These situations cause unsafe driver behavior, such as sudden braking, last moment merging, and high variability in speed. In turn, these elevate driver stress even more and thus increase the probability of errors, accidents, and congestion.

Work zone traffic control plans define how signs, pavement markings, barricades, channelizing devices, object markers, and flashing warning lights are to be combined to delineate a specific situation, such as a temporary lane closure or a pavement drop-off. However, many work zones involve the combination of these situations, some of which overlap. Often this results in a large number of devices being implemented in order to meet the requirements of each of the traffic control plans. In some cases the combined set of devices can be visually overwhelming and actually cause confusion for drivers trying to navigate through the zone.

Therefore, engineers need guidance as to the combined effects of roadway, roadside environment, and traffic flow characteristics on driver information loads and safety, so that they can make well-grounded design decisions that accommodate human abilities. As a first step in this complex study, the present investigations were conducted. The research goal was to quantitatively describe drivers' behavior and reactions at different information loads and to make a comparative analysis with the purpose of determining the applicability of the proposed approach for further experimental observations.

3.2 Methodology of Field Observations

First, it is very important to highlight the definition of "information" used in this study. "Information" was determined as all objects in a driver's field of view that have an impact on traffic operation and require driver analysis for appropriate behavior selection. "Information" includes all traffic control devices, roadway parameters, and traffic volume.

For this initial study the quantitative description of information load was not formulated. Three qualitative levels of information load were investigated: low, medium, and high. Three different highway sections were selected for field observations. All sections were located on the same urban freeway in Texas.

Section 1, an exit freeway area, exemplifies a low information level (Fig 3.2). There are three signs informing drivers of further connections placed at 1,400, 750, and 290 meters upstream from the exit ramp gore. Because of the significant effect of the intersection, traffic flow begins to get compressed in the area of the first guide sign. When drivers unfamiliar with this area recognize directional guidelines, they try to merge, but compressed flow on the right lane limits their ability to select appropriate gaps. Pilot observation of traffic operation indicated frequent unsafe and last-moment merging of vehicles on the given section.

Section 2 was determined to represent a medium information level. This section is a temporary roadway through the work zone (Fig 3.3). Narrowed lanes, the absence of shoulders, and concrete barriers on both sides were the major traffic-affecting factors. At the same time, a well-developed traffic control plan and the absence of exit and entrance ramps on the relatively long freeway section create stable traffic conditions with minimal weaving of vehicles between lanes.

Section 3, classified as a high information environment, is an entrance ramp from city arterial street to freeway (Fig 3.4). Work zone influence, the absence of shoulders, and numerous control devices such as barricades, drums, and concrete barriers increase the negative impacts of the given ramp on highway traffic, and, in turn, affect traffic on the ramp. For appropriate behavior selection drivers need to analyze many factors simultaneously, such as gaps available for merging on the freeway lane, the distance to the end of the acceleration lane, vehicle's lateral clearance relative to the heavy traffic control devices, and behavior of the leading and following vehicles. Therefore, such conditions require a high level of driver attention and provide very limited time for decision making and behavior corrections.

Figure 3.2 General View of Section 1

Figure 3.3 General View of Section 2

Figure 3.4 General View of Section 3

Because direct comparison of these different highway sections is not available, the relative characteristics were compared. Drivers' behavior and reactions on the investigated sections were compared to their values on the control sections, and the "investigated-to-control" ratio was used for comparative analysis. Control sections were similar to investigated highway sections with adequate traffic volumes, but with ideal design features. The following control sections were selected:

Section 1c. Freeway exit area (Fig 3.5). Adequate signage and stable traffic flow in this area allow drivers to easily select the appropriate gap and merge to the exit.

Section 2c. Located upstream from section 2 and outside of work zone influence, this section has three 12-foot traffic lanes in one direction and full-size shoulders on the both sides (Figure 3.6).

Section 3c. The entrance ramp from city arterial street to freeway was selected as a control sample for section 3 (Figure 3.7). A large sight distance, together with a wide multilane roadway, full-size shoulders, and stable freeway flow, can be noted as major criteria for this selection.

A comparison of sections 3 and 3c provides information regarding changes in the investigated parameters under major increases in information, sections 2 and 2c for light information differences, and sections 1 and 1c for low information.

Figure 3.5 General View of Section 1c

Figure 3.6 General View of Section 2c

Figure 3.7 General View of Section 3c

Observations of all sections were made in similar weather conditions and with adequate traffic volume. Test driving with each driver was conducted twice, once at normal business hours and once at peak hours, in other words, at medium and heavy traffic volumes. A total of eight drivers participated in the experimental observations. Ages of test drivers ranged from 22 to 36 years, and their driving experience ranged from 5 to 20 years. Each driver was directed to drive to some destination point on the given route, which included all investigated and control sections. Test drivers had no other instructions and did not know about the purpose of the observations or the locations of the investigated highway sections. To avoid the impact of fatigue on drivers' reactions, the total trip time did not exceed fifty minutes.

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

Based on the review of other investigations of drivers' psycho-physiological reactions to real driving, the drivers' pulse rates were selected as the most informative ECG characteristic for this study. To allow for differences in drivers' psycho-physiological states at the time of observation, their basic or pretest electrocardiograms were recorded before each test drive at nondriving conditions. For further analysis relative characteristics, such as, drivers' pulse rates at the investigated conditions as a percent of basic value, were used.

For the determination of a driver's emotional state, results from previous investigations of probability of driver errors at different emotional tension levels (represented in Figure 3.1) were used. The research showed that if a driver's pulse rate as a percentage of basic value is less than 100%, it indicates that the driver has a low attention level and a high probability of errors. The variation of this characteristic between 100% and 120% means a good attention level with minimal probability of errors, and exceeding 120% indicates high emotional tension and a high probability of errors.

3.3 Collected Data

As has been noted, information loading was divided into three qualitative groups: low, medium, and high. Thos, collected data were classified into three groups, and they are represented in Appendices B, C, and D, respectively.

3.3.1 Test 1. Low Information Level

Observations of speed history on section 1 (representing low information) and section 1c (control section) showed that for practically all drivers and under both investigated traffic conditions, mean speed values were greater on the control section. At medium traffic volume for different drivers, mean speed varied from 20 to 42 km/h on section 1, and from 55 to 89 km/h on the control section. The corresponding values for heavy traffic volume were from 31 to 45 km/h and from 47 to 86 km/h. The average for all drivers' mean speed on section 1 was 45 km/h or 56% less at medium traffic volume and 42 km/h or 50% less at heavy traffic volume than on the control section. Speed variation was also greater on the control section for the majority of drivers (six out of eight). Standard deviation of speed distribution at medium traffic volume varied from 5.4 to 28.07 km/h on section 1 and from 18.74 to 36.8 km/h on the control section. For high volume corresponding values were from 6.19 to 17.92 km/h and from 10.23 to 32.02 km/h. The average of standard deviations of speeds for all drivers on sections 1 and 1c was observed to be around 9 km/h, or 40% higher, for the control section.

Combined data on acceleration and deceleration distribution indicate less stability of traffic flow on section 1, which is reflected by smaller mean values and greater standard deviations for section 1 than for the control section. Separate analysis of those characteristics leads to the same conclusion. While mean values of realized accelerations and decelerations showed no significant differences for investigated sections, at high volume their standard deviation was typically higher (around 0.45 m/sec.sq. on average) for the insufficient information section than for the control section.

Data of mean values for the ratio of driver pulse rate to basic value do not indicate significant differences between sections or for investigated traffic volume intervals for all drivers. At the same time, the standard deviation of pulse rate for four of the eight drivers was greater in section 1 by 25% and 27% on average, respectively, at medium and high traffic compared to the control section. The other four drivers had no significant differences for medium volume, but for heavy traffic on section 1 they had low standard deviation of pulse rate on an average of 19%.

Detailed analysis of pulse rate distribution showed that at medium volume on section 1, four of the eight drivers (versus only two on the control section) had pulse rates greater than 120% compared to basic, indicating that they experienced high emotional tension. At high volume on both sections, the same emotional state was observed for two drivers. For all of the above-mentioned cases, high emotional tension did not happen for more than 10% of the total driving time. Data also indicated a significant amount of time when the drivers had low attention levels. On average, for around 40% and 50% of total driving time at medium and heavy traffic volumes, respectively, low attention was identified (pulse rate as a percentage of basic is less than 100%). At heavy volume on section 1, five of the eight drivers had low attention for an average of 71% of total driving time, versus 58% on the control section.

3.3.2 Test 2. Medium Information Level

Observations of speed history through the work zone (section 2) and non-work zone (section 2c) showed differences for all drivers. At medium traffic volume, the mean speed varied from 26 to 102 km/h in the work zone, and from 83 to 110 km/h in the control section. Those values for heavy traffic volume were from 37 to 65 and from 54 to 102 km/h, respectively. The average of mean speed for drivers in the work zone was 26 km/h or 25% less at medium volume and 25 km/h or 28% less at heavy traffic volume than in the control section. At medium traffic volume speed variance was greater for the majority of drivers (six out of eight) in the work zone, and standard deviation of speed distribution varied from 4 to 18 km/h. For heavy volume traffic, the opposite situation was observed, with five of the eight drivers showing a speed variance significantly greater in the control section. Standard deviation of speed distribution for those drivers varied from 9 to 19 km/h in the work zone compared to 26 to 33 km/h in the control section. Comparison of standard deviation of speed for all drivers showed that there was greater difference between sections 2 and 2c at medium volume (6.27 km/h or 201% on average higher on section 2) than at heavy volume (7.74 km/h or 140% less on section 2).

One of the very important characteristics of traffic operation in the investigated sections is "acceleration noise," which is represented by the standard deviation of acceleration/deceleration distribution. Data showed that this characteristic at medium traffic volume varied from 0.55 to 0.98 m/sec.sq. in the work zone and from 0.56 to 0.8 m/sec.sq. in the control section. Corresponding values for heavy traffic volume were from 0.78 to 1.32 and 0.74 to 1.26 m/sec.sq. On average, standard deviation on section 2 was 0.14 m/sec.sq. or 23% greater at medium volume and 0.06 m/sec.sq. or 8% greater at heavy volume than on control section.

Separate analysis of acceleration showed that there is no significant difference between mean acceleration for all drivers at both observed traffic conditions. At medium volume the majority of drivers (five out of eight) had greater standard deviation of realized accelerations: on average, 131% in the work zone compared to control section. For those drivers, such values varied from 0.24 to 0.64 m/sec.sq. and 0.12 to 0.26 m/sec.sq., respectively. At heavy volume acceleration variation was greater in the control section for five of the eight drivers than in the work zone, and the observed difference in standard deviation was 28% on average. The duration of acceleration as a percentage of total driving time was greater in section 2 for practically all drivers. At medium volume, acceleration duration in section 2 on average was 3% longer than in section 2c. For heavy volume this difference was 2%.

Analysis of deceleration distribution also failed to show a significant difference between mean deceleration values in the work zone and control section, and identified differences in standard deviation at medium and heavy traffic volume, similar to acceleration. At medium volume six of the eight drivers had the standard deviation of utilized deceleration on average 125% greater in the work zone than in the control sections, and for five of the eight drivers this characteristic was on average 16% greater in the control section. It is necessary to note that in both cases average differences of standard deviation were around 0.25 m/sec.sq. Duration of deceleration as a percentage of total driving time was also longer in section 2 at medium volume (3.5% average), and practically no difference was observed at heavy volume.

No significant differences between sections, nor for investigated traffic volume intervals, were observed for mean values of the drivers' pulse rates. Analysis of pulse rate variations showed that at both investigated traffic conditions, drivers' pulse rates on section 2 had greater dispersion compared to the control section. Standard deviation of pulse rate distribution for five of the eight drivers was on average greater by 15% at medium volume and 21% at high volume in section 2 compared to section 2c.

Detailed analysis of pulse rate distribution showed that at medium volume in section 2, three of the eight drivers, versus two in the control section, had a short-term high emotional tension reading (pulse rate in percentage to basic greater than 120%). At high volume in both sections, such emotional states were observed for three drivers. On average for all drivers, for around 40% and 60% of the total driving time at medium and heavy traffic volumes, low attention was identified (pulse rate as percentage of basic was less than 100%). In section 2 the majority of drivers (five out of eight) had shorter low-attention duration than in the control section. On average this duration was 37% of total driving time in section 2 and 47% on the control section.

3.3.3 Test 3. High Information Level

Significant speed differences between sections 3 and 3c were observed for all drivers. At medium traffic volume mean speed for different drivers varied from 18 to 47 km/h in section 3 and from 61 to 73 km/h in the control section. At heavy volume those values were 9 to 50 km/h and 62 to 106 km/h, respectively. Comparison of mean speed difference between sections for all drivers showed that in section 3 mean speeds were 33% to 75% lower than in section 3c at medium volume and from 37% to 87% lower at heavy volume. Generally, an individual driver had greater speed differences in sections 3 and 3c at heavy volume.

Some differences in speed variation were observed as well. At medium traffic volume, the majority of drivers had greater variance in speed in section 3, where standard deviation of speed distribution was observed as 9% to 49% higher than in the control section. The collected data does not allow any conclusions, regarding difference in speed variance at heavy volume. Three drivers had no significant differences, two drivers had greater, and the other three drivers had lower speed variation in section 3 compared to section 3c.

Collected data clearly indicate that acceleration is predominant in the control section, while deceleration is prevalent in section 3 for all investigated traffic conditions for all drivers. Because the investigated highway sections are entrance ramps, one of the major characteristics of traffic operation is acceleration rate. Logically, vehicles should accelerate more steadily and smoothly in normal driving environments than in overloaded environments. Collected data showed that there was no significant difference between mean acceleration values for sections both at medium and heavy traffic volumes for almost all drivers. Variation of acceleration was greater in section 3c, where standard deviation of acceleration distribution was observed as 6% to 88% higher than in section 3. This can be explained by the speed difference on the ramps described above. At the same time the analysis of stability of acceleration showed that for all drivers at both traffic volumes, the percentage of time when drivers constantly accelerated was much greater in the control section and varied from 20% to 49%, compared to 5% to 20% in section 3. This clearly indicates a less stable traffic operation in high-information environment.

Analysis of deceleration distribution on the investigated ramps leads to the same conclusion. Drivers in section 3 were forced to reduce speed more frequently and intensively. Mean value of deceleration was around 2 m/sec.sq and percentage of total time related to speed reductions was up to 25%, while in the control section these values did not exceed 1.6 m/sec.sq. and 5%.

Data regarding mean values of drivers' pulse rates do not indicate significant differences between sections, and neither do data regarding traffic volume intervals. At the same time analysis of pulse rate variations shows the differences in distribution of drivers' pulse rates in section 3 compared to those in the control section. Standard deviation of pulse rate distribution for four of the eight drivers was on average 59% greater at medium and 31% greater at high volume in section 3 compared to section 3c. The inverse situation was observed with the other four drivers, for whom had value was greater in the control section by 29% and 22% on average at medium and high volumes, respectively.

Detailed analysis of pulse rate distribution shows that at medium volume in section 3, two of the eight drivers (versus three drivers on the control section) experienced high emotional tension (pulse rate as a percentage of basic was greater than 120%). At high volume in sections 3 and 3c, the same emotional state was observed for four and two drivers, respectively. On average for 35% (section 3) and 20% (section 3c) of the total driving time at medium volume, low attention was identified (pulse rate as a percentage of basic was less than 100%). At heavy volume those values were 35% and 42%. In section 3 four of the eight drivers had much longer low-attention duration than in the control section (on average 56% of total driving time versus 27%). At heavy volume for the majority of drivers (six of eight), this duration on average was 35% of total driving time in section 3 and 53% in the control section.

3.4 Data Comparison

As has been noted, in this study only the qualitative description of information loading was used, based on "lower-higher" criteria. The informational increase is greater from section 3 to 3c than from section 2 to 2c. Thos, the section 3 to 3c comparison was classified as representing a high information level, and section 2 to 2c as medium. Again, this classification does not mean that a "high" information level has a really high value; it is merely higher than the other one, classified as "medium" level. The major differences between section 1 and its control section, 1c, is that the first one provides limited motorist advance information regarding the given traffic conditions. Therefore, compared to other data sets, this section 1 to 1c comparison represents the lowest information level and was classified as "low" level.

The purpose of the comparative analysis was to determine available relations between the level of information loading and drivers' behavior and reactions. Tables 3.1 and 3.2 summarize the obtained results. Data represented in those tables characterize the differences in investigated characteristics on the main sections (1, 2, and 3) compared to corresponding control sections (1c, 2c, and 3c) at medium and heavy traffic volumes. Figures 3.8 and 3.9 graphically represent samples of test-to-control differences of driver reactions at different levels of information loading.

For deciding whether the three observed independent samples (low information, medium, and high information increase) are from different populations, the Kruskal-Wallis analysis was used. In all cases the null hypothesis was formulated as: There is no difference in the given characteristic (speed, acceleration, etc.) at low information, medium, and high information increase. Due to limited data, the tables represent the probability of null hypothesis acceptance, instead of simple acceptance or rejections at the standard significance level (0.05).

Analysis of the investigated characteristics has demonstrated a relationship between drivers' behavior and reactions and the level of information loading. There is lower probability of such relationships at heavy traffic volume, which can be explained by the reduction of general differences in traffic conditions between the investigated sections and control sections.

Table 3.1 Changes in Different Characteristics on the Investigated Sections Compared to Control Sections at Medium Traffic Volume

Driver	Characteristics														
	Speed		Acceleration/Deceleration			Acceleration			Deceleration			Driver's Pulse Rate		Duration of Driver's State	
	Mean	Std.Dev.	Mean	Std.Dev.	Duration	Mean	Std.Dev.	Duration	Mean	Std.Dev.	Duration	Mean	Std.Dev.	low attent.	overload
	km/h	km/h	m/sec.sq.	m/sec.sq.	% of total	m/sec.sq.	m/sec.sq.	% of total	m/sec.sq.	m/sec.sq.	% of total	bpm	bpm	% of total	% of total
Test 1. Low Information Level															
1	6.047	-14.94	0.276	-0.08	-0.41	0.128	0.24	6.33	0.28	-0.50	-6.74	0.228	0.95	8.21	0.00
2															
3	-52.35	6.51	0.22	0.09	0.24	0.173	0.49	6.51	-0.07	-0.01	-6.26	-0.712	2.19	-1.85	0.00
4	-68.466	-7.50	0.312	0.03	3.30	0.323	0.59	7.90	0.36	-0.12	-4.60	4.329	0.83	-33.23	0.87
5	-13.037	-12.62	0.042	0.09	1.76	-0.302	-0.47	3.32	-0.21	0.50	-1.55	-3.812	-1.60	30.82	-3.24
6	-46.133	2.27	0.204	0.18	4.32	0.103	0.39	8.37	-0.28	0.23	-4.05	8.659	0.32	-43.11	2.07
7	-55.254	-2.69	0.239	0.17	5.56	0.225	0.47	9.28	0.02	-0.03	-3.72	0.98	-0.43	0.00	1.35
8	-37.413	7.82	0.139	0.27	9.32	0.478	0.62	8.06	-0.07	-0.16	1.26	-0.25	-0.03	0.43	0.00
Test 2. Medium Information Increase															
1		9.88	0.03	0.31	7.79	0.27	0.46	4.67	0.21	0.40	3.12	2.63	0.40	-18.02	0.69
2	-10.03	-2.76	0.04	0.02	1.14	0.02	0.12	1.84	0.00	0.01	-0.71				
3	-1.06	-2.40	-0.01	-0.08	-2.64	0.02	-0.04	-2.04	-0.12	-0.26	-0.61	3.44	-1.28	-1.99	0.00
4	-32.03	15.32	-0.05	0.35	10.13	-0.06	-0.19	5.31	0.45	0.66	4.82	1.20	0.68	-13.87	0.00
5	-9.70	0.69	-0.05	0.08	1.77	0.09	0.24	-0.55	0.08	0.25	2.32	0.67	0.07	-11.77	-0.65
6	-11.94	8.39	-0.03	0.16	4.14	0.20	0.31	0.65	0.07	0.16	3.48	0.43	1.22	-1.48	1.84
7	-25.51	8.88	-0.04	0.09	3.29	0.01	0.08	0.56	0.05	0.14	2.73	0.38	0.38	0.00	7.10
8	-30.70	12.13	-0.05	0.23	9.06	-0.09	-0.31	4.76	0.28	0.22	4.29	-0.19	-0.83	7.01	0.00
Test 3. High Information Increase															
1	-33.63	1.69	-0.90	0.03	-10.74	-0.18	-0.28	-28.41	0.28	0.31	17.67	-1.16	-1.93	-4.73	-9.39
2	-46.67	2.25	-0.84	-0.09	-40.45	-0.03	-0.14	-40.64	-0.15	0.19	12.04				
3	-52.56	-4.64	-0.97	0.03	-14.34	-0.31	-0.50	-27.44	2.49	1.62	13.10	-8.60	3.14	48.77	0.00
4	-24.44	-1.39	-0.87	0.28	-7.08	0.61	0.72	-27.84	1.91	0.91	20.76	0.69	-1.60	-7.74	0.00
5	-21.51	3.65	-0.64	0.50	-0.70	0.30	0.08	-14.59	2.76	1.30	13.89	-10.16	-2.36	57.42	-2.86
6	-30.76	7.07	-1.00	0.11	4.88	-0.57	-0.70	-18.24	0.54	0.88	23.12	4.06	0.43	0.23	2.59
7	-38.56	6.29	-0.97	-0.06	-6.84	-0.27	-0.25	-26.81	-0.39	0.68	19.97	-4.62	0.80	0.00	-42.40
8	-26.36	-2.16	-1.09	-0.21	-12.98	-0.14	-0.05	-34.41	1.69	0.36	21.43	-1.64	2.87	13.66	0.00
Kruskal-Wallis Analysis															
H	5.727	4.650	19.565	0.389	10.052	3.781	5.637	18.639	4.455	10.677	18.936	4.282	0.052	1.288	-16.712
p	0.100	0.100	0.001	0.98	0.01	0.200	0.100	0.001	0.200	0.010	0.001	0.200	0.900	0.700	1.000

Table 3.2 Changes in Different Characteristics on the Investigated Sections Compared to Control Sections at Heavy Traffic Volume

Driver	Characteristics														
	Speed		Acceleration/Deceleration			Acceleration			Deceleration			Driver's Pulse Rate		Duration of Driver's State	
	Mean	Std.Dev.	Mean	Std.Dev.	Duration	Mean	Std.Dev.	Duration	Mean	Std.Dev.	Duration	Mean	Std.Dev.	low attent.	overload
	km/h	km/h	m/sec.sq.	m/sec.sq.	% of total	m/sec.sq.	m/sec.sq.	% of total	m/sec.sq.	m/sec.sq.	% of total	bpm	bpm	% of total	% of total
Test 1. Low Information Level															
1	-36.76	-0.35	0.17	0.05	-0.41	0.12	0.27	1.94	-0.02	-0.05	-4.934	3.08	0.10	-34.35	0.00
2	-47.34	-3.26	0.29	0.29		0.28	0.37	5.02	-0.21	0.29	-6.196	-2.86	-0.43	4.94	0.00
3	-52.18		0.00	0.00	0.24	-0.01	-0.62	10.08	-0.26	0.16	-6.777	-1.48	1.83	13.82	1.77
4	-55.65	-9.98	0.00	0.84	3.30	-0.07	-0.12	8.35	0.230	-0.77	-6.831	-1.39	1.42	21.75	0.00
5	-4.76	-22.75	0.08	-0.16	1.76	-0.03	-0.29	0.08	0.38	-0.50	-1.113	-2.27	-1.65	11.94	-2.37
6	-45.77	3.93	0.16	0.48	4.32	0.22	0.60	4.81	-0.44	0.92	-2.976	6.38	2.44	-32.63	6.74
7	-52.05	-7.00	0.25	0.19	5.56	0.36	0.61	-35.96	-0.12	0.12	-8.781	1.55	-0.97	-11.57	0.00
8	-37.03	-6.69	0.29	-0.20	9.32	0.00	0.17	4.86	0.25	-0.44	-10.234	-1.37	-0.47	15.33	0.00
Test 2. Medium Information Level															
1	-41.26	-17.21	0.31	-0.16	1.47	0.09	0.04	1.81	-0.46	-1.21	-0.348	2.11	0.62	-18.62	0.00
2	-8.52	-22.11	0.02	0.00	-0.27	0.06	-0.08	0.80	0.00	-0.06	-1.071	-2.38	0.47	2.53	0.00
3	-15.04	-22.54	-0.08	-0.26	-6.17	-0.09	-0.13	-5.34	-0.10	-0.20	-0.837	1.07	1.50	-3.00	0.44
4	-0.66	-7.78	0.35	0.05	2.75	0.06	-0.10	0.84	-0.08	-0.13	1.908	-0.22	-1.15	6.33	0.00
5	0.45	-17.44	0.08	0.14	0.86	0.03	-0.18	1.59	0.18	0.05	-0.726	1.88	1.72	-7.52	0.00
6	-39.03	3.66	0.16	0.13	3.08	0.11	0.31	2.55	-0.05	-0.10	0.527	4.33	0.74	-15.69	3.92
7	-45.05		0.09	0.44	3.12	0.22	0.51	3.43	0.62	1.15	-0.309	-0.06	-0.93	-1.04	-3.34
8	-51.54	7.62	0.23	0.17	6.09	0.06	-0.31	3.32	0.16	0.20	2.771	-2.78	-0.09	26.08	0.28
Test 3. High Information Level															
1	-25.06	3.14	-1.43	-0.09	9.88	0.09	0.10	-2.23	0.97	0.97	12.11	3.77	-2.31	-60.40	0.00
2	-57.49	-11.15	-0.81	-0.42	-9.65	-0.18	-0.06	-18.86	0.28	0.28	8.209	4.95	-1.10	-8.29	0.00
3	-24.31	2.21	-1.04	0.07	31.63	0.29	0.46	15.65	0.19	0.19	15.981	0.97	-2.58	-12.27	-13.56
4	-38.13	-0.48	-0.84	-0.08	-6.03	-0.22	-0.17	-23.61	1.77	1.77	17.587	-4.79	0.07	53.18	0.00
5	-39.97	0.24	-0.91	-0.25	1.53	-0.33	-0.36	-13.84	2.02	2.02	15.457	2.13	0.68	-9.49	0.00
6	-30.38	-5.17	-1.18	-0.53	-9.19	-0.26	-0.20	-23.47	0.47	0.47	14.275	5.64	0.50	-15.25	22.31
7	-61.03	-6.41	-1.01	-0.42	-10.33	-0.07	0.20	-21.00	2.02	2.02	10.669	0.13	-0.29	0.00	-2.34
8	-37.15	0.99	-0.84	-0.24	-11.21	-0.02	-0.35	-25.56	-0.33	-0.33	14.352	5.47	1.41	-3.84	20.39
Kruskal-Wallis Analysis															
H	2.625	2.298	15.365	7.453	2.704	4.905	1.295	6.605	6.965	6.62	20.48	2.58	1.415	1.040	-33.790
p	0.200	0.500	0.001	0.050	0.300	0.1	0.7	0.05	0.05	0.05	0.001	0.3	0.5	0.700	1.000

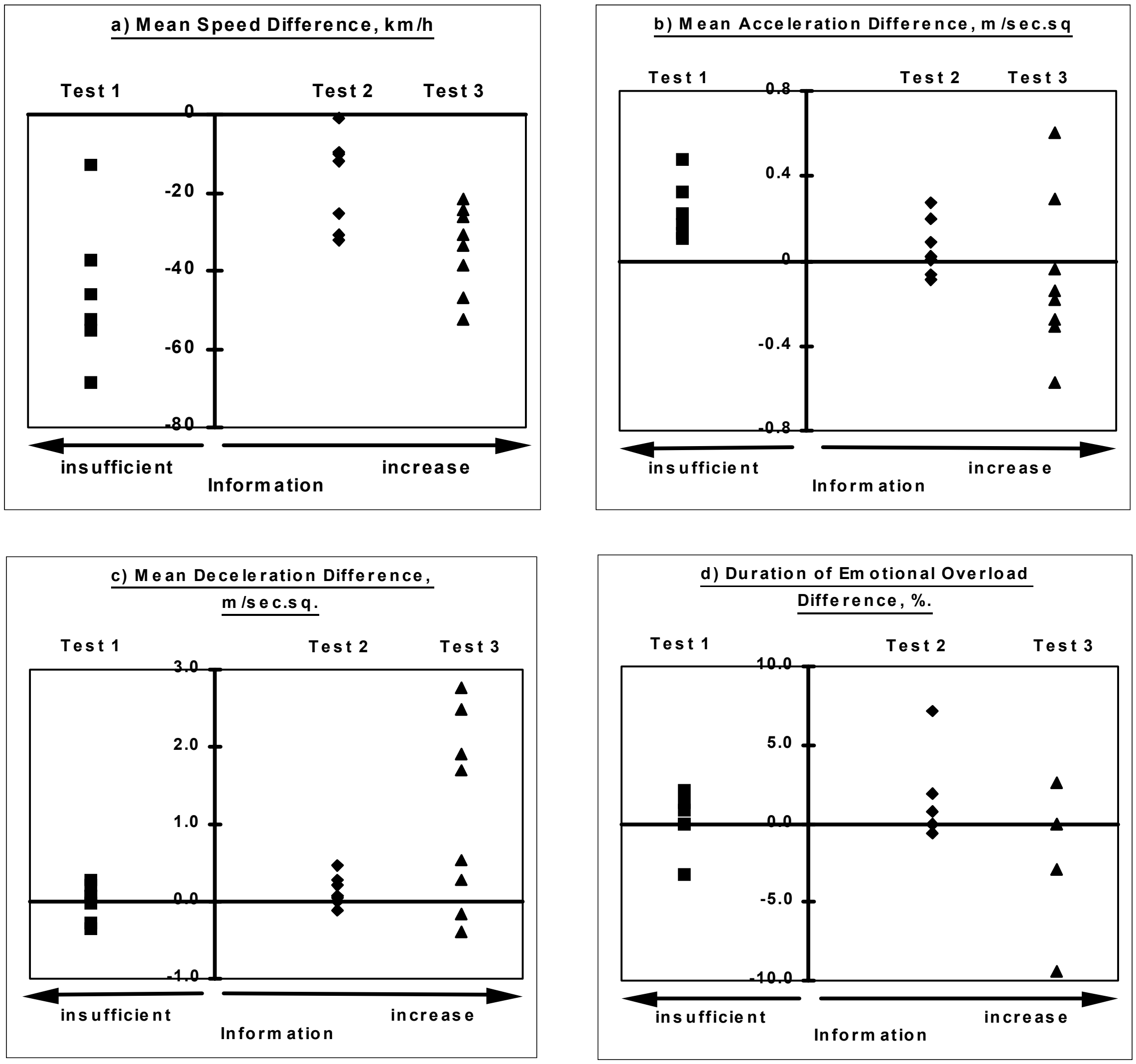


Figure 3.8 Test-to-Control Difference of the Selected Characteristics of Driver's Reactions at Medium Traffic Volume

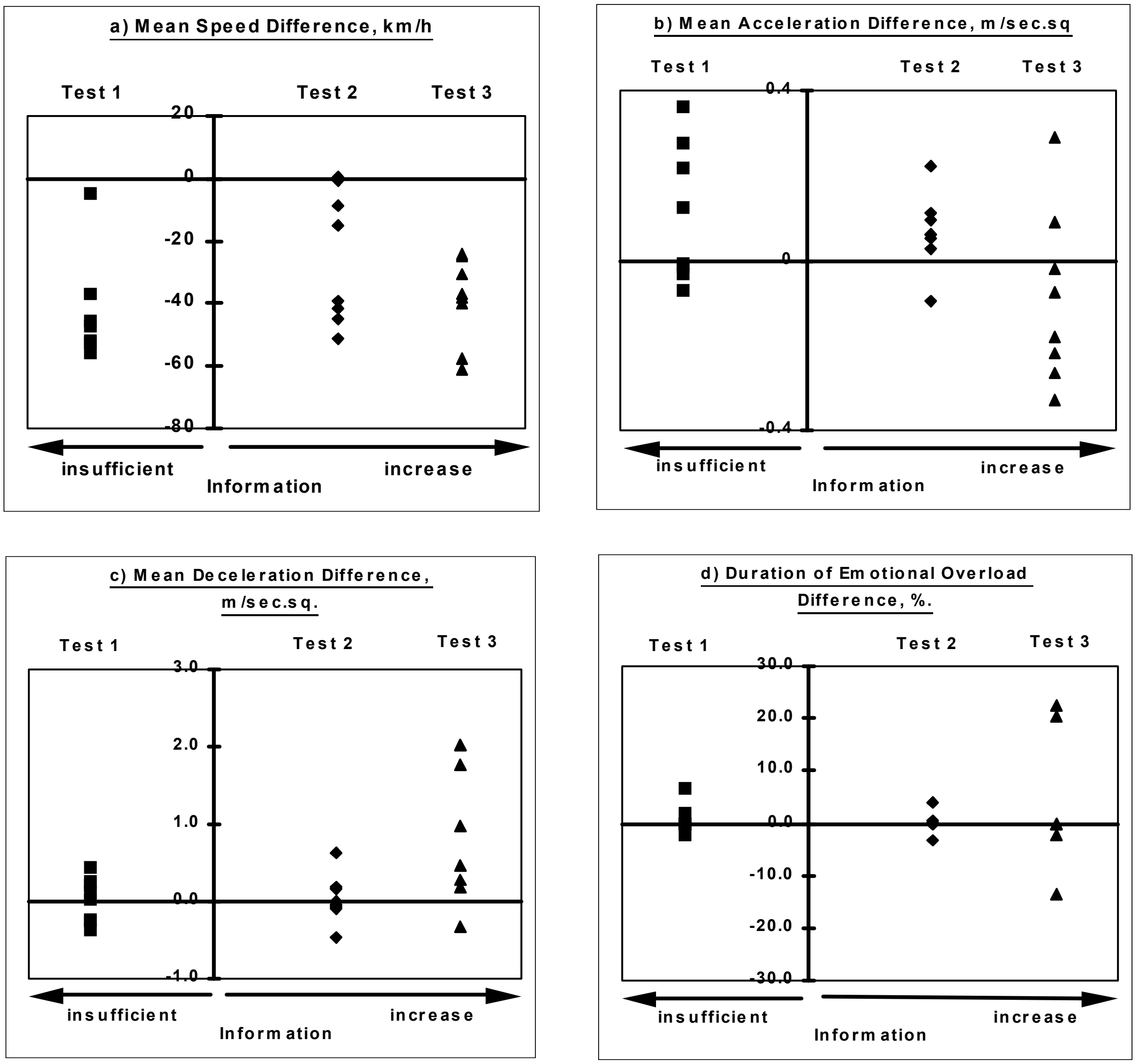


Figure 3.9 Test-to-Control Difference of the Selected Characteristics of Driver's Reactions at High Traffic Volume

3.5 Conclusions

This limited research was not aimed at drawing correlations between drivers' behavior and reactions and information levels. The main purposes were to investigate the existence of such relationships and to examine the experimental approach for further detailed research. The following conclusions can be formulated:

1. With high probability, significant impact of information levels on the investigated characteristics can be expected.
2. The data obtained allowed hypothesizing the form of those relations as parabolic. Both low and high information levels cause similar changes in drivers' behavior and reactions. Minimal impacts were observed at a medium information increase. Therefore, the existence of an optimal information level can be assumed.
3. The effect of information loading decreased at heavy traffic volumes. This phenomenon can be explained by the lower flow speed and by the reduction of drivers' behavioral choices in condensed traffic flow.
4. Observed situations did not indicate a significant increase in drivers' emotional tension. At the same time, long durations of low driver attention, even in complicated traffic conditions, were observed for practically all drivers. If further investigations prove this phenomenon, it will lead to the development of special countermeasures for ensuring a fair level of drivers' attention.
5. Investigations showed that the implemented approach for experimental observations is sensitive enough and applicable for use in further studies.

The investigations reviewed in this report clearly indicate the need for further studies in order to improve the traffic control system. The next step in determining optimal information levels should be the development of a methodology for quantitatively describing different information levels and detailed investigations of corresponding drivers' responses.

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Appendix A
Estimation of Lane Changing Opportunity at Different Traffic Volumes

TABLE A.1 Two Lanes in One Direction Freeways with Right Lane Closed

Traffic Volume			Section 1 (3000 to 2000 feet upstream)						Section 2 (2000 to 1000 feet upstream)						Section 3 (1000 to 0 feet upstream)					
			Tr. Volume		Headways > 2 sec.		Merging 40%	Difference	Tr. Volume		Headways > 2 sec.		Merging 30 (50)%	Difference	Tr. Volume		Headways > 2 sec.		Merging 30 (50)%	Difference
Total vph	Right vphpl	Left vphpl	Right vphpl	Left vphpl	%	hph	vph	vph	Right vphpl	Left vphpl	%	hph	vph	vph	Right vphpl	Left vphpl	%	hph	vph	vph
500	267	233	267	233	85.97	200	107	94	160	340	82.43	280	80	200	80	420	79.77	335	80	255
600	303	297	303	297	83.85	249	121	128	182	418	79.82	334	91	243	91	509	76.81	391	91	300
700	339	361	339	361	81.73	295	136	159	203	497	77.22	383	102	282	102	598	73.85	442	102	340
800	375	425	375	425	79.60	338	150	188	225	575	74.62	429	113	317	113	687	70.88	487	113	375
900	411	489	411	489	77.48	379	164	214	247	653	72.02	471	123	347	123	777	67.92	528	123	404
1000	447	553	447	553	75.35	417	179	238	268	732	69.42	508	134	374	134	866	64.96	562	134	428
1100	483	617	483	617	73.23	452	193	258	290	810	66.81	541	145	396	145	955	62.00	592	145	447
1200	519	681	519	681	71.11	484	208	276	312	888	64.21	571	156	415	156	1044	59.04	617	156	461
1300	555	745	555	745	68.98	514	222	292	333	967	61.61	596	167	429	167	1133	56.08	636	167	469
1400	591	809	591	809	66.86	541	237	304	355	1045	59.01	617	177	439	177	1223	53.12	649	177	472
1500	627	873	627	873	64.74	565	251	314	376	1124	56.41	634	188	446	188	1312	50.16	658	188	470
1600	663	937	663	937	62.61	586	265	321	398	1202	53.80	647	199	448	199	1401	47.20	661	199	462
1700	699	1001	699	1001	60.49	605	280	325	420	1280	51.20	656	210	446	210	1490	44.23	659	210	449
1800	735	1065	735	1065	58.37	621	294	327	441	1359	48.60	660	221	440	221	1579	41.27	652	221	431
1900	771	1129	771	1129	56.24	635	309	326	463	1437	46.00	661	231	430	231	1669	38.31	639	231	408
2000	807	1193	807	1193	54.12	645	323	322	484	1516	43.39	658	242	415	242	1758	35.35	621	242	379
2100	844	1256	844	1256	51.99	653	337	316	506	1594	40.79	650	253	397	253	1847	32.39	598	253	345
2200	880	1320	880	1320	49.87	659	352	307	528	1672	38.19	639	264	375	264	1936	29.43	570	264	306
2300	916	1384	916	1384	47.75	661	366	295	549	1751	35.59	623	275	348	275	2025	26.47	536	275	261
2400	952	1448	952	1448	45.62	661	381	280	571	1829	32.99	603	285	318	285	2115	23.51	497	285	212
2500	988	1512	988	1512	43.50	658	395	263	593	1907	30.38	580	296	283	296	2204	20.55	453	296	156
2600	1024	1576	1024	1576	41.38	652	409	243	614	1986	27.78	552	307	245	307	2293	17.59	403	307	96
2700	1060	1640	1060	1640	39.25	644	424	220	636	2064	25.18	520	318	202	318	2382	14.62	348	318	30
2800	1096	1704	1096	1704	37.13	633	438	194	657	2143	22.58	484	329	155	329	2471	11.66	288	329	-41
2900	1132	1768	1132	1768	35.01	619	453	166	679	2221	19.97	444	340	104	340	2560	8.70	223	340	-117
3000	1168	1832	1168	1832	32.88	602	467	135	701	2299	17.37	399	350	49	350	2650	5.74	152	350	-198
3100	1204	1896	1204	1896	30.76	583	482	102	722	2378	14.77	351	361	-10	371	2729	3.11	85	371	-286
3200	1240	1960	1240	1960	28.63	561	496	65	744	2456	12.17	299	372	-73	445	2755	2.25	62	445	-383
3300	1276	2024	1276	2024	26.51	537	510	26	766	2534	9.57	242	383	-140	523	2777	1.52	42	523	-481
3400	1312	2088	1312	2088	24.39	509	525	-16	803	2597	7.48	194	401	-207	608	2792	1.03	29	608	-580
3500	1348	2152	1348	2152	22.26	479	539	-60	869	2631	6.36	167	434	-267	702	2798	0.80	23	702	-679
3600	1384	2216	1384	2216	20.14	446	554	-107	938	2662	5.32	142	469	-327	796	2804	0.62	17	796	-779
3700	1420	2280	1420	2280	18.02	411	568	-157	1009	2691	4.38	118	505	-387	892	2808	0.47	13	892	-878
3800	1456	2344	1456	2344	15.89	372	582	-210	1084	2716	3.53	96	542	-446	988	2812	0.35	10	988	-978
3900	1492	2408	1492	2408	13.77	332	597	-265	1161	2739	2.76	76	580	-505	1085	2815	0.25	7	1085	-1078
4000	1528	2472	1528	2472	11.65	288	611	-323	1240	2760	2.09	58	620	-563	1183	2817	0.18	5	1183	-1178

TABLE A.2 Two Lanes in One Direction Freeways with Left Lane Closed

Traffic Volume			Section 1 (3000 to 2000 feet upstream)						Section 2 (2000 to 1000 feet upstream)						Section 3 (1000 to 0 feet upstream)					
			Tr. Volume		Headways > 2 sec.		Merging 40%	Difference	Tr. Volume		Headways > 2 sec.		Merging 30 (50)%	Difference	Tr. Volume		Headways > 2 sec.		Merging 30 (50)%	Difference
Total vph	Right vphpl	Left vphpl	Right vphpl	Left vphpl	%	hph	vph	vph	Right vphpl	Left vphpl	%	hph	vph	vph	Right vphpl	Left vphpl	%	hph	vph	vph
500	267	233	267	233	84.85	227	93	133	360	140	81.75	294	70	225	430	70	79.43	342	70	272
600	303	297	303	297	83.65	253	119	135	422	178	79.71	336	89	247	511	89	76.75	392	89	303
700	339	361	339	361	82.45	280	144	135	483	217	77.66	375	108	267	592	108	74.06	438	108	330
800	375	425	375	425	81.26	305	170	135	545	255	75.61	412	127	285	673	127	71.38	480	127	353
900	411	489	411	489	80.06	329	196	134	607	293	73.57	446	147	300	753	147	68.70	518	147	371
1000	447	553	447	553	78.86	353	221	131	668	332	71.52	478	166	312	834	166	66.02	551	166	385
1100	483	617	483	617	77.67	375	247	129	730	370	69.48	507	185	322	915	185	63.33	579	185	394
1200	519	681	519	681	76.47	397	272	125	792	408	67.43	534	204	329	996	204	60.65	604	204	400
1300	555	745	555	745	75.27	418	298	120	853	447	65.38	558	223	334	1077	223	57.97	624	223	401
1400	591	809	591	809	74.08	438	323	115	915	485	63.34	579	243	337	1157	243	55.28	640	243	397
1500	627	873	627	873	72.88	457	349	108	976	524	61.29	598	262	337	1238	262	52.60	651	262	389
1600	663	937	663	937	71.69	476	375	101	1038	562	59.25	615	281	334	1319	281	49.92	658	281	377
1700	699	1001	699	1001	70.49	493	400	93	1100	600	57.20	629	300	329	1400	300	47.24	661	300	361
1800	735	1065	735	1065	69.29	510	426	84	1161	639	55.16	640	319	321	1481	319	44.55	660	319	340
1900	771	1129	771	1129	68.10	525	451	74	1223	677	53.11	649	339	311	1561	339	41.87	654	339	315
2000	807	1193	807	1193	66.90	540	477	63	1284	716	51.06	656	358	298	1642	358	39.19	644	358	286
2100	844	1256	844	1256	65.70	554	503	52	1346	754	49.02	660	377	283	1723	377	36.50	629	377	252
2200	880	1320	880	1320	64.51	567	528	39	1408	792	46.97	661	396	265	1804	396	33.82	610	396	214
2300	916	1384	916	1384	63.31	580	554	26	1469	831	44.93	660	415	245	1885	415	31.14	587	415	172
2400	952	1448	952	1448	62.11	591	579	12	1531	869	42.88	656	435	222	1965	435	28.45	559	435	125
2500	988	1512	988	1512	60.92	602	605	-3	1589	911	40.94	651	455	195	2045	455	25.83	528	455	73
2600	1024	1576	1024	1576	59.72	611	631	-19	1635	965	39.42	645	482	162	2118	482	23.41	496	482	13
2700	1060	1640	1060	1640	58.53	620	656	-36	1680	1020	37.93	637	510	127	2190	510	21.00	460	510	-50
2800	1096	1704	1096	1704	57.33	628	682	-53	1724	1076	36.47	629	538	91	2262	538	18.61	421	538	-117
2900	1132	1768	1132	1768	56.13	635	707	-72	1767	1133	35.04	619	566	53	2334	566	16.23	379	566	-188
3000	1168	1832	1168	1832	54.94	642	733	-91	1809	1191	33.64	609	595	13	2405	595	13.87	334	595	-262
3100	1204	1896	1204	1896	53.74	647	758	-111	1851	1249	32.26	597	625	-27	2448	652	12.44	304	652	-348
3200	1240	1960	1240	1960	52.54	651	784	-133	1891	1309	30.91	585	654	-70	2476	724	11.50	285	724	-439
3300	1276	2024	1276	2024	51.35	655	810	-154	1931	1369	29.60	572	684	-113	2503	797	10.62	266	797	-532
3400	1312	2088	1312	2088	50.15	658	835	-177	1970	1430	28.31	558	715	-157	2528	872	9.79	248	872	-625
3500	1348	2152	1348	2152	48.95	660	861	-201	2008	1492	27.05	543	746	-203	2551	949	9.02	230	949	-719
3600	1384	2216	1384	2216	47.76	661	886	-225	2045	1555	25.81	528	777	-250	2573	1027	8.29	213	1027	-814
3700	1420	2280	1420	2280	46.56	661	912	-251	2081	1619	24.61	512	809	-297	2594	1106	7.60	197	1106	-909
3800	1456	2344	1456	2344	45.37	661	938	-277	2117	1683	23.43	496	842	-346	2613	1187	6.97	182	1187	-1005
3900	1492	2408	1492	2408	44.17	659	963	-304	2151	1749	22.29	479	874	-395	2631	1269	6.37	168	1269	-1102
4000	1528	2472	1528	2472	42.97	657	989	-332	2185	1815	21.17	463	908	-445	2647	1353	5.81	154	1353	-1199

TABLE A.3 Three Lanes in One Direction Freeways with Right Lane Closed

Traffic Volume			
Total vph	Right vphpl	Middle vphpl	Left vphpl
2500	1014	969	517
2600	1045	1003	551
2700	1076	1037	587
2800	1105	1071	624
2900	1133	1104	663
3000	1161	1137	703
3100	1187	1170	744
3200	1212	1202	786
3300	1236	1234	830
3400	1259	1266	875
3500	1282	1297	921
3600	1303	1329	969
3700	1323	1360	1017
3800	1342	1390	1068
3900	1360	1421	1119
4000	1377	1451	1172
4100	1393	1481	1226
4200	1408	1510	1282
4300	1422	1540	1338
4400	1435	1569	1396
4500	1447	1597	1456
4600	1458	1626	1516
4700	1467	1654	1578
4800	1476	1682	1642
4900	1484	1710	1706
5000	1491	1737	1772
5100	1496	1764	1839
5200	1501	1791	1908
5300	1505	1817	1978
5400	1507	1844	2049
5500	1509	1870	2121
5600	1509	1895	2195
5700	1509	1921	2270
5800	1507	1946	2347
5900	1505	1971	2424
6000	1501	1995	2503

	Section 1 (3000 to 2000 feet upstream)					
	Tr. Volume		Headways > 2 sec.		Merging 40%	Difference
Total vph	Right vphpl	Middle vphpl	%	hph	vph	vph
2500	1014	969	62	596	405	191
2600	1045	1003	60	606	418	188
2700	1076	1037	59	615	430	185
2800	1105	1071	58	623	442	181
2900	1133	1104	57	630	453	177
3000	1161	1137	56	636	464	172
3100	1187	1170	55	642	475	167
3200	1212	1202	54	647	485	162
3300	1236	1234	53	651	495	156
3400	1259	1266	52	654	504	150
3500	1282	1297	51	657	513	144
3600	1303	1329	50	659	521	138
3700	1323	1360	49	660	529	131
3800	1342	1390	48	661	537	124
3900	1360	1421	47	661	544	117
4000	1377	1451	46	661	551	110
4100	1393	1481	45	660	557	102
4200	1408	1510	44	658	563	95
4300	1422	1540	43	656	569	87
4400	1435	1569	42	653	574	79
4500	1447	1597	41	650	579	71
4600	1458	1626	40	646	583	63
4700	1467	1654	39	642	587	55
4800	1476	1682	38	637	590	46
4900	1484	1710	37	632	594	38
5000	1491	1737	36	626	596	30
5100	1496	1764	35	620	599	21
5200	1501	1791	34	613	600	13
5300	1505	1817	33	606	602	5
5400	1507	1844	32	599	603	-4
5500	1509	1870	32	591	604	-12
5600	1509	1895	31	583	604	-20
5700	1509	1921	30	575	604	-29
5800	1507	1946	29	566	603	-37
5900	1505	1971	28	557	602	-45
6000	1501	1995	27	548	601	-53

	Section 2 (2000 to 1000 feet upstream)					
	Tr. Volume		Headways > 2 sec.		Merging 30 (50)%	Difference
Total vph	Right vphpl	Middle vphpl	%	hph	vph	vph
2500	608	1375	48	661	304	357
2600	627	1421	47	661	314	348
2700	645	1467	45	660	323	338
2800	663	1513	43	658	331	326
2900	680	1557	42	654	340	314
3000	696	1601	41	649	348	301
3100	712	1644	39	643	356	287
3200	727	1687	38	636	364	272
3300	742	1729	36	628	371	257
3400	756	1770	35	619	378	241
3500	769	1810	34	608	384	224
3600	782	1850	32	597	391	207
3700	794	1889	31	586	397	189
3800	805	1927	30	573	403	170
3900	816	1965	28	560	408	152
4000	826	2002	27	546	413	132
4100	836	2038	26	531	418	113
4200	845	2074	25	516	422	93
4300	853	2108	24	500	427	73
4400	861	2143	23	484	430	53
4500	868	2176	21	467	434	33
4600	875	2209	20	450	437	13
4700	880	2241	19	433	440	-8
4800	886	2273	18	415	443	-28
4900	890	2303	17	397	445	-48
5000	894	2333	16	379	447	-68
5100	898	2363	15	361	449	-88
5200	901	2391	14	342	450	-108
5300	903	2419	13	324	451	-128
5400	908	2443	13	308	454	-146
5500	917	2461	12	295	459	-163
5600	926	2479	11	283	463	-180
5700	934	2496	11	271	467	-196
5800	941	2512	10	259	471	-212
5900	948	2528	10	247	474	-227
6000	953	2543	9	236	477	-241

	Section 3 (1000 to 0 feet upstream)					
	Tr. Volume		Headways > 2 sec.		Merging 30 (50)%	Difference
Total vph	Right vphpl	Middle vphpl	%	hph	vph	vph
2500	304	1679	38	637	304	333
2600	314	1735	36	626	314	313
2700	323	1790	34	614	323	291
2800	331	1844	32	599	331	268
2900	340	1897	31	583	340	243
3000	348	1949	29	565	348	217
3100	356	2000	27	546	356	190
3200	364	2050	26	526	364	162
3300	371	2099	24	504	371	133
3400	378	2147	22	481	378	103
3500	384	2195	21	458	384	73
3600	391	2241	19	433	391	42
3700	397	2286	18	407	397	11
3800	403	2330	16	381	403	-21
3900	408	2373	15	354	408	-54
4000	413	2415	14	327	413	-86
4100	418	2456	12	299	418	-119
4200	422	2496	11	271	422	-152
4300	427	2535	10	242	427	-185
4400	430	2573	8	213	430	-217
4500	434	2610	7	184	434	-250
4600	437	2646	6	155	437	-282
4700	448	2674	5	132	448	-316
4800	471	2688	4	120	471	-350
4900	493	2700	4	110	493	-384
5000	515	2712	4	99	515	-416
5100	537	2723	3	90	537	-447
5200	558	2734	3	81	558	-478
5300	579	2743	3	72	579	-507
5400	600	2751	2	66	600	-535
5500	622	2756	2	60	622	-562
5600	643	2762	2	56	643	-587
5700	663	2767	2	51	663	-612
5800	682	2771	2	47	682	-635
5900	700	2775	2	44	700	-657
6000	718	2779	1	40	718	-677

TABLE A.4 Three Lanes in One Direction Freeways with Left Lane Closed

				Section 1 (3000 to 2000 feet upstream)						Section 2 (2000 to 1000 feet upstream)						Section 3 (1000 to 0 feet upstream)					
Traffic Volume				Tr. Volume		Headways > 2 sec.		Merging 40%	Difference	Tr. Volume		Headways > 2 sec.		Merging 30 (50)%	Difference	Tr. Volume		Headways > 2 sec.		Merging 30 (50)%	Difference
Total vph	Right vphpl	Middle vphpl	Left vphpl	Left vphpl	Middle vphpl	%	hph	vph	vph	Left vphpl	Middle vphpl	%	hph	vph	vph	Left vphpl	Middle vphpl	%	hph	vph	vph
2500	1014	969	517	517	969	62	596	207	390	310	1176	55	643	155	488	155	1331	50	659	155	504
2600	1045	1003	551	551	1003	60	606	221	385	331	1224	53	650	165	484	165	1389	48	661	165	496
2700	1076	1037	587	587	1037	59	615	235	380	352	1272	51	655	176	479	176	1448	46	661	176	485
2800	1105	1071	624	624	1071	58	623	250	373	375	1320	50	659	187	471	187	1508	44	658	187	471
2900	1133	1104	663	663	1104	57	630	265	365	398	1369	48	661	199	462	199	1568	42	653	199	454
3000	1161	1137	703	703	1137	56	636	281	355	422	1418	47	661	211	450	211	1629	40	646	211	435
3100	1187	1170	744	744	1170	55	642	297	344	446	1467	45	660	223	437	223	1690	38	635	223	412
3200	1212	1202	786	786	1202	54	647	314	332	472	1516	43	658	236	422	236	1752	36	623	236	387
3300	1236	1234	830	830	1234	53	651	332	319	498	1566	42	653	249	404	249	1815	33	607	249	358
3400	1259	1266	875	875	1266	52	654	350	304	525	1616	40	647	262	385	262	1878	31	589	262	326
3500	1282	1297	921	921	1297	51	657	368	289	553	1666	38	640	276	363	276	1942	29	568	276	291
3600	1303	1329	969	969	1329	50	659	387	272	581	1716	37	630	291	340	291	2007	27	544	291	253
3700	1323	1360	1017	1017	1360	49	660	407	253	610	1767	35	619	305	314	305	2072	25	516	305	211
3800	1342	1390	1068	1068	1390	48	661	427	234	641	1817	33	606	320	286	320	2138	23	486	320	166
3900	1360	1421	1119	1119	1421	47	661	448	214	672	1868	32	592	336	256	336	2204	21	453	336	117
4000	1377	1451	1172	1172	1451	46	661	469	192	703	1920	30	575	352	224	352	2271	18	416	352	64
4100	1393	1481	1226	1226	1481	45	660	490	169	736	1971	28	557	368	189	368	2339	16	375	368	8
4200	1408	1510	1282	1282	1510	44	658	513	145	769	2023	27	537	384	153	384	2408	14	332	384	-53
4300	1422	1540	1338	1338	1540	43	656	535	120	803	2075	25	515	402	113	402	2477	11	284	402	-117
4400	1435	1569	1396	1396	1569	42	653	559	94	838	2127	23	491	419	72	419	2546	9	234	419	-185
4500	1447	1597	1456	1456	1597	41	650	582	67	873	2180	21	465	437	28	437	2617	7	179	437	-258
4600	1458	1626	1516	1516	1626	40	646	607	39	910	2233	20	437	455	-18	455	2687	4	121	455	-334
4700	1467	1654	1578	1578	1654	39	642	631	10	947	2286	18	407	474	-66	540	2693	4	116	540	-424
4800	1476	1682	1642	1642	1682	38	637	657	-20	985	2339	16	376	493	-117	609	2714	4	97	609	-512
4900	1484	1710	1706	1706	1710	37	632	683	-51	1024	2392	14	342	512	-170	682	2734	3	80	682	-602
5000	1491	1737	1772	1772	1737	36	626	709	-83	1063	2446	13	306	532	-226	758	2752	2	65	758	-693
5100	1496	1764	1839	1839	1764	35	620	736	-116	1104	2500	11	268	552	-284	836	2768	2	50	836	-786
5200	1501	1791	1908	1908	1791	34	613	763	-150	1145	2554	9	228	572	-345	917	2782	1	38	917	-880
5300	1505	1817	1978	1978	1817	33	606	791	-185	1187	2609	7	185	593	-408	1001	2794	1	27	1001	-975
5400	1507	1844	2049	2049	1844	32	599	820	-220	1450	2443	13	308	725	-417	1142	2751	2	66	1142	-1076
5500	1509	1870	2121	2121	1870	32	591	849	-257	1530	2461	12	295	765	-470	1235	2756	2	60	1235	-1174
5600	1509	1895	2195	2195	1895	31	583	878	-295	1612	2479	11	283	806	-523	1329	2762	2	56	1329	-1273
5700	1509	1921	2270	2270	1921	30	575	908	-333	1695	2496	11	271	848	-577	1424	2767	2	51	1424	-1373
5800	1507	1946	2347	2347	1946	29	566	939	-372	1780	2512	10	259	890	-631	1521	2771	2	47	1521	-1474
5900	1505	1971	2424	2424	1971	28	557	970	-412	1867	2528	10	247	933	-686	1620	2775	2	44	1620	-1576
6000	1501	1995	2503	2503	1995	27	548	1001	-453	1955	2543	9	236	978	-742	1719	2779	1	40	1719	-1679

TABLE A.5 Four Lane in One Direction Freeways with Right Lane Closed.

Traffic Volume					Section 1 (3000 to 2000 feet upstream)						Section 2 (2000 to 1000 feet upstream)						Section 3 (1000 to 0 feet upstream)					
					Tr. Volume		Headways > 2 sec.		Merging 40%	Difference	Tr. Volume		Headways > 2 sec.		Merging 30 (50)%	Difference	Tr. Volume		Headways > 2 sec.		Merging 30 (50)%	Difference
Total vph	Right vphpl	Second vphpl	Third vphpl	Left vphpl	Right vphpl	Second vphpl	%	hph	vph	vph	Right vphpl	Second vphpl	%	hph	vph	vph	Right vphpl	Second vphpl	%	hph	vph	vph
4500	690	1335	1471	1006	690	1335	49	659	276	383	414	1611	40	648	207	441	207	1817	33	606	207	400
4600	703	1351	1495	1051	703	1351	49	660	281	379	422	1632	40	645	211	434	211	1843	33	599	211	388
4700	716	1367	1520	1097	716	1367	48	661	287	374	430	1654	39	642	215	427	215	1869	32	592	215	377
4800	730	1383	1544	1144	730	1383	48	661	292	369	438	1674	38	638	219	419	219	1893	31	584	219	365
4900	743	1398	1567	1193	743	1398	47	661	297	364	446	1695	37	635	223	412	223	1918	30	576	223	353
5000	756	1412	1591	1242	756	1412	47	661	302	359	453	1714	37	631	227	404	227	1941	29	568	227	341
5100	768	1426	1614	1292	768	1426	46	661	307	354	461	1733	36	627	231	396	231	1964	29	560	231	329
5200	781	1439	1636	1344	781	1439	46	661	312	349	469	1752	36	623	234	388	234	1986	28	551	234	317
5300	794	1452	1658	1396	794	1452	45	661	318	343	476	1770	35	619	238	380	238	2008	27	543	238	305
5400	806	1465	1680	1449	806	1465	45	660	323	338	484	1787	34	614	242	372	242	2029	26	534	242	293
5500	819	1477	1701	1504	819	1477	45	660	327	332	491	1804	34	610	246	364	246	2050	26	526	246	280
5600	831	1488	1722	1559	831	1488	44	659	332	327	499	1821	33	606	249	356	249	2070	25	517	249	268
5700	843	1499	1743	1616	843	1499	44	659	337	321	506	1836	33	601	253	348	253	2089	24	509	253	256
5800	855	1509	1763	1673	855	1509	44	658	342	316	513	1852	32	597	257	340	257	2108	24	500	257	244
5900	867	1519	1783	1731	867	1519	43	657	347	311	520	1866	32	593	260	332	260	2126	23	492	260	231
6000	879	1529	1802	1791	879	1529	43	657	352	305	527	1880	31	588	264	325	264	2144	23	483	264	219
6100	891	1538	1821	1851	891	1538	43	656	356	300	534	1894	31	584	267	317	267	2161	22	475	267	207
6200	902	1546	1840	1913	902	1546	42	655	361	294	541	1907	30	580	271	309	271	2177	21	466	271	196
6300	914	1554	1858	1975	914	1554	42	655	365	289	548	1919	30	576	274	302	274	2193	21	458	274	184
6400	925	1561	1876	2039	925	1561	42	654	370	284	555	1931	30	572	278	294	278	2209	20	450	278	173
6500	936	1568	1894	2103	936	1568	42	653	375	279	562	1942	29	568	281	287	281	2223	20	442	281	161
6600	947	1574	1911	2168	947	1574	41	652	379	273	568	1953	29	564	284	280	284	2237	19	435	284	150
6700	958	1580	1928	2235	958	1580	41	652	383	268	575	1963	29	560	288	273	288	2251	19	427	288	140
6800	969	1585	1944	2302	969	1585	41	651	388	263	582	1973	28	557	291	266	291	2264	19	420	291	129
6900	980	1590	1960	2371	980	1590	41	651	392	259	588	1982	28	553	294	259	294	2276	18	413	294	119
7000	991	1594	1976	2440	991	1594	41	650	396	254	594	1991	28	550	297	253	297	2288	18	406	297	109
7100	1001	1598	1991	2511	1001	1598	41	650	401	249	601	1998	27	547	300	246	300	2299	17	400	300	99
7200	1012	1601	2006	2582	1012	1601	41	649	405	245	607	2006	27	544	304	240	304	2309	17	393	304	90
7300	1022	1604	2020	2655	1022	1604	40	649	409	240	613	2013	27	541	307	235	307	2319	17	387	307	81
7400	1032	1606	2035	2728	1032	1606	40	649	413	236	619	2019	27	539	310	229	310	2329	16	382	310	72
7500	1042	1608	2048	2803	1042	1608	40	648	417	231	625	2025	26	536	313	224	313	2338	16	376	313	64
7600	1052	1609	2062	2878	1052	1609	40	648	421	227	631	2030	26	534	316	218	316	2346	16	371	316	56
7700	1062	1610	2075	2955	1062	1610	40	648	425	223	637	2035	26	532	319	214	319	2353	16	367	319	48
7800	1072	1610	2087	3032	1072	1610	40	648	429	219	643	2039	26	531	322	209	322	2360	15	362	322	41
7900	1082	1610	2099	3111	1082	1610	40	648	433	216	649	2042	26	529	325	205	325	2367	15	358	325	34
8000	1091	1609	2111	3191	1091	1609	40	648	437	212	655	2045	26	528	327	200	327	2373	15	354	327	27

TABLE A.6 Four Lane in One Direction Freeways with Left Lane Closed.

					Section 1 (3000 to 2000 feet upstream)						Section 2 (2000 to 1000 feet upstream)						Section 3 (1000 to 0 feet upstream)					
Traffic Volume					Tr. Volume		Headways > 2 sec.		Merging 40%	Difference	Tr. Volume		Headways > 2 sec.		Merging 30 (50)%	Difference	Tr. Volume		Headways > 2 sec.		Merging 30 (50)%	Difference
Total vph	Right vphpl	Second vphpl	Third vphpl	Left vphpl	Left vphpl	Third vphpl	%	hph	vph	vph	Left vphpl	Third vphpl	%	hph	vph	vph	Left vphpl	Third vphpl	%	hph	vph	vph
4500	690	1335	1471	1006	1006	1471	45	660	402	258	603	1873	32	591	302	289	302	2174	22	468	302	166
4600	703	1351	1495	1051	1051	1495	44	659	420	239	630	1916	30	577	315	262	315	2231	20	438	315	123
4700	716	1367	1520	1097	1097	1520	43	657	439	218	658	1959	29	562	329	233	329	2288	18	406	329	77
4800	730	1383	1544	1144	1144	1544	42	655	458	198	687	2002	27	546	343	202	343	2345	16	372	343	29
4900	743	1398	1567	1193	1193	1567	42	653	477	176	716	2045	26	528	358	170	358	2402	14	335	358	-23
5000	756	1412	1591	1242	1242	1591	41	651	497	154	745	2088	24	509	373	137	373	2460	12	296	373	-77
5100	768	1426	1614	1292	1292	1614	40	648	517	131	775	2131	23	489	388	102	388	2518	10	254	388	-133
5200	781	1439	1636	1344	1344	1636	39	644	538	107	806	2174	22	468	403	65	403	2577	8	210	403	-193
5300	794	1452	1658	1396	1396	1658	39	641	558	83	838	2217	20	446	419	27	419	2636	6	164	419	-255
5400	806	1465	1680	1449	1449	1680	38	637	580	57	870	2260	19	422	435	-13	447	2682	5	125	447	-322
5500	819	1477	1701	1504	1504	1701	37	633	602	32	902	2303	17	397	451	-54	505	2700	4	110	505	-395
5600	831	1488	1722	1559	1559	1722	37	629	624	5	936	2346	16	371	468	-97	564	2717	3	95	564	-469
5700	843	1499	1743	1616	1616	1743	36	625	646	-22	991	2368	15	358	495	-138	633	2725	3	88	633	-545
5800	855	1509	1763	1673	1673	1763	35	620	669	-49	1053	2383	15	348	526	-179	705	2731	3	83	705	-622
5900	867	1519	1783	1731	1731	1783	35	615	693	-77	1116	2398	14	338	558	-220	778	2736	3	79	778	-700
6000	879	1529	1802	1791	1791	1802	34	610	716	-106	1180	2413	14	328	590	-262	852	2741	3	74	852	-778
6100	891	1538	1821	1851	1851	1821	33	605	740	-135	1246	2427	13	319	623	-304	927	2746	3	70	927	-857
6200	902	1546	1840	1913	1913	1840	33	600	765	-165	1312	2440	13	310	656	-347	1003	2750	2	66	1003	-937
6300	914	1554	1858	1975	1975	1858	32	595	790	-195	1380	2453	12	301	690	-389	1079	2754	2	63	1079	-1017
6400	925	1561	1876	2039	2039	1876	31	589	815	-226	1449	2466	12	292	725	-432	1157	2758	2	59	1157	-1098
6500	936	1568	1894	2103	2103	1894	31	584	841	-257	1519	2478	11	284	760	-476	1235	2761	2	56	1235	-1179
6600	947	1574	1911	2168	2168	1911	30	578	867	-289	1590	2489	11	275	795	-520	1315	2765	2	53	1315	-1262
6700	958	1580	1928	2235	2235	1928	30	573	894	-321	1662	2500	11	267	831	-564	1395	2768	2	50	1395	-1345
6800	969	1585	1944	2302	2302	1944	29	567	921	-354	1735	2511	10	260	868	-608	1476	2771	2	48	1476	-1428
6900	980	1590	1960	2371	2371	1960	29	561	948	-387	1810	2521	10	252	905	-653	1558	2774	2	45	1558	-1512
7000	991	1594	1976	2440	2440	1976	28	555	976	-421	1885	2531	10	245	942	-698	1640	2776	2	43	1640	-1597
7100	1001	1598	1991	2511	2511	1991	28	550	1004	-455	1961	2541	9	238	981	-743	1723	2778	1	41	1723	-1683
7200	1012	1601	2006	2582	2582	2006	27	544	1033	-489	2038	2550	9	231	1019	-788	1808	2781	1	39	1808	-1769
7300	1022	1604	2020	2655	2655	2020	27	538	1062	-524	2117	2558	9	224	1058	-834	1892	2783	1	37	1892	-1856
7400	1032	1606	2035	2728	2728	2035	26	532	1091	-559	2196	2567	8	218	1098	-880	1978	2785	1	35	1978	-1943
7500	1042	1608	2048	2803	2803	2048	26	527	1121	-595	2276	2575	8	212	1138	-926	2064	2787	1	33	2064	-2031
7600	1052	1609	2062	2878	2878	2062	25	521	1151	-630	2357	2582	8	206	1179	-973	2152	2788	1	32	2152	-2120
7700	1062	1610	2075	2955	2955	2075	25	515	1182	-667	2440	2590	8	200	1220	-1020	2239	2790	1	30	2239	-2209
7800	1072	1610	2087	3032	3032	2087	24	510	1213	-703	2523	2597	7	195	1261	-1067	2328	2791	1	29	2328	-2299
7900	1082	1610	2099	3111	3111	2099	24	504	1244	-740	2607	2603	7	189	1303	-1114	2417	2793	1	28	2417	-2390
8000	1091	1609	2111	3191	3191	2111	24	499	1276	-778	2692	2610	7	184	1346	-1162	2507	2794	1	26	2507	-2481

Appendix B
Investigated Characteristics on Section 1 and Section 1c

TABLE B.1 Speed Distribution

Driver	Mean Speed				Standard Deviation			
	Value		Difference		Value		Difference	
	Sec. 1	Sec. 1c	Sec. 1 — Sec. 1c		Sec. 1	Sec. 1c	Sec. 1 — Sec. 1c	
	km/h	km/h	km/h	%	km/h	km/h	km/h	%
Medium Traffic Volume								
1	93.68	87.64	6.05	6.90	5.40	20.35	-14.94	-73.45
2		84.19				18.74		
3	30.34	82.69	-52.35	-63.31	28.07	21.55	6.51	30.22
4	20.26	88.73	-68.47	-77.17	11.19	18.69	-7.50	-40.11
5	42.19	55.23	-13.04	-23.60	24.18	36.80	-12.62	-34.29
6	37.95	84.09	-46.13	-54.86	27.39	25.12	2.27	9.02
7	24.93	80.18	-55.25	-68.91	20.35	23.04	-2.69	-11.67
8	39.58	76.99	-37.41	-48.60	27.52	19.70	7.82	39.69
Heavy Traffic Volume								
1	44.94	81.70	-36.76	-44.99	9.88	10.23	-0.35	-3.44
2	38.10	85.44	-47.34	-55.40	13.30	16.56	-3.26	-19.68
3	30.48	82.66	-52.18	-63.12				
4	30.56	86.21	-55.65	-64.55	7.40	17.37	-9.98	-57.42
5	41.87	46.63	-4.76	-10.21	9.28	32.02	-22.75	-71.04
6	35.57	81.33	-45.77	-56.27	17.92	13.99	3.93	28.07
7	35.14	87.19	-52.05	-59.70	11.78	18.78	-7.00	-37.28
8	42.41	79.44	-37.03	-46.62	6.19	12.87	-6.69	-51.94

TABLE B.2 Acceleration/Deceleration Distribution

Driver	Mean Acceleration/Deceleration				Standard Deviation				Duration		
	Value		Difference		Value		Difference		Value		Difference
	Sec. 1	Sec. 1c	Sec. 1 — Sec.1c		Sec. 1	Sec. 1c	Sec. 1 — Sec.1c		Sec. 1	Sec. 1c	Sec. 1 — Sec.1c
	m/sec.sq.	m/sec.sq.	m/sec.sq.	%	m/sec.sq.	m/sec.sq.	m/sec.sq.	%	% of total time		
Medium Traffic Volume											
1	-0.067	-0.343	0.276	-80.466	0.781	0.863	-0.082	-9.502	21.953	22.360	-0.407
2		-0.344				0.890				37.263	
3	-0.106	-0.326	0.220	-67.485	1.001	0.910	0.091	10.000	26.142	25.898	0.244
4	0.007	-0.305	0.312	-102.30	1.031	1.005	0.026	2.587	25.822	22.520	3.302
5	-0.156	-0.198	0.042	-21.212	1.123	1.029	0.094	9.135	23.029	21.265	1.764
6	-0.120	-0.324	0.204	-62.963	1.164	0.986	0.178	18.053	24.746	20.428	4.318
7	-0.069	-0.308	0.239	-77.597	0.959	0.791	0.168	21.239	26.089	20.533	5.556
8	-0.158	-0.297	0.139	-46.801	1.289	1.022	0.267	26.125	31.428	22.106	9.322
Heavy Traffic Volume											
1	-0.042	-0.210	0.168	-80.000	1.149	1.101	0.048	4.360	20.835	23.830	-2.995
2	-0.003	-0.295	0.292	-98.983	1.378	1.085	0.293	27.005	21.309	22.486	-1.177
3	0.182	0.181	0.001	0.552	0.021	0.023	-0.002	-8.696	28.353	25.048	3.305
4	-0.003		-0.003		0.839		0.839		22.564		22.564
5	-0.031	-0.114	0.083	-72.807	1.265	1.420	-0.155	-10.915	21.541	22.575	-1.034
6	-0.066	-0.229	0.163	-71.179	1.442	0.964	0.478	49.585	22.479	20.649	1.830
7	-0.071	-0.323	0.252	-78.019	1.122	0.937	0.185	19.744	19.691	64.428	-44.737
8	0.057	-0.228	0.285	-125.00	0.753	0.951	-0.198	-20.820	20.599	25.972	-5.373

TABLE B.3 Acceleration Distribution

Driver	Mean Acceleration				Standard Deviation				Duration		
	Value		Difference		Value		Difference		Value		Difference
	Sec. 1	Sec. 1c	Sec. 1 — Sec.1c		Sec. 1	Sec. 1c	Sec. 1 — Sec.1c		Sec. 1	Sec. 1c	Sec. 1 — Sec.1c
	m/sec.sq	m/sec.sq	m/sec.sq	%	m/sec.sq	m/sec.sq	m/sec.sq	%	% of total time		
Medium Traffic Volume											
1	1.67	1.55	0.13	8.28	0.30	0.07	0.24	363.08	8.77	2.44	6.33
2		1.53				0.10				7.48	
3	1.78	1.61	0.17	10.75	0.60	0.11	0.49	450.93	10.56	4.06	6.51
4	1.90	1.57	0.32	20.53	0.75	0.16	0.59	361.73	12.94	5.04	7.90
5	1.62	1.93	-0.30	-15.68	0.29	0.76	-0.47	-61.72	9.85	6.54	3.32
6	1.74	1.64	0.10	6.29	0.46	0.08	0.39	506.58	11.60	3.23	8.37
7	1.78	1.56	0.23	14.44	0.53	0.06	0.47	778.33	11.17	1.89	9.28
8	2.04	1.56	0.48	30.66	0.72	0.10	0.62	600.00	12.76	4.70	8.06
Heavy Traffic Volume											
1	3.04	2.92	0.12	4.25	0.31	0.03	0.27	797.06	7.05	5.11	1.94
2	3.19	2.91	0.28	9.55	0.41	0.04	0.37	876.19	8.58	3.56	5.02
3	1.91	1.92	-0.01	-0.73	0.86	1.48	-0.62	-41.81	15.64	5.56	10.08
4	1.64	1.71	-0.07	-4.15	0.32	0.44	-0.12	-26.65	11.29	2.95	8.35
5	3.17	3.20	-0.03	-1.03	0.36	0.65	-0.29	-44.53	7.66	7.58	0.08
6	3.14	2.92	0.22	7.42	0.60	0.00	0.60		8.15	3.35	4.81
7	3.29	2.92	0.36	12.35	0.61	0.00	0.61		5.60	41.56	-35.96
8	1.61	1.62	0.00	-0.31	0.32	0.14	0.17	120.83	12.07	7.21	4.86

TABLE B.4 Deceleration Distribution

Driver	Mean Deceleration				Standard Deviation				Duration		
	Value		Difference		Value		Difference		Value		Difference
	Sec. 1	Sec. 1c	Sec. 1 — Sec.1c		Sec. 1	Sec. 1c	Sec. 1 — Sec.1c		Sec. 1	Sec. 1c	Sec. 1 — Sec.1c
	m/sec.sq	m/sec.sq	m/sec.sq	%	m/sec.sq	m/sec.sq	m/sec.sq	%	% of total time		
Medium Traffic Volume											
1	1.61	1.90	-0.28	-14.92	0.15	0.65	-0.50	-77.38	13.19	19.92	-6.74
2		1.55				0.26				29.78	
3	1.87	1.81	0.07	3.65	0.70	0.71	-0.01	-0.71	15.58	21.84	-6.26
4	1.84	2.20	-0.36	-16.27	0.73	0.85	-0.12	-14.29	12.88	17.48	-4.60
5	2.35	2.14	0.21	9.91	1.42	0.91	0.50	55.09	13.18	14.73	-1.55
6	2.46	2.18	0.28	12.86	1.18	0.96	0.23	23.49	13.15	17.20	-4.05
7	1.79	1.81	-0.02	-0.99	0.55	0.59	-0.03	-5.47	14.92	18.64	-3.72
8	2.17	2.11	0.07	3.18	0.94	1.10	-0.16	-14.86	18.67	17.41	1.26
Heavy Traffic Volume											
1	1.81	1.79	0.02	1.12	0.66	0.71	-0.05	-7.29	13.78	18.72	-4.93
2	2.17	1.96	0.21	10.45	1.08	0.79	0.29	36.38	12.73	18.93	-6.20
3	2.24	1.98	0.26	13.07	1.14	0.99	0.16	15.79	12.71	19.49	-6.78
4	1.71	1.94	-0.23	-11.86	0.64	1.41	-0.77	-54.50	11.27	18.10	-6.83
5	1.93	2.31	-0.38	-16.24	0.74	1.24	-0.50	-40.27	13.88	15.00	-1.11
6	2.21	1.77	0.44	24.90	1.52	0.60	0.92	153.58	14.33	17.30	-2.98
7	1.75	1.63	0.12	7.55	0.59	0.47	0.12	24.36	14.09	22.87	-8.78
8	1.63	1.88	-0.25	-13.52	0.28	0.72	-0.44	-60.50	8.53	18.76	-10.23

TABLE B.5 Driver Pulse Rate Distribution

Driver	Mean Pulse Rate				Standard Deviation			
	Value		Difference		Value		Difference	
	Sec. 1	Sec. 1c	Sec. 1 — Sec.1c		Sec. 1	Sec. 1c	Sec. 1 — Sec.1c	
	bpm	bpm	bpm	%	bpm	bpm	bpm	%
Medium Traffic Volume								
1	71	71	0	0	3.38	2.43	0.95	39.19
2								
3	106	106	-1	-1	7.88	5.68	2.19	38.61
4	92	87	4	5	5.31	4.48	0.83	18.52
5	82	86	-4	-4	5.34	6.94	-1.60	-23.07
6	96	87	9	10	6.26	5.95	0.32	5.37
7	82	81	1	1	2.04	2.47	-0.43	-17.45
8	71	71	0	0	5.23	5.26	-0.03	-0.65
Heavy Traffic Volume								
1	70	67	3	5	2.89	2.79	0.10	3.70
2	84	87	-3	-3	2.79	3.22	-0.43	-13.26
3	95	96	-1	-2	8.27	6.44	1.83	28.36
4	86	87	-1	-2	4.82	3.40	1.42	41.84
5	86	88	-2	-3	5.87	7.52	-1.65	-21.98
6	85	78	6	8	9.32	6.87	2.44	35.55
7	73	71	2	2	2.42	3.38	-0.97	-28.52
8	72	73	-1	-2	4.17	4.64	-0.47	-10.11

TABLE B.6 Percentage of Total Driving Time With Different Pulse Rate Ratios

Driver	Percentage of Total Driving Time With Pulse Ratio:								
	less than 100		Difference	100-120		Difference	120-130		Difference
	Sec. 1	Sec. 1c	Sec. 1 — Sec.1c	Sec. 1	Sec. 1c	Sec. 1 — Sec.1c	Sec. 1	Sec. 1c	Sec. 1 — Sec.1c
	%	%		%	%		%	%	
Medium Traffic Volume									
1	15.61	7.4	8.21	84.39	92.6	-8.21	0	0	0
2									
3	81.5	83.35	-1.85	18.5	16.65	1.85	0	0	0
4	34.22	67.45	-33.23	64.91	32.55	32.36	0.87	0	0.87
5	55.39	24.57	30.82	42.18	69.77	-27.59	2.42	5.66	-3.24
6	14.56	57.67	-43.11	83.38	42.33	41.05	2.07	0	2.07
7	0	0	0	92.52	93.87	-1.35	7.48	6.13	1.35
8	87.68	87.25	0.43	12.31	12.75	-0.44	0	0	0
Heavy traffic Volume									
1	50.43	84.78	-34.35	49.57	11.74	37.83	0	0	0
2	100	95.06	4.94	0	4.94	-4.94	0	0	0
3	61.15	47.33	13.82	37.08	52.68	-15.6	1.77	0	1.77
4	58.66	36.91	21.75	41.34	63.09	-21.75	0	0	0
5	89.07	77.13	11.94	10.93	20.5	-9.57	0	2.37	-2.37
6	16.22	48.85	-32.63	68.79	48.12	20.67	9.76	3.02	6.74
7	1.13	12.7	-11.57	98.87	87.3	11.57	0	0	0
8	46.56	31.23	15.33	53.43	68.78	-15.35	0	0	0

Appendix C
Investigated Characteristics on Section 2 and Section 2c

TABLE C.1 Speed Distribution

Driver	Mean Speed				Standard Deviation			
	Value		Difference		Value		Difference	
	Sec. 2	Sec. 2c	Sec. 2 — Sec. 2c		Sec. 2	Sec. 2c	Sec. 2 — Sec. 2c	
	km/h	km/h	km/h	%	km/h	km/h	km/h	%
Medium Traffic Volume								
1	26.17	109.80	-83.63	-76.17	12.40	2.53	9.88	391.13
2	73.29	83.32	-10.03	-12.03	4.24	7.00	-2.76	-39.39
3	101.53	102.59	-1.06	-1.03	4.00	6.40	-2.40	-37.53
4	65.33	97.36	-32.03	-32.89	18.02	2.69	15.32	568.71
5	95.23	104.93	-9.70	-9.24	4.76	4.07	0.69	17.10
6	91.75	103.69	-11.94	-11.51	11.94	3.55	8.39	236.28
7	73.08	98.59	-25.51	-25.88	12.49	3.61	8.88	246.41
8	61.87	92.57	-30.70	-33.16	17.61	5.48	12.13	221.63
Heavy Traffic Volume								
1	54.15	95.40	-41.26	-43.24	12.55	29.76	-17.21	-57.82
2	48.89	57.41	-8.52	-14.84	10.91	33.03	-22.11	-66.96
3	56.19	71.23	-15.04	-21.11	8.44	30.98	-22.54	-72.76
4	64.94	65.60	-0.66	-1.01	18.43	26.21	-7.78	-29.68
5	53.44	52.99	0.45	0.86	13.02	30.46	-17.44	-57.25
6	56.27	95.30	-39.03	-40.96	18.15	14.50	3.66	25.24
7	56.41	101.46	-45.05	-44.40	14.96	1.09	13.86	1267.00
8	36.54	88.08	-51.54	-58.51	14.09	6.47	7.62	117.69

TABLE C.2 Acceleration/Deceleration Distribution

Driver	Mean Acceleration/Deceleration				Standard Deviation				Duration		
	Value		Difference		Value		Difference		Value		Difference
	Sec. 2	Sec. 2c	Sec. 2 — Sec.2c		Sec. 2	Sec. 2c	Sec. 2 — Sec.2c		Sec. 2	Sec. 2c	Sec. 2 — Sec.2c
	m/sec.sq.	m/sec.sq.	m/sec.sq.	%	m/sec.sq.	m/sec.sq.	m/sec.sq.	%	% of total time		
Medium Traffic Volume											
1	0.03	0.00	0.03	°	0.96	0.66	0.31	46.42	23.93	16.15	7.79
2	0.03	-0.01	0.04	-333.33	0.82	0.80	0.02	3.14	28.07	26.94	1.14
3	0.01	0.02	-0.01	-62.50	0.55	0.63	-0.08	-13.02	11.62	14.26	-2.64
4	-0.06	-0.01	-0.05	533.33	0.91	0.56	0.35	62.03	21.78	11.65	10.13
5	-0.05	0.01	-0.05	-866.67	0.73	0.65	0.08	12.25	17.68	15.91	1.77
6	-0.02	0.01	-0.03	-300.00	0.77	0.61	0.16	26.23	18.15	14.01	4.14
7	-0.04	0.00	-0.04	4100.00	0.73	0.65	0.09	13.16	18.78	15.49	3.29
8	-0.03	0.02	-0.05	-326.67	0.98	0.75	0.23	31.28	25.57	16.51	9.06
Heavy Traffic Volume											
1	0.04	-0.10	0.14	-136.00	1.10	1.26	-0.16	-12.79	19.57	18.10	1.47
2	-0.03	-0.05	0.02	-40.38	1.13	1.12	0.00	0.36	20.95	21.21	-0.27
3	0.01	-0.05	0.06	-120.00	0.78	1.04	-0.26	-25.02	19.81	25.98	-6.17
4	-0.01	0.00	-0.01	175.00	0.87	0.82	0.05	6.49	19.58	16.83	2.75
5	-0.01	-0.05	0.05	-88.46	1.31	1.17	0.14	11.51	20.94	20.08	0.86
6	0.01	-0.08	0.09	-107.41	1.21	1.08	0.13	11.99	21.89	18.82	3.08
7	0.06	-0.01	0.06	-914.29	1.32	0.89	0.44	49.49	19.58	16.46	3.12
8	0.01	0.01	0.00	-10.00	0.91	0.74	0.17	22.88	21.73	15.64	6.09

TABLE C.3 Acceleration Distribution

Driver	Mean Acceleration				Standard Deviation				Duration		
	Value		Difference		Value		Difference		Value		Difference
	Sec. 2	Sec. 2c	Sec. 2 — Sec.2c		Sec. 2	Sec. 2c	Sec. 2 — Sec.2c		Sec. 2	Sec. 2c	Sec. 2 — Sec.2c
	m/sec.sq	m/sec.sq	m/sec.sq	%	m/sec.sq	m/sec.sq	m/sec.sq	%	% of total time		
Medium Traffic Volume											
1	1.89	1.62	0.27	16.74	0.64	0.18	0.46	265.14	12.66	7.99	4.67
2	1.54	1.52	0.02	1.25	0.24	0.12	0.12	105.13	15.02	13.18	1.84
3	1.60	1.58	0.02	1.33	0.16	0.20	-0.04	-21.21	5.83	7.86	-2.04
4	1.58	1.65	-0.06	-3.71	0.15	0.34	-0.19	-56.08	10.67	5.35	5.31
5	1.72	1.62	0.09	5.67	0.50	0.26	0.24	94.92	7.49	8.03	-0.55
6	1.79	1.59	0.20	12.54	0.51	0.21	0.31	149.76	8.14	7.49	0.65
7	1.62	1.61	0.01	0.50	0.26	0.19	0.08	41.62	8.26	7.70	0.56
8	1.57	1.66	-0.09	-5.13	0.18	0.50	-0.31	-63.23	13.52	8.76	4.76
Heavy Traffic Volume											
1	3.09	2.99	0.09	3.18	0.45	0.41	0.04	10.49	7.49	5.67	1.81
2	3.09	3.03	0.06	2.08	0.31	0.39	-0.08	-20.10	7.59	6.79	0.80
3	1.65	1.74	-0.09	-5.40	0.40	0.53	-0.13	-24.38	7.80	13.14	-5.34
4	1.70	1.64	0.06	3.78	0.40	0.49	-0.10	-19.84	9.96	9.12	0.84
5	3.14	3.11	0.03	0.87	0.31	0.50	-0.18	-37.10	8.24	6.66	1.59
6	3.06	2.94	0.11	3.77	0.49	0.18	0.31	168.85	8.20	5.65	2.55
7	3.15	2.92	0.22	7.66	0.51	0.00	0.51	°	8.82	5.39	3.43
8	1.74	1.69	0.06	3.26	0.59	0.90	-0.31	-34.53	11.38	8.06	3.32

TABLE C.4 Deceleration Distribution

Driver	Mean Deceleration				Standard Deviation				Duration		
	Value		Difference		Value		Difference		Value		Difference
	Sec. 2	Sec. 2c	Sec. 2 — Sec.2c		Sec. 2	Sec. 2c	Sec. 2 — Sec.2c		Sec. 2	Sec. 2c	Sec. 2 — Sec.2c
	m/sec.sq	m/sec.sq	m/sec.sq	%	m/sec.sq	m/sec.sq	m/sec.sq	%	% of total time		
Medium Traffic Volume											
1	1.82	1.61	0.21	13.14	0.57	0.17	0.40	231.40	11.27	8.16	3.12
2	1.53	1.53	0.00	0.00	0.12	0.11	0.01	7.27	13.05	13.76	-0.71
3	1.56	1.68	-0.12	-7.04	0.17	0.42	-0.26	-60.99	5.79	6.40	-0.61
4	2.03	1.57	0.45	28.90	0.88	0.22	0.66	305.53	11.11	6.29	4.82
5	1.67	1.59	0.08	4.78	0.39	0.14	0.25	174.47	10.19	7.88	2.32
6	1.70	1.63	0.07	4.17	0.43	0.27	0.16	60.74	10.00	6.52	3.48
7	1.66	1.61	0.05	3.04	0.36	0.22	0.14	61.36	10.52	7.79	2.73
8	2.01	1.74	0.28	15.88	0.95	0.73	0.22	30.44	12.05	7.76	4.29
Heavy Traffic Volume											
1	1.65	2.10	-0.46	-21.73	0.51	1.73	-1.21	-70.28	12.08	12.43	-0.35
2	1.75	1.75	0.00	-0.23	0.64	0.70	-0.06	-8.62	13.36	14.43	-1.07
3	2.01	2.11	-0.10	-4.60	0.73	0.93	-0.20	-21.35	12.01	12.84	-0.84
4	1.93	2.01	-0.08	-3.88	0.86	0.99	-0.13	-12.77	9.62	7.71	1.91
5	2.08	1.90	0.18	9.49	0.90	0.85	0.05	5.99	12.70	13.42	-0.73
6	1.79	1.84	-0.05	-2.82	0.80	0.91	-0.10	-11.48	13.69	13.16	0.53
7	2.11	1.48	0.62	42.08	1.34	0.19	1.15	621.62	10.76	11.07	-0.31
8	1.84	1.68	0.16	9.48	0.89	0.70	0.20	28.35	10.35	7.58	2.77

TABLE C.5 Driver Pulse Rate Distribution

Driver	Mean Pulse Rate				Standard Deviation			
	Value		Difference		Value		Difference	
	Sec. 2	Sec. 2c	Sec. 2 — Sec.2c		Sec. 2	Sec. 2c	Sec. 2 — Sec.2c	
	bpm	bpm	bpm	%	bpm	bpm	bpm	%
Medium Traffic Volume								
1	72	69	3	4	2.81	2.41	0.40	16.60
2	°	°	°	°	°	°	°	°
3	106	102	3	3	5.74	7.03	-1.28	-18.26
4	91	90	1	1	4.63	3.96	0.68	17.05
5	84	84	1	1	4.47	4.40	0.07	1.57
6	90	90	0	0	6.57	5.34	1.22	22.89
7	82	81	0	0	2.43	2.06	0.38	18.30
8	72	72	0	0	3.49	4.32	-0.83	-19.14
Heavy Traffic Volume								
1	70	68	2	3	4.13	3.51	0.62	17.69
2	83	85	-2	-3	4.12	3.65	0.47	12.73
3	93	92	1	1	8.20	6.70	1.50	22.36
4	83	83	0	0	3.65	4.79	-1.15	-23.92
5	86	85	2	2	6.80	5.08	1.72	33.94
6	84	80	4	5	4.95	4.21	0.74	17.66
7	73	73	0	0	2.38	3.31	-0.93	-28.07
8	70	73	-3	-4	4.94	5.03	-0.09	-1.83

TABLE C.6 Percentage of Total Driving Time With Different Pulse Rate Ratios

Driver	Percentage of Total Driving Time With Pulse Ratio:								
	less than 100		Difference	100-120		Difference	120-130		Difference
	Sec. 2	Sec. 2c	Sec. 2 — Sec.2c	Sec. 2	Sec. 2c	Sec. 2 — Sec.2c	Sec. 2	Sec. 2c	Sec. 2 — Sec.2c
	%	%		%	%		%	%	
Medium Traffic Volume									
1	3.23	21.25	-18.02	96.08	78.75	17.33	0.69	0	0.69
2									
3	90.7	92.69	-1.99	9.3	7.31	1.99	0	0	0
4	32.23	46.1	-13.87	67.77	53.9	13.87	0	0	0
5	22.98	34.75	-11.77	77.03	64.6	12.43	0	0.65	-0.65
6	36.98	38.46	-1.48	61.18	61.54	-0.36	1.84	0	1.84
7	0	0	0	90.77	97.87	-7.1	9.23	2.13	7.1
8	90.44	83.43	7.01	9.56	16.57	-7.01	0	0	0
Heavy traffic Volume									
1	52.09	70.71	-18.62	47.9	29.29	18.61	0	0	0
2	100	97.47	2.53	0	2.53	-2.53	0	0	0
3	71.49	74.49	-3	28.06	25.51	2.55	0.44	0	0.44
4	79.58	73.25	6.33	20.42	26.75	-6.33	0	0	0
5	87.44	94.96	-7.52	12.56	5.04	7.52	0	0	0
6	8.02	23.71	-15.69	87.72	75.94	11.78	4.26	0.34	3.92
7	2.21	3.25	-1.04	97.79	93.41	4.38	0	3.34	-3.34
8	66.47	40.39	26.08	34.03	58.39	-24.36	1.5	1.22	0.28

Appendix D
Investigated Characteristics on Section 3 and Section 3c

TABLE D.1 Speed Distribution

Driver	Mean Speed				Standard Deviation			
	Value		Difference		Value		Difference	
	Sec. 3	Sec. 3c	Sec. 3 – Sec. 3c		Sec. 3	Sec. 3c	Sec. 3 – Sec. 3c	
	km/h	km/h	km/h	%	km/h	km/h	km/h	%
Medium Traffic Volume								
1	27.18	60.81	-33.63	-55.30	19.93	18.25	1.69	9.24
2	23.26	69.94	-46.67	-66.74	16.92	14.67	2.25	15.36
3	17.93	70.50	-52.56	-74.56	11.86	16.49	-4.64	-28.11
4	39.22	63.66	-24.44	-38.40	12.38	13.77	-1.39	-10.11
5	43.20	64.71	-21.51	-33.25	16.26	12.61	3.65	28.90
6	33.96	64.71	-30.76	-47.53	21.65	14.59	7.07	48.47
7	30.51	69.07	-38.56	-55.83	21.66	15.38	6.29	40.89
8	46.97	73.33	-26.36	-35.95	14.06	16.22	-2.16	-13.30
Heavy Traffic Volume								
1	43.36	68.42	-25.06	-36.62	23.23	20.09	3.14	15.63
2	14.65	72.14	-57.49	-79.69	6.88	18.03	-11.15	-61.83
3	48.87	73.18	-24.31	-33.22	16.80	14.60	2.21	15.11
4	30.45	68.58	-38.13	-55.60	12.99	13.46	-0.48	-3.54
5	22.09	62.06	-39.97	-64.41	16.63	16.38	0.24	1.48
6	42.16	72.54	-30.38	-41.88	13.46	18.63	-5.17	-27.75
7	9.02	70.04	-61.03	-87.13	11.13	17.54	-6.41	-36.54
8	30.67	67.82	-37.15	-54.78	16.53	15.54	0.99	6.37

TABLE D.2 Acceleration/Deceleration Distribution

Driver	Mean Acceleration/Deceleration				Standard Deviation				Duration		
	Value		Difference		Value		Difference		Value		Difference
	Sec. 3	Sec. 3c	Sec. 3 – Sec. 3c		Sec. 3	Sec. 3c	Sec. 3 – Sec. 3c		Sec. 3	Sec. 3c	Sec. 3 – Sec. 3c
	m/sec.sq.	m/sec.sq.	m/sec.sq.	%	m/sec.sq.	m/sec.sq.	m/sec.sq.	%	% of total time		
Medium Traffic Volume											
1	-0.24	0.65	-0.90	-137.31	1.08	1.04	0.03	3.35	31.00	41.74	-10.74
2	-0.15	0.69	-0.84	-121.13	0.79	0.88	-0.09	-10.32	8.64	49.09	-40.45
3	-0.16	0.81	-0.97	-119.83	1.22	1.19	0.03	2.35	23.02	37.36	-14.34
4	-0.21	0.66	-0.87	-132.37	1.22	0.95	0.28	29.21	28.38	35.46	-7.08
5	0.02	0.66	-0.64	-96.96	1.54	1.04	0.50	48.03	32.24	32.94	-0.70
6	-0.37	0.63	-1.00	-158.80	1.23	1.12	0.11	10.09	35.78	30.90	4.88
7	-0.17	0.80	-0.97	-121.38	1.14	1.20	-0.06	-5.00	33.18	40.02	-6.84
8	-0.26	0.83	-1.09	-130.93	0.92	1.13	-0.21	-18.74	27.56	40.54	-12.98
Heavy Traffic Volume											
1	-0.41	1.02	-1.43	-140.57	1.47	1.56	-0.09	-5.85	39.38	29.50	9.88
2	0.07	0.88	-0.81	-92.57	1.10	1.52	-0.42	-27.60	17.80	27.45	-9.65
3	-0.18	0.86	-1.04	-120.93	1.18	1.11	0.07	6.61	41.66	10.03	31.63
4	-0.09	0.75	-0.84	-111.47	1.03	1.11	-0.08	-7.19	29.40	35.43	-6.03
5	-0.18	0.72	-0.91	-125.17	1.21	1.46	-0.25	-16.80	22.93	21.40	1.53
6	-0.19	0.98	-1.18	-119.51	1.09	1.62	-0.53	-32.71	20.72	29.92	-9.19
7	-0.02	0.98	-1.01	-102.44	1.16	1.58	-0.42	-26.62	16.56	26.88	-10.33
8	-0.13	0.71	-0.84	-118.26	1.02	1.27	-0.24	-19.13	24.29	35.50	-11.21

TABLE D.3 Acceleration Distribution

Driver	Mean Acceleration				Standard Deviation				Duration		
	Value		Difference		Value		Difference		Value		Difference
	Sec. 3	Sec. 3c	Sec. 3 – Sec. 3c		Sec. 3	Sec. 3c	Sec. 3 – Sec. 3c		Sec. 3	Sec. 3c	Sec. 3 – Sec. 3c
	m/sec.sq	m/sec.sq	m/sec.sq	%	m/sec.sq	m/sec.sq	m/sec.sq	%	% of total time		
Medium Traffic Volume											
1	1.62	1.80	-0.18	-10.14	0.33	0.61	-0.28	-45.90	10.50	38.91	-28.41
2	1.49	1.52	-0.03	-2.30	0.12	0.26	-0.14	-54.09	8.26	48.90	-40.64
3	1.75	2.06	-0.31	-15.08	0.52	1.02	-0.50	-48.97	9.93	37.36	-27.44
4	2.39	1.78	0.61	34.02	1.36	0.64	0.72	113.50	7.62	35.46	-27.84
5	2.23	1.94	0.30	15.21	0.91	0.83	0.08	9.28	18.35	32.94	-14.59
6	1.57	2.14	-0.57	-26.73	0.10	0.80	-0.70	-88.08	11.12	29.36	-18.24
7	1.82	2.09	-0.27	-13.09	0.62	0.88	-0.25	-28.88	12.59	39.39	-26.81
8	1.91	2.05	-0.14	-6.69	0.75	0.80	-0.05	-5.99	6.14	40.54	-34.41
Heavy Traffic Volume											
1	3.29	3.20	0.09	2.78	0.68	0.57	0.10	17.94	26.32	28.55	-2.23
2	3.05	3.23	-0.18	-5.54	0.53	0.60	-0.06	-10.89	7.77	26.63	-18.86
3	1.83	1.54	0.29	18.74	0.58	0.12	0.46	384.17	20.83	5.18	15.65
4	1.86	2.08	-0.22	-10.52	0.64	0.81	-0.17	-20.47	11.81	35.43	-23.61
5	3.00	3.33	-0.33	-9.89	0.31	0.67	-0.36	-53.71	5.92	19.76	-13.84
6	3.07	3.33	-0.26	-7.92	0.46	0.66	-0.20	-30.11	4.41	27.88	-23.47
7	3.28	3.35	-0.07	-2.24	0.88	0.68	0.20	28.51	5.89	26.88	-21.00
8	2.14	2.16	-0.02	-0.88	0.71	1.05	-0.35	-33.11	8.10	33.66	-25.56

TABLE D.4 Deceleration Distribution

Driver	Mean Deceleration				Standard Deviation				Duration		
	Value		Difference		Value		Difference		Value		Difference
	Sec. 3	Sec. 3c	Sec. 3 – Sec. 3c		Sec. 3	Sec. 3c	Sec. 3 – Sec. 3c		Sec. 3	Sec. 3c	Sec. 3 – Sec. 3c
	m/sec.sq	m/sec.sq	m/sec.sq	%	m/sec.sq	m/sec.sq	m/sec.sq	%	% of total time		
Medium Traffic Volume											
1	2.00	1.72	0.28	16.45	0.71	0.41	0.31	74.57	20.51	2.84	17.67
2	1.48	1.63	-0.15	-9.42	0.38	0.19	0.19	103.24	15.84	3.80	12.04
3	2.49	0.00	2.49		1.62	0.00	1.62		13.10	0.00	13.10
4	1.91	0.00	1.91		0.91	0.00	0.91		20.76	0.00	20.76
5	2.76	0.00	2.76		1.30	0.00	1.30		13.89	0.00	13.89
6	2.18	1.63	0.54	33.11	0.88	0.00	0.88		24.66	1.54	23.12
7	1.93	2.32	-0.39	-16.85	0.68	0.00	0.68		20.60	0.63	19.97
8	1.69	0.00	1.69		0.36	0.00	0.36		21.43	0.00	21.43
Heavy Traffic Volume											
1	2.43	1.46	0.97	66.28	1.23	0.00	1.23		13.06	0.95	12.11
2	1.74	1.46	0.28	18.95	0.70	0.00	0.70		10.04	1.83	8.21
3	1.83	1.63	0.19	11.69	0.58	0.00	0.58		20.83	4.85	15.98
4	1.77	0.00	1.77		0.60	0.00	0.60		17.59	0.00	17.59
5	2.02	0.00	2.02		0.88	0.00	0.88		17.10	1.64	15.46
6	1.90	1.43	0.47	33.12	0.76	0.05	0.71	1361.54	16.32	2.04	14.28
7	2.02	0.00	2.02		0.98	0.00	0.98		10.67	0.00	10.67
8	1.88	2.21	-0.33	-15.00	0.55	0.81	-0.26	-32.51	16.18	1.83	14.35

TABLE D.5 Driver Pulse Rate Distribution

Driver	Mean Pulse Rate				Standard Deviation			
	Value		Difference		Value		Difference	
	Sec. 3	Sec. 3c	Sec. 3 – Sec. 3c		Sec. 3	Sec. 3c	Sec. 3 – Sec. 3c	
	bpm	bpm	bpm	%	bpm	bpm	bpm	%
Medium Traffic Volume								
1	71	72	-1	-2	3.12	5.04	-1.93	-38.21
2								
3	108	117	-9	-7	7.37	4.23	3.14	74.23
4	92	91	1	1	2.14	3.74	-1.60	-42.73
5	77	88	-10	-12	4.04	6.39	-2.36	-36.84
6	100	96	4	4	5.00	4.57	0.43	9.51
7	81	85	-5	-5	2.80	1.99	0.80	40.29
8	75	76	-2	-2	5.49	2.61	2.87	109.83
Heavy Traffic Volume								
1	72	68	4	6	2.53	4.84	-2.31	-47.73
2	90	85	5	6	2.24	3.35	-1.10	-32.98
3	107	106	1	1	5.61	8.19	-2.58	-31.50
4	85	90	-5	-5	3.19	3.12	0.07	2.34
5	89	87	2	2	4.79	4.11	0.68	16.50
6	87	81	6	7	5.44	4.95	0.50	10.09
7	77	76	0	0	2.15	2.44	-0.29	-11.86
8	81	76	5	7	3.86	2.45	1.41	57.62

TABLE D.6 Percentage of Total Driving Time With Different Pulse Rate Ratios

Driver	Percentage of Total Driving Time With Pulse Ratio:								
	less than 100		Difference	100-120		Difference	120-130		Difference
	Sec. 3	Sec. 3c	Sec. 3 – Sec.3c	Sec. 3	Sec. 3c	Sec. 3 – Sec.3c	Sec. 3	Sec. 3c	Sec. 3 – Sec.3c
	%	%		%	%		%	%	
Medium Traffic Volume									
1	10.72	15.45	-4.73	89.28	75.16	14.12	0	9.39	-9.39
2									
3	70.35	21.58	48.77	29.65	78.42	-48.77	0	0	0
4	10.59	18.33	-7.74	89.41	81.67	7.74	0	0	0
5	85.17	27.75	57.42	14.83	69.38	-54.55	0	2.86	-2.86
6	3.08	2.85	0.23	94.33	97.15	-2.82	2.59	0	2.59
7	0	0	0	93.11	50.71	42.4	6.89	49.29	-42.4
8	66.57	52.91	13.66	33.43	47.09	-13.66	0	0	0
Heavy traffic Volume									
1	27.86	88.26	-60.4	72.14	11.74	60.4	0	0	0
2	91.71	100	-8.29	8.29	0	8.29	0	0	0
3	5.05	17.32	-12.27	87.74	61.91	25.83	7.21	20.77	-13.56
4	66.49	13.31	53.18	33.51	86.69	-53.18	0	0	0
5	84.9	94.39	-9.49	15.1	5.61	9.49	0	0	0
6	0	15.25	-15.25	76.28	84.75	-8.47	22.31	0	22.31
7	0	0	0	94.82	92.49	2.33	5.18	7.52	-2.34
8	0	3.84	-3.84	79.61	96.16	-16.55	20.39	0	20.39