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16. Abstract

Traffic control devices are intended to convey information to drivers enabling them to safely and efficiently negotiate highway systems. In addition to information from control devices, drivers gather information from surrounding traffic streams, highway geometry, the vehicle itself, and many off-road visual information sources. Driving on urban freeways demands a high level of driver attention to many, sometimes competing, information sources, and the driver must quickly filter these data—interpreting that which is important—and continually prepare for the next elements in the information stream. Drivers have finite abilities to receive, filter, and process information per time unit, and if the information flow reaches or exceeds typical human limits, driver stress levels may increase and important bits of information may be missed completely or misinterpreted.

Relationships between information flow, driver stress, driver performance and accident experience have been hypothesized. This study classifies urban freeways in Dallas, Houston, and San Antonio, Texas, regarding the intensity of information flow or information load presented to drivers. Crash statistics for 1999, 2000, and 2001 are compared to information load rates and significant correlations are identified. Test drivers experience each of the twenty-seven information load levels identified for the freeways in the three Texas cities as they negotiate selected driving routes. A portable data acquisition system records the driver's field of view, vehicle trajectory data, driver electro-cardiogram, and eye movements as the drivers experience the real world information flow situations. Correlations between driver stress level, characterized by heart rate or electrocardiogram wave form and information load, are identified.

Thresholds for minimum and maximum desirable numbers of traffic control signs per unit distance are developed for freeways having two, three or four, and five or more lanes per direction. A methodology for classifying urban freeways regarding information loads presented to drivers is described.

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Driver Responses to Urban Freeway Information Loads

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Research Report 0-4621-2

Research Project 0-4621
Optimum Level of Roadside Information to Reduce Driver Stress

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in cooperation with the
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Products

This report contains Product P4 "Methodology for estimation of driver informational loads on urban freeways" that is described in Chapter 6.3.

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1. Informational Dimensions of Urban Freeways

The driver is the key element of the complex traffic system; understanding the tasks that the motor vehicle operator should perform while driving has crucial importance for insuring effective and safe operation of the whole system.

1.1 The Driving Task

Numerous components are involved in the driving task, including observing the roadway, signs, pavement markings, and other vehicles, judging the traffic situation and selecting appropriate behavior, and performing necessary corrective actions. These components are grouped into two major classes: on-road and off-road tasks (Refs 1, 2). On-road task categories include:

1. Basic control (e.g., steering)
2. General driving (e.g., surveillance)
3. Traffic conditions (e.g., passing)
4. Roadway characteristics (e.g., intersections)
5. Environment (e.g., weather)
6. Vehicle (e.g., emergencies)

Off-road task categories include pre-trip planning, maintenance, and legal responsibilities.

As outlined in the Positive Guidance (PG) concept, the driving task can be divided into three main elements—control, guidance, and navigation (Ref 2). The control level reflects task performance related to driver interaction with the vehicle, controlling it in terms of speed, path, and direction by using the steering wheel, accelerator, and brakes. At this level, the driver obtains information from the vehicle displays, visual observation of changes of surrounding objects, and tactile sensing. Because information processing and vehicle control are mainly determined by driver experience, and with experience are performed almost without conscious thought, the control level is often considered to have less complexity compared to other driving tasks.

The guidance level includes the driver's selection and maintenance of a safe speed and path. The driver observes and analyzes the immediate environment, and using judgment, estimates, and predictions, translates changes into control actions needed for vehicle position and speed corrections. Several studies indicate that other vehicles, in close proximity, have major impacts and, depending on traffic volume, capture driver attention for up to 60 percent of the time (Refs 2, 3, 4). These studies also indicate that drivers spent up to 30 percent of their time analyzing the general traffic situation ahead, up to 20 percent of their time controlling vehicle position on the roadway relative to the left and right lane edges, and around 5 percent of their time observing road signs. Information sources at this level include speed and relative position of other vehicles, roadway horizontal and vertical alignment, road signs and signals, pavement markings, and other traffic control devices.

The navigation level includes tasks of planning and executing a trip from origin to destination. Drivers evaluate route identification (highway number, street name, etc.), cardinal directions, and route key points. During the trip along the selected route, drivers make navigational decisions at roadway junctions. Information sources are maps, guide signs, landmarks, and past experience.

Due to the fact that control tasks are mainly performed on an unconscious level and considering that navigation tasks while driving practically overlap with the guidance level, the information sources of major importance from the traffic engineering perspective are primarily:

1. Traffic (reflects impact of other road users)
2. Highway (represents roadway characteristics)
3. Traffic control (reflects effect of traffic control system measures)

In addition, it is necessary to take into account that urban freeways are typically surrounded by numerous objects not related to traffic that can divert driver attention or create inappropriate backgrounds for road signs and therefore interfere with perception of more vital information. This group of sources with potentially adverse effects can be named "Visual noise," and include commercial electronic billboards, commercial static billboards, buildings, and any other objects, which consume driver attention without facilitating the driving tasks.

The combinations and levels of the above-mentioned groups of information sources including visual noise will represent total information input to drivers.

1.2 Classification of Informational Dimensions of Urban Freeways

The Center for Transportation Research (CTR) at The University of Texas at Austin, based on the extensive field observations, determined typical combinations of the above-mentioned information sources on urban freeways and developed a quantitative description technique to classify informational dimensions of urban freeways (Ref 5).The developed methodology contains three analysis phases.

In phase one, the freeway is divided into homogenous sections that are usually delineated by major interchanges. Inventories of freeway characteristics in Dallas, Houston, Austin, and San Antonio indicated that in the majority of the cases, sections between major interchanges were characterized by uniform dimensions. For general section descriptions, the following information is collected: freeway name; section direction, boundaries, and length; annual average daily traffic volume; and design or 85-percentile speed.

In the second phase, each section is described in terms of the three groups of information sources: (1) highway characteristics, (2) traffic control, and (3) visual noise. For highway characteristics input, the section is subdivided into segments based on number of traffic lanes and the lengths of segments with same numbers of lanes are summarized. Traffic lanes designated for special use, such as transit traffic, are considered separately. The field inventory clearly indicated that most other roadway design characteristics are well correlated with the number of lanes and hence can generally be excluded from the data input.

The information input for the traffic control group is characterized by the total number of signs, including lane control signals (LCS) and dynamic message signs (DMS). The collected sign frequency statistics for all investigated freeways indicated that guide signs are overrepresented on urban freeways compared to other signs. For visual noise characteristics, the total number of objects is input into the model.

The objective of the third phase is section classification. The obtained data indicated some parameter variability within sections based on the implemented sectioning technique. Reducing the variability within sections would require shorter sections but these could destroy the real picture of driver information perception. Therefore, sections could be classified using statistical measures of central tendency such as maximum, mean, or mode (predominant value). Due to the continuous nature of driver information processing, and results of the observations that showed the dominance of one characteristic value, use of mode or predominant value to classify sections was chosen.

The freeway sections were classified based on the three separate criteria: number of lanes, frequency of signs and signals, and level of visual noise. For Group 1 of the information sources (Highway) the following classes characterized by the number of highway lanes were implemented: (1) Two Lane, (2) Three and Four Lanes, and (3) Five and Six Lanes.

For classification by traffic control, the number of signs per second is calculated using the design speed, speed limit, or 85-percentile speed and the length of section. The section is analyzed separately for each of the three highway subgroups. For two-lane freeways, the traffic control information load should be characterized as low if the average frequency of road signs is equal to or less than 0.14 signs per second, medium if greater than 0.14 but equal to or less than 0.18 signs per second, and high if greater than 0.18 signs per second.

For three- and four-lane freeways, traffic control information load should be characterized as low if the average frequency of road signs is equal to or less than 0.15 signs per second, medium if greater than 0.15 but equal to or less than 0.21 signs per second, and high if greater than 0.21 signs per second.

For five- and six-lane freeways, traffic control information load should be characterized as low if the average frequency of road signs is equal to or less than 0.20 signs per second, medium if greater than 0.20 but equal to or less than 0.25 signs per second, and high if greater than 0.25 signs per second.

Similar to signs, the intensity of visual noise information loading is measured by the number of objects per second and classification is performed separately for each of the three highway subgroups:

For two-lane freeways, low intensity of visual noise should be defined as the appearance frequency of objects being equal to or less than 0.05 objects per second, medium if greater than 0.05 but equal to or less than 0.12 objects per second, and high if greater than 0.12 objects per second. For three- and four-lane freeways low intensity of visual noise should be defined as the appearance frequency of objects equal to or less than 0.09 objects per second, medium if greater than 0.09 but equal to or less than 0.19 objects per second, and high if greater than 0.19 objects per second. For five and six lane freeways low visual noise intensity should be defined as equal to or less than 0.10 objects per second, medium if greater than 0.10 but equal to or less than 0.24 objects per second, and high if greater than 0.24 objects per second.

The combinations of the above-mentioned three groups representing the classifications based on roadway design, traffic control, and visual noise determine section classes and include twenty-seven levels of information load as represented in Table 1.1.

Table 1.1 Class Designation Number Matrix Resulting from Classification Technique

Freeways	**Sign Frequency Level**								
	Low			**Medium**			**High**		
	Visual Noise Intensity								
	Low	**Med**	**Hi**	**Low**	**Med**	**Hi**	**Low**	**Med**	**Hi**
2 Lane	1	2	3	4	5	6	7	8	9
3-4 Lane	10	11	12	13	14	15	16	17	18
5-6 Lane	19	20	21	22	23	24	25	26	27

These classified levels of information load based on the frequency of different information sources can be arranged in order of increasing complexity (e.g., level 1 has lower informational input than 3). Quantification of information loading is based on the logical conclusion that a greater quantity of objects in the driver's field of view will cause higher informational input. However, the classified information load levels, by themselves, do not easily allow identification of problematic information loads and selection of improvement countermeasures. To provide traffic and safety professionals with a practical tool to analyze and affect urban freeway driver information load, the developed methodology should be evaluated considering driver perception and performance.

At the evaluation stage the impact of other motorists (traffic group of information sources) on general driver information load should be included in the analysis. It is obvious that the behavior of other motorists is very important due to the high level of unpredictability and possible consequences, such as incidents. Therefore, driver attention is frequently concentrated on the surrounding vehicles.

At low traffic volumes, traffic density is low, and individual drivers have minimal interaction with other drivers. There is little or no restriction on maneuverability due to the presence of other vehicles and so such conditions reflect minimal effects of traffic on the general information load.

As traffic volume grows, higher density reduces driver ability to manage interactions with other motorists, so drivers must devote more effort to observing more surrounding vehicles in order to select their own speed, change lanes, or pass. In conjunction with little or no reduction of the traffic flow speed, this increases the number of information sources per unit of time, hence an increased information load. Taking into account that in higher density flows the driver can observe only a limited number of surrounding vehicles, further traffic volume increases do not increase the number of surrounding vehicle informational sources, and with speed reduction there is a reduction of this type of information load. Figure 1.1 presents a hypothetical relationship between traffic and driver information load.

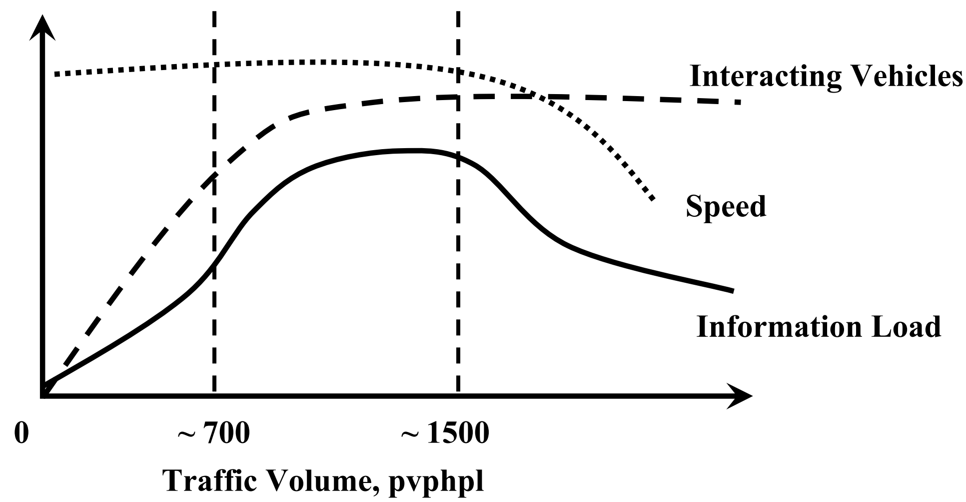


Figure 1.1 Hypothetical Relationship between Traffic Volume, Speed, Number of Interacting Vehicles, and Information Load Caused by Other Motorists

Therefore, from an information load perspective, the worst situations include traffic volume that exceeds free flow conditions but does not cause significant speed reduction. The Highway Capacity Manual (HCM) indicates that on multi-lane urban freeways, traffic volumes up to around 700 pvphpl can be characterized as free flow conditions, and speed tends to reduce after the traffic volume exceeds 1500 pvphpl (Ref 6). As indicated in Figure 1.1, it is reasonable to assume that traffic volume from 700 to 1500 pvphpl will cause maximal surrounding vehicle informational input. Information load levels based on combinations of other information sources should thus be evaluated considering such worst-case scenarios.

Different criteria can be implemented for evaluation of the identified information load levels. The first criterion, crash frequency, is based on the assumption that greater informational load may cause higher probability of driver errors and in turn increase crash frequency. So, multiyear crash statistics were selected for this evaluation phase to study the possible associations between different levels of informational load and corresponding crash frequencies.

However, each traffic collision is a statistically random event, due to the fact that it is not controllable, and therefore the contributing factors cannot be accurately systematized. Considering this fact, the absence of traffic collisions does not guarantee the absence of dangerous traffic conditions or unsafe driver behavior. So, it was concluded that, compared to the criterion of collision absence, the criterion of normal behavior that does not cause conflicts reflects safety better. This criterion defines safety as the absence of systematic dangerous traffic conditions or inadequate driver behavior (Ref 4). Therefore, based on analysis of traffic conditions and road user behavior, researchers can identify situations that can potentially lead to collisions and develop improvement countermeasures. Analyzing the driver-vehicle-road-environment (DVRE) system is complex, but this concept adds a systematic approach to traffic safety studies, with major emphasis on understanding driver behavior and reactions as a key element of the traffic system.

1.3 Summary

Therefore, at the next evaluation stage, described in the next chapter, driver behavioral and psycho-physiological responses will be investigated in each of the section classes obtained by the above-mentioned methodology.

2. Crash Statistics Analysis

The urban freeway driving environment requires that drivers must have a constant high level of alertness due to exposure to high traffic volumes and speeds, numerous exit and entrance ramps, weaving, and significant visual noise. Such traffic conditions may be conducive to development of driver information overload, which can reduce available time for decision making and behavioral corrections. Due to the limitations of the human information processing system, such conditions increase the probability of missing bits of information or improperly interpreting information leading to improper driver responses.

Sometimes the driving environment provides insufficient information for drivers to safely navigate their course. The information is either not provided or not adequately recognized and perceived by drivers. If important traffic signs are not given the proper attention, insufficient information transfer can also create unsafe conditions, such as last-minute merging, large speed changes, and abrupt braking.

Therefore, one might reasonably assume that both an insufficient and an overloaded informational environment may increase the possibility of traffic incidents and might be reflected by crash frequency. Identification of the potential relationships between different levels of information load and crash occurrence is the major objective of the analysis represented in this chapter.

2.1 Data Collection

For purposes of this study, the statewide crash database for the State of Texas, provided by the Texas Department of Public Safety (TxDPS) was used. The data set includes all reported freeway crashes from 1999 to 2001. Data describing each crash includes crash date, time, severity, type, manner of collision, location, information about lighting conditions, traffic control at accident site, and surface conditions. The data shows that on the Texas freeway system a total of 311,701, 318,990, and 323,958 crashes occurred in 1999, 2000, and 2001, respectively.

Crash statistics for a carefully selected sample of sections was extracted from the statewide comprehensive database. The selected sections are part of the CTR-developed Texas Urban Freeway Database (TUFD), which describes in detail the information load character of freeways. The selected freeway sections represent all twenty-seven levels of information load corresponding with the developed methodology for quantitative description of informational dimensions of urban freeways (see Chapter 1). The sample is comprised of sections from the cities of Austin, Dallas–Fort Worth, Houston, and San Antonio. A total of 86,864 accidents took place on the sample sections during the observed three years.

Using Texas Department of Transportation (TxDOT) Annual Average Daily Traffic Volume (AADT) maps, each section was assigned a traffic volume for each year of crash data. A new data set for the 254 selected sections was constructed. It included length, AADT for each year, number of lanes, sign frequency, visual noise object frequency, and crash data for the years 1999, 2000, and 2001.

2.2 Data Analysis

The analysis of accident statistics will follow the categorization adopted in the descriptive methodology mentioned earlier. Based on the driver information load, concepts freeway sections were categorized into three groups according to the number of lanes: Group 1—two lanes, Group 2—three and four lanes, and Group 3—five and six lanes. Each group was further classified into three sub-categories based on frequency of road signs, and each of them was also classified by the visual noise intensity. Therefore, the analysis was performed in the same order as the freeway information load categorization. Table 2.1 shows the class designation matrix resulting from adopting this classification technique with the number of sections analyzed in each group.

Table 2.1 Class Designation Number Matrix and Quantity of the Analyzed Sections

Freeways	Sign Frequency Level								
	Low			Medium			High		
	Visual Noise Intensity								
	Low	Med	Hi	Low	Med	Hi	Low	Med	Hi
Group 1	1 (5)	2 (5)	3 (3)	4 (5)	5 (9)	6 (5)	7 (5)	8 (4)	9 (8)
Group 2	10 (22)	11 (14)	12 (22)	13 (19)	14 (25)	15 (29)	16 (12)	17 (20)	18 (29)
Group 3	19 (3)	20 (4)	21 (2)	22 (2)	23 (1)	24 (1)	25 (1)	26 (1)	27 (1)

*Numbers of sections pertaining to the sub-categories are shown in parenthesis.

Crash frequency and severity were selected as major characteristics for detailed analysis. In addition, crash types and number of vehicles involved were analyzed. For comparative analysis of the crash statistics on different freeway sections, the accident ratio (AR) representing the number of accidents per million automobile traveled miles was used.

Once accident ratios were calculated for the highway sections, mean accident ratios and variances can be compared for the sample of freeway sections characterized by different informational dimensions. To determine the significance of any differences in means between samples, a statistical significance test was performed. Although a t-test or one-way analysis of variance is often used to determine if two samples originated from different populations, these tests cannot be used with data in this study because the accident frequencies are not normally distributed.

Instead, the nonparametric Krukal-Wallis test was selected because it eliminates the need for normality in a population by ordering the combined observations by rank, then computing the sum of ranks for each sample. The Krukal-Wallis method is also advantageous because it yields a P-value, allowing for simple calculation of significance levels.

To test correlation between investigated parameters, the Spearman rank correlation coefficient was selected due to the same reasons as explained above.

For the study of certain crash variables, accident ratio analysis was not always appropriate. Also, detailed classification of accidents by variables such as severity or collision manner may cause limited sample sizes of analyzed groups that will reduce the validity of test results. In such cases, the analyzed characteristics were combined to increase sample sizes and were described as percentages of the total observed values.

2.3 Crash Frequency

This initial analysis focused on a general comparison of crash frequencies for freeway sections characterized by different levels of information load. Accident ratios were calculated for each freeway section using the total number of crashes that occurred on each section, the length of each section, and the average AADT of each section.

As a first step the pattern of accident ratios for freeway sections with different numbers of traffic lanes (Group 1, Group 2, and Group 3) is presented in Figure 2.1.

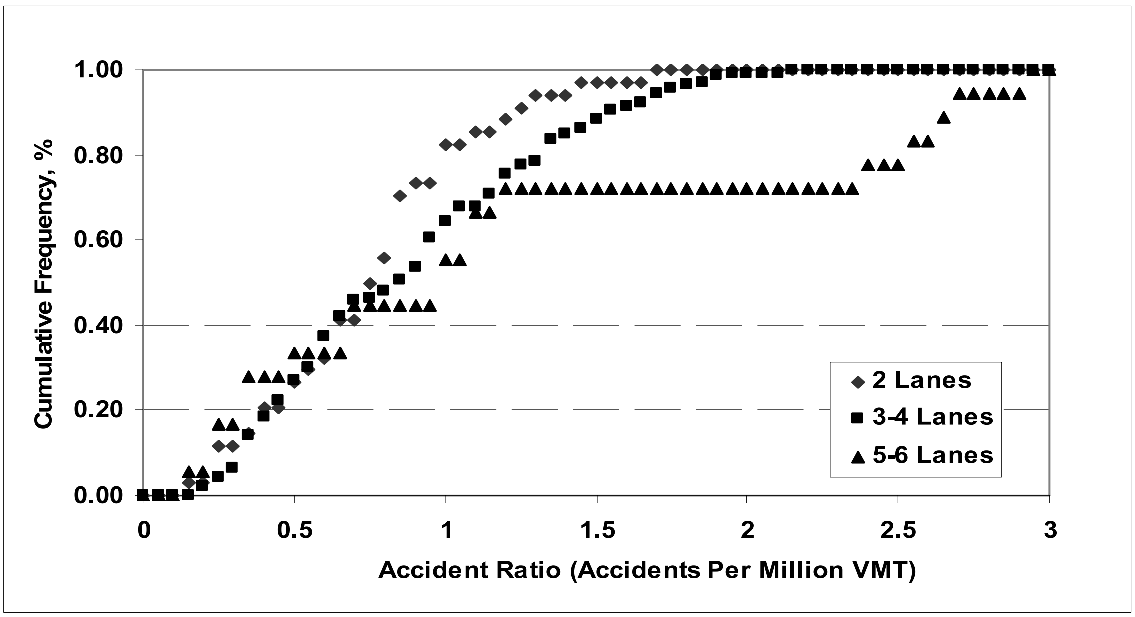


Figure 2.1 Distribution of Accident Ratios by Freeway Group

The data shows that crash frequency increases with increasing number of lanes. The highest crash frequency was observed on freeways with five and six traffic lanes. On average, 1.19 accidents per million VMT occurred on such freeways, followed by three- and four-lane freeways (0.87 accidents per million VMT), and two-lane freeways (0.74 accidents per million VMT).

To justify the statistical significance of the observed difference between freeway groups, the Kruskal-Wallis analysis was conducted. The null hypothesis was formulated to state that there is no difference in accident ratio among freeways with different numbers of lanes. Analysis was conducted for all three freeway groups as well, separately for each pair of freeway groups. The calculated H values varied from 0.7 to 5.96, which allowed rejection of the null hypothesis at significance levels that varied from 0.60 to 0.98. The lowest significance level was observed between freeways from groups 1 and 2, while the highest levels were found when comparing group 3 with group 1 or 2.

For more adequate comparison of freeway groups, the observed sections were detailed into low, medium, and high sign frequency subgroups. Table 2.2 and Figure 2.2 represent the statistical characteristics of the accident ratio distribution.

Table 2.2 Statistical Characteristics of Accident Ratios by Sign Frequency and Freeway Group

Number of Lanes	Sign Frequency							
	Overall		Low		Medium		High	
	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
2	0.75	0.36	0.50	0.26	0.81	0.32	0.88	0.43
3-4	0.87	0.47	0.70	0.41	0.84	0.45	1.11	0.46
5-6	1.19	0.98	1.60	1.21	1.09	0.81	0.64	0.40

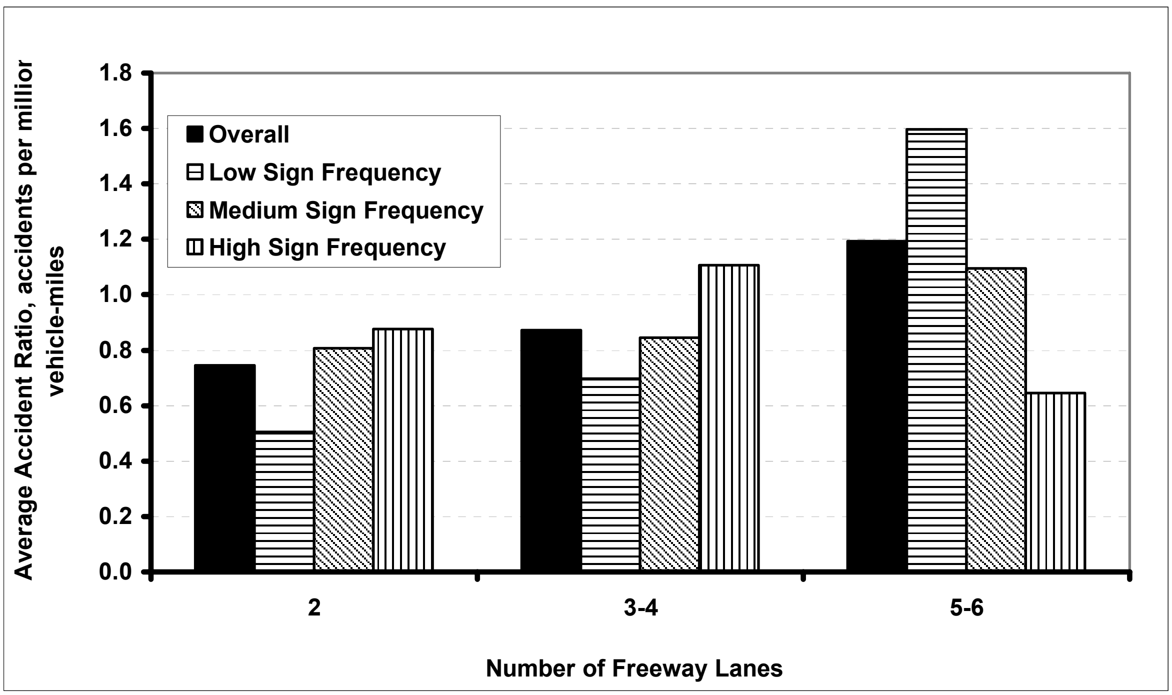


Figure 2.2 Average Accident Ratios for Freeway Groups and Varying Sign Frequencies

Statistical analysis at this level also indicated a significant difference between observed subgroups with significance levels varying from 0.5 to 0.95. Freeways with five and six lanes show the highest differences compared to the other groups at all levels of sign frequency. Data indicated that at low and medium sign frequency accident ratios increased with increasing number of lanes, while at high sign frequency freeways with five and six lanes have the lowest crash frequency.

Overall, the analysis indicated that the observed freeway groups differ based on accident ratio criteria; therefore, further analysis should be performed separately for each freeway group.

As identified in the previous analysis (see Figure 2.2), within the same freeway group accident ratios varied depending on sign frequency class. The next set of analyses targeted identification of a possible relationship between sign frequency and accident ratio. Figure 2.3 represents crash frequency on freeway sections characterized by different levels of sign intensity and at all levels of visual noise.

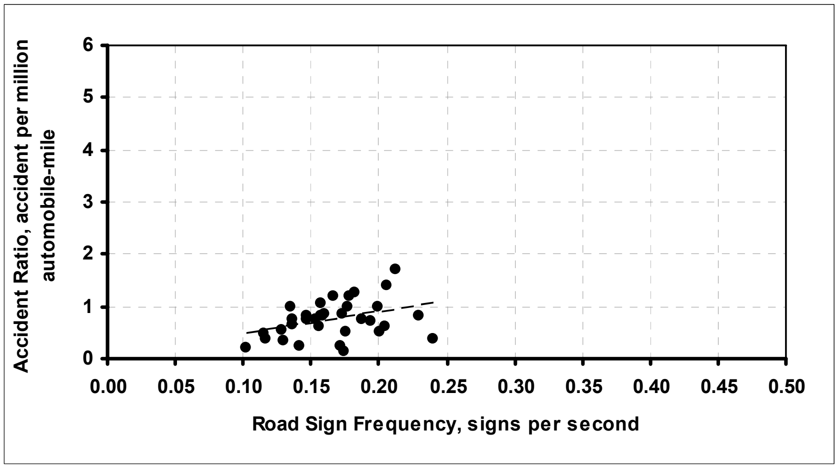
The data shows that on freeways with two and three and four lanes accident ratio increases with increasing sign frequency, while on freeways with five and six lanes the increase of sign frequency causes a reduction in accident ratio. The calculated Spearman rank correlation coefficients for observed parameters were valued at +0.38, +0.43, and -0.25 for the above-mentioned freeway groups and allow for the conclusion that a significant correlation exists. Table 2.3 shows the results of the analysis.

Table 2.3 Spearman Rank Correlation Values of Accident Frequency versus Sign Frequency for Freeway Groups

Number of Lanes	Spearman Statistic	P-Value	Sample Size
2	0.38	0.03	34
3-4	0.43	0.00	140
5-6	-0.25	0.32	18

The analysis permits quantification of the signage intensity that corresponds to the minimal crash frequency. On freeways with two and three to four traffic lanes the minimum crash frequency was observed at signage intensity less than 0.14 and 0.15 signs per second, respectively. On freeways with five to six traffic lanes, the minimum crash frequency was observed with 0.25 and greater signs per second. Based on the most frequent speed limits on Texas urban freeways (60 mph), these values correspond to 9, 10, and fifteen signs per mile. The crash increases on smaller freeways (two, three and four lanes) with more signs allows for the hypothesis that more information on such freeways causes driver information overload. The opposite hypothesis can be made for larger freeways (five to six lanes) where lower sign frequency may reflect some driver information underload.

a)



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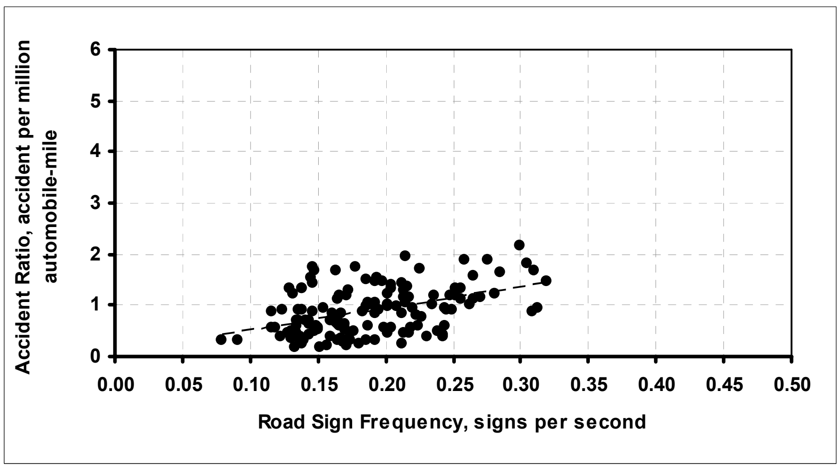

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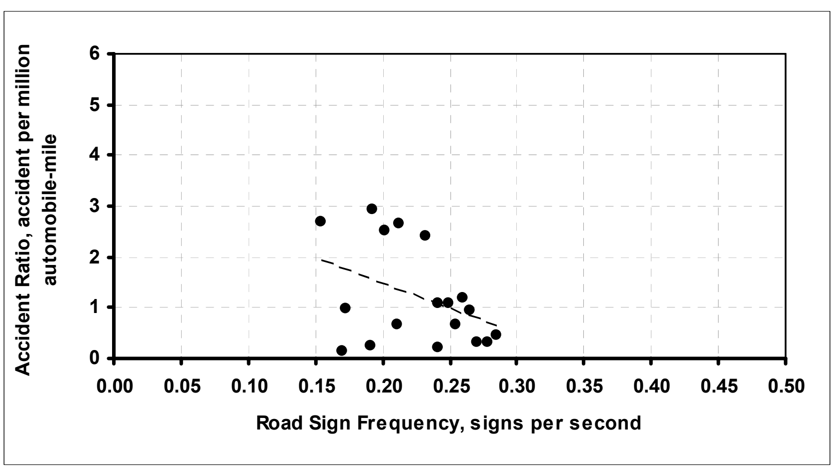


Figure 2.3 Distribution of Accident Ratios by Road Sign Frequency (All Visual Noise Levels) a) 2 Lanes b) 3-4 Lanes c) 5 Lanes

The last factor tested in the general analysis was visual noise level of the driving environment. The data were further detailed into three subgroups representing freeway sections with low, medium, and high visual noise levels corresponding with the quantitative criteria determined in Chapter 1.

Such detailed data classification leads to very small sample sizes for each subgroup for freeways with two and five to six lanes that do not allow for valid comparisons to be made. Therefore data for those freeways were separated by visual noise class without regard to sign frequency, and statistical characteristics of crash frequency are represented in Table 2.4.

Table 2.4 Statistical Characteristics of Accident Ratios by Visual Noise Intensity

Number of Lanes	Visual Noise Intensity					
	Low		Medium		High	
	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
2	0.47	0.27	0.79	0.35	0.94	0.31
5-6	1.98	0.89	1.54	0.89	0.33	0.18

An increase in mean crash frequency values with visual noise intensity growth was observed for freeways with two traffic lanes. Therefore, the hypothesis can be made that visual noise may have an impact, but the elimination of sign frequency from the analysis does not allow for a strong conclusion. For highways with five to six lanes, there was a reduction in crash frequency with higher visual noise levels, but the assumptions in analysis mentioned above again limits the strength of this conclusion. Also, it should be noted that a review of surroundings on freeways of five to six lanes characterized by high visual noise indicated that such sections have numerous landmarks, such as buildings and car dealerships, that in turn can provide drivers with some guidance for destination identification and therefore create a better driving environment.

Extensive data for highways with three to four lanes permitted statistical analysis of the possible visual noise effect to be conducted with respect to sign frequency. Table 2.5 shows average accident ratios for each combination of road sign and visual noise frequency.

Table 2.5 Mean Accident Ratios for Freeways with 3-4 Lanes

Visual Noise Intensity	Sign Frequency		
	Low	Medium	High
Low	0.47	0.62	1.12
Medium	0.72	0.69	1.22
High	0.93	1.14	1.03

The Kruskal-Wallis statistics indicated that freeway sections with three to four lanes and low and medium signing frequency have significant increases in crash frequency with an increase in visual noise intensity. The probabilities of null hypothesis rejection were valued around 0.99 for the analyzed samples. However, similar analyses for sections with high levels of signing do not show a statistically significant impact of visual noise. The higher adverse affect of visual noise with lower signing can be explained by the phenomenon that at lower sign intensity, increased visual noise distractions will have a higher chance of causing a driver to miss needed guidance information. At higher sign frequency, distractions will have less of an impact because more opportunities exist for the driver to identify needed information.

Summarizing all findings of the conducted analyses leads to the conclusion that there is a U-shaped relationship between driver information load and crash frequency, with increases occurring both at driver information under and overloads.

2.4 Accident Type

The TxDPS crash database contains detailed information concerning the manner in which accidents occurred and allowed for examination of the following accident types: rear end, sideswipe, and overturn or collision with a fixed object, as well as the total number of vehicles involved in the accident. These frequencies were compared for all sign intensity levels within each freeway group, as shown in Tables 2.6 and 2.7.

Based on the hypothesis that information insufficiencies may cause last moment maneuvering or intense braking, from this perspective, analysis was focused on rear end, angle, and sideswipe collisions.

Overall, the percentage of rear-end accidents varies little among the three freeway groups (37.7 percent for freeways with two lanes, 40.0 percent for freeways with three to four lanes, and 38.9 percent for freeways with five to six lanes). However, freeways with two lanes have significantly higher percentages of rear-end accidents at medium and high sign frequencies with the highest, 44.0 percent, occurring at medium sign frequency. Freeways with three to four lanes also show a slight increase in rear-end accidents (4.2 percent) as sign frequency increases, but freeways with five to six lanes show the opposite effect: the percentage of such accidents slightly decreases (4.9 percent) with increasing sign frequency.

The occurrence of angle and sideswipe collisions shows some tendency to increase on freeway sections with a greater number of traffic lanes due to the increased necessity of lane-change maneuvers on freeways with more lanes. The frequency of such collisions on freeways with five to six lanes averaged 30.9 percent of all cases, while on highways with 2 and three to four lanes, these values were 19.9 and 26.6 percent, respectively.

As with rear end collisions, there is evidence to support the hypothesis that information overload on freeways with fewer lanes causes more collisions related to improper maneuvering. On freeways with two lanes, the highest percentage of angle and sideswipe collisions was observed at high sign frequency. Conversely, increasing sign frequency on larger freeways (five to six lanes), which may be characterized by information underload, reduced the percentage of such accidents to 7.1 percent.

As evident in the data represented in Table 2.7, the majority of accidents occurring on analyzed freeway sections were two-vehicle collisions, which account for around 57 percent of all crashes. As expected, freeways with fewer lanes (two lanes) have the highest number of single-vehicle crashes (33.6 percent) with a simultaneous lower frequency of multiple-vehicle collisions (11.9 percent), while on larger freeways (five to six lanes) such crashes were observed as 23.9 and 17.6 percent, respectively.

Data indicated that on smaller freeways, an increase in sign frequency caused an increase of around 15 percent in two and more vehicle collisions, which possibly can be a sign of driver information overload. Again, data shows that sparse signing on larger freeways may be related to driver information underload, as reflected by an 18 percent reduction in multiple-vehicle collisions with signage increases.

Table 2.6 Distribution of Accidents by Accident Type

Accident Type	Number of Lanes	Accident Percentage at Sign Frequency							
		Overall		Low		Medium		High	
		Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
Rear-End	2	37.3	15.4	28.1	11.5	44.0	17.2	35.4	11.0
	3-4	40.0	10.5	37.8	10.7	40.5	11.1	41.9	9.0
	5-6	38.9	13.1	41.9	15.6	35.9	11.7	37.0	11.4
Angle and Sidewipe	2	19.9	9.9	19.0	10.9	16.0	5.5	27.2	11.3
	3-4	26.6	7.8	27.3	9.7	27.9	6.7	23.9	6.2
	5-6	30.9	11.4	34.6	12.6	28.4	13.1	27.5	7.7
Fixed Object and Overturn	2	32.7	14.7	42.9	14.6	29.5	14.0	27.8	12.0
	3-4	25.5	8.7	26.1	8.6	23.9	8.8	27.2	8.5
	5-6	24.4	9.8	19.1	6.6	28.2	10.5	29.2	10.9

Table 2.7 Distribution of Accidents by Number of Vehicles Involved

Number of Vehicles Involved	Number of Lanes	Accident Percentage at Sign Frequency							
		Overall		Low		Medium		High	
		Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
1	2	33.6	14.1	43.5	13.2	31.1	13.8	28.2	11.7
	3-4	25.4	8.9	26.3	9.1	23.5	8.7	27.1	8.5
	5-6	23.9	9.4	19.4	7.3	27.7	10.6	27.3	9.8
2	2	54.5	11.9	49.5	12.1	54.9	12.3	58.7	10.3
	3-4	58.5	7.7	59.3	7.0	58.7	8.6	57.4	6.9
	5-6	58.5	6.9	62.6	6.6	55.4	6.5	55.1	4.6
3 or Greater	2	11.9	7.5	7.0	4.6	14.0	9.3	13.1	3.3
	3-4	15.8	6.3	14.5	5.8	17.1	6.2	15.5	6.7
	5-6	17.6	8.2	18.0	8.1	16.9	10.7	17.6	7.5

2.5 Severity

The TxDPS accident database contains information concerning injuries and fatalities occurring to drivers and occupants of all vehicles involved in crashes. Five severity levels are given: property damage only (PDO), possible injury, non-incapacitating injury, incapacitating injury, and fatality. For this analysis, possible injury, non-incapacitating injury, and incapacitating injury accidents were combined into one group of accidents labeled "injury." Results are detailed in Table 2.8.

Over all freeway groups, injury accidents account for approximately two-thirds of all crashes, while PDO accidents make up the remaining third. Fatalities comprise less than 1 percent or all accidents. Values are very similar across all freeway groups, but injury accidents do slightly increase as the number of freeway lanes increases, from 61.5 percent for two-lane freeways to 65.9 percent for three- to four-lane freeways to 67.1 percent for five- to six-lane freeways. As sign frequency increases, injury accidents on two-lane freeways increase by around 12 percent, but remain fairly constant across all sign groups on highways with three to four and five to six lanes.

Table 2.8 Distribution of Accidents by Severity

Severity	Number of Lanes	Accident Percentage at Sign Frequency							
		Overall		Low		Medium		High	
		Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
Fatal	2	1.1	1.4	2.4	2.0	0.7	0.8	0.6	0.6
	3-4	1.0	1.3	1.3	1.9	0.8	0.9	0.8	6.6
	5-6	0.7	0.5	0.6	0.4	0.6	0.2	0.9	0.8
Injury	2	61.5	8.9	55.3	5.7	61.6	9.6	67.5	5.9
	3-4	65.9	6.7	66.5	7.6	66.5	6.0	64.3	6.6
	5-6	67.1	4.1	67.5	4.8	68.0	4.5	65.6	3.0
PDO	2	37.4	8.7	42.3	6.5	37.7	9.5	32.0	5.9
	3-4	33.2	6.4	32.2	6.8	32.7	5.8	34.9	6.7
	5-6	32.2	4.2	31.9	4.6	31.4	4.7	33.5	3.7

2.6 Summary of Crash Statistics Analysis

The analysis described in this chapter leads to the following summary statements:

The analyzed freeway groups differ from a crash frequency perspective with a tendency to increase as the number of lanes increases.

Increased signing on highways with two, three, and four lanes causes a growth in general accident frequency with a simultaneous increase of multiple-vehicle collisions and in some cases crash severity. Based on this, one might hypothesize that such conditions cause driver information overload. The analyzed data indicated that exceeding sign frequencies of 0.18 and 0.21 signs per second on freeways with two and three to four lanes, respectively, causes major impacts, and therefore such values can be assumed as threshold values for driver information overload identification.

Analysis indicated that freeway sections with five and six traffic lanes at lower sign frequency are characterized by increased crash frequencies. This phenomenon supports the hypothesis that such traffic conditions may cause driver information underload and corresponds with sign frequency of 0.25 signs per second and less.

Though the analyzed data does not allow for strong conclusions to be made regarding visual noise impacts, the findings show some tendency that at lower sign intensity, increased visual noise distractions may have a higher chance of causing a driver to miss needed guidance information. At higher sign frequency, distractions may have less of an impact because more opportunities exist for the driver to identify needed information.

The next chapter introduces the concepts of relationships between driving stress and driving performance and attempts to relate these ideas to the hypotheses developed through the crash data analysis.

3. Driving Stress and Driver Performance

As mentioned in Chapter 1, the second evaluation stage for the information load levels is based on identification of driver behavior that does not cause conflicts and foresees an investigation of driver responses to information loads. With an objective of identifying a valid technique for such investigations, the present chapter reviewed basic driving stress and mental workload models, as well as driver responses to real driving environments.

3.1 Driving Stress Model

The automobile is an important part of the daily life of most urban and suburban residents, as well as the primary mode of transportation for nearly 90 percent of the U.S. labor force (Ref 7). In addition, in major metropolitan areas the proportion of automobile commuters ranges from 85 percent to 93 percent. With increasing traffic congestion in such areas, daily commutes become longer and more difficult, placing increasing demands on the individual driver. In one study of transportation related problems, 33 percent of respondents characterized their driving problems as “sizable” or “great” (Ref 8).

Stress is most usefully defined as a mismatch between an individual’s perception of the demand present in a situation and that individual’s perception of his or her own ability to cope with the demand. Among the different models of stress, the transactional model provides a suitable framework for explaining the subjective and objective correlates of the driver stress scales (Refs 8, 9). This driving stress model is shown in Figure 3.1 (Ref 8).

The crucial element in transactional theories is a cognitive appraisal process. The basic idea of cognitive appraisal is that the stress-inducing qualities of an event are dependent on the individual’s perception and interpretation of that event. The level of demand in the perceived driving situation, which is a function of the actual situation and of other non-driving variables, is compared with the level of perceived coping abilities, which is a function of actual abilities and other individual difference variables. If coping abilities are judged to be inadequate to deal with the immediate situation, stress results. This involves both a subjective emotional response and specific psycho-physiological changes. Active attempts to cope with the stressors in a driving situation are primarily behavioral (i.e., steering, acceleration, and deceleration). These coping responses change the situation, which is then reappraised. If the overall situation is still stressful, the cycle continues.

Driver stress is a term that refers to the cumulative negative psychological, physiological, and behavioral reactions that occur as a consequence of driving. The stress involved in driving is not attributable to any single source. The driving task, the set of operations required to keep a vehicle on the road and avoid accidents, is only one potentially stress-inducing aspect of the driving situation. The transport task, with the goal of getting from point A to point B within a certain period of time, is another potential

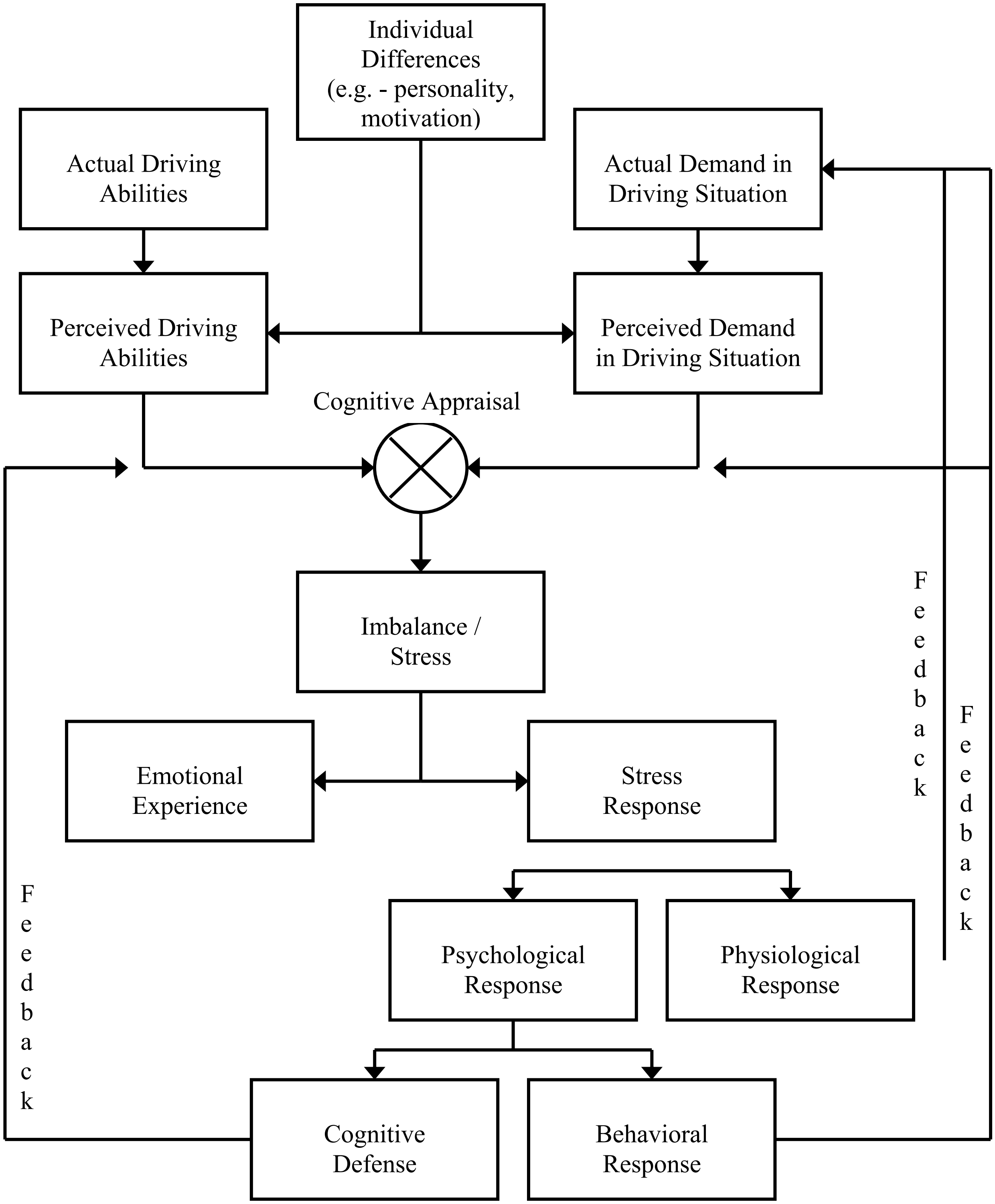


Figure 3.1 A Transactional Model of Driving Stress

stressor. Studies of discomforts experienced by automobile drivers indicated such diverse concerns as the fear of being late (reported by 14 percent of the respondents) and the fear of being involved in an accident (reported by 61 percent) (Ref 10). Even within the driving task, there may be several different factors that contribute to the experience of driving stress.

The Driver Behavior Inventory (DBI), developed as an instrument to measure driving stress, assesses three major aspects of stress vulnerability (Ref 11):

- Aggression relates to feelings of anger, frustration, and impatience, and to self-reports of behaviors such as tailgating and frequent overtaking.
- Dislike of driving is associated with anxiety, lack of enjoyment, and sensitivity to difficult driving conditions.
- Alertness relates to awareness of risk and active search for potential hazards.

Additionally, stressors may include such influences as noise, vibration, heat, and dim lighting, as well as personal health states, quality of family life, employment situation, and any stressful life events.

Clearly, the reduction of driving stress is a very complex task, which includes effects of vehicle design, quality of roadway, driver education, as well as general life events. From the traffic engineering view, the crucial point is to provide the traffic participant with the necessary information, ensuring adequate time for decision making and corrections to avoid stressful situations.

3.2 Information Load and Driver Performance

The amount of information is one of the major characteristics that determine driver mental workload. In turn, drivers can manage workload by processing and arranging information in order of use or by reducing speed, thereby reducing information flow rates and increasing time available to process information. If such corrections are not available, the driver will experience an increase of emotional tension. A model of workload is of greatest importance in the design phase of systems operated by humans in order to predict which configurations will maximize performance efficiency and still leave operators some “residual capacity” to meet unexpected task demands.

A simplified model of a hollow sphere with input and output streams might be useful for understanding the basic relationship between mental information processing, mental capacity, and mental workload (Ref 12). The input stream represents the amount of information imposed on the driver during a particular driving task. That stream will be regulated by the speed of the vehicle and the characteristic of the roadway (i.e., horizontal/vertical alignment, cross section, roadside environment). The output stream represents the amount of processed information. The channel capacity depends on the available preprocessed information and the individual capabilities of the driver. Preprocessing and arranging of information leads to an increased attention level and performance. Conversely, the greater the input stream, the lower the mental capacity; the lower the output stream, the greater will be the pressure and the stress (e.g., workload levels).

Engineering psychology has formulated a general rule that any given labor activity will be most effectively undertaken when the operator is at a corresponding optimal level of emotional tension. The Yerkes Dodson Law, represented in Figure 3.2, is defined by an inverted U-shaped pattern relating emotional tension to human performance (Ref 13).

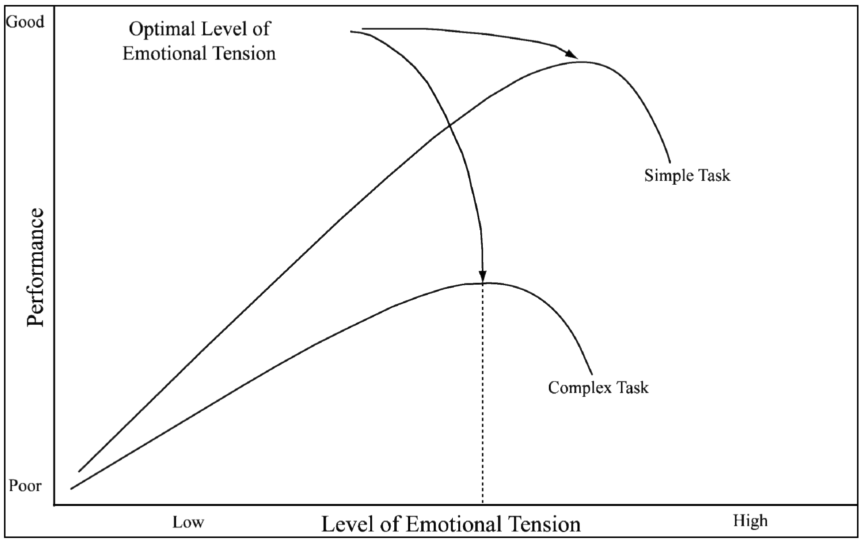


Figure 3.2 The Yerkes Dodson Law (Ref 13)

The application of this law to driver performance is represented in Figure 3.3, showing the probability of driver errors for different emotional tension levels (Ref 3). When information is practically absent, a driver will have very low emotional tension, and a high probability of errors at duties may result. In turn, when a driver must process a lot of information simultaneously, his emotional tension significantly increases, which also causes an increased probability of errors. It is important to clarify the definition of “information” in relation to driving tasks. “Information” was defined as all objects in a driver’s field of view that impact traffic operation, and which require driver analysis for appropriate behavior selection. As such, information includes vehicles, roadway parameters, traffic control devices, and other traffic participants.

The Center for Transportation Research (CTR) at The University of Texas at Austin conducted studies of driver behavior and reactions at different information load levels (Ref 14). Field studies capturing the driver electrocardiogram, driver visual field, and vehicle dynamics during complex driving tasks quantitatively described driver reactions during samples of information loading, thereby permitting comparative analysis. Three situations were investigated: insufficient information and minor and major information increases. This pilot study was employed only for qualitative descriptions of information loading based on “lower-to-higher” criteria. Driver behavior and reactions were quantitatively described based on vehicle speed profile and electrocardiogram analysis. The research showed that the majority of the investigated characteristics support the existence of relations between driver behavior and reactions, and levels of information loading. At low information load, much of the time drivers experienced low emotional tension (46 percent on average). Increased information loading causes reduction of this to 39 percent. At the same time the frequency of high emotional tension increased from 0.5 percent to 2 percent of total driving time. Thus, the data showed increased duration of high emotional tension with simultaneous reductions of low tension during information load growth.

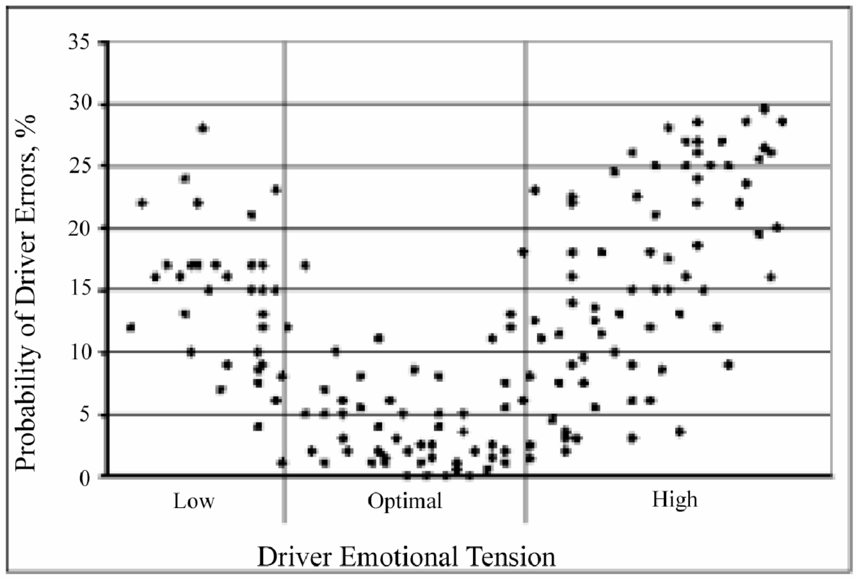


Figure 3.3 Probability of Driver Errors and Emotional Tension (Ref 3)

3.3 Driver Responses and Their Estimation

All driver responses to the driving environment can be classified as external, which is characterized by the vehicle speed profile and moving trajectory, and internal, characterized by the driver's psycho-physiological reactions.

3.3.1 Driver External Responses

The external or behavioral responses are corrective actions, which the driver performs during the actual driving situation and are reflected by the vehicle speed and trajectory. For quantitative description of these responses, such parameters as speed, longitudinal and diametrical acceleration, braking frequency, steering wheel movements, maneuvering frequency, and frequency of gear changing are typically analyzed. The most developed characteristics are based on speed history analysis. Many studies have been conducted to identify relations between traffic operational characteristics and safety, which have lead to developments of several methods for quantitative estimation of driver performance, such as "Acceleration Noise," "85-percentile Speed Difference," and "Speed Reduction Coefficient."

Acceleration noise represents the standard deviation of the acceleration/deceleration distribution on the given highway section. Based on investigations of collision levels under different traffic conditions, acceleration noise values between 0.1 and 0.56 reflect quiet traffic conditions, while those exceeding 1.05 correspond to increased driver mental workload and in turn a higher probability of collisions (Ref 15).

The 85th percentile speed difference method recommends calculating the difference between the 85th-percentile speeds on adjacent highway sections. Investigations of traffic conditions and collision statistics indicate that speed reduction equal to or less than 10 km/h corresponds to normal operational fluctuations (Ref 16). Speed reduction from 10 km/h to 20 km/h and greater than 20 km/h reflects complicated traffic conditions with minor and major inconsistencies between successive highway sections and may lead to higher collision frequencies and severity.

Another approach to analyze 85th-percentile speed differences on adjacent highway sections is the speed reduction coefficient (SRC). This methodology calculates the 85-percentile speed ratio on the investigated and upstream consecutive sections. Also this method takes into consideration the magnitude of initial speed before speed reduction and the deceleration rate. Depending on speed before reduction and braking intensity, SRC descending from 0.85 to 0.45 reflects increasing driver mental workload and probability of collisions (Ref 17).

Changes in speed and trajectory are the last step of the complex process of driver perception and reaction to traffic conditions. Lowering speed or changing trajectory may allow drivers to manage workload by reducing information flow rates and increasing time available to process information. If such corrections are not available, the driver will experience an increase of mental workload and high emotional tension.

3.3.2 Driver Internal Responses

Internal responses reflect driver mental workload and involve both a subjective emotional reaction and specific psycho-physiological changes due to the driving environment.

The assessment of mental workload is described abundantly in the literature. The three most commonly used categories of workload measurement techniques are self-reports, measures of task performance, and physiological measures.

Self-report technique. At the conclusion of a task, the operator is asked to rate task difficulty on one or more dimensions, with the results often combined into a single workload estimate. This introspective method is the basis for such rating scales as the Rating Scale Mental Effort (RSME), the Subjective Workload Assessment Technique (SWAT), the Task Load Index (TLX), and the Overall Workload (OW) scale (Refs 18, 19). The major difference among scales is the number of dimensions that have to be rated by the operator. In general, unidimensional scales, such as RSME, have an advantage compared to multiple scales, because it is fairly easy for the operator to give an overall rating of effort. This rating is more reliable than a summed overall rating based on multiple dimensions (Ref 19). While very useful in controlled situations, rating scales are usually administered ex post facto, permitting time and operator self-image considerations to moderate the results (Ref 18).

Performance measurements. This approach initially includes an estimation of primary task workload and unallocated, or spare, capacity by measuring the performance degradation on a subsidiary task designed to absorb unallocated resources relevant to the primary task. Many subsidiary tasks have been utilized over more than four decades, but the resulting literature is often conflicting and provides little guidance in the selection of a subsidiary task for a specific activity (Ref 18). The major drawback of this technique is that having to perform an artificial secondary task usually interferes with primary-task performance. Exceptional in this respect is so-called embedded secondary task, a sub-task that is performed as part of the whole task but that has a lower priority, for example the frequency of rearview mirror scans (Ref 19).

Another approach for performance measurements for driving reflects performance on lateral and longitudinal vehicle control. Many researchers have identified increases in workload as having a significant impact on frequency patterns and standard deviation of steering wheel movements and vehicle speed. This reflects driver ability to control the car.

Physiological measurements. This approach assumes that information processing involves central nervous system activity and that manifestations of this activity produce physiological consequences as task loading increases. A number of physiological measures have been used to infer workload including:

- Electroencephalogram (EEG)—reflects rhythms from impulses generated in the neurons under different brain activity
- Electrocardiogram (EKG) —a measure of heart activity
- Electro-oculogram (EOG) —recording eye movements and position
- Galvanic Skin Response (GSR) —a measure of skin electrical conductance
- Electromyogram (EMG) —a measure of muscle activity
- Pupillogram—a measure of the size of the eye pupil

Numerous research efforts conducted over fifty years have provided sufficient evidence regarding applicability of these parameters for determination of different levels of driver mental workload and emotional tension. Table 3.1 represents a sample classification of driver emotional tension based on quantitative description of human physiological responses (Ref 3).

Table 3.1 Determination of Driver Emotional Tension Based on Physiological Characteristics

Level of Emotional Tension	**Physiological Responses**		
	EKG, heart rate in percentage to basic	**GSR, mV**	**EOG, number of eye fixations per second**
Under load	90 - 100	0 - 0.1	0.7 - 0.8
Low	100 - 105	0.1 - 0.15	1.2 - 1.4
Optimal	110 - 125	0.2 - 0.5	1.6 - 2.2
High	135 - 140	0.7 - 1.0	0.5 - 3.0
Overload	150 and greater	1.0 and greater	0.2 - 1.0

Physiological measures permit continuous data collection during task performance and estimation of overall task loading. On other hand, most of them require that electrodes be attached or some degree of physical constraints be imposed. These constraints will influence user acceptance, so to minimize adverse effects the measures should be limited to those absolutely necessary for the particular tasks and special adaptation time should be provided for each driving test.

3.4 Summary

The review of techniques for measuring driver mental workload indicates that the heart rate and derived parameters (heart rate variability) have proven to be most useful for stress identification from physiological measurements (Refs 3, 8, 18, 19). The analysis of heart activity allows, not only the identification of stress, but also quantitative description of other emotional states of drivers, thereby providing tools for determination of optimal levels of information load. The next chapter provides a description of the field testing program using the selected physiological measurement processes.

4. Field Test Design

The review of methodologies for estimation of driver external responses showed that the most developed at the present time are those based on speed history. Many previous studies of operator labor activity showed that among different techniques for measuring driver internal responses the most accurate are physiological measurements. They allow quantitative description of different levels of driver emotional states, thereby providing tools for determination of optimal workload levels.

Therefore, for the investigation of driver's responses to the driving environment, the following parameters should be monitored during experiments:

- Vehicle speed-time history, for driver behavioral reactions analysis
- Visual stimuli sensed by the driver's eye, for qualitative assessment of traffic situations and identification of available stressors
- Driver electrocardiogram for internal reactions analysis

Two principle approaches are currently in use for the investigations of driver behavior and responses—real traffic experiments and studies with driving simulators. The real traffic experiment is the major technique for investigations of the combined effects of roadway, traffic control, traffic flow, and the environment on driver behavior and reactions. Hence, such experiments retain the driver's real feeling of danger providing the best solution to determine driver emotional tension and with it the most accurate data for mental workload estimation.

4.1 Portable Measuring System for Real Traffic Experiments

For field tests a special portable device developed by CTR was used. This device includes:

- An electronic monitoring module that is connected to the vehicle on-board diagnostic system (OBD) allowing continuous scanning of vehicle systems while driving
- A digital camcorder for video recording the driver's field of view
- A module for monitoring and continuous recording of the driver's psycho-physiological responses through an electrocardiogram (wave form)
- A notebook computer, which records all information

This portable device can be installed on any modern car in ten to fifteen minutes, and this portability allows the research team to easily switch among test vehicles, not depending on a particular experimental vehicle.

Figure 4.1 represents a general view and the connection diagram of the vehicle diagnostic module. The vehicle OBD system is easily connected through the vehicle's diagnostic connector and scan tool unit (the device used produced by the EASE Diagnostics) to a notebook computer, as a simple "plug-in" operation.

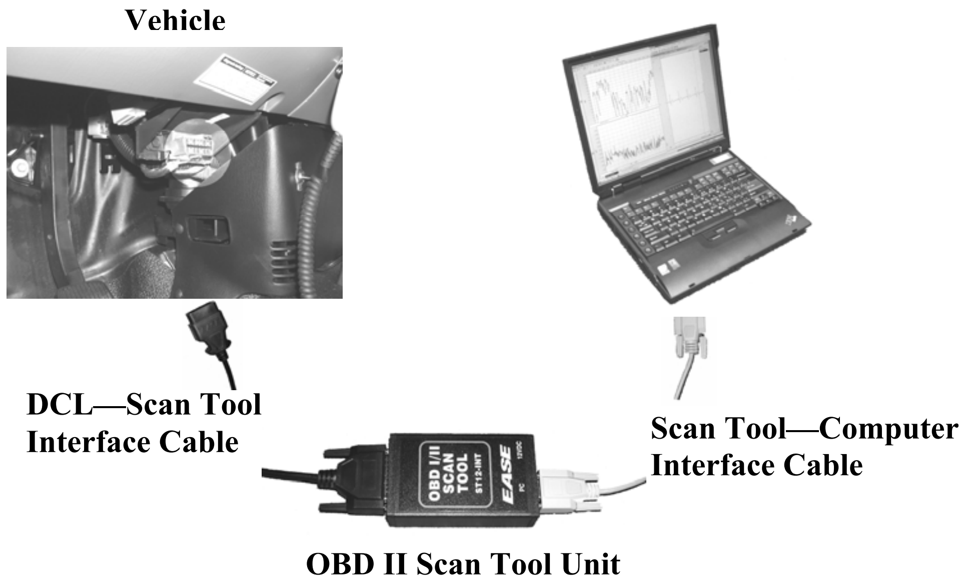


Figure 4.1 Connection Diagram of the Vehicle Diagnostic Module

For electrocardiogram recording a unit named PowerLab (model 4/25), manufactured by ADInstruments, was selected. The PowerLab is a smart peripheral device specifically designed to perform all functions needed for data acquisition, signal conditioning, and pre-processing. Together with the bio amplifier unit (BioAmp) this system allows the recording of different biological signals, including an electrocardiogram (EKG), from human sources. The BioAmp has been designed for safe connection to humans and conforms to the requirements of IEC601-1, its addenda, and various harmonized standards worldwide.

Since driving is largely a matter of visual information processing, recording of driver eye movements was selected as well. Driver eye muscle electro potentials (electro-oculogram) were registered using an ADInstruments AC-coupled Bio Amplifier. Two channels, vertical and horizontal, were recorded with a +-1000 microvolts amplitude range, 0.02Hz–50Hz frequency bandwidth, sample frequency of 100 samples/sec. Vertical movements are detected by electrodes placed above and below the eyes, while horizontal movements are detected by electrodes placed on either side of the eyes.

Figure 4.2 shows a general view and the connection diagram of the biological module.

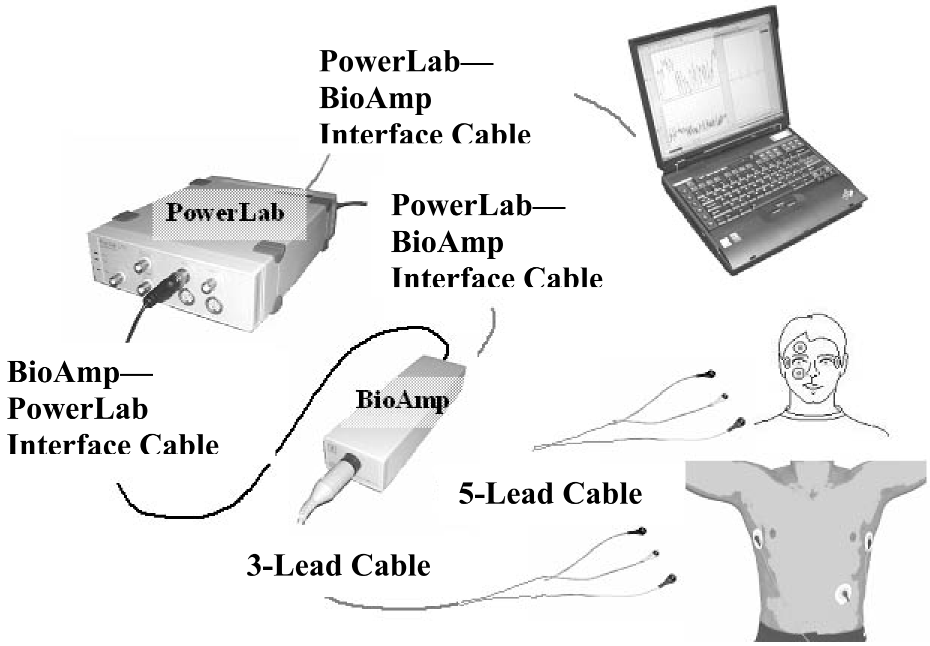


Figure 4.2 Connection Diagram of the Biological Module

The vehicle diagnostic module, biological module, and laptop computer were assembled in one portable system. System installation into the experimental vehicle requires only plugging in the DCL Scan Tool Interface cable and placement of electrodes on the driver's body.

The utilized portable measuring system allows simultaneous recording of the situation on the road, vehicle speed history, driver electrocardiogram (EKG), and electro-oculogram (EOG).

4.2 Test Routes

For the investigations of the combined effects of roadway, traffic control, traffic flow, and the environment on driver behavior and responses, real traffic experiments were selected because this approach allows estimation of the driver mental workload. Therefore, freeway sections representing each of the information load classes shown in Table 1.1 were to be selected for test driving. The observations of informational dimensions of urban freeways indicated that it is not possible to select test sections in a single city and cover all the classes. Table 4.1 represents the number of freeway sections with informational dimensions classified with the developed methodology for the major metropolitan areas in Texas.

Table 4.1 Number of Freeway Sections Characterized by Different Combinations of Information Source Groups

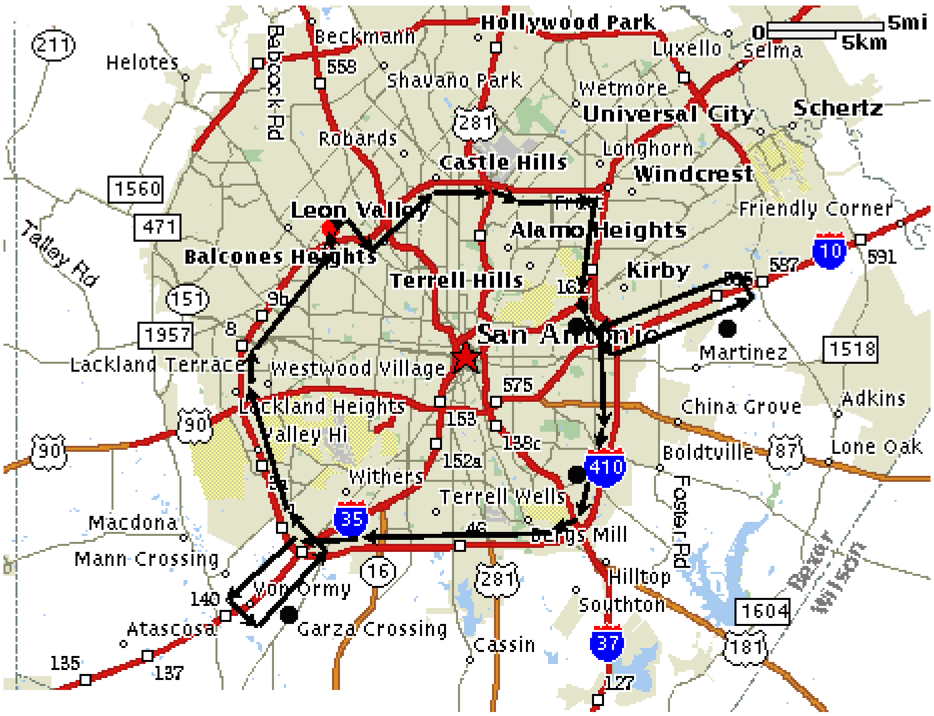
Freeways	Signs - Visual Noise Class Combinations								
	1-1	1-2	1-3	2-1	2-2	2-3	3-1	3-2	3-3
	Number of Freeway Sections								
Austin									
2 Lanes	0	0	4	1	1	1	0	0	1
3-4 Lanes	0	4	8	6	1	5	2	2	0
5 and More Lanes	0	0	0	0	0	0	0	0	0
Dallas - Fort Worth									
2 Lanes	0	2	2	1	1	6	1	3	6
3-4 Lanes	20	16	6	18	24	11	17	16	21
5 and More Lanes	1	0	0	0	0	1	0	0	3
Houston									
2 Lanes	8	3	0	2	0	1	2	0	0
3-4 Lanes	5	32	8	1	13	17	0	5	6
5 and More Lanes	4	3	2	3	4	2	0	2	3
San Antonio									
2 Lanes	3	5	1	5	8	2	6	4	6
3-4 Lanes	0	0	1	0	1	3	4	13	16
5 and More Lanes	0	0	0	1	0	0	1	2	0

In Table 4.1 class combinations beginning with 1, 2, and 3 respectively represent low, medium, and high intensity of road signs or visual noise objects. As evident from Table 4.1, only San Antonio has sections covering all combinations of information load classes for two-lane freeways, and hence was selected for experiments on two-lane freeways. For the same reason Dallas was chosen for investigations on three- and four-lane freeways, and Houston for five- and six-lane freeways.

In each selected city, nine sections that represent each of the nine combinations of traffic control and visual noise classes were chosen. This selection process took into account the proximity between sections so that a single test-drive will not exceed two hours to avoid driver fatigue. Therefore it was determined that two test routes in each city that accommodate at least one section for four or five information load levels should be selected to match the above-mentioned criteria.

The maps of the test routes selected in each city are shown in Figures 4.3, 4.4, and 4.5. Tables 4.2, 4.3, and 4.4 represent the selected freeway sections and their major characteristics for San Antonio, Dallas, and Houston, respectively. Sections are shown in the tables in order of their appearance from the beginning of the respective test drives.

Route 1



Route 2

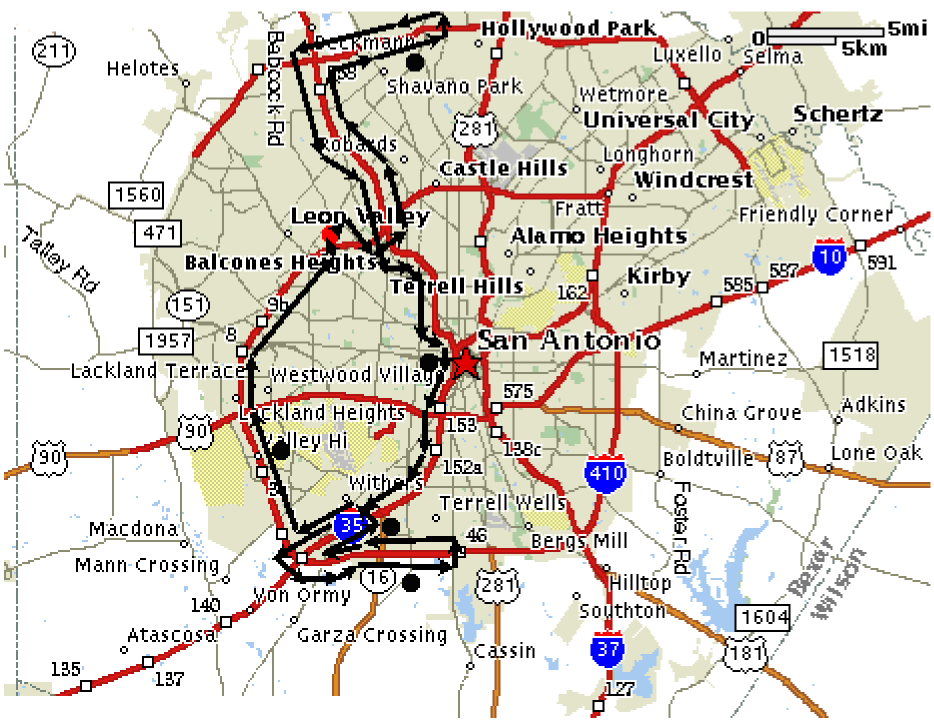
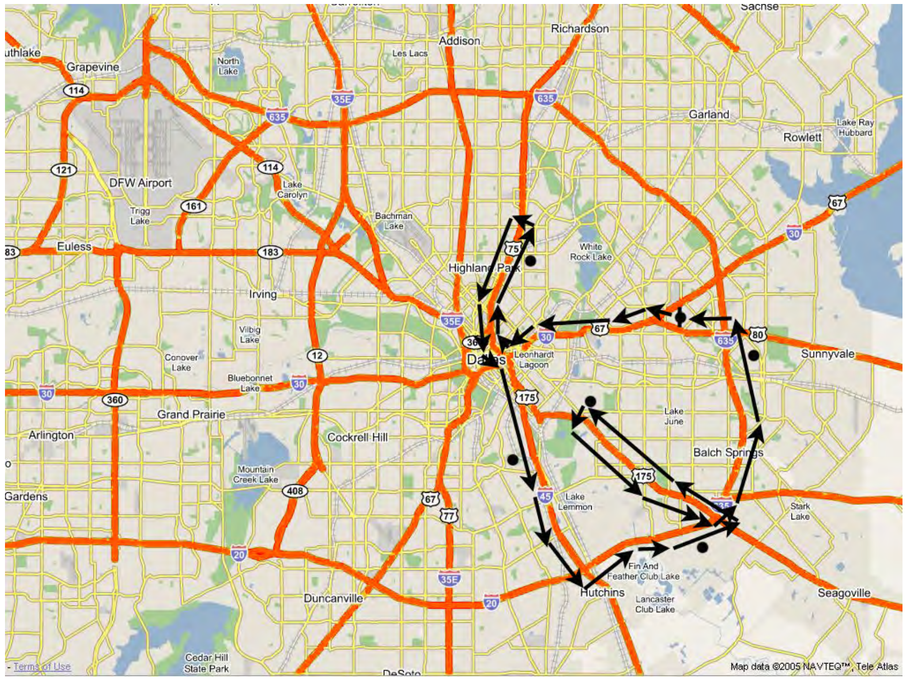


Figure 4.3 Selected Test Routes in San Antonio

Route 1



Route 2

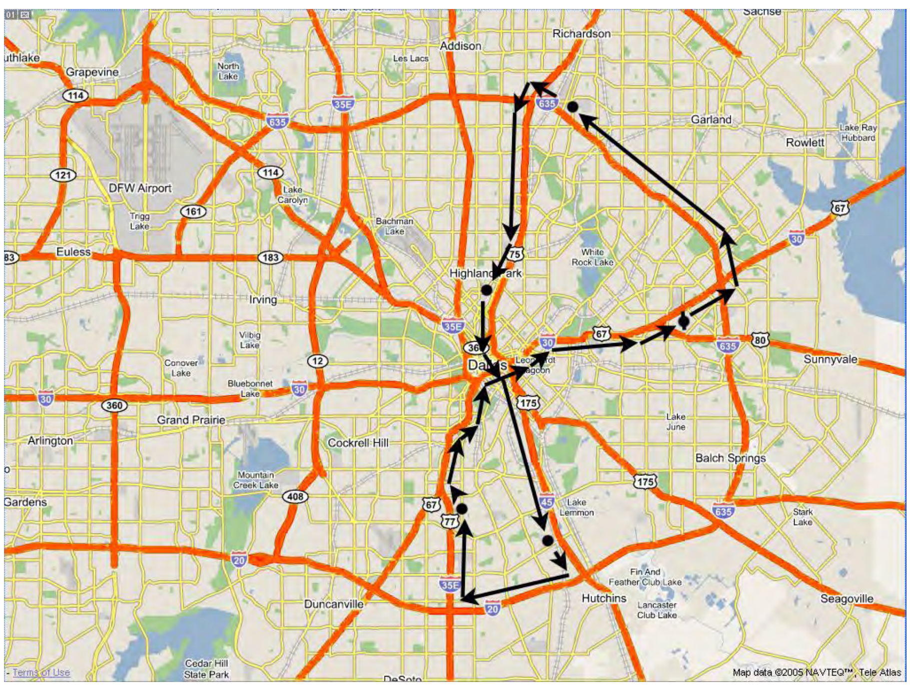
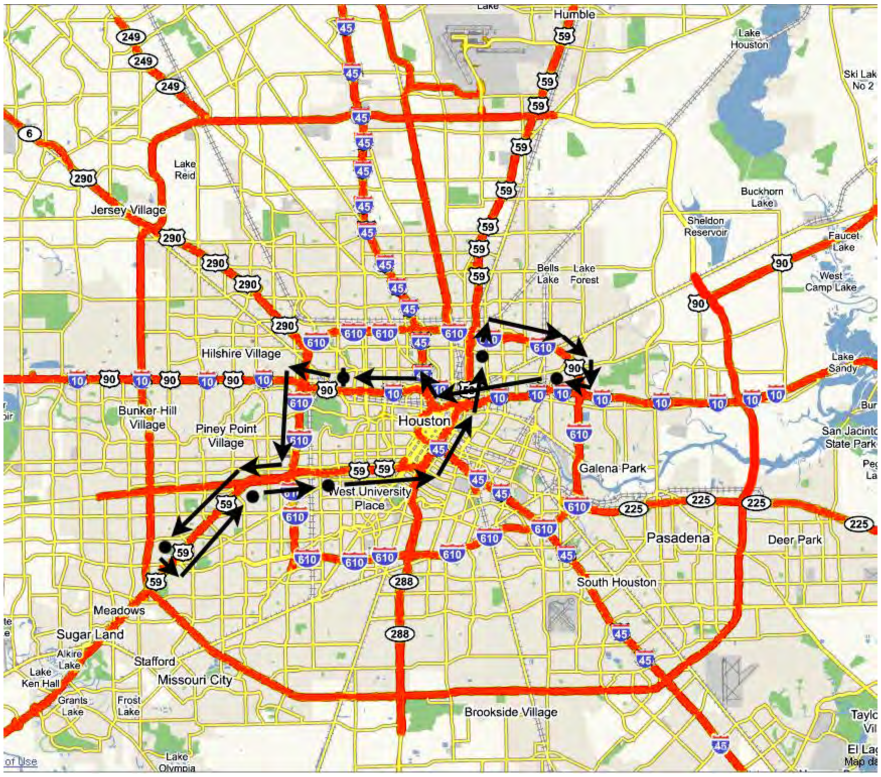


Figure 4.4 Selected Test Routes in Dallas

Route 1



Route 2

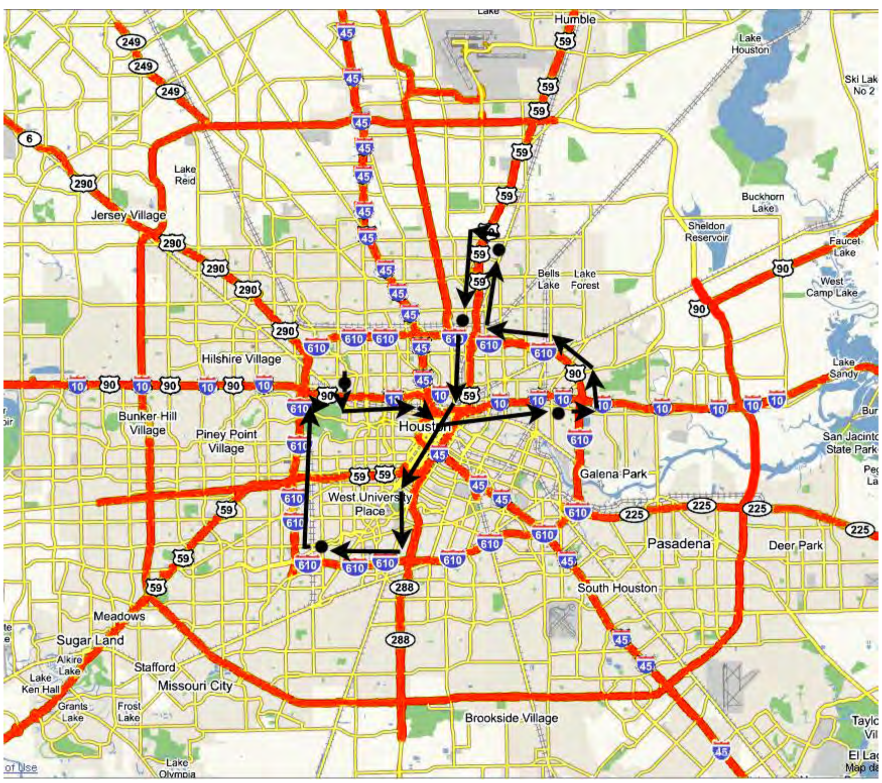


Figure 4.5 Selected Test Routes in Houston

Table 4.2 General Characteristics of Test Sections in San Antonio

Freeway	Direction	Section Boundaries		Number of Lanes	Length, mile	Speed Limit, mph	ADT (vpd)	Signs per sec	Visual Noise per sec	Sign Class	Noise Class
		from	to								
Route 1											
IH 410	South	Exit to IH 35 South	Exit to Dietrich Rd.	2	3.03	60	17250	0.22	0.07	3	2
IH 10	East	IH 410	Exit to Converse	2	6.19	70	11634	0.13	0.13	1	3
IH 10	West	Entrance from Converse	Exit to IH 410	2	6.14	70	11634	0.14	0.16	1	3
IH 410	South	Entrance from IH-10	US 87	2	2.55	70	14875	0.13	0.11	1	2
IH 410	South	US 87	Exit to W.W. White Rd.	2	5.06	70	10084	0.12	0.03	1	1
IH 410	West	IH-37	US 281	2	3.79	70	8875	0.17	0.03	2	1
IH 410	West	US 281	Exit to IH-35	2	7.85	70	8084	0.12	0.01	1	1
IH 35	South	Entrance from IH-410	Exit to Benton City Rd.	2	6.09	65	37500	0.09	0.16	1	2
IH 35	North	Entrance from Benton City Rd.	Exit to 410	2	6.09	70	37500	0.11	0.20	1	3
IH 410	North	Entrance from IH-35	US 90	2	6.11	70	14834	0.17	0.05	2	1
Route 2											
Lp 1604	East	Entrance from IH10	Exit to Stone Oak Pkwy	2	8.01	70	22834	0.15	0.13	2	3
Lp 1604	West	Entrance from Stone Oak	Exit to IH10	2	7.97	70	22834	0.15	0.09	2	2
IH 35	South	Exit to IH 10	SPUR 422	2	3.87	70	8875	0.14	0.05	1	1
IH 35	South	Spur 422	Exit to IH 410	2	4.28	70	9375	0.14	0.07	1	2
IH 410	East	Entrance from IH-35	Exit to Zarzamora	2	7.87	70	8084	0.20	0.01	3	1
IH 410	West	Entrance from Zarzamora	Exit to IH 35 N	2	7.85	70	8084	0.12	0.01	1	1
IH 35	North	Entrance from IH-410	Exit to Somerset Rd.	2	4.24	70	9375	0.20	0.52	3	3
IH 35	South	Entrance from Somerset Rd.	Exit to IH 410	2	4.28	70	9375	0.14	0.07	1	2
IH 410	North	Entrance from IH 35	Exit to Valley Hill Dr.	2	6.11	70	14834	0.17	0.05	2	1

Table 4.3 General Characteristics of Test Sections in Dallas

Freeway	Direction	Section Boundaries		Number of Lanes	Length, mile	Speed Limit, mph	ADT (vpd)	Signs per sec	Visual Noise per sec	Sign Class	Noise Class
		from	to								
Route 1											
IH 30	West	Lp 12	Exit to IH 45	3-4	5.89	60	46667	0.22	0.31	3	3
US 75	North	Entrance from IH 30 W	Exit to Lowers Ln.	3-4	6.67	60	54875	0.22	0.29	3	3
US 75	South	Entrance from Lowers Ln.	IH 30	3-4	6.56	60	54875	0.19	0.26	2	3
IH 45	South	IH 30	Exit to Illinois Av.	3-4	5.70	60	23500	0.11	0.10	1	2
IH 45	South	Lp 12	Exit to IH 20	3-4	3.15	60	15500	0.16	0.02	2	1
IH 20	East	Entrance from IH 45 S	Exit to St. Augustine	3-4	6.34	65	25000	0.12	0.06	1	1
US 175	West	Entrance from IH 20 E	Lp 12	3-4	3.33	60	13250	0.17	0.12	2	2
US 175	West	Lp 12	Exit to Bexar St.	3-4	6.70	60	15313	0.25	0.09	3	1
US 175	East	Entrance from Bexar St.	Lp 12	3-4	6.73	60	15313	0.25	0.09	3	1
US 175	East	Lp 12	Exit to IH 20	3-4	3.33	60	13250	0.22	0.14	3	2
IH 635	North	Entrance from US 175	Exit to Scyene	3-4	7.13	60	31688	0.16	0.11	2	2
Route 2											
IH 30	East	US 80	Exit to IH 635 N	3-4	3.52	60	33750	0.22	0.16	3	2
IH 635	West	Entrance from IH 30 E	SH 78	3-4	3.97	60	44875	0.13	0.16	1	2
IH 635	West	SH 78	Exit Greenville Ave	3-4	6.86	60	50417	0.13	0.22	1	3
US 75	South	Entrance from IH 635	Lp 12	3-4	3.70	60	56875	0.17	0.34	2	3
US 75	South	Lp 12	Exit Haskill Av.	3-4	6.56	60	54875	0.19	0.26	2	3
IH 45	South	IH 30	Lp 12	3-4	5.70	60	23500	0.11	0.10	1	2
IH 45	South	Lp 12	Exit Simpson Stuart Rd.	3-4	3.15	60	15500	0.16	0.02	2	1
IH 20	West	Entrance from IH 45	Exit IH 35E	3-4	5.79	65	30584	0.14	0.12	1	2
IH 35E	North	Entrance from IH 20	Exit Overton Rd.	3-4	4.15	60	46625	0.27	0.18	3	2
IH 35E	North	Entrance from Overton	Exit IH 30	3-4	4.15	60	46625	0.27	0.18	3	2
IH 30	East	Entrance from IH 35E	IH 45	3-4	2.30	60	49500	0.30	0.08	3	1
IH 30	East	IH 45	Lp 12	3-4	5.89	60	46667	0.25	0.27	3	3
IH 30	East	Lp 12	Exit Big Town Blvd	3-4	3.52	60	33750	0.22	0.16	3	2

Table 4.4 General Characteristics of Test Sections in Houston

Freeway	Direction	Section Boundaries from	Section Boundaries to	Number of Lanes	Length, mile	Speed Limit, mph	ADT (vpd)	Signs per sec	Visual Noise per sec	Sign Class	Noise Class
Route 1											
US 59	South	IH 610	Hillcroft	5-6	2.56	60	87250	0.24	0.40	2	3
US 59	South	Hillcroft	Exti to Bissonet St.	5-6	5.19	60	75875	0.17	0.51	1	3
US 59	North	Hillcroft	Exit to Chimney Rock Rd.	5-6	2.62	60	87250	0.19	0.31	1	3
US 59	North	IH 610	Exit to Kirby Dr.	5-6	2.45	60	79500	0.28	0.38	3	3
US 59	North	IH10	Exit to Cavalvade	5-6	3.01	55	46000	0.19	0.06	1	1
IH 10	West	IH 610	Exit to McCarty Dr.	5-6	1.60	60	41250	0.26	0.24	3	2
IH 10	West	IH 45	Exit to Washington Ave.	5-6	5.03	60	52750	0.17	0.14	1	2
Route 2											
IH 10	East	IH 610	IH 45	5-6	4.73	60	52750	0.21	0.14	1	2
IH 10	East	ALT 90	Exit to Gellhorn Dr.	5-6	1.65	60	41250	0.24	0.18	2	2
US 59	North	IH 610	Exit to Little York Rd.	5-6	4.26	65	51417	0.21	0.15	1	2
US 59	South	Entrance from Little York Rd.	Exit to Crosstimbers Rd.	5-6	4.36	65	51417	0.23	0.09	2	1
US 59	South	IH 610	IH 10	5-6	2.98	60	46000	0.20	0.10	1	1
IH 610	West	TX 288	Exit to N. Braeswood Blvd.	5-6	4.36	60	48667	0.22	0.29	2	3

4.3 Test Drivers

The test drivers were selected based on the following criteria:

Familiarity. The driver should ideally be unfamiliar with the test sections or at least not be a frequent commuter on the selected freeway test sections.

Age. Drivers between twenty-five and fifty-five years old were selected, as this research does not target investigation of special road user populations: younger (less than twenty-one years old) and older (more than sixty).

Driving experience. Previous studies of driver performance as well as accident statistics allow the assumption that there are no significant differences in driving behavior between drivers of the selected age group, regardless of driving experience. Considering the fact that in the United States the majority of people start driving at the age of eighteen, people of ages in the above-mentioned group already have extensive driving experience.

Gender. Both male and female drivers participated in the experiments without further separation of the obtained data by driver gender.

Test drivers were selected from the TxDOT employees who permanently live and work out of the cities designated for experiments. Eight drivers in each city (in total 20 male and 4 female) with ages varying from 23 to 55 years participated in the experiments.

Each driver was directed to drive to some destination point on the given route, which included test sections. After reaching the given destination, the driver was provided with the next target. Test drivers were informed that the purpose of the observations was general investigation of traffic conditions on urban freeways and were asked not to use a car radio or a cell phone. They had no other instructions and did not know about the study objectives and locations of the investigated sections. Test drives were made on the same vehicle (Ford Freestar minivan) and in similar weather conditions during the summer of 2005.

To avoid the influence of differences in driver psycho-physiological states not related to the driving task, basic or pre-test electrocardiograms were recorded under non-driving conditions before each test drive. For further analysis, relative characteristics were used, including driver pulse rate at the investigated conditions expressed as a percentage of the basic value.

To determine the relationship between EOG amplitude (recorded in microvolts) and eye movement angle, special calibration was performed with each driver before the test. The subject was asked to look at fixed marker points with known distances from the eyes that permitted determining microvolt to angle conversion coefficients. The calibration test was performed with the poster placed at a distance of 1 m from driver eyes and with markers on it corresponding to 15 degrees of eye movements. To eliminate potential measurement errors possible on a short distance with the subject's head not fixed, the test was duplicated with greater distance to the fixed targets. Figures 4.6, 4.7, and 4.8 show the positions of EOG electrodes on the subject's face, and the eye movement calibration procedure for both above-mentioned cases.

Figure 4.6 The Position of EOG Electrodes on Driver's Face

Figure 4.7 Eye Movement Angular Calibration for 15 Degree Marks

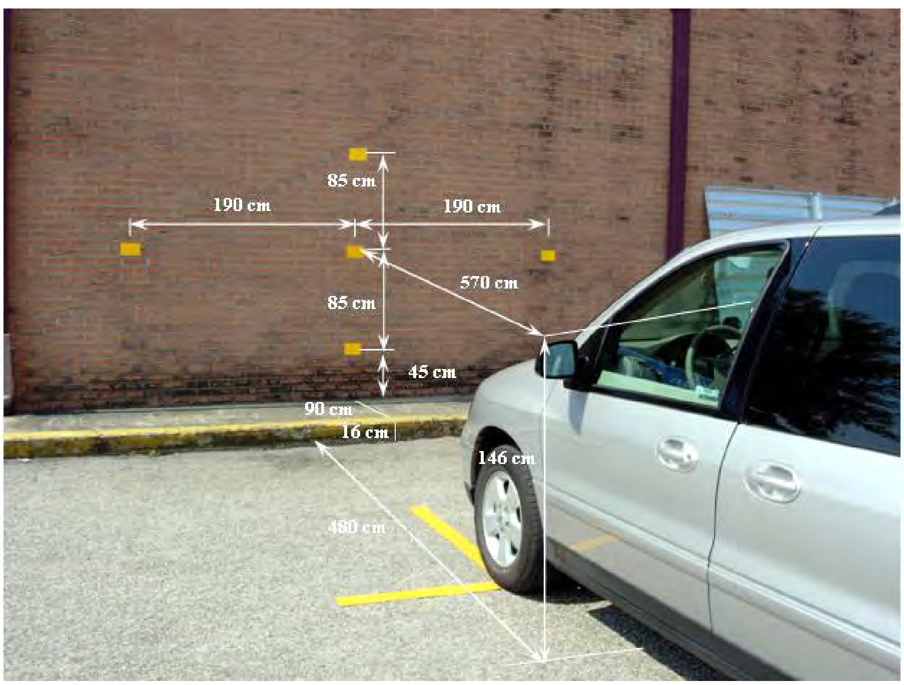


Figure 4.8 Eye Movement Angular Calibration for Distant Marks

4.4 Summary

This chapter has provided a description of the equipment and procedures employed in the experimental driving program. The next chapter provides information derived from the experimental program.

5. Driver Responses to Information Load Levels

The objective of the conducted study was to evaluate driver information load levels, identify abnormal situations, and conceive a foundation for development of engineering countermeasures for driver information load correction. Real driving experiments were selected as a preferred investigation approach.

Test driving on the selected urban freeways representing typical combinations of information load were conducted. The experimental vehicle was equipped with special portable devices allowing continuous scanning of vehicle systems as well as driver psycho-physiological responses (see Chapter 4.1).

Field experiments were conducted in three major metropolitan areas in Texas. Test sections selected in San Antonio represent typical combinations of informational sources on freeways with two traffic lanes in one direction, in Dallas for freeways with three and four lanes, and in Houston test sections were selected from sections with five and six traffic lanes. The detailed information regarding test sections is provided in Chapter 4.2.

In total, twenty-four drivers (eight in each city) participated as test drivers. Each driver was asked to drive to some destination via the same route that included the selected combinations of information load. Route selection criteria are described in Chapter 4.2 and route maps for each city are shown in Figures 4.3, 4.4, and 4.5. Test drivers were informed that the purpose of the observations was general investigation of traffic conditions on urban freeways and were asked not to use the car radio or cell phone. They had no other instructions and did not know about the study objectives and locations of the investigated sections. Test drives were made on the same vehicle (Ford Freestar minivan) and in similar weather conditions during the summer of 2005. The experiments were conducted at different traffic volumes representing conditions ranging from free flow to condensed-but-not-congested flow.

For estimating driver external responses, that is, actions which the driver performs during the actual situation, speed-time histories were analyzed. Internal or psycho-physiological responses reflecting driver mental workload and involving both a subjective emotional reaction and specific psycho-physiological changes due to the driving environment were estimated based on the driver's electrocardiogram.

For comparative analysis, the obtained data were classified based on traffic conditions during the test drive. Initial observations showed that at the same hourly traffic volume on any freeway section, traffic conditions during different tests varied between free flow conditions and driving within a condensed platoon. Therefore, each data set was reviewed to identify the existing traffic situation and based on the predominant conditions, was classified onto levels A, B, or C representing low, medium, or high vehicle interaction, respectively. This criterion was named Vehicle Interaction Level (VIL) and its characteristics are represented as follows:

VIL-A: During approximately 75 percent of the travel time, no vehicles are in close proximity, headways between vehicles mostly exceed four seconds, drivers can select speed, travel path, and maneuver with little required consideration of other vehicles.

VIL-B: During approximately 50 percent of the travel time, the test vehicle is surrounded by other vehicles, predominant headways are two to three seconds, moderate maneuver difficulties, actions of other vehicles may require test driver corrective actions, occasional vehicle condensation.

VIL-C: More than 50 percent of the travel time is spent driving in dense platoons, all traffic lanes are uniformly occupied, headways two seconds or less, vehicle maneuvering difficult and actions of other vehicles require immediate test driver correction responses.

For the analysis, the following characteristics were selected: mean speed, frequency and intensity of speed reductions, heart rate, and frequency of eye fixations in different areas of the driver's visual field.

For quantitative estimation of driver behavioral responses, a speed reduction technique was implemented hypothesizing that reduction of speed over 10 km/h indicates some insufficiencies in traffic conditions (Ref 16).

For quantitative estimation of driver psycho-physiological responses the heart rate analysis determined that increases of heart rate over 115 percent compared to the pre-test level, indicated increased emotional tension (Refs 3, 4).

The statistical significance of the differences between obtained data was tested using non-parametric Kruskal-Wallis statistic.

Using the developed methodology for quantitative description of freeway informational dimensions described in Chapter 1, evaluation of information load classes 1 through 27 was performed.

5.1 Freeways with Two Traffic Lanes

As indicated in Table 1.1, urban freeways with two traffic lanes in one direction are characterized by information load classes 1 through 9. Tables 5.1 and 5.2 and Figures 5.1, 5.2, and 5.3 represent the data characterizing driver behavioral responses on freeway sections with these information load classes.

Table 5.1 Average Statistical Characteristics of Speed Distribution for Information Load Classes 1 through 9

Information Load Class	Vehicle Interaction Level					
	A	B	C	A	B	C
	Mean Speed, km/h			Speed Standard Deviation, km/h		
1	101.88	99.00	102.43	5.79	5.79	4.01
2	101.20	96.62		5.54	5.80	
3	99.43	98.10		7.19	7.12	
4	102.80	101.47	99.60	3.77	5.14	4.94
5	97.73	100.33	97.97	6.77	6.91	8.43
6	100.37	95.50	95.18	5.07	16.58	5.56
7	100.28	100.43	100.96	6.95	5.19	4.32
8	90.77	84.51	86.70	5.99	5.99	7.07
9	94.76	95.03		6.59	7.02	

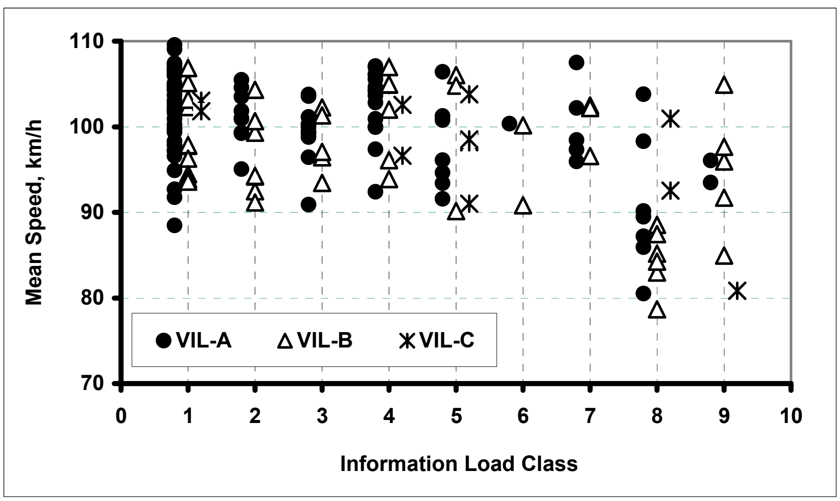


Figure 5.1 Average Test Driver Mean Speed Versus Information Load Classes (1–9) at Different Vehicle Interaction Levels

a)

b)

c)

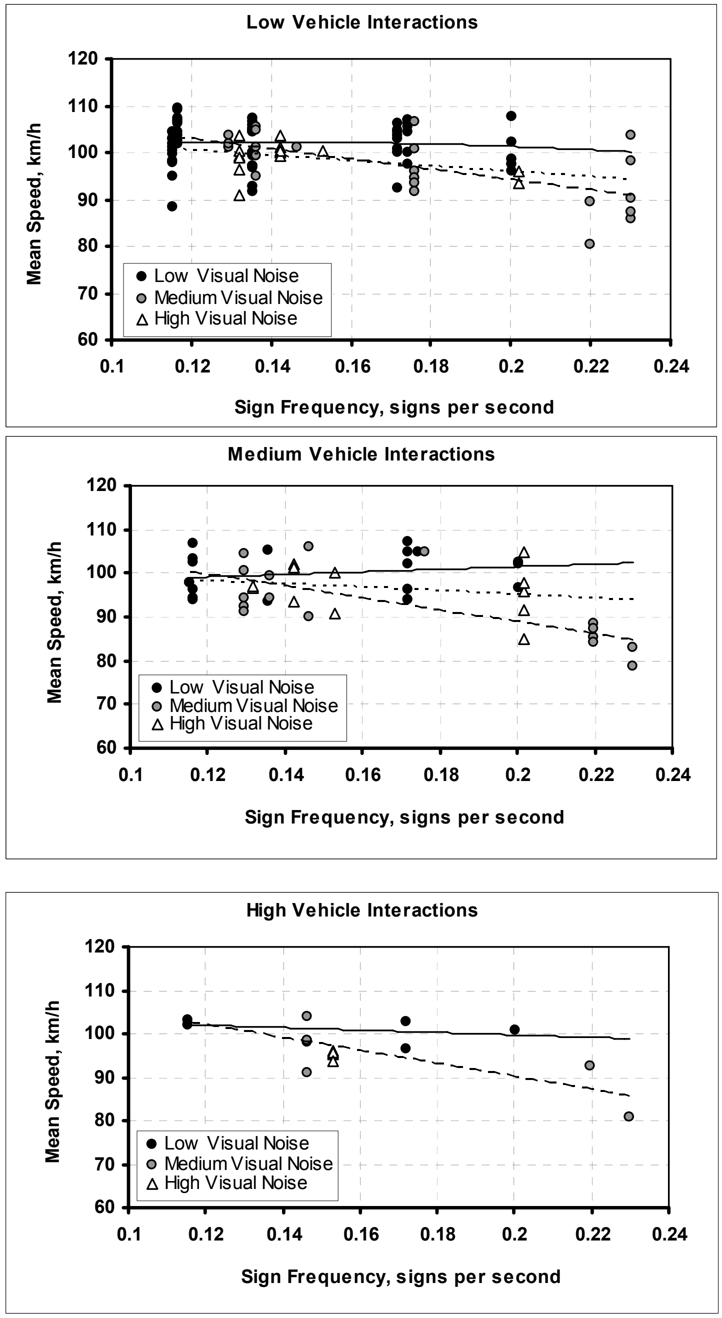


Figure 5.2 Average Test Driver Speed at Different Road Sign and Visual Noise Object Frequencies for Information Load Classes 1 through 9: a) Low, b) Medium, and c) High Vehicle Interaction Levels

Table 5.2 Average Frequency of Braking over 10 km/h for Information Load Classes 1 through 9

Information Load Class	Vehicle Interaction Level A	B	C
	Frequency of Braking over 10 km/h, % of total		
1	3.37	2.85	1.38
2	0.64	1.02	
3	4.02	4.12	
4	1.49	0.00	2.00
5	3.79	1.11	6.93
6	5.07	5.83	3.29
7	7.48	4.44	4.32
8	0.81	2.08	3.90
9	9.17	4.03	

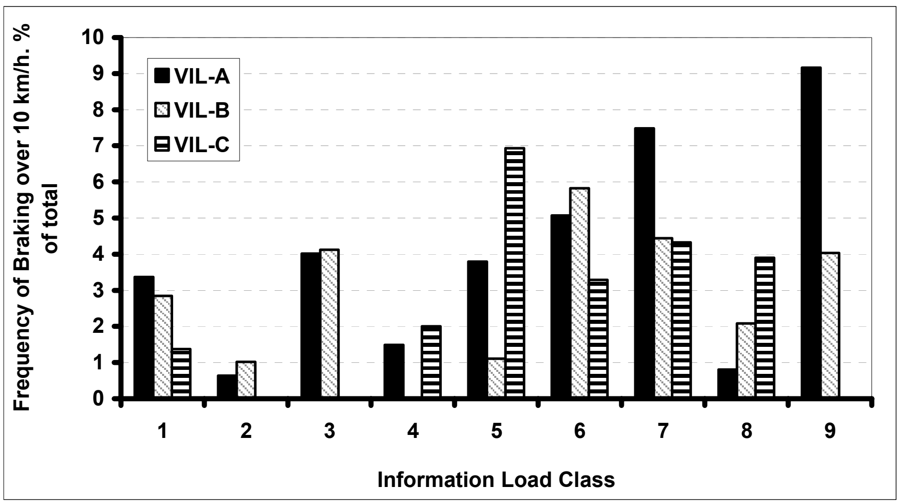


Figure 5.3 Average Frequency of Braking over 10 km/h for Information Load Classes 1 through 9 and Different Vehicle Interaction Levels

The statistical analysis indicated that information load classes 8 and 9 significantly differ from all other classes and are characterized by average speed reductions of up to 20 km/h (12.5 mph) (Fig. 5.1). The detailed data analysis represented in Figure 5.2 shows that the effect of sign frequency on average speed varies depending on intensity of visual noise objects. So, at low visual noise, speed reduction was not observed with higher sign frequency and at all levels of vehicle interaction, while on freeway sections with more frequent visual noise objects, average speed drops with highest impact at levels of heavier vehicle interaction.

It was hypothesized that because greater information load requires longer processing time as well as possible increased probability of missing stimuli or their delayed identification, driver responses in such situations may be more intensive. Analysis of frequency of braking over 10 km/h indicated that information load classes 1 through 4 overall are characterized by the lowest values of such braking frequency, while classes 5 through 9 significantly differ and showed the highest values at least at one level of vehicle interaction. Figure 5.3 indicates the highest impact comes from traffic conditions with low vehicle interaction and this may be explained by continuous high speed in such conditions.

Some impact of visual noise on intensive speed reduction was observed as well. For example, at similar sign frequency, on freeways with low visual noise intensity (class 1) drivers reduced speed over 10 km/h during approximately 3 percent of all braking actions, while 10 km/h reductions represented roughly 4 percent at high visual noise intensity (class 3). For classes 7 and 9, from the information load representing high sign frequency, this difference was also 1 percent. The greatest differences were observed for the middle range sign frequency group (classes 4–6) and represented roughly 5 percent of all braking actions.

Combining the findings among the nine investigated information load classes, classes 1 through 4 seem to characterize traffic conditions that cause minimal driver behavioral responses, while conditions described by classes 5 through 9 more often causes heightened driver activity.

Table 5.3 and Figures 5.4, 5.5, and 5.6 represent data of driver heart activity characteristics at different information loads.

Table 5.3 Average Heart Activity for Information Load Classes 1 through 9

Information Load Class	Vehicle Interaction Level					
	A	B	C	A	B	C
	Heart Rate Standard Deviation, bpm			Heart Rate Greater than 115% of Basic, % of total time		
1	4.41	3.96	5.55	8.78	7.00	6.34
2	3.73	4.36		4.58	11.02	
3	4.42	3.23		12.81	13.63	
4	4.12	3.27	4.56	4.14	2.31	3.43
5	4.70	3.29	3.59	3.07	0.75	10.01
6	5.92	3.17	4.59		0.62	23.41
7	3.98	3.93	5.10	0.99	3.99	
8	3.53	3.36	6.08	12.90	19.96	27.80
9	7.33	3.53		4.95	1.98	

The data indicate that information load classes 6 and higher are characterized both by increased heart rate variation and times when drivers experienced increased emotional tension at least during high levels of vehicle interaction.

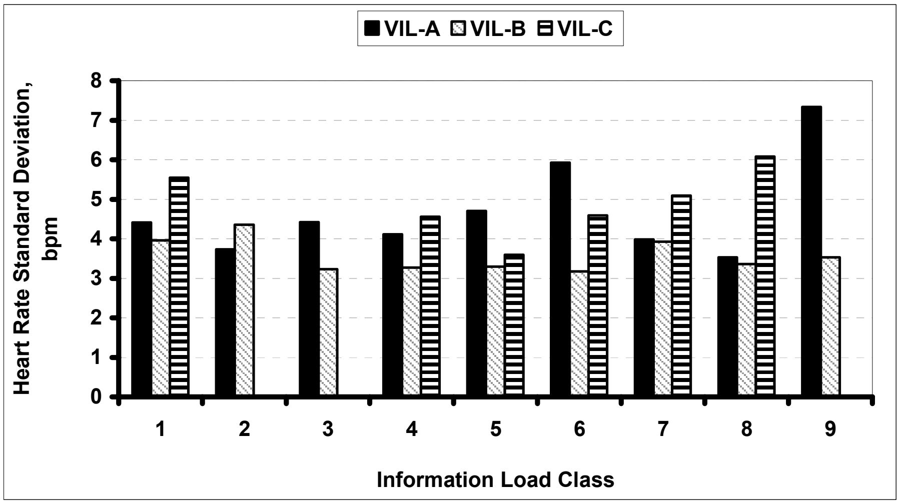


Figure 5.4 Average Heart Rate Variation for Information Load Classes 1 through 9 and Different Vehicle Interaction Levels

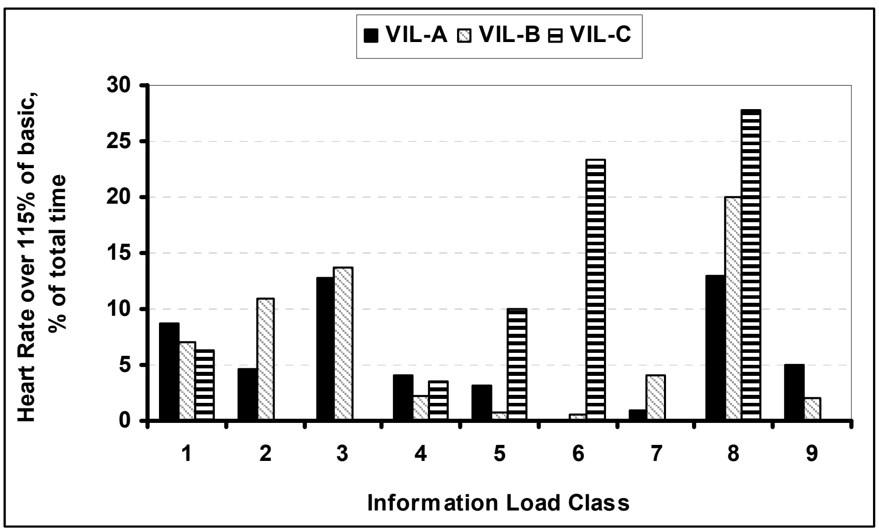
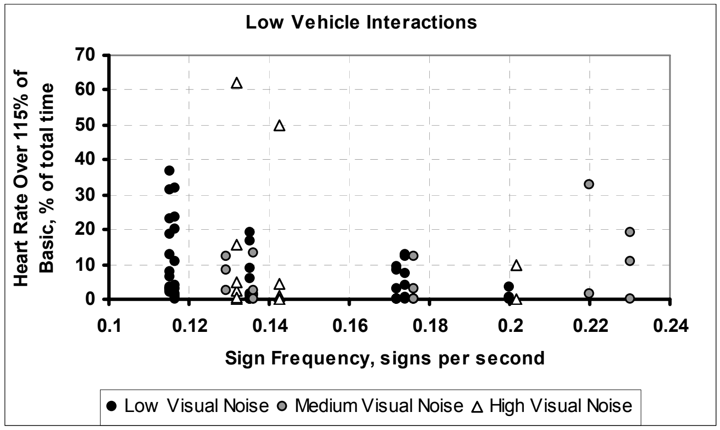
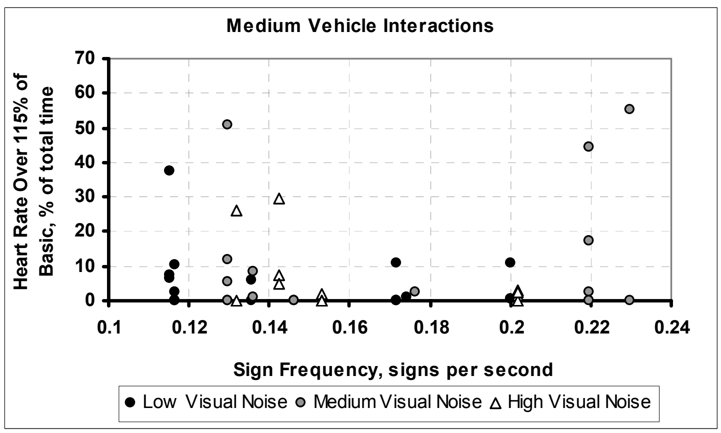


Figure 5.5 Average Frequency of Heart Rate Greater Than 115% of Basic for Information Load Classes 1 through 9 and Different Vehicle Interaction Levels

a)



b)



c)

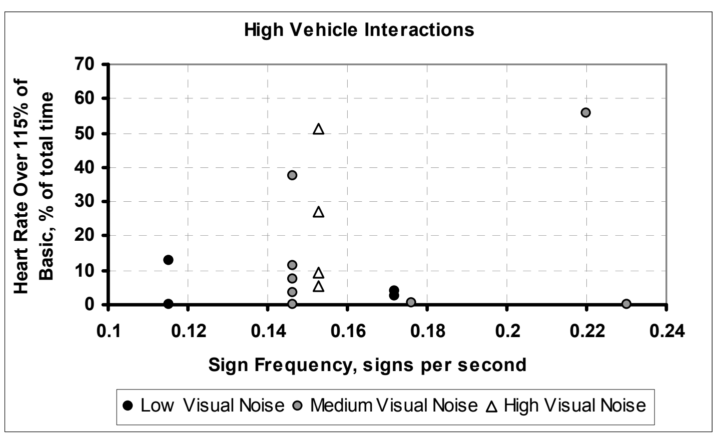


Figure 5.6 Frequencies of Increased Heart Rate at Different Road Sign and Visual Noise Object Frequencies for Information Load Classes 1 through 9: a) Low, b) Medium, and c) High Vehicle Interaction Levels

Some increased responses were also observed for information classes 1, 2, and 3. Considering that such classes caused the smallest behavioral responses, it is reasonable to suggest that high speed and less driver awareness lead to this phenomenon.

Because the data indicated a U-shape of the relationship between internal driver responses and information load classes, a more detailed identification of the conditions that correspond to the minimal values is necessary.

Figure 5.6 shows frequency of increased heart rate on freeways with different sign frequency and visual noise intensity for different levels of vehicle interaction. Increased driver emotional tension was observed at sign frequencies less than 0.16 signs per second and greater than 0.20 signs per second. Thus, sign frequency 0.16 and 0.20 signs per seconds can be assumed as lower and upper threshold values of traffic conditions causing minimal driver responses.

During experiments the angular dimensions of driver eye movements and corresponding targets of driver attention were identified and are represented in Table 5.4.

Table 5.4 Angular Dimensions of Eye Movements and Areas of Driver Attention

Area	Eye Movement Angle, degree		Object of Driver Observation
	Horizontally	Vertically	
1	< -10	< -10	vehicle left mirror
2	> +10	< -10	vehicle right mirror
3	-10 < x < +10	< -10	vehicle instrument pannel
4	< -10	-10 < x < +10	observations of adjacent vehicle on the left side
5	> +10	-10 < x < +10	observations of adjacent vehicle on the righ side
6	any	> +10	other

Eye movements described with dimensions of areas 1, 2, and 3 were typically followed by head movement. Comparison of EOG data and video recording of the driver's head tended to confirm the indicated eye movement angles.

Eye movements in areas 4 and 5, in addition to the adjacent vehicles, were also caused by driver observation of objects not on the roadway (buildings, commercial billboards, etc.). In the majority of such cases, head movements followed the eyes. The implemented technique does not permit necessary corrections, so those situations were excluded from computer analysis. This assumption eliminated the potential impact of visual noise objects from the computer analysis. Therefore, areas 4 and 5 represent only eye activity regarding driver observations of adjacent vehicles. These areas were combined with areas 1 and 2, and the summary group was named the "Control Area." The control area reflects driver observation of the adjacent lanes and behind the vehicle. Area 6 represents driver irregular eye movements due to vehicle vibration caused by the pavement defects.

Table 5.5 and Figure 5.7 show results regarding distribution of driver eye movements among the above-mentioned areas.

Table 5.5 Average Frequency of Eye Movements to Visual Field Areas for Information Load Classes 1 through 9

Information Load Class	Vehicle Interaction Level											
	A	B	C	A	B	C	A	B	C	A	B	C
	Areas of Eye Fixations											
	Zone of Clear Vision			Control Area			Instrument Panel			Other		
	percent of total time											
1	62.72	55.76	51.70	21.48	17.65	18.07	5.42	7.69	14.53	10.38	9.82	15.70
2	62.01	56.67		23.08	26.46		5.22	7.67		9.70	9.21	
3	67.94	59.18		17.80	28.17		5.52	4.45		8.74	8.20	
4	63.19	62.42	68.06	19.54	18.24	22.42	6.70	6.43	2.52	10.57	12.90	7.00
5	61.38	66.29	68.18	20.58	18.75	17.54	7.86	8.31	3.92	10.18	6.66	10.36
6	60.98	52.40	67.64	18.44	25.90	20.00	9.45	8.22	2.90	11.13	13.49	9.46
7	63.01	66.04	62.59	15.56	21.56	18.15	12.16	0.87	7.45	9.27	11.53	11.81
8	67.92	75.43	47.55	10.69	13.67	12.29	0.77	2.44	34.98	3.96	8.45	5.18
9	76.95	70.06		18.11	18.11		1.01	3.29		3.92	8.54	

The data shows that with increased sign frequency drivers spend greater time visually searching in the zone of clear vision. This occurs at the expense of less attention to traffic in adjacent lanes and behind the vehicle as well as the vehicle instrument panel. Reduced attention to adjacent vehicles may cause inadequate estimation, a hypothesis supported by crash statistics described in Chapter 2.

Also, a high dispersion of driver eye fixations was observed on freeway sections with low signage. One could hypothesize that with lack of sufficient information from road signs, drivers are forced to search the surrounding environment for additional navigational information.

An interesting phenomenon was observed in that the relationship between the distribution of driver eye movements to the observed target areas and sign frequency was not dependent on the traffic intensity level. This could possibly result from the exclusion of visual noise from the analysis.

Figure 5.7 graphically presents the fractions of time spent by drivers visually observing the three target zones. The extensive driver concentration in zone of clear vision (advanced visual searching) at high sign frequency may be the cause of increased driver mental workload identified for such conditions during the heart activity analysis.

a)

b)

c)

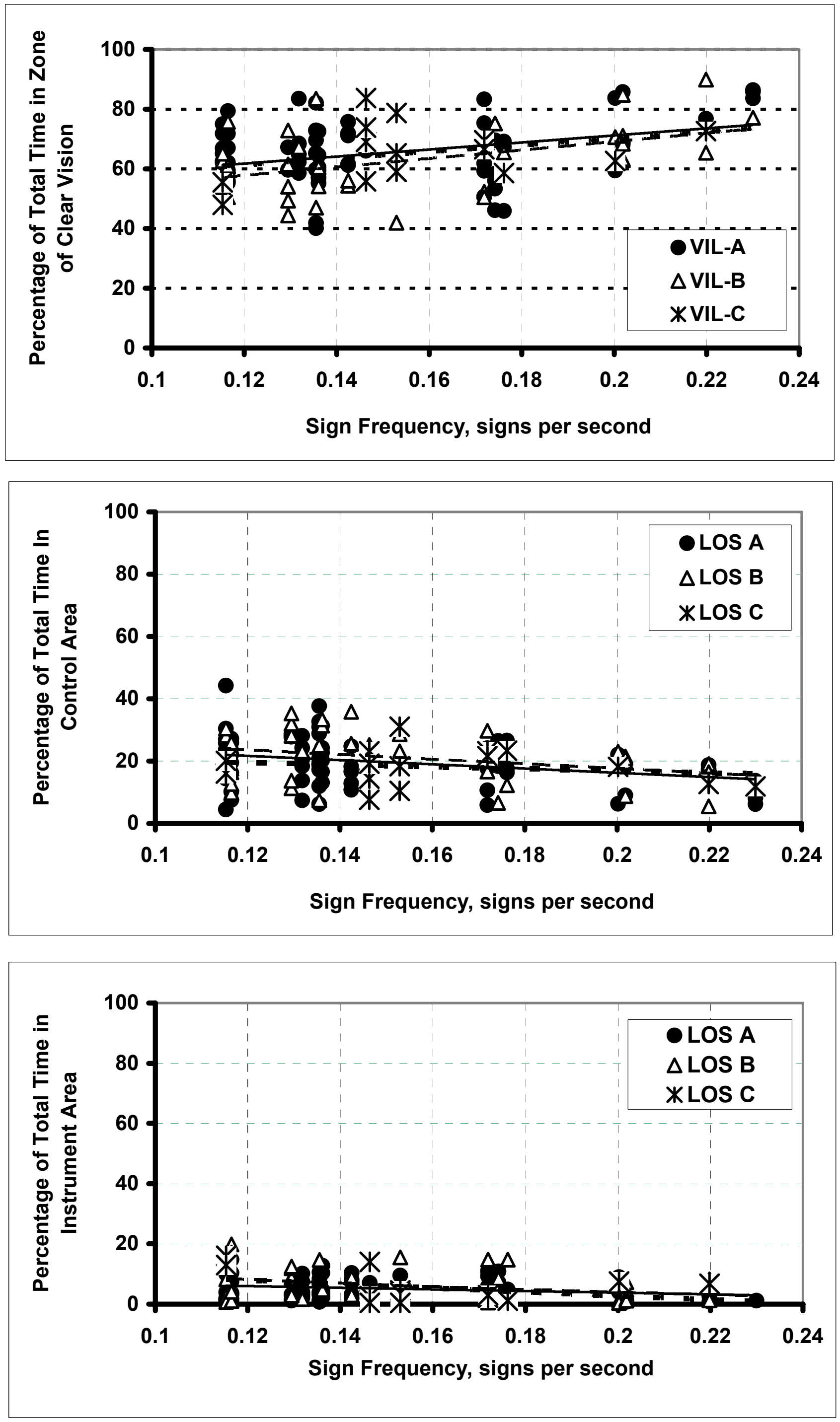


Figure 5.7 The Distribution of Driver Visual Searching While Experiencing Information Load Classes 1 through 9: a) Zone of Clear Vision, b) Control Area, and c) Instrument Panel

Considering findings of the analysis of all investigated external and internal driver responses, the following statements can be made:

On freeways with two traffic lanes in one direction, the optimal level of driver information load exists at sign frequencies between 0.16 and 0.20 signs per second with no significant dependence on visual noise intensity and level of vehicle interaction.

Intensive driver responses on freeway sections with sign frequency lower than 0.16 signs per second may indicate insufficient information, while sign frequency over 0.20 signs per second may lead to driver information overload. In turn, both of these cases increase the probability of stressful situations, especially when combined with extensive visual noise and high vehicle interaction levels.

5.2 Freeways with Three and Four Traffic Lanes

Information load classes 10 through 18 representing urban freeways with three and four lanes in one direction were tested, the results if which are described below. Tables 5.6 through 5.9 and Figures 5.8 through 5.14 show the characteristics of driver external and internal responses obtained for these freeways at different information loads.

As for two-lane freeways, the tendency of speed reductions with information load growth was observed (Fig 5.8) with the major impacts at information load classes 15 and higher and with increased levels of vehicle interactions. The significant effect of visual noise on the relationship between average speed and sign frequency was indicated only in medium vehicle interactions (Fig 5.9).

Frequency of braking over 10 km/h represented in Table 5.7 and Figure 5.10 indicated that sections described by information load classes 16, 17 and 18 are characterized by significantly more such braking activity especially at high levels of vehicle interaction.

Therefore, combining the obtained findings one might surmise that among the nine investigated information load classes, classes 10 through 15 characterized traffic conditions that cause minimal driver behavioral responses, while conditions described by classes 16, 17, and 18 cause heightened driver activity. With sign frequency greater than 0.22 signs per second, speed reduction exceeds 10 km/h (6.2 mph). This value thus might be a threshold for traffic condition changes.

Data of driver heart activity is represented in Table 5.8 and Figures 5.11 and 5.12. These presentations show a U-shaped relationship between driver internal reactions and information load with the minimal effect for the middle range information load classes (13, 14, and 15).

The greatest impact on driver emotional tension was observed at the lowest information load classes (10, 11, and 12) with the medium level of vehicle interactions. However, on sections described by the highest information load classes (16, 17, and 18) increased internal reactions were indicated at high levels of vehicle interaction, but these increases were much less than for the lowest classes.

Analysis of increased emotional tension, characterized by heart rate over 115 percent of the basic, versus road sign intensity, showed minimal driver reactions at sign frequencies between 0.18 and 0.22 signs per second for all levels of vehicle interaction (Fig 5.13). Also, the data show some increases in driver heart activity on sections with high visual noise levels.

Analysis of the intensity of driver visual searching showed the same results as for two-lane freeways, but the threshold value of sign frequency was identified around 0.20 signs per second (Table 5.9 and Figure 5.14).

Summarizing all of these findings, one might suggest that the optimal information load and the minimal probability of stressful situations on freeways with three and four traffic lanes in one direction is reached with sign frequencies greater than 0.18 signs per second and less than 0.22 signs per second, considering all levels of vehicle interaction.

Table 5.6 Average Statistical Characteristics of Speed Distributions for Information Load Classes 10 through 18

Information Load Class	Vehicle Interaction Level					
	A	B	C	A	B	C
	Mean Speed, km/h			Speed Standard Deviation, km/h		
10	100.21	97.00	100.41	5.47	5.97	4.13
11	100.48	95.24	95.27	4.19	6.52	5.93
12		97.94	91.89		7.26	6.16
13	100.28	95.57		6.30	5.35	
14	96.82	96.14	89.07	5.02	6.15	6.64
15	92.97	90.74	88.41	3.82	6.49	6.42
16	99.94	95.07	79.46	4.83	5.60	9.67
17	97.18	93.22	89.22	5.27	6.37	8.62
18		88.41	89.07		6.23	6.83

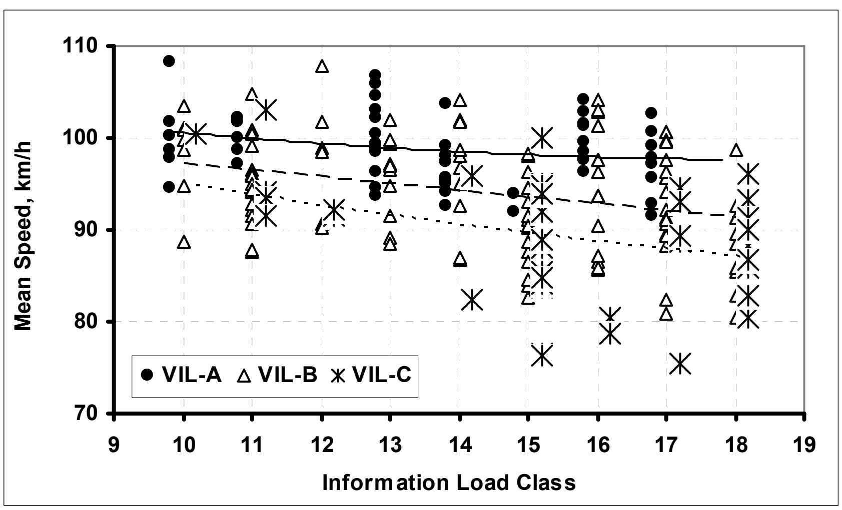
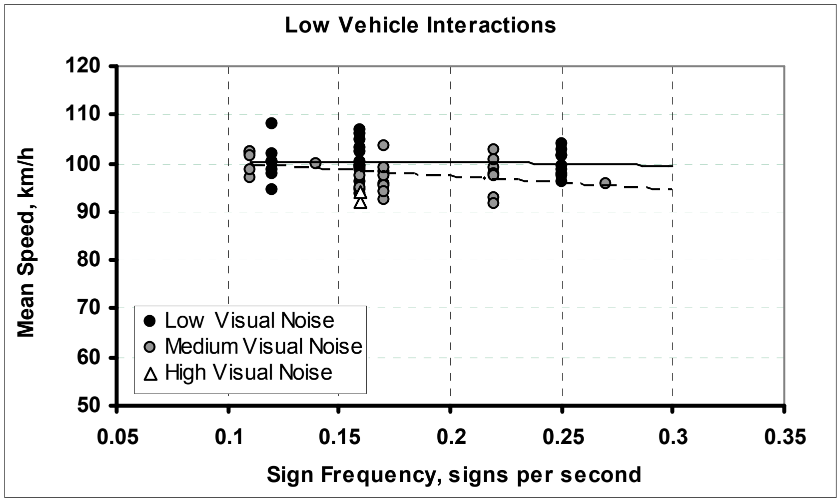
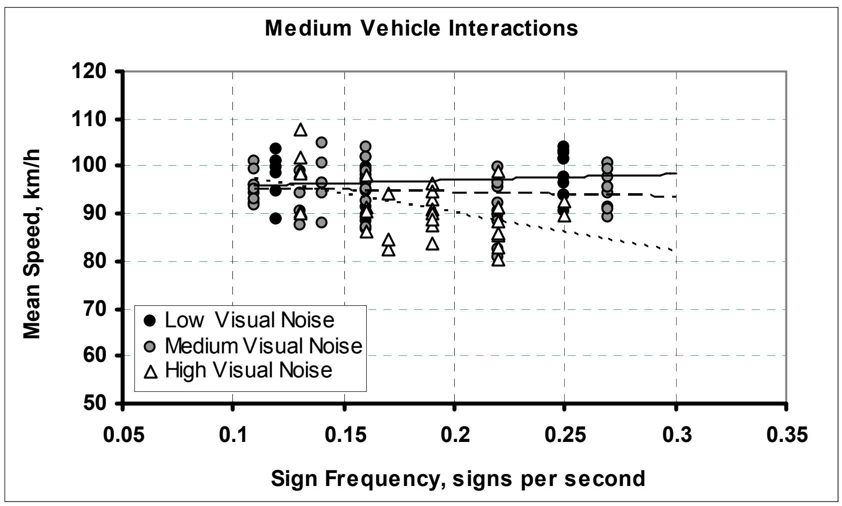


Figure 5.8 Mean Test Driver Speed versus Information Load Classes (10–18) at Different Vehicle Interaction Levels

a)



b)



c)

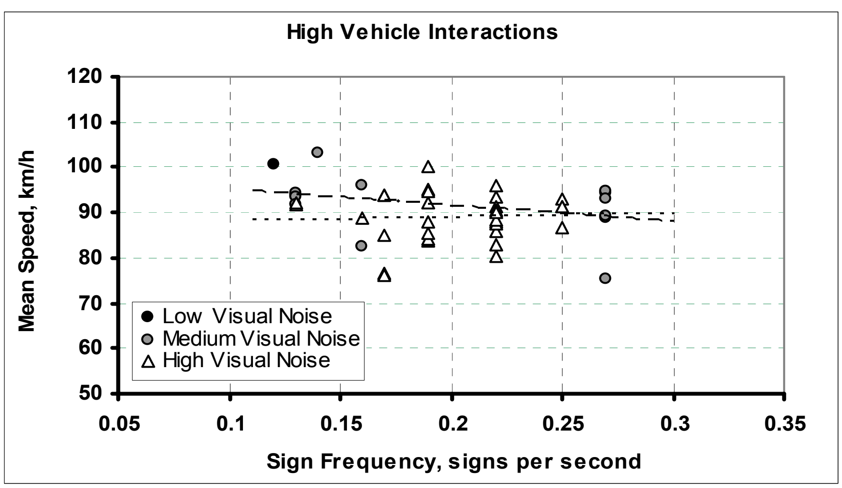


Figure 5.9 Mean Test Driver Speed at Different Road Sign and Visual Noise Frequencies for Information Load Classes 10 through 18: a) Low, b) Medium, and c) High Vehicle Interaction Levels

Table 5.7 Average Frequency of Braking over 10 km/h for Information Load Classes 10 through 18

Information Load Class	Vehicle Interaction Level		
	A	B	C
	Frequency of Braking over 10 km/h, % of total		
10	2.59	1.73	0.00
11	0.45	2.26	1.95
12		4.25	7.81
13	3.52	1.81	
14	3.43	3.87	7.14
15	0.00	2.97	4.80
16	5.43	2.68	19.89
17	5.67	8.85	15.47
18		5.33	8.47

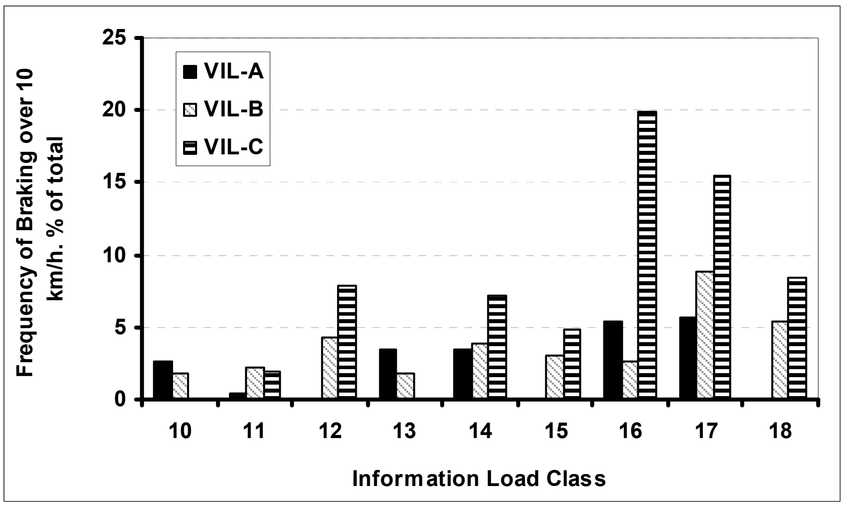


Figure 5.10 Average Frequency of Braking over 10 km/h for Information Load Classes 10 through 18 and Different Vehicle Interaction Levels

Table 5.8 Average Test Driver Heart Activity Statistics for Information Load Classes 10 through 18

Information Load Class	Vehicle Interaction Level					
	A	B	C	A	B	C
	Heart Rate Standard Deviation, bpm			Heart Rate Greater then 115% of Basic, % of total time		
10	3.82	4.98	2.54	0.83	6.82	0.00
11	3.48	3.96	4.34	0.13	15.83	0.11
12		3.26	3.66		38.93	0.00
13	3.74	3.85		0.10	6.15	
14	3.74	4.77	4.95	2.38	1.58	0.00
15	5.68	4.17	3.82	7.14	0.60	1.55
16	5.43	4.45	2.75	2.52	1.16	11.90
17	4.21	4.39	3.36	0.41	2.11	10.48
18		4.68	4.36		3.21	3.16

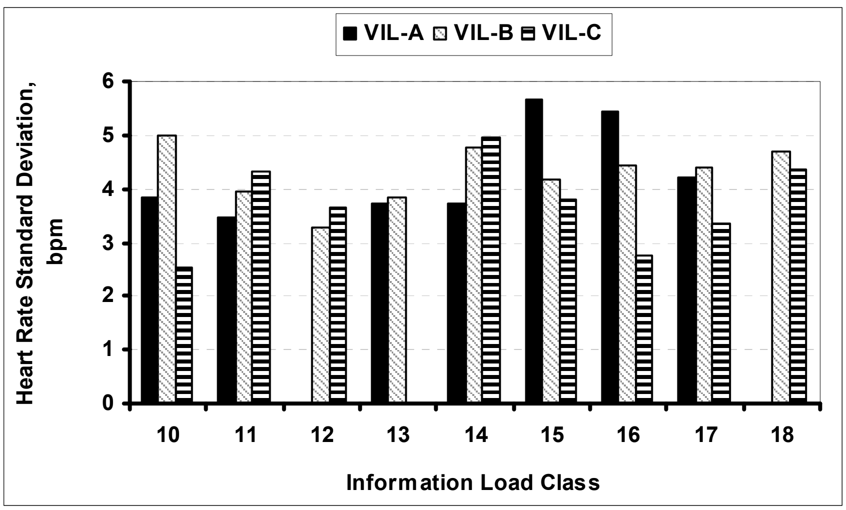


Figure 5.11 Average Test Driver Heart Rate Variation for Information Load Classes 10 through 18 and Different Vehicle Interaction Levels

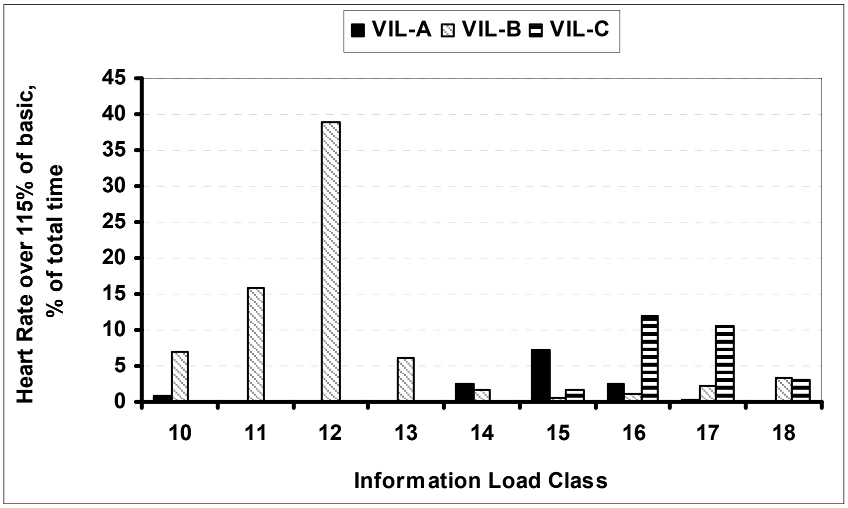


Figure 5.12 Frequency of Heart Rate over 115% of Basic for Information Load Classes 10 through 18 and Different Vehicle Interaction Levels

a)

b)

c)

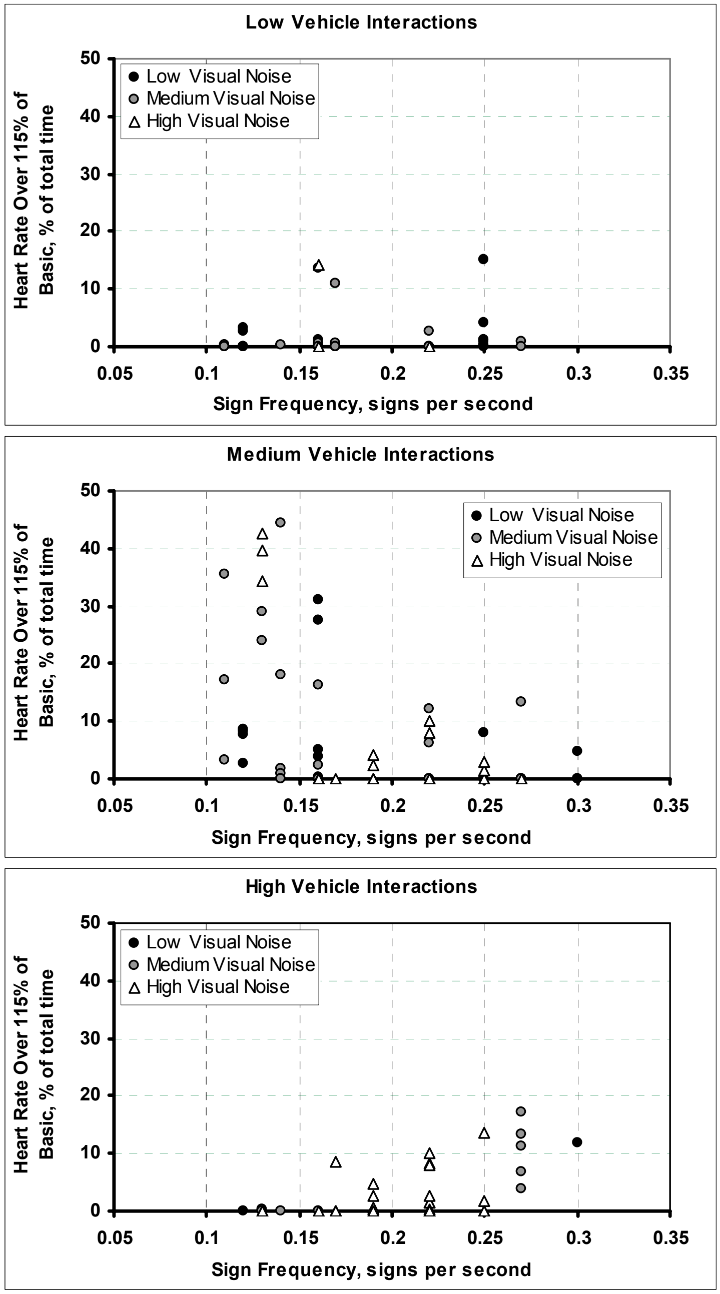
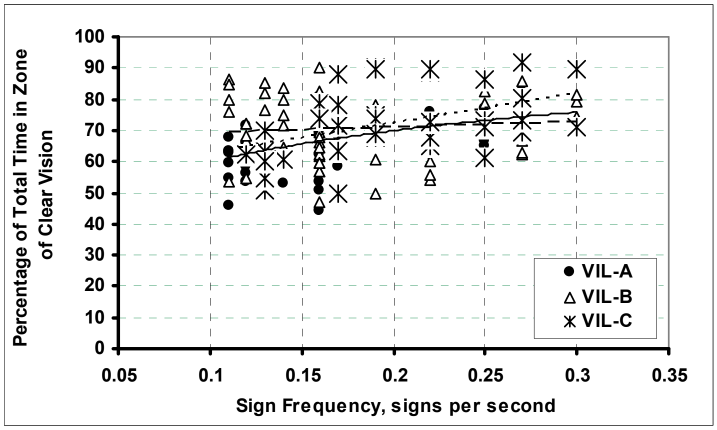


Figure 5.13 Frequency of Increased Heart Rate at Different Road Sign and Visual Noise Intensities, for Information Load Classes 10 through 18: a) Low, b) Medium, and c) High Vehicle Interaction Levels

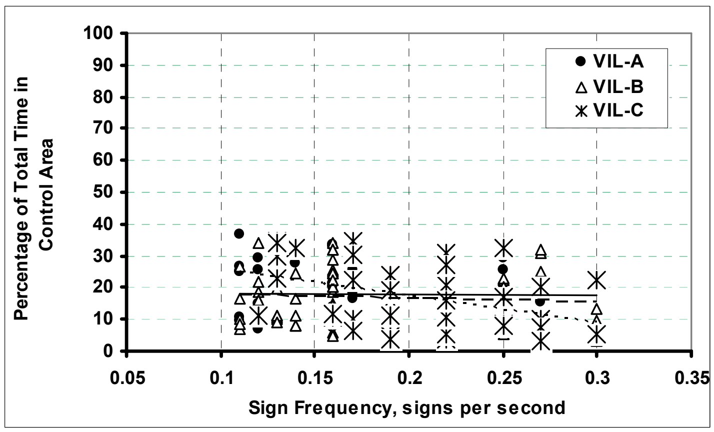
Table 5.9 Average Frequencies of Eye Movements to Visual Field Areas for Information Load Classes 10 through 18

Information Load Class	Vehicle Interaction Level											
	A	B	C	A	B	C	A	B	C	A	B	C
	Areas of Eye Fixations											
	Zone of Clear Vision			Control Area			Instruments Panel			Other		
	percent of total time											
10	61.38	66.85	62.27	16.00	20.09	11.16	4.16	4.71	11.97	9.33	8.36	14.59
11	58.20	74.25	57.36	22.98	14.80	31.14	3.85	2.49	3.20	9.02	8.13	8.30
12		69.90	65.05		17.03	28.38		3.38	0.89		7.63	5.67
13	67.19	71.77		15.92	16.90		3.30	3.90		8.07	9.14	
14	73.36	68.61	73.65	15.44	21.03	11.80	3.50	3.07		6.87	7.29	14.55
15	76.62	68.80	74.49	20.18	13.38	16.42	0.11	3.49	2.72	3.09	13.70	6.36
16	67.14	77.56	80.33	20.63	11.59	13.78	4.67	5.09	0.36	7.80	8.72	5.54
17	74.75	68.02	77.49	14.63	19.02	9.78	3.18	3.29	2.38	7.44	9.13	7.07
18	64.84	66.88	74.59	30.71	19.83	15.57	0.75	4.54	2.86	3.70	6.10	6.47

a)



b)



c)

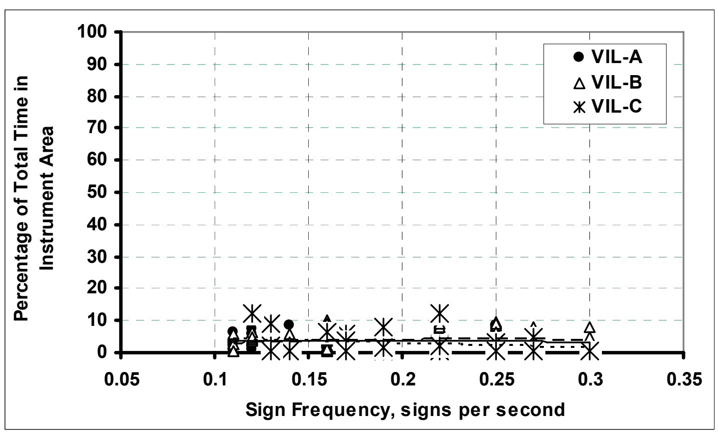


Figure 5.14 Distribution of Driver Visual Searching While Experiencing Information Load Classes 10 through 18: a) Zone of Clear Vision, b) Control Area, and c) Instrument Panel

5.3 Freeways with Five and Six Traffic Lanes

Information load classes 19 through 27 representing urban freeways with five and six lanes in one direction were tested using the same types of test driving techniques used for the other two freeway types. The results are described below.

Tables 5.10 through 5.13 and Figures 5.14 through 5.21 show the characteristics of driver external and internal responses obtained for this type of freeway at different information loads. Data represented in Table 5.10 and Figures 5.15 and 5.16 indicated that there are no significant differences in average speed on sections characterized by the above-mentioned information load classes at all investigated sign frequency and visual noise intensity.

At the same time some tendency for extensive braking reduction on sections of higher information load classes can be noted (Table 5.11 and Figure 5.17). A similar tendency can be seen in Table 5.12 and Figures 5.18–5.20 which show data for driver heart activity. On freeway sections characterized by information load classes 25, 26, and 27 (i.e., those with the highest loads), the frequency of driver increased emotional tension was not observed at any level of vehicle interactions (Fig 5.19). Comparison of driver increased heart rate versus sign frequency shows that 0.25 signs per second can be assumed as a threshold value (Fig. 5.20).

Analysis of the intensity of driver visual searching in the previously described target areas does not indicate any significant relationship between this characteristic and sign frequency (Table 5.13 and Figure 5.21). The limited samples drawn from this freeway group reduce the validity of the previously noted findings, but together with the crash statistics results they seem to indicate that five- and six-lane freeways should have signing frequencies greater than 0.25 signs per second to ensure the best driver performance.

Table 5.10 Characteristics of Speed Distribution for Information Load Classes 19 through 27

Information Load Class	Vehicle Interaction Level					
	A	B	C	A	B	C
	Mean Speed, km/h			Speed Standard Deviation, km/h		
19	96.68	99.49	105.74	4.87	4.92	7.29
20	98.49	95.99	94.09	6.98	6.47	5.84
21	88.89	90.05	91.19	3.89	5.10	4.67
22	99.19	99.66	92.27	4.57	5.64	7.63
23	97.09	96.64	87.52	4.93	4.10	5.67
24		93.31	94.12		5.02	6.31
25						
26	90.24			2.69		
27	90.50	92.82	99.01	5.78	5.39	5.36

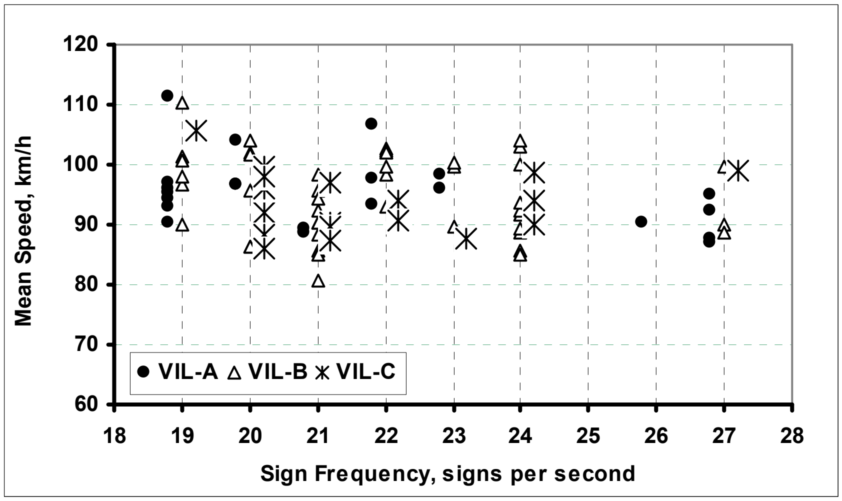
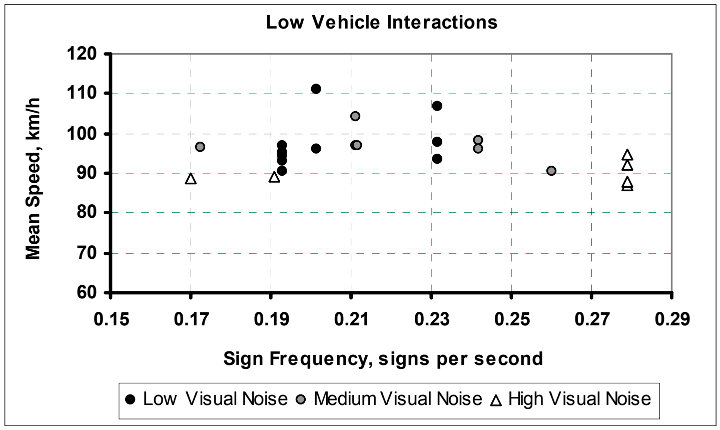
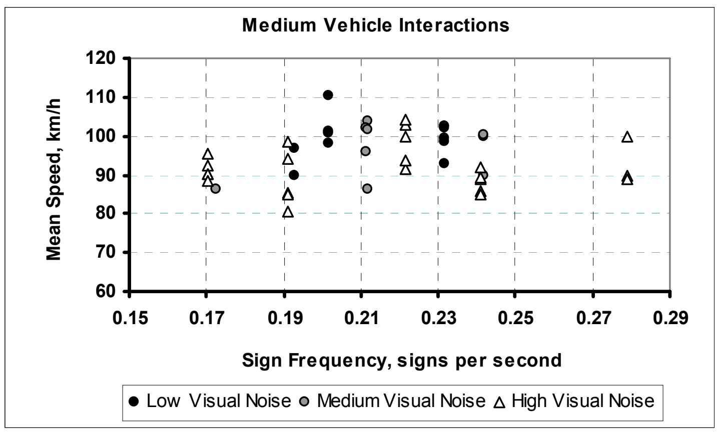


Figure 5.15 Test Driver Mean Speed versus Information Load Classes (19-27) at Different Vehicle Interaction Levels

a)



b)



c)

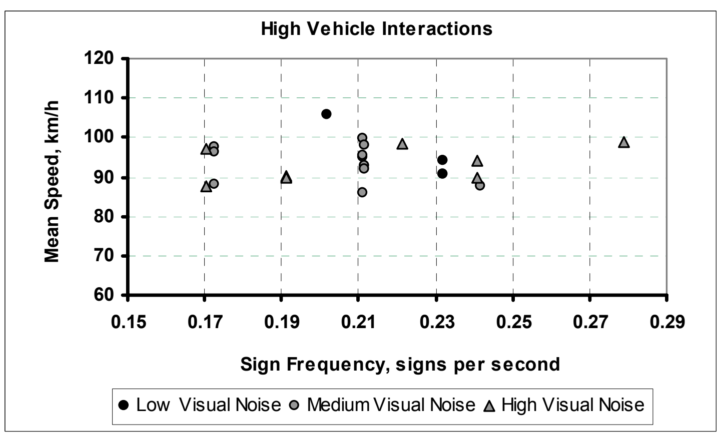


Figure 5.16 Test Driver Mean Speed at Different Road Sign and Visual Noise Object Frequencies for Information Load Classes 19 through 27: a) Low, b) Medium, and c) High Vehicle Interaction Levels

Table 5.11 Average Frequency of Braking over 10 km/h for Information Load Classes 19 through 27

Information Load Class	Vehicle Interaction Level A	Vehicle Interaction Level B	Vehicle Interaction Level C
	Frequency of Braking over 10 km/h, % of total		
19	2.86	10.67	11.11
20	3.46	3.37	7.25
21	6.67	2.86	9.96
22	6.25	3.14	7.14
23	0.00	0.00	
24		5.38	6.88
25			
26	0.00	0.00	
27	0.00	0.00	0.00

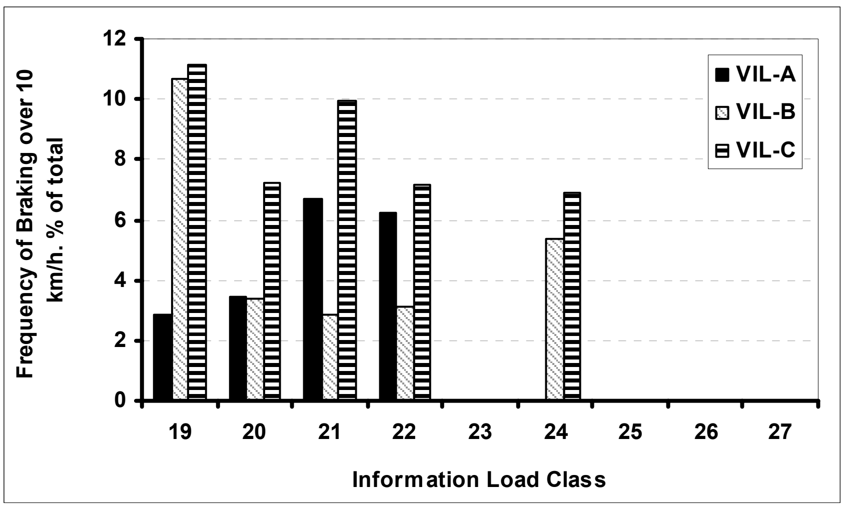


Figure 5.17 Average Frequency of Braking over 10 km/h for Information Load Classes 19 through 27 and Different Vehicle Interaction Levels

Table 5.12 Average Heart Activity Statistics for Information Load Classes 19 through 27

Information Load Class	Vehicle Interaction Level					
	A	B	C	A	B	C
	Heart Rate Standard Deviation, bpm			Heart Rate Greater then 115% of Basic, % of total time		
19	2.77	3.74	4.44	0.95	0.88	0.00
20	3.21	4.94	4.55	0.82	1.76	0.94
21	3.58	2.95	3.63	0.48	0.89	2.07
22	2.06	3.10	2.54	0.00	1.57	0.00
23	2.22	2.85	3.24	0.00	0.00	
24		3.23	4.17		0.93	1.06
25						
26	1.70	3.47	2.77	0.00	0.00	0.00
27	2.77	3.11	3.31	0.00	0.00	0.00

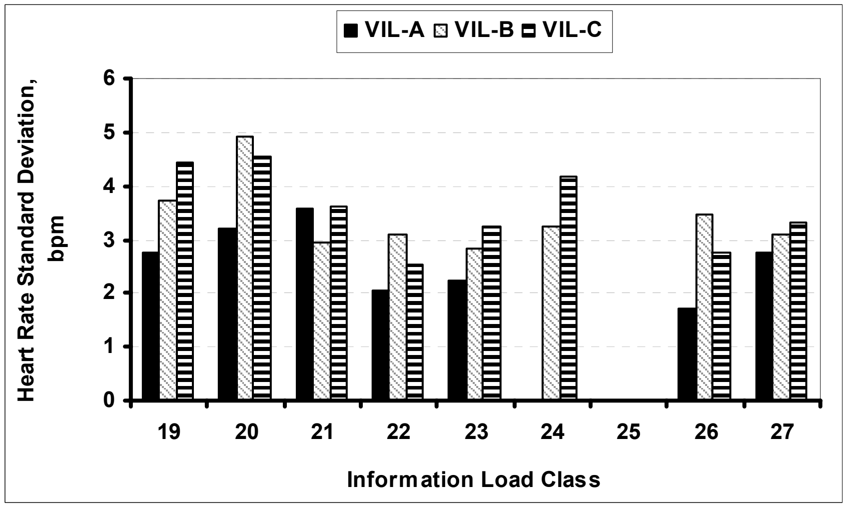


Figure 5.18 Average Heart Rate Variation for Information Load Classes 19 through 27 and Different Vehicle Interaction Levels

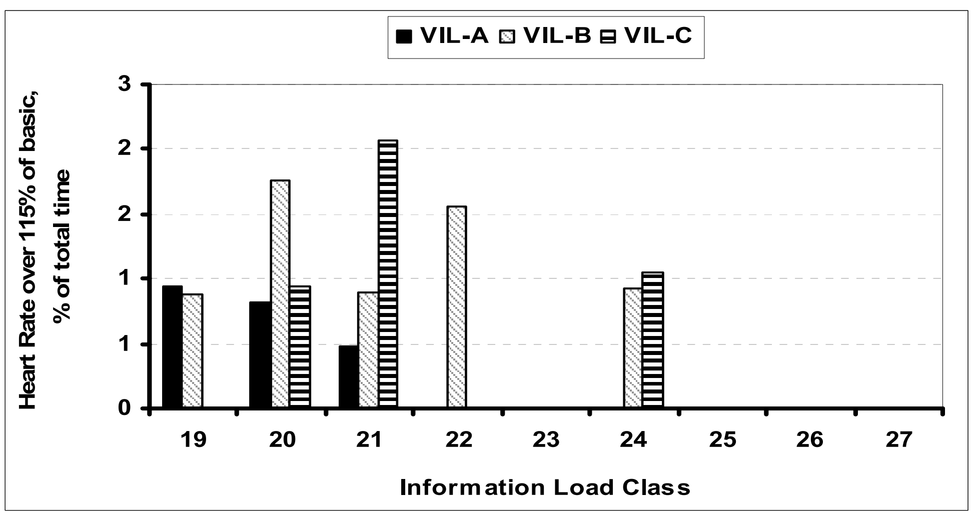
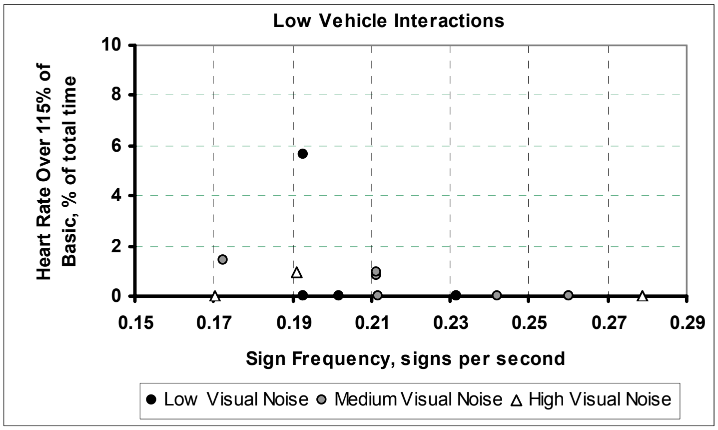
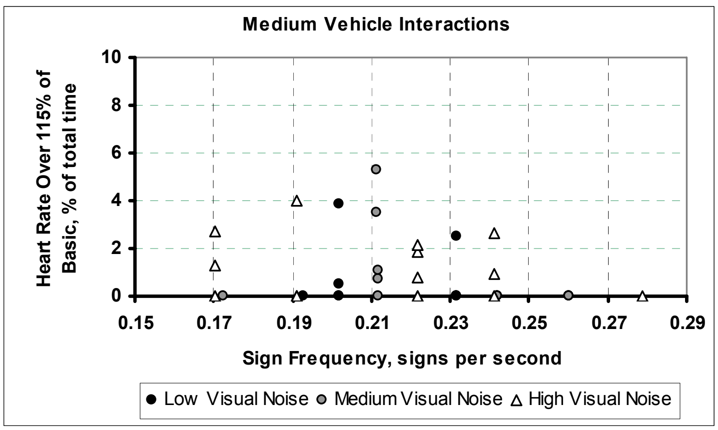


Figure 5.19 Average Frequency of Heart Rate Exceeding 115% of Basic for Information Load Classes 19 through 27 and Different Vehicle Interaction Levels

a)



b)



c)

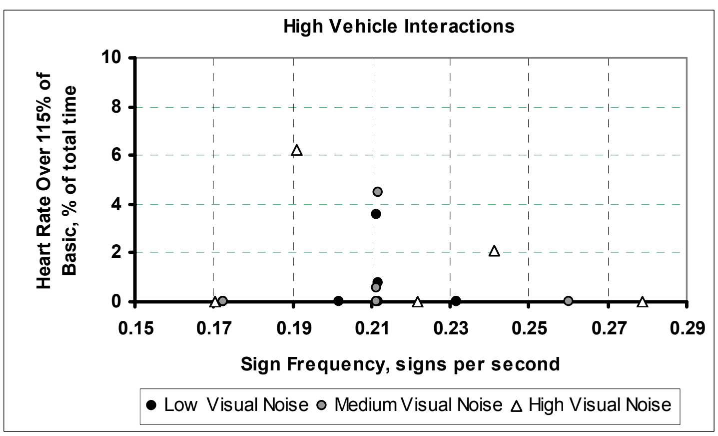
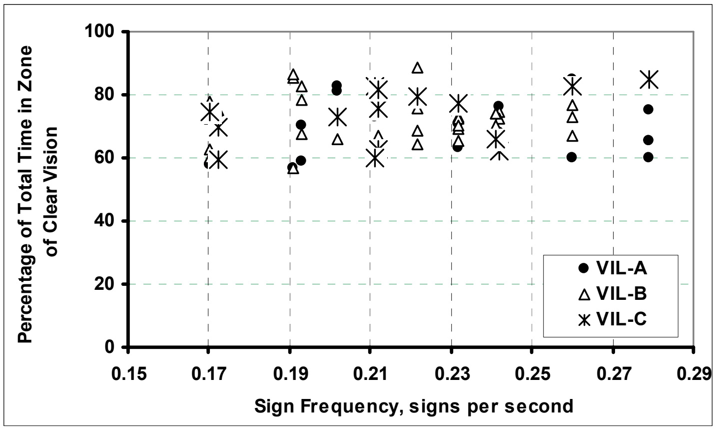


Figure 5.20 Frequency of Increased Heart Rate for Different Intensities of Road Signs and Visual Noise Objects, for Information Load Classes 19 through 27: a) Low, b) Medium, and c) High Vehicle Interaction Levels

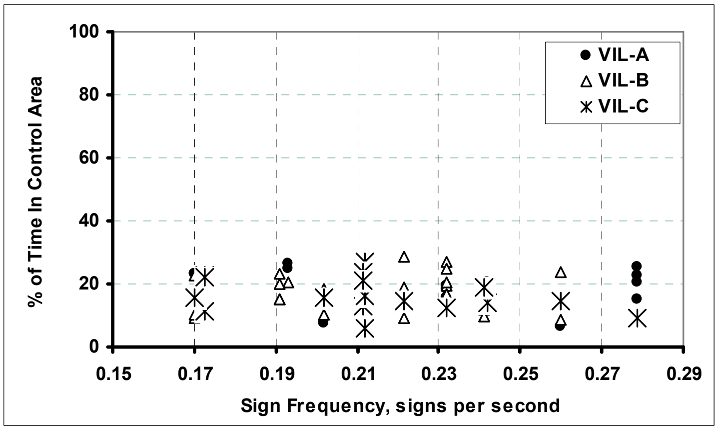
Table 5.13 Frequencies of Eye Movements to Visual Field Areas for Information Load Classes 19 through 27

Information Load Class	Vehicle Interaction Level											
	A	B	C	A	B	C	A	B	C	A	B	C
	Areas of Eye Fixations											
	Zone of Clear Vision			Control Area			Instruments Panel			Other		
	percent of total time											
19	71.47	73.69	73.10	19.88	15.80	15.89	3.00	3.94	2.73	6.86	6.58	8.29
20	73.58	71.14	70.19	12.00	17.68	18.05	4.04	3.63	6.43	10.37	6.66	7.62
21	57.27	73.52	74.72	23.07	16.57	15.64	6.38	4.37	1.14	7.84	6.78	8.49
22	69.83	69.49	77.24	17.79	21.64	12.53	3.67	2.36	2.18	7.83	6.69	8.05
23	72.28	72.46	62.01	20.15	18.35	14.04	4.05	2.51	n/a	5.54	6.67	n/a
24	n/a	71.87	72.67	n/a	15.80	16.82	n/a	4.86	2.66	n/a	7.47	7.85
25	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
26	72.54	72.10	82.46	11.11	15.91	14.83	5.83	2.42	n/a	8.50	4.93	2.71
27	66.40	n/a	84.67	20.90	n/a	9.42	6.32	n/a	0.74	7.96	n/a	5.16

a)



b)



c)

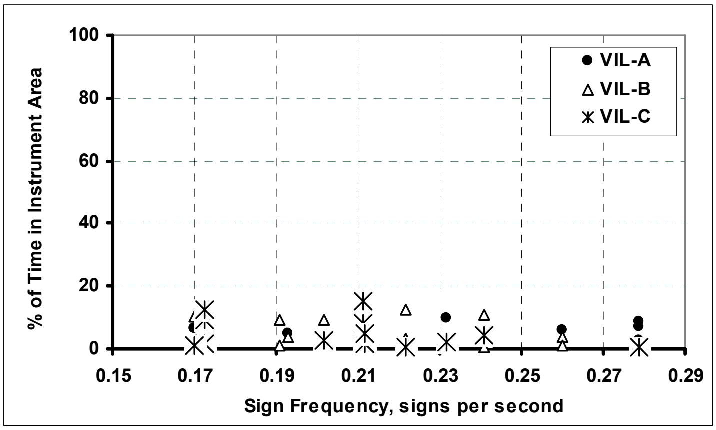


Figure 5.21 Distribution of Driver Visual Searching Time for Information Load Classes 19 through 27: a) Zone of Clear Vision, b) Control Area, and c) Instrument Panel

6. Summary and Recommendations

This report presents four related developments designed to help determine how drivers react to information streams composed of traffic control devices, adjacent vehicles, and visual noise. These developments include an analysis of possible relationships between accident statistics and information loads, a portable data collection system for monitoring driver responses to information load, test driver responses to urban freeway information loads, and a methodology for classifying urban freeways regarding intensity of information streams or information loads presented to drivers.

6.1 Crash Statistics Versus Information Loads

Accident data for urban freeways, specifically freeways in Dallas, Houston, and San Antonio, were examined to identify relationships between crash frequency and driver information load. The crash statistics analysis led to the following conclusions.

Increased sign frequency on urban freeways with two, three, and four lanes seemed to be related to growth in general accident frequency with a simultaneous increase of multiple-vehicle collisions and in some cases crash severity. This seemed to be a basis for a hypothesis that very frequent signs might cause driver information overload. The data implied that exceeding sign frequencies 0.18 and 0.21 signs per second on freeways with two and three to four lanes, respectively, caused major impacts, and therefore these sign frequencies were interpreted as driver information overload threshold values.

Freeway sections with five and six traffic lanes seemed to show a pattern of accident experience versus information load that was opposite to that of the two, three, or four-lane facilities. Smaller sign frequencies were characterized by more accidents (Figure 2.2). This observation seemed to support the hypothesis that less information (fewer signs on the observed wide cross section freeways) might contribute to driver information under-load. For the studied facilities, this condition seems to correspond with sign frequencies of 0.25 signs per second and less.

Although the analyzed data does not allow for strong conclusions to be drawn regarding visual noise impacts, a pattern of increasing accident experience with increasing visual noise was observed (Table 2.5). The findings tend to indicate that at lower sign frequencies, visual noise distractions may be associated with a greater chance of drivers missing needed guidance information. At higher sign frequencies, distractions may have less impact because more opportunities may exist for the driver to identify needed information.

6.2 Test Driver Responses to Information Loads

Test driver behavior, including heart rates, ECG waveforms, eye movements, and vehicle trajectory, was monitored as drivers negotiated selected freeway sections having chosen traffic stream characteristics and information loads. Results of these field measurements produced the following thoughts:

Freeways with four or fewer traffic lanes in one direction characterized by high visual noise intensity seem to exhibit a pattern of decreasing speed with increasing sign frequency. Freeways with more than four lanes per direction seem to show a less pronounced but similar pattern.

Freeways with four or fewer lanes tend to have more frequent intense braking activity as information loads increase. The opposite situation was observed on wider cross section freeways (more than four lanes) where the most frequent intense braking occurred during low and medium information loads.

Data indicated a U-shaped relationship between internal driver responses and information load with the most ideal driver reactions associated with the middle range information classes on freeways with four or fewer traffic lanes. However, for five and six lane freeways, the most desirable driver responses were measured at the highest information loads.

Intensive driver responses, including rapid heart rates and intensive braking on freeway sections with infrequent signs, may indicate insufficient information load, while very frequent signs may lead to driver information overload. Both cases increase the probability of driver stress, especially when combined with extensive visual noise and high vehicle interaction levels.

On freeways with four or fewer lanes, increasing sign frequency seemed to be associated with drivers spending increased visual search time in the zone of clear vision. This occurred at the expense of less attention to traffic in adjacent lanes and behind the vehicle. No such relationship was observed on freeways with more than four lanes.

Additionally, great dispersion of driver eye movements was observed on freeway sections with minimal signage, and this leads to a hypothesis that a lack of sufficient information from road signs may cause drivers to search the surrounding environment to gather additional navigational information. The extensive driver concentration of eye movements in the zone of advanced visual search during high sign frequencies, as well as wider areas of visual search at lower sign frequencies, may be a cause of the observed increased driver mental workload.

Combining the findings, one might suggest that the following sign frequencies correspond to optimal levels of driver performance, mental workload, and reduced driving stress:

- On two-lane freeways - from 0.16 to 0.20 signs per second (10-12 signs per mile for speed limit 60 mph)
- On three and four-lane freeways – from 0.18 to 0.22 signs per second (11-13 signs per mile)
- On five and six-lane freeways – from 0.25 to 0.29 signs per second (15-17 signs per mile)

6.3 Methodology for Estimating Driver Information Loads on Urban Freeways

Freeway Sectioning

Homogenous sections should be chosen so that numbers of lanes and traffic volumes are uniform within sections. Each traffic direction must be analyzed separately. Section boundaries should be chosen as intersections with interstate or state highways, as well as intersections with arterial streets causing significant differences in traffic volumes on the investigated freeway. Sections should also be no less than 2 miles in length to avoid unusually large or small sign frequency values associated with very short sections lengths.

Section Characteristics

Required characteristics that must be known and recorded include:

- Section length
- Number of traffic lanes and the length of segments with the same number of lanes.
- Total number of road signs including lane control signals (LCS) and dynamic message boards (DMS). *An LCS is counted as a single sign regardless of how many lane control units are installed in one sign bridge.*
- Visual noise intensity should be classified according to the following criteria:
  Low: visual noise objects appear occasionally in the driver's visual field, or there is only a small concentration of such objects in one location along the investigated section;
  Medium: driver's visual field frequently contains four or five objects of visual noise; and
  High: numerous visual noise objects are continuously in the driver's visual field.

Samples of visual noise objects are shown in the Figure 6.1.

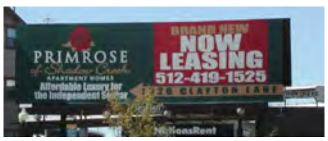
The simple objects (Figure 6.1 a, b, c) are easily perceived by drivers and do not require more than a single eye fixation to understand the information provided. They include familiar logos, billboards with simple text, or graphics that are of low priority to an average driver.

The complex objects (Figure 6.1 d-i) either require multiple eye fixations to read and understand and can capture the driver's attention for a relatively long time. This group includes electronic billboards, billboards with multiple text messages (more than five words) or with small text sizes, commercial signs in close proximity, multiple signs on a single pole, signs with difficult-to-comprehend shapes, and many kinds of artwork.

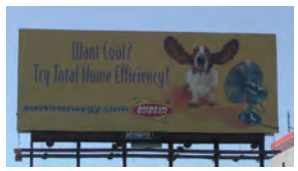
a) Familiar Logo

b) Simple Text

c) Single Dominant



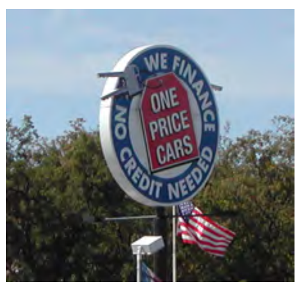
d) Multiple text



e) Artwork

f) Artwork

g) Multiple signs



h) Difficult to read

i) Close proximity

Figure 6.1 Samples of Visual Noise Objects

Section Classification

Sections should be classified into three groups based on predominant number of traffic lanes:

- two lanes
- three and four lanes
- five and six lanes

The following technique is employed in the above classification. The length of each freeway section segment with the same number of lanes should be represented as a percentage of total section length. The values are summarized for all segments of each section, and the maximum value determines the section subgroup.

For each section of each freeway group, sign frequency should be calculated and driver information load estimated. Detailed procedures for these calculations are provided in Chapter 1 of this document; Table 6.1 presents a summary.

Table 6.1 Estimation of Driver Information Load on Urban Freeways

Freeway	Sign Frequency, signs per second	Driver Information Load	Driver Emotional Tension	Impacts on Driver Behaviour	Crash Frequency	Multi-Vehicle and Severe Collisions, percentage
2 Traffic Lanes	less than 0.16	underload	high	high average speed, low frequency of intense braking	low	low
	0.16 - 0.20	optimum	normal	stable speed, lowest frequency of intense braking	low	low
	greater than 0.20	overload	high	reduced speed, high frequency of intense braking	high	medium
3-4 Traffic Lanes	less than 0.18	underload	very high	high average speed, low frequency of intense braking	low	medium
	0.18 - 0.22	optimum	normal	stable speed, lowest frequency of intense braking	low	medium
	greater than 0.22	overload	high	reduced speed, high frequency of intense braking	high	high
5-6 Traffic Lanes	less than 0.25	underload	high	high average speed, high frequency of intense braking	high	very high
	0.25-0.29	optimum	normal	no speed reduction, lower frequency of intense braking	low	medium
	greater than 0.29	n/a	n/a	n/a	n/a	n/a

6.4 Improvement Concepts

As these driver information classification techniques are applied to selected freeways, some sections will clearly be diagnosed as ideal. However, others will be found to be associated with driver information overload or underload. Solutions or counter-measures must be identified to correct identified information flow problems. The following presents concepts that might be applied to derive such solutions.

Freeways diagnosed as potential driver information under-load cases (less than 10, 11, or 15 signs per mile at 60 mph for two, three to four and five to six lane freeways, respectively) are most often associated with a lack of guidance information. The obvious solution is provision of additional guide signs.

Freeways diagnosed as potential driver information overload cases (more than 12, 13, or 17 signs per mile at 60 mph for two, three-four and five-six lane freeways respectively) are a more difficult situation. The following improvement countermeasures can be recommended:

If adjacent freeway sections are not currently in a state of information overload and can accept more signs, the redistribution of signs from the overloaded section to an adjacent section should be considered.

As a first step, specific-service signs as well as recreational and cultural interest area signs and tourist-oriented directional signs that are not related to the problem section should be relocated.

Next, the above-mentioned signs as well as regulatory and warning signs related to the problem section should be analyzed from the perspective of relocation to an adjacent section.

Because information overloaded sections are typically in an area of major intersections, the number of guide signs may be difficult to reduce. Therefore, the alternative implementation of pavement guide markings could be considered. Note: this recommendation is not applicable for guide signs providing advanced information but can be used to replace, for example, directional signs within the approach to an intersection.

If all possible sources of sign intensity reduction are exhausted, speed reduction, which will in turn reduce the amount of information provided per unit time, can be considered. At the same time, it is necessary to note that extreme information overload situations may reflect freeway section design inadequacies, such as insufficient distance between interchanges and the associated entry-exit ramps.

Although the data do not yield clear conclusions regarding visual noise, the largest observed visual noise levels tended to distract drivers, thereby causing them to miss needed guidance information, especially at lower sign intensity. Therefore, to minimize the potential adverse effects of visual noise, one might recommend that the frequency of such objects be less than 0.12 objects per second for freeways with two lanes, and 0.19 and 0.24 objects per second for freeways with three or four and five or six lanes, respectively. Samples of objects that should be classified as visual noise are represented in Figure 6.1.

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