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16. Abstract
In an urban environment drivers typically have numerous information sources contributing to performance of driving tasks. An objective of this research is development of a practical tool to help traffic and safety professionals analyze driver information load and select countermeasures for information level corrections.
The first task to accomplish the project objective was development of a methodology for quantitative description of informational dimensions of urban freeways, taking into account the complex impact of different information sources.
Corresponding with a Positive Guidance concept, all sources of information were classified into three groups in relation to highway, traffic control, and traffic.
The first group includes such roadway design features as horizontal and vertical alignments, number of traffic lanes, width of traffic lanes and shoulders, entrance and exit ramps. The traffic control group includes road signs, signals, and pavement markings. The third group, traffic, characterizes impacts of other vehicles on driver information load.
In addition, the analysis considers that urban freeways are typically surrounded by numerous objects that are not related to traffic but can take driver attention or create inappropriate background for road signs and therefore interfere with perception of more vital information. These include commercial electronic billboards, commercial static billboards, buildings, and any other objects that consume driver attention but do not relate to traffic.
With the purpose of determining typical combinations of the above-mentioned information sources, urban freeways in Texas were investigated. Based on joint analysis of the information load and principles of driver information processing, information quantification criteria were identified and the methodology for quantitative description of informational dimensions of urban freeways was developed. The structure of the utilized information load matrix isolates impacts of different information sources, and, therefore, with further investigations of their impact on driver behavior and reactions, will allow determination of each source contribution.

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The University of Texas at Austin

QUANTITATIVE DESCRIPTION OF INFORMATIONAL DIMENSIONS OF URBAN FREEWAYS

Alexei R. Tsyganov
Randy B. Machemehl
Lucio Vasquez
Ahmed Qatan
Dinesh Natarajan Mohan

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

www.utexas.edu/research/ctr

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Project Engineer: Randy B. Machemehl

Professional Engineer License State and Number: Texas No. 41921

P. E. Designation: Research Supervisor

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1. Introduction and Overview

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 1). 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 2). In another study, 12 percent of the men and 18 percent of the women sampled reported that at times, they “could gladly kill another driver” (Ref 3).

The immediate psychological and physiological effects of driving stress, however, are only part of its total effect. Continued exposure to driving stresses also has a cumulative effect on the individual, causing long-term changes in the health and subjective well-being of the driver. These effects are not limited to the driving process, but may affect other aspects of the individual's life, such as work productivity and residential satisfaction.

The modern driving environment, especially in urban areas, is very complicated and often extremely stressful for drivers. Multilane roadways, high traffic volumes and speeds, numerous exits and entrances, and visually noisy environments that cause information overload require a high level of driver attention and provide limited time for decision-making and behavior correction. Paradoxically, drivers may suffer from insufficient information when they are not provided with or cannot adequately recognize and perceive important signs. These situations cause unsafe driver behavior, such as sudden braking, last minute merging, and wide variations in speed. In turn, these behaviors increase driver stress even more and increase the probability of errors, which may lead to accidents and congestion.

Accident investigations have determined that driver errors caused by the limitations of the human information processing system are the major contributors to traffic accidents (Ref 4). With more incoming information, mental workload is increased, but there are limits to the mental demands that can be tolerated while carrying out a task, especially one such as driving.

In the urban environment, drivers are typically involved in situations where there are many sources of information that determine performance of different driving tasks. The most common driving tasks are classified into three major groups: control, guidance, and navigation (Ref 5). Control involves the driver's interaction with the vehicle in terms of speed and direction (accelerating, braking, steering). Relevant information comes mainly from the vehicle and its displays. Guidance refers to maintaining a safe path and speed. Information comes from roadway alignment, potential hazards, traffic control devices, and other traffic participants. Navigation means planning and executing a trip from one location to another with information coming from maps, guide signs, landmarks, etc. While the control task is mostly related to vehicle design and technical state, guidance and navigation are determined by information sources provided by highway design and the traffic control system. The "information" in relation to driving tasks can be 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 roadway parameters, traffic control devices, roadside environment, and other traffic participants.

Therefore, from a traffic engineering viewpoint it is important to provide drivers with necessary information ensuring adequate time for perception and decision-making to avoid stressful situations. The objectives of the project were formulated as:

- investigate possible relationships between information load and driving stress on urban freeways,
- develop a practical tool to help TxDOT traffic and safety professionals analyze driver information load and select countermeasures for information level corrections,
- develop guidelines for traffic control plan designs better reflecting human abilities and behavior.

A series of tasks are foreseen to accomplish the project objectives. The first of them, development of methodology for quantitative description of informational dimensions of urban freeways, taking into account the complex impact of different information sources, is described by this report.

2. General Approach to Quantitative Description of Informational Dimensions of Urban Freeways

2.1 Driver Perception of Information

Drivers simultaneously receive and analyze numerous facts regarding personal vehicle performance, position among other vehicles and their behavior, roadway parameters, and traffic control devices. Information for controlling the vehicle is received by the driver through his or her natural sense mechanisms as visual, audile, and tactile signals. Because driving is largely a matter of visual information processing and vehicle control, it is essential to understand how drivers acquire this information.

Certain characteristics of visual acuity are of special interest in transportation: dynamic visual acuity, peripheral vision, and depth perception.

Dynamic visual acuity is the ability to see and perceive stimuli in a moving field. The most acute vision is within a narrow cone (cone of clear vision) of 3 to 5 degrees, although the limit of fairly clear sight is within 10 to 12 degrees (Refs 6, 7). In view of this fact it is necessary to place signs or other important informative devices within this 10 to 12 degree-cone of vision, and certainly within 20 degrees. This characteristic is a major consideration for driver information provision regarding roadway parameters, traffic control devices, and behavior of other traffic participants.

For speed analysis, peripheral vision has the most importance. This relates to the field of view within which an individual can see objects, but without clear detail or color. The angle of peripheral vision field normally varies from 120 to 180 degrees.

Another visual factor determining driver perception of speed and distance is depth perception. The primary mechanism that human beings utilize for depth perception is through binocular vision, although monocular parallax and other cues also assist in this process.

An important impact on the driver's zone of clear vision and peripheral vision is speed. As speed increases, visual concentration increases. If the zone of clear vision is a rectangular visual field, its dimensions are 22 (horizontal) by 6 (vertical) degrees at 60 km/h (37 mph), while only 15 by 4 degrees at 100 km/h (62 mph) (Ref 6). As speed increases, the point of visual concentration extends further ahead. In other words, the eyes feel their way ahead of the vehicle and try to allow the driver sufficient time for emergencies. At speeds less than 80 km/h (50 mph) the driver is focusing from 60 to 120 meters (79 to 157 feet)ahead, while at 100 km/h (62 mph) it is 600 meters (784 feet) ahead. As speed increases, the peripheral vision field diminishes. For a speed increase from 80 km/h (50 mph) to 100 km/h (62 mph) the horizontal angle of peripheral vision narrows from 65 degrees to less than 40 degrees (Refs 6, 7).

Drivers extract necessary visual information from the environment using techniques called "systematic seeing" (Refs5, 6, 7, 8, 9). Systematic seeing involves three important steps: (1) centering on the travel path, (2) scanning and searching the traffic scene, and (3) checking mirrors and instruments. A considerable amount of research allows describing driver eye-scanning behavior and determining where drivers fixate their eyes when driving. Figure 2.1 shows the points of drivers' eye fixations on multilane freeways (Ref 7).

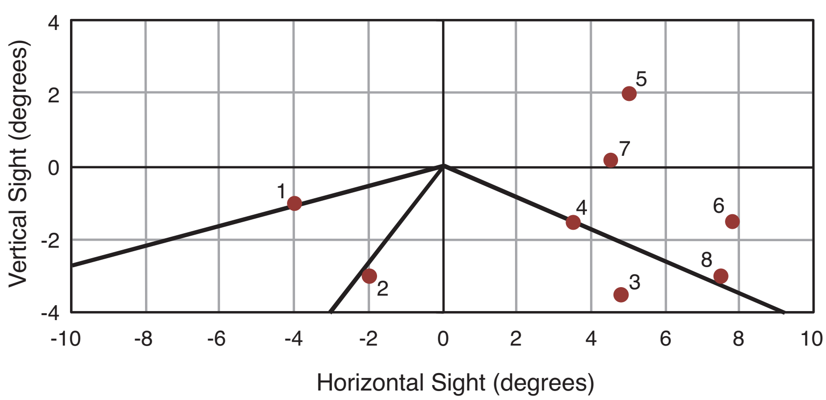

Figure 2.1 Points of Driver's Eye Fixation on Multilane Freeway

The points on the figure represent driver eye fixation for the following purposes:

1 and 6: observation of situation on the left and right adjacent traffic lanes;

2 and 8: control of vehicle position, relative to the left and right lane edges;

3: observation of pavement quality;

4: observation of a leading vehicle;

5: observation of road signs;

7: visual field center of gravity.

It should also be remembered that a driver obtains detailed visual information around the center of the fixation point. The size of this visual circular area depends on the fineness of the visual detail needed and the amount of detailed information in that circle. For very fine visual information and a large density of such information around the fixation point, the diameter of such a visual cone can be from less than 1 degree to a few degrees (Ref 9). Information about larger objects will be picked up by the visual system outside this visual cone and, if it is of interest to a driver, the information will most likely trigger a movement of the eyes to this object with a subsequent eye fixation or several subsequent eye fixations to acquire, process, and verify the visual information at a detailed level within a driver's expectation and memory.

The next step in a complex process of information perception by drivers is information recognition, which involves the identification and understanding of the stimuli.

Eye fixation on an object by itself does not guarantee attention to that object or proper recognition of information provided. This phenomenon fixating on an object yet still failing to “see” it was named “looking without seeing” (Refs 5, 6, 7, 10).

Studies of several thousand U.S. accidents indicated human factors as the dominating causes of road traffic accidents and classified the type of human errors involved, as represented in the Figure 2.2 (Ref 4).

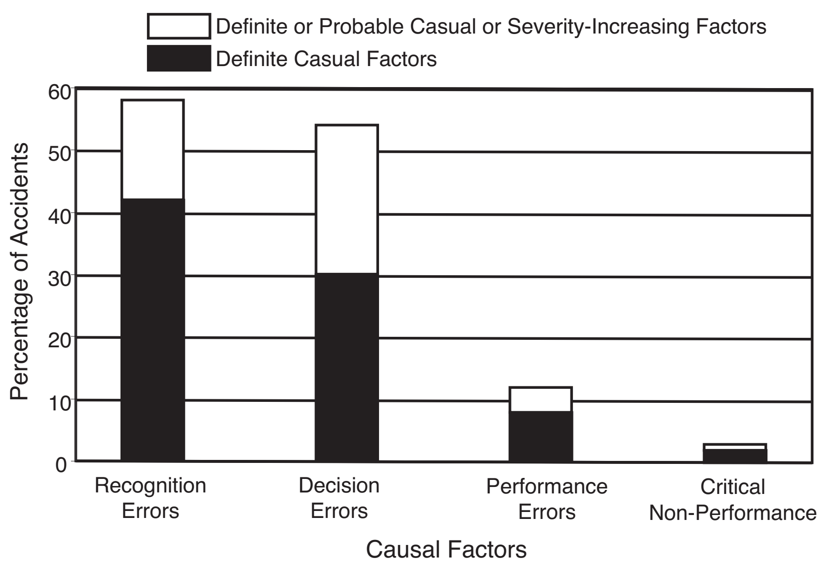

Figure 2.2 Percentage of Accidents in which Human Factors were Identified as Definite or Probable Causal Factors Ref 4).

As can be seen, recognition errors (perception and comprehension) and decision errors predominate. These types of errors could be assembled under the heading “inappropriate information acquisition and processing” (Ref 4).

Among the different reasons such as driver inattention, human physical or mental state, stimuli shape, dimensions, color and contrast, noise level, etc., that may cause this problem, it can be explained by the limitation of human mental capacity in information processing. With increase of incoming information, mental workload is increased, and there are limits to the mental demands that can be tolerated while driving.

A simplified model of a hollow sphere with in- and output streams might be useful for understanding the basic relationship between mental information processing, mental capacity, and mental workload (Refs 11, 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; and the lower the output stream, the greater will be the pressure and the workload level.

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 may experience information overload and insufficient time for processing information provided. The urban freeway conditions are typically overloaded by different objects at the same time characterized by condensed and high speed traffic flow, therefore leaving very limited possibility for a driver to manage his or her mental workload by behavioral corrections, which in turn increases probability of missing information.

2.2 Driving Tasks and Information Sources

Driving is a complex task involving a variety of skills, the most important of which is the acquisition and processing of information and the ability to make appropriate and timely decisions based on this information. From this perspective, the positive guidance (PG) concept is a tool for understanding driver information needs and the transmission of information to driver.

The PG concept incorporates driver's information needs into the design of highways and vehicles, as well as into design and placement of traffic control devices. This concept formulates that information should be "presented unequivocally, unambiguously and with sufficient conspicuity to allow the driver to detect a hazard in a roadway environment that may be visually cluttered, recognize the hazard or its threat potential, select an appropriate speed and path, and initiate and complete the required maneuver safely" (Ref 5).

The PG concept considers driving as a perceptual-motor task and recognizes three levels of driver performance: control, guidance, and navigation.

Control level reflects task performance related to a driver's interaction with the vehicle, controlling it in terms of speed, path, and direction, through the steering wheel, accelerator, and brakes. At this level, the driver obtains information from the vehicle displays, observation of visual changes of the surrounding objects, and as a tactile sense. Because information processing and vehicle control are mainly determined by a driver's experience, and with its advance performed almost without conscious thought, control level ranked with the lowest complexity among the other driving tasks.

The guidance level reflects task performance related to a driver's selection and maintenance of a safe speed and path. The drivers observe and analyze their immediate environment and use judgments, estimates, and predictions to translate changes into control actions needed for vehicle position and speed corrections. Different studies indicated that other vehicles, e.g., the behavior of other traffic participants in close proximity, have major impact and, depending on traffic volume, capture driver attention up to 60 percent of the time (Refs 5, 6, 7). These studies also indicated that drivers spent up to 30 percent of driving time analyzing general traffic situations ahead of them,, up to 20 percent of the time controlling vehicle position on the roadway relative to the left and right lane edges, and around 5 percent of the time observing road signs.

Therefore, information sources at this level can be classified as following in relation to:

- traffic, includes speed and relative position of other vehicles
- highway, includes horizontal and vertical alignment, and crossectional dimensions
- traffic control, includes road signs and signals, pavement marking, other traffic control devices

The navigation level is related to the tasks of planning and execution of 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 choice points. Information sources are maps, guide signs, landmarks, and past experience.

At the guidance and navigation levels, information processing has highest complexity and drivers need more time to perceive, recognize, and respond to information input, especially on urban freeways typically characterized by high speed and heavy traffic, numerous road signs, and a visual noisy environment.

2.3 Quantification of Information

After identification of information sources related to driving task performance, the question of their quantitative description arises.

Formally, the information theory defined information as the reduction of uncertainty and quantifies the amount of information conveyed by a statement, stimulus, or event. (Ref 11). Before the occurrence of an event (which conveys information), a person has a state of knowledge that is characterized by uncertainty about some aspect of the world. After the event, that uncertainty is normally lessened. The amount of uncertainty reduced by the event is defined as the average minimum number of true-false questions that would have to be asked to reduce the uncertainty. The question-asking procedure assumes that all alternatives are equally likely to occur and in such case the information conveyed by an event H_s, in bits (binominal digits), can be expressed by the formula:

$$H_s = \log_2 N$$

where N is the number of equally likely alternatives.

For example, from the perspective of guidance driving tasks' performance, the information conveyed by the road sign "Speed Limit 55 mph" is 1 bit because the answer to one true-false question "My speed is greater than 55 mph" (true) is sufficient to reduce the previous uncertainty.

While this approach theoretically can be implemented for quantification of the amount of information provided by the road signs, it is extremely difficult to utilize it for description of other information sources, such as pavement markings, highway alignment, and other traffic participants. For example, longitudinal pavement markings providing driver with information regarding his or her position on the traffic lane do not require driver's conscious attention and are perceived mostly by peripheral vision, meaning information is processed on a subconscious level. Also, the information theory does not reflect that a human is a complex, self-educated system and in such a case accumulated knowledge and experience has a great impact on information processing.

Taking into consideration the project's objectives, it was decided to quantify information load based on the highway design characteristics and frequency of different information sources, using for their comparative analysis lower-higher criteria. The detail description of the selected approach is provided below.

Corresponding with the PG concept, all sources of information are classified into three groups in relations to highway, traffic control, and traffic.

The first group, related to highway, includes such roadway design features as horizontal and vertical alignments, number of traffic lanes, width of traffic lanes and shoulders, and entrance and exit ramps. Based on numerous researches of traffic operation and safety, it is possible to make the assumption that information level increase with:

- increasing number of traffic lanes,
- increasing frequency of horizontal and vertical curves and reducing their radiuses,
- reducing width of lanes and shoulders,
- increasing frequency of exit and entrance ramps.

The design standards require implementation of lowest grades and highest radiuses of curves on urban freeways, and so horizontal and vertical alignment are uniform and have very little impact on driver performance and can be excluded from further consideration.

Other sources can be quantitatively described by the number of traffic lanes (#), width of lanes and shoulders (feet or meters), and frequency of ramps per unit of freeway length (# per mile or kilometer).

The traffic control group includes road signs, signals, and pavement markings. Again, the uniformity of urban freeways reduces the number of available combinations. The majority of signs on urban freeways are guide signs providing motorists with directions to destinations, advance notice of the approach to intersections, and directing driver into appropriate lane selections. Due to high speeds and high traffic volumes on urban freeways, guide signs provide information of crucial importance. Special studies of information load imposed on drivers from freeway guide signs were conducted under the National Cooperative Highway Research Program and lead in developments of the driver information load (DIL) model (Ref 13). The DIL model is based on determining the driver information load associated with a particular sign array and allows identifying potential information overload problems and selecting the effective alternatives for the design and placement of guide signs. Therefore, the impact of guide sign dimensions on drivers was excluded from the present project and the study was focused on the investigation of driver information load in response to the complex of all information sources, including guide signs in general.

Other signs, mostly regulatory and warning, are represented on urban freeways in small variations and have uniform parameters in each group. The principles of visual information processing indicate that similar information sources, which have the same importance level, have similar impact on driver perceptions and performance. Therefore, it is unnecessary to estimate particular effects of specific signs; rather, information input on driver might be quantitatively characterized simply by the frequency of signs of particular group per unit distance (number per mile or kilometer).

The assumption that greater frequency of signs causes greater information load was made for comparison of different freeway sections.

Pavement markings on urban freeways are represented practically by longitudinal lane separation and pavement edge lines. These markings have a crucial importance for driver information regarding vehicle position on the roadway and have impact on performance of all guidance and navigational driving tasks. Because of their uniformity it is reasonable to assume that they produce a constant level of information load, and can be quantitatively described by the treated section length (miles or kilometers).

The traffic group characterizes impacts of other vehicles on information load. The behavior of other motorists has greatest importance due to the high level of unpredictability and possible consequences, such as accidents. Therefore, driver attention is mainly concentrated on surrounding vehicles. With free-flow conditions, drivers may choose greater distances from other vehicles and therefore have minimal interaction with them. As traffic volume grows, the traffic flow condensation reduces driver ability to manage interaction with other motorists, the driver observes surrounding vehicles more, and in turn experiences increased information load.

Thus, traffic volume can be a good descriptive characteristic of information load caused by other drivers. It is necessary to highlight that this project does not consider congested traffic flow when vehicles' speed significantly drop, which may cause reduction of driver information load due to greater time for information processing.

It is necessary to take into account that urban freeways are typically surrounded by numerous objects not related to traffic that can take driver attention or create inappropriate background for road signs and therefore interfere with perception of more vital information. Such objects, named visual noise, include commercial electronic billboards, commercial static billboards, buildings, and any other objects that consume driver attention but do not relate to traffic. A greater quantity of visual noise objects in the driver's field of view would definitely make it more difficult to perceive information sources determining the performance of driving tasks. Quantitatively, visual noise might be described by the frequency of such objects in driver's field of view per unit distance (# per mile or kilometer).

The combinations of different levels of these groups of information sources with consideration of visual noise will represent total information input to drivers and can be graphically shown by the block-scheme in Figure 2.3.

The structure of the utilized information load matrix isolates impacts of different information sources, and, therefore, with further investigations of their impact on driver behavior and reactions, will allow determining each source contribution.

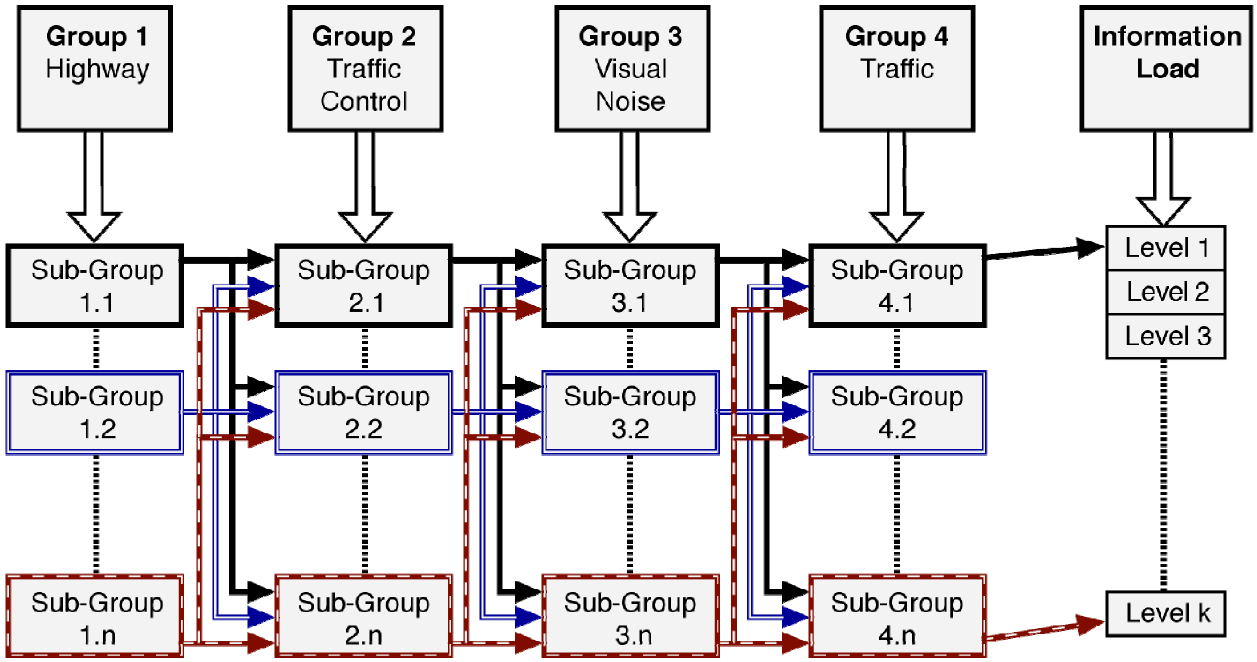

Figure 2.3 Block-Scheme of Quantitative Description of Freeway Informational Dimensions

3. Characteristics of Texas Urban Freeways

The developed concept for description of informational dimensions of urban freeways, represented in the Figure 2.3, allows, theoretically, to have unlimited quantity of different information-source combinations depending on the classification characteristics thresholds. To identify the necessary sub-classification of different groups of information sources, the field observations of urban freeways in major metropolitan areas in Texas were conducted.

3.1 Data Collection

Corresponding with the quantification criteria discussed in Section 2.3, the following characteristics should be collected for description of different groups of information sources:

Group 1. Highway:

- Number of traffic lanes
- Width of traffic lanes and shoulders
- Number of exit and entrance ramps

Group 2. Traffic Control:

- Number of road signs (guide, regulatory, warning, etc.)
- Length of longitudinal pavement markings.

Group 3. Visual Noise:

- Number of different visual noise objects

Group 4. Traffic:

- Traffic volume

Video recording was selected as a major observation technique for data collection that provides the investigators with visual information about roadway design characteristics, traffic control devices, and objects of visual noise in the driver's field of view. A test vehicle with a digital camcorder installed was used to record the driver's field of vision while the continuous speed history of the vehicle was recorded by an electronic module connected to the vehicle's on-board diagnostic system.

Lane and shoulder widths were measured using the special calibration scale through the recorded video.

Annual average daily traffic (AADT) volumes on observed freeways were obtained from the traffic maps of the Texas Department of Transportation.

In addition to these major parameters, the data regarding traffic direction separation technique, roadway lighting, lane control signals, dynamic message boards, and traffic operational characteristics such as spot speed, travel speed, and travel time were collected as well.

Test drives were conducted during normal business hours when traffic volume on urban freeways is typically high but the speed is not reduced.

To determine traffic operational characteristics, the car following methodology was employed. The car following methodology requires several test drives (typically 30 to 50) on one section to determine speed distribution with a confidence level of 95 percent. Taking into consideration that this project's task was not targeting detailed investigation of speed history and that the obtained data is used only for comparative analysis of freeway sections, the following adjustment to the methodology was made. The driver of the test vehicle drives such that the number of vehicles passed is equal to the number of passing vehicles that provide acceptable accuracy for determination of average speed and travel time.

All the freeways within the city limits of Austin, Dallas, Fort Worth, Houston, and San Antonio were investigated. Their maps are represented in the Appendix A.

3.2 Freeways Description

For the quantitative description of information load, the freeways were divided into sections. The observed freeways were reviewed and divided into sections using the information uniformity and based on the subjective judgment of the research team. In the majority of the cases, the selected freeway sections were between major intersections.

In calculation of the number of traffic lanes, only lanes designated for transit traffic were considered and acceleration/deceleration lanes were not counted.

Shoulders were classified into two groups, namely full size and narrow. A shoulder was classified as full size (10 ft) if the majority of the passenger cars can completely stay within it. Shoulders with widths less than 10 feet were considered narrow.

The direction separation techniques were classified as concrete traffic barriers, metal-beam guard fences, median, etc.

The length of the roadway with different values of these parameters as a percentage of the total length of the section was selected as the measuring unit. For example, if an investigated section has a different number of lanes, the description is as follows: 70 percent with three lanes and 30 percent with four lanes.

For the quantitative description of ramps frequency, number of ramps per mile was calculated.

Tables 3.1 and 3.2 show a sample section's general and roadway design descriptions, respectively.

The features of traffic control studied include the different categories of road signs measured in numbers per mile. Road signs are classified into three categories, guide, warning, and regulatory, in accordance with Manual on Uniform Traffic Control Devices (MUTCD). All signs that do not fall into the three categories are classified in a separate group named "Others." In addition, dynamic message signs (DMS) and lane control signals (LCS) were registered separately. A sample of the section traffic control description is presented in Table 3.3.

Table 3.1 General Description of a Sample Section

General Description	
City	Austin
Freeway	IH 35
Section #	6
Direction	Northbound
Location	
From	US 183 interchange
To	Parmer Ln. overpass
Length	5.2 miles
Average daily traffic volume	87,167 vpd
Average spot speed	62 mph
Average travel time	5 minutes

Table 3.2 Roadway Design Characteristics of the Sample Section

Roadway Design	
Characteristics	**% of length**
Number of Lanes	
2	0
3	98
4	2
5	0
Lane Width	
12 feet	100
Shoulders	
Outside	
Full size	100
Inside	
Full size	60
Narrow	40
Direction Separation	
Concrete Traffic Barrier	100
Roadway Lighting	100
Ramps	**# per mile**
Entrance	0.8
Exit	0.8
Total	1.5

Table 3.3 Traffic Control Characteristics of the Sample Section

Traffic Control	
Signs	**# per mile**
Guide	2.69
Warning	2.3
Regulatory	0.38
LCS	0.58
DMS	0
Other	2.11

The objects of visual noise were classified into simple and complex based on the potential to capture driver attention and possible impact in time. The simple objects 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 multiple messages with single dominant information, and any other commercial information that is of low priority to an average driver. Figure 3.1 shows samples of simple visual noise objects.

a) Familiar Logo b) Simple Text c) Single Dominant d) Low priority

Figure 3.1 Samples of Simple Objects of Visual Noise

The objects in the complex group either require multiple eye fixations to read and understand or for some reason can capture driver's attention for a relatively long period of time. This group includes electronic billboards, billboards with multiple text (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 any kind of artwork, including unusual architectural and landscape objects. Figure 3.2 shows samples of complex visual noise objects.

Table 3.4 represents the visual noise characteristics for the sample section.

The collected materials were compiled into Texas Urban Freeway Database and Appendix B shows a screenshot of the developed layout.

The average characteristics of the observed freeways are shown in Tables 3.5 through 3.9. The total mileage in the tables represents freeway lengths for both traffic directions and the percentage refer to these values.

In average for all investigated freeways, roadways with three and four lanes predominate and contain 43.42 percent (746 miles) and 26.28 percent (452 miles) respectively. For two, five, and six lanes these values are 20.81 percent, 7.25 percent, and 2.24 percent or 357, 125, and 39 miles, respectively. Detailed distribution of freeways with different number of traffic lanes for the investigated Texas cities is represented in the Table 3.5.

a) Multiple text

b) Small text sizes

c) Close proximity

d) Multiple signs

e) Difficult to read shapes

f) Artwork 1

g) Artwork 2

h) Unusual architecture

Figure 3.2 Samples of Complex Objects of Visual Noise

Table 3.4 Visual Noise Characteristics of the Sample Section

Visual Noise	
Objects	**# per mile**
Simple	10.56
Complex	7.29
Total	17.85

Table 3.5 Freeway Mileage by the Number of Traffic Lanes

City	Number of Lanes											
	2		3		4		5		6		Total	
	mile	%	mile	%	mile	%	mile	%	mile	%	mile	%
Austin	23.3	18.1	92.4	71.6	12.8	9.9	0.6	0.5	0.0	0.0	129.1	100.0
Dallas-Fort Worth	86.4	11.1	383.1	49.2	246.2	31.6	47.9	6.2	14.9	1.9	778.4	100.0
Houston	63.9	14.4	144.7	32.6	151.9	34.2	62.9	14.2	20.2	4.6	443.6	100.0
* San Antonio	183.8	50.1	125.7	34.3	40.6	11.1	13.2	3.6	3.4	0.9	366.7	100.0

Traffic lane width for all investigated freeways was observed for 12 feet, except a limited number of sections with on-going construction projects.

As indicated by data represented in Table 3.6, shoulders on the outside were full-size (10 feet and greater) in at least 90 percent of freeway mileage for each city. Except for San Antonio, full-size shoulders were predominant on the inside as well. In San Antonio, practically equal frequency of full-size (46 percent of mileage) and narrow (55 percent of mileage) shoulders on the inside were observed, which can be explained by the high mileage of two lane freeways in this city.

Table 3.6 Freeway Mileage by Shoulder Widths

City	Shoulders									
	Outside				Inside					
	Full		Narrow		Full		Narrow		Total	
	mile	%	mile	%	mile	%	mile	%	mile	%
Austin	116.9	90.5	12.2	9.5	78.7	60.9	50.4	39.1	129.1	100.0
Dallas-Fort Worth	727.3	93.4	51.1	6.6	596.3	76.6	182.2	23.4	778.4	100.0
Houston	404.3	92.2	34.4	7.8	284.0	64.7	154.7	35.3	438.6	100.0
San Antonio	339.1	92.5	27.5	7.5	166.7	45.5	200.0	54.5	366.7	100.0

Overall for the observed cities, 77 percent of freeway mileage has traffic direction separated by concrete barriers (Table 3.7) and 79 percent has roadway lighting (Table 3.8).

Table 3.7 Freeway Mileage by Traffic Direction Separation Technique

City	Direction Separation					
	Barrier		Median		Total	
	mile	%	mile	%	mile	%
Austin	95.8	74.2	33.3	25.8	129.1	100.0
Dallas-Fort Worth	598.6	76.9	179.9	23.1	778.4	100.0
Houston	427.7	96.4	15.9	3.6	443.6	100.0
San Antonio	227.7	62.1	139.0	37.9	366.7	100.0

Table 3.8 Freeway Mileage by Roadway Lighting

City	Roadway Lighting					
	Yes		No		Total	
	mile	%	mile	%	mile	%
Austin	110.1	85.3	19.0	14.7	129.1	100.0
Dallas-Fort Worth	541.4	69.6	236.7	30.4	778.4	100.0
Houston	436.3	98.4	7.3	1.6	443.6	100.0
San Antonio	230.5	62.9	136.2	37.1	366.7	100.0

No significant difference between the cities was observed in exit and entrance ramps frequency (Table 3.9). The average number of both exit and entrance ramps on the investigated freeways vary from 2.03 ramps per mile in Houston to 2.25 in the Dallas-Fort Worth area.

Table 3.9 Ramp Frequency Statistics

City	Ramps Frequency			
	Min	Max	Mean	Std.Dev.
	ramps per mile			
Exit Ramps				
Austin	0.00	2.14	1.16	0.49
Dallas-Fort Worth	0.00	3.16	1.22	0.44
Houston	0.00	2.37	1.07	0.47
San Antonio	0.00	2.30	1.11	0.46
Entrance Ramps				
Austin	0.00	1.79	0.91	0.42
Dallas-Fort Worth	0.00	2.27	1.03	0.45
Houston	0.00	3.49	0.96	0.45
San Antonio	0.00	2.30	0.99	0.42
Overall				
Austin	0.84	3.58	2.07	0.66
Dallas-Fort Worth	0.45	5.26	2.25	0.68
Houston	0.37	5.59	2.03	0.75
San Antonio	0.85	3.93	2.10	0.75

Tables 3.10 and 3.11 represent statistics of frequencies of road signs and visual noise objects on the investigated freeways.

Table 3.10 Road Signs Frequency Statistics

City	Road Signs Frequency			
	Min	Max	Mean	Std.Dev.
	signs per mile			
Guide Signs				
Austin	1.35	11.65	5.39	2.12
Dallas-Fort Worth	0.72	16.83	6.11	1.91
Houston	0.77	16.06	5.25	2.48
San Antonio	1.67	16.39	6.53	2.69
Warning Signs				
Austin	0.00	5.04	2.20	1.15
Dallas-Fort Worth	0.63	8.66	3.86	1.37
Houston	0.00	7.65	2.60	1.35
San Antonio	1.55	10.68	4.35	2.14
Regulatory Signs				
Austin	0.00	4.30	0.88	0.87
Dallas-Fort Worth	0.00	4.71	0.91	0.86
Houston	0.00	5.78	1.29	1.20
San Antonio	0.00	2.19	0.81	0.48
Lane Control Signals				
Austin	0.00	1.26	0.36	0.41
Dallas-Fort Worth	0.00	1.30	0.08	0.24
Houston	0.00	1.39	0.14	0.35
San Antonio	0.00	5.40	1.00	1.18
Dynamic Message Signs				
Austin	0.00	0.68	1.70	0.21
Dallas-Fort Worth	0.00	1.31	0.12	0.21
Houston	0.00	1.59	0.24	0.30
San Antonio	0.00	1.53	0.24	0.29
Overall				
Austin	4.79	15.13	8.94	2.57
Dallas-Fort Worth	1.97	26.30	11.08	3.15
Houston	1.42	24.48	9.51	3.75

Among the four cities, Austin has the lowest sign density (in average 8.94 signs per mile) and San Antonio the highest (in average 13.2 signs per mile) of all types of road signs. Analysis of sign frequencies for different groups indicated that guide signs represent the major group in freeway signing. Their frequency in average for city vary from 5.25 signs per mile in Houston to 6.53 signs per mile in San Antonio. For warning signs, the extreme values were 2.2 signs per mile (Austin) and 4.35 (San Antonio), and for regulatory signs 0.81 signs per mile (San Antonio) and 1.29 signs per mile (Houston).

The highest frequency of lane control signals was observed in San Antonio, in average 1 sign per mile. It is necessary to note that several plates above one traffic lane in one location were counted as one LCS because, from the information processing perspective, they are perceived by the driver as a single object.

The greatest numbers of dynamic message signs were observed on Austin freeways where their average frequency exceeds all other cities by around ten times.

Longitudinal pavement markings were observed through all mileage of the investigated freeways.

The conducted observations showed that freeways in all four cities, especially in central parts, have very "visually noisy" environments. The maximum numbers of objects classified as visual noise contain up to around 32 objects per mile (Table 3.11). However, the most noisy freeways were identified in Austin with an average 9.58 objects per mile; the majority of these objects can be classified as simple, while in San Antonio which has the lowest average frequency of 7.93 objects per mile; such objects are mostly complex. Dallas and Houston show similar high visual noise intensity with slightly higher number of complex objects.

Table 3.11 Visual Noise Intensity Statistics

City	Visual Noise Intensity			
	Min	Max	Mean	Std.Dev.
	objects per mile			
Simple Objects				
Austin	0.43	17.75	6.13	4.08
Dallas-Fort Worth	0.00	17.11	3.04	3.05
Houston	0.00	15.67	4.12	3.91
San Antonio	0.00	6.55	1.60	1.63
Complex Objects				
Austin	0.00	9.84	3.45	2.71
Dallas-Fort Worth	0.00	22.36	5.64	3.96
Houston	0.00	18.01	5.32	5.17
San Antonio	0.50	25.64	6.33	5.09
Overall				
Austin	0.43	26.45	9.58	6.33
Dallas-Fort Worth	0.00	32.17	8.69	6.20
Houston	0.00	31.14	9.44	8.64
San Antonio	0.50	26.82	7.93	6.25

3.3 Sub-Classification of Different Groups of Information Sources

Based on the collected data, the selection of quantitative criteria for the sub-classification of the groups of information sources defined above was performed and is described below.

Group 1: Highway

Urban freeways in Texas are represented by the roadways with two, three, four, five, and six lanes in one direction. In terms of driving task complexity, it is possible to assume that the freeways with two lanes will represent lowest informational input. Such freeways were selected as a subgroup 1; freeways with three and four lanes will represent medium informational input (subgroup 2); and freeways with five and six lanes will represent highest informational input to driver (subgroup 3).

To identify the further sub-classification of Group 1, the analysis of other roadway characteristics was performed separately for freeways with two, three and four, and five and six traffic lanes. The results are summarized in Table 3.12.

Table 3.12 Freeways Roadway Characteristics

Freeways	Percentage of Freeway Mileage with						Average Number of Ramps per mile
	Shoulders (outside - inside)				Direction Separation by		
	full - narrow	narrow - narrow	full - full	narrow - full	barrier	median	
Austin							
2 Lanes	64.4	0.0	35.6	0.0	61.2	38.8	1.7
3 - 4 Lanes	30.9	3.9	61.4	3.8	76.4	23.6	2.2
5 - 6 Lanes	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Dallas - Fort Worth							
2 Lanes	37.0	8.2	54.8	0.0	44.5	55.5	2.4
3 - 4 Lanes	16.7	2.5	78.7	2.0	77.1	22.9	2.2
5 - 6 Lanes	14.5	0.0	85.5	0.0	100.0	0.0	3.0
Houston							
2 Lanes	81.7	8.0	5.3	5.0	100.0	0.0	1.6
3 - 4 Lanes	26.4	3.8	67.8	2.0	93.4	6.6	2.0
5 - 6 Lanes	0.0	0.0	100.0	0.0	100.0	0.0	2.2
San Antonio							
2 Lanes	90.0	5.3	4.7	0.0	9.9	90.1	2.0
3 - 4 Lanes	5.4	2.2	91.2	1.2	99.7	0.3	2.7
5 - 6 Lanes	52.3	0.0	47.7	0.0	100.0	0.0	3.9
Overall							
2 Lanes	74.9	6.2	17.9	1.0	38.1	61.9	1.91
3 - 4 Lanes	18.7	2.9	76.3	2.1	84.1	15.9	2.27
5 - 6 Lanes	8.5	0.0	91.5	0.0	100.0	0.0	3.01

The collected data showed that all observed freeways have 12 foot traffic lanes. Also, the data indicated that the dimensions of shoulders and direction separation are uniformly distributed on Texas urban freeways with the same number of traffic lanes. The majority of two lane freeways has full-size shoulders on the outside and narrow on the inside and median as a direction separation technique, while the majority of freeways with 3-4 and 5-6 lanes have full-size shoulders on both sides and a barrier to separate directions. Similarly, the frequency of ramps is uniformly distributed on freeways with the same number of traffic lanes and directly proportional to it. Therefore, the above-mentioned roadway design characteristics are already captured by the number of lanes and hence do not need to be separately considered for sub-classification of the highway group of information sources.

Group 2: Traffic Control

The traffic control group in the case of urban freeways includes road signs and pavement markings.

Because of their existence in all freeway mileage, the impact of longitudinal pavement markings can be assumed as a constant in determining freeway informational dimensions.

The statistics of different sign frequencies for all investigated freeways by cities (Table 3.10) along with consideration of the number of traffic lanes (Table 3.13) indicates that guide signs are overrepresented on urban freeways compared to other signs. Regulatory, warning, DMS, and LCS are represented on urban freeways in small variations. This fact allows application of general frequency of signs as criteria for sub-classification of the traffic control group of information sources.

From the perspective of driver information processing and with the purpose to include speed of traffic flow into further analysis, instead of the number of signs per unit distance, it was selected to implement number of signs per unit time calculating, based on speed limit value.

Figure 3.3 shows the distribution of signs frequency on the observed freeways considering the number of traffic lanes.

Table 3.13 Road Signs Frequency by the Freeway Types

Freeways	Average Number of Signs per mile				
	Guide	Warning	Regulatory	LCS	DMS
Austin					
2 Lanes	4.64	2.00	1.44	0.00	0.00
3-4 Lanes	5.60	2.25	0.71	0.46	0.13
5-6 lanes	n/a	n/a	n/a	n/a	n/a
Dallas - Fort Worth					
2 Lanes	5.76	4.08	0.82	0.01	0.09
3-4 Lanes	6.15	3.85	0.92	0.08	0.13
5-6 lanes	7.90	5.07	1.44	0.12	0.16
Houston					
2 Lanes	3.66	2.40	1.68	0.07	0.00
3-4 Lanes	5.14	2.48	0.95	0.19	0.25
5-6 lanes	6.76	3.17	2.28	0.02	0.37
San Antonio					
2 Lanes	4.90	3.63	0.68	0.69	0.13
3-4 Lanes	7.93	5.05	0.88	1.35	0.36
5-6 lanes	10.19	5.43	1.03	1.03	0.22

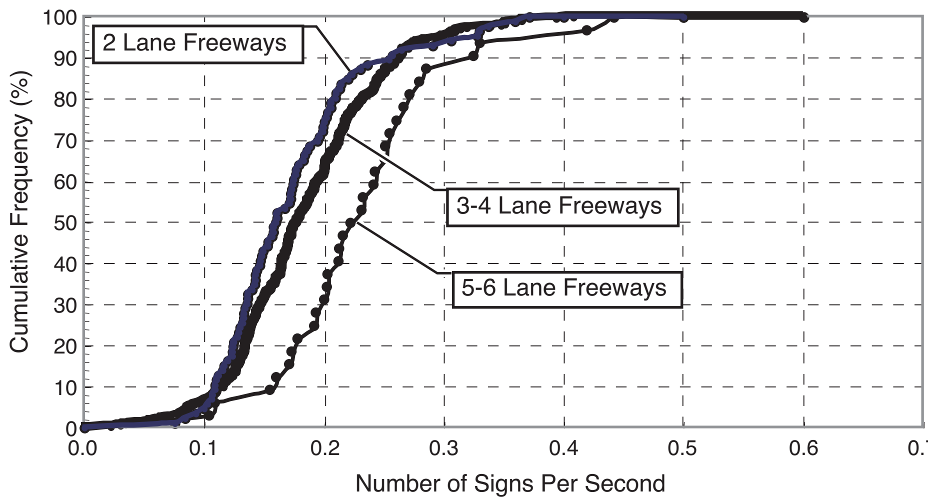

Figure 3.3 Road Signs Frequency Distribution

The non-parametric statistical analysis (Kruskal-Wallis) was conducted on the data and the null hypothesis that the three groups (freeways with 2, 3-4, and 5-6 lanes) come from the same population was accepted with probability of 0.001. This indicated that the three groups differ in terms of sign frequency.

The observed distribution of signs frequency (Figure 3.3) indicated that 33 percent of the two-lane freeway sections have less than 0.14 signs per second, three and four lane freeways, 0.15, and five and six lane freeways, 0.20 signs per second, while 66-percentile values were 0.18, 0.21, and 0.25, respectively.

Therefore, traffic control group of information sources can be divided into three sub-groups based on the above-mentioned values as:

Sub-group 1: Low frequency of signs (equal or less than 33-percentile value)

Sub-group 2: Medium frequency of signs (greater than 33-percentile but equal or less than 66-percentile values)

Sub-group 3: High frequency of signs (greater than 66-percentile value).

Group 3: Visual Noise

Since the utilized classification of visual noise objects is subjective even though it is based on the basic principles of human visual perception, it was decided not to differentiate between simple and complex objects in the methodology, but to use the total number of objects.

Similar to road signs, the intensity of visual noise is measured by the number of objects per second. The observed data are summarized in Table 3.14.

Table 3.14 Visual Noise Intensity Statistics by Freeway Types

Freeways	Road Signs Frequency			
	Min	Max	Mean	Std.Dev
	signs per second			
2 Lanes	0.00	0.52	0.10	0.08
3 - 4 Lanes	0.00	0.56	0.16	0.12
5 - 6 lanes	0.05	0.54	0.21	0.14

The Kruskal-Wallis statistical analysis conducted on the data showed that the three groups (freeways with 2, 3-4, and 5-6 lanes) differ in terms of visual noise intensity. Therefore, section classification based on visual noise should be performed separately for each of the three groups representing classification by roadway design.

The distribution of visual noise frequency represented in the Figure 3.4 indicated that 33 percent of the two-lane freeway sections have less than 0.05 objects per second, three and four lanes freeways, 0.09, and five and six lanes freeways, 0.10 objects per second, while 66-percentile values were 0.12, 0.19, and 0.24, respectively.

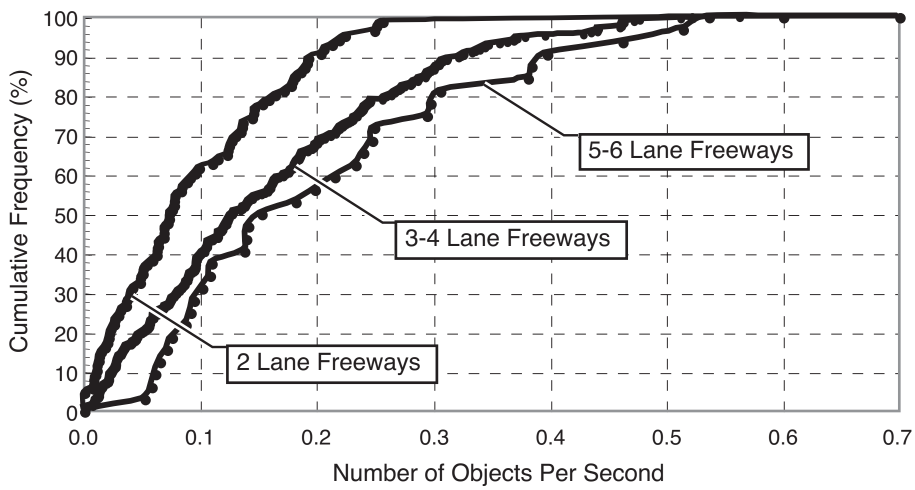

Figure 3.4 Visual Noise Frequency Distribution

Based on these values, freeway sections are classified into three groups:

Sub-group 1: Low intensity of visual noise (equal to or less than 33-percentile value)

Sub-group 2: Medium intensity of visual noise (greater than 33-percentile but equal to or less than 66-percentile values)

Sub-group 3: High intensity of visual noise (greater than 66-percentile value).

Group 4: Traffic

As is described in Section 2.3, this group of information sources characterizing the impacts of other vehicles on general information load and traffic volume was selected as a quantification criterion.

At low traffic volumes, density of traffic flow is low as well and individual drivers have minimal interaction with other traffic participants. There is little or no restriction in maneuverability because of the presence of other vehicles. Such conditions reflect the minimal input of traffic into the general information load.

As traffic volume grows, the traffic flow condenses. This reduces driver ability to manage interaction with other motorists. Drivers must observe more surrounding vehicles in order to choose their own speed, change lanes, or pass. When traffic flow condenses and there is no reduction of the traffic flow speed, this increases of the number of information sources per unit of time, increasing driver information load.

Taking into account that, in condensed flow, a driver can observe only a limited number of surrounding vehicles, an increase in traffic volume does not increase the number of informational sources and with speed reduction it causes reduction of information load. Therefore, in terms of information load, it is necessary to consider traffic volume that exceeds free flow conditions but does not cause significant speed reduction.

Numerous traffic operations summarized in the Highway Capacity Manual (HCM) indicate that on multi-lane urban freeways, traffic volumes up to around 700 pvphpl characterized free flow conditions, and speed tends to reduce after the traffic volume exceeds 1500 pvphpl (Ref14).

Therefore, the traffic volume around 1500 pvphpl reflects the worst-case scenario with respect to driver information processing and driver performance on all section classes. Based on this assumption it seems unnecessary to provide more detailed sub-classification, but further evaluation of the impacts of other groups of information sources on driver mental workload must be performed at the above-mentioned traffic worst-case scenario.

4. Methodology for Quantitative Description of Informational Dimensions of Urban Freeways

The conducted field observations and the obtained data allowed developing a three-phase methodology for quantitative description of informational dimensions of urban freeways.

Phase One: Freeway Sectioning and General Information

The collected data indicated that, in the majority of the cases, freeway sections between major intersections are characterized by uniform informational dimensions. Therefore, this criterion is recommended for freeway sectioning.

Intersections with interstate or state highways should be classified as major. In addition, an intersection with arterial streets should be classified as major if there is significant difference in traffic volumes on the investigated freeway before and after the intersection.

The opposite traffic directions should be analyzed separately.

For each section, the general information is input into a layout:

General Section Description	
City	
Freeway	
Direction	
Boundaries	
From	
To	
Section Code	
Section Length, miles	
Annual Average Daily Traffic, vpd	
Design or 85-percentile Speed, mph	

Phase Two: Section Characteristics Input

The section characteristics are input into the estimation model corresponding with the three groups of information sources: (1) highway, (2) traffic control, and (3) visual noise.

Highway characteristics input.

The source for all roadway design characteristics is "Plans of Proposed State Highway Improvements: Plan and Profile Sheets."

The section is subdivided into segments based on the number of traffic lanes and the length of segments with the same number of lanes:

Number of Lanes	Length, miles
2	
3	
4	
5	
6	

Only traffic lanes designated for transit traffic are considered. Other roadway design characteristics are already captured by the number of lanes and hence excluded from the data input.

Traffic control characteristics input.

The source for all traffic control characteristics is "Plans of Proposed State Highway Improvements: Traffic and Traffic Control Plans."

The information input of this group is characterized by the total number of signs including LCS and DMS and included into estimation as follows:

	Total Number
Signs, LCS, DMS	

Visual noise characteristics input.

Because it was decided not to differentiate between simple and complex objects, only the total number of objects is input into the model.

	Total Number
Visual Noise Objects	

Phase Three: Section Classification

The obtained data indicated some variation of parameters on freeway sections selected based on the implemented sectioning technique. To ensure complete uniformity, more detailed sectioning is required, however, it may lead to very short sections and thus destroy the real picture of driver information perception. So, sections can be classified using various criteria such as maximum, average, or predominant values of the characteristics. Due to the continuous nature of information processing by driver, and the results of the observations that showed the dominance of one value of a characteristic, use of predominant value to classify sections was chosen.

The freeway sections are classified based on the three separate criteria: number of lanes, frequency of signs and signals, and level of visual noise.

For Group 1 of information sources (Highway) the following classification is implemented:

Sub-group 1: Two-Lane Freeways

Sub-group 2: Three- and Four-Lane Freeways

Sub-group 3: Five- and Six-Lane Freeways.

To determine these classifications, the lengths of freeway section segments with the same number of lanes as summarized at the data input phase are calculated as a percentage of the total section length. The values are summarized according to the sub-group classification, with the maximum value determining the section sub-group.

For classification by traffic control, the number of signs per second is calculated by 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 sub-groups:

For two-lane freeways:

Sub-group1: Equal to or less than 0.14 signs per second

Sub-group 2: Greater than 0.14 but equal to or less than 0.18 signs per second

Sub-group 3: Greater than 0.18 signs per second

For three- and four-lane freeways:

Sub-group 1: Equal to or less than 0.15 signs per second

Sub-group 2: Greater than 0.15 but equal to or less than 0.21 signs per second

Sub-group 3: Greater than 0.21 signs per second

For five- and six-lane freeways:

Sub-group 1: Equal to or less than 0.20 signs per second

Sub-group 2: Greater than 0.20 but equal to or less than 0.25 signs per second

Sub-group 3: Greater than 0.25 signs per second

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

For two-lane freeways:

Sub-group 1: Equal to or less than 0.05 objects per second

Sub-group 2: Greater than 0.05 but equal to or less than 0.12 objects per second

Sub-group 3: Greater than 0.12 objects per second

For three- and four-lane freeways:

Sub-group 1: Equal to or less than 0.09 objects per second

Sub-group 2: Greater than 0.09 but equal to or less than 0.19 objects per second

Sub-group 3: Greater than 0.19 objects per second

For five- and six-lane freeways:

Sub-group 1: Equal to or less than 0.10 objects per second

Sub-group 2: Greater than 0.10 but equal to or less than 0.24 objects per second

Sub-group 3: Greater than 0.24 objects per second

The combinations of these three groups representing the classifications based on roadway design, traffic control, and visual noise will determine section class and contain in total twenty-seven levels of information load. Table 4.1 represents the number of observed freeway sections with informational dimensions classified with the developed methodology.

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

Freeways	Signs - Visual Noise Groups 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

5. Future Research

The developed methodology that allows quantitative description of urban freeway informational dimensions is one of the base lines in understanding combined effects of different information sources on driver performance and traffic safety.

To help traffic engineers analyze driver informational load and select countermeasures for informational level corrections, identified levels of information load should be evaluated by their impact on driver reactions.

Different evaluation criteria can be implemented for this purpose. One example is the analysis of traffic accident statistics. For this purpose multiyear accident data for major metropolitan areas in the state of Texas will be collected and analyzed including accident type and severity, weather, and time of day, all of which are contributing factors. Statistical analysis of these variables will be conducted for all identified classes of freeway sections, and the associations between different levels of informational load and corresponding accident statistics will be evaluated.

At the next evaluation stage, driver responses will be investigated in each of the section classes obtained by the previously mentioned methodology.

The literature review indicated that current driving stress research has been predominantly conducted using driving simulators or questionnaire surveys, and there are very few investigations based on real driving conditions. Such research approaches have provided important knowledge in understanding driver behavior, but only limited insight to identification of stress levels. The major problem of all questionnaire surveys is their highly subjective nature. The driving simulator-based studies are limited as a result of the vast difference between driver perceptions under laboratory and real conditions. Therefore, the research approach for the proposed study is the investigation of driver behavior and reactions in real traffic conditions.

All driver responses to the driving environment can be classified into two groups: external and internal.

The external, or behavioral responses, are corrective actions, which the driver performs during the actual driving situation and which are reflected by the vehicle speed and trajectory. For the quantitative description of the driver behavioral 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 led to developments of several methods for quantitative estimation of driver performance, such as "Acceleration Noise," "85-percentile Speed Difference," and "Speed Reduction Coefficient."

Internal responses reflect driver mental workload and involve subjective emotional reaction and specific psycho-physiological changes due to the driving environment. The three most commonly used categories of workload measurement techniques are self-report, measures of task performance, and physiological measures. Many previous studies of operator labor activity showed that among different techniques for measuring mental workload the most applicable for the real driving experiments are physiological measurements. They allow not only the identification of stress but also quantitative descriptions of other emotional states of drivers, thereby providing tools for determination of optimal levels of workload. Heart rate and derived parameters (heart rate variability) have proven to be most useful for stress identification from physiological measurements.

Therefore, for the investigation of drivers' responses to the driving environment the following parameters were selected for recording during field experiments: vehicle speed-time history, for driver behavioral reactions analysis, and driver electrocardiogram, for internal reactions analysis.

Figure 5.1 represents the hypothesized relationships between driver reactions, traffic control intensity, and visual noise.

These relationships will be studied separately for two-lane, three- and four-lane, and five- and six-lane freeways, considering worst-case traffic scenario.

The selected approach allows estimating the impact of different information load classes, and therefore identifies characteristics of abnormal classes.

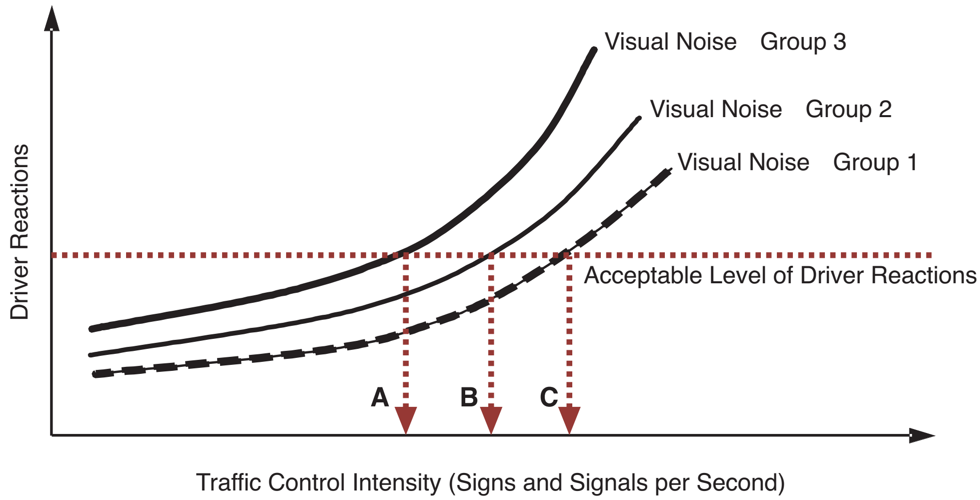

Figure 5.1 Information Load Evaluation Concept

To test the hypothesis relationships, freeway sections representing each of the information load classes were selected. The observed data showed that it is not possible to conduct field investigations in a single city and cover all the classes.

As evident from Table 4.1, only San Antonio has sections covering all different combinations of information load sources for two-lane freeways, thus, it was selected for experiments. 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 groups have been chosen. To avoid driver fatigue, this selection process took into account the proximity between sections so that a single test-drive will accommodate four or five test sections, while not exceeding two hours.

The test-drivers will be selected based on the following characteristics:

- Familiarity: The driver should be unfamiliar with the test sections, because the impact of information sources on ISD and DTD will be maximal on such drivers.
- Age: Drivers between 30 and 55 years old will be selected, as this research does not target investigation of special road user populations, such as younger (less than 25 years old) and older (more than 60 years).

- 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 18, people of ages in the above-mentioned group already have extensive driving experience.
- Gender: Both male and female drivers will participate in the experiment.

To evaluate driver performance at different levels of information loads, subjects will be provided with the destination and asked to locate and approach it.

The following characteristics will be measured: identification of destination, vehicle position on the roadway, maneuvering frequency, speed, acceleration/deceleration, and driver heart activity.

In addition, the driver performance will be evaluated on all freeway sections, including those without a set destination.

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