DRIVER RESPONSES AT DIFFERENT INFORMATION LOADS ON URBAN FREEWAYS

A.TYGANOV
Center for Transportation Research, University of Texas at Austin, USA
TSYGANOV@MAIL.UTEXAS.EDU
R.MACHEMEHL
Department of Civil, Architectural, and Environmental Engineering, University of Texas at Austin, USA
rbm@mail.utexas.edu

ABSTRACT

Driver mental errors committed due to inappropriate information processing are a major contributing factor in traffic crashes. Both increased and insufficient incoming information, raise the driver's mental workload, and cause dangerous driver behaviour.

Corresponding to driving tasks, all sources of information were classified into: "Highway" – includes roadway design features, "Traffic Control" – reflects the traffic control system, and "Traffic" - characterizes impacts of other vehicles.

Based on the analysis of principles of human information processing and investigation of the freeways in the major metropolitan areas of Texas, quantification criteria for the above-mentioned information sources and their typical combinations were identified.

To determine whether relationships between driver information loads and crash rates can be found, over eighty thousand crashes which occurred on selected urban freeways were compared to information load rates.

In the next stage, test driving of an instrumented vehicle on the selected urban freeways representing typical combinations of information load were conducted. Based on the analysis of speed variations, frequency of intense braking, heart activity characteristics, eye-scanning processes, as well as a crash statistics analysis, freeway informational dimensions that cause abnormal driver responses were identified.

1. 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 to the understanding of driver information needs and the transmission of information to the driver [1]. The PG concept considers driving as a perceptual-motor task and recognizes three levels of driver performance: control, guidance, and navigation.

The 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 and observation of visual changes of the surrounding objects.

The guidance level reflects task performance related to a driver's selection and maintenance of a safe speed and path. Drivers observe and analyze the immediate environment and using judgments, estimates and predictions, translate changes into control actions needed for vehicle position and speed corrections. Information sources at this level include: (1) speed and relative position of other vehicles, (2) roadway design features, and (3) traffic control devices.

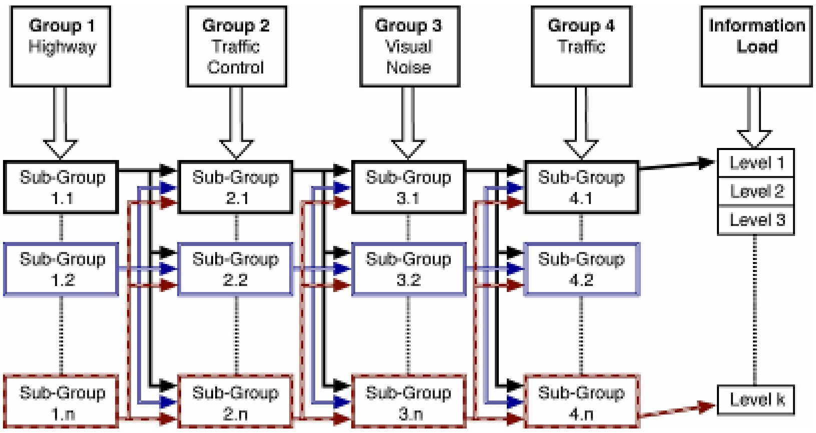
The navigation level is related to tasks of planning and execution of a trip from origin to destination. Drivers evaluate route identification (highway number, street name, etc.), cardinal directions, and route key points. Information sources are maps, guide signs, landmarks, and past experience.

So, 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 behaviour selection. As such, "information" includes roadway parameters, traffic control devices, roadside environment, and other traffic participants and all sources of information can be classified into three groups in relation to highway, traffic control, and traffic.

In addition, it is necessary to take into account that urban freeways are typically surrounded by numerous objects, such as roadside advertisements, that are not related to traffic but can take up driver attention or create an inappropriate background for road signs and therefore interfere with perception of more vital information.

2. CLASSIFICATION OF INFORMATION LOAD LEVELS ON URBAN FREEWAYS

The combinations of different levels of the above-mentioned groups of information sources will represent the total information input to drivers and can be graphically shown by the block-scheme in Figure 1. Sub-groups are arranged in order of increasing complexity (for example sub-group 2.1 has lower informational input than 2.3 and combinations of lower sub-groups correspond to lower total information load levels.



"Figure 1 - Block-Scheme of Freeway Informational Load Class Designation".

To determine the representation of urban freeway features that characterize each group of information sources, extensive field observations of all freeways in major Texas metropolitan areas (Austin, Dallas, Fort Worth, Houston, and San Antonio) were conducted [2].

The first group of information sources named "Highway", includes such roadway design features as horizontal and vertical alignment, number of traffic lanes, width of traffic lanes and shoulders, entrance and exit ramps.

Observations showed that urban freeways in Texas are represented by roadways with two, three, four, five, and six traffic lanes in one direction and that the majority of roadway design features are represented uniformly and are directly proportional to the number of traffic lanes Therefore, the highway group of information sources can be classified by three sub-groups with hypothesized ascending driver information load: (1) freeways with two traffic lanes in one direction, (2) freeways with three and four traffic lanes in one direction, and (3) freeways with five and six traffic lanes in one direction.

The “Traffic Control” group includes road signs, signals, and pavement markings. The statistics of different sign frequencies for all investigated freeways indicate that guide signs are overrepresented on urban freeways, while other signs (regulatory, warning, dynamic message signs, and lane control signals) are represented in small variations.

Considering the predominance of guide signs on urban freeways, their crucial importance on high speed facilities, uniformity of information provided, and assumed constant informational input by pavement markings, the general frequency of signs as criteria for sub-classification of the traffic control group of information sources was selected.

Because of the great importance of information flow velocity on human information processing, instead of the number of signs per unit distance, the number of signs per unit time calculated based on speed limit values, was implemented.

Conducted statistical analysis indicated that the selected three groups of freeways differ in terms of sign frequency. Taking into account the threshold character of human perception, and the observed variation of freeway sign frequencies, it was assumed to separate the traffic control group into three sub-groups utilizing 33-percentile values as a classification criteria. The observed distribution of sign frequency indicated that for two lane freeways, the 33-percentile value is less than 0.14 signs per second, three and four lane freeways, 0.15 signs per second, and five and six lane freeways, 0.20 signs per second, while the 66-percentile values were 0.18, 0.21, and 0.25 respectively. In absolute values this means an addition of 3-4 signs per kilometer of freeway with speed limit of 96 km/h (60 mph) per each sub-group. Therefore, for each freeway category, traffic control group of information sources should be divided into three sub-groups based on “lower-higher” criteria utilizing the above-mentioned values as: (1) low sign frequency (equal or less than 33-percentile value), (2) medium sign frequency (greater than 33-percentile but equal or less than 66-percentile values), and (3) high sign frequency (greater than 66-percentile value).

The “Visual Noise” group reflects the impacts of roadside objects which may consume driver attention but are not related to traffic or create inappropriate background for road signs and therefore interfere with perception of more vital information. These include commercial electronic and static billboards, artworks, architectural and landscape objects. The conducted observations showed that the maximum concentration of such objects contains up to around 20 objects per kilometer and on average is valued from 3 to 8 objects per kilometer of freeway. Similar to road signs, the intensity of visual noise was measured by the number of objects per second, and the observed distribution of visual noise frequency indicated that two lane freeways have a 33-percentile value of less than 0.05 objects per second, three and four lane freeways, 0.09 and five and six lane freeways, 0.10 objects per second, while 66-percentile values were 0.12, 0.19, and 0.24 correspondingly. Based on the above-mentioned values, the visual noise group was classified into three sub-groups: (1) low intensity (equal to or less than 33-percentile value), (2) medium intensity (greater than 33-percentile but equal to or less than 66-percentile values), and (3) high intensity of visual noise (greater than 66-percentile value).

The combinations of the above-mentioned three groups representing the classifications based on the roadway design, traffic control, and visual noise determine the freeway section class and contain in total twenty seven levels of information load, as represented in Table 1.

“Table 1 - Information Load Class Designation Matrix”.

Freeways	Road Signs Frequency Level								
	Low			Medium			High		
	Visual Noise Intensity								
	Low	Med	Hi	Low	Med	Hi	Low	Med	Hi
	Information Load Class								
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 are based on the intensity of different information sources, using for their comparison lower-higher criteria and arranged in order of increasing complexity (for example level 1 has lower informational input than 3). In such a case, quantification of information is based on the logical conclusion that a greater quantity of objects in the driver’s field of view will cause higher informational input. At the same time, the provided information loads classification still does not consider the most important factor – the impact of other vehicles.

The “Traffic” group of information sources characterizes impacts of other vehicles on information load. It is obvious that the behaviour of other motorists is of greatest importance due to the high level of unpredictability and possible consequences, such as incidents. Therefore, driver attention is mainly concentrated on surrounding vehicles and traffic volume can be a good descriptive characteristic of information load caused by other drivers.

At low traffic volumes, an individual driver has minimal interaction with other traffic participants. There is little or no restriction in maneuverability due to presence of other vehicles and so such conditions reflect the minimal input of traffic into general information load. As traffic volume grows, the condensing traffic flow reduces driver ability to manage interaction with other motorists and drivers need to observe more surrounding vehicles to select their own speed, change lanes, or pass. Together with no reduction of the traffic flow speed, this means increases in the number of information sources per unit of time. Taking into account that in condensed flow, a driver can observe only a limited number of surrounding vehicles, further increasing of traffic volume does not increase the number of informational sources and with speed reduction it causes reduction of information load.

Numerous traffic operations studies 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 [3]. So, it is reasonable to assume these values as thresholds for traffic group classification.

Different criteria can be implemented for the evaluation of the identified information load levels.

The first criteria, which can be named “crash frequency,” is based on the assumption that greater informational load may cause higher probability of driver errors and in turn increase crash frequency. Thus, a multiyear crash statistic analysis was selected for this evaluation phase, to study the possible associations between different levels of informational load and corresponding crash frequencies.

At the same time, absence of traffic collisions does not guarantee absence of dangerous traffic conditions or inadequate behaviour of road users that sometimes can cause the collision. So, it was concluded that, compared to the criterion of collision absence, the criterion of normal behaviour, which does not cause conflicts, is a better indicator of safety. This criterion defines safety as absence of systematic dangerous traffic conditions or inadequate driver behaviour [4]. In such a case, based on the analysis of traffic conditions and road users' behaviour, researchers identify and systematize situations that can potentially lead to collisions and develop improvement countermeasures. Therefore at the next evaluation stage, driver behavioural and psycho-physiological responses were investigated at each of the information load classes obtained by the above-mentioned methodology.

3. CRASH STATISTIC ANALYSIS

For purposes of this study, the state-wide crash database for the State of Texas, provided by the Texas Department of Public Safety (TxDPS) was used. 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.

From the general database, crash statistics for a sample of sections pulled from Texas Urban Freeway Database (TUFD) were extracted, which describe in detail the freeways characteristics. The selected freeway sections represented all 27 levels of information load. A total of 86,864 accidents took place on the sample sections during the observed three years.

A new data set for the 254 selected sections was constructed. It included length, annual average daily traffic volume (AADT) for each year, number of lanes, road sign frequency, visual noise object frequency, and the information about occurred crashes for the years 1999, 2000, and 2001.

For comparative analysis of the crash statistics on different freeway sections the accident ratio (AR) representing the number of accidents per million vehicle miles travelled was used.

This initial analysis focused on a general comparison of crash frequencies for freeway sections characterized by different levels of information load. Table 2 represents the obtained statistical characteristics of the accident ratio distribution.

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).

“Table 2 - Statistical Characteristics of Accident Ratios by Freeway Group and Sign Frequency”.

Freeways	Overall		Road Sign Frequency					
			Low		Medium		High	
	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
	Accident Ratio, accidents per million vehicle-miles							
2 Lane	0.75	0.36	0.50	0.26	0.81	0.32	0.88	0.43
3-4 Lane	0.87	0.47	0.70	0.41	0.84	0.45	1.11	0.46
5-6 Lane	1.19	0.98	1.60	1.21	1.09	0.81	0.64	0.40

Statistical analysis indicated a significant difference between observed sub-groups with significance levels varying from 0.5 to 0.95. Freeways with 5-6 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 5 and 6 lanes have the lowest crash frequency.

The next set of analyses targeted identification of a possible relationship between sign frequency and accident ratio. Figure 2 represents crash frequency on freeway sections characterized by different levels of sign intensity and at all levels of visual noise intensity.

The data shows that on freeways with 2 and 3-4 lanes, the accident ratio increases with increasing sign frequency while on freeways with 5-6 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.

The conducted analysis allows for the quantification of signage intensity that corresponds to the minimal crash frequency. On freeways with 2 and 3-4 traffic lanes the minimum crash frequency was observed at signage intensity of less than 0.14 and 0.15 signs per second, respectively. On freeways with 5-6 traffic lanes, the minimum crash frequency was observed at 0.25 and greater signs per second. Based on the most frequent speed limits on Texas urban freeways of 60 mph (97 km/h), these values correspond to 9, 10, and 15 signs per mile (5, 6, and 10 signs per kilometer). The crash increases on smaller freeways (2, 3, and 4 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 (5-6 lanes) where lower sign frequency may reflect some driver information underload.

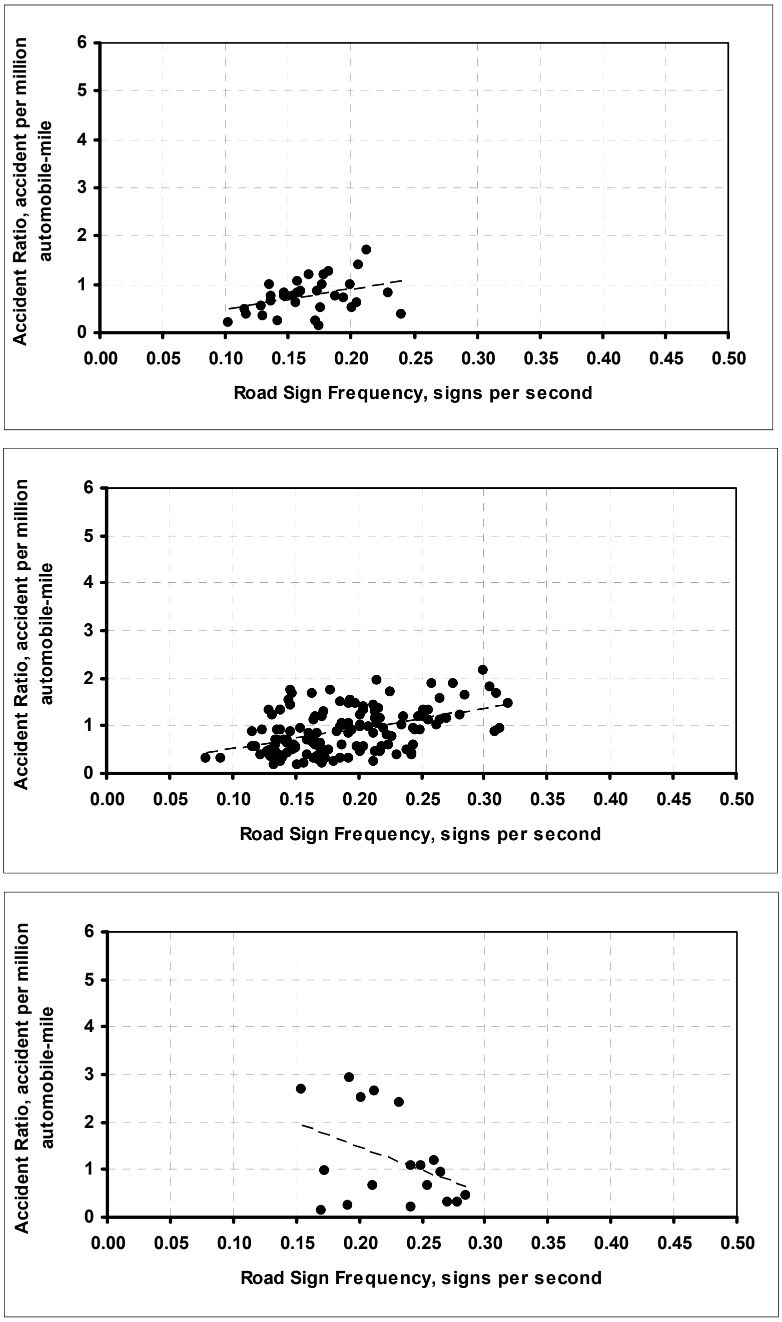
With further data separation by visual noise intensity, the limited sample sizes for freeways with two and three-four lanes do not allow to make valid conclusions. For freeways with three and four lanes, the statistical analysis indicated significant increases of crash frequency with an increase in visual noise intensity. At low road sign frequency, the observed increase of the accident ratio was on average from 0.47 to 0.93 accidents per million VMT, while at medium road sign frequency, those values increased from 0.62 to 1.14 accidents per million VMT.

The analyzed crash database contains detailed information concerning the manner in which accidents occurred, total number of vehicles involved in the accident, as well as the crash severity level. These frequencies were compared for all sign intensity levels within each freeway group, as shown in Tables 3, 4, and 5.

a)

b)

c)



"Figure 2 - Distribution of Accident Ratios by Road Sign Frequency on Freeway Sections with: a) 2 Lanes, b) 3-4 Lanes, and c) 5-6 Lanes".

"Table 3 - 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 4 - 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

“Table 5 - 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

Overall, the percentage of rear-end accidents varies little among the 3 freeway groups. However, freeways with 2 lanes have significantly higher percentages of rear-end accidents at medium and high sign frequencies with the highest, 44.0%, occurring at medium sign frequency. Freeways with 3-4 lanes also show a slight increase in rear-end accidents (4.2%) as sign frequency increases, but freeways with 5-6 lanes show the opposite effect: the percentage of such accidents slightly decreases (4.9%) with increasing sign frequency.

The rear end collision analysis as with occurrence of angle and sideswipe collisions, there is evidence to support that increased information load on freeways with fewer lanes causes more collisions related to improper maneuvering. On freeways with 2 lanes, the highest percentage of angle and sideswipe collisions was observed at high sign frequency. Conversely, increasing sign frequency on larger freeways (5-6 lanes), which may have been previously characterized by information underload, reduced the percentage of such accidents by 7.1 percent.

As evident in the data represented in Table 4, the majority of accidents occurring on analyzed freeway sections were 2-vehicle collisions, which account for around 57% of all crashes. As expected, freeways with fewer lanes (2 lanes) have the highest number of single-vehicle crashes (33.6%) with a simultaneous lower frequency of multiple-vehicle collisions (11.9%), while on larger freeways (5-6 lanes) such crashes were observed at 23.9 and 17.6 percent respectively.

Data indicated that on smaller freeways, an increase in sign frequency caused an increase of around 15% in 2 and more vehicle collisions that may be related to driver information overload. Again, data shows that low signage on larger freeways may cause driver information underload, as reflected by an 18% reduction in multiple-vehicle collisions with signage increase.

The accident database classifies five severity levels as: property damage only (PDO), possible injury, non-incapacitating injury, incapacitating injury, and fatality. For this study, possible injury, non-incapacitating injury, and incapacitating injury accidents were combined into one group of accidents labelled “injury”.

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% 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% for 2-lane freeways to 65.9% for 3-4 lane freeways to 67.1% for 5-6 lane freeways. As sign frequency increases, injury accidents on 2-lane freeways increase by around 12%, but remain fairly constant across all sign groups on highways with 3-4 and 5-6 lanes.

The conducted analysis leads to the following conclusions:

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 2, 3, and 4 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, it can be hypothesized that such conditions cause driver information overload. The analyzed data indicated that exceeding sign frequencies over 0.18 and 0.21 signs per second on freeways with 2 and 3-4 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 5 and 6 traffic lanes at lower sign frequency are characterized by increased danger of the driving environment. 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.

4. EXPERIMENTAL OBSERVATIONS OF DRIVER RESPONSES IN REAL TRAFFIC ENVIRONMENT

The second evaluation stage of the information load levels utilizes the criterion of driver behaviour, which does not cause conflicts, and is based on investigation of driver responses.

All driver responses to the driving environment can be classified into external or behavioral responses, which are corrective actions that the driver performs during the actual driving process and are reflected by the vehicle speed and trajectory, and internal, which reflect driver mental workload and involve both a subjective emotional reaction and specific psycho-physiological changes due to the driving environment.

Based on the review of methodologies for the estimation of driver responses to the driving environment the following parameters were selected for registering during experiments:

- Vehicle speed-time history, for driver behavioural reaction analysis;

- Visual stimuli sensed by the driver's eye, for qualitative assessment of traffic situations and identification of available stressors; and
- Driver electrocardiogram (ECG) and electrooculogram (EOG) for internal reaction analysis.

Field tests were conducted utilizing a special portable device that 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 in the driver's field of view,
- A module for monitoring and continuous recording of the driver's psycho-physiological responses.
- A notebook computer, which records all information.

Freeway sections representing each of the information load classes shown in Table 1 were selected for the test drive, and test routes that accommodate at least one section for four or five information load classes were designated. The selection of test routes took into account the proximity between investigated sections so that a single test-drive will not exceed two hours to avoid driver fatigue. Because only San Antonio has sections covering all different combinations of information load classes for two-lane freeways, it was selected for experiments on two-lane freeways. Due to the same reason, Dallas was chosen for investigations on three- and four-lane freeways, and Houston for five and six lane freeways.

Test drivers were selected from the TxDOT employees who permanently live and work outside of the cities designated for experiments, to avoid the familiarity effect. Eight drivers per city (in total 20 male and 4 female) with age 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 the test sections. After reaching the given destination, the driver was provided with the next target, etc. 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 stereo 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 in different traffic volumes representing conditions from free flow to condensed but not congested flow.

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

To determine the relationship between EOG amplitude (recorded in microvolts) and eye movement angle, standard calibration was performed with each driver before the test. For identifying the points of driver eye fixations, a technique developed by CTR, which allows overlaying an electropotential of eye movements onto a video recorded driver visual field, was implemented.

For comparative analysis, the obtained data were classified based on traffic conditions during the test drive. The initial observations showed that at the same hourly traffic volume on the investigated freeway section, traffic conditions during different tests may vary between free 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 in traffic flow respectively. This criterion was named Vehicle Interaction Level (VIL) and its quantification characteristics are represented below:

VIL-A: Around 75 percent of travel time no vehicles are in close proximity, headways between vehicles mostly exceed 4 seconds, drivers can select speed, travel path, and maneuver with little required consideration of other vehicles.

VIL-B: Around 50 percent of travel time surrounded by other vehicles, predominant headways 2 to 3 seconds, moderate maneuvering difficulties, actions of other vehicles may require test driver correction actions, occasional vehicle condensation.

VIL-C: More than 50 percent of travel time driving in dense platoons, all traffic lanes uniformly occupied, headways 2 second 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, formulating that reduction of speed over 10 km/h indicates some insufficiencies in traffic conditions [5]. For quantitative estimation of driver psycho-physiological responses the heart rate analysis determined that increase of heart rate over 115% as compared to the pre-test level, indicates increased emotional tension [6].

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

Tables 6 and 7, and Figure 3 represent the sample of the general trend of the obtained data of driver responses on freeway sections characterized by different information load classes.

The statistical analysis of drivers' behavioral responses indicated that among information load classes 1 through 9 (two lanes freeways) classes 5 to 9 significantly differ and are characterized by highest average speed reduction and increased frequency of intense braking.

On freeways with three and four traffic lanes (information load classes 10 through 18), the tendency of heightened driver activity with information load growth was observed as well, with the major impacts at information load classes 15 and higher and with increased levels of vehicles interactions.

Data indicated that there are no significant differences in speed distribution on freeways with five and six traffic lanes, characterized by information load classes 19 through 27. At the same time tendency of reduction of extensive braking on sections of higher information load classes (23 and higher) can be noted overall for all vehicles interaction levels.

“Table 6 - Average Test Driver Characteristics of Speed Distribution for Different Information Load Classes”.

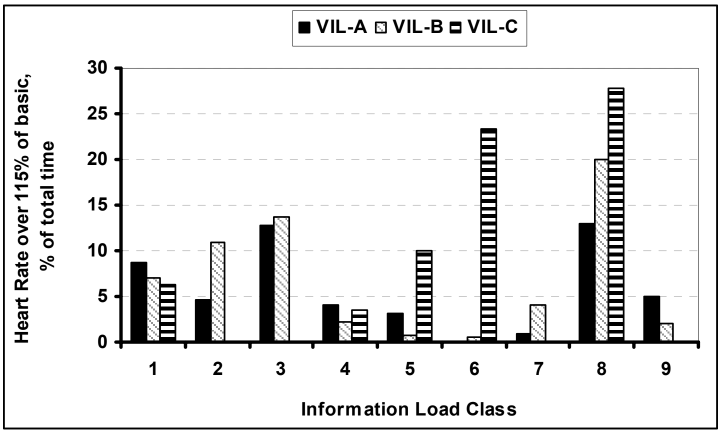
Information Load Class	Vehicle Interaction Level								
	A	B	C	A	B	C	A	B	C
	Mean Speed, km/h			Speed Standard Deviation, km/h			Frequency of Braking over 10 km/h, % of total		
2 Lanes Freeways									
1	101.88	99.00	102.43	5.79	5.79	4.01	3.37	2.85	1.38
2	101.20	96.62	no data	5.54	5.80	no data	0.64	1.02	no data
3	99.43	98.10	no data	7.19	7.12	no data	4.02	4.12	no data
4	102.80	101.47	99.60	3.77	5.14	4.94	1.49	0.00	2.00
5	97.73	100.33	97.97	6.77	6.91	8.43	3.79	1.11	6.93
6	100.37	95.50	95.18	5.07	16.58	5.56	5.07	5.83	3.29
7	100.28	100.43	100.96	6.95	5.19	4.32	7.48	4.44	4.32
8	90.77	84.51	86.70	5.99	5.99	7.07	0.81	2.08	3.90
9	94.76	95.03	no data	6.59	7.02	no data	9.17	4.03	no data
3-4 Lanes Freeways									
10	100.21	97.00	100.41	5.47	5.97	4.13	2.59	1.73	0.00
11	100.48	95.24	95.27	4.19	6.52	5.93	0.45	2.26	1.95
12	no data	97.94	91.89	no data	7.26	6.16	no data	4.25	7.81
13	100.28	95.57	no data	6.30	5.35	no data	3.52	1.81	no data
14	96.82	96.14	89.07	5.02	6.15	6.64	3.43	3.87	7.14
15	92.97	90.74	88.41	3.82	6.49	6.42	0.00	2.97	4.80
16	99.94	95.07	79.46	4.83	5.60	9.67	5.43	2.68	19.89
17	97.18	93.22	89.22	5.27	6.37	8.62	5.67	8.85	15.47
18	no data	88.41	89.07	no data	6.23	6.83	no data	5.33	8.47
5-6 Lanes Freeways									
19	96.68	99.49	105.74	4.87	4.92	7.29	2.86	10.67	11.11
20	98.49	95.99	94.09	6.98	6.47	5.84	3.46	3.37	7.25
21	88.89	90.05	91.19	3.89	5.10	4.67	6.67	2.86	9.96
22	99.19	99.66	92.27	4.57	5.64	7.63	6.25	3.14	7.14
23	97.09	96.64	87.52	4.93	4.10	5.67	0.00	0.00	no data
24	no data	93.31	94.12	no data	5.02	6.31	no data	5.38	6.88
25	no data	no data	no data	no data	no data	no data	no data	no data	no data
26	90.24	no data	no data	2.69	no data	no data	0.00	0.00	no data
27	90.50	92.82	99.01	5.78	5.39	5.36	0.00	0.00	0.00

“Table 7 - Average Test Driver Frequency of Eye Fixations for Different Information Load Classes”.

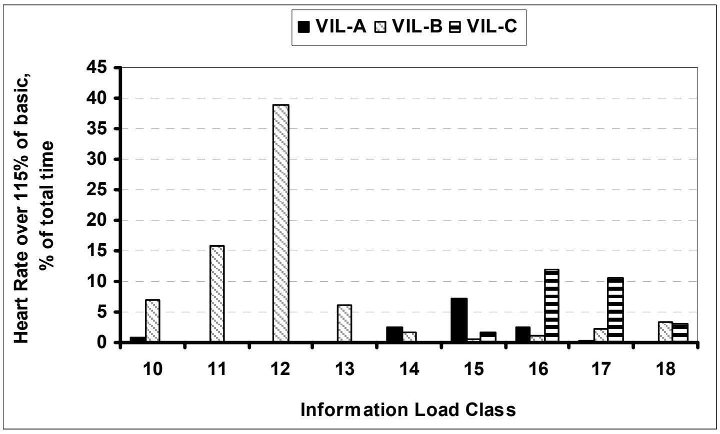
Information Load Class	Vehicle Interaction Level											
	A	B	C	A	B	C	A	B	C	A	B	C
	Areas of Eye Fixations											
	Zone of Clear Vision *			Control Area **			Instruments Panel			Other		
	percent of total time											
2 Lanes Freeways												
1	62.72	55.76	51.70	21.48	17.65	18.07	5.42	7.69	14.53	10.38	9.82	15.70
2	62.01	56.67	no data	23.08	26.46	no data	5.22	7.67	no data	9.70	9.21	no data
3	67.94	59.18	no data	17.80	28.17	no data	5.52	4.45	no data	8.74	8.20	no data
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	no data	18.11	18.11	no data	1.01	3.29	no data	3.92	8.54	no data
3-4 Lanes Freeways												
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	no data	69.90	65.05	no data	17.03	28.38	no data	3.38	0.89	no data	7.63	5.67
13	67.19	71.77	no data	15.92	16.90	no data	3.30	3.90	no data	8.07	9.14	no data
14	73.36	68.61	73.65	15.44	21.03	11.80	3.50	3.07	no data	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
5-6 Lanes Freeways												
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	no data	5.54	6.67	no data
24	no data	71.87	72.67	no data	15.80	16.82	no data	4.86	2.66	no data	7.47	7.85
25	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
26	72.54	72.10	82.46	11.11	15.91	14.83	5.83	2.42	no data	8.50	4.93	2.71
27	66.40	no data	84.67	20.90	no data	9.42	6.32	no data	0.74	7.96	no data	5.16

* driver vision area within +/- 10 degrees horizontaly and vertically

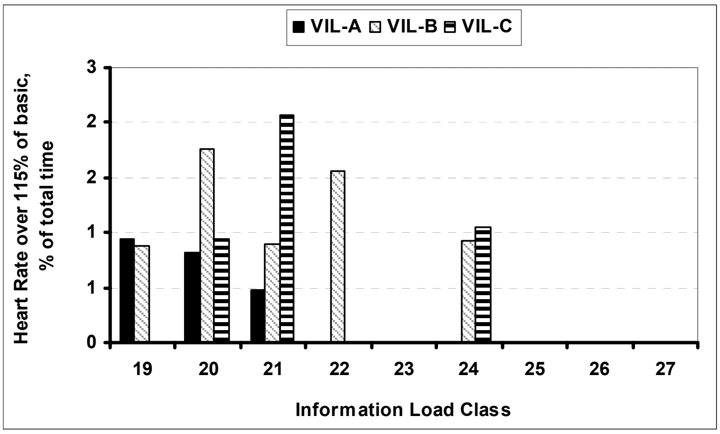
** driver eye fixations on the left and right outside mirror, inside rear-view mirror, adjacent vehicles on the right and left sides a)



b)



c)



"Figure 3 - Average Frequency of Drivers Heart Rate Greater Than 115% of Basic on Freeways with: a) 2 Lanes, b) 3-4 Lanes, and c) 5-6 Lanes".

The obtained data indicated a U-shape of the relationship between internal driver responses and information loads. Overall vehicle interaction levels on freeways with four or fewer lanes, driver lowest emotional tension was observed at information load classes characterized by medium road sign frequency (classes 4 and 5 for two-lane freeways and 13 to 15 for three and four-lane freeways).

The data for two, three and four lane freeways shows that with increased sign frequency, drivers spend greater time for visual search in the zone of clear vision. This occurs at an expense of lower attention to traffic situation on adjacent lanes and behind the vehicle as well as the vehicle instrument panel. Reduced attention to nearest traffic situations may cause inadequate estimation and behaviour. This hypothesis is supported by the crash statistic analysis.

Also, a high dispersion of driver eye fixations was observed on freeway sections with low signage. It is possible to hypothesize that with lack of sufficient information from road signs, drivers are forced to search the surrounding environment for some landscape marks or other objects to gather additional navigational information.

On freeways with five and six traffic lanes, driver internal responses showed a tendency to reduce with information load increase, with the minimal values at information load classes 25 and higher.

To determine more detailed threshold characteristics within the information load levels, the investigated characteristics of driver responses were plotted versus road sign frequency as in the sample represented in Figure 4. Together with the findings of crash statistic analysis, the obtained results identify the following road sign frequencies that correspond to minimal optimal levels of driver performance, mental workload, and reduced 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)

5. CONCLUSIONS

Combining the obtained findings of crash statistic analysis and investigation of driver responses, the following major conclusions can be made.

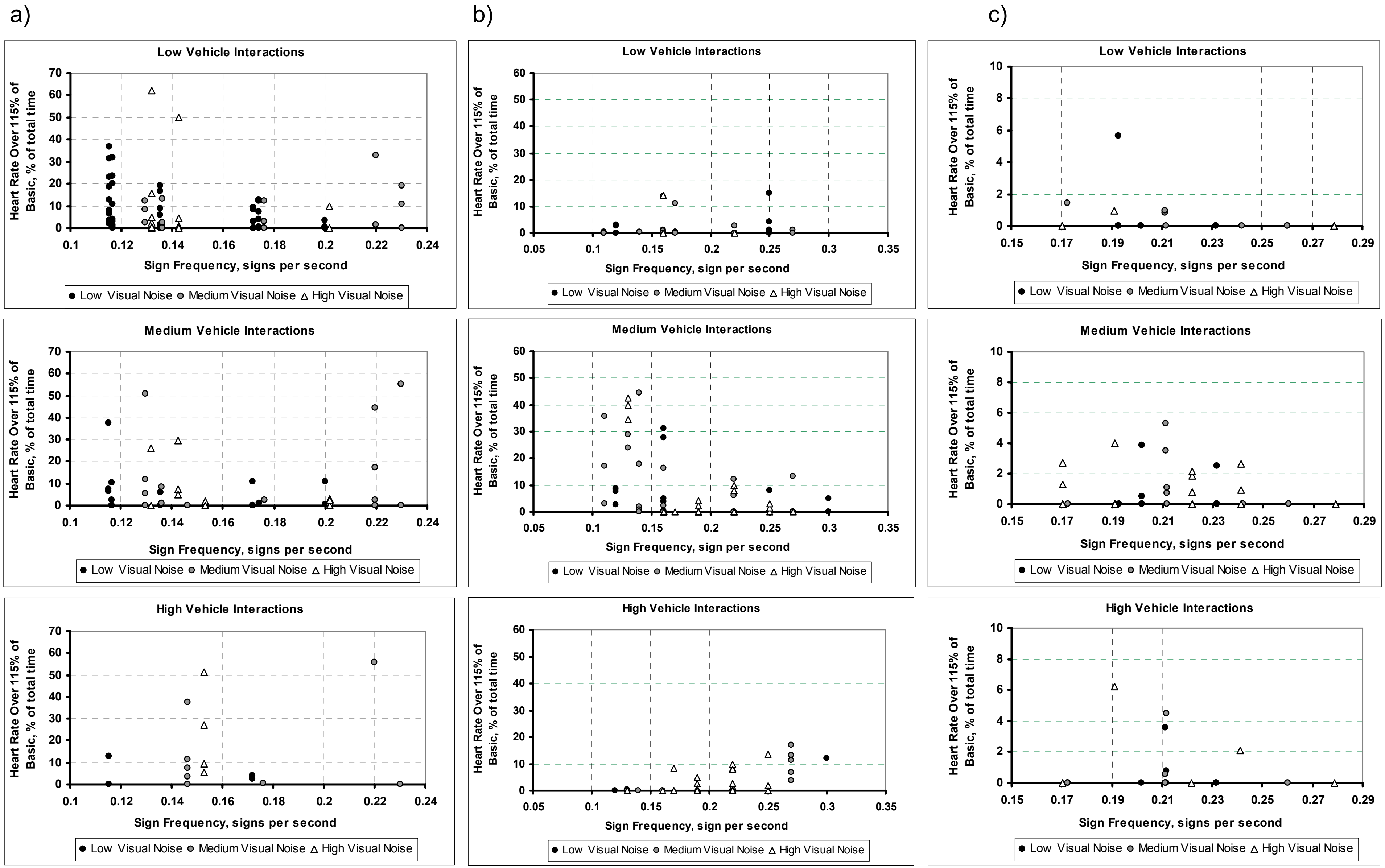
Increased sign frequency on urban freeways with two, three, and four lanes seemed to be related to growth in general accident frequency with a simultaneous increase of multiple-vehicle collisions and in some cases crash severity. This seemed to be a basis for a hypothesis that very frequent signs might cause driver information overload. On the other hand, on freeways with five and six traffic lanes, smaller sign frequencies were characterized by more accidents. This observation supports the hypothesis that less information (fewer signs on the observed wide cross section freeways) might contribute to driver information under-load.

Data indicated a U-shaped relationship between internal driver responses and information load with the most ideal driver reactions associated with the middle range of information classes on freeways with four or fewer traffic lanes.

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.

However, for five and six lane freeways, the most desirable driver responses were measured at the highest information loads that indicate a necessity of extended information provision on such facilities.

The summary of the obtained findings is represented in Table 8.



"Figure 4 - Frequency of Driver Increased Heart Rate on Freeway Sections with Different Road Signing Intensity: a) Two-Lane Freeways, b) Three and Four-Lane Freeways, and c) Five and Six-Lane Freeways".

“Table 8 - Drivers Performance and Responses at Different Information Load Levels 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 speed, low frequency of intense braking	low	low
	0.16 - 0.20	optimum	normal	high 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	high	high speed, low frequency of intense braking	low	medium
	0.18 - 0.22	optimum	normal	high 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 speed, high frequency of intense braking	high	very high
	0.25-0.29	optimum	normal	high speed, lower frequency of intense braking	low	medium
	greater than 0.29	n/a	n/a	n/a	n/a	n/a

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