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Effect of Freeway Level of Service and Driver Education on Truck Driver Stress - Phase 1

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16. Abstract
This research primarily deals with truck driver stress and its nature, stressors, and their mutual relationship. During the study, the different demands of driving that are related to roads, vehicle, traffic conditions, driver predisposition to stress and the surrounding environmental conditions were explored. The two distinct clusters of "Low Stress Level" and "High Stress Level" were identified in the stress distribution. The binary logistic regression method was used to relate these two conditions of stress with wide range of stressors. The result found that truck driver training was a statistically significant factor in predicting the low stress level. Other statistically significant factors increasing the likelihood of high stress levels were right turning maneuvers, passive overtaking and the traffic control related factors, such as the presence of a STOP sign as a control of the intersection. The drivers own personal dispositions to the stress were highly correlated with stress levels. The driving duration, the vehicle parameters like lateral velocity and co-axial acceleration were also significant variables in explaining stress levels. The study clearly identified that the provision of driving training could lower the driving stress level. Additionally, the significance of surrogate factors for level of service like passive overtaking, controls, acceleration and turn maneuvers also implied that the improvement of Level of Services (LOSs) of Freeway segments and intersections would play an important role in reducing driver stress.

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List of Abbreviations

Mid-America Transportation Center (MATC)
Central Community College (CCC)
Level of Service (LOS)
Intelligent Transportation System (ITS)
Charge Coupled Device (CCD)
State Trait Anxiety Inventory (STAI)
Coordinated Universal Time (UTC)
Greenwich Mean Time (GMT)

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Disclaimer

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Abstract

This research primarily deals with truck driver stress and its nature, stressors, and their mutual relationship. During the study, the different demands of driving that are related to roads, vehicle, traffic conditions, driver predisposition to stress and the surrounding environmental conditions were explored. The two distinct clusters of “Low Stress level” and “High Stress level” were identified in the stress distribution. The binary logistic regression method was used to relate these two conditions of stress with wide range of stressors. The result found that truck driver training was a statistically significant factor in predicting the low stress level. Other statistically significant factors increasing the likelihood of high stress levels were right turning maneuvers, passive overtaking and the traffic control related factors, such as the presence of a STOP sign as a control of the intersection. The drivers own personal dispositions to the stress were highly correlated with stress levels. The driving duration, the vehicle parameters like lateral velocity and co-axial acceleration were also significant variables in explaining stress levels. The study clearly identified that the provision of driving training could lower the driving stress level. Additionally, the significance of surrogate factors for level of service like passive overtaking, controls, acceleration and turn maneuvers also implied that the improvement of Level of Services (LOSs) of Freeway segments and intersections would play an important role in reducing driver stress.

Executive Summary

This research was aimed on identifying the sources of stress during driving, studying the nature of driving stress and defining its relationship with the demands. The focus of this study was novice truck drivers. The ultimate goal was to seek and identify practices, like traffic control and driver training, that can be instrumental in lowering driver stress. Stress is an important parameter to be controlled to maintain safe operating conditions on the road. This study used volunteer participation of truck driving trainees attending six-week truck driving training sessions in Central Community College (CCC) in Hastings, Nebraska. An integrated portable sensor system was utilized for real time data acquisition. The physiological sensor from Biopac was used to collect the heart beat rate from the subject. The Xsens MTi-G GPS and IMU Unit were used to collect the spatial location, velocity and acceleration information. The Charge Couple Device (CCD) machine vision camera was used to collect the visual information.

The driver specific information was collected using standard questionnaires. The data analysis performed on 23,716 data points, showed two distinct levels of stress which were defined as “Low Stress level” and “High Stress level”. The binary logistic model performed on the data identified 13 different statistically significant parameters impacting truck driver stress levels. In this study, the truck driving training was found useful in lowering the stress in trainee truck drivers. Driver predisposition to the stress, like the Trait Anxiety score and State Anxiety score, was found statistically significant in stress level prediction. The vehicle and traffic related parameters, like right turn maneuvers, the presence of STOP as control, passive overtaking, longitudinal and lateral component of acceleration and velocity, were found statistically significant on stress level prediction. The surrogate factor also gave the sense that the deteriorated LOS could give rise to high stress level. Similarly, the road types, such as collector

and minor arterial, and the time elapsed from the start to the instant of driving, were also found significant in stress level prediction. From the study, it is conferred that improving the intersection, level of services of segments and providing the driving education would play significant roles in reducing truck driver stress.

Chapter 1 Introduction and Objective

According to McGrath (1970), the state of imbalance between environmental demands and the response capabilities of the person or system to cope with these demands gives rise to “Stress”. It consists of a unique set of intellectual, emotional and physiological responses to a stimulus (Orris et al., 1997). “Stressor” is the element in the surrounding environment which disturbs the equilibrium and hence affects the performance. The third term, “stress reactions,” stands for the adverse health and behavioral consequences due to the failure to cope with the environmental demands. Stress among drivers could be the function of a driver’s own predisposition to stress as well as their reactions to the environment, which include road condition, geometry, weather, land use and temporal factors. In addition, the driving events in reaction to surrounding traffic and expected turn maneuvers essential to moving towards the destination add more workload on drivers which may cause stress. Furthermore, the exhibition of dual task paradigms such as using cell phones, eating, drinking and talking while driving can further increase the stress levels.

Stress has become an essential factor to be controlled to maintain a safe operating condition of our transportation systems. The growing importance is evident in recent transportation research focused on measuring, analyzing and developing the control mechanism of the stress during driving. It is an emerging field of transportation research. This study primarily deals with stress among novice truck drivers. Due to the size of body and the load the truck carries, it won’t be insensible to make a guess that truck drivers will experience higher stress level during driving than ordinary automobile drivers. Still, the measurement of cognitive factors in relation to the transportation in itself is a challenge for transportation professionals, in particular. This study was conducted in conjunction with the City Community College, Truck

Driving School located on Hastings, Nebraska. All the data collection was performed on the truck trainee drivers attending the six week training session conducted by the same school. The data collection was based on volunteer participation. The study used the physiological marker, the heart beat rate (BPM), as a measure of stress. The latest sensor technologies, like Biopac physiological sensors, GPS sensors and Charge-Coupled Device (CCD) machine vision camera connected with a portable computer, embedded in a test vehicle (truck) were used for real time data acquisition. Similarly, the psychological parameters were measured through standard questionnaires. This study attempted to solve the questions such as what are the environmental demands among truck drivers that cause stress, are they all significant, if not, which factors are significant and in what magnitude/direction do they affect drivers. In short, the objectives can be summarized in the following points.

1. To identify the broad range of probable stressors related to truck driving.
2. To analyze the distribution of stress levels.
3. To model the stress levels and to analyze the magnitude and direction of the effects of significant stressors.

The ultimate goal of this study was to find the controllable parameters that can be altered so that driver stress levels can be lowered. Driver training was among those parameters. It was hypothesized that driver training would be helpful in reducing stress during driving for the novice truck drivers. Similarly, the traffic control related parameters and the parameters that can be altered with changing controls, like turn maneuvers, and the congestion were also important parameters that needed to be evaluated in terms of the relationship with stress during driving.

The methodology conceived to achieve these objectives begins with the review of past works done by the researchers. The review of past works is compiled in Chapter 2 Literature

Review. The method and the devices used for data collection are described in Chapter 3 Data Collection. The process involved in data processing and the identification of probable stressors causing stress during driving are explained in Chapter 4 Data Processing and Identification of Stressors. The whole steps of analysis, which involved pre-modeling analysis, modeling and model performance tests, are included in Chapter 5 Data Analysis. The conclusion of the study based on model results and the further recommendations for the studies are presented in Chapter 6 Conclusion and Recommendation.

Chapter 2 Literature Review

This chapter summarizes a detailed literature review in the domain of driver stress, driver behavior and driver performance. According to the relevancy of the literature, the literature review is presented in the different sections as followings.

2.1 Driver Stress: Types and Indices

According to the definition by Spielberg (1983), the predisposition to the stress, “Trait Anxiety,” similar to potential energy, refers to the individual differences in reactions. In contrast, “State Anxiety,” similar to kinetic energy, refers to the intensity of a reaction at a specific time. State anxiety is often transitory in nature, which may recur when evoked by appropriate stimuli. Spielberg developed self-report scales to measure state and trait anxiety called State-Trait Anxiety Inventory (STAI). The developed state anxiety (STAI form Y-1) and trait anxiety (STAI form Y-2) scales comprised of 20 statements each evaluating how respondents feel at the particular time and how respondents generally feel, respectively. The STAI scaled was used in this research to measure a driver’s predisposition to be in a higher stress level and also to quantify the stated stress level.

Driver predisposition to stress has been found to be a significant factor affecting a driver’s stress level under a given scenario. Gulian, Matthews, Giendon and Davies (1989) developed the Driving Behavior Inventory (DBI) to study the dimensions of driver stress. They found 40% variation of driving stress governed by driving aggression, dislike of driving, tension and frustration related to unsuccessful or successful overtaking attempts, alertness and concentration. Matthews, Dorn and Glendon (1991) used Extraversion Psychoticism (EPQ) and DBI over 78 men and 81 women to study the relationship between personality and driver stress. They found driver stress positively correlated with EPQ scale, frequency of daily hassles and aggressiveness. Higher driver stress could be defined with poorer self-rated attention.

Instantaneous driver stress is often measured by using different quantifiable surrogate measures like heart rate, galvanic skin conductance, etc. Healey and Picard (1997) used such physiological signals as Electromyogram (EMG), Electrocardiogram (ECG), Galvanic Skin Response (GSR) and respiration through chest activity expansion (R) to detect the patterns of driving stress. Yamakoshi, Rolfe, Yamakoshi and Hirose (2009) used cardiovascular parameters on a beat by beat basis to measure a physiological index for driver's activated state (DAS) under simulated monotonous driving conditions. They investigated cardiovascular parameters in response to the application of electrical test stimulus (ETS) to develop a new DAS Index (DASI). From the 11 healthy male volunteers experimented on, they found a useful relationship between physiological variables and the objective judgment level (OJL) indicating that cardiovascular parameters are an important indicator of DAS. Rigas, Goletis and Fotiadis (2012) studied about the real time methodology for the detection of stress events while driving, based on physiological signals as electrocardiogram, electrodermal activity, respiration and past observations of driving behaviors. They obtained 82% accuracy in detection based only on physiological features. With the incorporation of driving information in the stress event detection model, the efficiency was increased to 96%.

In summary, it was found that most of the past studies have successfully used physiological markers such as ECG, GSR, BP, etc. as indices of stress. The drivers' own personal dispositions to stress were measured using questionnaires. The proposed study used heart rate and STAI to quantify surrogate of stress and driver predisposition, respectively.

2.2 Driver Stress: Relation to Traffic Conditions

Past studies indicate the existence of a relationship between driving conditions and driver stress. Hulbert (1957), through his research, showed that the traffic conditions could affect driver stress. The test on 21 male students clearly indicated that 91% variations on stress could be explained by traffic conditions: the actual interruption of traffic (complete blocking of path), possible interruption (potential for complete blocking), actual infringement (partial blocking of path) and the possible infringement (potential for partial blocking). Novaco, Stokols, Campbell & Stokols (1979), studied the traffic congestion as a behavioral constraint among the commuters. They measured congestion in relative terms of distance and speed. The distance and speed of the commute to work was found significantly affecting the physiological arousal measured in terms of blood pressure. Similarly, Hennessey and Wiesenthal (1997) were also able to support their hypothesis that the highly congested traffic condition would lead to higher state stress than low congested traffic among automobile drivers. They also showed that driver aggressiveness would also increase if the congestion increased from low to high. Although the stress level for all the drivers in congested traffic condition was high, it was found that the driver who has high predisposition to stress would react more to the congested traffic condition. Although, the relationship between driver stress and aggregate environment show a relationship between congested conditions and driver stress, there is a limited research to construct microscopic models between driver stress level and instantaneous driving conditions. The literature becomes even scarcer when truck drivers are the subject of focus as compared to car drivers. This research was focused to microscopically identify the statistically significant stressors faced by truck drivers. The results from this study can be used to mitigate stress inflicting conditions.

Pompei, Sharon, Buckley and Kemp (2002) built a driver activity monitoring system using smart sensors to track such driving factors as driving conditions, driver reactions, control usage, driver reflexes and passenger interaction. This automobile–integrated monitoring system was used to assess the drivers’ cognitive load and the reactions. The study is ongoing and is aimed to identify the most stressful driving events and the logical steps to reduce day-to-day driving distraction risks. Peeta and Zhou (2005) introduced stress factors during truck-car interaction in the existing car following model. They also proposed a simulation based framework alternative to mitigate car-truck interactions. Wallis and Horswill (2007) used the fuzzy signal detection theory to determine the reason behind the faster responses in the hazard perception test for experienced and trained drivers. They did tests on 25 trained novices, 27 untrained novices and 17 untrained experienced drivers and found that the group differences were not explaining the hazard perception test results. There was no relationship between hazard rating and hazard perception reaction times. Wang (2009) worked on the development of the intellidrive based red light running (RLR) collision avoidance system for signalized intersection safety. They observed both isolated motion and car following status of the vehicles to predict signal violation. They found that after the incorporation of the car following status, the detection rate improved significantly. The communication latency was a critical parameter for the proactive safety system as it governed all red extension requests. The test proved that intellidrive supported the reliable prediction of RLR.

2.3 Driver Stress: In Context of Different Types of Drivers

Driver stress can vary significantly with the mode of transportation. Hartley and Hassani (1994) found the occupational demand as the main reason behind the stress among truck drivers. However, psychological health, age, experience and aggression were the main reasons of stress among car drivers. They came to conclusion based on the Driver Behavior Inventory (DBI) with an additional survey of violation involvement of truck and car drivers. A similar study by Orris et al. (1997) confirmed that truck drivers would have psychological distress above the average level of the U.S. working population. The truck drivers perceived more daily stressful events than average working adults. A study by Kompier and Di Martino (1995) about the bus driver's occupational stress and stress prevention identified high and conflicting demands, low autonomy and support, threats and violence, work schedules and work-leisure relationship as the constraints in the working situation. Some important factors that could be preventive measures for stress are the ergonomics of the bus cabin, job rotation and combination of jobs, work routines, breaks and shift of the schedules, and the management. In a similar study, Kloimuller, Karazman, Geissler, Karazman-Morawetz and Haupt (2000) analyzed the relationship of age, Workability Index (WAI) and stress inducing factors and found a strong correlation between stressors and stress symptoms of WAI. A weak correlation between WAI with age was found. Matthews, Tsuda, Xin and Ozeki (1999) studied about individual difference in driver stress vulnerability in a Japanese sample and they compared it with the UK sample. The relationship between the driver stress factors, demographic and life stress variables in the Japanese and UK samples were similar. However, there were some minor differences, such as reactions to overtaking, in the two cultures due to the provision of different traffic laws.

The above literature review explained the different type of drivers and their occupation stressors. This proposed study concentrated on truck driver trainees and minimization of the stress occurring due to the occupational stressors and fatigue related to the traffic environment induced stresses.

2.4 Driver Characteristics and Performance

Driver characteristics like age, gender, experience and level of training were found to have influence on the driving behaviors of decision making, risk taking, decelerating, hazard anticipating and situational awareness. Also, the effect of roadside environment and the dual task paradigm can impact driving performance.

Driver age affects the decision making and risk taking behavior. A study by Konecni, Ebbesen and Konecni (1976) about driver response on the decision process and risk taking in the onset of a yellow light examined the drivers’ position in the approach of the intersection and the probability that driver would choose to proceed through the intersection. They found that young drivers drove faster and even increased their speed in the intersection. Similarly, the effect of age and gender on driving behavior was reflected in a study by El-Shawarby, Rakha, Inman and Davis (2007). With the observations of driver deceleration behavior at signalized intersections, they found male drivers demonstrating a slightly higher rate of deceleration than female drivers. The young drivers (age less than 40) and older drivers (age greater or equal to 60) decelerated at higher a rate than the drivers in the 40-59 year age group. The level of training could vary the hazard anticipation behavior of the drivers. Regarding the hazard anticipation behavior, Fisher, Pradhan, Pollatsek and Knodler (2007) did an empirical evaluation of it on the field and on a driving simulator using an eye tracker. They considered five scenarios. The scenarios that were similar to those seen during training were considered as near transfer cases and the other five scenarios that were different in surface features than those seen in training were considered as far transfer cases. They found trained drivers recognizing the risk 41.7% more than untrained drivers in near transfer scenarios on testing with the simulator. The same result for the far transfer case was 32.6%. In the field, trained drivers recognized the risk by 38.8% and 20.1% more than untrained drivers for near transfer and far transfer cases, respectively. Similarly, a study done by Lee, Olsen and Simons-Morton (2006) about eye glance behavior of novice teen and experienced adult drivers indicated the novice teens lacking the situational awareness more than the experienced adults.

The driver performance can be influenced with the presence of in-road facilities and off-road features. A study by Van der Horst and Ridder (2007) about the influence of road side infrastructure on driving behavior found drivers moving laterally and slowing down because of the safety barrier. The trees that are within 2 m distance from the road edge could also cause the driver to slow down for a short period of time. The dual task paradigm also affects driver performance and even could risk the driver's life. The use of mobile phones is a good example of it. Kawano, Iwaki, Azuma, Morriwaki and Hamada (2005) studied about the distraction of using mobile phones with degraded voices, such as spectral distortions, delay and interruptions. The use of mobile phones would utilize the resources for auditory perception and auditory attention, which is imperative for driving. The more the voice is degraded, the more will be the use of those resources. Hence, more risk is involved in a moving car than parked car due to the higher chance of the voice being degraded. Similarly, Schattler, Pallerito, McAvoy and Datta (2006) assessed driver distraction from cell phone use using a simulator. They assessed driver performance based on overall driving scores, speed profiles, vehicular lateral placement within travel lanes and the number of crashes that occurred during the simulator experiment. The study concluded that using cell phones while driving could significantly degrade the driving performance.

The above literature review explained the effect of specific driver characteristics, training and environment on driver behavior and performance. This will help in understanding several drivers and environmental related characteristics to identify their impact on driver stress levels for the proposed study.

2.5 Social Stress and other Psychiatric Factors Affecting Safety on the Road

Psychiatric characteristics and stress introduced due to factors other than driving can also impact the driver safety on the road. Selzer, Rogers and Kern (1968) did a study aimed to identify the role of psychopathology (paranoid thinking, suicide, depression, violence, etc.), social stress and acute disturbance on fatal crashes. They found psychopathology as a major reason behind the fatal crashes. The acute disturbance also played an important role in fatal crashes. However, the social stress was found having less impact on fatal crashes. Brener and

Selzer (1969) also did a similar study in which they analyzed the risk of occurrence of fatal crashes due to alcoholism, psychopathology and social stress using similar methodology. They found that risk of fatal crashes occurring increased with alcoholism. Drivers with psychopathological manifestations were four times more vulnerable to fatal crashes than ordinary drivers. Similarly, the drivers with social stress were five times more vulnerable to fatal crashes than ordinary drivers. Selzer and Vinokur (1974) did a study on life events, subjective stress and traffic crashes which was aimed to find out how transitory life events and current subjective stress would affect the crash occurrence. They found demography and personality weakly correlated with crashes whereas life change and subjective stress significantly correlated with crashes. The drivers who were aware of broad social and ecological issues such as crime were less likely to be involved in crashes. Tsuang, Boor and Fleming (1985) studied about psychiatric aspects of crashes. They used past literatures to describe the relationship of psychological variables, suicidal tendencies, life events, alcohol and drugs to crashes. They found a strong relationship existing between crashes and violations with psychological issues. The role of stress on crashes was more evident in earlier studies than in later studies. The use of alcohol and drugs had been increasing the crash frequencies and it had been receiving increased attention. Mayou, Bryant and Duthie (1993) studied about psychiatric consequences of road traffic accidents. For this specific purpose, they interviewed 188 crash victims attending the emergency at the hospital. They found acute and moderately severe emotional distress on 1/5 of the victims characterized with mood disturbance and horrific memories of the accident. Post-trauma was common on 1/10 of the victims. Emotional disorder was associated with pre-accident psychological or social problems. There are factors other than driving induced stress that can contribute to fatal accidents but these factors can rarely be controlled by traffic engineers. This study will concentrate on traffic related factors and driving conditions.

This chapter provided the information about stress, its types, the method of measurement, stressors, its relevancy to traffic and its effect on driver performance and safety. Based on the literature, it was decided to collect the drivers' heart rate as a physiological index during data collection, which is described in detail in Chapter 3. The literature review also provided the basis to identify the types of stress and stressors which are dealt with in detail in both Chapters 3 and 4.

Chapter 3 Data Collection

This chapter primarily deals with the type, methodology and schedule of data collection implemented in the study. The methodology includes the details about the participant assignment, time, the devices/technology and time synchronization method used in data collection.

3.1 Data Collection Methodology

The study was conducted during a six-week truck driving certification course offered by Central Community College's Truck Driving Program in Hastings, Nebraska. The subjects were the participants of the truck driving certification course. The assignment was done on a voluntary basis where the subjects were required to complete signed consent forms. The subjects who successfully complete the study were compensated with $100 each. There were no compulsions to participants; they could opt out of the study at any time. The subjects were provided with random identification numbers which were used for identification of the subjects in the study.

The flow chart depicted in figure 3.1 provides the details of the data collection methodology. As shown in figure 3.1, the data collection was done both by real time measurement and through inventory using questionnaires. The study consists of two types of questionnaires.

a. Background information questionnaires: The background information forms contained questions related to general background information like gender, level of education, average miles driven in a week, involvement in crashes, etc. The background information was taken on the same day when base heart rate was taken and the consent forms were signed with the participants.

b. Self-evaluation questionnaires for State-Trait Anxiety Inventory (STAI): The STAI forms have 40 different statements. There are 20 statements related to state anxiety (eg: I feel calm, I feel strained, I feel steady, etc.) dealing with a person's feeling at the instant of action. Each statement has four levels of choices. State anxiety was measured two times during driving. One was before driving and the other was after driving. Similarly, there were 20 statements related to trait anxiety (eg: I feel nervous and restless, I am happy, I am content, etc.) dealing with a person's behavior. Trait anxiety was taken during a non-driving period on the same day base heart rate, consent form and background information was taken. The samples of the consent and background information forms are included in Appendix A.

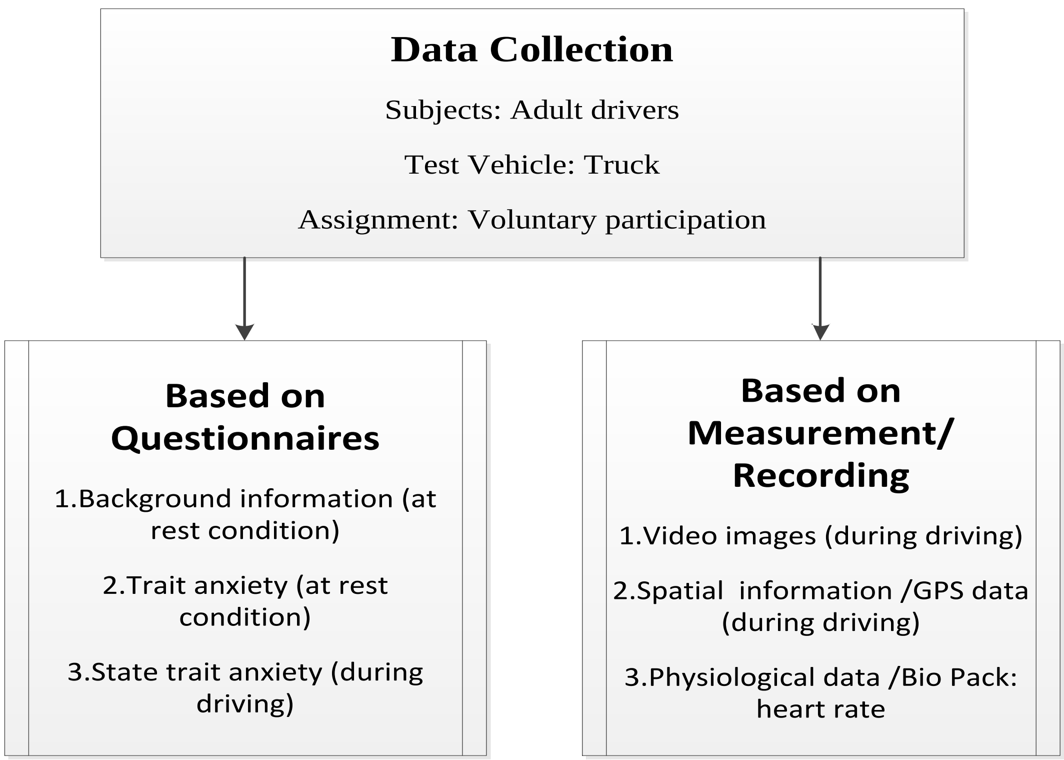


Figure 3.1 Data Collection Methodology

As explained in the flow chart depicted in figure 3.1, three types of data were collected based on measurement and recording.

1. Video Images: Video images were recorded by camera during driving. Separate video files were stored for each driver for each day of driving.
2. Spatial information: Spatial information includes velocity, acceleration and the driving locations of each driver. It was recorded with GPS for each driver for each day of driving.
3. Physiological data: The heart rate both at rest condition and driving condition were acquired from the subjects as physiological data. The heart rate at rest condition, which is also known as base heart rate, was taken for 5-10 minutes duration only once for one driver for each training session. The driving heart rate was taken during driving for each driver for each day of driving. The Biopac was used for acquiring physiological data.

3.2 Devices used for Data Collection and the Time Synchronization

For the data collection, the following three devices were used and connected with Logisys truck computer (4). Figure 3.2 depicts the devices used for data collection. Figure 3.3 depicts the images of the subject and test vehicles.

1. Prosilica Camera
2. Xsens MTi-G GPS and IMU unit
3. Biopac MP 150 with TEL100MC

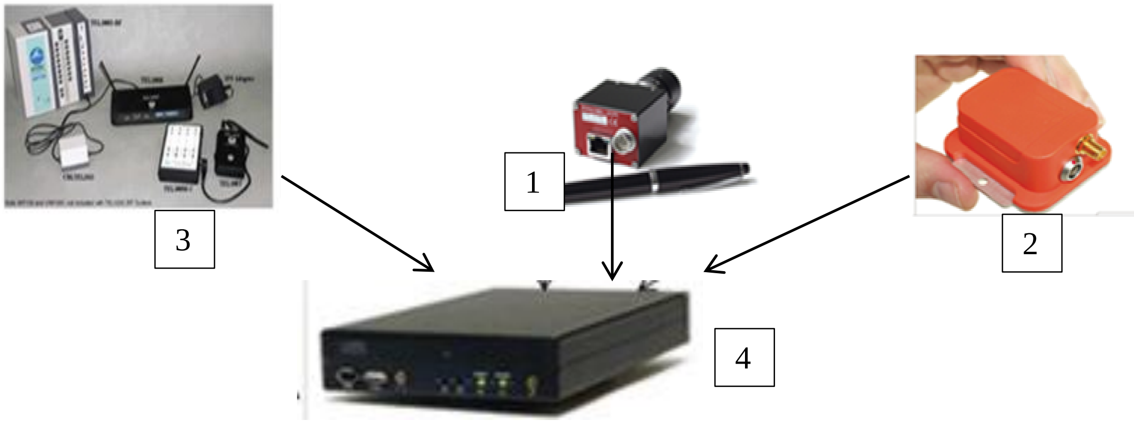


Figure 3.2 Set Up of the Devices

Figure 3.3 The Subject and the Test Vehicles

3.2.1. Prosilica Camera

The Prosilica GC 650 C is a compact and high performance charge-coupled device (CCD) machine vision camera. It is provided with Gigabit Ethernet Interface (Gig E Vision®) which allows them to have a 90 frames per second (fps) frame rate and long cable lengths (cited in Allied Vision Technologies, 2012). In the test vehicle-truck, the Prosilica camera was mounted at the front of the truck near the front-windscreen connected to Logisys Truck computer with Ethernet. Table 3.1 shows the important features of the Prosilica GC 650 C.

Table 3.1 Features of Prosilica GC 650 C

Characteristics	**Capacity**	**Characteristics**	**Capacity**	**Characteristics**	**Capacity**
Resolution	659 (h) 493(v)	Sensor Size (inch)	1/3	Color/B & W	Color/B&W
Frame Rate (fps)	90	Sensor Type	CCD	Sensor Device	Sony IC x 424
Pixel Size	7.4(h) 7.4 (v)	A/D Bits	12	Shutter Speed (μs)	call
Interface	GigE	Voltage(VDC)	12V	Power (watts)	3
Lens Mount	C	Shutter Type	call	Weight (grams)	99
S/N Ratio (dB)	Call	External Trigger	call	Dimensions (mm)	38Lx46Wx33H

Note: The features are based on the information provided by Allied Vision Technologies

3.2.2 Xsens MTi-G GPS and IMU Unit

The Xsens MTi-G integrated with Inertial Measurement Unit (IMU) was featured with a navigation system known as the Attitude and Heading Reference System (AHRS) processor. It was comprised of MicroElectroMechanical Systems (MEMS) inertial sensors, a miniature GPS receiver and a 3D magnetometer and static pressure sensor. It provides drift- free, GPS enhanced, 3D Orientation estimates, as well as calibrated 3D acceleration, 3D rate of turn, 3D earth magnetic field data and static pressure. It is extensively used in robotics, aerospace, autonomous vehicles, marine industry and automotive applications (MTi-G user manual and technical documentation, 2009). In a study by Feliz, Zalama and Garcia-Bermejo (2009) about pedestrian tracking using inertial sensors, MTi-G was found providing the reliable and accurate measurement with an accuracy level of about a thousandth of all measurements. Similarly, Gourati, Mannamanni, Afilal and Handrich (2012) used IMU to develop and to validate the human body movement estimation. Research conducted by Aviation Engineering Centre, Ohio University also found reliable attitude and heading accuracy of MTi-G even in high dynamic flight tests (Xsens, 2012). Table 3.2 shows the calibrated data performance specification of MTi-G.

Table 3.2 Calibrated Data Performance Specification of MTi-G

		Rate of return	**Accel-eration**	**Magnetic field**	**Temp-erature**	**Static pressure**
Unit		deg/s	m/s^2	mGauss	^0C	Pa
Dimensions		3 axes	3 axes	3 axes		
Full Scale	Units	+/-300	+/-50	+/-750	-	30 - 120.10^3
Linearity	% of FS	0.1	0.2	0.2		0.5
Bias Stability	[units of 1 σ][22]	1	0.02	0.1	0.5[23]	100 /year
Scale factor stability	[%1 σ][22]	-	0.03	0.5	-	-
Noise density	Deg	.05[24]	0.002	0.5(1σ)[25]	-	4[26]
Alignment error	Hz	0.1	0.1	0.1	-	-
Banwidth		40	30	10	-	-

Note: The information is based on MTi-G User Manual.

In the truck, MTi-G was placed orienting X in the driving direction of the truck. The whole unit was connected to the USB port of Logisys truck computer with Xsens USB–serial cable.

3.2.3. Biopac MP 150 with TEL100MC

The MP 150 system is a physiological Ethernet- ready data acquisition system and analysis that allows recording, viewing, saving and printing the data. It can record multiple channels with different sample rates with the speed up to 400 KHz (Biopac System Inc., 2012). The whole workstation was comprised of an MP 150 acquisition unit, TEL 100 MC and the interactive software known as Acq*Knowledge* ®. It has very wide applications, such as in biomechanics, cardiovascular hemodynamics, cardiology, electroencephalography, electrogastrogram, electromyography, eye movement, evoked response, etc. Dhillon and Rekhi (2011) used Biopac to measure the emotional state of humans through electrocardiogram. Thus measured electrocardiogram reflected the difference in emotional state and the rest state in 90.93% of the subjects. Similarly, Singh, Singla and Jha (2009) measured the effect of mental states on blood pressure and cardiogram using Biopac. Thus measured blood pressure could differentiate the tasks like motor action and thoughts and the cardiogram could differentiate the memory related tasks and emotions. Some information about performance characteristics of MP 150 is shown in table 3.3. In the truck, Biopac was placed on the floor. The electrodes from TEL 100 MC were connected to the subject's body to acquire cardiogram in the manner shown in figure 3.4.

Table 3.3 Some Features of MP 150 Data Acquisition

Characteristics	**Range**
Resolution	16 bit
Speed	up to 400 KHz
Sample rates	Record signals at unique sample rates to maximize storage efficiency
Inputs/Outputs	16 analogue input, 2 independent analog outputs
Has Digits I/O lines	_
Online calculation channels	16

Note: The information is based on MRI Research for the Life Sciences Catalog

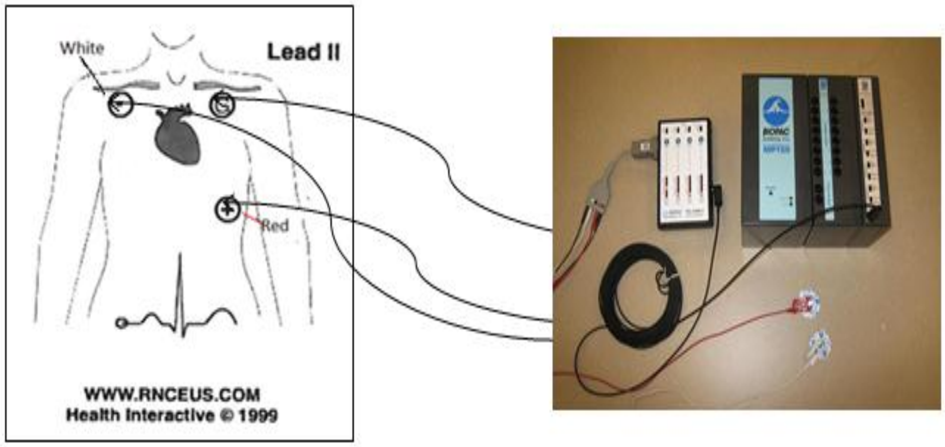


Figure 3.4 Set Up for Acquiring Cardiogram

3.2.4. Time Synchronization

During data collection, the physiological data and the video images were recorded with the computer time which was set according to the Central Time Zone for eastern Nebraska. The GPS data were recorded with GPS time which was default at UTC/GMT. The difference between Central Time Zone and UTC/GMT is 6 hours during Standard Time (November 4 to March 11) and 5 hours during Daylight Savings Time (other than Standard Time). It was necessary to have the computer and GPS to be time synchronized. For this purpose, the time synchronization was done by adjusting the computer clock according to the GPS clock. The error was adjusted later during processing. The screen shot of the video image with two synchronized clocks is depicted in figure 3.5.

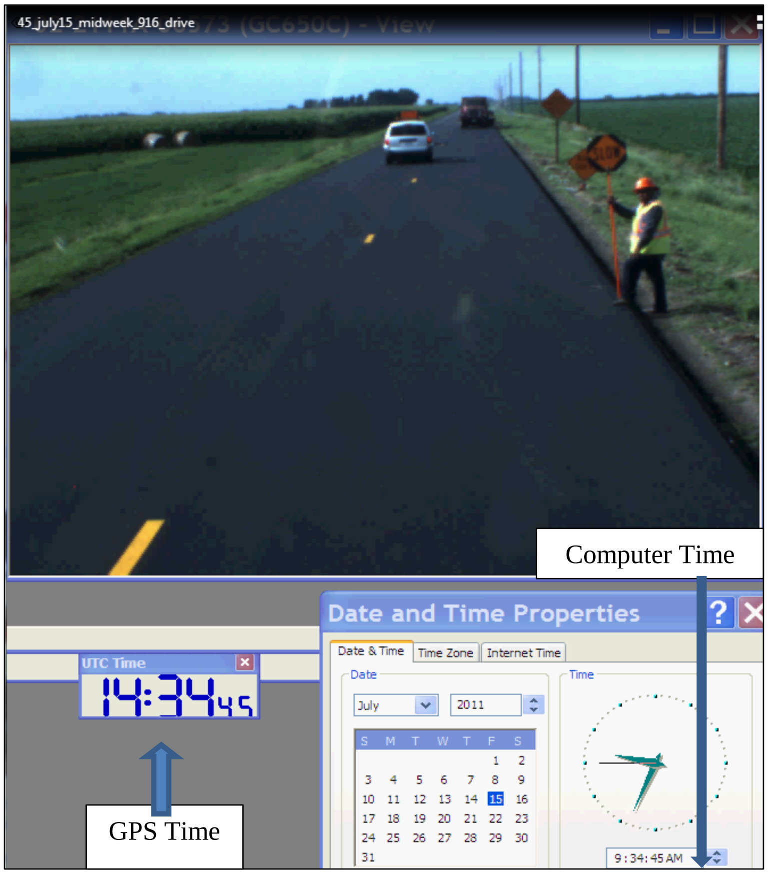


Figure 3.5 Video Image with Synchronized Time

3.3 Collected Data

The data was collected over nine months intermittently at different sessions starting from April 2011 to December 2011. The screen shot of the cardiogram is depicted in figure 3.6. The R-R interval shown in figure 3.6 represents the time elapsing between two consecutive R waves and provides the basis to calculate heart rate (heart rate = 60/R-R interval). The GPS data retrieved in excel is depicted in figure 3.7. The GPS data has time acceleration, velocity, gyrations and the coordinates. Table 3.4 presents the schedule of data collection. A total of 26 data sets for different driving days were collected.

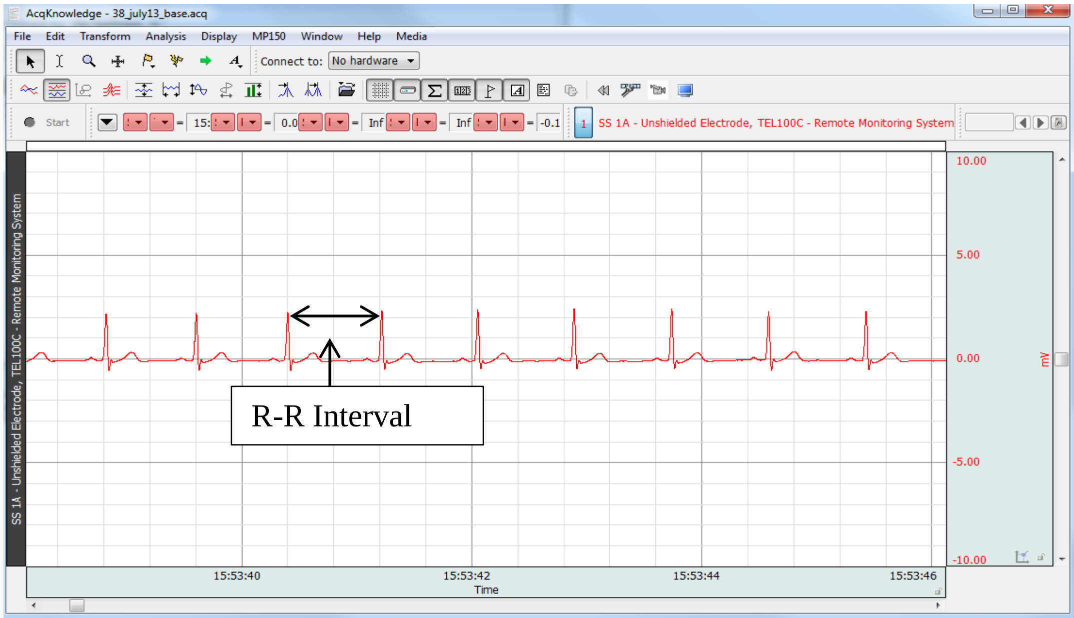


Figure 3.6 Screen Shot of Cardiogram Acquired by Biopac and Retrieved on AcqKnowledge®

Year	Month	Day	Second	Counter	Acc_X	Acc_Y	Acc_Z	Gyr_X	Gyr_Y	Gyr_Z	Mag_X	Mag_Y	Mag_Z	Quat_w	Quat_x	Quat_y	Quat_z	Latitude	Longitude	Altitude	Vel_X	Vel_Y	Vel_Z
0	0	0	0.0	48689	0.172	0.608	9.963	-0.005	0.000	0.002	-0.078	0.069	-0.294	0.400	0.000	-0.010	-0.917	40.574	-98.328	560.983	-0.111	0.046	0.085
2011	8	2	48560.2	48690	-0.032	0.077	9.788	-0.016	-0.017	0.006	-0.077	0.069	-0.295	0.400	0.000	-0.010	-0.917	40.574	-98.328	560.984	-0.111	0.048	0.085
2011	8	2	48560.2	48691	-0.024	0.341	9.968	-0.003	0.000	0.019	-0.077	0.056	-0.298	0.400	0.000	-0.010	-0.917	40.574	-98.328	560.984	-0.109	0.047	0.087
2011	8	2	48560.2	48692	0.165	-0.125	10.199	0.013	0.025	0.008	-0.077	0.068	-0.295	0.400	0.000	-0.010	-0.917	40.574	-98.328	560.985	-0.112	0.049	0.090
2011	8	2	48560.2	48693	-0.068	-0.164	9.673	0.005	-0.006	0.008	-0.077	0.056	-0.295	0.400	0.000	-0.010	-0.917	40.574	-98.328	560.986	-0.114	0.052	0.089
2011	8	2	48560.2	48694	0.184	0.180	9.872	0.011	0.005	0.001	-0.078	0.055	-0.295	0.400	0.000	-0.010	-0.917	40.574	-98.328	560.987	-0.115	0.052	0.090
2011	8	2	48560.2	48695	0.280	0.580	9.452	0.000	-0.005	-0.005	-0.078	0.055	-0.294	0.400	0.000	-0.010	-0.917	40.574	-98.328	560.988	-0.113	0.048	0.086
2011	8	2	48560.2	48696	-0.007	0.360	9.344	-0.018	0.006	0.010	-0.078	0.061	-0.292	0.400	0.000	-0.010	-0.917	40.574	-98.328	560.989	-0.111	0.047	0.081
2011	8	2	48560.3	48697	0.207	0.258	10.017	-0.008	-0.006	0.004	-0.077	0.067	-0.294	0.400	0.000	-0.010	-0.917	40.574	-98.328	560.990	-0.111	0.046	0.084
2011	8	2	48560.3	48698	0.139	0.132	9.722	-0.022	-0.013	-0.004	-0.076	0.070	-0.296	0.400	0.000	-0.010	-0.917	40.574	-98.328	560.990	-0.112	0.046	0.083
2011	8	2	48560.3	48699	-0.197	-0.131	9.827	0.007	0.011	0.005	-0.078	0.068	-0.294	0.400	0.000	-0.010	-0.917	40.574	-98.328	560.991	-0.113	0.050	0.083
2011	8	2	48560.3	48700	-0.029	0.107	10.326	0.023	0.007	-0.001	-0.076	0.071	-0.294	0.400	0.000	-0.010	-0.917	40.574	-98.328	560.992	-0.112	0.051	0.088

Figure 3.7 Screen Shot of GPS Data Retrieved in Excel®

Table 3.4 Schedule of Collected Data (April 2011 to December 2011)

Drivers' random IDs	Driving on freeways	Driving on non-freeways	First day of driving	Day elapsed in training (days)
4	29-Apr	11-May	11-Apr	18/31
21		27-Apr	11-Apr	16
19		10-Jun	11-May	30
86		10-Jun	11-May	30
97		10-Jun	11-May	30
86		20-Jun	11-May	40
67		22-Jun	11-May	42
97		22-Jun	11-May	42
45		15-Jul	11-Jul	4
51		15-Jul	11-Jul	4
39	25-Jul		11-Jul	14
81	25-Jul		11-Jul	14
39		29-Jul	11-Jul	18
81		29-Jul	11-Jul	18
45		2-Aug	11-Jul	22
51		2-Aug	11-Jul	22
6		7-Oct	3-Oct	4
69		7-Oct	3-Oct	4
70		7-Oct	3-Oct	4
6		19-Oct	3-Oct	16
69		19-Oct	3-Oct	16
58		21-Nov	7-Nov	14
95		21-Nov	7-Nov	14
58		5-Dec	7-Nov	28
95		5-Dec	7-Nov	28

Note: Repetition of same ID indicates same subject being tested on more than one driving day

This chapter provided the information about all the data collected in the field and its methodology. The raw data thus collected were stored and processed. The proceeding chapter deals with data processing in further details.

Chapter 4 Data Processing and Identification of Stressors

This chapter deals with two different activities. The first one is the retrieval of data collected in the field in proper format, processing them to get required information and merging them. The second process is the identification of probable stress causing parameters and their categories.

4.1 Overall Process

The overall data processing flowchart is depicted in figure 4.1. It involves two processes. In the first process the total event table was prepared based on the drivers’ background information, visual information from video images and respective state and trait anxieties scores. The data merging was done for each day’s data set. In the second process, the spatial information from GPS data and the physiological data that is the driving heart rate were merged with the event table. The merging was done taking in reference of the time, which is the time of events from video images, the time of heart rate data in heart rate and the GPS time. The final product was total aggregated data with all the information in one sheet. The whole process is described in details in the following subsections.

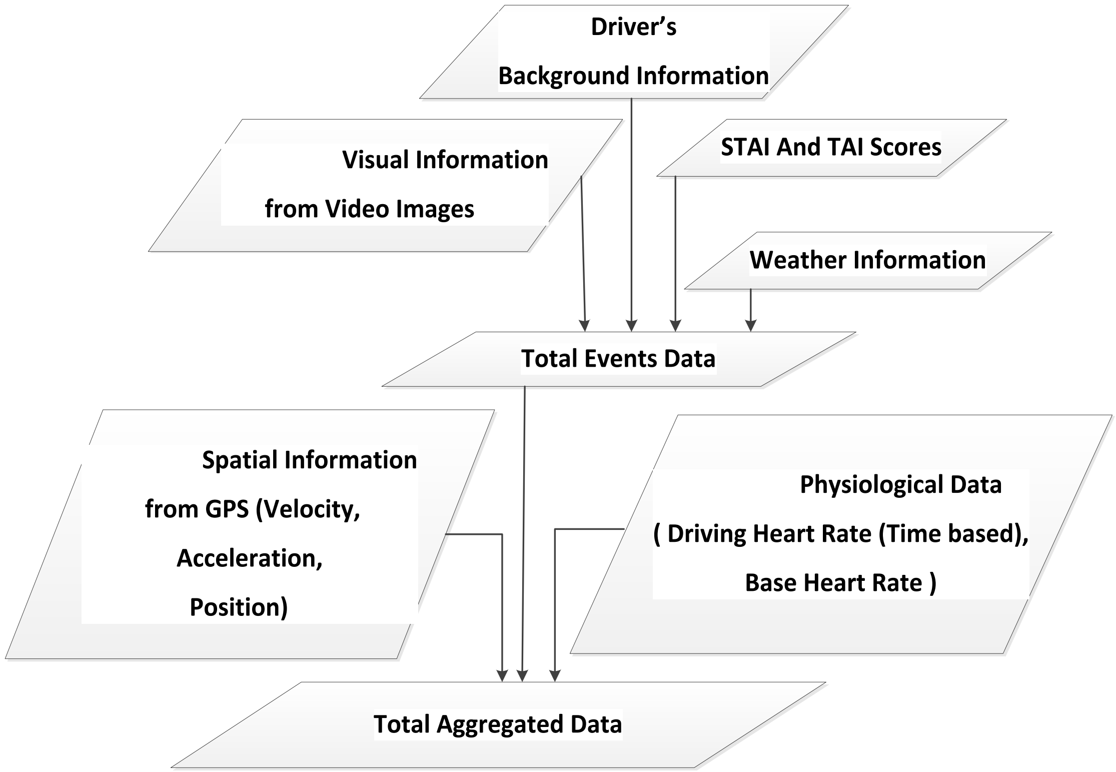


Figure 4.1 Data Processing

4.2 Questionnaires Based Data

The background information, state anxiety and trait anxiety related data, which were collected through questionnaires, were transferred into a Microsoft Excel® sheet. Each driver's state anxiety and trait anxiety scores were obtained through processing STAI using the method prescribed in Spielberg (1983). The example processing is included in Appendix B. The final outcomes were the state and trait anxiety scores which could be used in the analysis.

4.3 Measured/Recorded Data

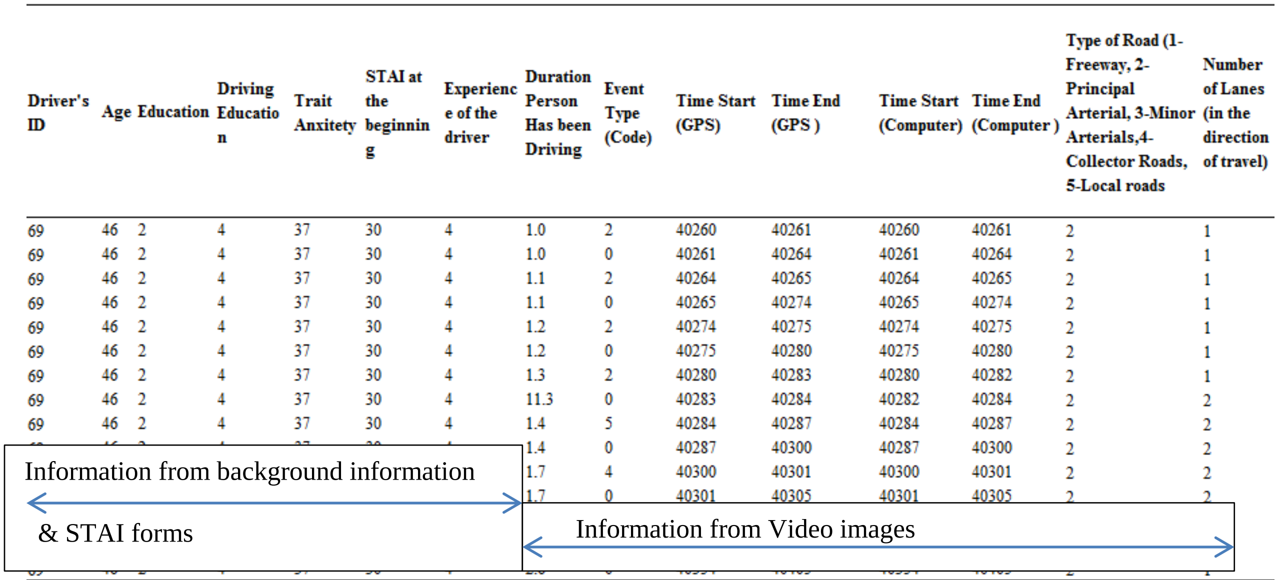
The cardiograms retrieved in AcqKnowledge 4.1® software were processed to develop the heart rate tables for both rest and driving conditions. Similarly, GPS data retrieved in text format with XSENS MT Manger® were exported to a Microsoft Excel® sheet. The KMZ plots of the test routes were performed using XSENS MT Manger®, examples of which are depicted in Appendix C. Based on observations in video images and the review of literature, the stress related parameters as depicted in table 4.1 and the driving events as depicted in table 4.4, were listed. The events represent the time during which any driving related task is completed. Each event was observed in video images with GPS and computer time at the start and end of the events being recorded.

Table 4.1 Stress Related Parameters Observed from Video Images

S. No.	Related parameters
1	Geometry of road
2	Land use
3	Side vehicle type
4	Number of vehicle present in same or parallel lane.
5	Duration of driving till the time of measurement
6	Position of truck in the road (lane)
7	Number of lanes in the segment in the direction of travel
8	Number of lanes in the opposing segments

4.4 Total Event Data

The total event data was comprised of driving events recorded from video images combined with the drivers' background information, scores processed from state trait anxiety forms and weather information. One total event data sheet consisted of one driving data set. Hence, 25 total event data sheets were prepared for each 25 data sets. The merging of data was done simply by adding the data from different sources to the event table. The total event data also consisted of a road classification of the location of each driving event. The classification was done using a national functional road classification map which is described in detail in the subsection 4.6.4. The screen shot of part of the event table is depicted in figure 4.2.

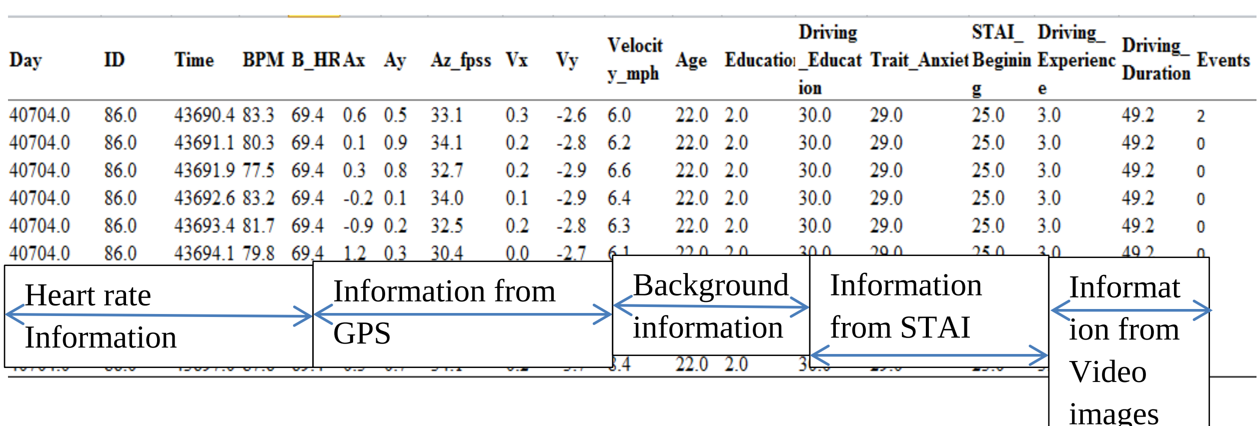


Driver's ID	Age	Education	Driving Education	Trait Anxiety	STAI at the beginning	Experience of the driver	Duration Person Has been Driving	Event Type (Code)	Time Start (GPS)	Time End (GPS)	Time Start (Computer)	Time End (Computer)	Type of Road (1-Freeway, 2-Principal Arterial, 3-Minor Arterials,4-Collector Roads, 5-Local roads	Number of Lanes (in the direction of travel)
69	46	2	4	37	30	4	1.0	2	40260	40261	40260	40261	2	1
69	46	2	4	37	30	4	1.0	0	40261	40264	40261	40264	2	1
69	46	2	4	37	30	4	1.1	2	40264	40265	40264	40265	2	1
69	46	2	4	37	30	4	1.1	0	40265	40274	40265	40274	2	1
69	46	2	4	37	30	4	1.2	2	40274	40275	40274	40275	2	1
69	46	2	4	37	30	4	1.2	0	40275	40280	40275	40280	2	1
69	46	2	4	37	30	4	1.3	2	40280	40283	40280	40282	2	1
69	46	2	4	37	30	4	11.3	0	40283	40284	40282	40284	2	2
69	46	2	4	37	30	4	1.4	5	40284	40287	40284	40287	2	2
							1.4	0	40287	40300	40287	40300	2	2
							1.7	4	40300	40301	40300	40301	2	2
							1.7	0	40301	40305	40301	40305	2	2

Figure 4.2 Screen Shot of Total Event Table

4.5 Total Aggregated Data

The total aggregated table was the final table after merging velocity and acceleration data from the GPS table, and the heart rate data. The data merging was done in reference to GPS time, time from heart rate data and the time of the total event data. These three tables were joined in MATLAB®. Thus prepared, the final table contained all the information in a single sheet. The screen shot of the part of total aggregated data table is depicted in figure 4.3.



Day	ID	Time	BPM	B_HR	Ax	Ay	Az_fpss	Vx	Vy	Velocity_mph	Age	Educatio	Driving_Education	Trait_Anxiet	STAI_Begining	Driving_Experience	Driving_Duration	Events
40704.0	86.0	43690.4	83.3	69.4	0.6	0.5	33.1	0.3	-2.6	6.0	22.0	2.0	30.0	29.0	25.0	3.0	49.2	2
40704.0	86.0	43691.1	80.3	69.4	0.1	0.9	34.1	0.2	-2.8	6.2	22.0	2.0	30.0	29.0	25.0	3.0	49.2	0
40704.0	86.0	43691.9	77.5	69.4	0.3	0.8	32.7	0.2	-2.9	6.6	22.0	2.0	30.0	29.0	25.0	3.0	49.2	0
40704.0	86.0	43692.6	83.2	69.4	-0.2	0.1	34.0	0.1	-2.9	6.4	22.0	2.0	30.0	29.0	25.0	3.0	49.2	0
40704.0	86.0	43693.4	81.7	69.4	-0.9	0.2	32.5	0.2	-2.8	6.3	22.0	2.0	30.0	29.0	25.0	3.0	49.2	0
40704.0	86.0	43694.1	79.8	69.4	1.2	0.3	30.4	0.0	-2.7	6.1	22.0	2.0	30.0	29.0	25.0	3.0	49.2	0

Figure 4.3 Screen Shot of Total Aggregate Data Table

4.6 Stressors during Driving

Based on the literature review, video images and questionnaires, the factors that would probably have an effect on stress during driving were identified. All these factors were included in the total aggregated table. The factors were classified into five categories as depicted in the flowchart in figure 4.4. Each variable related to these five categories are explained in the subsections 4.6.1 to 4.6.6. The dual task paradigm was excluded as it was not noticed during driving.

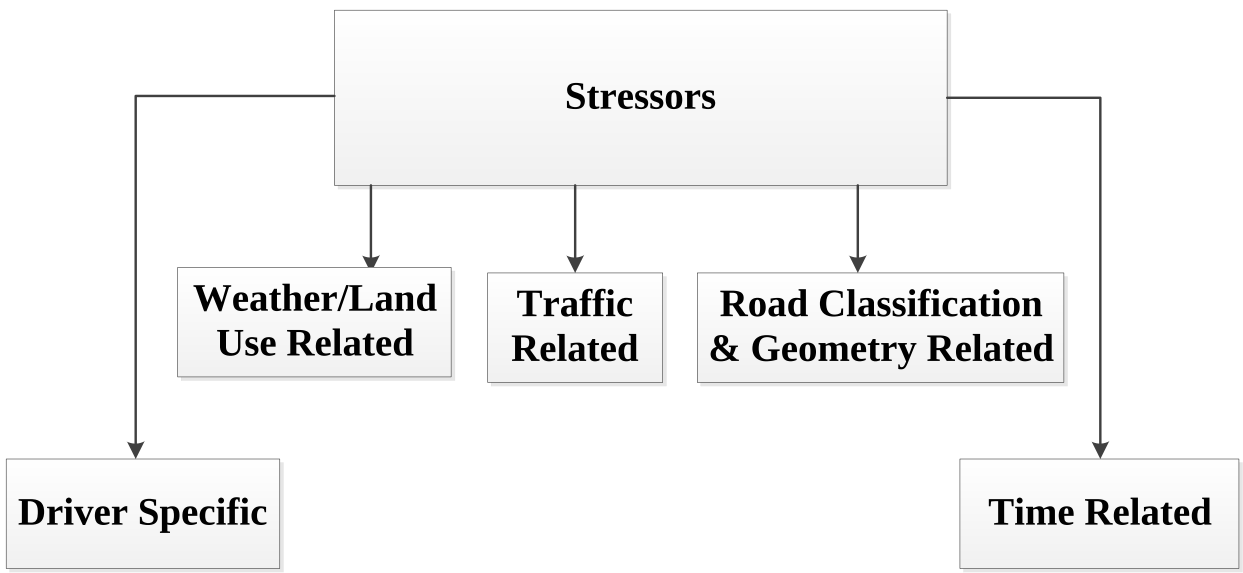


Figure 4.4 Classification of Factors Related to Stress

4.6.1 Driver Specific Parameters

Among driver specific parameters, base heart rate and driving heart rate were physiological indices of stress. Base heart rate was measured when the subject was at rest condition. In contrast, driving heart rate was measured when the subject was driving the truck. Both were measured in Beat Per Minute (BPM) units. Table 4.2 depicts the list of driver specific parameters. The code mentioned in the table is the pseudo name of each variable used in SPSS® for statistical analysis. The code mentioned in the table is related to statistical analysis in Chapter 5.

Table 4.2 Driver Specific Parameters

S. No.	Description	Parameters	Code
1	Physiology related	Base heart rate (BPM)	
2		Driving heart rate (BPM)	
3	Psychology related	Trait anxiety score of the driver	Trait_Anxiety
4		State anxiety scores during the beginning and end of driving on the test day	STAI_begining
5	General	Age of the driver	Age
6	Education related	Driving education (No. of days the subject spent on the driving training from the start to the last driving day)	Driving_education
7		Driving Experience	Driving_experience
8		General education	Education

The trait anxiety score and state anxiety score, as explained in the previous section, are obtained by processing the STAI. During the study, trait anxiety inventory was taken when the subject was at rest condition. State anxiety was taken at the time just before driving and just after driving. State anxiety shows the driver's feelings at the moment. It is critical to know how the stress level would change if the driver is already stressed before driving. The general and educational related parameters were measured using the background information form. Age represents the age of the subject in years. Driving education represents the number of days the subject spends in training starting from the first driving day. It is measured in days. Driving experience represents how many years the subject has been driving. The general education represents the educational qualifications of the subject. The level of education was provided in sequence starting from primary school, high school, 2-year College, 4-year College to MS or higher.

4.6.2 Weather and Land Use Related Parameters

The weather related parameters were sunny, cloudy and rainy conditions of weather at the time of driving. The weather information was recorded at the site. Weather and land use related parameters are listed in table 4.3 below. The code mentioned in the table is related to statistical analysis in Chapter 5.

Table 4.3 Weather and Land Use Related Parameters

S. No.	Description	Parameters	Code
1		Sunny	Sunny
2	Weather Related	Cloudy	Cloudy
3		Rainy	Rainy

The two types of land use were considered for this study. The first was the presence of any structures, such as houses, factories, shops, etc., that could be the traffic generator. All other conditions in exception to those conditions were categorized as second type. Land use information was recorded observing video images. The code mentioned in the table is related to statistical analysis in Chapter 5. Figure 4.5 shows the land use classification.

Table 4.3 Weather and Land Use Related Parameters Contd...

S. No.	Description	Parameters	Code
4	Land Use	Land use (1= Houses/factories/any structures in the side of road which could be traffic generators, 2= Barren land/forests/grass/or any other features other than 1)	Land_use

Landuse Type 1

Landuse Type 2

Figure 4.5 Land Use

4.6.3 Traffic Related Parameters

Traffic related parameters are listed in table 4.4. Among these parameters, there are 14 driving events related parameters which were recorded while observing the video images. The code mentioned in the table is related to statistical analysis in Chapter 5.

- No events represent the condition (time) while driving when no other driving events, as listed in table 4.4, were observed.
- The event right turning represents the time to right turn at the uncontrolled approach of the intersection or right turning to any exits.
- The event presence of vehicle in opposing lane represents the time for which the vehicle in the opposing lane is approaching at the immediate side of truck.
- The event presence of intersection + through movement, represents the time beginning from the moment when the truck coming from a controlled approach just approaches the stop bar, to the time it approaches the stop bar of the departure.
- The event passive overtaking represents the time when the vehicle moving in the same direction overtakes the truck.
- The event lane change represents the time taken by the truck to change lanes. The event left turning represents the time starting from the moment when the truck coming from a controlled approach just approaches the stop bar, till the time it completes its left turn maneuver.
- The event presence of sharp curve represents the time during which the truck moves along the sharp curve.
- The event interaction + passive overtaking represents the time during which the truck simultaneously is within a 2 s time gap with the lead vehicle and a vehicle moving in the same direction is overtaking it**.** The time gap of 2 s is based on a past study done by Peeta and Zhou in 2005.

- The event presence of intersection+ right turning represents the time beginning from the moment when the truck coming from a controlled approach just approaches the stop bar, to the time it completes the left turn maneuver.

Table 4.4 Traffic Related Parameters

S. No.	Description	Parameters	Code
1	Driving events related	No events	No_events
2		Right turning to the exit/or from uncontrolled approach of the intersection	Right_turning
3		Presence of vehicle on the opposing lane	vehicle_opposing
4		Presence of intersection + through movement	Presence_of_intersection
5		Passive Overtaking	Passive_overtaking
6		Lane change	Lane_change
7		Left turning	left_turn_intersection
8		Presence of sharp curve	Sharp_curve
9		Interaction + passive overtaking	Interaction_passiveovertaking
10		Presence of intersection+ right turning	Right_turning_intersection
11		Interaction	Time_gap
12		Active Overtaking	Active_overtaking
13		Presence of vehicle on the opposing lane + interaction	Opposing_timegap
14		Presence of sharp curve + Presence of vehicle on the opposing lane	Opposing_sharpcurve

Note: Interaction is related to the condition when lead and trailing vehicles are within or exact on 2 s time gap.

- The event interaction represents the time at which the truck remains within a 2 s time gap with the lead vehicle.
- The event active overtaking is the time it takes for the truck to overtake the vehicle moving along same direction.
- The event presence of sharp curve + presence of vehicle on the opposing lane, represents the time when the truck is moving along the sharp curve and, simultaneously, it meets the vehicle in the opposing lane.

Table 4.4 Traffic Related Parameters Cont'd…

S. No.	Description	Parameters	Code
15	Traffic control related	Green	Green
16		Yellow	Yellow
17		Red	Red
18		Stop	Stop
19		Yield	Yield
20	Side and opposing vehicles types related	Presence of Car/Suv	Car_suv
21		Presence of Pick-Up/Big Truck	Pick_up_big_truck
22		Presence of both Car/Suv and Pick-Up/Big Truck in a platoon	Combination_vehicles
23	Traffic congestion related	Number of vehicles in same or parallel lane	Vehicles_in_same_or_parallel_lane
24	Vehicle dynamics related	X- component of velocity	Vx
25		Y-component of velocity	Vy
26		X- component of acceleration	Ax
27		Y-component of acceleration	Ay
28		Z-component of acceleration	Az

- The traffic control related events represent the type of control, the presence of stop or yield controls and the signal phases being green, red or yellow at the approach when the truck is at the stop bar.
- The parameters related to the side and opposing vehicles are classified into three categories. The first one represents presence of car or SUV vehicle types at the immediate side. The second one represents the presence of pick up or big trucks at the immediate side. The third one represents the condition when a platoon of all types of vehicles (first and second type) is at the immediate side of the truck.
- The traffic congestion related parameter includes the number of vehicles present in the same or parallel lane.
- The vehicle dynamics related parameter includes the X and Y component of the velocity and X, Y, and Z components of acceleration. X components represent the movement towards the truck's direction. Y components represent the lateral movement, during maneuvers like lane changing and overtaking. The Z component represents the vertical movements.

4.6.4 Road Classification and Geometry Related Parameters

Table 4.6 depicts the list of road classification and geometry related parameters. Curve/Straight represents the geometry of the road on which the truck is moving along being curved or straight. The lane configuration represents the number of lanes in the direction of travel and the number of lanes in the opposite direction of travel. The road classification was done according to the national functional classification maps as freeway, principle arterial, minor arterial, collector and local for rural and urban roads. Figure 4.5 depicts the example classification of common test routes. The code mentioned in the table is related to statistical analysis in Chapter 5.

Table 4.5 Road Classification and Road Geometry Related Parameters

S. No.	Description	Parameters	Code
1	Curve/Straight	Geometry (Straight =1, Curve =2)	Geometry_of_Road
2	Lane configuration	Number of lanes in the direction of travel	No_of_lanes_samedirection
3		Number of lanes in opposite direction of travel	No_of_lanes_oppositedirection
4	Road classification	Freeway (Urban/Rural)	Freeway
5		Principle arterial (Urban/Rural)	Principle_arterial
6		Minor arterial (Urban/Rural)	Minor_arterial
7		Collector (Urban/Rural)	Collector
8		Local (Urban/Rural)	Local

Note: 1. Classification is based on National Functional Classification Maps

4.6.5 Time Related Parameters

Table 4.6 depicts the list of time related parameters. Duration of driving till the time of measurement represents the time elapsed in driving starting from the start of driving. It was measured in minutes. The code mentioned in the table is related to statistical analysis in Chapter 5.

Table 4.6 Time Related Parameters

S. No.	Description	Parameters	Code
1	Time related	Duration of driving till the time of measurement	Driving_Duration

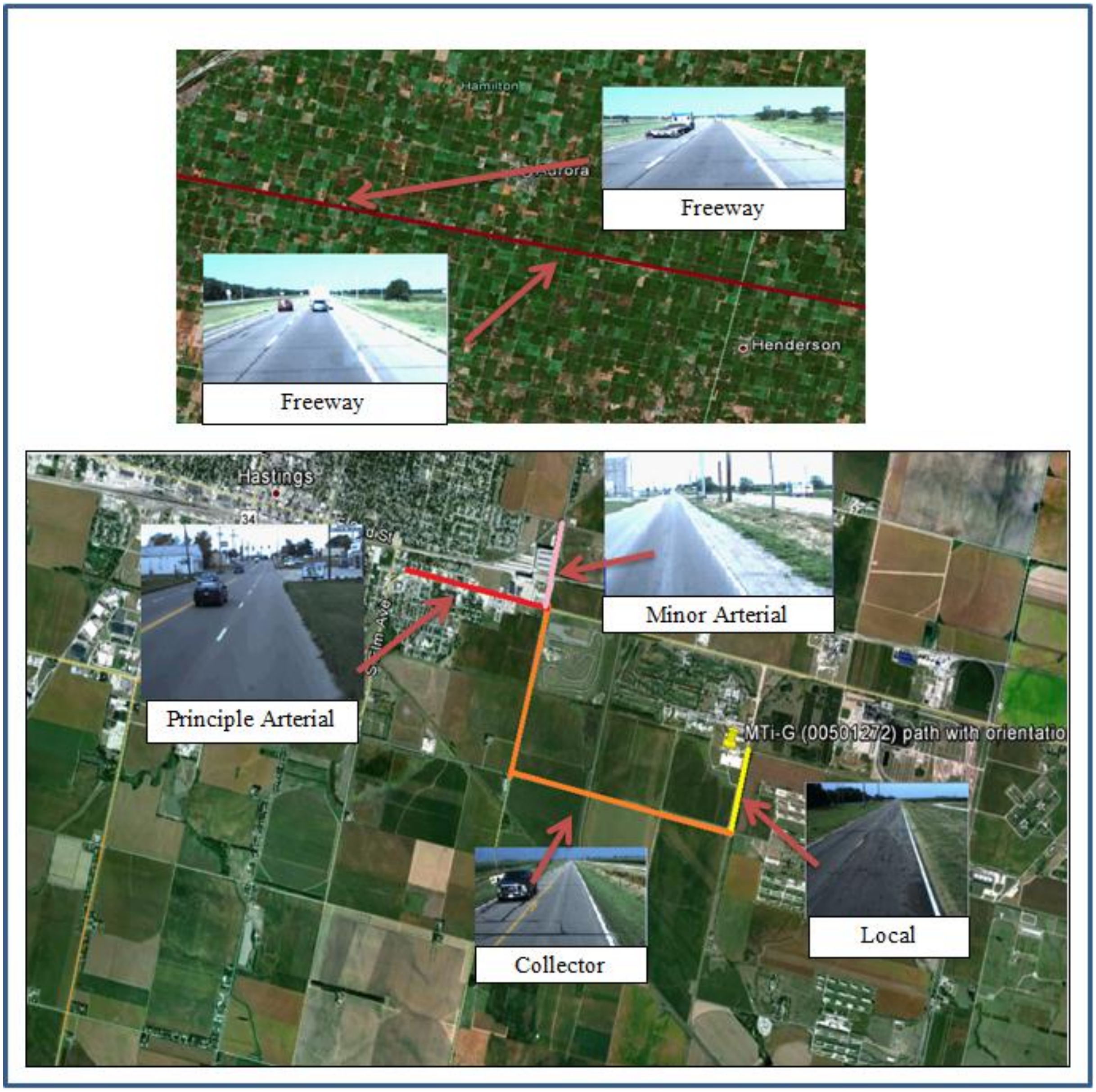


Figure 4.6 Road Classification

In summary, this chapter explained in detail about the processing of raw data collected with videos, GPS, Biopac and the questionnaires. It dealt with the detailed process of database management, for example, forming an event data table, final aggregated table, identifying and categorizing stressors, etc. Using a database process like this, the statistical analysis was performed and is described in detail the proceeding chapter.

Chapter 5 Analysis

This chapter primarily deals with the statistical analysis of the data. The data analysis was performed in three steps: Pre-Modeling Analysis, Modeling and Model Performance Analysis. The last part of the chapter also explains about the result of the statistical analysis**.**

5.1 Pre-Modeling Analysis

Pre-modeling analysis includes all the analyses performed on the data prior to doing the statistical modeling. Pre-modeling analysis was done in three steps described in the following sub-sections.

5.1.1 Variables

The stressors (except related to the physiological index) listed in tables 4.2 to 4.8 were considered as independent variables. As shown in these tables, code names were provided to represent these variables. The dependent variable "Z" was computed using the following relation. Table 5.1 depicts the average base heart rate of the drivers.

$$Z = \frac{\text{Driving Heart Rate (BPM)} - \text{Average Base Heart Rate (BPM)}}{\text{Standard Deviation of Base Heart Rate}} \tag{5.1}$$

Table 5.1 Base Heart Rate (BPM)

S. No.	Drivers' random IDs	Average base heart rate (BPM)	S. No.	Drivers' random IDs	Average base heart rate (BPM)
1	4	78	9	81	90.4
2	21	101.3	10	6	80.3
3	86	69.4	11	69	80.9
4	97	141.7	12	70	68.2
5	67	89	13	58	91.5
6	45	73.3	14	95	74.9
7	51	59.8			
8	39	90.9			

5.1.2 Noise Detection

There were possibilities of getting distorted cardiogram during data collection. To acquire cardiogram, the electrodes were connected to the drivers' chests with the help of strips which had a sticky base. Particularly, the movement of the driver's body during driving and the vehicle's jerk caused the electrodes to loosen this connection with the strips or become detached from the strips which led to noisy or inaccurate data. In addition, the electrode strips slipped off the driver's chest frequently, especially in the case of the driver having oily skin/excessive body hair which led to a distortion in the cardiogram. So, it was necessary to identify the period's high inaccuracy and purge this data prior to the data analysis. For that specific purpose, the time series plots of driving heart rate (BPM) and Z-value were done for all 25 driving data sets (see Appendix D). The excessive variance of heart rate (BPM) (outside the feasibility range) was used to differentiate between inaccurate and accurate data sets. Figure 5.1 gives an example of a usable and non-usable data set being identified using a feasible heart rate (BPM) range. Table 5.2 shows the data used for analysis based on the amount of noisy data.

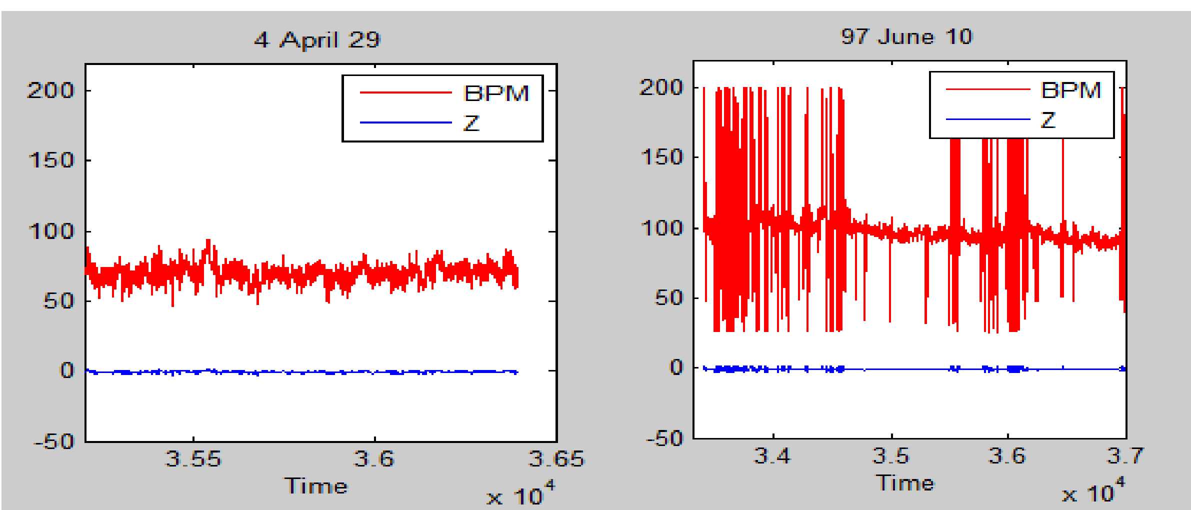


Figure 5.1 Time Series Plot of Usable Data (4 April 29) and Unusable Data (97 June 10)

Table 5.2 Data Included in the Analysis Based on Less Noise Presence

S. No.	Random Id of the drivers	Date of the test driving	S. No.	Random Id of the Drivers	Date of the test driving
1	21	April 27, 2011	8	51	July 25, 2011
2	4	April 29, 2011	9	39	July 29, 2011
3	4	May 11, 2011	10	51	August 2, 2011
4	19	June 10, 2011	11	69	October 7, 2011
5	45	July 15, 2011	12	69	October 19, 2011
6	39	July 25, 2011	13	95	December 2, 2011

5.1.3 Normality Test and Clustering

To identify the nature of the data and to decide on which modeling tool needed to be applied, a normality test was performed and the clusters distribution of the dependent variable Z was observed. The normality test presented in table 5.3 shows that the Kolmogorov-Smirnov (K-S) test is significant, and the values of skewness and kurtosis are far above zero. The Kolmogorov-Smirnov test is based on the largest vertical difference between hypothesized and empirical distribution. For the K-S test of normality, the hypothesized distribution was assumed to be normal distribution (Razali & Wah, 2011). The result confers that the distribution of the Z values was not normal.

Table 5.3 Normality Test

	Kolmogorov-Smirnov (K-S)			
	Statistic	**df**	**Sig.**	
Z	0.2	23716	0	
Skewness =	1.9	**Kurtosis** =	5.6	

Similarly, the normality plot depicted in figure 5.2 shows the data clusters in two distinct non-normal clusters in the range of Z less than 7, “Low Stress level,” and Z greater than 7, “High Stress level”.

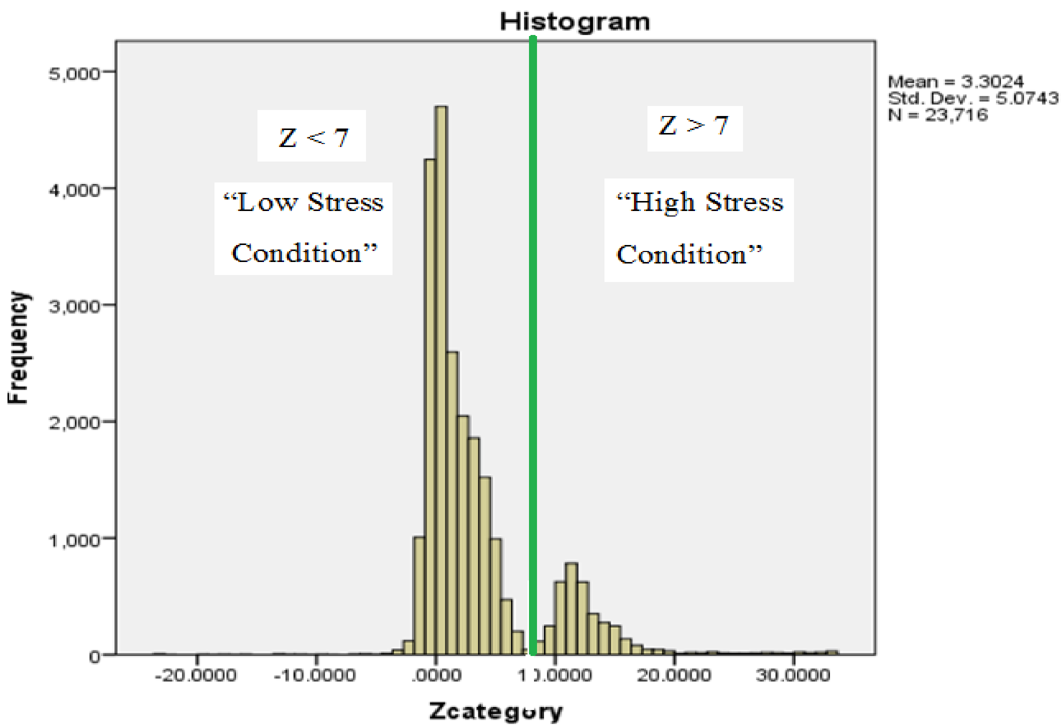


Figure 5.2 Histogram Showing Two Clusters of the Dependent Variable

5.2 Modeling

Based on the clustering explained in 5.1.3, the dependent variable Z was categorized into 0 and 1 for the corresponding Z values less than 7 and greater than 7, respectively. All the qualitative independent variables that could not be ranked were also dichotomously coded (0 or 1/1or 2). The total data points were 23,716 and out of them 5% data (validation data set) were set aside for validation purposes. On 95% of the total data (training data set), the binary logistic regression modeling was performed using the SPSS® software. The SPSS output is presented in

Appendix D. The results of the modeling are tabulated in the following tables (table 5.4 to table 5.7). Tables 5.4 and 5.5 represent the model fit which is described in detail in section 5.6. The mean and parameter coding of the categorical variables and standard deviation of significant non-categorical variables is listed in table 5.6. The frequencies of the variables that are significant in the model are presented in table 5.7. The trait anxiety score has the mean value of 42.2, with a range of a minimum 31 to a maximum 54. State anxiety at the beginning has the mean value of 40.8 with a minimum 31 to a maximum 54 range. The number of days in training has the mean value of 15.4 days ranging from a minimum 4 to a maximum 31. Driving duration has the range of a minimum 1 minute to the maximum of 90 minutes, starting from the beginning of driving. Table 5.8 depicts the list of all the significant variables, along with the coefficient, P value, Wald and odd ratio. The value 0 represents the absence of variable and the value 1 represents the presence of variable. The detailed description of the information from table 5.8 is presented in section 5.2.

Table 5.4 Model Summary

Step	**-2 Log Likelihood**	**Cox & Snell R square**	**Nagelkerke R square**
1	1634.9	0.6	0.95

Table 5.5 Chi-square Table

		Chi-square	df	Sig.
	Step	16213.1	13	0
Step 1	Block	16213.1	13	0
	Model	16213.1	13	0

Table 5.6 The Non-categorical Variables

Variables	Mean	Std. Deviation
Trait_Anxiety	42.2	7.7
STAI_Begining	41.8	11.3
Driving_Education	15.4	8.6
Driving_Duration	Range = 1minute to 90 minute	-

Table 5.7 Categorical Variable Coding in Model Equation

Variables	**Frequency**	**Description**	**Parameter coding**
Collector	18026	Absence	0
	4505	Presence	1
Right_turning_intersection	21874	Absence	0
	657	Presence	1
Right_turning	22219	Absence	0
	312	Presence	1
Stop	21726	Absence	0
	805	Presence	1
Car_suv	21633	Absence	0
	898	Presence	1

Table 5.7 Categorical Variable Codings in Model Equation Contd...

Variables	Frequency	Description	Parameter coding
Minor_arterial	15939	Absence	0
	6592	Presence	1
Passive_Overtaking	21981	Absence	0
	550	Presence	1

Table 5.8 Variables in Equation

Variables	B	S.E.	Wald	df	P value	Exp(B)
Trait_Anxiety	0.9	0.0	381.8	1.0	0.0	2.4
STAI_Begining	-0.2	0.0	77.3	1.0	0.0	0.8
Driving_Education	-0.2	0.03	48.1	1.0	0.0	0.8
Passive_Overtaking	1.8	0.5	13.8	1.0	0.0	5.9
Right_turning_intersection	0.9	0.5	3.9	1.0	0.0	2.4
Right_turning	1.8	0.6	10.7	1.0	0.0	6.2
Ax	-0.3	0.1	6.9	1.0	0.0	0.7
Vy	0.1	0.0	55.7	1.0	0.0	1.1
Stop	1.5	0.4	19.2	1.0	0.0	4.6
Car_suv	-1.2	0.6	4.5	1.0	0.0	0.3
Minor_arterial	0.8	0.3	7.5	1.0	0.0	2.2
Collector	-1.6	0.3	27.0	1.0	0.0	0.2
Driving_Duration	0.1	0.0	134.6	1.0	0.0	1.1
Constant	-31.0	0.9	1135.1	1.0	0.0	0.0

Model Equation: *Log (odd) = -31.004+0.858* Trait_Anxiety -0.214* STAI_Begining -0.180* Driving_Education +1.779* Passive_Overtaking +0.895* Right_turning_intersection +1.827* Right_turning -0.325* Ax +0.051* Vy +1.517* Stop -1.170* Car_suv +0.777* Minor_arterial -1.600* Collector +0.092* Driving_Duration*

Note: odd= P/ (1-P), where P is the probability of happening event 1

5.3 Discussion on the Model

5.3.1 Model Fit

According to tables 5.3 and 5.4, the generated model has a good fit. The Pearson Chi-Square Test has a P value less than 0.05, indicating that the model would improve significantly by the predictors. The Cox and Snell R^2, and the Nagelkerke's R^2, provide supplementary support for measuring the goodness of fit (Peng, Lee and Ingersoll, 2002). The maximum value of Cox and Snell R^2 is 0.75. The maximum value of Nagelkerke's R^2 is equal to 1. For the model, Cox and Snell R^2 indicated that 61.4% of the variation of dependent variables could be explained by the model. The Nagelkerke's R^2 indicated the existence of a strong relationship of 94.6% between the predictors and the prediction.

5.3.2 Significant Variables

Table 5.8 depicts the list of independent variables (13 nos.) that can significantly explain the variation in the dependent variable, Z, as evident by the P value of the Wald Test being less than 0.05. The B value represents the model coefficient and Exponential (B) represents the odd ratio for respective independent variables. The independent variables with an odds ratio greater than 1 indicates a high likelihood of their increment in magnitude (being 1 in the case of categorical variables) causing the stress level defined by Z greater than 7; that is, the "high stress level". Similarly, the independent variables with a odds ratio less than 1 indicates a high likelihood of their increment in magnitude (being 1 in case of categorical variables) causing the stress level defined by Z less than 7; that is, the “low stress level”. This inference can also be taken by observing the sign of coefficients (direction), the negative coefficients are favorable for the condition of Z to be less than 7 and the positive coefficients are favorable for the condition of Z to be greater than 7. The relationships of these two conditions with each significant independent variable are shown in detail in table 5.9. The variables, including trait anxiety, passive overtaking, presence of intersection + right turning (which represents the right turning from the controlled approach of the intersection), right turning (which represents the right turning from the uncontrolled approach or right turn to exit), Y-component of the velocity, presence of stop control in the intersection, the presence of minor arterial, and the driving duration when increased in their magnitude, will cause the likelihood of stress being more at the Z>7 region; that is, the high stress level. STAI score taken at the start of driving, the driving education (which represents the number of days in training the subject attended since the starting day of driving), the presence of a car or SUV at the immediate side of the truck, and the presence of collector road type, will cause the likelihood of stress being more at the Z<7 region; that is, the low stress level when increased in magnitude.

Table 5.9 Summary of the Result

Significant independent variables	More likelihood of conditions:	Significant independent variables	More likelihood of conditions:
Trait_Anxiety Passive_Overtaking Right_turning_intersection Right_turning Vy Stop Minor_arterial Driving_Duration	Z >7, "The High Stress Level"	STAI_Begining Driving_Education Ax Car_suv Collector	Z < 7, "The Low Stress Level"

5.4 Model Performance Analysis

Model performance analysis on the training data set was done looking at the classification table from the statistical analysis. Table 5.10 depicts the model performance analysis on the training data set.

Table 5.10 Model Performance on Training Data Set

		Predicted		
Observed		**Z**		
		0	**1**	**Percentage correct**
Z	**0**	13253	83	99.4
	1	88	3618	97.6
Overall percentage				**99.0**

As shown in table 5.8, the accurate prediction of 0 and 1 compared to the observation 1 was found to be overall 99%. It indicates that model performance of the training set is quite good. The same model was also applied for the validation data set (5% of the total data) which was not used for modeling. This is shown in table 5.11.

Table 5.11 Model Performance on Validation Data Set

Observed		**Predicted**		**Percentage correct**
		Z		
		0	**1**	
Z	0	849	185	82
	1	5	182	97
Overall percentage				90

Table 5.11 shows that the accurate prediction of 0 by the model comparing to the observed value was found to be 82 % and similar to that of 1, which was found to be 97%. The overall prediction was 90%, which clearly favored the validity of the model.

Chapter 6 Conclusion and Recommendation

6.1 Conclusion

As described in previous chapters, the study developed the relationship of stress with stressors. The stressors were in five categories: driver specific, weather/land use related, traffic related, road classification and road geometry related, and time related. The study also identified the pattern of distribution of stress which was clearly non-normal and with two distinct clusters: Z less than 7 and Z greater than 7. The binary logistic regression was conceived as the best modeling technique to relate stress with stressors for this particular type of data. The binary logistic regression model of Z versus significant independent variables was developed and the model development led to the following findings.

6.1.1 Effect of Driver Specific Parameters on Stress during Driving

The psychology related parameters trait anxiety and state trait anxiety were found to have a significant effect on stress prediction. The higher the trait anxiety, the higher the likelihood it is to have a high stress level, ($Z>7$). Hence, an anxious driver is more likely to be stressed during driving. However, a high STAI value increased the likelihood of the occurrence of a lesser stress level ($Z<7$) during driving. This result suggests that some anxiety at the start of the trip is helpful in reducing the higher stress during the trip. The drivers had to plan the route they are planning to take prior to the start of the drive. Possibly, the person who frets more during the planning phase does a better job in planning, which can lead to less stress while driving. The drivers' education was found to be significant in increasing the probability of a lower stress level. The drivers' training provided the appropriate driving technique to cope with different situations of traffic and roads, which was helpful in reducing the driver stress level.

6.1.2 Effect of Weather and Land Use Related Parameters on Stress during Driving

None of the weather and land use related parameters were found significant in predicting stress from the statistical analysis. The driving tasks in the truck driving training were generally scheduled during clear weather conditions and very extreme weather conditions were never observed during data collection. The variance of land use was also limited between rural and semi-urban environments. The route never went through any drastic changes in land use. A future study is suggested to further investigate the effect of weather and land use related parameters.

6.1.3 Effect of Traffic Related Parameters on Stress during Driving

The driving events right turning from the controlled approach of the intersection, right turning in the exits or from the uncontrolled approach of the intersection, and passive overtaking increased the likelihood of high stress levels. Both right turning maneuvers add driving work load as well as stress because of the safe merging process where the driver has to look for safe gaps prior to turning. Additionally, the size of truck makes the right turn maneuvers more complicated. The complication is high if the intersections are narrow. Therefore right turning maneuvers are associated with the likelihood of a high stress level. Presence of STOP controlled intersections was found to increase the stress level. Similar to the right turning, the additional work load induced to safe gap acceptance decision at the stop sign. The effect is more if the intersection lacks required sight distance.

The vehicle dynamic related parameters as longitudinal component of acceleration (Ax) of the truck and the trans-axial component of velocity of truck (Vy) were found to significantly affect the stress prediction. The driver tends to accelerate his vehicle ahead if there is sufficient distance between him and the lead vehicle that is the condition of less congestion. Therefore, high Ax displays the condition of low congestion where a driver doesn't have to invest too much of his attention and the driver is less stressed. Hence, it is reasonable to conclude that Ax increases the likelihood of a low stress level. The second factor, Vy, is displayed during the lateral movement of trucks, especially during lane changing or overtaking, which requires extra attention and causes stress. Vy was found to increase the likelihood of a high stress level.

The presence of vehicle types such as cars and SUVs, instead of a heavy vehicle, at the immediate side of the vehicle, whether they were on the parallel segment or on the opposing lane, increased the likelihood of the occurrence of a lesser stress level.

The presence of control and the turn maneuvers are related to the delays in intersections or impeded speed reductions in road segments. Similarly, high Ax also indirectly represents low congestion. The delay and the speed are the Measure of Effectiveness (MoE) of Level of Service (LOS) of the intersections and the segments, respectively. Since these parameters were related to the likelihood of the occurrence of a high stress level, it can be conferred that deteriorated LOS (LOS decreasing from A to lower level) would lead to an increase in the likelihood of the occurrence of a high stress level during driving.

6.1.4. Effect of Road Classification and Road Geometry Related Parameters on Stress during Driving

It was found that driving on minor arterial (rural or urban) and collector (rural or urban) roads significantly impacted the stress levels. Travel through a minor arterial resulted in an increase in the likelihood of a high stress level, whereas travel on a collector resulted in lowering the likelihood of a high stress level. The collector road collects traffic from local roads and feeds the traffic to minor arterials. There are less controls and lower traffic volume in collectors than minor arterials. Therefore, the collector is related to the likelihood of a lesser stress level. In contrast, minor arterials have relatively large numbers of traffic and generally more controls. Drivers have to pay additional attention during driving in the minor arterials and hence it is related to the likelihood of a high stress level.

6.1.5 Effect of Time Related Parameters on Stress during Driving

Driving duration was found to significantly impact the stress level. An increase in driving duration increased the likelihood of a high stress level. This is a very important result which shows the cumulative nature of the stress. The stress induced due to events while driving keeps on building.

6.1.6 Overall

This research provides traffic engineers with handles that can be used to reduce the likelihood of high stress levels. Driving education is a good example of it. By providing driving training, it is possible to lower the stress level among truck drivers. Similarly, right turn maneuvers can be made comfortable to lower the stress level by improving the intersections, such as channelizing the right turn lane, widening the intersection, avoiding right turns on red or making the right turn movement protected. It is also possible to lower the stress level in STOP controlled intersections by removing sight obstructions to maintain the required sight distance. In extreme cases, STOP control can be replaced by a higher level of control, such as signal control. The surrogates of level of service, passive overtaking, controls, acceleration and turn maneuvers which were found significant imply that improving the intersections and Freeway level of service can lead to lower stress levels.

6.2 Recommendation for Future Study

Study 1: From the study, it was found that such traffic related parameters as turn maneuvers, passive overtaking, control type and the side vehicle types were significant in explaining stressed driving conditions. It would be very interesting if a detailed study could be conducted focusing on a controlled intersection. The study would provide more insight on how different type of controls would influence driving, and how the stress would vary temporally and spatially while approaching the controlled intersection. This would include the study of the section before the dilemma zone, the dilemma zone and the core intersection area. This study will contribute to the setting of some demarcations on deciding the control type as well as re-timing of signal phases, in relation to the stress level to mitigate the driver discomfort problem.

Study 2: A safety study could be performed in the intersections classified as "high crash locations" by NDOR. This study would be effective in the high crash locations where the causal factors for the crash occurrence couldn't be determined by analyzing crash history (frequency, type, severity, locations, etc.). The driver behavior study on that location will be helpful to find out whether or not the crash occurrences were related to the behavior parameters. It is useful to include weather, land use, driver education, driving maneuvers and the presence/absence of dual task paradigms as well. Findings of these studies will be helpful in developing the countermeasures of those crashes which can't be analyzed with conventional methods as well as producing training materials for safe driving.

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Appendix A Contract Documents

INFORMED CONSENT FORM

IRB#   (Labeled by IRB)

Identification of Project:

Truck Driver Stress Study

Purpose of the Research:

This project aims to model truck driver's stress while driving on the road as a function of transportation variables such as: level of service, time of day, weather conditions, and level of driver training etc. The insights gained from this study will be useful in designing better traffic control and road geometries to minimize truck driver stress.

Procedures:

Your driving stress will be measured using physiological markers electrocardiogram and skin conductance.

The study would be conducted during your six-week stay in truck driving certification course offered by Central Community College's Truck Driving Program. The study will consist of:

i) Two general information questionnaire (filled once):

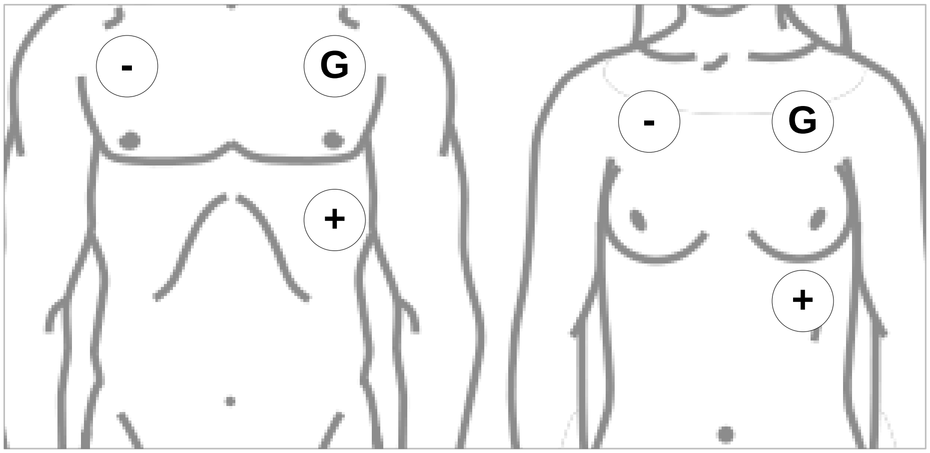
a. Background information form (Example question: Level of Education, How many miles you drive in an average week) (Length: 8 Multiple Choice)

b. Personality (Type A/B) Questionnaire (Example question: When faced by unfamiliar problem, what do you usually do?) (Length: 20 Multiple Choice)

ii) One mid-training experience questionnaire (filled once):

a. Driver Experience Questionnaire (Example question: Driving usually makes me feel aggressive) (Length: 40 yes/no questions)

iii) Physiological data collection during 3 simulations (25 min each including a 5 min break), 3 training and 2 real-world driving tasks taken during the Truck Driving Program. The driver will have to wear 3 probes as shown in the figure below. The driver also fills out one stress level questionnaire after each session. The skin conductance data will only during simulations. The electrodes would be placed on index and middle finger of left hand.



Risks and/or Discomforts:
The electrodes used for collecting the ECG might cause skin irritation for some people. About 2 % of the population will react to any adhesives and gels put on a skin, regardless of composition or concentration. The EL 502 electrode used in this research is solid gel. Solid gels are gentler on the skin than WET gels at the same salt concentration. The salt content in all SOLID gel electrodes from BIOPAC is 4%. This universal gel can be used short and long term, and is suitable for adult and infants. Please report if you have any skin irritation from gel on the body.

The driving risks in this study does not fall outside the realm of normal driving or training done under Truck Driving training program. The trainer is already observing the study participants while they are driving. So, no “undue” observational stress is induced due to data collection.

Benefits:
After personality test the subjects will be informed the results. Based on their results they might be able to better understand their driving temperaments and train themselves accordingly. The results of this study would be used to further improve the driving conditions on the highways. This will in general reduce the highway fatalities and long term fatigue related diseases.

Alternatives:
You can choose not to participate in this research study and just do the truck driving training. The participation or opting out from the study will not affect the evaluations of Truck Driver Training Program.

Confidentiality:

You have rights regarding the privacy of your health information collected in course of this research.

Only the senior person of the project will have access to your identifiable information. This information includes demographic information (like your address and birth date) and the results of ECG and GSR. You have the right to limit use and sharing of your information. After you have successfully completed the study and have been paid. The identifiable record that can tie back the information to you will be deleted and data recorded would be randomly assigned an identification number. The data analysis will only begin after an id is has been assigned to a record.

By signing this consent form, you are allowing the research team to have access to your information. The research team includes the investigators listed on the consent form.

Your information will be shared, as necessary, with the Institutional Review Board (IRB) and with any person or agency required by law. All of these persons or groups are obligated to protect your information.

You may cancel this authorization to use and share your information at any time by contacting the principal investigator in writing. The unidentifiable information obtained in this study may be published in scientific journals or presented at scientific meetings but the data will be reported as aggregated data.

Compensation:

Participants who successfully complete the study would be $ 100 each. Participants can opt out of study at any time. If participants opt of the study in between there would be no compensation. The participants who successfully complete the study will be contacted by Kelly Christensen (Associate Dean of Instructions) and will be required fill out Presenter Agreement. The checked will mailed to them in the address provided on the Presenters Agreement.

Opportunity to Ask Questions:

You may ask any questions concerning this research and have those questions answered before agreeing to participate in or during the study. Or you may call the investigator at any time, office phone, (402) 472-6391, or after hours (765) 430-0023. Please contact the investigator:

- if you want to voice concerns or complaints about the research
- in the event of a research related injury.

Please contact the University of Nebraska-Lincoln Institutional Review Board at (402) 472-6965 for the following reasons:

- you wish to talk to someone other than the research staff to obtain answers to questions about your rights as a research participant
- to voice concerns or complaints about the research
- to provide input concerning the research process
- in the event the study staff could not be reached,

Freedom to Withdraw:

Participation in this study is voluntary. You can refuse to participate or withdraw at any time without harming your relationship with the researchers or the University of Nebraska-Lincoln, or in any other way receive a penalty or loss of benefits to which you are otherwise entitled. If participants opt of the study in between there would be no compensation made for this study.

Consent, Right to Receive a Copy:

You are voluntarily making a decision whether or not to participate in this research study. Your signature certifies that you have decided to participate having read and understood the information presented. You will be given a copy of this consent form to keep.

Signature of Participant:

____

____

Signature of Research Participant *Date*

Name and Phone number of investigator(s)

Anuj Sharma, PhD, Principal Investigator *Office: (402) 472-6391*

Michael Hall,Truck Driver Trainer, Secondary Investigator Office (402) 461-2550

John Eastman, Truck Driver Trainer, Secondary Investigator Office(402) 4602189

Figure A.1 Consent Form

PERSONAL DATA FORM

Name: ______ Gender: 1 □ male 2. □ Female
Age:______

What is your highest level of education?

1 □ Primary school 2 □ High school 3 □ 2-year college 4 □ 4-year college 5 □ MS or higher

Are you currently:

1 □ Employed for wages 2 □ Self-employed 3 □A student

5 □ Out of work for less than 1 year 6 □ Out of work for more than 1 year

How many years have you been driving vehicles?

1. □ 0-2 2. □ 3-5 3. □ 6-9 4. □ 10 or more

How frequently do you drive now?

1. □ Every day 2. □ 2 or 3 days/week 3. □once a week 4. □ less often

How many miles do you drive in an average week?

1. □ less than 60 2. □ 60-300 3. □300-1500 4. □ more than 1500

How many hours do you drive in a day?

1. □ 0-2 2. □ 2-4 3. □ 4-6 4. □ 6-8 5. □ 8-12 6. □ more than 12

Have you been involved as a driver in road accident? : 1 ☐ Yes 2 ☐No

If YES, how long ago was the accident with you driving?

1. ☐ Past few months 2. ☐ During last year

3. ☐ Between 1 and 2 years 4. ☐ More than two years

How serious was that accident?

1. ☐ Very serious 2. ☐ Serious 3. ☐ Minor

Health status:

1. ☐ Good 2. ☐ moderate 3. ☐ poor

Number of current diseases diagnosed by a physician?

1. ☐ 0 2. ☐ 1 3. ☐ 2 4. ☐ 3 or more

Figure A.2 Background Information

Appendix B STAI Data Processing

Table B.1 Processing Trait Anxiety Score

Statements	**Questionnaires**	**Scale (Driver Id :39, Male, Startweek, Date :13/07/11)**	**Score**
21	I feel pleasant	4	4
22	I feel nervous and restless	2	2
23	I feel satisfied with myself	3	1
24	I wish I could be as happy as others seem to be	2	2
25	I feel like a failure	2	2
26	I feel rested	3	2
27	I am "calm, cool, and collected"	3	2
28	I feel that difficulties are piling up so that I cannot overcome them	1	1
29	I worry too much over something that really doesn't matter	2	2
30	I am happy	4	1
31	I have disturbing thoughts	1	1
32	I lack self-confidence	2	2
33	I feel secure	3	2
34	I make decisions easily	3	2
35	I feel inadequate	2	2
36	I am content	4	1
37	Some unimportant thought runs through my mind and bothers me	3	2
38	I take disappointments so keenly that I can't put them out of my mind	3	2
39	I am a steady person	3	2
40	I get in a state of tension or turmoil as I think over my recent concerns and interests	3	3
		Total	38

Table B.2 Processing State Trait Anxiety Score

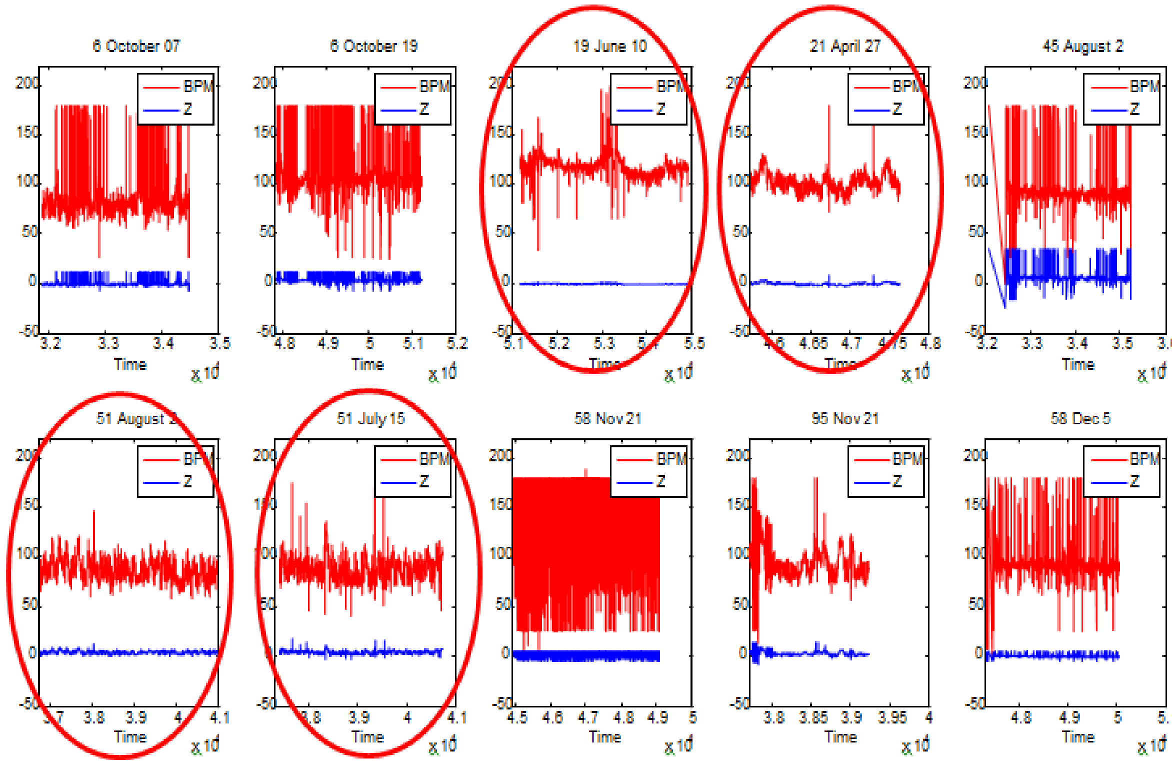
Statements	Questionnaires	Driver Id : 45, Male, Midweek, Date :15/07/11	
		Before Driving (S)	Before Driving (Score)
1	I feel calm	3	2
2	I feel secure.	3	2
3	I am tense	2	2
4	I feel strained	2	2
5	I feel at ease	3	2
6	I feel upset	1	1
7	I am presently worrying over possible misfortunes	2	2
8	I feel satisfied	3	2
9	I feel frightened	1	1
10	I feel comfortable	3	2
11	I feel self-confident	3	2
12	I feel nervous	1	1
13	I am jittery	1	1
14	I feel indecisive	2	2
15	I am relaxed	1	4
16	I feel content	2	3
17	I am worried	2	2
18	I feel confused	2	2
19	I feel steady	1	4
20	I feel pleasant	3	2
		Total	41

Appendix C Test Routes

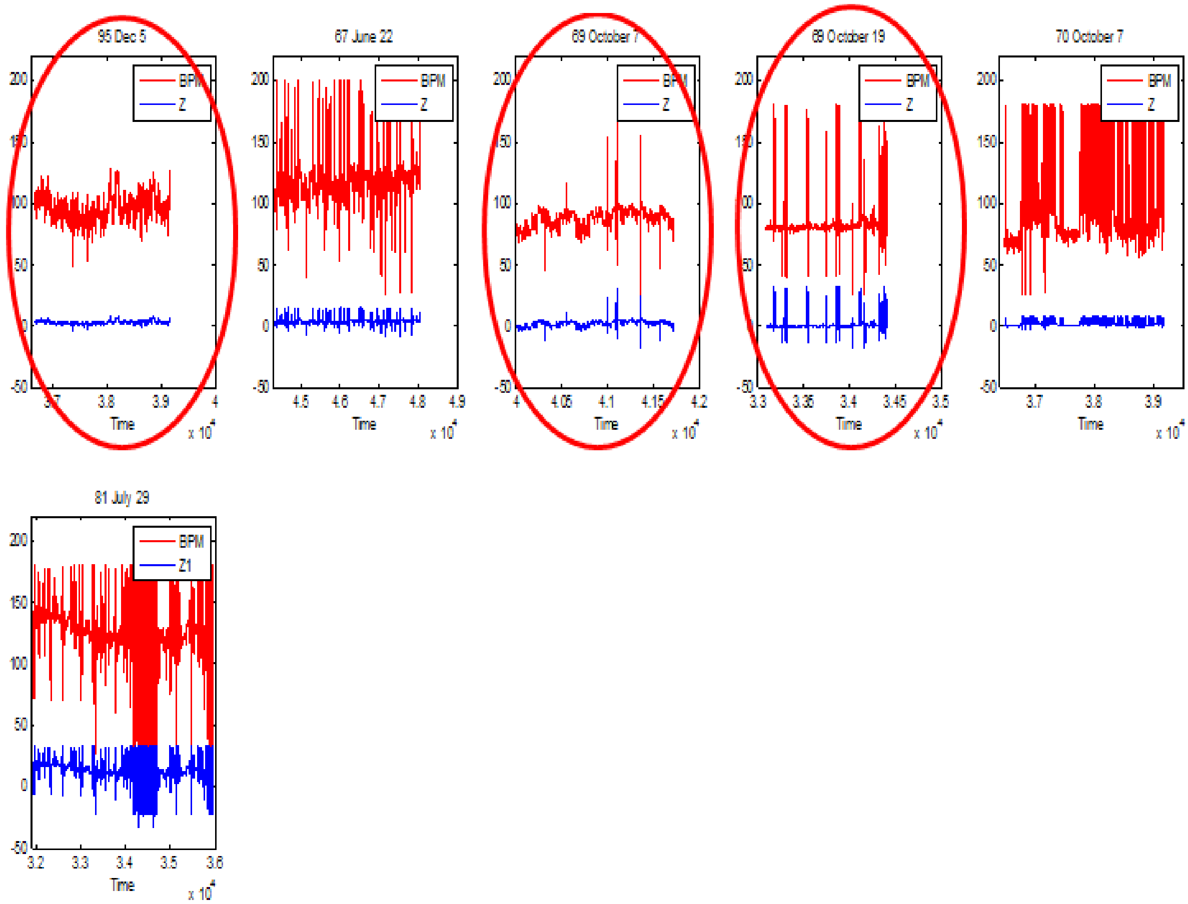
Figure C.1 Example KMZ Plots of Test Routes

Appendix D Analysis Related

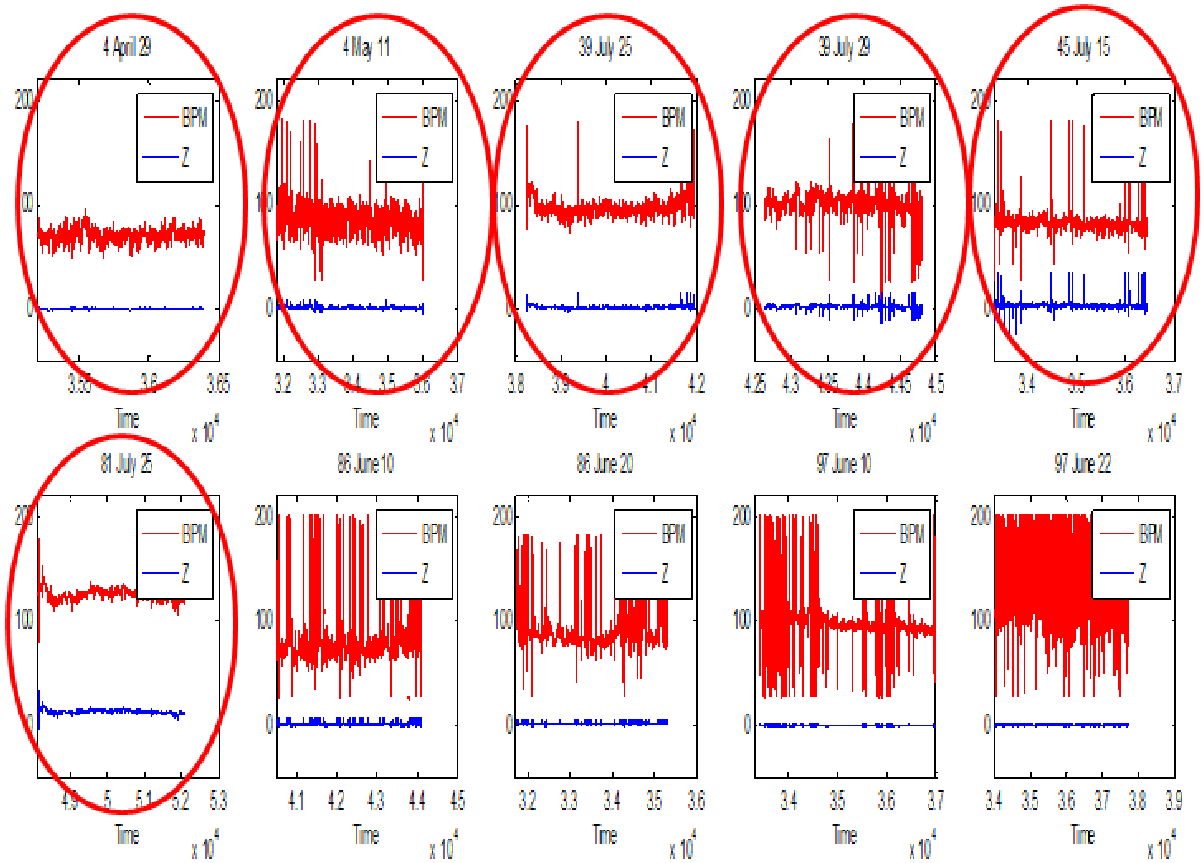
D.1 Noise Detection



Note: Circled data sets are the data sets which were chosen for the analysis purpose.



Note: Circled data sets are the data sets which were chosen for the analysis purpose.



Note: Circled data sets are the data sets which were chosen for the analysis purpose.

D.2 SPSS Output

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	17042	75.6
	Missing Cases	5489	24.4
	Total	22531	100.0
Unselected Cases		0	.0
Total		22531	100.0

a. If weight is in effect, see classification table for the total number of cases.

Dependent Variable Encoding

Original Value	Internal Value
.00	0
1.00	1

Classification Table[a,b]

	Observed		Predicted		
			Z		Percentage Correct
			.00	1.00	
Step 0	Z	.00	13336	0	100.0
		1.00	3706	0	.0
	Overall Percentage				78.3

a. Constant is included in the model.

b. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 0	Constant	-1.281	.019	4755.313	1	.000	.278

Variables not in the Equation

			Score	df	Sig.
Step 0	Variables	Trait_Anxiety	13055.202	1	.000
		STAI_Begining	9528.601	1	.000
		Driving_Education	267.416	1	.000
		Passive_Overtaking	17.540	1	.000
		Right_turning_intersection	5.307	1	.021
		Right_turning	10.534	1	.001
		Ax	7.688	1	.006
		Vy	4667.934	1	.000
		Stop	68.767	1	.000
		Car_suv	33.461	1	.000
		Minor_arterial	373.725	1	.000
		Collector	806.331	1	.000
		Driving_Duration	.107	1	.743
	Overall Statistics		14062.020	13	.000

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	16214.133	13	.000
	Block	16214.133	13	.000
	Model	16214.133	13	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	1634.902[a]	.614	.946

a. Estimation terminated at iteration number 10 because parameter estimates changed by less than .001.

Classification Table[a]

	Observed		Predicted		
			Z		Percentage Correct
			.00	1.00	
Step 1	Z	.00	13253	83	99.4
		1.00	88	3618	97.6
	Overall Percentage				99.0

a. The cut value is .500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Trait_Anxiety	.858	.044	381.759	1	.000	2.358
	STAI_Begining	-.214	.024	77.336	1	.000	.808
	Driving_Education	-.180	.026	48.130	1	.000	.835
	Passive_Overtaking	1.779	.479	13.786	1	.000	5.925
	Right_turning_intersection	.895	.452	3.922	1	.048	2.448
	Right_turning	1.827	.559	10.675	1	.001	6.212
	Ax	-.325	.124	6.881	1	.009	.723
	Vy	.051	.007	55.735	1	.000	1.052
	Stop	1.517	.346	19.209	1	.000	4.560
	Car_suv	-1.170	.550	4.521	1	.033	.310
	Minor_arterial	.777	.284	7.507	1	.006	2.175
	Collector	-1.600	.308	27.030	1	.000	.202
	Driving_Duration	.092	.008	134.568	1	.000	1.096
	Constant	-31.004	.920	1135.134	1	.000	.000

a. Variable(s) entered on step 1: Trait_Anxiety, STAI_Begining, Driving_Education, Passive_Overtaking, Right_turning_intersection, Right_turning, Ax, Vy, Stop, Car_suv, Minor_arterial, Collector, Driving_Duration.