University of Southampton

Faculty of Engineering, Science and Mathematics

School of Civil Engineering and the Environment

Transportation Research Group

The Effects of Heavy Goods vehicles (HGVs) on Driver Behaviour while Car-Following

By

Mahdi Shehab

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ABSTRACT

FACULTY OF ENGINEERING, SCIENCE & MATHEMATICS
SCHOOL OF CIVIL ENGINEERING AND THE ENVIRONMENT

Doctor of Philosophy

THE EFFECTS OF HEAVY GOODS VEHICLES (HGVs) ON DRIVER BEHAVIOUR WHILE CAR-FOLLOWING

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Car-following is instrumental when studying traffic flow at the microscopic level. Various factors are believed to influence the car-following process, some relate to driver characteristics while others relate to environmental, road and traffic conditions. The current state of knowledge regarding the effects of lead vehicle type, and especially those of heavy goods vehicles (HGVs), on the car-following process is very limited. Contradicting findings have been inferred from previous studies on the effects of HGVs as lead vehicles on car-following behaviour. Furthermore, the sources of the effects of HGVs on car-following have not been addressed.

This study addresses the effects of HGVs as lead vehicles on drivers' car-following behaviour. This was done by utilizing 30 test subjects to drive the TRG's instrumented vehicle in the traffic stream, where it was found that drivers increase their time gaps while following HGVs compared to following vans and cars. Furthermore, the effects of HGVs on driver behaviour were found to increase on upgrade sections. As regards driver characteristics' effects on car-following, male drivers were observed to follow at smaller headways than female drivers. Moreover, older drivers followed at the largest headways while no differences in headways were observed between young and middle aged drivers. Young female drivers and middle aged drivers of both genders displayed the greatest stability in driver behaviour while old drivers of both genders and young male drivers displayed less stable behaviour. Additionally, no effect of trailing vehicle type on driver behaviour while following was observed in this study. This study confirmed two of the hypothesized sources of HGVs' effects on driver behaviour, those being vision obscuration and psychological impacts. Another valuable contribution of this study was testing whether time headway is constant for an individual driver, where it was found that drivers do not maintain constant time gaps from one following process to another. Finally, a linear model was developed to enable prediction of time gaps.

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Part I

Introduction and Literature Review

Chapter 1

Introduction

1.1 Background

Over the last few decades, the demand for using the road network has increased dramatically. This increase in demand could not be matched by a corresponding increase in supply in the form of building more roads or widening existing ones due to the limited availability of resources. This has led to the escalation of the two main problems encountered on the roads, namely traffic accidents and traffic congestion. Among the several measures taken to reduce these problems, two measures stand out as the most promising; the first involves carrying out more research that may lead to better management of the existing resources while the second entails crafting new in-vehicle technologies that would lead to more efficient use of the current resources.

One tool that is utilized frequently in the first approach is simulation models, models that try to reproduce the conditions on the road in order to enable the identification of the sources of problems and the assessment of the different proposed strategies. Simulation models are usually developed at two different levels, microscopic and macroscopic. In microscopic simulation models, two processes are of prominent significance, car-following and lane changing. The prominent significance of these two processes stems from the fact that models that describe these two processes constitute the major components of microscopic simulation models. For these models to be effective and yield their intended benefits, they must endeavour to emulate traffic conditions on the roads as closely as possible. However, a closer examination of some of the underlying assumptions of the car-following algorithms used in these models reveals that these models treat cars and heavy goods vehicles (HGVs) similarly in terms of their effects on driver behaviour while following. This requires a closer examination of the effects of HGVs on driver behaviour to determine with certainty whether this assumption is justified.

Another approach to mitigating traffic problems on the roads entails developing new technologies that aid the driver in achieving optimum control of the vehicle or that would take over the control of the vehicle entirely. A wide range of technologies have been and are being developed, among the most common of which are Adaptive Cruise Control (ACC) systems, Advanced Vehicle Control and Safety Systems (AVCSS) and Collision Warning Systems. At the heart of these technologies is the requirement to control the distance gap between the host vehicle and the vehicle in front in a manner that ensures safety and efficiency. At the same time, these technologies should emulate the behaviour of drivers so as to make drivers comfortable with allowing such systems to be in partial or full control of the vehicle. In spite of this, algorithms that are the bases for these technologies operate under the assumption that driver behaviour while following does not change regardless of the vehicle type being followed. This again requires further investigation to determine whether this assumption is warranted.

Many attempts have been carried out to further our knowledge on driver behaviour in general. Few of these studies addressed the effects of HGVs on driver behaviour while following as described in chapter 5 of this thesis. Previous studies addressing HGVs' effects on driver behaviour had limitations due to the methodologies employed for data collection. The instrumented vehicle assembled at the Transportation Research Group (TRG) of the University of Southampton provides an opportunity to conduct research into various aspects of driver behaviour. This tool will overcome many of the limitations associated with previous research about driver behaviour, yielding more reliable results. This is essential in providing fundamental understanding of driver behaviour while car-following, which can also improve the effectiveness of microscopic simulation models and in-vehicle technologies.

1.2 Study Objectives

This study aims at investigating the effects of HGVs on driver behaviour while following. Within this scope, the variation of these effects with some driver demographics and roadway geometric elements will be examined. In addition, this study is unique in its attempt to investigate some of the possible sources of the effects of HGVs on following drivers' behaviour. To fulfil the aim of the study, a set of objectives was defined in order to make this study as comprehensive as possible within the time limits of the research project and the available resources. The objectives of this research study are:

1- Determine the effects of HGVs on driver behaviour while following.

Fulfilling this objective will give an indication of whether HGVs have any effects on the behaviour of drivers while car-following. If these effects exist, the analysis can go into specific factors relating to the variation of these effects and the sources of the effects.

2- Investigate the effects of HGVs on drivers' car-following behaviour on sections of gradient.

This objective will provide information as to the extent to which the effects of HGVs on driver behaviour change on sections of gradient.

3- Compare drivers' behaviour while following HGVs with their behaviour while following other vehicles that obscure following drivers' vision, i.e., vans.

This objective can potentially shed some light on whether the sources of the effects of HGVs are limited to them obscuring following drivers' vision or whether these effects stem from other factors in addition to vision obscuration.

4- Determine the effects of age on drivers' car-following behaviour.

This aspect of the study addresses the variation of driver behaviour while following with driver age, with emphasis on the effects of age interaction with vehicle type on driver behaviour while following.

5- Determine the effects of gender on the following behaviour of drivers.

Another driver characteristic, driver gender, is addressed through this objective. The variation of driver behaviour while car-following based on drivers' gender is tested. In addition, the interactions of driver gender with lead vehicle type and their effects on drivers' following behaviour will be scrutinized.

6- Determine the effects of being followed by an HGV on driver behaviour while following.

The effects of HGVs on driver behaviour may not be limited to situations where they are lead vehicles. It is likely that drivers are more aware when trailed by HGVs than when not trailed by other vehicles or when trailed by cars. Addressing this objective may yield more comprehensive knowledge regarding the effects of HGVs on driver behaviour.

7- Examine drivers' assessment of risk while following HGVs.

A possible source for the effects of HGVs on driver behaviour could be that they are perceived by drivers to be more hazardous than other types of vehicles. This possibility is investigated through this objective.

8- Investigate whether time headway maintained by a single driver remains constant from one following process to another.

This objective deals with car-following behaviour in general regardless of lead vehicle type. It is widely believed that time headway remains constant for the individual driver at different speeds. However, this finding may be questioned due to the methodologies employed to arrive at such conclusion. Data collected in this study should allow for accurate examination of this view.

9- Explore driver stability while following different vehicle types according to driver age and gender.

Another aspect that is as important as studying measured driver behaviour is studying the stability of driver behaviour while following different vehicle types.

This can be done by studying the variation of driver behaviour while following different vehicle types according to driver age and gender.

10- Develop a model that can predict time gap based on a set of predictor variables.

It is important that once the effects of various factors that influence driver behaviour while following are identified and analyzed, a method is developed that would enable predicting headways based on a set of certain predictor variables. This will pave the way for incorporating the effects of vehicle type into car-following algorithms used in microscopic simulation models and in-vehicle technologies.

Fulfilling these objectives will enable definitive assessment of the effects of HGVs on driver behaviour while following. This in turn may lead to vastly improved microscopic simulation models and more effective in-vehicle technologies.

1.3 Approach

This thesis is made up of twelve chapters divided into three parts, of which this is the first chapter of the first part. The rest of part I consists of literature review, made up of five chapters. Chapter two deals with the car-following process, followed by a chapter on driver behaviour. Chapter four addresses car-following models. Chapter 5 shifts the focus of the literature review to the specific aim of this study, namely the effects of lead vehicle type, and in particular of HGVs, on driver behaviour while following. The last chapter of part I provides a summary of what was inferred from the literature review part. Part II of the study revolves around the methodology employed in this research. Chapter seven gives an overview of the apparatus utilized for data collection, the TRG's instrumented vehicle. Next, the study methodology implemented in this research is described in detail. The final chapter of part II presents a detailed procedure for the analysis that is carried out. The last part of this thesis presents the main findings and contributions of this study. This part begins with presenting the results in chapter 10 followed by a chapter that presents a detailed discussion of the results and their implications. The last chapter of part III, and the thesis, presents the conclusions of the research along with possible future research to follow from this study.

Chapter Two

The Car-Following Process

Traffic flow is usually studied at two basic levels, macroscopic, where the overall characteristics of the traffic stream are studied and analyzed; and microscopic, where the behaviour of the individual entities in the traffic stream is investigated. In addition, traffic flow may also be studied at a level more detailed than the macroscopic level and more aggregated than the microscopic level, which is the mesoscopic level. At this level, individual groups of traffic entities are studied at a low-detailed level (Hoogendoorn and Bovy 2001). When traffic flow is studied at the microscopic level, the two fundamental activities that provide insight on driver behaviour are drivers' behaviour while following other vehicles and their behaviour during lane change manoeuvres. According to Krauss (1997), car-following is a process that serves as one of the bases for microscopic simulation models. It also serves as a basic tool in traffic flow theory, which tries to describe the behaviour of and interaction between individual vehicles at the microscopic level and the overall traffic characteristics at the macroscopic level. Chakroborty and Kikuchi (1999) defined the car-following process as " a control process in which the driver of the following vehicle attempts to maintain a safe distance between his/her car and the vehicle ahead by accelerating or decelerating in response to the actions of the vehicle ahead."

At low traffic densities, the interactions between vehicles are almost non-existent, thus allowing more freedom for drivers to operate their vehicles at their desired speeds. The theory of car-following is mainly applicable to situations where traffic density is medium to high, but not at low densities since drivers at these conditions are generally free from interacting with other vehicles (Gazis *et al.* 1960). This exemplifies the importance of studying car-following since traffic conditions that lie between free flow conditions and stop-and-go conditions, conditions where car-following is most prevalent, are the conditions most commonly encountered on the road network (Chakroborty 2006). Car-following may be characterized by the following vehicle not driven at the desired speed of its driver, and that may be considered a characteristic that distinguishes vehicles in car-following mode from free vehicles. In order to identify vehicles involved in a car-following process, a distinction must be made between these vehicles and free vehicles. Hoogendoorn and Bovy (1998) made this distinction between free vehicles (unconstrained) and those in car-following mode (constrained vehicles). According to the authors, a vehicle is classified as being free if it satisfies three conditions:

1- The headway between the vehicle and the one preceding it is adequately large and is sustained for a considerable duration.
2- The vehicle can overtake without the need to alter its time-space course as it approaches the vehicle ahead of it.
3- When passed by another vehicle, the overtaking vehicle continues to build an opening speed so as not to affect the independent status of the free overtaken vehicle.

Vehicles not satisfying these conditions are labelled as constrained vehicles, meaning that they are in car-following mode (Hoogendoorn and Bovy 1998).

Car-following theory is built on the concept that the actions of a driver (speed, separation, acceleration and deceleration) are dictated by the motion and behaviour of the vehicle immediately ahead. The lead vehicle is perceived to provide the stimuli based on which the following vehicle's driver reacts. An underlying assumption to car-following is that all vehicles travel in one lane and that no lane change manoeuvres are carried out (Chundury and Wolshon 2000 and Wolshon and Hatipkarasulu 2000).

The car-following process is instigated when a faster moving vehicle approaches a slower moving vehicle ahead, where the faster moving vehicle is forced to remain behind the slower moving vehicle, operating at a speed less than the desired speed of the approaching vehicle's driver. When in the car-following mode, the driver of the following vehicle is forced to drive his/her vehicle at the speed of the lead vehicle, which is lower than the desired speed of the following vehicle's driver (Chakroborty *et al.* 2004). The actions of drivers during the approach process which leads to the instigation of the car-following process are governed by two factors; Optic flow, the rate of change of the angle subtended by the lead vehicle over time, and Time-to-Collision which will be discussed in detail in the next chapter (Vogel 2003 and Brackstone *et al.* 2000).

In this chapter, various aspects of car-following will be addressed. First, the distinct features describing the process will be presented. Then, a discussion of the stimuli governing the actions of drivers in car-following will be given. An important aspect of car-following, that of steady-state car-following, is addressed next followed by a discussion of the safety and stability of the car-following process. The factors affecting the process are addressed after that.

2.1 The Distinct Features of the Car-Following Process

The car-following process has five distinct features that govern the behaviour of drivers when in the car-following mode. These distinct features are:

1- Car-following behaviour is approximate in nature: ambiguity is associated with the way drivers perceive stimuli, their analysis of such stimuli and in responding with the appropriate actions to these stimuli. Thus, the car following process is deemed approximate in nature (Chakroborty 2006 and Chakroborty and Kikuchi 1999).

2- Response to stimuli is asymmetric: the magnitude of response, whether acceleration or deceleration, is governed by the circumstances. Differences in the magnitudes of responses have been observed in response to equal but opposite stimuli (e.g., the magnitude of response to positive relative speed differs from the magnitude of response associated with an equal but negative relative speed) (Chakroborty 2006 and Chakroborty and Kikuchi 1999).

3- Closing-in and shying-away occur in car-following: two frequently observed phenomena in car following are closing-in and shying-away. When a driver is following a vehicle at a distance greater than his/her desired following distance, the driver will accelerate even if the lead vehicle is decelerating. On the other hand, a driver following too close behind a lead vehicle will decelerate to regain the desired spacing even if the lead vehicle is accelerating (Chakroborty *et al.* 2004 and Chakroborty and Kikuchi 1999).

4- The drift phenomenon is observed in car-following: the stable distance headway usually is not a value that can be precisely maintained by the following vehicle's driver as he/she follows a lead vehicle. Rather a phenomenon called "drift" is observed where the following vehicle's driver wishing to gain on the lead vehicle to establish the desired headway gets closer than intended and starts decelerating to achieve the desired space headway, where the driver overcompensates. The process is repeated and results in oscillation of the actual space headway around the desired space headway. This "drift" phenomenon is a result of drivers' inability to accurately determine the lead vehicle's speed and the driver's inability to maintain the intended speed accurately (Wu *et al.* 2003, Chakroborty and Kikuchi 1999, McDonald *et al.* 1997 and Michaels 1963).

5- The car-following process is locally and asymptotically stable: disturbances introduced into two vehicles in a platoon of vehicles in car-following mode dissipate over time (between the two vehicles) and the effects of these disturbances diminish as they propagate further back in the platoon of vehicles. The stable distance headway is only a function of stable speed, irrespective of initial conditions and how that state was achieved (Chakroborty *et al.* 2004 and Chakroborty and Kikuchi 1999).

The nature of the car-following process is exemplified in a plot of distance headway (or gap) vs. relative speed, as shown in figure 1. The approximate nature of car-following and the "drift" phenomenon are clearly demonstrated in this plot. It is clear from the figure that distance headway does not remain constant but varies as the driver attempts to achieve his/her desired spacing with the lead vehicle.

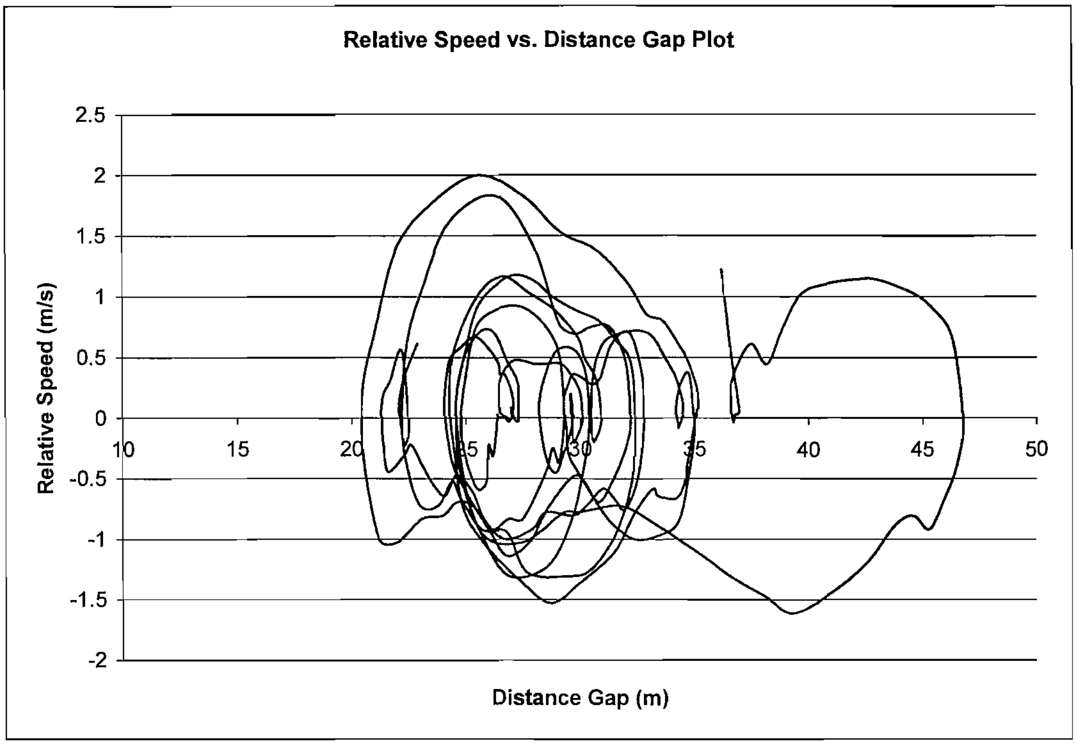

Figure 1: Variation of distance headway with relative speed

2.2 Sources of Information in Car-Following

In the process of car-following, the trajectory of the following vehicle is dictated by the stimuli perceived by the following vehicle's driver and how that driver changes his/her behaviour in response to such stimuli. The main factors affecting decisions of the following vehicle's driver, which may be considered as the main stimuli, are separation distance with the leader, relative velocity and relative acceleration (Chakroborty 2006 and Cheng *et al* 2005). Chakroborty (2006) further postulates that relative velocity and relative acceleration are used by the driver to anticipate forthcoming actions required. It has widely been accepted, however, that the main sources of information governing the behaviour of following drivers are the relative speed (the difference between the speed of the lead vehicle and the speed of the following vehicle) and the distance gap (the distance between the front bumper of the following vehicle and the rear bumper of the lead vehicle) (Cheng *et al.* 2005, Michaels and Solomon 1962 and Herman and Potts 1961). Michaels and Solomon (1962) and Cheng *et al* (2005) further suggest that of the two main sources of information, the primary source used by drivers in controlling their following headways is the change in speed of the lead vehicle as perceived by the following vehicle's driver (relative speed). Cheng *et al.* (2005) attributes drivers' higher reliance on relative speed to the greater difficulty endured by drivers in estimating distance headways as compared to estimating relative speed. The view of drivers' higher dependence on relative speed as the main stimulus was also supported by Herman and Rothery (1963), who found that the responses of a following vehicle's driver (in the form of acceleration or deceleration) are highly correlated with the speed difference between the lead vehicle and the following vehicle. This does not contradict the conclusion drawn by Hoffman and Mortimer (1996) based on 12 subjects viewing film clips while approaching a lead vehicle that in most situations while car-following, the threshold for noticing change in separation distance is exceeded before that of noticing change in relative speed. This conclusion cannot be interpreted as implying that separation distance is the primary source of information. Michaels (1963) indicated the existence of an interaction between relative speed and separation distance as pertains the primary source of stimuli. He states that drivers exhibit higher sensitivities to changes in relative speed with their leaders at shorter following distances than they do at longer following distances. Thus, it could be said that a driver's sensitivity to changes in relative speed is a function of separation headway, the relation being inversely proportional.

Hoffman and Mortimer (1996) viewed drivers' use of relative speed and separation distance as cues in car-following in a slightly different manner. They state that when drivers are following at large separation headways, cues available to the driver about relative speed are available from change in distance headway between the driven vehicle and the one ahead. However, at small separation headways, direct information about relative speed in the form of change of angular velocity is the one utilized by drivers to decide on the change in relative speed. A not dissimilar view on drivers' use of separation distance information and lead vehicle speed was provided by Mulder *et al.* (2005), where they noticed that drivers can identify the characteristics of lead vehicles' speed, and that as the bandwidth of disturbance in lead vehicle's speed increases, following drivers' performance improves due to increasing their efforts to cope with such disturbances. In addition, the authors also observed that drivers demonstrate greater performance when the separation headway with their leaders is small than when the separation headway is large.

An essential, yet not an independent, source of information believed to influence driver behaviour during car-following is the optic flow field. Michaels (1963) states that a driver may realize that he/she is closing by noticing an increase over a certain time period of the angle subtended by a lead vehicle to his/her eyes. This rate of change of the visual angle allows the driver to perceive changes in relative speed, which would trigger his/her actions. This does not, however, provide the driver with any clues of the rate of change of the separation distance. The optic flow field has also been found to provide indirect information that affects driver behaviour while following. Van der Horst (1991), Schiff and Detwiler (1979) and Lee (1976) argue that the optic flow field provides the information required by drivers to estimate time-to-collision, which is then used by drivers to judge on the appropriate instant for instigating the braking process and controlling that process thereafter. More specifically, the information comprising stimuli for drivers of following vehicles as they follow lead vehicles is the visual angle subtended by the lead vehicle at the eyes of the following vehicle's driver and the rate of change of that angle, the ratio of which yields TTC (van der Horst 1991 and Lee 1976) as will be shown in a subsequent chapter. Thus, an argument can be made that the optic flow field represents the source of information that allows drivers to detect changes in relative speed, which is then used by drivers to decide on the appropriate actions to be taken.

Another source of information that is believed to provide stimuli to which following vehicles' drivers react is the lead vehicle's acceleration and deceleration. Sultan *et al.* (2004) found from an instrumented vehicle study with 6 subjects that sufficient evidence exists to support the notion that drivers are able to perceive information about the lead vehicle's acceleration and/or deceleration and that drivers base part of their driving actions on the lead vehicle's acceleration and/or deceleration. However, establishing perception thresholds for changes in acceleration that can be perceived is very difficult. Nonetheless, drivers do not perceive the information obtained regarding the lead vehicle's acceleration/deceleration to be as critical as relative speed and changes in distance headway, which govern the majority of actions taken by drivers.

Various other sources of information are believed to be used in the car-following process. Sultan *et al.* (2004) make the argument that driver behaviour is not only based on the information perceived by drivers during the process of driving, but also on recently obtained information. This contention is supported by Wilde (1982), where it is argued that drivers use the knowledge gained from previous decisions and subsequent outcomes associated with these decisions in analysing and deciding on future situations. Kim and Lovell (2005) state that the actions of drivers in car-following are more appropriately determined by studying the sequence of circumstances that led to the current condition rather than studying the current circumstances regardless of how these circumstances were reached. In addition, it has been demonstrated that drivers base their decisions not only on the vehicle immediately ahead, but also on the actions of vehicles further ahead (Mehmood *et al.* 2003 and Parker 1996). Chandler *et al.* (1958) make the argument that drivers utilize information other than those available from the immediate leader in their efforts to attain stable driving conditions. Drivers often look beyond the vehicle immediately ahead for cues, and this was also supported by Triggs and Harris (1982). In line with these findings, Macadam (2003) contends that drivers look ahead to gain information that would help them forecast the required actions in their continued effort to attain stable driving conditions. He further states that drivers use information other than those available from their visual fields, in the form of motion influences and auditory information, to supplement information obtained from the visual field. Moreover, Rakha and Crowther (2003, 2002) argue that in addition to utilizing cues from vehicles further downstream of the lead vehicle, drivers also utilize the vehicle immediately behind and downstream traffic control devices for additional cues on which to base part of their decisions.

In addition to the sources discussed above, various other sources of information are hypothesized to influence driver behaviour. Evans and Rothery (1976) contend that the perceived spacing between two vehicles is not influenced by the size (width) of the lead vehicle. However, changes in image size of the lead vehicle provide a primary source of information for judging the spacing between vehicles, as found by the authors.

The various stimuli obtained are processed according to a certain mechanism that characterizes the nature by which human drivers process such information. The responses of a driver of a following vehicle to stimuli by the lead vehicle depend on the perception time of the following driver, his/her response time and the vehicle's performance characteristics (Chandler *et al.* 1958). Thus, there is an element of delay associated with the reactions of drivers to various events. This delay results from perceiving certain stimuli, processing what has been perceived and then deciding on the proper action. This delay is partly offset by drivers looking ahead (of the vehicle immediately ahead) in order to attain information on which to base their actions (Macadam 2003).

2.3 Steady-State Car-Following

The aspect of car-following of most interest in microscopic traffic flow theory is steady-state car-following. Steady-state car-following influences the speed of vehicles at different densities, capacity of the road and the length of forming queues (Rakha and Crowther 2003). From a theoretical stand point, steady-state car-following occurs when both the lead vehicle and following vehicle travel at the same speed and adopt the same car-following behaviour (Rakha and Crowther 2003). Steady-state car-following has been characterized by the speed and acceleration of the lead vehicle and the following vehicle being equal (Aycin and Benekohal 1998 and Gazis *et al.* 1959). In order to maintain the steady-state condition, the following vehicle's driver responds to changes of the lead vehicle's speed by trying to equal that speed (Michaels and Solomon 1962). From a practical stand point, however, some differences between speed of the lead vehicle and speed of the following vehicle must be tolerated while still qualifying the process as steady-state car-following. Michaels (1963) argues that the steady-state car-following process, in reality, should not be characterized by the speeds of the lead vehicle and following vehicle being exactly equal, but rather by the angular velocity of the lead vehicle being below the detection threshold of the following vehicle's driver. In other words, the steady-state phase of the car-following process takes place when the following vehicle's driver is within his/her thresholds for detection of relative velocity and separation distance changes.

While engaged in a car-following process, various perturbations are introduced between the pair of vehicles in the form of braking and acceleration which disrupt the steady-state car-following process. This causes the pair of vehicles involved in car-following to shift from one steady-state to another. The movement of a pair of vehicles in car-following from one steady-state to another is governed by the acceleration characteristics of vehicles, driver aggressiveness and road and environmental conditions (Rakha and Crowther 2003).

The time headway adopted by drivers during the steady-state phase of car-following may be considered to be the preferred time headway of drivers as they follow other vehicles. This preferred time headway represents the time available to the following vehicle's driver to reach the same deceleration level as that of the lead vehicle (Taieb-Maimon and Shinar 2001, Aycin and Benekohal 1998 and van Winsum and Heino 1996).

2.4 Safety and Stability of the Car-Following Process

In order to enable modelling of the phenomenon, the theory describing car-following operates under the assumption that the process is safe and stable. Safety of the car-following process relates to the percentage of time where the following vehicle's driver will not be able to stop if the lead vehicle were to apply maximum deceleration (Kikuchi *et al.* 2003). The concept of safe headway is introduced into car-following theory to facilitate the development of models that describe car-following. Safe headway is defined by Parker (1996) as the following distance between two vehicles in car-following mode deemed by the follower to be sufficient in avoiding collision with the lead vehicle under any circumstances. Kim and Lovell (2005) argue that different drivers have different perceptions as to what constitute a safe following distance.

While defining such safe headways can theoretically be done with relative ease, many drivers may find it difficult to define, and in some situations even implement such safe following headways while driving. Taieb-Maimon and Shinar (2001) found that drivers may have the ability to perceive what a safe headway is and adopt that headway while driving; however, they may lack the ability to numerically quantify that perceived safe headway. Sadeghhosseini and Benekohal (1997) state that a large percentage of vehicles were observed to follow at distance headways that would not enable them to safely stop their vehicles without colliding with the lead vehicle if that lead vehicle were to decelerate abruptly. The authors observed that most drivers adopt time headways of less than the recommended 2 second headway. Taieb-Maimon and Shinar (2001) found that a significant portion of drivers adopted minimum time headways that were smaller than their brake reaction times, implying that these drivers will not be able to avoid colliding with their leaders were the lead vehicle to apply maximum deceleration unexpectedly.

Stability of the car-following process relates to the variation in spacing between different pairs of vehicles in car-following mode over time due to the introduction of a perturbation (Kikuchi *et al.* 2003). Studying the stability of the car-following process, and hence traffic stability, provides information on the behaviour of a vehicle or a platoon of vehicles in response to a disturbance by the platoon leader or the lead vehicle (Kikuchi and Chakroborty 1992). As the lead vehicle's driver reverts to a constant speed after changing speed for some time due to a perturbation, the following vehicle's driver will change speed and distance headway in a manner that would revert the distance headway to the safe distance headway and yield a relative speed of zero (Chakroborty *et al.* 2004).

Two aspects of stability of the car-following process are of interest, local stability and asymptotic stability. Local stability addresses the behaviour of one driver in response to perturbations introduced by the vehicle immediately ahead. Of interest in this regard is the amount of oscillation in the responses of the following vehicle's driver as a result of these perturbations. Stated differently, local stability addresses the temporal variation of the responses of the following vehicle's driver due to perturbations in the motion of the lead vehicle. Asymptotic stability of the car-following process deals with the propagation of the disturbances introduced by a platoon leader further up-stream among a platoon of following vehicles. Observations in this regard are focused on whether these disturbances are magnified or dampened as they propagate backward through the platoon of following vehicles (Zhang and Jarrett 1997, Herman and Potts 1961 and Herman *et al.* 1959).

Herman and Rothery (1963) argue that in a platoon of vehicles operating at steady-state, disturbances in the form of accelerations of the leader propagate through the platoon of following vehicles slower than decelerations of the platoon leader do. They further postulate that the responses of following vehicles' drivers in opening situations might be significantly different from their responses in closing situations. The car-following process is said to be stable (both locally and asymptotically) if the responses of interest are damped, non-oscillatory. Oscillatory responses, whether damped or un-damped, characterize unstable car-following processes, which are considered hazardous (Zhang and Jarrett 1997).

Ranijitkar *et al.* (2003) found that average driver responses are locally and asymptotically stable. Herman and Rothery (1963) state that in general, drivers exhibit stable behaviour when following other vehicles. However, drivers do occasionally exhibit behaviour that is very close to being unstable when following other vehicles.

Headways adopted by drivers are believed to influence the stability of the car-following process. Following at short headways, according to Michaels (1963), may lead to instability of the car-following process since the time available for the following vehicle's driver to take corrective action in response to speed changes may not be sufficient and may lead to oscillations in the responses, which causes the car-following process to be unstable.

2.5 Factors Affecting the Car-Following Process

Various factors have been found to affect car-following. Some of these factors relate to driver characteristics (i.e., age, gender, driver state, driving experience, etc.), while other factors affecting car-following may be considered situational factors relating to traffic conditions, road characteristics and environmental conditions (i.e., weather, time of day, lighting conditions, traffic density, road geometrics, etc.) (Kim and Lovell 2005 and Panwai and Dia 2005). In most cases, the effects imposed on the process result from the interaction of more than one factor. Factors affecting the car-following process that relate to the characteristics of the driver will be taken up in the next chapter. Some of the other factors will be taken up in this section.

One of the factors affecting the process of car-following is traffic density. Dijker *et al.* (1998) argue that car-following behaviour varies with density (e.g., congested conditions vs. non-congested conditions). Dijker *et al.* (1998) observed that for passenger vehicles, distance gaps between vehicles in congested conditions were consistently larger than distance gaps in non-congested conditions at the same speed levels. The differences were most noticeable for the fast lane, and least obvious for the slow lane. The authors postulate that differences in the fundamental macroscopic traffic flow diagrams between the congested and non-congested regimes may be thought of as merely reflections of the variation in car-following behaviour between the two regimes. Furthermore, the existing discontinuities in the fundamental macroscopic traffic flow diagrams, according to the authors, may be attributed to differences in car-following behaviour between the two regimes. This conclusion was reached via experiments utilizing car-following simulation algorithms. When separate car-following algorithms for congested and non-congested conditions were utilized in a simulation model, the resulting macroscopic traffic flow diagrams matched the observed data better than when using a single car-following algorithm for both regimes, especially at heavy congestion.

Another of the factors affecting car-following is weather conditions. Goodwin (2002) states that inclement weather affects various aspects of driver behaviour, especially while car-following where drivers feel inclined to adopt larger headways. Zhang *et al.* (2005) also state that drivers' speed and headway are affected by weather conditions. Peeta *et al.* (2005) reported that the effects of HGVs on driver behaviour are more pronounced during inclement weather. Sterzin (2004) affirms that driver behaviour is affected by weather conditions, this effect manifesting in the form of speed reduction and increased headways while following during inclement weather. Meanwhile, it was observed in a driving simulator study with 47 subjects that in foggy conditions, most drivers reduce their headway in an effort to maintain visible contact with their leaders, which would enable them to obtain cues to base their actions on (Broughton *et al.* 2006).

Another factor believed to affect the car-following behaviour of drivers is visibility. Andersen *et al.* (2004) indicated that reduced visibility due to inclement weather and night driving causes the performance of drivers while car-following to diminish, according to results obtained from a driving simulator study utilizing 6 subjects. Furthermore, time of the day (day time vis-à-vis night time) is also believed to influence driver behaviour while following. Hoogendoorn and Bovy (1998) state that evidence obtained from data collected by a pair of rubber tube detectors supports the hypothesis that drivers' car-following behaviour varies at different times of the day. They found that for passenger vehicle drivers, headways increase as the day progresses, being highest during evening periods and smallest during morning periods. In contrast, headways adopted by HGVs' drivers decrease as the day progresses, being highest during the morning period and lowest during the evening period.

Another factor related to vehicle characteristics that is believed to influence the car-following process is the dimensions and geometrics of the following vehicle. According to Evans and Rothery (1976), the perceived spacing between two vehicles is influenced by the geometrics of the following vehicle. As the portion of the road obscured by the geometrics of a vehicle increases, the perceived distance between that vehicle and the one leading it decreases. This indicates that a possible source of information in judging the spacing between the two vehicles is the amount of road obscured by the geometrics of the vehicle driven. This may provide an explanation for smaller vehicles, which obscure smaller portions of the road, being driven at smaller headways than larger vehicles (Evans and Rothery 1976). Lead vehicle size is also believed to have an effect on the car-following process. This factor will be discussed in detail in a forthcoming chapter, as it is this factor that constitutes the main focus of the current study.

2.6 Conclusions

The literature shows that the car-following process is continuous in nature. It begins with the approach process, which then stabilizes into the steady-state phase of car-following that might be interrupted by perturbations by the leader. The nature of this process cannot be captured by any tool that fails to recognize the time-dependant nature of car-following. The main sources of stimuli for actions of a following vehicle's driver during car-following are the relative speed and separation distance with the vehicle immediately ahead. This implies that the lead vehicle provides the main source of information utilized by drivers as they follow other vehicles. A range of factors were found to affect the car-following process, including traffic density levels, weather conditions, time of day, visibility conditions and lead vehicle type. Since the main stimuli for drivers' actions in car-following come from the vehicle ahead, and since lead vehicle type is believed to affect car-following, it is vital that more knowledge is acquired regarding the effects of different lead vehicle types on car-following.

Chapter Three

Driver Behaviour

Driver behaviour at the microscopic level is studied with regard to lane changing behaviour and car-following behaviour (McDonald *et al.* 1997). At this level, according to Chakroborty *et al.* (2004), driver behaviour can be fully described by defining behaviour at four main situations:

1- Driver behaviour at free flow conditions, where the actions of drivers are not constrained by other vehicles in the traffic stream.
2- Driver behaviour in car-following situations, where the speed at which the driver operates the vehicle is dictated by the speed of the lead vehicle, which is usually less than the desired speed of the following vehicle's driver.
3- Driver behaviour in passing situations.
4- Driver behaviour in the presence of on-coming vehicles.

It is widely believed that the behaviour of drivers under any circumstances is dictated by two objectives: (1) the driver's concern for his/her own safety and (2) the driver's urgency to reach the trip destination at minimal time (Chakroborty *et al.* 2004 and Krauss 1997). Chandler *et al.* (1958) state that this balance between safety and urgency that dictates driver behaviour is sustained even in the absence of interfering vehicles. Chakroborty *et al.* (2004) also state that at the microscopic level, the actions of a driver, and thus his/her driving behaviour, are represented by the lateral position of the vehicle and its speed profile.

In this study, the behaviour of drivers while car-following is of prime interest. This chapter addresses various aspects of driver behaviour. The various indicators that are typically used to measure driver behaviour are discussed in the first section. Many factors influence driving behaviour, and these factors may serve as a tool to categorize the driving population into groups of similar general traits and characteristics. Some of the driver attributes influencing driver behaviour while following are discussed briefly in a forthcoming section. Following that will be a brief discussion of the risk taking behaviour of drivers. Few of the recent studies addressing driver behaviour are presented in the next to last section, with the chapter concluding with a section presenting an overview of what was learned regarding different methodologies that are usually employed to study driver behaviour.

3.1 Measures of Driver Behaviour while Following

A variety of measures and indicators have been employed to investigate driver behaviour while following. Some of the more common measures include separation headway (time or distance), Time-to-Collision (TTC) and the braking performance of drivers. The following subsections will discuss these measures in detail.

3.1.1 Preferred Headway

With regard to the behaviour of drivers when car-following, Ohta (1993) identified three types of drivers based on the relationship of speed with distance headway. This was inferred from an instrumented vehicle study using 31 students as subjects. The first type was of drivers who attempt to maintain constant time headway. Drivers belonging to this group adjust their distance headway at different speeds to maintain the time headway at their preferred value. The second type was of drivers who maintain constant distance headway irrespective of the speed at which the vehicle is travelling. The third type was that of drivers who show no sensitivity of distance headway associated with speed, but for whom the car-following behaviour changes with the type of road (e.g. motorway, arterial, etc).

Van der Hulst *et al.* (1999) contend that time headway can be taken to represent the safety margin of drivers as it represents the amount of time available to the driver to take evasive action in order to avoid colliding with the lead vehicle. Based on results obtained from a driving simulator study with 54 male subjects, van Winsum and Heino (1996) argue that the preferred time headway may be thought of as a reflection of time available to a driver to respond to a decelerating lead vehicle, in other words, preferred time headway reflects the braking abilities of drivers. It could then be hypothesized, according to the authors, that preferred time headway should not vary with speed for the same driver since it represents drivers' braking skills. The preferred time headway, however, should vary from driver to driver. Taieb-Maimon and Shinar (2001) concur with these findings by stating that time headway is consistent for the same driver, but varies between drivers. This was elicited from an experiment using both an instrumented vehicle and a simulator to observe the driving behaviour of 30 subjects. Drivers, according to Taieb-Maimon and Shinar (2001) and van Winsum and Heino (1996), adjust their distance headways at different speeds in a manner that maintains time headway constant for the individual driver, which results in time headway being constant over speed for the same driver. This result was also reached by van Winsum and Brouwer (1997) in another driving simulator study using 16 subjects. A similar result was also obtained in Heino *et al.* (1992) using an instrumented vehicle with 42 male subjects following an experimental lead vehicle driven by one driver at a pre-specified speed for the whole duration of the study. However, the conclusion here was only drawn on drivers who follow at time headways of 2 seconds or less. Further support for this view was provided by Cassidy and Windover (1998) from a study that utilized detector stations to measure headways maintained by drivers on motorways in congested conditions. The authors state that individual drivers adopt constant headways, and that headways adopted by drivers reflect their personalities. Drivers, according to Cassidy and Windover (1998), remember their personalities in the headways they adopt, where drivers possessing aggressive personalities adopt small headways and those possessing tentative personalities choose to follow at longer headways. Cassidy and Windover also concluded that drivers go back to their preferred headways after facing a disturbance which forces them to temporarily change their headways. Evans and Wasielewski (1983) found that drivers adopt similar headways on different trips. This conclusion was reached by measuring headways on motorways using photographic techniques. This conclusion was also reached by Kim and

Lovell (2005) in an instrumented vehicle study, although the authors state that this finding is only valid at high speeds.

Based on these findings, it can be concluded that time headway is a good measure of driver behaviour while following. Van der Hulst *et al.* (1999A) further argue that standard deviation of time headway is a measure of driving performance in terms of ability to maintain constant headway while following. Thus, variation of time headway can be considered a good measure of driver stability.

Although time headway has been shown to remain relatively constant for the individual driver, as supported by previous research, van Winsum (1999) stated that other factors may result in changing time headway for the individual driver. He identified some of these factors to include driver's state (when fatigued, drivers adopt larger headways), visibility (poor visibility may force drivers to adopt larger headways than they normally would) and willingness to increase mental effort. Kim and Lovell (2005) state that the behaviour of an individual driver is not consistent irrespective of surrounding conditions. Rather, the behaviour displayed by a driver in car-following varies according to surrounding conditions. Van Winsum (1999) argues that in situations where drivers are under time pressure, it has been acknowledged that such drivers adopt shorter headways. This is compensated for by increasing mental effort, shown by drivers increasing the attention and awareness to the actions of the lead vehicle. This argument is also made by van der Hulst *et al.* (1999A) based on observations from a driving simulator study with 24 subjects. In this study, it was observed that drivers adopt larger headways in foggy conditions only if not under time pressure. They also observed reduced variability in drivers' headways when under time pressure. Van der Hulst *et al.* (1999) state that drivers reduce criticality that might accrue from adopting smaller headways when under time pressure by increasing awareness, displayed by more accurate reactions to decelerating lead vehicles.

The preferred time headway is also believed to be influenced by the driver's expectation of the forthcoming actions of the lead vehicle. This was based on another simulator study utilizing 24 subjects, in which van der Hulst *et al.* (1999) noticed that headways maintained by drivers following deceleration of a lead vehicle were much shorter when the deceleration was unexpected compared with situations where the deceleration was expected. The authors contend that drivers of following vehicles took action by increasing their headways with their leaders prior to the actual deceleration of the lead vehicle when the deceleration was expected, thus maintaining the headway after the lead vehicle had decelerated in conformity with their preferred time headways.

3.1.2 Time-to-Collision (TTC)

Time-to-Collision (TTC) is defined as the time required for a collision to take place if the two vehicles were to proceed on the same course at the same speed, usually measured as the ratio of distance headway to relative speed (DX/DV). As can be seen from the definition, TTC provides information as to how dangerous a given situation is. It can also be seen from the definition that TTC can only be defined if the speed of the following vehicle is greater than the speed of the lead vehicle, that is, where the relative speed is greater than zero (Vogel 2003 and van Winsum and Heino 1996). Thus, Sauer *et al.* (2003) state that TTC is of limited use as a measure of driver behaviour in car-following, for the aim in car-following is to reach a steady-state where relative velocity is zero which would yield an infinite TTC. Time-to-collision may, however, be used as a measure of risk, indicating how critical a situation is (van der Hulst *et al.* 1999A). In fact, Minderhoud and Bovy (2001) state that time-to-collision has been utilized as a safety indicator in safety studies. However, it must be noted that this indicator only articulates indirect safety concerns regarding longitudinal control of vehicles while driving.

Vogel (2003) also makes the distinction between TTC and time headway, stating that TTC and time headway are independent of each other for following vehicle drivers. While small time headway represents a potentially dangerous situation, small TTC represents imminent danger. A vehicle in the car-following mode may have a large and even infinite TTC even if the time headway is small. This takes place when the speed of the lead vehicle is greater than the speed of the following vehicle, which results in relative speed being less than or equal to zero. While it is possible for small time headway to be associated with a large TTC, it is impossible for a small TTC to be associated with large time headway. It is worth noting here that TTC can never be smaller than the time gap between two vehicles, as this would indicate a lead vehicle travelling towards the following vehicle (reversing) (Vogel 2003).

Time-to-collision can be calculated in two ways, differing in the source of information utilized. The first method of calculating TTC, known in the literature as the cognitive method, uses velocity and spacing information of a lead vehicle and a following vehicle in order to obtain the value of TTC. In this method, TTC is calculated as follows (Hoffman and Mortimer 1994):

$$TTC = DX / DV \qquad (1)$$

where DX is the distance headway between the two vehicles and DV is the relative speed between the two vehicles involved in a car-following process.

The other method of obtaining TTC utilizes information available directly from the optic flow field to calculate the value of TTC. This is a more direct method, and is believed to be the one used by drivers to estimate TTC (van der Horst 1991, McLeod and Ross 1983, Schiff and Detwiler 1979 and Lee 1976). In this method, TTC is calculated using the following formula (Hoffmann and Mortimer 1994 and Schiff and Detwiler 1979):

$$TTC = \theta / (d\theta / dt) \qquad (2)$$

where θ is the visual angle subtended by the lead vehicle at the eyes of the following vehicle's driver and $(d\theta / dt)$ is the rate of change of that angle over time.

In addition to the reason given earlier for TTC being a poor measure of driver behaviour while following, another reason that makes this an unreliable measure of drivers' following behaviour is that drivers have been observed to consistently underestimate TTC (van Winsum and Heino 1996, Hoffman and Mortimer 1994, Groeger and Cavallo 1991, Cavallo and Laurent 1988, McLeod and Ross 1983 and Schiff and Detwiler 1979). The under-estimation of TTC may be attributed to many factors, as various factors are believed to influence drivers' estimation of TTC. Speed is unanimously believed to influence the accuracy of TTC estimation, where better estimates are obtained at higher speeds (Sidaway *et al.* 1996, Hoffman and Mortimer 1994, Groeger and Cavallo 1991, Cavallo and Laurent 1988 and McLeod and Ross 1983). The same consensus is not found regarding the effects of many other factors on the accuracy of TTC estimation. One of these factors is viewing time. While Hoffman and Mortimer (1994) and Groeger and Cavallo (1991) found that increasing viewing time leads to better estimates of TTC, McLeod and Ross (1983) and Sidaway *et al.* (1996) found that viewing time had no effect on the accuracy of TTC estimation. This discrepancy regarding the effects of viewing time cannot be attributed to the methodology employed, as all 4 studies utilized video films in controlled environments with the number of subjects in these studies ranging from 8 to 24. The same disagreement is found regarding the effect of actual TTC value on the accuracy of TTC estimation. Groeger and Cavallo (1991) and Schiff and Detwiler (1979) concluded from studies utilizing films shown to subjects in controlled environments that the lower the actual value of TTC, the better the estimates obtained for TTC. However, this effect was not confirmed by Cavallo and Laurent (1988), who concluded from a study conducted on subjects seated in the passenger seat of a vehicle driven on the road that the actual value of TTC had no effect on the accuracy of TTC estimation. In addition, gender was found to affect TTC estimation, where males were found to be better estimators of TTC than females (McLeod and Ross 1983). Cavallo and Laurent (1988) concluded that more experienced drivers are better estimators of TTC than beginners, and that the accuracy of TTC estimation improved as the available visual field increased.

The values of TTC at certain points in time portray various information on the criticality of the situation and the behaviour of drivers. Brackstone *et al.* (2000) observed an approximately linear relation between the minimum value obtained for TTC, TTC_{min}, and the maximum rate of deceleration achieved. It was found that the smaller TTC_{min}, the larger the maximum braking during the deceleration process. TTC_{min}, therefore, measures "how imminent a collision is" during the braking process (van Winsum and Heino 1996). Another value of TTC that provides information about the braking process is TTC_{t0}, the value of TTC at the moment the lead vehicle starts braking. According to van Winsum and Heino (1996), this value may be taken as an indicator of the criticality of the situation. The smaller it is, the more critical the situation is. Thus, the intensity of braking response is strongly related to TTC_{t0}. Such TTC information is usually used by drivers to decide when to start the braking process. This tends to confirm the argument mentioned earlier that TTC is a good measure of drivers' risk while following other vehicles.

3.1.3 The Braking Performance of Drivers

As indicated by van Winsum and Brouwer (1997), the process of braking response is divided into three phases; brake-reaction time, open-loop motor response time and closed-loop motor response time. Each of these three phases will be discussed separately in the following subsections.

3.1.3.1 Brake-Reaction Time

Van Winsum and Heino (1996) defined brake-reaction time (BRT) as the elapsed time between the perception of a stimulus and the beginning of application of the braking process, i.e. releasing the accelerator. Taieb-Maimon and Shinar (2001) view the preferred time headway adopted by drivers during steady-state car-following as a reflection of the maximum brake-reaction time available to the following vehicle's driver to respond to actions of the lead vehicle. Brake-reaction time varies between drivers and also varies for the same driver under different circumstances (Kim and Lovell 2005, Li 2003, Taieb-Maimon and Shinar 2001 and Sadeghhosseini and Benekohal 1997). In a study employing a platoon of 10 vehicles equipped with GPS receivers on test tracks, Ranijitkar *et al.* (2003) found that the variation in reaction times for the same subject under different conditions is higher than the variation in reaction times between drivers.

Various factors and conditions are believed to affect brake-reaction time. Reaction times vary with traffic density, being lower at high densities (Castillo *et al.* 1994). In addition, reaction times vary with headway, following vehicle's speed and lead vehicle's acceleration (Ozaki 1993). Triggs and Harris (1982) argue that reaction times of drivers depend on the nature of the situation, the criticality and the operating speed. The authors further postulate that time headway and vehicle speed affect the reaction times of the following vehicle's driver independently. Moreover, as found by Ranijitkar *et al.* (2003), individual performance affects reaction time. This finding was also indicated in an earlier study by Michaels and Solomon (1962) who found significant variation in reaction times between drivers as well as for the individual driver under different conditions. Another factor believed to affect reaction time is the expectancy of events. Brake-reaction times were found to be smaller for expected events than for unexpected events (Taieb-Maimon and Shinar 2001, van Winsum and Heino 1996 and Triggs and Harris 1982). Van der Hulst *et al.* (1999) found that faster decelerations by lead vehicles trigger faster responses (shorter reaction times) than slower decelerations. Thus, the level of lead vehicles' decelerations influences the reaction times of following vehicles' drivers.

By investigating the nature of BRT, a close association can be found between BRT and TTC. Van Winsum and Heino (1996) ascertained that BRT is related to TTC in that BRT must be smaller (faster) if TTC at the instant when the lead vehicle brakes is smaller. They contend that instigation of braking, measured by BRT, is affected by criticality, measured by TTC.

3.1.3.2 Open-Loop Motor Response

Open-loop motor response of braking, also known as open-loop movement time, is defined as the interval between the driver releasing the accelerator and that driver touching the brake pedal (van Winsum 1998). Van Winsum and Brouwer (1997) found that the time interval of open-loop motor response is greatly affected by criticality, represented by TTC, at the moment the lead vehicle deceleration is detected. When TTC is small, and thus criticality is higher, the duration of the open-loop motor response is smaller, indicating that drivers move their feet faster from the accelerator to the brake pedal. This sensitivity of open-loop motor response to TTC is higher for short followers than for long followers, meaning that the movement is faster for short followers.

3.1.3.3 Closed-Loop Motor Response

Closed-loop motor response of braking, also known as closed-loop movement time, is defined as the process of controlling the braking response based on visual information (van Winsum 1998).

3.1.3.4 Braking Performance as a Measure of Following Behaviour

Various differences have been observed between the braking performance of drivers who follow at short headways and those who adopt larger headways. In a simulator study where 18 subjects participated in driving experiments, Van Winsum (1998) found that drivers with small open-loop movement time follow at small time headways. He states that drivers with poor braking performance compensate by adopting larger time headways. The braking performance of drivers who follow at shorter headways, measured by the motor responses of braking, was found to be influenced by TTC more than the motor responses of braking for drivers who adopt larger headways. Motor responses of braking for large headway followers did not change according to the criticality of the situation, while those responses were greatly affected by the criticality of the situation for shorter headway followers (van Winsum 1998).

Van Winsum and Heino (1996) observed that short followers instigate braking at lower TTC values than long followers. The minimum value of TTC reached during the braking process is smaller for short followers than for long followers. In addition, the value of TTC at maximum braking was smaller for short followers than for long followers. It was also observed that the maximum braking for short followers was larger than that for long followers, and so was maximum deceleration. Moreover, short followers were observed to start braking at lower TTC (higher criticality), and also tolerate lower TTC values during braking compared to larger headway followers. These findings may indicate superior overall braking abilities of short followers as compared to the braking abilities of large headway followers, which may explain the shorter headways adopted by these drivers (van Winsum and Heino 1996).

An explanation given by van Winsum and Heino (1996) for the large preferred time headways adopted by long followers is that it is an attempt to compensate for lower competence in braking. This explanation was not supported by Taieb-Maimon and Shinar (2001) who state, based on the results of their study, that evidence did not support the hypothesis that the adopted headway reflects a driver's braking abilities. However, this discrepancy between the two studies results from each study's definition of braking abilities. In the van Winsum and Heino study, the term braking ability referred to the three stages of the braking process expressed earlier, namely reaction time, open-loop motor response and closed-loop motor response. On the other hand, braking ability in the Taieb-Maimon and Shinar study referred to brake-reaction time. In fact, van Winsum and Heino concluded that reaction time was not related to preferred time headway, which is in agreement with the conclusion from Taieb-Maimon and Shinar. This result was confirmed by van Winsum and Brouwer (1997) who found that preferred time headway was not affected by drivers' reaction times but was affected by the other two components of the braking process, namely open-loop motor responses and closed-loop motor responses. Thus, it was concluded by van Winsum and Brouwer that the variation in driving behaviour while car-following is related to the variation in braking abilities among drivers, where those possessing better braking abilities follow at closer headways than those with less braking abilities. In a study utilizing a pair of vehicles equipped with GPS data collection devices conducted with only one subject, Wolshon and Hatipkarasulu (2000) found that drivers who follow more closely are characterized by faster reaction to the speed changes of lead vehicles, although no clear indication was given whether faster reactions were to indicate shorter reaction times or better overall braking abilities.

TTC information along with maximum deceleration values are used to judge on the efficiency of the braking process. The most efficient control of braking is obtained if the instant where TTC is at its minimum value is closest to the moment where maximum deceleration is applied. If the moment of maximum deceleration precedes the moment when TTC is minimal by some time, criticality will still be increasing when the driver relaxes his/her foot from the decelerator. On the other hand, if the moment of maximum deceleration occurs sometime after the moment of minimum TTC, deceleration will be increased unnecessarily (van Winsum and Heino 1996).

3.2 Driver Characteristics Affecting Driving Behaviour

A variety of factors are believed to influence the behaviour of drivers while car-following. Some of these factors are individual factors that pertain to the characteristics of the driver and the vehicle, while others are situational factors like weather conditions, day of the week, time of the day, pavement conditions, etc. (Wang *et al.* 2004). Some of the situational factors were discussed in chapter 2. Some of the factors relating to drivers' characteristics are taken up in this section.

It has long been accepted that age is one of the main factors affecting driver behaviour. From an instrumented vehicle study with 61 subjects carrying out driving tests without being accompanied by an experimenter, Boyce and Geller (2002) found that younger drivers maintain safe speed less often than older and middle aged drivers and follow at a safe headway less often than older and middle aged drivers. Evans and Wasielewski (1983) observed that younger drivers follow other vehicles more closely than older drivers. Dingus *et al.* (1997) found from another instrumented vehicle study utilizing 108 subjects that young drivers follow at smaller minimum headways than older drivers. Taieb-Maimon and Shinar (2001) also reported that minimum and comfortable time headways increase with age, being smallest for younger drivers. Jonah (1986) states that young drivers operate their vehicles at higher speeds than do older drivers and follow other vehicles at shorter headways. From yet another instrumented vehicle study where 108 subjects drove 10 instrumented vehicles unaccompanied by experimenters, Sayer *et al.* (2000) found that space and time headway increase systematically with age, and that space and time headway are not affected by the driver's gender. More specifically, the authors observed that for females, the systematic increase in space and time headway with age was more pronounced than for males, where the largest space and time headways were associated with middle aged males followed by older males and then younger males.

Unlike the situation with driver age, more uncertainty is associated with the effects of other factors on driving behaviour. While some researchers found that female drivers tend to adopt larger headways than their male counterparts (Evans and Wasielewski 1983 and Wang *et al.* 2004), others have concluded that there is no evidence to support the hypothesis that gender affects driver behaviour when car-following (Boyce and Geller 2002, Taieb-Maimon and Shinar 2001 and Sayer *et al.* 2000). Mannering (1993) studied the differences in accident risk between males and females. Although it was shown that differences in driver characteristics and accident risk exist between male and female drivers (in terms of elapsed time before being involved in an accident), the study did not address whether there are any differences in driver behaviour between male and female drivers. Similar uncertainty also exists with respect to the effects of driving experience on driver behaviour. While Wang *et al.* (2004) found that experienced drivers follow at shorter time headways than novice drivers, Heino *et al.* (1996) and Heino *et al.* (1992) concluded that driving experience has no influence on headways adopted by drivers while following other vehicles.

Another factor believed to influence the behaviour of drivers while following, where a consensus on the effects of which is also lacking, is driver personality type. Boyce and Geller (2002) and Brackstone (2003) found that drivers with Type A personality traits (sensation seekers) follow at smaller headways than other drivers. Heino *et al.* (1996) concluded from an instrumented vehicle study with 42 subjects that drivers with type A personalities, sensation seekers, followed other vehicles at shorter headways than sensation avoiders. Sensation seekers differ from other drivers in that they do not perceive hazardous situations while driving to be as risky as viewed by other drivers. A similar conclusion regarding this factor was also reached by Heino *et al.* (1992). On the other hand, Brackstone (2003) concluded that the hypothesis that sensation seekers follow at closer headways is not supported at high speeds. Methodological differences could have contributed marginally for these differences as the Brackstone (2003) study also utilized an instrumented vehicle for data collection, but only with 11 subjects.

Differences in driver behaviour have also been observed between accident free drivers and drivers with previous accident histories, and between drivers with no violations and those with previous violations. Evans and Wasielewski (1982) conducted a study where headways between vehicles were obtained by photographing with a camera and then eliciting arrival times from the photographs. Previous histories of accidents and violations were obtained from driving records based on photographed license plate numbers. It was concluded that accident involved drivers and drivers with history of violating traffic laws follow at smaller time headways than accident free drivers and drivers without traffic violations. The difference was more profound between drivers with previous violations and violation free drivers than between accident involved and accident free drivers. This finding was confirmed by a later study that implemented a similar methodology by the same authors (Evans and Wasielewski 1983), where it was found that drivers with no previous history of traffic violations or accidents are less likely to be observed following at short headways. Evans and Wasielewski (1983) also found an effect for vehicle size on driver behaviour, where it was observed that drivers of medium sized vehicles (mass ranging from 1500 to 1900 kg) follow at the shortest headways compared to other vehicle sizes. This was in relative conformance with an earlier study by Evans and Rothery (1976), where it was found that drivers of small vehicles follow at shorter headways than drivers of large vehicles, although only two vehicle sizes were examined in that study. In the Evans and Wasielewski study (1983), it was also found that drivers of newer vehicles followed at shorter headways.

3.3 Drivers' Risk Taking Behaviour

It is widely hypothesized that much of the driving behaviour displayed by drivers is related to their risk taking behaviour. As such, Musselwhite (2006) identified four driver groups based on their risk taking behaviour:

1- Unintentional risk takers: this group is associated with the lowest level of risk taking behaviour. In the sample of drivers used for the study, this group was represented by the largest number of participants. Participants falling in this group had the highest mean age compared with members of the other groups and members of this group were more likely to be females.

2- Continuous risk takers: this group demonstrates the highest level of risk taking behaviour. In the study sample, this group was the least represented, had the lowest mean age compared with the other groups and was comprised mainly of male drivers.
3- Calculated risk takers: this group is characterized by members who would take risk in situations that can be assessed as less risky. This group was comprised mostly of male drivers in the study sample.
4- Reactive risk takers: members of this group would involve in risky driving behaviour when under time pressure and female drivers made the majority of this group of drivers in the study sample.

Different drivers display different levels of willingness to accept risk. This might be related to differences among drivers in their perceptions of risk, variation in the perceived benefits of undertaking risks by different drivers, or a combination of both. Two aspects of risk that are related to each other are risk perception, the perceived level of danger associated with carrying out a certain act; and risk utility, the benefits incurred by carrying out risky behaviours. On the one hand, risk utility may be used as a tool that modifies perceptual information. On the other hand, risk perception may be used as input for evaluating the utility (or disutility) of certain behaviours (Matthews and Moran 1986). The perceived risk associated with any act carried out while driving is subjective; different drivers associate different levels of risk to the same driving act. Similarly, the utility of risk (advantages gained by undertaking a certain act while driving) is also subjective in that different drivers view the outcomes of executing a certain driving act in different ways (Jonah 1986).

The different characteristics that influence risk taking behaviour of drivers may be merely reflections of differences among drivers in these two aspects of risk. It is believed that the shift in the balance between these two aspects of risk is what induces drivers to undertake or avoid risky driving acts. Thus, it is hypothesized that the behaviour demonstrated by drivers, whether risky or safe, is merely a reflection of how risky they perceive an act to be, and what they believe they can gain from undertaking such act (Jonah 1986). Based on such hypothesis, it can be argued that some of the factors that influence risk taking by drivers are also the ones that influence risk perception and/or risk utility among drivers. Jonah (1986) provides support for this hypothesis by stating that young drivers' higher involvement in risky driving behaviours may be stemming from their failure to recognize hazardous driving situations, which is a reflection of their risk (mis)perception. Evidence in support of this hypothesis was also provided by Matthews and Moran (1986) and Finn and Bragg (1986) as will be shown later in this section. In addition, according to Jonah (1986), risky driving is viewed as having greater utility among young drivers than among older drivers, while the consequences of risky driving (disutility) are underestimated by young drivers. Taken together, these two factors may explain the greater tendencies among young drivers to be involved in more risky driving behaviours. Ulleberg and Rundmo (2003) seem to disagree with Jonah (1986), concluding that young drivers' demonstration of risky driving behaviours is not a result of their misperception of risk, although this result is questioned by the authors due to the unreliability of the measures adopted to display risk perception.

The level of risk adopted by individuals (they are willing to accept) depends on four main factors (Wilde 1998):

1- The utilities of risky behaviour (shortening trip duration, fulfilling the need for stimulation, etc.)
2- The costs of participating in risky behaviour (fines, injuries, property damage, etc.)
3- The utilities of safe behaviour (injury prevention, insurance discounts, etc.)
4- The costs of safe behaviour (boredom, discomfort due to wearing seat belt, etc.)

Various indicators may be utilized to measure the risk taking behaviour of drivers. Heino *et al.* (1996) implemented following headway as a measure of risk acceptance behaviour. They state that following another vehicle at some distance/time headway is an aspect of driver behaviour which reflects the likelihood of a driver being involved in an accident. Thus, following at a small headway represents greater willingness by the driver to accept risk. Therefore, time headway may be utilized as a measure of risky behaviour by drivers. Evans and Wasielewski (1983) also support the notion that following at closer headways is an indicator of greater willingness to accept risk by drivers. Other studies have used speed as a measure of risky behaviour. Horswell and Coster (2002) employed speed as the measure of risk taking behaviour. The justification given for using speed as a measure is that speed has been observed to be a very reliable predictor of future accident involvement as well as previous accident histories of drivers. Time-to-collision also is used as an indicator of risk while car-following, since it provides information on how critical a situation is (Minderhoud and Bovy 2001 and van der Hulst 1999).

Drivers of varying characteristics have displayed different levels of risk taking behaviour. However, full agreement on the specific characteristics that lead drivers to exhibit risky driving behaviour is lacking. Nonetheless, the main traits that have been found in the literature to be associated with various levels of risk taking include driver's age, gender, driving experience, personality type and various other psychological aspects. Finn and Bragg (1986) and Evans and Wasielewski (1983) concluded that young drivers exhibit more risky driving behaviour than older drivers, and this finding was supported by Boyce and Geller (2002), who found that younger drivers exhibit more risky driving behaviour than older drivers by driving at higher speeds and shorter following headways. Iverson and Rundmo (2004) also found from questionnaire responses from 2614 drivers that younger male drivers (with less than 10 years of driving experience) are involved in riskier driving acts than older male drivers and female drivers. They attributed this to their finding that younger male drivers exhibit more negative attitudes towards safety than older and female drivers. Heino *et al.* (1996) argue that the source of young drivers' problems while driving is not entirely due to the lack of driving experience, the need for stimulation also plays a prominent role in these problems. This was based on their finding that the need for stimulation also influences the behaviour of more experienced drivers, motivating them to be involved in risky driving behaviour. The young driving population, however, should not be treated as a homogeneous group, as was found by Begg and

Langley (2001) from interviewing 936 young drivers aged either 21 or 26 years old. In their investigation of the variation of risky driving behaviour among young drivers of the two different ages, they concluded that participation in risky driving behaviour among young male drivers is observed to be significantly lower among 26-year-olds than among 21-year-olds. This indicates that young male drivers loose the urge to involve in risky driving behaviour as they mature.

Another factor believed to play a role in drivers adopting risky behaviour while driving is personality type. Jonah *et al.* (2001) and Heino *et al.* (1996) state that drivers with high sensation seeking personalities were observed to be involved in more aggressive and riskier driving behaviours than low sensation seekers, and this was observed for both genders. However, as stated by Heino *et al.* (1992), sensation seekers did not perceive the shorter headways as being more risky than sensation avoiders. This may indicate that sensation seekers have similar target levels of risk as sensation avoiders, but differ from them in evaluating the level of risk (risk perception). Ulleberg and Rundmo (2003), on the other hand, argue that personality traits, such as sensation seeking, may not have a direct effect on exhibiting risky driving behaviour, but an indirect one by affecting drivers' attitudes towards traffic safety. By analyzing responses from 3942 questionnaires, Ulleberg and Rundmo (2003) found that high sensation seekers, drivers with high "normlessness" traits and aggressive drivers had negative attitudes towards traffic safety, which led in turn to higher involvement in risky driving activities. This was in line with the results from Owsley *et al.* (2003), who found that drivers with impulsive personalities were more likely to be involved in risky driving behaviours, regardless of their age. Schwebel *et al.* (2006) correlated risky driving with sensation seeking and some other driver traits. They state that risky driving behaviours are highly correlated with drivers' sensation-seeking, anger/hostility and conscientiousness measures. These factors, however, operate independently to some extent. Nonetheless, sensation-seekers, hostile/angry drivers or drivers with low conscientiousness display riskier driving behaviours than drivers without these traits. Musselwhite (2006) states that drivers in general exhibit risky behaviours more often when under time pressure.

From analyzing responses to questionnaires completed by 46 subjects as well as stated ratings of a sequence of video films undertaken by the same subjects, Matthews and Moran (1986) concluded that young drivers see themselves as less at risk than their peers, and they assessed their risk of being involved in a car accident as similar to that of an older driver. They further postulate that older drivers viewed their risks of being involved in a crash as similar to other drivers of their age group, but significantly lower than the risks of young drivers being involved in an accident. Based on these two statements and from various field observations, Matthews and Moran (1986) concluded that the perception of risk is correlated with one's perceived abilities. Drivers who rate their driving abilities very highly view themselves as being less at risk of being involved in an accident, thus having lower perceptions of risk. In addition to perceived abilities, according to the authors, young drivers consistently underestimate the risks associated with certain actions and behaviours during driving due to their limited prior experiences in being exposed to different driving situations. Finn and Bragg (1986) corroborate with the findings in Matthews and Moran (1986), stating that young drivers do not perceive risky situations while driving the same way that older drivers do, they consistently underestimate the risks associated with hazardous situations while driving.

Vehicle characteristics have also been associated with drivers' risk taking behaviour. Horswell and Coster (2002) found that higher vehicle performance is significantly associated with riskier driving behaviour in the form of higher speeds and shorter following distances. They concluded, based on data gathered from radar speed detectors and video cameras, that drivers of higher performance vehicles choose to operate their vehicles at higher speeds than those driving lower performance cars. Thus, it may be stated that those driving higher performance cars are involved in more risky driving behaviours than drivers of lower performance cars. However, the relationship between vehicle performance and risky driving was found to be a two-directional one. On the one hand, drivers who exhibit risky driving behaviour may opt to purchase higher performance vehicles that would facilitate riskier driving. On the other, the higher performance of vehicles may induce drivers to be involved in riskier driving behaviours (Horswell and Coster 2002).

It is evident from the literature that differences in risky driving behaviours result from the variation in risk perception and risk utility among the driving population. While many factors that influence drivers' perception of risk have been addressed in the literature, drivers' perception of risk towards different vehicle types, and specifically towards HGVs, has not been addressed.

3.4 Previous Studies Addressing Driver Behaviour

A number of studies have addressed driver behaviour using various methodologies. Kim and Lovell (2005) carried out an instrumented vehicle study were the instrumented vehicle was utilized as a lead vehicle while monitoring the driving behaviour of following drivers during non-rush hour conditions. The study concluded that drivers differ in their perceptions of safe following headways. Moreover, perceptions of safe following headways differ for the individual driver according to traffic, geometric and environmental conditions. The study also found that time gaps were more stable at high speed. Hence, the assumption of constant time headways for the individual driver was found to be warranted at high speeds, but not at low speeds. The authors argued, based on findings from the study, that following behaviour demonstrated by a driver may be better explained by investigating previous conditions that lead to current ones rather than studying current conditions only. The main limitations associated with results obtained from this study stem from some methodological shortcomings. While the methodology benefited from the fact that actual driver behaviour of a diverse group of drivers was recorded in real traffic conditions, the methodology employed resulted in uncertainty in deciding on some driver characteristics that have been found to affect driver behaviour. Furthermore, certain factors that were found to affect driver behaviour such as driver state and whether the driver is under time pressure could not be accounted for. Another of the shortcomings stemming from the methodology is the underlying assumption that the particular instrumented vehicle used for the study driven by one driver represents all vehicles that belong to this vehicle type and that the driving behaviour of the instrumented vehicle's driver encompasses the diversity of driving behaviours that can be encountered on the roads. It is also worth noting that such methodology is not appropriate when aiming to investigate the effects of different lead vehicle types on driver behaviour.

Taieb-Maimon and Shinar (2001) conducted a study which had four main objectives. The first objective was to determine the minimum safe headways and comfortable headways as perceived by drivers. The second objective was to compare the various methods of estimating headways by drivers. The third objective was to find out whether time headway remained constant with varying speed. The last objective of the study was to investigate the relationship between minimum safe headways adopted by drivers and their BRTs. An instrumented vehicle was utilized to collect the required data, where 30 test subjects drove this instrumented vehicle accompanied by one researcher while following another vehicle driven by another researcher. The test subjects then carried out a BRT test conducted in a laboratory simulator. During the instrumented vehicle driving part, the subjects were asked to estimate headway at various instants by either distance (in meters), time (in seconds) or by car lengths. The ANOVA modelling approach was then used to analyze the data. The authors found that minimum and comfortable time headways for an individual driver remain constant at different speeds, but vary between drivers. No gender effect was observed on the car-following behaviour in this study, as male and female drivers were observed to follow at similar minimum and comfortable time headways. For headway estimation, drivers showed better and more accurate ability of estimation when the unit of measure was car-lengths or meters. Estimation of time headway in seconds was less accurate, and resulted in overestimating the headway by drivers. The variation in headway estimation errors was smallest when estimating by car-lengths, followed by metres and then seconds. Male and female drivers showed similar abilities in estimating safe headways when the unit of measure was metres or car-lengths. Male drivers were observed to be better estimators of headways than female drivers when the unit of measure was time in seconds. As stated earlier, the authors found no relationship between headways adopted by drivers and their BRTs. This study suffers from a limitation resulting from drivers following a single lead vehicle driven by the same driver for the entire duration of the experiment. This approach carries an underlying assumption that drivers' following behaviour is not affected by the wide range of driving styles displayed by different lead vehicles' drivers.

McDonald *et al.* (1999) aimed at eliciting information about the behaviour of drivers when following other vehicles using an instrumented vehicle. For that, the researchers utilized 11 test subjects to drive an instrumented vehicle supplemented with an optical speedometer for speed measurements, a radar range finder for distance measurements and an audio-video system. The experiments were conducted on motorway sections at clear and dry conditions. The study found that the type of lead vehicle had an effect on the distance headway adopted by followers, where larger distance headways were observed when the lead vehicle was a van as opposed to situations where the lead vehicle was a car. In addition, it was concluded that distance headway varies among drivers of the same age group, and that younger drivers have lower stability in car-following than older drivers. With regard to stability, it was found that a driver's stability in car-following may change from day to day. The researchers state that linear statistical modelling may not be appropriate for modelling distance headway relations and car-following. The study had some weaknesses. The small sample size used to make inferences on some of the specific factors may undermine the reliability of the findings. In addition, results from this study suffer from a limitation that is commonly associated with this methodology, that of presence of an experimenter while drivers carried out the experiments. Although this may cause participating subjects to alter their driving behaviours due to the fact that their behaviour is being monitored, the presence of this effect for all subjects partaking in the experiment reduces this effect considerably. Furthermore, the linear statistical modelling technique may not have been used properly, where the researchers judged linear statistical modelling techniques to be unsuitable for such analysis based on inferences made on the intercept term, b_0. However, the intercept term was outside the scope of the model, rendering this term meaningless.

Van Winsum (1998) conducted a study investigating whether there are differences in sensitivity of motor responses to TTC based on following headway. To achieve that, eighteen test subjects, characterized as either normal headway followers or large headway followers, drove a simulated vehicle. The drivers' lateral tracking abilities, longitudinal tracking abilities and reaction times were of interest. With regard to longitudinal tracking, it was concluded that normal headway followers perform better towards achieving that task than large headway followers. Normal headway followers showed better abilities in maintaining constant (stable) distance headway and keeping their speed in accordance with the lead vehicle's speed. Furthermore, normal followers did not overreact as much as large followers in response to speed variations of the lead vehicle. As for the braking performance, it was found that larger rates of deceleration by the lead vehicle generally resulted in faster movement of the driver's foot from the accelerator to the brake pedal. This was more obvious, however, for normal headway followers than for large headway followers. Thus, it was concluded that normal headway followers are superior in braking abilities to large headway followers, which may explain the larger headways adopted by the latter group. Moreover, normal headway followers showed better ability in lateral tracking than did large headway followers. As with the case of any simulator study, a weakness of this study is that the artificial driving environment created may lead to different decisions by the same driver when confronted with similar but actual driving situations. Decisions taken while driving a simulator do not have any safety effects, and thus might be considered hypothetical decisions. In addition, normal and large headway followers were classified based on photo-preference tests rather than actual measurements.

Van Winsum and Heino (1996) conducted a study that had among its objectives determining the variation in time headway with speed, the variation in time headway between drivers and the variation in the relationship between brake-reaction time and time-to-collision based on the adopted distance headway of drivers. To achieve that, 54 male test subjects were utilized to drive a simulator believed to be representative of actual driving conditions. The speed of the lead vehicle and the simulator (following vehicle), distance headway, acceleration and percentage of brake pressed were obtained at a 10 Hz frequency. From the data, time headway and TTC were calculated, and then analysis of covariance and repeated measures multivariate ANOVA techniques were utilized to examine the results and make inferences. The researchers concluded that the preferred time headway is constant over speed, consistent for the same driver. Furthermore, the study showed that drivers who adopt shorter following distances are more efficient in controlling the braking process. This was apparent from the smaller difference between the time when TTC was minimal and the time when maximum deceleration was achieved for short followers as compared to the difference between these two times for drivers who adopted larger headways. As for any other simulator study, the results obtained may not be truly representative of actual driving behaviour due to the artificial environment in which the experiment was conducted. Another weakness of the study is that the subjects used in the experiment may not be representative of the driving population since all the subjects were of the same gender.

Chen *et al.* (1995) examined the effects of absolute speed, weather, illumination, traffic density, driver intentions, driver experience and gender on the car-following behaviour at pre-determined velocities. Two tools were utilized towards achieving the objective of the study. Video recording of traffic at interstate freeway sites was the method used to investigate the effects of weather, illumination and density on the car-following behaviour. The measure of interest for this part was distance headway. A simulator was employed to gather data to be used for inferences regarding the effects of drivers' intention to pass, driving experience and gender on the car-following behaviour. Twenty-four subjects were utilized in the experiment, from which distance headway distributions and reaction time distributions were obtained. On the effects of weather, it was found that distance headway was not affected by wet conditions at high speeds but was affected at low speeds. This led the authors to conclude that wet conditions affect car-following behaviour in congested traffic conditions but not in free flow conditions. The same was observed for illumination effects, where it was found that illumination affected car-following behaviour for night-driving in congested conditions, but not for free flow conditions. An interesting finding of the study was the conclusion that traffic density has no effect on car-following behaviour. It was also found that drivers' intentions, experience and gender had significant effects on the car-following behaviour of drivers. The methods used for data collection, namely video recording and the simulator; represent the main weaknesses of the study. Video recording does not capture the nature of car-following which requires a method that can depict the prolonged nature of the process. It is difficult to ascertain the stage of the car-following process at which the video was captured, which may have been at a steady-state stage, a perturbation stage, just before a lane change manoeuvre or while engaged in any other driving activity. In addition, little information is available on the characteristics and state of the driver. Furthermore, data collected by a simulator may not be representative of actual driving behaviour due to the artificial environment and lack of criticality of decisions made.

3.5 Conclusions

From the literature, it can be concluded that the nature of driver behaviour lends itself to the diversity of principles with which it is explained. Many measures can be employed to assess driver behaviour. Since the aspect of driver behaviour of interest in this study is during car-following processes, following headway is deemed most appropriate for measuring driver behaviour. The literature showed that driver behaviour while following varies with several factors, including driver's age, gender, driving experience, personality type, driving history among various other factors. Some of these factors will be investigated in the current study to learn of their impact on the variation in behaviour while following HGVs. It has also been demonstrated that risk taking behaviour in general, and risk perception in particular, play a major role in determining driving styles. This factor will be studied at some depth to determine its correlation with lead vehicle type in affecting driver behaviour.

Numerous methodologies have been employed to measure driver behaviour while following. Driving simulators, video cameras, still photography, questionnaire surveys and instrumented vehicles have been employed to monitor drivers' car-following behaviour. Furthermore, instrumented vehicles have been used in different ways such as with test subjects on test tracks, with test subjects in real traffic while following one vehicle only driven by one driver, without test subjects where the instrumented vehicle serves as the lead vehicle while the behaviour of several other drivers is monitored and with test subjects following different vehicles in real traffic. Each of the methodologies listed above can result in limitations of the findings obtained. However, the most realistic results are obtained by monitoring the behaviour of randomly selected drivers while driving in real traffic following different vehicles of the same type as well as following different vehicle types.

The number of subjects utilized in driver behaviour studies varied significantly from one study to another. While some studies utilized a number of subjects as low as 4, others had a much larger sample size in terms of subjects used, 108 subjects in some studies. The number of subjects employed in a study might be a function of the amount of data that can be obtained from each subject as well as the quality of data obtained. What is clear from the literature, however, is that an agreement on the number of subjects that may be considered adequate in obtaining valid results is lacking, and so is a clearly defined criteria that can be used to decide on the number of subjects to be included in a study.

Chapter Four

Car-Following Models

Traffic flow is usually modelled at three different levels of detail (Hoogendoorn and Bovy 2001):

1- Microscopic: highly detailed level of modelling where each entity of the traffic stream (vehicle and/or driver) is tracked and described.

2- Mesoscopic: moderately detailed level of modelling where individual entities' behaviour is not of interest, but rather the behaviour of groups of entities described in a more aggregate manner is, as in utilizing probability distribution functions.

3- Macroscopic: low detailed level of modelling where the individual behaviour of entities is not addressed at all. Rather, interest revolves around parameters describing the entire stream of traffic.

Microscopic flow models describe the individual driving behaviour based on drivers' car-following behaviour, which describes the longitudinal speed and distance headway relationship, and lane changing behaviour, which describes the lateral movement of a vehicle between lanes (Brackstone and McDonald 1995 and McDonald *et al.* 1994). These models are constructed to predict drivers' responses to certain driving situations (Chakroborty *et al.* 2004). It must be noted, though, that the diversity, variation and unpredictability of driver behaviour in real world traffic cannot be captured completely and accurately by a microscopic simulation model (Minderhoud and Bovy 2001). This is largely due to the fact that car-following, like all human processes, is an approximate process governed by perception thresholds that are not clearly defined (Chakroborty 2006).

Microscopic simulation models employ car-following models as one component that aids in simulating the movement of vehicles. Car-following models play the role of simulating the longitudinal motion of vehicles in a single lane (Rakha *et al.* 2004). These models define the relationship between desired speed and distance headway between two vehicles in a steady-state car-following mode (Rakha and Crowther 2003 and Rakha and Crowther 2002). By doing so, these models describe the interaction between a lead vehicle and a following vehicle in moderately congested traffic conditions (Chakroborty and Kikuchi 1999). The basic aim of car-following models is to predict the car-following behaviour of drivers, represented by the speed at which they choose to operate their vehicles and the separation headway they maintain with their leaders, in response to stimuli by the lead vehicle, mainly in the form of speed change. Lane-changing behaviour does not receive any consideration in these models (Mehmood *et al.* 2003).

Car-following models are developed as a tool that generates realistic car-following processes theoretically. Thus, these models determine the acceleration rate of the following vehicle, whether positive or negative, at certain times in response to the actions of the lead vehicle (Mehmood *et al.* 2003). The basic principle of modelling the car-following process is to have an equation of motion describing the steady-state car-following process supplemented by a set of constraints controlling the transitional phases when vehicles move from one steady-state to another. Two constraints are commonly utilized to fully describe the car-following process, to make it in conformance with the actual car-following process. The first pertains to the acceleration/deceleration behaviour of vehicles, ensuring that acceleration values utilized in models are realistic. The second relates to the safe distance headway that would prevent a following vehicle from crashing into a lead vehicle in the event that lead vehicle were to decelerate abruptly (Rakha *et al.* 2004, Rakha and Crowther 2003 and Rakha and Crowther 2002).

For car-following models to be useful, they must produce car-following processes that are balanced. The produced car-following process must not be too conservative by generating separation headways that are too large, thus resulting in reductions in capacity. On the other hand, the produced car-following process must not be too dangerous by assigning separation headways that are very small (Parker 1996). A requirement for any car-following model is that it must produce car-following processes that are stable, both locally and asymptotically (Wu *et al.* 2003).

Similar to modelling any phenomenon, modelling the process of car-following is not without shortcomings. Most car-following models suffer from downsides stemming from some of the underlying assumptions in these models. Some of these underlying assumptions include (Kim and Lovell 2005, Mehmood *et al.* 2003 and Li 2003):

1- Assuming drivers can perceive relative speed between the following vehicle and the lead vehicle and also speed and/or acceleration of the lead vehicle at all times.
2- Assuming that drivers base their decisions on the actions of the vehicle immediately ahead only, without regard to information from vehicles further downstream.
3- Assuming that drivers' reactions to actions of their leaders are uniform.
4- Assuming that drivers' reactions to actions of their leaders are governed by a deterministic relationship.

In addition to these downsides, car-following models that implement the stimulus-response concept suffer from the fact that this concept cannot explain all driving behaviour, as one-third of driving behaviour could not be explained by that concept (Ranijitkar *et al.* 2003). Moreover, most car-following models have the underlying assumption that drivers follow at constant safe headways. In reality, this assumption has proven to be false, as a large number of vehicles in traffic have been observed to follow at headways that are unsafe (Brackstone and McDonald 2003). Another drawback that is applicable to most car-following models is that the majority of these models base the actions of drivers on two stimuli of the vehicle immediately ahead, those being relative speed and distance headway. However, it is argued that drivers base their decisions on the actions of several vehicles ahead, the vehicle immediately behind and downstream traffic control devices (Rakha and Crowther 2003). In addition, as argued by Wang *et al.* (2004), the majority of existing car-following models suffer from an obvious limitation that leads to their outputs being impractical in many instances. The cause for this limitation is that these models are built on the assumption that drivers seek to improve continually in order to achieve their optimal performance level of driving. This neglects the fact that many drivers seek to achieve the task at hand (driving from point A to Point B) irrespective of whether they are driving at an optimum level. While significant improvements have been made in the field of modelling the car-following process, the models still suffer from their inability to model the cognitive behaviour of drivers objectively and correctly (Wang *et al.* 2004).

A wide array of car-following models has been developed over the years. These models were developed using a variety of concepts and mechanisms. Some of the more widely used models will be discussed in some detail in the following sections.

4.1 GM Models (GHR Models)

The General Motors (GM) models are stimulus-response models. The response of the following vehicle's driver, which takes the form of either acceleration or deceleration, is governed only by one stimulus, that being the relative speed between the following vehicle and the lead vehicle (Kikuchi *et al.* 2003, Wolshon and Hatipkarasulu 2000 and Chakroborty and Kikuchi 1999). This response is presumed to have a delay factor due to the reaction time of the following vehicle's driver (Zhang and Jarrett 1997). The general formulation of the GM models takes the form (Brackstone and McDonald 1999):

$$a_{n(t)} = c\ v^{m}(t)\ [\Delta v(t-T)]\ /\ [\Delta x^{l}(t-T)] \qquad (3)$$

where: $a_{n(t)}$ is the acceleration of vehicle n at time t

$v_n(t)$ is the speed of vehicle n at time t

Δv is the relative speed between the lead and following vehicles

Δx is the relative spacing between the lead and following vehicles

T is the perception-reaction time of the following vehicle's driver

c, m and ℓ are constants to be determined

A sensitivity factor is included in GM models to explain the variation in responses of following vehicles' drivers that can be observed under fluctuating distance headway and traffic speed conditions (Herman and Potts 1961). According to the GM models, small values of sensitivity or reaction time ensure that disturbances are damped over time, thus resulting in stable car-following processes. On the other hand, larger values of sensitivity or reaction times result in overcompensation in the responses of following vehicles' drivers to changes in speed of their leaders, and this leads to the emergence of oscillations. The process may yet be stable given that these oscillations are damped. If, on the other hand, sensitivity and/or reaction time values are too large, oscillations will not be damped and may even be magnified over time, resulting in local instability; or as they propagate down the platoon of following vehicles, resulting in asymptotic instability (Zhang and Jarrett 1997).

The GM models have undergone various attempts for calibration, the main focus of which was finding appropriate values for the parameters m, l and c. Very few of the calibration attempts, however, used reliable data collection techniques (Brackstone and McDonald 1999).

Some of the criticism associated with the development of these models relate to the techniques used for collection of the original data upon which these models were developed. Data was collected at low speed conditions and without variation in speed. Furthermore, data collection took place on test tracks (Wu *et al.* 2003).

These models have been the most widely used for a long time. However, various conceptual drawbacks are associated with these models. Some of these drawbacks are:

1- They are deterministic in nature, operating under the assumption that distance headway and relative speed between the following vehicle and the lead vehicle can be precisely determined by the following vehicle's driver, whose actions in terms of acceleration or deceleration are also precise. In addition, these models also assume that drivers are capable of perceiving very small changes in relative speed, and that these subtle changes in relative speed lead to actions by drivers even at large distance headways. This is contrary to the approximate nature of car-following and the perception abilities of human drivers (Kikuchi et al 2003, Mehmood *et al.* 2003, Hoogendoorn and Bovy 2001, Chakroborty and Kikuchi 1999, Zhang and Jarrett 1997 and Kikuchi and Chakroborty 1992).

2- The models are symmetric in their responses, assuming that the magnitude of response to a certain stimulus is the same regardless of whether the stimulus (relative speed) is positive or negative. This again contradicts the asymmetric nature of car-following, where drivers' responses in deceleration situations are observed to be higher in magnitude than their responses in acceleration situations (Kikuchi et al 2003, Mehmood *et al.* 2003, Chakroborty and Kikuchi 1999, Zhang and Jarrett 1997 and Kikuchi and Chakroborty 1992).

3- The phenomena of closing-in and shying-away are not accounted for in these models. GM models are single stimulus models, basing the actions of the following vehicle's driver solely on relative speed. This implies that when relative speed is zero, no actions will be taken regardless of the distance headway, which does not conform to actual driving behaviour (Mehmood *et al.* 2003, Kikuchi *et al.* 2003 and Chakroborty and Kikuchi 1999).

4- The stable distance headway as generated by these models is a function of the initial speed and distance headway in addition to the final (stable) speed. In reality, the stable distance headway is only dependent on the final speed, irrespective of how this stable speed was reached (Kikuchi *et al.* 2003 and Chakroborty and Kikuchi 1999).

5- The models assume that the initial condition (prior to disturbance) is a stable one, which may not always be the case (Kikuchi *et al.* 2003 and Chakroborty and Kikuchi 1999).

6- The models set no maximum limits on the acceleration/deceleration rates that are applied to reach the stable condition. This does not conform to reality, where vehicle performance dictates the maximum acceleration/deceleration rates. It is believed that the maximum limits set on acceleration and deceleration play the role of dampening the effects of perturbations, which result in the process being locally and asymptotically stable (Kikuchi *et al.* 2003 and Chakroborty and Kikuchi 1999).

7- Like most other models, GM models base the actions of following vehicles' drivers solely on the actions of the vehicle immediately ahead, discarding the frequently observed fact of drivers looking beyond the vehicle immediately ahead for additional information on which to base their actions (Mehmood *et al.* 2003).

8- Vehicles with poor performance characteristics (HGVs) are treated like other vehicles in that the models assume that these slower moving vehicles when following higher performance passenger vehicles will increase their speeds until they are slowed down by the higher performing passenger vehicle (Hoogendoorn and Bovy 2001).

9- The traffic stream is assumed to be homogeneous, made entirely of vehicles bearing the same performance characteristics (Hoogendoorn and Bovy 2001).

In addition to the downsides stated above, use of GM models has diminished due to the great variation in parameters obtained from the various calibration attempts, which has undermined the reliability of these models. This great variation in parameter values may be attributed to (Mehmood *et al.* 2003 and Brackstone and McDonald 1999):

i. the following behaviour may be expected to vary with traffic conditions

ii. the majority of calibration attempts have taken place either at low speed or in stop-and-go traffic, hardly reflective of the normal conditions where most car-following processes take place.

4.2 Safety Distance Models (Collision Avoidance Models)

Safety distance models have at their heart the assumption that drivers follow their leaders at distances that allow them to avoid collisions at all times, irrespective of the actions of the lead vehicle (Hoogendoorn and Bovy 2001). The basis for these models is specifying a "safe following distance", such that if a driver were to drive within it and the lead vehicle's driver were to apply large deceleration unpredictably, the following vehicle's driver would not be able to avoid colliding with the lead vehicle (Brackstone and McDonald 1999). The original formulation of the model is:

$$\Delta x(t-T) = \alpha\, v^2_{n-1}(t-T) + \beta_1\, v^2_n(t) + \beta\, v_n(t) + b_o \qquad (4)$$

where: Δx is the spacing between the lead and following vehicles

v_{n-1} is the speed of the lead vehicle

v_n is the speed of the following vehicle

T is the reaction time for the following vehicle's driver

α, β_1, β and b_o are constants

These models do not use a stimulus-response relationship; rather they specify a predetermined safe following distance that governs the behaviour of the following vehicle's driver, whose driving behaviour would then be dictated by attempting to achieve this safe following distance (Mehmood *et al.* 2003). Collision avoidance models have been widely used, especially as basis for many of the common microscopic simulation models such as SISTM, INTRAS, CARSIM, NETSIM, FRESIM (Mehmood *et al.* 2003 and Brackstone and McDonald 1999). The widespread use of this type of models may be attributed to the ease with which one can calibrate these models. Information required for calibration pertain to what is perceived to constitute logical driver behaviour, particularly with regard to maximum braking rates used by drivers and expected to be used by other drivers (Brackstone and McDonald 1999). Much of the common use of collision avoidance models is also due to the realistic behaviour produced by these models (Panwai and Dia 2005).

Although these models have served as bases for many microscopic simulation models, some weaknesses are associated with these models. One of these weaknesses is basing the actions of the driver solely on the safe separation headway, thus neglecting the fact that drivers use information from vehicles further downstream on which to base their actions (Mehmood *et al.* 2003 and Brackstone and McDonald 1999).

4.3 Linear Models (Helly Models)

These models are based on using linear modelling techniques where acceleration is the response variable. The original formulation of the model (proposed by Helly) takes the following form (Brackstone and McDonald 1999):

$$a_n(t) = C_1\ \Delta v(t-T) + C_2\ [\Delta x(t-T) - D_n(t)] \qquad (4)$$

$$D_n(t) = \alpha + \beta\ v(t-T) + \gamma\ \alpha_n(t-T) \qquad (5)$$

where: $a_n(t)$ is the acceleration of vehicle n at time t

C_1 and C_2 are constants

Δv is relative speed between the lead and following vehicles

Δx is relative distance between the lead and following vehicles

D_n is the desired following distance

T is the following driver's perception-reaction time

α, β and γ are linear regression coefficients

The main strength of these models is the inclusion of the "error" term in the model. The main criticism of these models is the difficulty of calibration (Brackstone and McDonald 1999). Linear models can provide good fits to actual data. However, the difficulty would be in calibrating the regression constants (Panwai and Dia 2005). The validity of these models is generally not better than GM models, as is the degree of calibration. Some of the noteworthy differences between these models and the GM models are (Brackstone and McDonald 1999):

1- There is some agreement on the values of the response to v
2- The values of response to Δx are about from 4-10 times less than those for the GM models.

4.4 Psychophysical Models (Action Point Models)

Action point models are based on the concept that drivers are capable of perceiving changes in relative velocity and distance headway, thus enabling them to ascertain whether they are opening or closing (Mehmood *et al.* 2003 and Brackstone and McDonald 1999). These models ordinarily use two stimuli that govern the actions of drivers in response to the actions of their leaders, those being relative speed and space headway divergence (Wu *et al.* 2000 and McDonald *et al.* 1997). According to these models, actions of drivers in car-following mode are governed by perceptual thresholds in the form of distance headway threshold, relative speed threshold and/or rate of change of visual angle threshold. When a driver is within these thresholds, he/she will not notice changes in the dynamic conditions of following and will attempt to maintain a constant acceleration (Wang *et al.* 2004 and Brackstone *et al.* 2002). Furthermore, as stated by Hoogendoorn and Bovy (2001), these models assume that when the separation headway between two vehicles is large, the following vehicle is not influenced by the actions of the lead vehicle.

Action point models are based on four general thresholds (Jenkins 2004, Wang *et al.* 2004 and Brackstone *et al.* 2002):

1- Minimum desired following distance threshold.
2- Maximum desired following distance threshold.
3- A threshold for noticing closing situations by recognizing small changes in closing (positive) relative speeds. This threshold also corresponds to the threshold of increasing visual angle.
4- A threshold for noticing opening situations by recognizing small changes in opening (negative) relative speeds. This threshold also corresponds to the threshold of decreasing visual angle.

When exceeding any of these thresholds, the driver will realize that a corrective action is required.

The first threshold that triggers actions of the driver concerns changes in relative velocity between a vehicle and the one preceding it. Perceiving relative velocity is done, based on these models, by noticing changes in the visual angle subtended by the lead vehicle at the eyes of the driver, θ. Once appreciable changes in the visual angle exceeding the perception threshold occur, drivers take actions (accelerating or decelerating) until a speed is reached at which they do not perceive noticeable changes in θ. This relative speed threshold constitutes the first of the thresholds upon which drivers base their actions. The second threshold relates to distance headway, which is used as the basis for drivers' actions at conditions of close headway car-following, where relative speed is normally below its perception threshold. This distance headway threshold is called the action point threshold. Exceeding the distance headway threshold, thus instigating actions, is done when spacing headway changes by a "just noticeable distance" (JND), which is taken to be a change in the visual angle of at least 10% for the closing situation and 12% for the opening situation. Once the distance headway threshold is reached, drivers will choose a certain value of acceleration or deceleration (as appropriate) and maintain that value of acceleration or deceleration until another threshold is exceeded, which will require another action (Brackstone and McDonald 1999).

The strength of action point models is in simulating actual driver behaviour, where the fundamental concepts of the model are based on sound concepts that emulate driver behaviour as seen in every day driving (Brackstone and McDonald 1999). The weakness of this approach is the difficulty in calibrating the thresholds of the model, which require continuous measurement of a variety of traffic and driving situations (Panwai and Dia 2005, Mehmood *et al.* 2003 and Brackstone and McDonald 1999).

4.5 Fuzzy Logic Based Models

The relationship between the actions of a following vehicle's driver and the stimuli provided by the lead vehicle is not deterministic in nature. Rather, a high degree of uncertainty is associated with this relationship. This makes the fuzzy logic technique of modelling very suitable for describing this relationship (Kikuchi and Chakroborty 1992).

The basis for these models is the assumption that driver behaviour (and subsequent actions) can be described by a set of logical rules of driving that has been obtained by experience. The rules that are the basis for these models are in the form of "IF... THEN...", which are set out to cover a wide range of driver behaviour (Mehmood *et al.* 2003). This line of modelling predicts drivers' actions based on the following principle: A human driver obtains necessary information from the surrounding environment, uses previous knowledge and experience to choose appropriate actions and carries out these actions in an approximate manner (Chakroborty and Kikuchi 1999).

Fuzzy logic provides an efficient tool to break-up complicated nonlinear relationships into simple "IF... THEN..." rules that can be used to cover various aspects of driver behaviour and the uncertainties associated with it (Das *et al.* 1999). The uncertainty associated with driver behaviour can be quantified through fuzzy logic in a manner that permits its incorporation into car-following models (Wu *et al.* 2000 and McDonald *et al.* 1997). Thus, fuzzy logic provides for a tool that can overcome an obvious weakness of previous car-following models, their inability to incorporate the uncertainty associated with the actions of drivers as they follow other vehicles. This makes models that utilize fuzzy logic more realistic, since they account for the subjective judgement of drivers (Brackstone 2000). Thus, it is argued that these models are more reflective of actual driver behaviour with regard to error and perception (or misperception) than other modelling techniques (Wu *et al.* 2003). The main difficulty with fuzzy logic based models is generating viable membership functions (Panwai and Dia 2005).

4.6 Conclusions

It is apparent from the review that while existing car-following models, which represent the basis for microscopic simulation models, emphasize the role of the lead vehicle as the primary source of information on which following drivers' decisions are based, they fail to account for the effects of different types of lead vehicles on drivers' following behaviours. Existing car-following models have the underlying assumption that drivers follow HGVs as they follow other vehicles in the traffic stream. Evidently, this leads to microscopic simulation models assigning similar following behaviour to drivers, regardless of the lead vehicle type. If the current study proves that drivers change their following behaviour while following HGVs, this would leave existing microscopic simulation models with a glaring flaw that needs to be rectified.

Chapter Five

HGVs' Effects on Driver Behaviour

Heavy goods Vehicles (HGVs) are characterized by large size and weight, increased emissions of gases and poor performance capabilities compared to passenger vehicles. Stutser (1999) states that HGVs on average weigh 20-30 times as much as passenger vehicles. They are also substantially longer than passenger vehicles. Mussa and Price (2004) state that HGVs on average lose 7% of their speed on upgrades in comparison to their speeds on flat sections. The effects of HGVs on traffic are compounded by the fact that the number of registered HGVs is and has been on the rise. In the United States, for instance, the number of registered HGVs weighing over 10,000 pounds has increased by 30% from 1990 to 2000, while the number of miles travelled by these vehicles has increased by 41% in that period (NHTSA 2001). This has led, according to Peeta *et al.* (2005), to HGVs contributing disproportionately to traffic congestion and accidents. The effects of HGVs on safety, capacity and driver behaviour in general have not received the proper amount of attention from the research community (Evans and Wasielewski 1983).

It has been argued that driver behaviour while following is highly dependent on lead vehicle type. The variation in following behaviour while following cars, light trucks and HGVs may be attributed to many factors, some of which include (Hoogendoorn and Bovy 2001A):

1- Differences in vehicle performance such as acceleration, deceleration, braking distance required, etc. The larger braking distance required by HGVs may result in cars following HGVs at smaller headways than when following cars.
2- Differences in traffic situation overview, where HGVs' drivers usually have a better view of the road and are not subject to vision obscuration by their leaders

due to their higher positions in their vehicles. This may lead to HGVs being driven at smaller headways than cars.

3- Differences in vehicle dimensions, where the dimensions of HGVs and light trucks result in obscuring following drivers' vision, especially when the following vehicle is a car. This results in cars following HGVs at larger headways.
4- Differences in driving experience, where HGVs are usually driven by trained drivers who spend a lot of time on the road, making them more competent and better prepared due to their increased exposure. This factor is believed to be independent of lead vehicle type.
5- Differences in fatigue levels, where HGVs' drivers are more exposed to fatigue while driving due to the fact that they drive for longer journeys. This factor also is believed to be independent of lead vehicle type.

This study attempts to address the influence of vehicle type, and in particular that of HGVs, on the car-following behaviour of drivers on motorways. Various aspects of the effects of HGVs on driver behaviour will be discussed in this chapter. First, the current practice in accounting for the effects of HGVs will be discussed, followed by a section addressing the nature of the impacts of HGVs on traffic operations and driver behaviour. The sources of the effects of HGVs on driver behaviour are discussed after that, followed with some of the previous efforts that have been directed towards addressing the effects of HGVs on driver behaviour.

5.1 Current Practice in Accounting for HGVs' Effects

When HGVs and passenger vehicles are driven on the same road, which is a daily occurrence in almost all motorways and highways, they are believed to interact in a manner that might result in reduced safety and capacity. This interaction is also believed to put passenger vehicle drivers at a clear disadvantage. Peeta *et al.* (2005) define this interaction as the change in driving behaviour of passenger vehicles' drivers stemming from their discomfort when in the vicinity of HGVs due to the HGVs' physical and operational characteristics. The large sizes of HGVs and their distinct appearances in the traffic stream lead to psychological impacts on passenger vehicle drivers, which translate into a change in driving behaviour while following these vehicles. This may lead to the increase of the effects of HGVs on capacity beyond those ordinarily calculated by traffic engineers (Grenzeback *et al.* 1990). However, the effects of HGVs on driver behaviour are not addressed appropriately in the current literature.

Parker (1996) and Peeta *et al.* (2005) argue that the current method used for quantifying the impacts of HGVs on traffic operations is limited to the Passenger Car Equivalents (PCE) measure accounting for the physical characteristics of HGVs, as done in the Highway Capacity Manual. However, according to Fisk (1990), replacing HGVs' flow with the equivalent passenger cars' flow, as done in the highway capacity manual's PCE method, does not account for the full effects of HGVs on traffic flow. This could be due to the failure of the approach to account for the performance characteristics of HGVs once they are replaced by the equivalent number of passenger vehicles.

A similar problem regarding the effects of HGVs is found in microscopic simulation models which utilize car-following models as one of their vital components. This was touched upon in the previous chapter on car-following models. Existing car-following models treat HGVs and passenger vehicles similarly as lead vehicles, thus assuming that the behaviour of drivers does not change whether following passenger vehicles or HGVs (Peeta *et al.* 2005 and Peeta *et al.* 2004). Schultz (2003) reports that in the current practice regarding the use of microscopic simulation models, all vehicle types are treated similarly, without provision for the effects of HGVs on driver behaviour and consequent effects on traffic operations. The failure to incorporate the effects of vehicle type into the calibration efforts of microscopic simulation models results in these models' outputs deviating from actual traffic conditions. Sterzin (2004) states that the overwhelming majority of microscopic simulation models fail to account for the change in driver behaviour when following HGVs as opposed to following other passenger vehicles.

The same problem also exists in developing new technologies such as Adaptive Cruise Control (ACC) systems, Advanced Vehicle Control and Safety Systems (AVCSS) and the like. Available literature on the development of many of these systems clearly shows that these systems are developed under the assumption that drivers display the same following behaviour irrespective of lead vehicle type. Santhanakrishnan and Rajamani (2000) and Wang and Rajamani (2004) developed a spacing policy to be used in ACC systems. No account was made of lead vehicle type. Rather, lead vehicle speed and relative velocity were the main factors controlling the resulting time gap. In fact, Wang and Rajamani (2004) state that the most common spacing policy in ACC systems is the constant time gap policy. Holve *et al.* (1996) also attempted to generate an algorithm for ACC systems, where adjustments for driver characteristics and behaviour were included in addition to speed and relative velocity, with no account of lead vehicle type. Robinson and Carter (1998) evaluated an intelligent cruise control system that was under development, and it was clear that no account was being made of lead vehicle type in the development of the system. Lee and Peng (2005) also evaluated several collision warning/collision avoidance algorithms, where it was also clear that lead vehicle type does not play any role in such algorithms. Ohno (2000) also attempted to analyze and model driver behaviour in ACC systems. It was clear that lead vehicle type had no effect on the selected time gap. It is therefore clear that the effects of HGVs on driver behaviour while following are not accounted for in microscopic simulation models or in new in-vehicle technologies.

5.2 HGVs' Impacts on Traffic Operations and Driver Behaviour

The effects of HGVs on capacity through their influence on driver behaviour have not yet been acknowledged. Kockelman and Shabih (2000) argue that headways adopted by drivers as they follow vehicles of different types depend on three factors: length of the lead vehicle, performance characteristics of the lead vehicle and the behaviour of the following vehicle's driver. Various studies have presented evidence that the presence of HGVs affects driver behaviour. Peeta *et al.* (2005) stated that driving behaviour of passenger vehicle drivers is influenced by the presence of HGVs due to their physical size and operational characteristics. Peeta *et al.* (2004) found that drivers overtake at higher speeds when overtaking an HGV compared to overtaking a passenger vehicle, implying that drivers are not comfortable with being adjacent to HGVs. In their study, Peeta *et al.* (2005) conducted a survey of drivers on an Indiana expressway which suggested that most drivers maintain larger headways when trailing HGVs than when trailing passenger vehicles, and are more likely to overtake HGVs than passenger vehicles. Survey respondents stated that the main reasons for discomfort when in the vicinity of HGVs are the physical size and resulting vision obscuration of passenger vehicles' drivers and the blind spots of HGVs' drivers.

In a study utilizing video cameras to capture headways on an expressway, Ozaki (1993) found that space headway maintained by passenger vehicle drivers as they followed HGVs was consistently larger (by two to three metres) than that of passenger vehicles following other passenger vehicles. Parker (1996) concluded that the presence of HGVs results in an overall increase of headways in the lanes they occupy. Krammes and Crowley (1986) found that passenger vehicle drivers follow HGVs at slightly larger distances than they follow other passenger vehicles, although this increase in following distance was not statistically significant in their study. However, the conclusion that drivers change their behaviour when following HGVs cannot be drawn on the entire driving population. Kostyniuk *et al.* (2002) found from fatal crash data that passenger vehicle drivers involved in fatal crashes maintain the same driving behaviour while following HGVs as they do when following other passenger vehicles. However, this finding is only applicable to the population of drivers investigated in the study, namely those drivers involved in fatal car crashes, the specific characteristics of whom are not identified. As for the behaviour of HGVs' drivers, Hoogendoorn and Bovy (1998) concluded from data obtained from rubber detectors that minimum headways maintained by large HGVs' (articulated trucks) drivers are larger than minimum headways maintained by passenger vehicles' drivers or light goods vehicles' (unarticulated trucks) drivers. Krammes and Crowley (1986) concluded that HGVs' drivers follow other HGVs at smaller headways than they follow other passenger vehicles.

5.3 Sources of HGVs' Effects

The effects of HGVs on traffic flow and driver behaviour may result from many factors. There is a general agreement in the literature on the specific characteristics of HGVs that lead to these impacts. From Sterzin (2004), Mussa and Price (2004), Muragula and Mussa (2003), Al-Kaisy *et al.* (2002), Parker (1996), West and Thurgood (1995), Mannering *et al.* (1993) and Krammes and Crowley (1986), it may be argued that the effects of HGVs on driver behaviour while following may be attributed to four main factors:

1- The large difference in size between HGVs and passenger vehicles resulting in HGVs occupying larger space than passenger vehicles.
2- The larger size of HGVs results in obscuring the vision of passenger vehicles' drivers in their vicinity, limiting the visibility to downstream events and traffic control devices.
3- Operational limitations of HGVs due to their characteristics such as low power/weight ratio, reduced acceleration capabilities, etc.
4- HGVs impose physical and psychological influences on passenger vehicles' drivers due to their distinct appearances in traffic.

Zhang and Ioannou (2006) argue that the limited acceleration capabilities of HGVs might be viewed as advantageous from the point of view of car drivers following HGVs. The limited acceleration of HGVs translates to smooth responses to disturbances introduced by HGVs' leaders, which in turn presents drivers following HGVs with a smoother speed trajectory to respond to.

In addition to the four sources for the effects of HGVs mentioned above, Sterzin (2004), Mussa and Price (2004), Mugarula and Mussa (2003), Mannering *et al.* (1993) and Krammes and Crowley (1986) touch on some additional sources of HGVs' effects. Those additional effects include the aerodynamic disturbances caused by HGVs, water and dirt sprayed by HGVs, their blockage of traffic control devices, oscillations of HGVs' loads, the increased stopping distance requirements for HGVs and their general perception of posing hazards on the road. Grenzeback *et al.* (1990) found that HGVs reduce traffic flow (in their lane) due to their speed and acceleration limitations and due to occupying more space than passenger vehicles. In addition to affecting traffic in their own lane, Grenzeback *et al.* (1990) state that HGVs affect traffic in adjacent lanes, which may be apparent by the slight increase in headways between passenger vehicles as they pass HGVs. This increase in headways may be attributed to HGVs' sizes (and subsequent vision obscuration), noise impacts and psychological effects.

Various external factors are believed to influence the effects of HGVs on driver behaviour. According to Peeta *et al.* (2005), the level of discomfort experienced by passenger vehicles' drivers varies according to the traits of drivers such as the socioeconomic characteristics, previous experience and behavioural trends. The level of discomfort also, according to the authors, depends on other factors like weather conditions, time of day and traffic flow levels. West and Thurgood (1995) state that the effects of HGVs on traffic change according to weather conditions and traffic flow levels. Al-Kaisy *et al.* (2002) argue that the effects of HGVs on the traffic stream are more pronounced at periods of high congestion than at lower flow levels. This is due in great part to the frequent formation of queues and discharging from these queues, which amplifies the performance limitations of HGVs. However, the specific influence of traffic flow levels on the effects of HGVs' is not clearly defined. This is clearly demonstrated by the findings from Webster and Elefteriadou (1999), who argue that the effects of HGVs on the traffic stream increase as traffic flow and free flow speed increase, according to results obtained from simulation models. These effects also increase with the increase of grade and grade length. On the other hand, according to the authors, these effects decrease as the percentage of HGVs in the traffic stream increases. However, these findings contradict earlier findings by the authors also obtained from simulation models (Elefteriadou *et al.* 1996), where it was found that the effects of HGVs on motorway traffic, represented by their PCEs, may be unaffected or may increase with the rise in the percentage of HGVs in the traffic stream. This increase was most pronounced on steep, sustained grades. On the other hand, as stated by Elefteriadou *et al.* (1996), the effects of HGVs on the traffic stream are unchanged or may slightly decrease as flow levels increase.

5.4 Previous Studies on the Effects of HGVs on Driver Behaviour

Various studies have targeted assessing the impacts of lead vehicle type on driver behaviour while following. Various tools and methods were utilized in these studies. Some studies used simulators, others used video recording. Instrumented vehicles and surveys were also utilized in these studies. Some of these studies are presented briefly next.

Peeta *et al.* (2004, 2005) attempted to qualitatively define the interactions between passenger vehicles and HGVs in a manner that facilitates the development of models which describe the behaviour of drivers when in the vicinity of HGVs. To achieve that, the study attempted to develop a measure to account for the behaviour of drivers when interacting with HGVs and incorporate that measure into microscopic simulation models. The researchers utilized the fuzzy logic approach to develop a model which would yield that measure. The necessary data for the development of the fuzzy logic model were obtained from an on-site survey which acquired data on the socioeconomic characteristics of respondents, their level of discomfort when in the vicinity of HGVs and their possible actions resulting from their discomfort levels. The surveys indicated that driver behaviour was not highly affected by HGVs in normal conditions. The effects of HGVs on driver behaviour, according to responses to the survey, were more pronounced in inclement weather. However, the surveys did reveal that the majority of drivers increase their headways while following HGVs. Furthermore, respondents indicated that the presence of HGVs had little effect on their driving behaviour during night time driving; however, the authors question this finding and attribute it to the nature of surveys, where very often the stated behaviour by respondents does not match their actual behaviour. With regard to density, the survey indicated that the effects of HGVs were negligible at low densities, and that the effects of HGVs on driver behaviour are most pronounced at medium to high densities followed by at high densities. The measure obtained from the model was incorporated into the FRESIM simulation model in an attempt to extend that model to account for the differences in following behaviour associated with the different types of lead vehicles. The new simulation model was then used to assess various proposed strategies that were aimed at mitigating the effects of HGVs on driver behaviour. However, the authors did not assess the performance of the simulation model after incorporating the measure that accounts for the effects of HGVs' on driver behaviour. Nonetheless, the authors did suggest that inclusion of HGVs' effects on driver behaviour into simulation models presents an opportunity to improve the performance of these models. The main weakness of this study was in inferring the actions of drivers on the basis of their responses to questionnaires. Previous experience suggests, and the authors concur, that the stated responses by drivers often do not match their actual behaviour when the hypothesized circumstances become real.

Parker (1996) examined the effects of HGVs' presence on the car-following behaviour of drivers at roadwork sites and how that in turn affects the capacity at these sites. Data was collected by video recording at 3 motorway sites undergoing roadwork and experiencing various flow conditions. Time and space headway and space gaps between the various vehicles in the traffic stream were obtained at different speeds. The study found that the smallest headways were associated with passenger vehicles following passenger vehicles, followed by headways of passenger vehicles following HGVs. The largest headways were observed for HGVs following HGVs. However, when distance gap was the measure, it was found that the distance gap between passenger vehicles following HGVs was smaller than that of passenger vehicles following other passenger vehicles both at low and high speeds, which was contrary to the researcher's expectations. The distance gap was largest for HGVs following HGVs followed by HGVs following passenger vehicles, as was the case when headway was the measure. The overall finding of the study was that the presence of HGVs increases the overall headways and that the following behaviour is not only dependent on the lead vehicle type, but also on the following vehicle type. The study had several limitations. The method used for data collection, video recording, was not the ideal method for the phenomenon being investigated, since it did not capture the variation of following behaviour over time. Moreover, distance headway was used inappropriately as a measure of drivers' following behaviour, since it was measured from the front of the lead vehicle to the front of the following vehicle. This is not appropriate when investigating the effects of lead vehicles significantly varying in length on drivers' following behaviour. This led to contradicting findings regarding HGVs' effects when distance gap was employed as the measure. Another of the limitations of the study was that it was conducted at roadwork sites, at which driver behaviour may be different from behaviour at non-roadwork sites. Thus, inferences made from this study are limited to the behaviour of drivers at roadwork sites. Furthermore, the vast differences in sample sizes for the different following categories observed may have skewed the results. The sample size for passenger vehicles following passenger vehicles was on the order of 10 to 20 times the sample size for any of the other categories.

Sayer *et al.* (2000) investigated the effects of lead vehicle type (limited to pick-up trucks, SUVs and vans which were considered to constitute the category "light truck") on the car-following behaviour of drivers. The study utilized 108 subjects to drive 10 instrumented vehicles as their personal vehicles for either a two-week or a five-week period, and data from 70 of these subjects was deemed reliable for use in analysis. Drivers were chosen from a large population of drivers based on their driving records, where drivers with history of traffic violations were excluded from the study. Data was collected via infrared sensors for distance measurements and video cameras. The study looked at 4 measures from which to infer conclusions regarding car-following behaviour: distance headway, time headway, velocity and the rate of change of distance headway. The study found that drivers of passenger vehicles followed light trucks at smaller headways than they followed other passenger vehicles, and that was consistent for all age groups. Velocity and the rate of change of distance headway showed no variation based on the size of the lead vehicle. It is worth noting that the same results regarding the effects of light duty trucks on the following headways of drivers were not reached by Kockelman and Shabih (2000), who investigated the following headways of drivers as they followed light duty trucks at signalized intersections and found that drivers followed light duty trucks at greater headways than they followed other passenger vehicles. Although the Sayer *et al.* (2000) study had many strengths, such as the nature of data collection method, the large sample size used, the time duration of the experiment and elimination of the effects of presence of an experimenter during data collection, the study was not without limitations. One of the limitations of the study was in the selection of the test subjects, where all the test subjects came from one region of one state and only drivers without previous history of traffic violations were included. Thus, the test subjects were not highly representative of the entire driving population. Another limitation of the study is that the results could only be applicable to the lead vehicle size investigated, light trucks in this study. The same inferences could not be made about other vehicles that also obscure following drivers' vision, i.e. HGVs. Other limitations of the study included the lack of information about traffic conditions behind and adjacent to the instrumented vehicles during data collection and the failure to account for factors like type of road and time of day.

Yoo and Green (1999) examined the effects of size and speed variation of the lead vehicle on driver behaviour while car-following. Data was collected by monitoring the driving behaviour of 16 test subjects while driving a simulated vehicle following different types of vehicles. The measures that were utilized to infer on car-following behaviour were mean headway and headway variance. The study concluded that lead vehicle type has some effects on the car-following behaviour of drivers. It was found that the following distance adopted by passenger vehicles' drivers increased by 10% when following light-trucks, buses and HGVs compared to when following other passenger vehicles. Various limitations were associated with this study. Since a simulator was used for data collection, the resulting behaviour could not be taken to be reflective of actual driver behaviour due to the artificial environment and lack of criticality of drivers' decisions. Furthermore, the specific simulator used resulted in further limitations of the results, since the simulator had a limited visibility of 600 ft and there were no vehicles following the simulated vehicle driven by the test subjects. In addition, the following processes were dictated by only one lead vehicle, neglecting the fact that drivers look beyond the vehicle immediately ahead for information on which to base their actions.

In addition to the studies discussed above, there have been other studies that have touched on headways maintained by drivers as they followed cars and HGVs. However, the main aim of these studies was not addressing the behaviour of drivers as they followed different types of vehicles. Mussa and Price (2004) and Muragula and Mussa (2003) observed following headways in their attempt to evaluate the efficiency of imposing lane restrictions on HGVs. They observed that the headways of passenger vehicles' drivers as they followed other passenger vehicles were slightly larger than when they followed HGVs for the same lane. However, the authors did not find this difference in following headways to be statistically significant. In a study regarding overtaking prohibitions for HGVs, Hoogendoorn and Bovy (2001A) found that in congested and non-congested conditions, cars were observed to follow HGVs at larger headways than following other cars. However, following behaviour for light truck drivers in congested conditions was different from that in non-congested conditions. In another study evaluating HGVs' restriction policies, Mannering *et al.* (1993) obtained contradicting results concerning the headways adopted by drivers. It was observed that headways of cars following HGVs at some sites were larger than those of cars following cars. On other sites, however, the opposite was observed, where headways of cars following cars were larger than headways of cars following HGVs. This discrepancy may be attributed to different data collection methods, where video recording was used in the first sites and loop detectors in the other sites. Another explanation for this discrepancy given by the authors was that drivers from the same region may have similar driving behaviours (Mannering *et al.* 1993).

5.5 Conclusions

It is evident from the literature that drivers treat HGVs differently from cars as lead vehicles. Although the literature clearly indicates that driver behaviour while following is affected by HGVs as lead vehicles, a consensus on the direction of these effects is lacking. The few studies that were dedicated to assessing these effects suffered from various methodological deficiencies, and this resulted in contradicting results as to the effects of HGVs on driver behaviour. It is also clear from the literature review that the hypothesized sources of the effects of HGVs have not been tested in order to determine their contributions to the effects of HGVs. Such information regarding the sources of HGVs' effects could prove valuable in devising policies to mitigate the effects of HGVs on traffic flow and in designing systems within vehicles that may help reduce the effects of HGVs on driver behaviour. Furthermore, studies found in the literature did not reveal whether HGVs' effects on driver behaviour are uniform for the entire driving population or if they are more pronounced for certain driving groups.

The current study adopts a sound methodology that avoids many of the methodological deficiencies associated with previous studies. It also attempts to shed some light on some of the possible sources of the effects of HGVs on driver behaviour as well as identifying groups for whom driver behaviour is more susceptible to HGVs' effects.

Chapter 6

Literature Review Conclusions

6.1 Current State of the Literature

It has been demonstrated that studying the car-following process is instrumental in furthering our understanding of traffic flow theory, which should lead to improving microscopic simulation models as well as in-vehicle technologies. The majority of cues available to the driver while car-following are obtained from the lead vehicle. The rate of change of optic flow, separation distance, relative speed and relative acceleration with the lead vehicle amount to the main stimuli that trigger following drivers' actions while car-following. The car-following process is affected by numerous situational factors including traffic flow levels, weather conditions and lead vehicle type. In addition, factors pertaining to drivers' characteristics such as age, gender, personality traits and driving experience also affect car-following by influencing driver behaviour while car-following.

While many studies have focused on the effects of driver characteristics on car-following as well as on the effects of environmental and surrounding conditions on car-following, limited research has been devoted to addressing the lead vehicle impact on driver behaviour while car-following. Little is known on the effects of HGVs as lead vehicles on car-following and how these effects vary with drivers' characteristics such as age and gender and with various motorway geometrics such as roadway gradient. In addition, there is a general lack of concrete knowledge on the sources of the effects of HGVs on driver behaviour. This uncertainty associated with the sources of HGVs' effects stems from the numerous possibilities as to the origins of these effects, where it could be argued that these effects result from performance limitations, vision obscuration, psychological impacts or a combination of these and other factors.

It was found in the literature that the majority of microscopic simulation models do not account for the effects of HGVs on driver behaviour, and this accounts for part of the discrepancies between these models' outputs and actual traffic data. The current method for accounting for the effects of HGVs in most microscopic simulation models is limited to the reduction in capacity due to HGVs' dimensions and their performance limitations. The performance of these models can be enhanced by incorporating changes in driver behaviour while following HGVs into these models. A similar shortcoming is associated with car-following algorithms embedded in in-vehicle technologies. This may seriously hinder the effectiveness of these technologies in achieving the objectives for which they were developed.

6.2 Methodologies Employed in Studying Driver Behaviour while Following

The literature review showed that various methodologies can be employed to measure driver behaviour. These methodologies differ in the tools utilized for data collection as well as the method of employing these tools. Some of these tools can provide a large quantity of data, but cannot capture the nature of car-following since observations are made at short instants. Video cameras and loop detectors fall into this category of data collection tools. Another method used for data collection is to conduct the experiment in a virtual environment. This is done by recruiting subjects to drive a driving simulator in a laboratory. This method suffers from a lack of applicability of results since the experiments take place in an artificial rather than a real environment. Thus, actions taken by drivers in such experiments lack the criticality and safety implications associated with driving in real traffic. Furthermore, the variation in driver behaviour observed in such experiments cannot match that observed in real driving conditions. Another method that has been used in studying driver behaviour while car-following is eliciting driver behaviour from questionnaires. However, often the behaviour stated by drivers in questionnaires does not match their actual driving behaviour.

Employing instrumented vehicles constitute another method that can be used to monitor driver behaviour. This tool can be used in different ways. One way is to use the instrumented vehicle as a lead vehicle while measuring driver behaviour of following drivers. This method has the drawbacks of lack of information on driver characteristics, failure to account for driver state, lack of information on factors that may influence driver behaviour and the limited control that can be exercised by the experimenter on car-following processes. This method is also not suitable when the aim of the study is investigating the effects of different types of lead vehicles on driver behaviour. Another method of using instrumented vehicles is to recruit subjects to drive the instrumented vehicle while following other vehicles on test tracks. However, this method suffers from the fact that many of the factors that influence driver behaviour while following relating to interactions with surrounding vehicles are removed from the experiment. A third way of using instrumented vehicles is to use them on actual roads driven by test subjects instructed to follow another experimental vehicle driven by a single driver for the duration of the experiment. This method does not account for the variation associated with following different vehicles driven by different drivers with diverse characteristics and behaviours. A fourth method of using instrumented vehicles is to recruit subjects to drive them in real traffic, following a variety of vehicles. Although the last three methods may have some limitations if the experimental design involves presence of an experimenter or drivers abiding by instructions specified by the researcher, the last method, with or without presence of an experimenter, avoids many of the more serious shortcomings associated with the other methodologies. Hence, the methodology to be followed in this study is to utilize test subjects to drive the TRG's instrumented vehicle in real traffic while following different vehicles as specified by an experimenter who is present during the experiments.

It was found in the literature that the number of subjects employed in studies dedicated to assessing driver behaviour varies significantly from one study to another. A direct method in deciding on the appropriate number of subjects to include in a study appears to be lacking. The number of subjects included in a study may thus be deemed to depend on the required level of significance as well as the amount of data obtained from each subject. In addition, the quality of data obtained may be viewed to be as important as the quantity of data in defining the number of subjects required.

Various measures have been employed to assess driver behaviour while following. Distance headway is one such measure. However, its high correlation with speed may yield unreliable results, especially when the study entails investigating the effects of types of lead vehicles that are usually driven at significantly different speeds. Another measure that can be used is time-to-collision. Since this measure is only defined when the following vehicle is closing on the lead vehicle, this leaves a significant portion of the car-following process unmeasured. Braking performance is yet another measure that can be used. However, its applicability is more suitable for safety studies and situations of large decelerations, which are not characteristics of the steady-state phase of car-following which is the focal point of studying car-following behaviour. Time headway was found to be the most appropriate measure due to its independence of speed and its variability between drivers in addition to portraying much of the information provided by distance headway. Furthermore, time headway is seen by many researchers to represent a safety margin while following other vehicles. It has been used as the measure of driver behaviour while following in the majority of studies dedicated to this topic. A measure synonymous with time headway, time gap, is thus used to assess driver behaviour in the current study. In addition, the variation of time gaps was found to be a good indicator of driver stability. This measure is utilized for that purpose in this study. As for measuring risk, TTC was found to be an appropriate measure to elicit drivers' risk taking behaviour, and hence is one of the measures employed for assessing risk taking behaviour here. Many other studies also used time headway as a measure of risk taking behaviour. In this study, the minimum time gap reached during a following process is used as an additional measure of drivers' risk taking behaviour.

6.3 The Need for the Current Study

Various attempts have been undertaken in an effort to shed some light on the effects of HGVs on driver behaviour while following. Most of these studies had limitations caused by the methodologies used. Laboratory simulators, survey questionnaires and video recording were the tools used in some of these studies, and as stated earlier; none of these methods is capable of capturing the nature of actual driving while following other vehicles. Another study utilized instrumented vehicles; however, the main focus of that study was light duty trucks as lead vehicles. The sources of the effects of HGVs on driver behaviour have not been addressed in any of the previous studies, nor have the identification of driver groups for whom HGVs' effects are most noticeable. Furthermore, the risk acceptance behaviour of drivers towards HGVs has not been addressed. Additionally, little is known on the specific nature of HGVs' effects on sections of gradient. Thus, it can be stated that a glaring gap exists regarding HGVs' effects on driver behaviour, the variation of these effects among the driving population and the sources of these effects. The current study intends to fill this gap.

The current study attempts to elucidate the effects of HGVs on driver behaviour while car-following, and how these effects vary among the driving population. Only few of the factors that influence the car-following process and driver behaviour while following are included in this study, since inclusion of all the factors that affect car-following and driver behaviour in one study is a very difficult task and would increase the scope of the study significantly. The variation of HGVs' effects according to following drivers' age and gender are addressed in this study. Furthermore, this study aims at investigating the possible sources of the effects of HGVs on driver behaviour as well as getting an understanding of the locations where the effects of HGVs are more pronounced. The latter task is represented in the study by investigating the effects of HGVs on driver behaviour at sections of gradient. Two of the possible sources of the effects of HGVs on driver behaviour will be tested, those being the effects stemming from vision obscuration and the psychological threat imposed on following drivers. The former will be investigated by utilizing other vehicles that obscure following drivers' vision as lead vehicles, while the latter will be assessed by examining drivers' risk perceptions towards HGVs as lead vehicles. Another contribution of the current study is examining a widely accepted view in the literature that time headway remains constant for the individual driver. Studies that have reached this conclusion had some methodological deficiencies. The current study may yield sufficient data to test this view with greater validity.

The tool used for this research, the instrumented vehicle, along with the methodology employed provide a great opportunity to overcome some of the limitations associated with previous research on this topic. The fact that the experiments are carried out by a diverse group of drivers in real traffic conditions while following a variety of vehicles should add to the strength of the study. Increasing the state of knowledge on the effects of HGVs on driver behaviour as well as boosting the validity with which results are obtained may prove instrumental in improving the performance of microscopic simulation models, making them more consistent with actual traffic conditions. This in turn will increase the credibility of these models and make their use more valuable for future traffic flow studies. A similar improvement can be achieved with regards to in-vehicle technologies, which can be improved by accounting for changes in driver behaviour while following HGVs.

Part II

The Methodology

Chapter 7

The Apparatus: TRG's Instrumented Vehicle

The last few decades have witnessed increased interest in driver behaviour. This increased interest has resulted from the vast growth in roadway miles travelled as well as the increasing number of individuals utilizing cars as their main means of transport. In order to accommodate this growth, the available resources in terms of existing roads and their capacities must be used very efficiently. This requires greater understanding by transportation officials of the behaviour of drivers. The enhanced knowledge and understanding of driver behaviour will have significant implications on a wide range of traffic applications including roadway capacities, traffic safety and transportation policy as well as on several traffic tools such as simulation models and new in-vehicle technologies.

The nature of driver behaviour makes it a difficult process to measure with high accuracy. Drivers do not display the same behaviour for the entire duration of a single trip, let alone from one trip to another. Thus, measuring car-following behaviour accurately requires a tool that monitors it over a prolonged period of time. Video cameras and loop detectors fail to achieve that since they are incapable of producing continuous measurements of the driver's actions. Measuring driver behaviour accurately also requires duplicating all the factors that may affect it in every day driving in the experiment. Laboratory simulators fail to fulfil this requirement since many of the road, psychological and environmental factors the driver is faced with in actual driving are eliminated in simulator studies. The tool most appropriate for fulfilling both requirements is an instrumented vehicle that is driven in real traffic conditions, where the behaviour of the instrumented vehicle's driver and/or the behaviour of drivers of vehicles in the vicinity of the instrumented vehicle can be accurately and continuously obtained for prolonged time periods.

The instrumented vehicle (IV) described here is the second one assembled at the Transportation Research Group (TRG) of the University of Southampton. The first instrumented vehicle was assembled in 1996. For more information on the first instrumented vehicle, refer to Sultan (2000) and Brackstone *et al.* (1999). The current instrumented vehicle is built on the same concept, but with vastly improved capabilities and more sophisticated devices. The current instrumented vehicle is a 2004 Fiat Stilo with a 2.4 L engine. It is equipped with various systems that enable it to perform the different data collection functions. It is equipped with an eye monitoring system, a differential Global Positioning System (dGPS), a lane guidance system, front and rear infrared laser devices, front and rear microwave radar devices and a set of video cameras. Each of these systems will be discussed separately in the following sections. It must be noted here that the figures provided in the following descriptions regarding the accuracies and ranges of the various devices are as supplied by each system's manufacturer. Diagrams illustrating the positions of the various sensors on the instrumented vehicle are shown in figures 2 and 3. The systems utilized for data collection in the current study are the radar system, the GPS system and the video cameras.

7.1 The AC10 Radar Sensor

The instrumented vehicle is furnished with front and rear AC10 radar sensors, shown in figure 4. The AC10 Radar Sensor employs MMIC (Monolithic Microwave Integrated Circuit) technology to identify targets (vehicles) in its detection field (Langheim *et al.* 2002). This technology is capable of detecting targets in all weather conditions. The radar is mounted onto a vehicle and connected to a power supply and a CAN bus. In order to yield the required information, the radar requires the speed and yaw rate of the instrumented vehicle, which are obtained from the GPS VBOX via a CAN bus at 50 Hz frequency (Bold 2005).

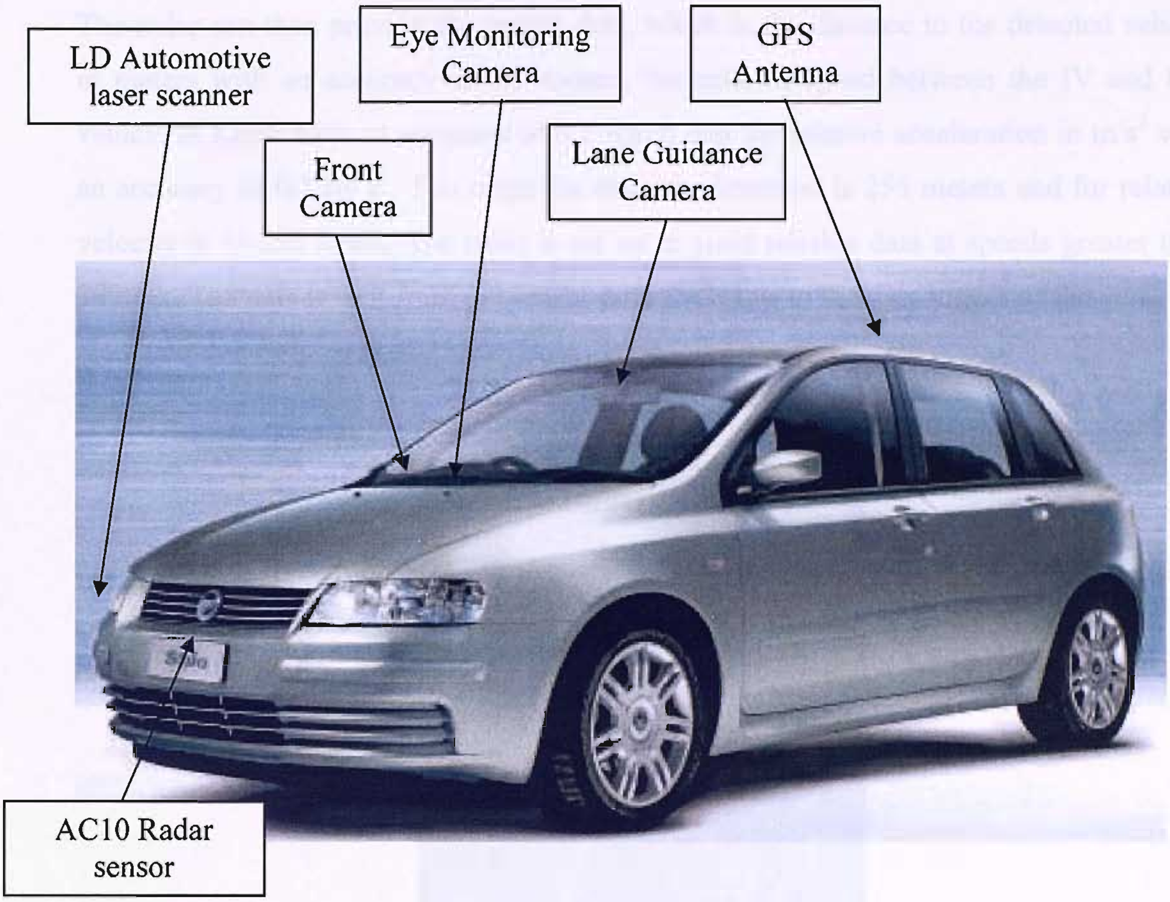

Figure 2: The Instrumented Vehicle with Various Sensors

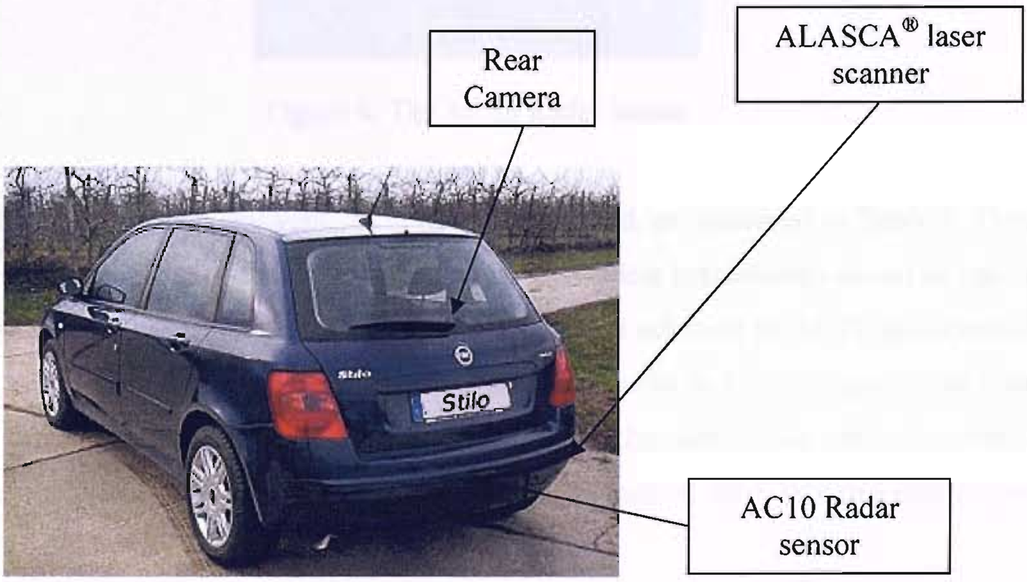

Figure 3: Sensors in the Instrumented Vehicle's Rear

The radar can then provide the output data, which is the distance to the detected vehicle in meters with an accuracy of 0.1 meters, the relative speed between the IV and that vehicle in Km/h with an accuracy of 0.1 Km/h and the relative acceleration in m/s^2 with an accuracy of 0.1 m/ s^2. The range for distance detection is 255 meters and for relative velocity is +/-255 Km/h. The radar is set up to yield reliable data at speeds greater than 30 mph. The data is sent from the sensor on a CAN bus to the data logger of the vehicle's computer at a frequency of 25 Hz (Bold 2005).

Figure 4: The AC10 Radar sensor

The radar can detect several vehicles in its detection field, as illustrated in figure 5. These are the vehicle in front of the radar (vehicle #1), the vehicle immediately ahead of vehicle #1 (vehicle #2), the vehicles occupying the traffic lanes adjacent to the IV lane (vehicle #3 and vehicle #4) and the vehicle in the far-side lane (vehicle #5). Altogether, the radar sensor can track five different vehicles simultaneously, and obtain data on relative distances, relative speeds and relative accelerations of each of these vehicles with respect to the IV (Bold 2005).

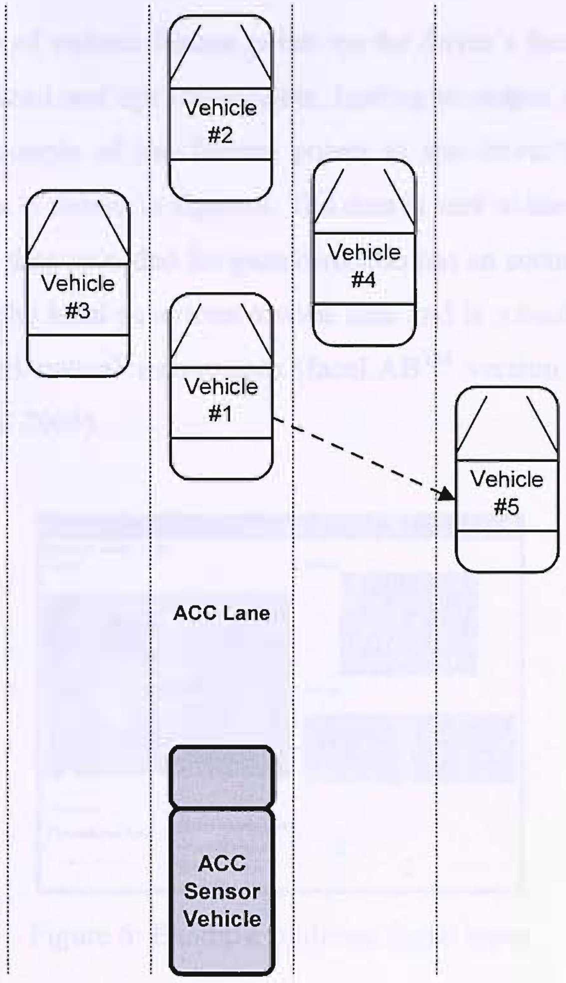

Figure 5: Vehicles tracked by the AC10 radar

7.2 The Eye Monitoring System

The instrumented vehicle is equipped with an eye monitoring system made up of two cameras that track the driver's eyes and head, a faceLAB^{TM} computer to receive and process the data and software that extracts the eye tracking data. Two computer programs are used for that purpose; faceLAB^{TM} version 4.0 is used to set up and operate the eye monitoring system while Client Tools SDK version 2.0 transforms data from faceLAB^{TM} into readable format. This system is capable of tracking the driver's eyelid movements and position, gaze direction, blink rates and head pose while driving in real traffic. The system can operate during daytime or night time driving. It operates without the need for a special helmet and can be used even if the driver is wearing contact lenses. The system's input consists of various feature points on the driver's face, which are then used to define the driver's head and eye movements, leading to output such as head pose and gaze direction. An example of the feature points in the driver's face that should be identified in the system is shown in figure 6. The data is sent to the faceLAB^{TM} computer at a rate of 60 Hz. The data provided for gaze direction has an accuracy of 1°. The system is capable of tracking the head pose over a wide area and is robust to partial occlusions, facial deformations and natural movements (faceLAB^{TM} version 4.2 2004 and Seeing machines media release 2004).

Figure 6: Example of driver facial input

7.3 The Lane Guidance System

The instrumented vehicle is fitted with a lane guidance system that traces the lateral path of the vehicle. This can be used to address the lateral control aspect of driver behaviour. The system is capable of obtaining information on lane width, the vehicle's position within the lane and the curvature of the road ahead. Furthermore, the system can also provide the lateral velocity of the vehicle as it drifts in the lateral direction. The lane guidance system is made up of a Lane Departure Warning (LDW) sensor supplemented by a camera. The camera is fitted against the windscreen, behind the rear-view mirror. The LDW sensor captures images, processes them and transmits them over a CAN bus. The LDW sensor and the attached camera are shown in figure 7. The system's output is a CAN message that details the geometry of the road, along with raw video images in

CameraLink format. The raw video images and the CAN message are then sent to the data logger of the host computer. The data is sent at a frequency of 30 Hz. The system's algorithm is developed to capture distinct features of the road, such as lane markings and road edges, and to transmit them to a lane estimation module. In order to provide the required data and video images, the system requires vehicle speed and yaw rate to be provided from a different CAN bus. These are provided from the dGPS VBOX. The lane guidance system is robust to inclement weather, and is designed to filter out noise from various sources. Figure 8 demonstrates the system when in operation as well as the robustness of the system to challenging conditions (Oyaide 2004).

Figure 7: LDW sensor and accompanying camera

The system operates at speeds greater than 25 mph (11 m/s). It can be used to provide information on lane guidance for a range of lane widths from 2.0 to 5.5 metres, with lane width accuracy and lateral position accuracy of +/- 5 cm. The system can also be used for lane guidance investigations on horizontal curves where the radius of curvature is greater than 125 metres. The system is capable of operating when the heading angle is within a range of +/- 7°, with an accuracy of +/- 0.12°. Lateral drift velocities covered by the system range from +/- 0.2 m/s to +/- 10 m/s with +/- 0.2 m/s accuracy. The system covers a horizontal field of 26°, while the vertical field covered is 48°. The system has been configured to provide a high degree of accuracy and robustness (Oyaide 2004).

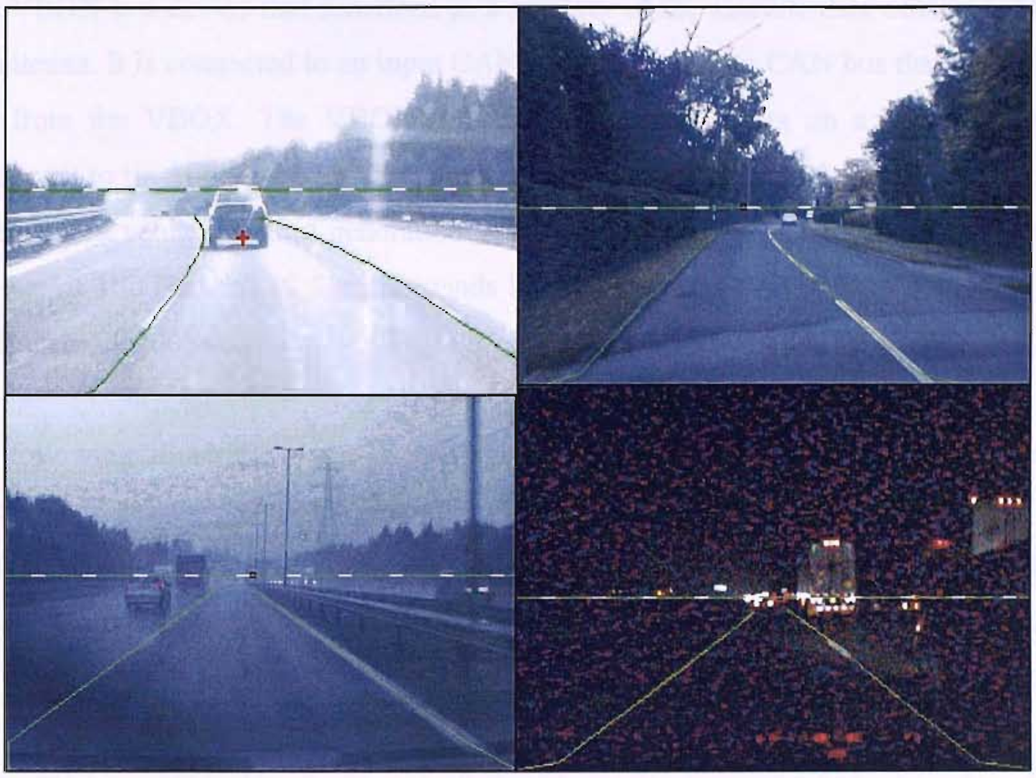

Figure 8: Lane guidance system in operation

7.4 The Differential Global Positioning System (dGPS)

The instrumented vehicle is equipped with a dGPS system that is capable of providing measurements on several parameters including longitude, latitude, altitude and velocity. The system is made up of an antenna, VBOX that receives data sent from the satellite, set of CAN buses that link multiple control systems together, a compact flash card for storing data, yaw rate sensor and a number of computer programs. Some of the computer software used include Racelogic Batch Processor software that extracts data from the VBOX, Racelogic Report Generator software which enables the data in the VBOX to be displayed instantly in a spreadsheet and VBOX Kalman Filter which converts original dGPS measurements into more accurate ones after smoothing. The filtering process is necessary since the original data may be poor due to interference with the satellite signal. The antenna is mounted on the roof of the vehicle, in a position that minimizes interference (Racelogic 2005 and Racelogic 2005a).

The VBOX is a device that functions as a receiver of the satellite data obtained through the antenna. It is connected to an input CAN bus and an output CAN bus that transmit the data from the VBOX. The VBOX transfers the received data on a CAN bus which transfers it to the vehicle PC or to a compact flash card that stores the data. In the current instrumented vehicle, a third generation VBOX (VBOXIII) is used, which transfers data at a rate of 100 Hz with 12.5 milliseconds latency to the host computer (Racelogic 2005 and Racelogic 2005a).

The following illustrates some of the system's units and accuracies of measurement (Racelogic 2005 and Racelogic 2005a):

1. Velocity: in units of knots, Km/h or mph with accuracy of 0.1 Km/h. The velocity information is provided at a rate of 100 Hz. The maximum velocity that can be recorded is 1000 mph, while the minimum velocity that the system can detect is 0.1 Km/h.
2. Distance: in units of metres or feet with an accuracy of 0.05% (less than 50 cm per kilometre). Information on distance is provided at a frequency of 100 Hz.
3. Absolute positioning: with an accuracy of 3 metres, enhanced to 1.8 metres by use of the differential GPS (dGPS), provided at a rate of 100 Hz.
4. Heading: with an accuracy of 0.1°.
5. Time: provided with an accuracy of 0.01 seconds.
6. Acceleration: with an accuracy of 0.5% at a frequency of 100 Hz.
7. Altitude: in units of metres.

The data transferred from the VBOX on the CAN bus consists of satellite number, latitude, longitude, velocity, heading, altitude, vertical velocity, distance, longitudinal acceleration, lateral acceleration, distance from trigger, trigger time and trigger velocity. This data appear in an output dGPS spreadsheet. It must be noted that for data collection in the current study, the normal, rather than the differential, GPS system was utilized. This was deemed to suffice as the data required from the GPS system consisted of vehicle speed and altitude only (Racelogic 2005 and Racelogic 2005a).

7.5 The Laser Distance Sensors

The instrumented vehicle is fitted with 2 laser systems as another means of measuring relative distance and speed. The system is made up of front and rear laser scanners, IPC (Industrial Personal Computer), CAN buses, ARCnet buses and an RS232 synchronization cable. The front laser scanner is an IBEO LD Automotive laser scanner, while the rear scanner is the improved ALASCA® laser scanner.

The IBEO LD Automotive and ALASCA® laser scanners are range-finding devices which are capable of measuring distances to objects surrounding the host vehicle. They are based on LIDAR technology (Light Detection and Ranging). The scanners survey the surroundings utilizing rotating infrared laser beams. The scanners send out short rapid-fire pulses, which are then reflected from the surrounding objects back to the scanners. Distances are then measured from the time elapsed between transmission and reception of these pulses and the velocity of light. The positions of the objects are determined from the angular position of each scanner's rotating mirror which deflects the emitted beams. The intensity of the received pulses is converted to voltages, where only voltage receptions exceeding threshold values are detected. This allows for elimination of noise from false objects. The scanners have multi-target capability made possible by the ability of each laser pulse to detect two echoes. The measurement range for distance with the ALASCA® laser scanner is between 0.3 – 80 m, with object tracking available for targets up to 80 m away. The distance repetition accuracy for the ALASCA® laser scanner is +/- 5 cm and the distance resolution is 1 cm. As for the LD Automotive scanner, the distance measurement range is 0.3 – 256 m, with object tracking ability of up to 50 m. The distance repetition accuracy for this scanner is similar to that of the ALASCA® laser scanner, namely +/- 5 cm, while the distance resolution is 3.9 mm (Langheim *et al.* 2002, Langheim *et al.* 2000, Willhoeft *et al.* 2004 and Willhoeft *et al.* 2001).

The ALASCA® laser scanner is a multi-layer scanner since it operates with 4 scan planes at different vertical angles, a feature advantageous for automotive application of the laser detection technology allowing the system to overcome problems arising from roadway geometry. The four vertical planes cover a range of vertical angles from -1.6° to +1.6° as shown in figure 9, resulting in a vertical field of view of 3.2° with a vertical angle resolution of approximately 0.8°. The LD Automotive laser scanner is a single plane laser scanner covering a vertical angle of 3°. The ALASCA® laser scanner can scan an area covering a horizontal angle up to 240° when the scanner is positioned in the middle of the vehicle's front or rear, whereas the LD Automotive scanner can scan an area covering a horizontal angle up to 270°. However, due to the positioning of the LD Automotive in the instrumented vehicle (in the front right corner of the vehicle), the area scanned covers only 180°. Both laser scanners have horizontal angle resolutions of 0.25° - 1.0°. The laser scanners can transmit scans at frequencies ranging from 10 to 40 Hz. In the current instrumented vehicle, the scanners are set up to transmit the data at a frequency of 10 Hz. A picture of the LD Automotive laser scanner is shown in figure 10, while the ALASCA® scanner is shown in figure 11 (Langheim *et al.* 2002, Langheim *et al.* 2000, Willhoeft *et al.* 2004 and Willhoeft *et al.* 2001).

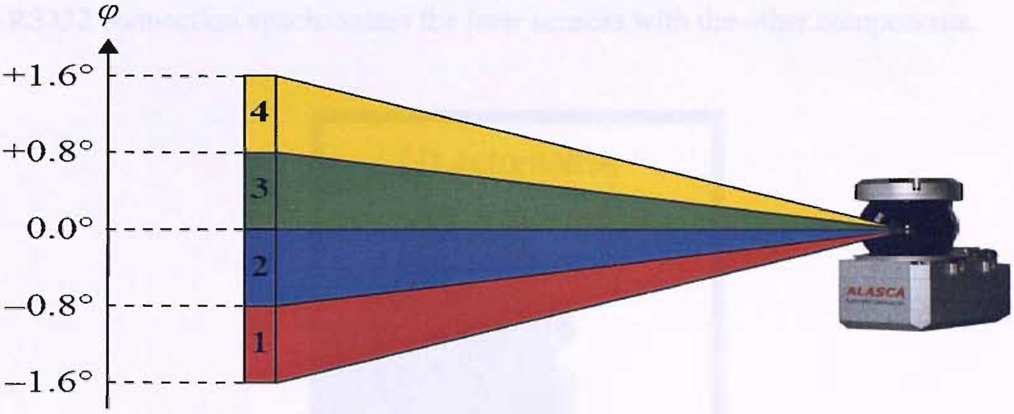

Figure 9: The vertical field covered by the ALASCA® scanner

The ARCnet bus sends commands from the IPC to the ALASCA® laser scanner and transfers raw data from the ALASCA® laser scanner to the IPC for processing. The data are sent from the IPC to the ALASCA® scanner and back at a rate of 10 MBit/s. The IPC rationally groups, interprets and assesses the raw data sent from the sensor. The IPC sends high-level description of the data to the vehicle's computer regarding the object number, distance, size, position and velocity. This data is sent after being smoothed by the Kalman filter. The CAN bus transfers the condensed data from the IPC to the vehicle computer, making it the means of communication between the IPC and the vehicle's computer. Data obtained from the LD Automotive laser scanner, on the other hand, does not go through the IPC. Rather, it is transferred by a CAN bus from the scanner. This CAN bus connects with the CAN bus transferring data from the IPC to the host computer. The RS232 connection synchronizes the laser sensors with the other components.

Figure 10: LD Automotive scanner

In the output files, the default units are as follows:

1. distance measured in metres
2. velocity measured in Km/h
3. angle in degrees
4. acceleration in m/s^2

The default conditions for objects to be identified and sent to the vehicle's computer are: (1) that an object has been tracked for at least 0.5 seconds, (2) that an object has been moving in the same direction as the host vehicle (the IV) and (3) that an object has been in the host vehicle's lane or either of the adjacent lanes. These conditions can be manipulated by the user.

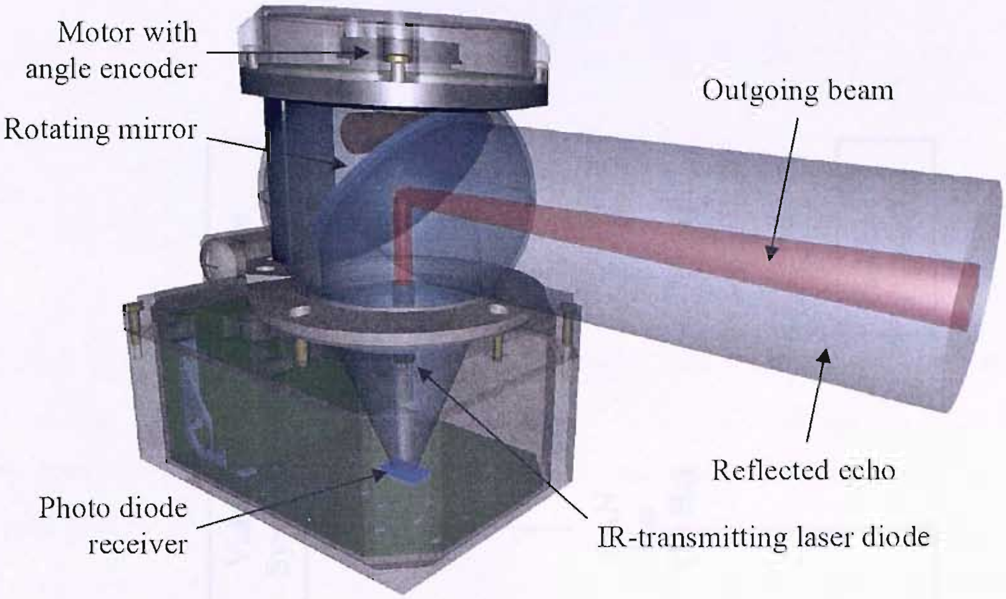

Figure 11: ALASCA® laser scanner

7.6 The Video System

The instrumented vehicle is equipped with a video system providing vital information on the road environment as well as on certain aspects of the driving process. The system is made up of a forward facing camera that monitors the road ahead, a rear facing camera covering the area behind the instrumented vehicle, a camera positioned in the middle of the interior over the left shoulder of the driver and a camera tracking the driver's foot movement. The video data is sent to the host computer at a frequency of 10 Hz.

The coordination of the various systems and how they send data to the host computer are illustrated in the diagram shown in figure 12.

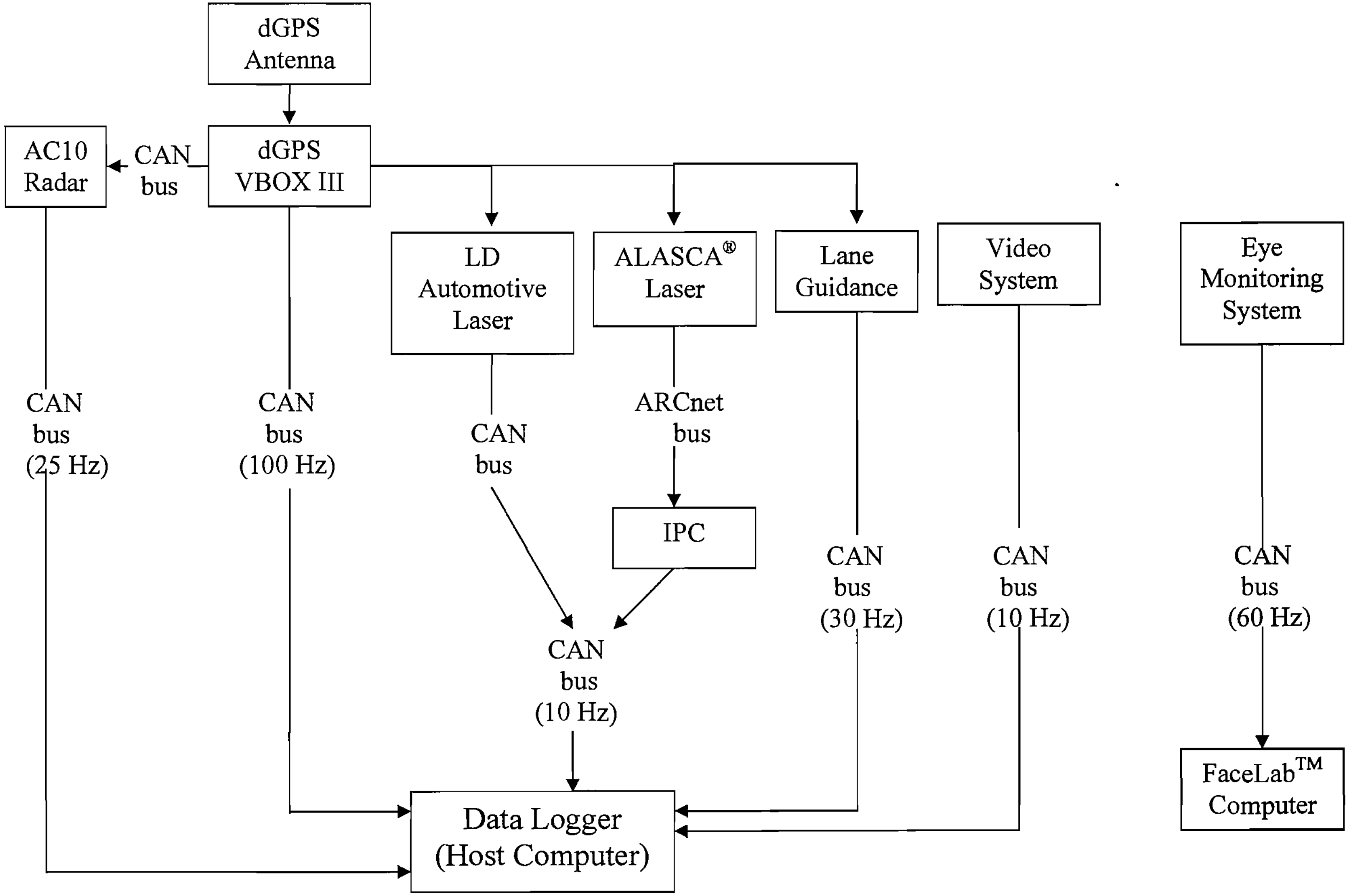

Figure 12: A diagram of the various systems in the instrumented vehicle

Chapter 8

Study Methodology

The methodology employed for data collection in this study involved recruiting subjects to drive the TRG's instrumented vehicle on the motorway following different vehicle types while conforming to certain instructions as advised by the researcher. Drivers were advised to follow a specific route during the experiment along motorways M27 and M3 that was selected mainly for its high volumes of HGVs. Data relating to the following behaviour of drivers was gathered via some of the systems fitted to the instrumented vehicle and reduced to facilitate statistical analysis. Of the various systems fitted to the TRG's instrumented vehicle, three systems were used for data collection in this study; the radar system, the GPS system and the video system. The experimental procedure that was followed in the study ensured that a large quantity of high quality car-following data was obtained. Various measures of driver behaviour were employed in this study, some devoted to assessing driver behaviour in general while others were specifically dedicated to evaluating drivers' risk taking behaviour and driver stability. In addition to data obtained from carrying out the experiments, information from questionnaires completed by the subjects was also used as a supplemental source of information on driver behaviour.

This chapter illustrates in detail the methodology used in this study. The apparatus that was used for data collection was discussed in chapter 7. The first section of this chapter addresses the reasoning behind employing the current methodology. The second section takes up the subject recruitment process and provides a summary of the subjects that participated in the driving experiments. The third section illustrates in detail the experimental procedure followed in this study. Following that is a section on the measures and indicators utilized. A section on data reduction follows with the chapter concluding with a section describing the questionnaires that were completed by the subjects to provide additional information on subjects' driver behaviour and attitudes towards HGVs.

8.1 Reasoning behind the Methodology

From the literature review, it was found that driver behaviour studies that utilize driving simulators, video cameras and questionnaires to make inferences on driver behaviour while following cannot yield sound results. Furthermore, it was concluded from the literature review that studies using instrumented vehicles driven in real traffic conditions to assess driver behaviour overcome many of the shortcomings associated with other methodologies employed to study driver behaviour.

Instrumented vehicles have been deployed in different ways in driver behaviour studies, as was shown in the literature review. One method of utilizing instrumented vehicles in driver behaviour research is to use the vehicle's driver in the active mode by monitoring the driving behaviour of subjects of known characteristics in conditions that can be controlled to some extent by the experimenter. This approach was adopted in this study. This method is not without drawbacks, the main two being that subjects perform the experiments while aware of being monitored, and that subjects must conform to certain instructions laid out by the experimenter (Kim and Lovell 2005). Another common method of using instrumented vehicles in driver behaviour research entails using the instrumented vehicle in the passive mode by driving it in front of other vehicles to monitor the driving behaviour of following drivers. While this method was not suitable for the current study since the main focus of the study is to compare driver behaviour while following different vehicle types, some of the other results obtained in this study that were independent of lead vehicle type can be deemed to have greater validity than those that would have been obtained if the experiment was carried out utilizing the instrumented vehicle in the passive mode. The reason for the potentially greater validity of the results obtained here is that using instrumented vehicles in the passive mode may result in even more serious downsides than those associated with the methodology employed here. One of these downsides is that very little accurate information can be obtained about drivers' characteristics; the only one to be obtained with certainty is driver gender. Another drawback to using the instrumented vehicle in the passive mode is that any result obtained from this method cannot be extended to situations where the lead vehicle is of different type. In fact, these results in many situations cannot be generalized on the entire spectrum of vehicles to which the instrumented vehicle belongs. Additionally, the variation in drivers' car-following behaviour with the various driving styles of their leaders is not accounted for. Moreover, the experimenter can exercise very little control, if any, on following processes, especially in terms of duration. Yet another limitation associated with using the instrumented vehicle in the passive mode stem from the inability to ascertain whether driver behaviour displayed by the following vehicle's driver was influenced by time pressure, driver state or any other factor that has been shown to affect driver behaviour.

Thus, it can be argued that while the method employed for data collection in this study has some drawbacks, it may still be considered among the most valid methodologies to obtain reliable, high quality data about driver behaviour. The validity of the methodology employed is further strengthened by the fact that a wide range of lead vehicles with varying driving styles were encompassed in this study. Furthermore, subjects driving the instrumented vehicle were not required to conform to any predetermined speed patterns during the car-following processes.

8.2 The Subjects

The main criterion for deciding on the number of subjects included in the study was obtaining a sample size of following processes that would yield the desired power and significance of the statistical tests, both set at 95% in this study. Hence, the number of subjects required was related to the number of following processes that can reasonably be obtained from each subject. Pilot experiments were carried out with 2 subjects to predict the number of following processes that can reasonably be executed by each subject as well as to find out whether any parts of the experiment needed adjustment. The pilot experiments demonstrated that 8 following processes while following HGVs and 5 while following cars can reasonably be attained. In addition, two processes while following vans were obtained from each of the two subjects in the pilot study.

Information from the pilot study combined with statistical procedures was then used to decide on the number of subjects required for the study. The number of subjects employed had to yield the necessary sample size of following processes to meet requirements relating to statistical power and significance. Sample sizes were planned assuming only one factor was included in the study, that of lead vehicle type. This was done to ensure a significantly more conservative estimate of the sample size required. Statistical procedures regarding planning of sample sizes indicated that for a single factor study with desired statistical power and desired significance of 95% each and with the minimum range of time gaps for which it was important to detect differences with high probability set to half a standard deviation, a sample size of 48 observations (following processes) was estimated to yield the necessary power and significance. According to the number of following processes obtained in the pilot study, this implied that a number of subjects as low as 4 should yield the desired statistical power and significance. This was lower than the number of subjects used in the majority of studies found in the literature. To increase the validity of the results, a sample size significantly greater than that estimated from the statistical procedures was desired. Numerous studies had utilized subjects to make inferences on driver behaviour while following. However, the number of subjects used in these studies varied from as low as 4 subjects to as high as 108. The average number of subjects from these studies was 34. Thus, the initial design of the experiment was to include 36 subjects, 6 representing each age/gender group. This number was later reduced due to the large quantities of data obtained from each subject.

Once an initial number of subjects required for the study was determined, the subject recruitment process was launched. Subjects were recruited in two stages; the first targeted the recruitment of older and middle aged drivers while the second aimed at recruiting younger drivers as well as those from the groups that were not fully represented in the first stage. The first stage consisted of distributing preliminary questionnaires at car parks soliciting participation in the driving experiment, where freepost envelopes were provided to facilitate responding to the questionnaires. The second stage of subject recruitment consisted of placing advertisements on various university bulletin boards as well as on the University of Southampton's portal website. Subjects recruited in the second stage were also required to complete the preliminary questionnaire to obtain information on their characteristics and their driving history.

Subjects were classified into 6 age/gender groups; young males, middle aged males, old males, young females, middle aged females and old females. An age limit of 25 years old was used to distinguish young drivers from middle aged drivers. This was based on results from Begg and Langley (2001) that significant differences in driver behaviour existed between drivers aged 21 and those aged 26 years old. This age boundary was also used in other studies found in the literature to distinguish young drivers from middle aged ones (Boyce and Geller 2002, Dingus *et al.* 1997 and Mathews and Moran 1986). However, since the instrumented vehicle's insurance requirements prescribed that no subjects under the age of 21 may be allowed to drive the instrumented vehicle, the young group in this study was made up of drivers aged 21-25 years old. The middle age group was deemed those between the ages of 26 and 55 years old, while the old group consisted of those who are over 55 years old. Specifying the age limit for the old group was dictated mainly by availability of subjects. It was also related to the instrumented vehicle's insurance requirements that no drivers over the age of 70 drive the instrumented vehicle. The literature did not show a clear age boundary that distinguishes middle aged drivers from old drivers. While some studies set this boundary at 65 years of age (Boyce and Geller 2002 and Dingus *et al.* 1997), others used a boundary of 60 to differentiate older drivers from middle aged ones (Sayer *et al.* 2000).

Subjects were screened based on their driving history, where subjects over the age of 25 were allowed to take part in the study only if they have not accumulated more than 3 penalty points on their driving licenses. Subjects of the younger age group, those between the ages of 21-25, were allowed to partake in the study if they had not accumulated any penalty points on their driving licenses. This screening was performed to meet the requirements as prescribed by the instrumented vehicle's insurance policy. In addition, all drivers had to have at least 3 years of driving experience in order to take part in the study. This was also a requirement laid down by the instrumented vehicle's insurance policy.

In total, 32 subjects participated in the experiments representing both genders and 3 age groups; young, middle age and old. Six subjects participated from the young male and young female groups. Seven subjects participated from the middle aged male group and five from the middle aged female group. The number of subjects in the older age groups was less than that in the young and middle aged groups, as there were only four male drivers over the age of 55 who participated in the study and four female drivers in that age group. Several other subjects were recruited to take part in the study but have cancelled for various reasons. Data obtained from two of the 32 subjects was eliminated since the entire experiment took place in rainy conditions; these subjects were a young female and a middle aged male. This resulted in the total number of subjects for whom data was obtained and analyzed to be 30 subjects; 6 young males, 5 young females, 6 middle aged males, 5 middle aged females, 4 old males and 4 old females. A large data base was compiled from the 30 subjects. More than 420 following processes were executed by the 30 subjects, resulting in over 38,000 seconds of car-following data. It was thus decided that the number of subjects included in the study was sufficient, and that no additional subject recruitment was required.

Table 1 illustrates the characteristics of the subjects that took part in this study. Several interesting remarks can be made regarding these characteristics. For young drivers, it can be seen that all drivers were between the ages of 21-25, as mentioned earlier, in order to comply with the instrumented vehicle's insurance policy. Furthermore, all young subjects had at least 3 years of driving experience and no penalty points on their licenses. An interesting remark about subjects in this group is that all but one were full time university students. Although the annual miles driven for this group varies, with some driving less than 5,000 miles per annum to 10,000-15,000, and the portion of that mileage driven on

subject	gender	age group	occupation status	years holding driving license	annual miles driven	% of annual miles on motorways	# penalty points	accidents in last 5 years
subject 1	Male	26-30	employed full time	5	5000-10000	25%-50%	none	no
subject 2	Female	over 65	retired	50	5000-10000	less than 25%	3	yes
subject 3	Male	51-55	self employed	36	more than 20000	less than 25%	3	yes
subject 4	Male	51-55	self employed	27	5000-10000	25%-50%	3	no
subject 5	Female	41-45	receiving state benefits	21	15000-20000	25%-50%	none	no
subject 6	Male	21-25	full time student	4	less than 5000	25%-50%	none	no
subject 7	Female	56-60	retired	26	5000-10000	25%-50%	none	no
subject 8	Male	21-25	full time student	7	less than 5000	25%-50%	none	no
subject 9	Male	21-25	full time student	3.5	5000-10000	25%-50%	none	no
subject 10	Female	31-35	employed full time	3	less than 5000	less than 25%	3	no
subject 11	Female	41-45	employed part time	26	less than 5000	less than 25%	none	no
subject 12	Female	21-25	full time student	4	10000-15000	25%-50%	none	no
subject 13	Female	21-25	full time student	4.5	10000-15000	more than 75%	none	no
subject 14	Male	21-25	full time student	4	less than 5000	25%-50%	none	no
subject 15	Male	21-25	full time student	6.5	5000-10000	50%-75%	none	no
subject 16	Female	56-60	retired	42	5000-10000	25%-50%	none	yes
subject 17	Female	26-30	full time student	9	5000-10000	less than 25%	none	no
subject 18	Male	41-45	employed full time	27	more than 20000	50%-75%	none	yes
subject 19	Male	36-40	employed full time	15	5000-10000	less than 25%	none	no
subject 20	Female	21-25	full time student	3.5	less than 5000	50%-75%	none	no
subject 21	Male	46-50	employed full time	32	5000-10000	less than 25%	none	no
subject 22	Male	over 65	self employed	50	10000-15000	25%-50%	none	no
subject 23	Female	26-30	employed full time	9.5	5000-10000	50%-75%	none	yes
subject 24	Male	56-60	employed full time	30	5000-10000	less than 25%	none	no
subject 25	Male	21-25	employed full time	7	5000-10000	25%-50%	none	no
subject 26	Female	56-60	employed full time	30	10000-15000	50%-75%	3	yes
subject 27	Female	21-25	full time student	3	5000-10000	more than 75%	none	no
subject 28	Female	21-25	full time student	5	less than 5000	25%-50%	none	yes
subject 29	Male	56-60	retired	40	5000-10000	25%-50%	none	no
subject 30	Male	61-65	employed full time	43	5000-10000	less than 25%	none	no

Table 1: Characteristics of subjects participating in the study

motorways is almost evenly spread between the four possible responses, the fact that almost all drivers in this group were full time students in addition to the various screenings performed to meet the insurance requirements indicates that this group is not highly representative of the actual population of drivers in this group. However, subject availability and the insurance requirements dictated that this sample is used to represent the young drivers group.

Although the middle age band in this study encompasses a wide range of age groups, every sub-age group falling within the range of 26 to 55 years was represented by at least one driver. Moreover, no sub-age group had more than 3 drivers in it. It can also be seen that the majority of subjects in this group were in full time employment, while some were self or part-time employed with one full time post graduate student and one receiving state benefits. This spread in employment status and drivers' age could be taken to indicate that a large spectrum of middle aged drivers was represented in this study. As regards driving experience, subjects in this group ranged in driving experience from 3 years to 36 years, with an average of 19.1 years of holding a driving license. Furthermore, more than one-half of the subjects in this group (6) reported annual miles driven between 5,000-10,000, with 2 reporting driving less than 5,000 miles and another 2 driving more than 20,000 miles a year. Similarly, 6 of the 11 subjects from this group reported driving less than 25% of their mileage on motorways, with the other 5 reporting either 25%-50% of mileage driven on motorways (3 subjects) or between 50%-75% of mileage driven on motorways (2 subjects). Finally, 3 of the eleven subjects had 3 penalty points on their licenses and another 3 had been involved in car accidents in the previous 5 years. Thus, no biases could be identified regarding representation of subject in this age group of the population of middle aged drivers.

Of the 8 drivers participating from the "old" age group, 5 were aged 56-60 years. This may result in some biases in results obtained from this group. However, the fact that 3 of these 5 drivers were retired from paid work may indicate that these drivers would share similar characteristics with drivers over 60 years of age as far as driving behaviour is concerned. The results of this study will show whether inclusion of drivers aged 55-60 in the old group results in any biases or misrepresentation of the population of drivers in this group. As for employment status, half of the subjects in this group were fully employed while the other half were retired. Driving experience for this group ranged from 26 years of licensed driving to 50 years, with the average being around 39 years. Of the 8 subjects in this group, 6 drive their vehicles for an annual mileage of 5,000-10,000, with the other two having a mileage of 10,000-15,000 miles per year. Half the subjects in this group drive less than 25% of their mileage on motorways, with 3 driving from 25%-50% of their mileage on motorways and one subject driving between 50%-75% of the mileage on motorways. Finally, 2 of the drivers in this group had 3 penalty points on their licenses and three of the drivers in this group had been involved in accidents in the previous 5 years. Although it is possible that better representation of the population of old drivers may be attained by including more drivers aged over 60 or 65, the overall characteristics do not suggest significant biases in representing this group of drivers in this study.

8.3 The Experimental Procedure

8.3.1 Overview

The experiment consisted of each subject driving the instrumented vehicle on the motorway for about 85 miles accompanied by the experimenter and a system technician. An acquaintance period was allowed for subjects to be familiarized with the experimental vehicle. This period was followed with the data collection part, during which subjects followed HGVs, cars and vans as prescribed by the experimenter. The experimental route included some 2-lane motorway sections, but the majority of the experiment took place on 3-lane motorway sections. Furthermore, sections of appreciable gradient occurred mainly on 3-lane sections. After completing the driving part of the experiment, subjects were asked to fill a detailed questionnaire, at the completion of which they were paid for their participation in the study. The driving experiments started on the 25th of April, 2006 and the last experiment took place on the 3rd of August 2006. All but one experiment started between 10:00 AM and 2:00 PM. One experiment started at 3:00 PM.

8.3.2 Subject Briefing and Instructions

After the subject's arrival, the details of the experiment were explained to the subject along with what was required of him/her. The subject was informed that he/she will be driving a semi-automatic car on a specified route while instructed to follow different types of vehicles in the slow lane along motorways M27 and M3. After explaining the route that would be followed for the experiment to the subject, he/she was shown the risk assessment form prepared for the experiment and then asked to read and sign a driver consent form. After signing the consent form, the experimenter explained to the subject the nature of the experiment without revealing the specific objectives of the study. The experimenter then advised the subject of the instructions to follow during the course of the experiment. These instructions were as follows:

1- Follow the specified lead vehicle at what you perceive to be your minimum safe following headway.
2- Follow the specified lead vehicle without trying to change lanes until the following process terminates, which will be conveyed to you by the experimenter.
3- During the experiment, drive the experimental vehicle the way you normally drive without taking any risks that you would not normally take.
4- If the lead vehicle changes lanes, the following process terminates, meaning that you do not have to follow it.
5- If at any point you are instructed to execute any manoeuvre that you do not feel comfortable with or feel you cannot execute safely, disregard the instructions.
6- Take as much time as you think is necessary to get comfortable driving the instrumented vehicle as if it was your own car before starting instructed following.

After advising the subject of the instructions to be followed during the experiment, the experimenter escorted the subject to the instrumented vehicle. A vehicle technician then illustrated to the subject the various controls in the vehicle and explained in detail how to drive the vehicle with emphasis on driving in the automatic mode. Once the subject felt comfortable operating the vehicle and was acquainted with the various controls, the experimental drive was initiated.

8.3.3 Experimental Route

The experimental drive started at the University of Southampton heading towards motorway M27 at Junction 5. The experimental route started on Junction 5 of motorway M27 heading westbound on motorway M27 for 10.2 miles to Junction 1, then returning on motorway M27 eastbound for 8 miles to Junction 4, where the subject was instructed to join motorway M3. Subjects then proceeded to drive on motorway M3 northbound for 20.8 miles to Junction 7 and then returning on motorway M3 driving southbound for 22.7 miles to Junction 14, where motorway M27 was joined again. Subjects drove eastbound on motorway M27 for 9.8 miles to Junction 9. Subjects then turned at Junction 9 to drive westbound on motorway M27 for 7.9 miles to Junction 5 where the experiment terminated. The experimental route is illustrated in figure 13. Each subject was asked between 20-25 minutes after the initiation of the driving experiment (after driving approximately 15 miles on the motorway) whether he/she felt comfortable driving the instrumented vehicle or if he/she needed more time to get acquainted with the vehicle. All but one subject indicated feeling comfortable driving the instrumented vehicle at the first time of asking. For the one subject who did not feel ready for instructed following at the first time of asking, an acquaintance period of 45 minutes was found to be sufficient.

8.3.4 Defining Vehicle Types

Three lead vehicle types were targeted for following processes; passenger vehicles (cars), HGVs and vans. In addition, another vehicle type was identified for the analysis of trailing vehicle type, that vehicle type is small truck. The term HGV in this study denotes articulated trucks commonly used for freight transport. The key criteria for inclusion of heavy vehicles into this category are that they must have distinctly large sizes (large lengths, widths and heights) so as to impose psychological impacts on following drivers

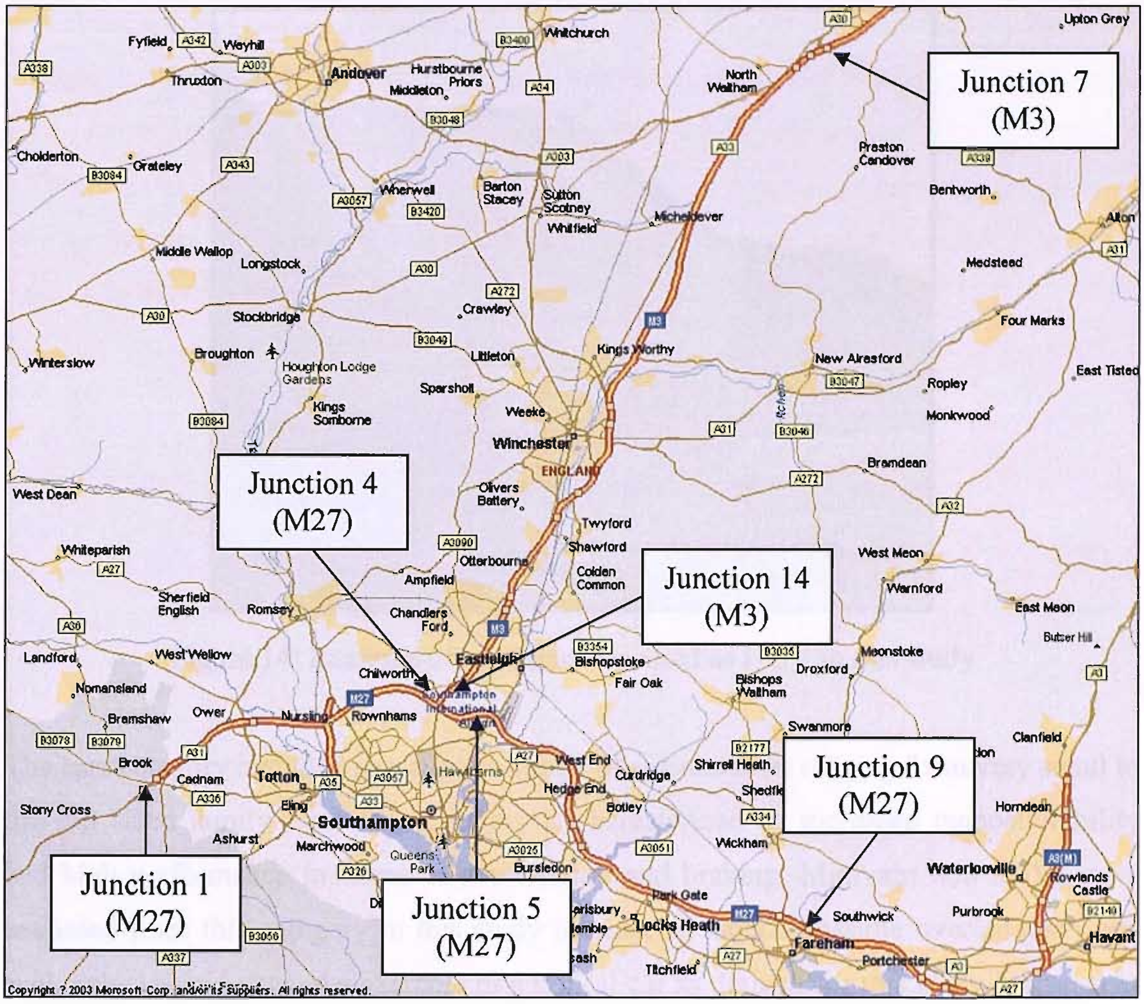

Figure 13: Map showing the experimental route (obtained from MapPoint)

and that they must obscure the following driver's vision. Car-transporters would fit this category if they obscure the vision of a following vehicle driver in the same manner that a normal HGV would. Typical vehicles fitting the criteria for HGVs include the combination tractor-semi-trailer, tractor-trailer and tractor-double-trailer. Vehicles included in this category are characterized by low performance capabilities and very limited manoeuvrability due to the low power-to-weight ratios associated with these vehicles. The lower performance and excess weights of these vehicles generally translate into requiring longer distances to accelerate and to stop. Vehicles classified as HGVs in this study typically had 4 or more axles, with some having as many as 8 axles. An example of a typical HGV as encountered in the current study is shown in figure 14.

Figure 14: Example of a vehicle classified as HGV in this study

The cars category included passenger vehicles of various sizes ranging from very small to the full sized family cars. This category is characterized by increased manoeuvrability and high performance in terms of acceleration and braking. Minivans and SUVs were excluded from this category in this study in order to reduce possible overlaps between such vehicles and vans. An example of a typical car as defined for this study is shown in figure 15.

Figure 15: An example of a typical car as encountered in this study

The term van in this study referred to vehicles often used by utility personal, which are larger than passenger minivans or SUVs. A key characteristic for a vehicle to be included as a van in this study is that it must obscure following drivers' vision. The performance characteristics of these vehicles in terms of acceleration and manoeuvrability are inferior to those of cars but better than those of HGVs. An example of a typical vehicle classified as a van in this study is presented in figure 16.

Figure 16: AN example of a typical van as encountered in this study

The term small truck, used in this study as a category of trailing vehicle type, refers to un-articulated single unit trucks that typically have two axles with one axle having more than two tyres, although other variations of this vehicle type are not uncommon. These vehicles are noticeably smaller in size than HGVs, with higher power-to-weight ratios compared with HGVs. On the other hand, their lengths and general appearances set them apart from vans. Although the performance characteristics of these vehicles do not differ significantly from those of vans, their appearance in traffic, especially while trailing, may result in distinctly different effects on driver behaviour than those of vans. Hence, these vehicles were included as a separate category for trailing vehicle type in order to clearly identify the effects of HGVs as well as those of other vehicle types on measured behaviour displayed by drivers whilst trailed by such vehicles. No inferences about small trucks are made in this study as will be shown later. Examples of small trucks include single-unit short-distance delivery trucks and tow trucks. An example of one of many vehicles that may be classified as small truck for purposes of this study is presented in figure 17.

Figure 17: An example of a small truck as encountered in this study

8.3.5 Data Collection

In executing the car-following processes during the experiments, the order of lead vehicles followed was randomly selected and depended on the availability of each vehicle type in the slow lane. However, if the same vehicle type had been followed four consecutive times, a different lead vehicle type would be targeted even if availability dictated otherwise. Towards the end of each experimental run, the selection of lead vehicle type depended on the number of following processes executed for each vehicle type as well as the availability of each vehicle type as lead vehicles. The type of vehicle that was available the most as a lead vehicle was HGV. This was due in large part to the slow speed at which these vehicles are normally driven and to their less frequent lane changes. Following cars and vans proved more difficult since drivers of these vehicles change lanes frequently in addition to the fact that the majority of these vehicles are driven at significantly higher speeds than HGVs. Thus, data obtained while following HGVs exceeded that of following cars and vans combined. It must be noted that targeting vans as lead vehicles was of secondary importance as this vehicle type only served to address one factor of the study, that of vision obscuration of HGVs.

A significant portion of following processes took place with the instrumented vehicle being followed by another vehicle, either during part of the following process or for the whole duration of the following process. In most cases, this occurred due to prevailing traffic conditions or due to the natural driving styles of the subject and the tailing vehicle's driver. In few cases where a relatively large gap existed between two successive HGVs or between an HGV and another preceding vehicle, the subject was instructed to cut-in between the two vehicles in order to execute a following process while followed by an HGV. Four different vehicle types were identified that trailed the instrumented vehicle during the experiments; HGVs, cars, vans and small trucks. The small truck category included vehicles that cannot be considered HGVs, yet their characteristics are different from those of vans or passenger vehicles. This category of vehicles was included to distinguish this vehicle type from other vehicle types that followed the instrumented vehicle during the experiments. Defining the times during car-following processes when the instrumented vehicle was followed by another vehicle along with identifying the type of vehicle following the instrumented vehicle allowed for the effects of trailing vehicle type on driver behaviour to be examined.

Gradient sections were clearly discernible from motorway terrain. The experiments were designed to carry out as many following processes while following HGVs on these sections as feasible. Executing such following processes was dictated by the presence of HGVs as lead vehicles on these segments and safety concerns. A significant number of following processes while following HGVs was executed on these segments of the motorway to address another of the study objectives pertaining to the effects of HGVs on sections of gradient. Following processes on these sections were carried out in a manner that would achieve a balance between data obtained on upgrade and downgrade sections.

Part of the data obtained was for following processes which took place without the subject being instructed to follow. They took place either due to prevailing traffic conditions or due to the natural driving style of the driver. While following processes executed upon the instructions of the experimenter took place exclusively on the left (slow) lane of the motorway, these "uninstructed" following processes were not limited to the slow lane of the motorway; some of them took place on the middle lane of a three-lane motorway section, while others took place on the fast lane, either on a two-lane or three-lane section of the motorway. These processes were obtained after the familiarization period, during the data collection part of the experiment.

During most following processes where the subject was instructed to follow, subjects were required to give verbal ratings of their perceived risk. Upon the experimenter's request, the subject was required to give one of three ratings of risk; low risk, medium risk or high risk. The instants when the subject was asked to provide the verbal risk rating were selected by the experimenter in a manner that would cover the entire duration of a following process. Subjects were also asked to provide risk ratings when the experimenter felt that the subject's risk might have changed. The number of risk ratings per following process varied based on the circumstances and the duration of the following process, with some following processes yielding 5 risk ratings while others yielding only one risk rating. During some of the following processes, no risk ratings were requested. In most of these cases, that was due to the following process not lasting long enough. It is worth noting that one subject of the older age group did not feel comfortable providing risk ratings while driving.

8.3.6 Conditions Encountered during the Experiments

Of the 32 experiments that were carried out, two took place entirely in relatively heavy rain. Data obtained from these two experiments was therefore eliminated from the data base to be used for analysis. For three other subjects, the latter parts of their experiments took place in rainy conditions. Data from following processes taking place in rainy conditions for these three subjects was discarded. This was done to eliminate the effects of external factors not controlled for in the study. All data used in the analysis was obtained from following processes taking place in dry, daytime conditions.

Traffic conditions encountered during the experiments varied during each experiment and also varied from one experiment to another. No means of formally computing traffic flow during the experiments was available, and obtaining this information from an outside source would prove cumbersome and would not add much to the findings of the study. Thus, traffic conditions were subjectively stratified based on the video captured during the experiments into three levels; light traffic conditions, moderate traffic conditions and heavy traffic conditions. The subjective stratification procedure resulted in moderate traffic conditions being the most frequently encountered, followed by light conditions. Heavy traffic conditions were not encountered very often. Since all but one of the experiments started between 10:00 AM and 2:00 PM, this distribution of traffic conditions conforms to expectations. Hence, it was deemed that the subjective categorization of traffic conditions would suffice for the purposes of the current study.

8.4 Measures/Indicators of the Study

The main measure used to assess driver behaviour while following was time gap. It is synonymous with time headway which was shown from the literature to be the most appropriate measure of driver behaviour while car-following (Heino *et al.* 1996 and Heino *et al.* 1992). The suitability of time headway as a measure of car-following behaviour is due in large part to it being independent of speed (Kim and Lovell 2005, Taieb-Maimon and Shinar 2001, van Winsum and Brouwer 1997 and van Winsum and Heino 1996). Time gap was preferred to time headway for two main reasons. First, time gap does not take lead vehicle's length into account, which is of paramount importance in this study since the types of vehicles investigated differ significantly in length. Second, the relative distance provided by the radar was from the rear of the lead vehicle to the front of the instrumented vehicle, which lent itself to using time gap as the measure. It must be noted that time headway could have been chosen as the measure by calculating the distance from the rear of the lead vehicle to the rear of the instrumented vehicle. However, since nothing was to be gained from that, and since it required extra calculations, time gap was the measure used.

Other measures of driver behaviour while following were also available, some of which include distance gap and time-to-collision (TTC). However, these measures were deemed not as reliable as time gap as indicators of drivers' following behaviour. Distance gap does not take the variation in vehicles' speed into account, which is vital in this study considering that the main focus of the study was comparing driver behaviour while following types of vehicles that differed significantly in terms of their operating speeds. With regard to TTC, it is only defined when the following vehicle is closing on the lead vehicle. Therefore, using TTC as a measure of driver behaviour would lead to significant portions of car-following processes being unaccounted for. Thus, neither distance gap nor TTC offer the advantages provided by time gap as a measure of driver behaviour while following. The variation of time gap is considered a good measure of driver stability as found by van der Hulst *et al.* (1999A). Hence, variance of time gap is employed in this study as a means of investigating driver stability.

Two other measures were utilized to determine drivers' risk taking behaviour. The first is time-to-collision, which is more suitable for measuring drivers' risk taking behaviour than general driver behaviour while following as shown in the literature (Minderhoud and Bovy 2001 and van der Hulst *et al.* 1999A). This measure was calculated as the ratio of distance gap over relative speed. The other measure utilized to assess drivers' risk taking behaviour was the minimum time gap achieved during each following process.

In this experiment, time gap was calculated as the ratio of distance gap over the instrumented vehicle's speed. The microwave radar continuously provided distances measured from the front of the instrumented vehicle to the rear of the lead vehicle. This distance was provided in units of metres. The GPS system provided the instrumented vehicle's speed in units of knots, which was converted to metres per second in order to obtain time gap in seconds. To make sure that time gaps obtained were consistent, the distances and speeds obtained from the instrumented vehicle were tested for their consistencies. For the distance test, several distance measurements each obtained over a 10-second period where distances were observed to vary marginally were extracted. This corresponded to several data strips of approximately 250 distance measurements each. The standard deviations of these distances were in the neighbourhood of about 0.260 m. Similarly, the consistency of speed was tested by extracting several speed measurement data covering 10 seconds each where speed was not observed to vary substantially. This yielded several strips of speed data of 1000 speed measurements each, the standard deviations obtained for which varied around a value of 0.221 m/s (0.7956 k/h). Since neither speed nor distance was constant during the 10 seconds of testing, it can be said that both distance and speed measurements obtained from the instrumented vehicle were consistent. Consequently, time gaps obtained were deemed consistent. The accuracy of distance measurements was calibrated by comparing distances obtained from the radar sensor with those obtained from the laser sensor. The comparisons showed little differences between the two sources of distance measurement, indicating sufficiently accurate measurements of distances obtained for data analysis. Thus, it was decided that time gaps obtained were adequately consistent and accurate.

8.5 Data Reduction

Raw data regarding the car-following processes was provided from two sources, the microwave radar data provided at a frequency of 25Hz and the GPS data provided at a frequency of 100 Hz. Raw data was obtained from both sources and reduced to yield data that gave one reading per second. The first reading at the turn of a second was obtained from both files to ensure synchronization between the two sources of data. A Microsoft Excel® macro was developed to perform the data reduction task once the raw data was obtained from the original files corresponding to the duration of a following process.

For a car-following process to be included, it had to last for at least 30 seconds, which at motorway speeds of 60 MPH translated to a following process covering approximately 0.5 mile. The instigation of the steady-state phase of a car-following process was taken to be the time at which the relative speed between the instrumented vehicle and the lead vehicle was equal to or lower than 1.5 m/s (5.4 kph). This number was conservatively chosen to ensure that the following process had stabilized and that the approach process that often preceded the steady-state phase of car-following had ended. This was performed mainly to make sure that data obtained was that of steady-state car-following processes as perceived by drivers. This also eliminated processes where the instrumented vehicle was driven behind another vehicle without significantly interacting with it.

For the majority of following processes, it was not difficult to judge whether the process constituted car-following, since the average time gap was around 2 seconds in these cases. Few following processes were observed where the average time gap was larger than 3.5 seconds. For these processes, a judgment had to be made whether the process actually constituted car-following or whether the driver happened to be driving behind another vehicle without interacting with it. In these cases, if the following process took place upon the instructions of the experimenter, it was considered a car-following process. For processes with high average time gaps that were executed without instructions from the experimenter, the speed profile of the instrumented vehicle was checked during the 30 seconds preceding commencement of the following process. If a noticeable decline in the instrumented vehicle's speed was observed and was associated with the instigation of the following process, the process would be judged to constitute car-following. Otherwise, it was eliminated.

Data obtained from following processes where the lead vehicle was an HGV had to be further classified according to gradient. To do that, a value had to be specified that would serve as the criterion based on which sections would be categorized as upgrade, flat or downgrade sections. A value of 2.5% was chosen as that criterion. This value was chosen for two reasons. First, this value was associated with noticeable change in HGVs' speeds on upgrade sections. Second, this value ensured reasonably large sample sizes for all three gradient types investigated. Gradient was calculated from altitudes provided by the GPS data and distance traversed, obtained by multiplying average speed on the upgrade/downgrade section (in m/s) by the time period while on these sections (in seconds). Plots of altitude vs. time were produced for each following process where an HGV was the lead vehicle to clearly identify the start and end points of gradient sections. An example of such plot is shown in figure 18. Once the change in altitude and distance traversed were obtained, gradient was calculated as the ratio of altitude change to distance traversed.

As for data reduction regarding trailing vehicle type, two criteria had to be met in order to consider the instrumented vehicle trailed by another vehicle with possible effects on driver behaviour. The first criterion was that a vehicle had to trail the instrumented vehicle for at least 20 seconds, which was considered the time required to allow the instrumented vehicle's driver to be aware of the trailing vehicle and to allow any possible change in driver behaviour to materialize. The second criterion was that the distance gap between the trailing vehicle and the instrumented vehicle had to reflect a time gap of no more than 2 seconds, within which the hypothesis regarding trailing vehicle effects was to be tested. To do that, the average speed of the instrumented vehicle was obtained (in metres per second) over the period where it was trailed by any vehicle. This was then multiplied by 2 to yield the distance limit beyond which the instrumented vehicle's driver was considered free from any effects of trailing vehicle on his/her driver behaviour.

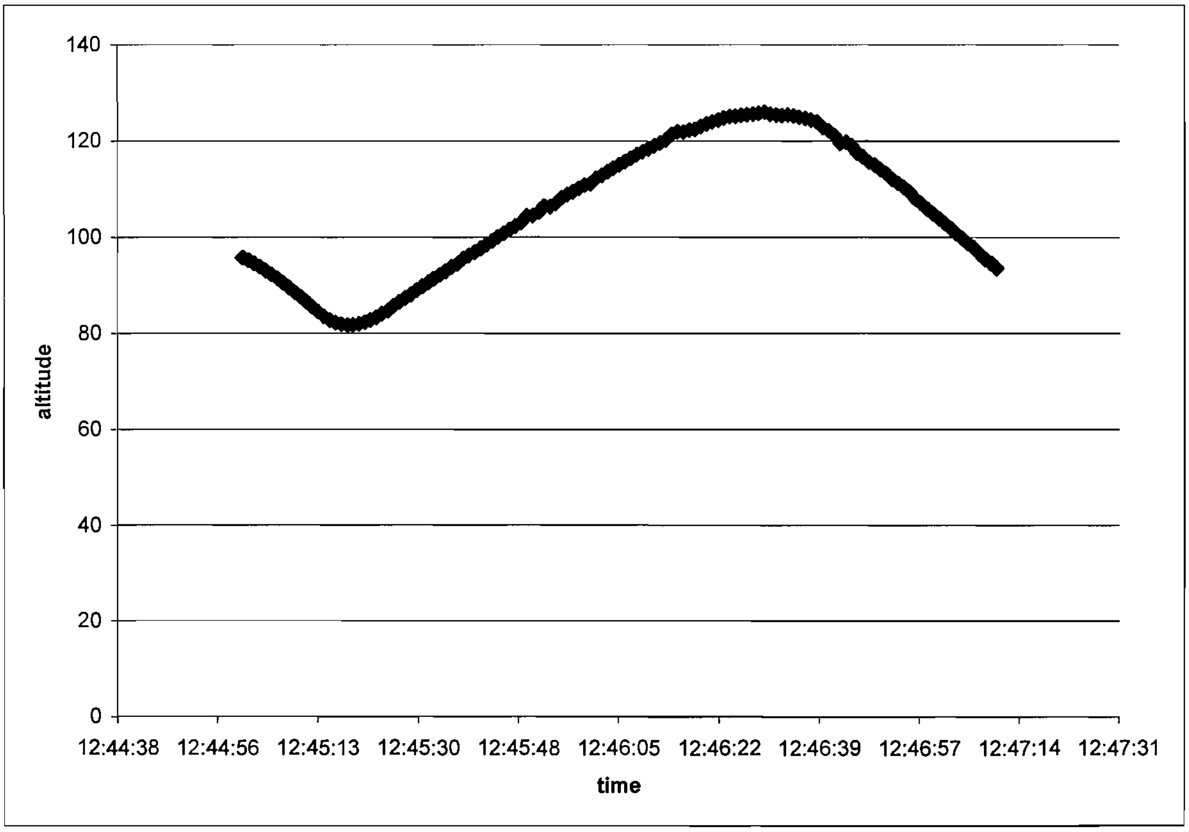

Figure 18: Altitude vs. time plot used in calculating gradient

8.6 The Questionnaires

Two different questionnaires were developed for this study. The first was a preliminary questionnaire aimed at recruiting subjects to participate in the research study as drivers and to provide the necessary information for subject screening. It provided basic information about driver demographics such as age group, gender, driving experience and driving history. In addition, it provided basic information about driving behaviour and respondents' views about the effects of HGVs on driver behaviour. A copy of this questionnaire is provided in Appendix A. The second questionnaire, the driver behaviour questionnaire, was more detailed and was completed by subjects who drove the instrumented vehicle. It solicited information about the driving behaviour of subjects in general as well as their attitudes towards HGVs. This questionnaire was made up of 6 parts. Part I obtained data about the general driving behaviour of subjects, with emphasis on identifying behaviours that might be deemed aggressive. Part II focused on the attitudes of drivers towards HGVs. Part III elicited information regarding HGVs' effects at different driving conditions. Part IV was directed towards attaining drivers' views as to the sources of HGVs' effects. Part V allowed subjects to add any comments they had about HGVs' effects while part VI consisted of showing subjects 2 series of pictures in order to determine drivers' preferred time gaps while following cars and HGVs. The two series of pictures were posted on a wall approximately 60 cm away from the desk where the subject completed the questionnaire. A copy of this questionnaire is provided in appendix B.

Chapter 9

Analysis Procedure

In this chapter, an overview of the procedure for analysis is given before presenting the results of the study. The analysis is made up of 6 parts, starting with performing some diagnostic tests to investigate the appropriateness of the ANOVA modelling technique that is used to analyze the data obtained from the experiments followed by various sensitivity analyses performed on the data. The remaining 4 parts are designed to obtain the results of the study.

9.1 ANOVA Diagnostics

Before analyzing the data with the ANOVA modelling technique, several diagnostic tests must be conducted to determine whether this method of analysis is appropriate to analyze the data. There are three main conditions that must be met in order to utilize the ANOVA modelling technique. The conditions are:

1- The error terms associated with the response variable, time gap in this study, must be normally distributed.
2- The error terms associated with the response variable must have equal variances.
3- Observations must be independent from one another.

Normality of the error terms is investigated through the Kolmogorov-Smirnov test for normality. However, since this test is conservative, and since ANOVA models are robust to moderate departures from normality (Kutner *et al.* 2004, Chapter 18), normality of the data will also be checked through histograms plotted for residuals obtained from the model. In addition, a normal probability plot of the residuals against their expected values under normality will be obtained once the data are fit to the model, and this plot provides more information to judge on the normality of the error terms. It must be mentioned here that the requirement of normality of error terms as prescribed by ANOVA models will be investigated after fitting the models and obtaining the residuals, as will be shown in chapter 10. Prior to fitting the model, the distribution of all time gaps observations will be investigated to determine whether time gaps obtained follow an approximately normal distribution.

Equivalency of the error variances can be checked by some formal tests. However, these tests are too conservative and may yield results that render error variances not equal when the differences in these variances are not substantial. Since the ANOVA I models and the associated F-tests are quite robust to non-severe departures from the equal variance assumption (Kutner *et al.* 2004), if the formal test for equal variances indicates that the error variances are not equal, additional investigations will be carried out to determine the extent of differences in error variances. Plots of fitted values vs. residuals can be used to investigate the severity of departures from the equal error variances assumption.

The independence of error terms cannot be checked in a straight forward manner as done with checking normality of error terms or constancy of error term variances. Sequence plots of time gaps vs. time provide the best means of testing for presence of correlations between successive observations. Although a large degree of independence of error terms was assured by the design of the experiment through randomization in the application of treatments, it is also important that each observation used in the analysis be as independent as possible from other observations. To investigate the presence of correlations in the data, sequence plots will be produced for several following processes with data sampled at one reading per second, one reading every 5 seconds and one reading every 10 seconds. In addition, the initial analysis will be performed on data sampled at one second, data presented at average time gap per following process and at a third sampling method as determined from the diagnostics for ANOVA part. From this, an appropriate sampling method will be chosen to use for the analysis.

9.2 Sensitivity Analysis

This part of the analysis is performed in order to determine whether some external factors have affected the data in such ways that may influence the validity of the results. At the conclusions of the sensitivity analysis, portions of the data might be removed if the analysis suggests that certain elements might have affected the homogeneity of the data. The data may also be split into portions if the analysis suggests that certain factors need to be included or controlled for. The sensitivity analysis is made up of the following parts:

1- Investigating whether there are differences between following processes where the subject was instructed to follow and following processes where the subject followed without being instructed to. If differences exist, the main analysis will only utilize data obtained from following processes where subjects were instructed to follow due to the much larger sample size and due also to the higher certainty with which these processes can be judged to constitute car-following processes.

2- Testing whether drivers' following behaviour while following the same vehicle type was affected by the lane in which the following process took place. This is aimed at determining whether data obtained from following processes taking place in the middle and fast lanes forms a homogeneous set with data obtained from following processes on the slow lane. Since all following processes taking place in the middle and fast lanes were uninstructed, this analysis would be carried out only if the first part indicates no differences between following processes where the subject was instructed to follow and those when the subject was not.

3- Exploring differences between data obtained from the left-lane of a 3-lane section of the motorway vs. data obtained from the left-lane of a 2-lane motorway section. This again is performed to ensure that the data being analyzed to determine the effects of the main factors under study is homogeneous and that no external factors distort the results. If the analysis implies that differences exist, the data will be split into two data sets, one for 2-lane sections and one for 3-lane sections. This split aims at focusing the analysis on the factors of interest in the study as well as reducing the possible interactions that may complicate the analysis.

4- Examining whether there are differences in the response variable related solely to traffic conditions. If such differences are present, traffic conditions will be included in the study as an additional independent variable in order to control for the effects of this variable.

These analyses are conducted both on individual levels, i.e. for each driver, and on an aggregated level, i.e. for the entire data set.

9.3 The Main Analysis

The main analysis focuses on the main factor under consideration in this study, namely the effects of HGVs on driver behaviour while car-following. The analysis is carried out utilizing ANOVA I models, which was the statistical tool used in most studies found in the literature that were similar to the current study. The data used for this analysis is dependent on the sensitivity analysis outcomes. In addition to investigating the effects of HGVs on driver behaviour, three other factors will also be examined in terms of their effects on driver behaviour while following. These factors are drivers' age, drivers' gender and trailing vehicle type. If interactions between these factors are found to be significant and important, analysis will focus on these interactions as well as on individual factors. If the analysis indicates that HGVs cause drivers to change their behaviour by adopting larger headways when following HGVs, the effects of HGVs on driver behaviour at sections of gradient will be investigated. This will be done to find out whether HGVs' effects are magnified on upgrade or downgrade sections.

One of the sources of the effects of HGVs on driver behaviour, that of vision obscuration, is addressed by comparing drivers' behaviour while following HGVs with their behaviour while following vans, another vehicle type which also obscures following drivers' vision.

If the effects of HGVs on driver behaviour stem exclusively from their vision obscuration, the behaviour displayed by drivers as they follow HGVs should not be different from their behaviour while following vans. However, differences in driver behaviour while following these two vehicle types would not indicate in any way that vision obscuration is not a source of the effects of HGVs on driver behaviour. Rather, that would imply that there are other sources for the effects of HGVs in addition to those of vision obscuration. Data from car-following processes is supplemented by responses from questionnaires to provide the necessary information to address this issue.

A linear model will be developed from the database to enable prediction of time gaps based on a set of variables. The set of predictor variables that is studied for possible inclusion in the model includes: speed, relative speed (relative speed at time t), relative speed in the previous second (relative speed at time t-1), vehicle type, age, gender, trailing vehicle type, traffic conditions, number of motorway lanes in the section and gradient type. In addition, some interaction terms and some higher power terms of the predictor variables may also be included. The variables included in the model will depend on the analysis conducted to investigate the presence of effects of the various factors. Appropriateness of the model will be examined through the F-test for lack of fit and through utilizing a plot of predicted values vs. residuals. Furthermore, the presence of multi-collinearities, outliers and the effects of outliers on the fit of the model will be investigated to ensure the suitability of the model. Presence of outliers will be investigated using studentized deleted residuals, while the effects of outliers will be determined by use of the Cook's distance statistic.

ANOVA tests will also be carried out on data obtained from each subject individually. This will help provide further support for the findings obtained from analyzing the aggregated data. Further, it will provide for greater understanding of whether drivers belonging to the same age/gender group display similar driver behaviour while following.

9.4 Stability Analysis

An aspect of driver behaviour that is equally as significant as measured driver behaviour is driver stability. This aspect measures how driver behaviour varies for drivers of different characteristics as well as how it varies for the same driver while following different vehicle types. Three aspects of driver stability will be investigated in this study. The first two pertain to driver stability in general, while the third relates to stability according to lead vehicle type. In the first approach, the variance of time gaps is employed as a measure to investigate the variation in driving behaviour while following, hence allowing for conclusions regarding driver stability to be drawn. Formal statistical tests will be carried out to determine whether differences between time gap variances of different groups are statistically significant. In the second approach of investigating driver stability, drivers' abilities to maintain relatively constant speeds with their leaders would be investigated. Stability would be judged based on the frequency of occurrence of large deviations in relative speeds which would be attributed to the following vehicle's driver. Finally, statistical tests will be used to compare stability for each age/gender group while following HGVs and cars. For statistical tests to be appropriate in the first and last aspects of stability analysis, the distribution of time gaps must be normal or not deviate noticeably from the normal distribution. Investigations into the normality of distributions will be carried out using the Kolmogorov-Smirnov tests and histograms of time gaps.

9.5 Risk Analysis

One of the possible sources of the effects of HGVs on driver behaviour is their hypothesized psychological influence on drivers due to their large sizes and masses. The validity of this factor as a source of HGVs' effects is tested in this part of the analysis. The analysis is made up of four parts that complement each other in a manner that increases the validity of the results.

The first part involves analyzing the verbal risk ratings obtained from subjects during the driving experiments. Before conducting the analysis, ratings that were given under similar conditions will be identified in order to limit the interference of external factors that may influence the given risk ratings. Some sensitivity tests will also be carried out to identify conditions at which risk ratings might be considered to form homogeneous groups. After preparing the data, the distribution of time gaps associated with low, medium and high risk while following cars and vans will be compared to the corresponding distributions while following HGVs. This should give an initial indication of whether drivers associate greater levels of risk while following HGVs than they do while following other vehicle types.

The second part of this analysis involves investigating the responses given in the driver behaviour questionnaires from specific questions tailored to elicit drivers' risk perceptions towards HGVs. This part is aimed at getting an understanding of drivers' general perceptions towards HGVs as sources of increased risk while driving.

The third and fourth parts of the analysis utilize measures that are synonymous with drivers' risk taking behaviour. Those measures are minimum time gap achieved during a following process and time-to-collision. The distribution of minimum time gaps reached during each following process while following HGVs will be compared with those while following cars and vans. This should yield further understanding on drivers' risk perceptions towards HGVs. Time-to-collision (TTC) distributions while following HGVs are also compared to those while following cars and vans. This is not as simple as obtaining minimum time gap distributions since time-to-collision is only defined in situations where the following vehicle is closing on the lead vehicle. In addition, in many of the closing situations, time-to-collision values are so high that no risk may be associated with the situation. Zheng and McDonald (2005) state that drivers start decelerating when the value of time-to-collision is less than 100 seconds. Thus, the distributions of TTCs when their values were below 100 seconds will be obtained to investigate drivers' risk taking behaviour while following HGVs, cars and vans.

9.6 Constancy of Time Headway

Although this was not one of the initial objectives of the current study, data collected in the experiments allowed for a commonly accepted view that time headway remains constant for the individual driver under different speeds but varies between drivers to be formally and soundly tested. This view was built on conclusions reached in many studies utilizing various methodologies as was shown in the literature review part (Kim and Lovell 2005, Taieb-Maimon and Shinar 2001, Cassidy and Windover 1998, van Winsum and Brouwer 1997, van Winsum and Heino 1996 and Heino *et al.* 1992). The large amount of data collected, the sound methodology employed and the diversity of subjects that participated in the study allowed for greater validity of results obtained here than results obtained in prior studies.

This investigation is carried out on four different levels. First, the distribution of time gaps for each following process is compared with the distribution of time gaps from each other following process carried out by the same driver while following the same vehicle type. If this shows that differences exist, then time gap distributions for each following process will be compared with the overall distribution of time gaps while following the same lead vehicle type for that driver. If this shows differences in time gaps compared, the third level of analysis will be carried out, which investigates whether the observed differences follow any specific pattern or sequence related to the order of the following processes or elapsed time from the start of the experiment. If this level proves that differences are random, the final level of the analysis will call for identifying following processes that took place under similar conditions in terms of position on the motorway, traffic conditions and trailing vehicle type. If all four levels of the analysis show differences in time gaps from one following process to another, this would indicate that time headway does not remain constant for the individual driver.

9.7 Analyzing the Questionnaire Responses

Responses from questionnaires completed by subjects that took part in the study will be analyzed for three purposes. The first pertains to eliciting information regarding the effects of HGVs on driver behaviour, the conditions where these effects are more pronounced and the possible sources of the effects of HGVs on driver behaviour. This should serve as a supplemental source of subjective information in addition to the car-following data obtained from the experiments. Another purpose of analyzing questionnaire responses is to determine whether drivers' behaviours as stated in questionnaires matches their behaviours as displayed in the driving experiments. The final purpose of analyzing questionnaire responses is to extract information that may help identify aggressive drivers. This may prove useful in providing explanations for some of the driving behaviours observed during the experiments.

Part III

Results, Discussion and Conclusions

Chapter 10

Results

After data reduction and extraction, the data obtained from conducting the experiments with 30 subjects constituted 38079 seconds of car-following data. Of those, 21165 seconds where of following processes while following HGVs, 12995 seconds while following cars and 3919 seconds while following vans. This data represents following processes that have taken place on all lanes of the motorway. Of the 38079 seconds of following data, 28657 seconds where for following processes where the subject was instructed to follow while 9422 seconds where for following processes where the subject was not instructed. As for the lane in which the following processes took place, 33820 seconds of the data were from following processes taking place on the left lane (slow lane) of the motorway and 4259 seconds were from following processes taking place either on the middle lane, the fast lane of a two-lane section or the fast lane of a three-lane section. The large database should allow for the objectives of the study to be fulfilled with significant credibility. All analyses in this study were conducted at the 95% confidence level ($\alpha = 0.05$).

The first section of this chapter will present the diagnostic tests performed to ensure appropriateness of the ANOVA modelling technique, followed by a section showing the various results of the sensitivity analyses. The third section demonstrates the results from the main analysis regarding the effects of lead vehicle type, age, gender, trailing vehicle type and gradient on drivers' following behaviour as well as presenting the linear model that is developed to enable predicting time gaps. Section four of this chapter presents the results of the stability analysis. Following that is a section demonstrating the results for risk analysis while following HGVs and cars. This is followed by a section that investigates the constancy of time gaps for the individual driver. The last section of this chapter presents some of the results obtained by analyzing responses to the driver behaviour questionnaires.

10.1 ANOVA Diagnostics

In this section, the assumptions of equal variances of error terms and the independence of observations, required for the ANOVA model to be the appropriate analysis tool, will be tested on the data obtained from the experiments. Testing for independence of observations is not as straight forward as testing for equal variances. Sequence plots will be used to decide on the best method to address possible correlations between observations. The assumption of normality of error terms, also a condition required to employ ANOVA models, will be investigated after fitting the model. This section will, however, investigate the normality of time gap observations obtained from the experiments.

10.1.1 Normality of Time Gap Observations

The formal test used to test whether the data is normally distributed is the Kolmogorov-Smirnov test, the results of which are shown in table 2. The test indicates that the data is not normally distributed. However, since this test is conservative, obtaining a histogram of the data may be more appropriate in judging on the normality of time gap observations. A semi bell-shaped histogram would suggest normality of observations. A histogram showing the distribution of time gaps is presented in figure 19. Although the histogram does not suggest a perfectly normal distribution, the departures from normality are only marginal. Hence, the distribution of time gap observations may be considered approximately normal, with departures from actual normality being very mild. The investigation of whether the error terms are normally distributed will utilize a histogram showing the distribution of the error terms, represented by residuals obtained from fitting the final model, as well as a normal probability plot of residuals against their expected values under normality. Those figures will be shown in a forthcoming section. As will be shown later, these graphs will support the appropriateness of ANOVA modelling for the data since the condition of normality of error terms is satisfied.

		Time Gap
N		38079
Normal Parameters(a,b)	Mean	1.736534
	Std. Deviation	.7412059
Most Extreme Differences	Absolute	.078
	Positive	.078
	Negative	-.070
Kolmogorov-Smirnov Z		15.303
Asymp. Sig. (2-tailed)		.000

Table 2: Results from the Kolmogorov-Smirnov test for normality

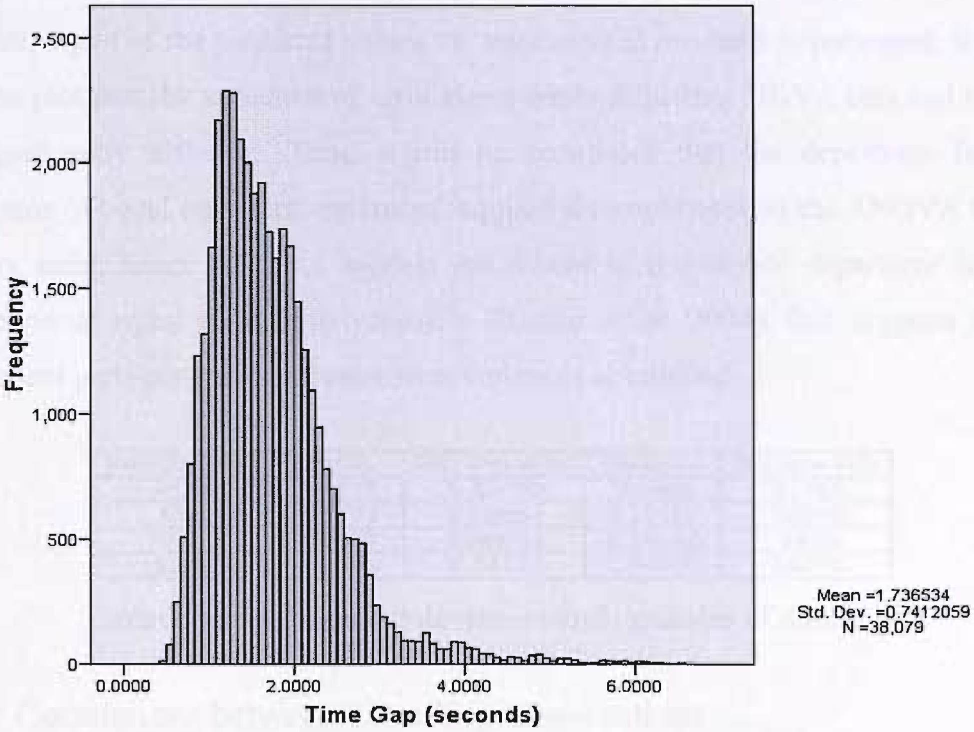

Figure 19: Histogram of all time gaps obtained in the study

10.1.2 Equivalency of Error Term Variances

For the ANOVA model to be appropriate for analyzing the data at hand, the error terms must have equal variances, or approximately equal variances. The ANOVA models and the F-tests associated with them are robust to non-severe departures from the assumption of equal variances (Kutner *et al.* 2004, Chapter 18). The formal Lavene's test, the results of which are not shown here, indicated that the variances of time gaps while following HGVs, cars and vans were not equal. To get a better view of how different these variances were, the variances were computed and plots of predicted values vs. standardized residuals were obtained when a model was fitted with only lead vehicle type as the predictor variable.

Table 3 presents the means, standard deviations, variances and sample sizes of time gaps while following HGVs, cars and vans. The table indicates that the differences in time gap variances while following HGVs, cars and vans were not very large, which implies that the departure from the assumption of equal variances of error terms is not severe. In figure 20, a plot of the predicted values vs. standardized residuals is presented. It is clear from the plot that the variances of error terms while following HGVs, cars and vans are not significantly different. Thus, it can be concluded that the departures from the assumption of equal error term variances required for implementing the ANOVA analysis are very mild. Since ANOVA models are robust to non-severe departures from the assumption of equal error term variances (Kutner *et al.* 2004), this suggests that the requirement pertaining to equal error term variances is satisfied.

Vehicle Type	Mean	Std. Deviation	Variance	Sample size
HGV	1.8519	0.80405	0.6465	21165
Car	1.5703	0.60954	0.37154	12995
Van	1.6647	0.66804	0.44628	3919
Total	1.7365	0.74121	0.54939	38079

Table 3: Means, standard deviations and variances of time gaps

10.1.3 Correlations between Time Gap Observations

Addressing the independence of time gap observations is more difficult than addressing the other two requirements of ANOVA models. Although randomization was utilized in applying the treatments (lead vehicle type in this study), it is also important that each time gap observation be as independent of the following observation as possible. To investigate the effects of correlations on the data, sequence plots of time vs. time gap were generated for following processes. These sequence plots were generated with data presented at one reading per second, one reading every 5 seconds and one reading every

10 seconds. Examples of such plots for a following process are presented in figures 21 to 23 for one reading per second, one reading every 5 seconds and one reading every 10 seconds, respectively. When the data was sampled at one second, the correlations between each observation and the one preceding it and/or the one succeeding it was high.

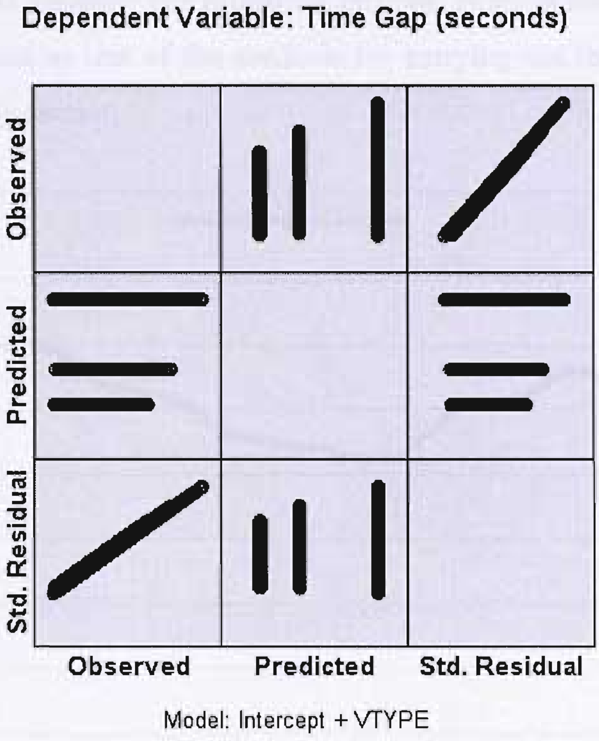

Figure 20: Residual Plot showing variation according to vehicle type

However, figure 23 shows that this dependence of each time gap on the one preceding it is severely reduced when data is presented at one reading every 10 seconds. Thus, it is clear from the figures that sampling the data at one reading every 10 seconds significantly reduces any correlations that might be present in the data which eliminates the risk of falsely inflating sample sizes which could in turn lead to inaccurate conclusions. As a result, conclusions inferred through analysis carried out on data sampled at 10 seconds have greater credibility.

It is also important to note that another alternative which would also reduce correlations significantly is to carry out the analysis on data presented at one reading per following process. Several difficulties are associated with this method, though. First, it is difficult to establish a suitable measure that can be used to represent a following process. Second, if a single measure is used to represent a following process (i.e. average time gap), much of the information contained within a following process would not be conveyed. Third, the conditions during most following processes did not remain unchanged, making it more difficult to use a single measure per following process. Nonetheless, the initial analysis will explore this method as one of the methods for carrying out the analysis as will be shown in a forthcoming section.

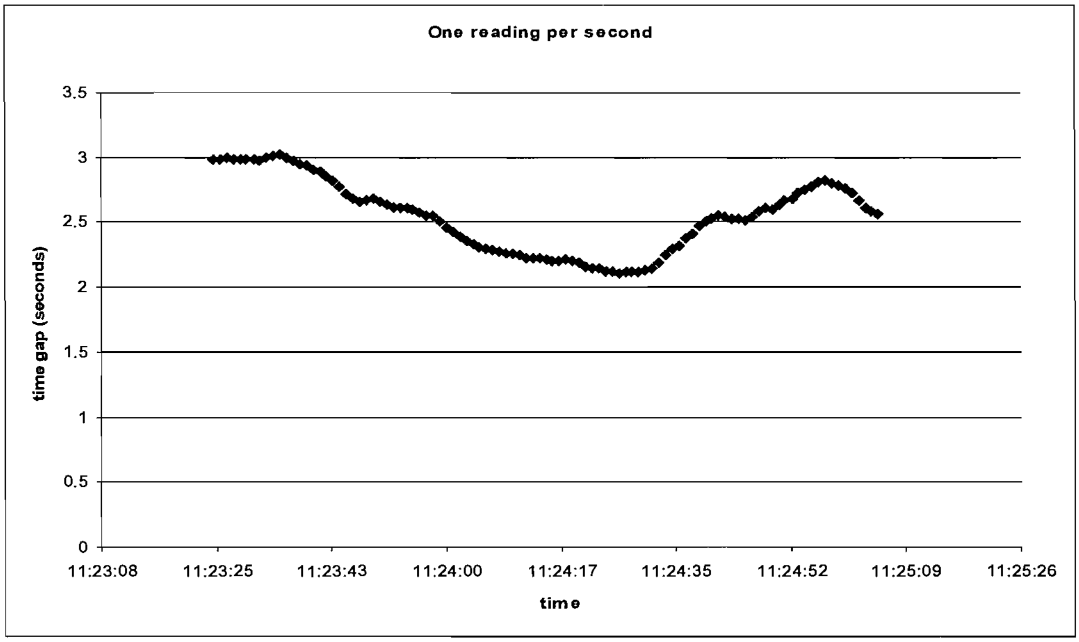

Figure 21: Time gap data presented at 1-reading per second

The preliminary analysis will be carried out on data reduced to one reading every 10 seconds. The main analysis will be carried out initially on data sampled at one reading per second as well as data reduced to one reading every 10 seconds. In addition, the initial main analysis will also be carried out on data presented as average time gap per following process as mentioned above in order to investigate the effects correlations may have on the analysis. From these three initial analyses, the appropriate method for presenting the data will be determined which will be used for the subsequent relevant analysis.

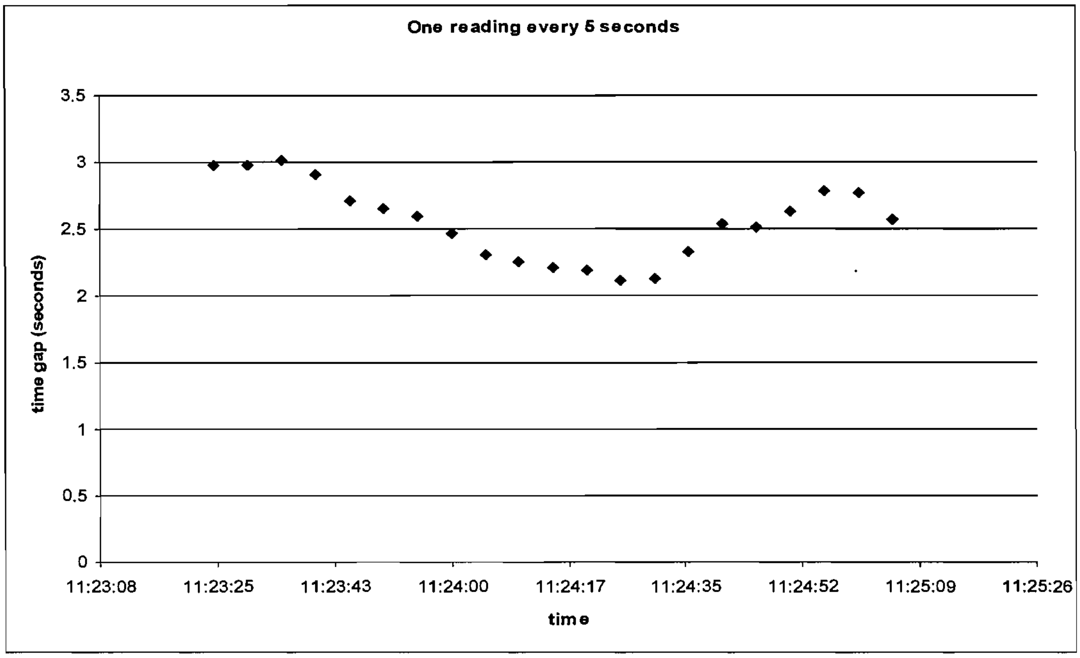

Figure 22: Time gap data presented at 1-reading every 5 second

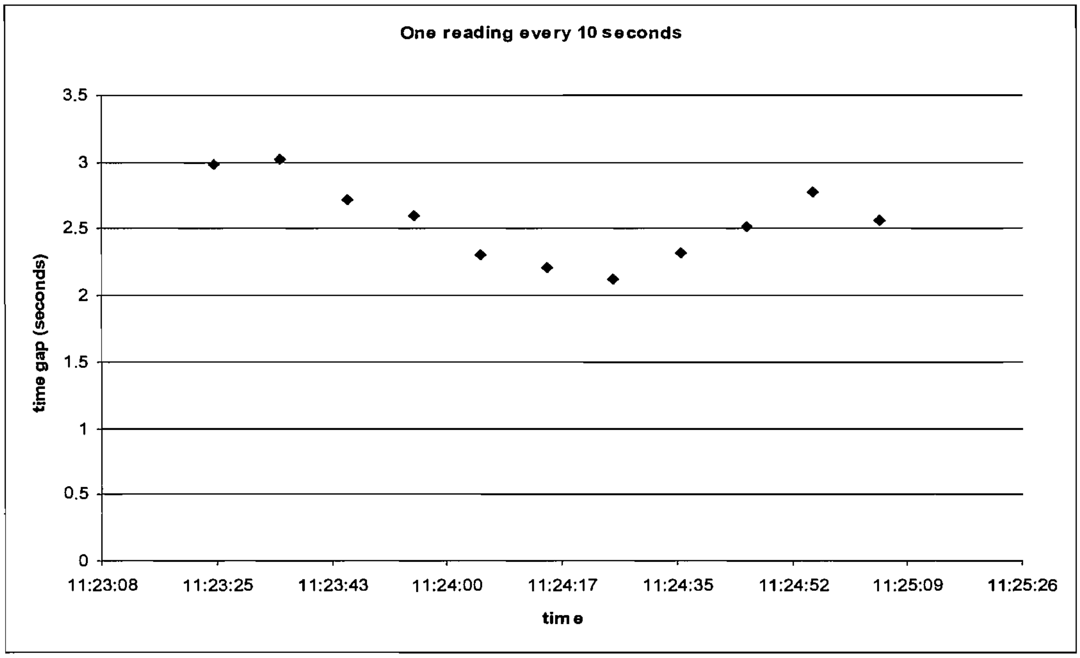

Figure 23: Time gap data presented at 1-reading every 10 second

10.2 Preliminary Analysis

10.2.1 “Instructed” vs. “Not Instructed” Analysis

The analysis to determine whether there were differences between following processes where the subject was instructed vs. following processes where the subject was not instructed was carried out on four smaller data sets to reduce the effects of external factors. The data sets corresponded to data for following cars on two-lane sections, following cars on three-lane sections, following HGVs on two-lane sections and following HGVs on three-lane sections. All these tests were carried out on data reduced to yield one reading every 10 seconds. For three of the four data sets, the tests suggested that there is a difference between following processes where the subject was instructed and following processes where the subject was not. In only one of the four tests (following cars on two-lane sections) were differences in time gaps not statistically significant. The estimated marginal means and the associated p-values are shown in tables 4-7. Interestingly, the mean time gap for “not instructed” following processes was smaller than that for “instructed” following processes while following cars. The opposite was found while following HGVs, where “not instructed” following processes had larger mean time gaps than “instructed” following processes. This observation is utilized in explaining the differences between time gaps between “instructed” and “not instructed” following processes. Thus, removing “not instructed” following processes will increase the validity of the results regarding the effects of HGVs on driver behaviour since an external factor that may have inflated the effects of HGVs was removed. In other words, removing following processes where the driver was not instructed makes the tests whether HGVs affect driver behaviour while following more conservative. Another interesting finding from this analysis which further supports exclusion of data obtained from “not instructed” following processes is the consistently larger standard error of the mean for “not instructed” following processes as compared to standard error of the mean for “instructed” following processes.

INST	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
instructed	1.646	.038	1.571	1.721
not instructed	1.607	.055	1.498	1.715

Table 4: Estimated marginal means for "instructed" vs. "not instructed" following processes for cars on two-lane sections (p-value = 0.558)

INST	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
instructed	1.683	.030	1.624	1.742
not instructed	1.539	.049	1.442	1.635

Table 5: Estimated marginal means for "instructed" vs. "not instructed" following processes for cars on three-lane sections (p-value = 0.013)

INST	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
instructed	1.890	.029	1.833	1.947
not instructed	2.131	.079	1.977	2.285

Table 6: Estimated marginal means for "instructed" vs. "not instructed" following processes for HGVs on two-lane sections (p-value = 0.004)

INST	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
instructed	1.851	.023	1.805	1.897
not instructed	2.155	.079	2.001	2.310

Table 7: Estimated marginal means for "instructed" vs. "not instructed" following processes for HGVs on three-lane sections (p-value = 0.000)

This sensitivity analysis was also carried out on individual bases, conducted on data obtained for every subject individually. Since not all subjects had valid following processes where they were not instructed to follow, individual data for this part was available for 15 of the 30 subjects. For 13 subjects, there were differences between "instructed" following processes and "not instructed" following processes. These results are not shown here.

In order to understand the reasons giving rise to these differences in time gaps between "instructed" and "not instructed" following processes, the nature of each must be investigated. For instructed following processes, it can be judged with high certainty that the driver was involved in a car-following process without attempting to change lanes and with the high likelihood that the speed he/she was driving at was less than his/her desired speed. In other words, the driver in these following processes was mainly focused on one major task, that of following the lead vehicle. Furthermore, the fact that the operating speed was less than the driver's desired speed means that the process satisfies the main characteristic of car-following processes. It must be noted that the driver during these following processes also had to be aware of vehicle cutting-in or merging at entrance points. "Not instructed" following processes occurred for one of two reasons, either due to the natural driving style of the driver or due to prevailing traffic conditions. If the following process took place due to the natural driving style of the driver, this would imply that his/her speed was not impeded by that of the lead vehicle, and that may result in disqualifying the process from car-following since a key characteristic of car-following is that the following driver operates his/her vehicle at a speed lower than the desired speed due to hindrance from the lead vehicle. Thus, although in this case the vehicles shared the same lane with relatively small time gaps between them that would imply interactions between the two vehicles, the fact that the following driver continued to follow even when conditions allowed for overtaking raises some questions as to the validity of these processes to be considered a car-following processes.

As for the second and more frequently observed reason causing drivers to be involved in "not instructed" following processes, prevailing traffic conditions, it is highly likely that the driver was searching for the proper gap to overtake the slower lead vehicle, and that such gap did not exist for some time due to moderately high to high flow levels. This may explain the lower time gaps while following cars and the larger time gaps while following HGVs in "not instructed" following processes, as was mentioned earlier. While trailing an HGV and looking for an appropriate gap to change lanes into, one would assume that the following driver would pull back to get a better view of the road ahead before changing lanes and also to allow his/her vehicle space to accelerate before changing lanes since HGVs are generally driven at considerably lower speeds than cars. However, while following cars, such need may not arise since cars are driven at higher speeds than HGVs and since they do not obscure the driver from obtaining a view of the road ahead. Thus, in such cases, the following vehicle would most likely be operating at speeds that would not require significant accelerations once an appropriate gap is found in an adjacent lane, which would explain the smaller time gaps in "not instructed" following processes of cars.

Hence, since there is more confidence that during instructed following processes the driver was focused mainly on the task of following without the provision of changing lanes, and since there is a greater likelihood that the speed of the following vehicle was impeded by that of the lead vehicle, data obtained from instructed following processes may be considered more appropriate for carrying out the various subsequent analyses regarding car-following. Although this is especially valid since the main aim in this study is conducting comparative analysis, the values of time gaps obtained may yet be valid for applications such as car-following algorithms. However, due to this uncertainty regarding the reality of time gaps obtained, it is highly recommended that time gap data obtained from this study is treated with caution as that data may not be completely representative of actual driver behaviour. It is highly recommended that similar studies are conducted where the experiments are designed to ensure the occurrence of car-following processes naturally, without drivers being given any instructions to follow. Such study would help verify the suitability of the numbers obtained in this experiment as well as validating the methodology employed.

Since data obtained from "not instructed" following processes is eliminated from the analysis, no sensitivity tests will be carried out to investigate differences between following processes taking place in the middle and fast lanes and following processes taking place in the slow lane. This is due to the fact that all following processes that took place in the middle and fast lanes were carried out by the subjects without being instructed to do so, and thus were removed from the analysis. The analysis from this point forward will focus on data obtained from following processes executed on the slow lane of the motorway.

10.2.2 Three-Lane Sections vs. Two-Lane Sections Analysis

This analysis is carried out to reduce external factors that may undermine the reliability of the results regarding the effects of HGVs on driver behaviour. Following processes taking place on the slow lane of a two-lane section were compared with following processes taking place on three-lane sections of the motorway for both cars and HGVs. The results of the analysis concerning estimated marginal means, standard errors and confidence intervals are shown in tables 8 and 9 for HGVs and cars, respectively. The results indicate that time gaps obtained on three-lane sections were not different from those recorded on two-lane sections for both HGVs and cars. The p-value while following cars was 0.463 and that while following HGVs was 0.308. Thus, it can be concluded that data obtained on two-lane sections formed a homogeneous group with data obtained on three-lane sections.

Motorway lane	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
3-lane section	1.851	.024	1.805	1.897
2-lane section	1.890	.030	1.830	1.949

Table 8: Estimated marginal means while following HGVs on two-lane vs. three-lane sections of the motorway (p-value = 0.308)

Motorway lane	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
3-lane section	1.683	.033	1.619	1.747
2-lane section	1.646	.039	1.570	1.722

Table 9: Estimated marginal means while following cars on two-lane vs. three-lane sections of the motorway (p-value = 0.463)

10.2.3 Traffic Conditions Analysis

Traffic conditions were obtained subjectively based on the videos recorded during the experiments. The subjective classification of traffic conditions resulted in significant differences in time gaps while following cars (p-value = 0.000). However, these differences in time gaps according to traffic conditions were not significant while following HGVs (p-value = 0.360). These results are shown in tables 10-11. In addition, the sensitivity analysis for traffic conditions was carried out on individual bases. While following HGVs, differences in time gaps according to traffic conditions were significant for 23 subjects and not significant for only 4 subjects. While following cars, those differences were significant for 14 subjects and not significant for 6 subjects. Traffic conditions will thus be included in the models, but only to serve for control purposes and no inferences regarding the effects of traffic conditions on driver behaviour will be made in this study as this requires accurate calculation of traffic flow.

Traffic Conditions	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
light	1.397	.045	1.309	1.484
moderate	1.789	.032	1.727	1.851
heavy	1.782	.069	1.646	1.918

Table 10: Estimated marginal means while following cars according to traffic conditions (p-value = 0.000)

Traffic Conditions	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
light	1.843	.040	1.765	1.921
moderate	1.885	.023	1.840	1.930
heavy	1.805	.060	1.687	1.924

Table 11: Estimated marginal means while following HGVs on according to traffic conditions (p-value = 0.360)

10.3 The Main Analysis

An ANOVA I model was used to analyze the data with 5 independent variables. The independent variables were lead vehicle type (HGV, car and van), driver age (young, middle aged and old), driver gender (male and female), trailing vehicle type, shown in the tables as following vehicle type (HGV, car, van, small truck or none) and traffic conditions (light, moderate and heavy). In order to determine the best format of presenting the data for analysis, initial analysis was performed on data sampled at 1-second, 10-second and for data representing average time gaps for each following process. It must be noted that the last format of the data was presented as the average time gap per following process if all the conditions (i.e. traffic, following vehicle, gradient, etc.) remained unchanged. For following processes where conditions changed during the process, each set of similar conditions was represented with the average time gap for the duration of these conditions, and the period of similar conditions will be termed following event hereafter. The output from the analysis on the data sampled at one second is presented in table 12, the output from one reading every 10 seconds is presented in table 13 and the output from the average time gap for each following event is presented in table 14.

The analysis performed on the data sampled at 1-second resulted in all independent variables having significant effects on time gaps, with all p-values equalling 0.000. Every traffic category was significantly different from any other category. The same trend also existed for driver age and lead vehicle type. There were also significant differences between many of the categories in the "following vehicle type" factor, resulting in this factor being considered significant. The ANOVA table from this analysis is presented in table 12.

The same analysis was carried out on data sampled at one reading every 10 seconds. The ANOVA output from this analysis is shown in table 13. Since reducing the data resulted in reducing the sample size of time gaps where the instrumented vehicle was followed by a small truck (a vehicle type described in chapter 8), these time gaps were removed. The sample size for being followed by small truck after reducing the data was 23 time gaps, much smaller than any other category of trailing vehicle type. It can be seen from the table that the analysis indicates that traffic conditions, driver gender, driver age and lead vehicle type had significant effects on time gaps while following. Following vehicle type,

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2765.298(a)	11	251.391	489.682	.000
Intercept	10189.425	1	10189.425	19847.890	.000
TrafCon	15.038	2	7.519	14.646	.000
Gender	584.353	1	584.353	1138.257	.000
age	1782.467	2	891.234	1736.026	.000
VType	122.033	2	61.016	118.853	.000
FollVeh	30.897	4	7.724	15.046	.000
Error	14087.544	27441	.513		
Total	105118.830	27453			
Corrected Total	16852.842	27452			

Table 12: ANOVA output from analysis conducted on data sample at 1-second

on the other hand, did not have significant effects on time gaps. In addition, further investigation which will be shown later demonstrate that time gaps for young and middle aged drivers were similar, and so were time gaps while following cars and vans. It must be noted that when this analysis was carried out including time gaps while followed by small truck, the factor "following vehicle type" was also not significant, the p-value for that factor being 0.069 as opposed to the value of 0.352 obtained here.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	327.046(a)	10	32.705	62.926	.000
Intercept	2737.125	1	2737.125	5266.457	.000
TRAF	6.019	2	3.010	5.791	.003
Gender	68.975	1	68.975	132.714	.000
AGE	205.182	2	102.591	197.394	.000
VTYPE	15.371	2	7.686	14.788	.000
FOLVEH	1.701	3	.567	1.091	.352
Error	1549.309	2981	.520		
Total	11638.928	2992			
Corrected Total	1876.355	2991			

Table 13: ANOVA output from analysis conducted on data sample at 10-second

The third analysis was carried out on average time gaps per following event. This analysis, the output for which is shown in table 14, yielded similar results to those obtained from data sampled at one reading every 10 seconds, with the difference being that traffic conditions were not significant in this analysis which was not the case with the one reading every 10-second analysis. The similarities between time gaps for young and middle aged drivers and for following cars and vans were also supported from this analysis. In addition, not shown in tables 12-14 were the results concerning motorway section type, where the one-second analysis indicated this factor to significantly affect time gaps, a finding not supported by any of the other two sampling methods.

It can thus be concluded that carrying out the analysis at one reading per second is not appropriate since correlations severely affect the data, resulting in artificially inflating the sample sizes, with the subsequent result being that the results obtained not being reflective the true effects of the various factors. Although data sampled at 10 seconds and data of average time gaps per following event yielded results that were not too dissimilar in the initial analysis, the data sampled at every 10 seconds may be deemed more appropriate since it allocates equal weights for all observations. With the data presented as average time gaps per following event, the weights were not equal since following processes of unchanged conditions lasting for a significant period of time were treated similarly to following events of similar conditions lasting for about 10 seconds or less. Since the discussion in the previous section showed that correlations were significantly reduced by adopting the 10-second sampling method, which was supported by the initial analysis here, the one reading per 10-seconds will be the sampling method adopted for the rest of the analysis.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	99.339(a)	11	9.031	19.152	.000
Intercept	394.001	1	394.001	835.561	.000
TRAF	.457	2	.229	.485	.616
Gender	24.723	1	24.723	52.429	.000
AGE	59.645	2	29.822	63.244	.000
VTYPE	3.409	2	1.704	3.614	.027
FOLVEH	1.007	4	.252	.534	.711
Error	383.834	814	.472		
Total	3203.146	826			
Corrected Total	483.173	825			

Table 14: ANOVA output from analysis conducted on data of average time gaps

The resulting sample sizes obtained from the 10-second sampling rate are shown in table 15. As was mentioned earlier, this analysis resulted in traffic, gender, age and lead vehicle type having significant effects on time gaps, while following vehicle type was not found to have significant effects on time gaps.

		Value Label	N
Traffic Conditions	1	Light	765
	2	moderate	1928
	3	heavy	299
Driver gender	1	Male	1741
	2	female	1251
Driver age	1	young	1154
	2	middle age	1186
	3	Old	652
Lead vehicle type	1	HGV	1939
	2	Car	741
	3	Van	312
Following Vehicle Type	1	HGV	398
	2	Car	458
	3	Van	137
	5	None	1999

Table 15: Sample sizes for the different factors investigated

10.3.1 The Effects of Lead Vehicle Type on Drivers' Time Gaps

Table 16 shows the Tukey Multiple comparisons results for lead vehicle type. The table demonstrates that there is no difference in time gaps between following cars and vans (p-value = 0.341). Time gaps while following HGVs were significantly larger than time gaps while following cars (p-value = 0.000) and vans (p-value = 0.011). The average time gaps while following HGVs, cars and vans were 1.921 s, 1.750 s and 1.860 s respectively. These results are illustrated in figure 24.

Vehicle Type 1	Vehicle Type 2	Mean Difference	Standard Error	Signif.	95% Confidence Level	
					Lower Bound	Upper Bound
HGV	car	0.195	0.031	0.000	0.122	0.268
	van	0.127	0.044	0.011	0.024	0.230
car	HGV	-0.195	0.031	0.000	-0.268	-0.122
	van	-0.068	0.049	0.341	-0.182	0.046
van	HGV	-0.127	0.044	0.011	-0.230	-0.024
	car	0.068	0.049	0.341	-0.046	0.182

Table 16: Tukey multiple comparisons output for lead vehicle type

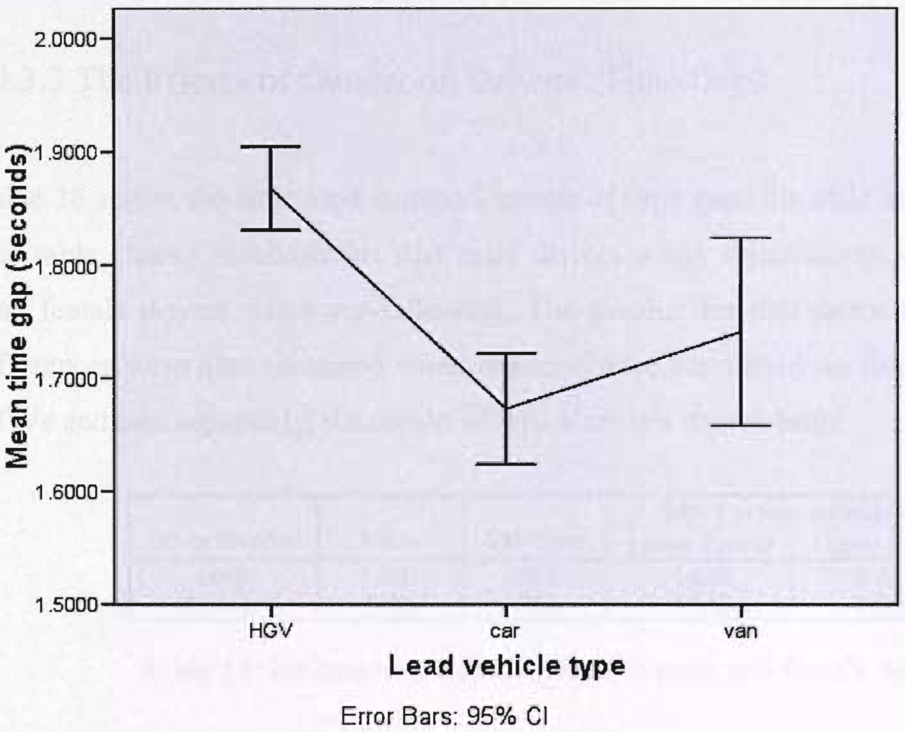

Figure 24: Mean time gaps according to lead vehicle type

10.3.2 The Effects of Age on Drivers' Time Gaps

Table 17 presents the Tukey multiple comparisons results for driver's age. It is clear from the table that old drivers followed at larger time gaps than young or middle aged drivers (p-value = 0.000). However, the table shows no significant differences in time gaps between young and middle aged drivers (p-value = 0.252). This trend was also observed when the analysis was carried out on data while following HGVs and cars separately, the results of which are not shown here. The overall average time gaps maintained by young, middle aged and old drivers were 1.660, 1.603 and 2.267, respectively.

Age Group 1	Age Group 2	Mean Difference	Standard Error	Signif.	95% Confidence Level	
					Lower Bound	Upper Bound
Young	Mid age	0.047	0.030	0.252	-0.023	0.117
	old	-0.642	0.035	0.000	-0.725	-0.559
Middle Aged	young	-0.047	0.030	0.252	-0.117	0.023
	old	-0.689	0.035	0.000	-0.771	-0.607
Old	young	0.642	0.035	0.000	0.559	0.725
	Mid age	0.689	0.035	0.000	0.607	0.771

Table 17: Tukey multiple comparisons output for age

10.3.3 The Effects of Gender on Drivers' Time Gaps

Table 18 shows the estimated marginal means of time gaps for male and female drivers. The table clearly demonstrates that male drivers adopt significantly smaller time gaps than female drivers while car-following. The p-value for this factor was 0.000. These differences were also sustained when analyses were conducted on data while following HGVs and cars separately, the results of which are not shown here.

Driver Gender	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
male	1.687	.028	1.632	1.742
female	2.000	.030	1.942	2.058

Table 18: Estimated marginal means of male and female drivers

10.3.4 The Effects of Trailing Vehicle Type on Drivers' Time Gaps

Of the five different categories used for trailing vehicle type (HGVs, cars, vans, small trucks and no following vehicles), the sample size for being followed by small truck was very small, thus time gaps of being followed by small truck were eliminated as mentioned earlier. The analysis showed that trailing vehicle type have no significant effects on time gaps while following (p-value = 0.352). Table 19 shows the Tukey multiple comparisons output for trailing vehicle type. The table clearly shows that none of the categories was significantly different from any of the other categories.

Following Vehicle Type	Following Vehicle Type	Mean Difference	Standard Error	Significance	95% Conf. Interval	
					lower bound	upper bound
HGV	car	0.041	0.049	0.843	-0.086	0.168
	van	0.079	0.071	0.684	-0.104	0.263
	none	0.026	0.04	0.911	-0.076	0.128
car	HGV	-0.041	0.049	0.843	-0.168	0.086
	van	0.039	0.07	0.947	-0.142	0.219
	none	-0.015	0.037	0.98	-0.111	0.081
van	HGV	-0.079	0.071	0.684	-0.263	0.104
	car	-0.039	0.07	0.947	-0.219	0.142
	none	-0.053	0.064	0.839	-0.217	0.111
none	HGV	-0.026	0.04	0.911	-0.128	0.076
	car	0.015	0.037	0.98	-0.081	0.111
	van	0.053	0.064	0.839	-0.111	0.217

Table 19: Tukey multiple comparisons output for trailing vehicle type

10.3.5 Gradient's Effects on Driver Behaviour while Following HGVs

For this analysis, data while following HGVs only was obtained, sampled at one reading every 10 seconds. Gradient was divided into three categories; upgrade, flat and downgrade. The sample sizes for the various gradient types are shown in table 20. The ANOVA output from the analysis carried out with gradient as the predictor variable is presented in table 21. The table shows that gradient had significant effects on time gaps while following HGVs (p-value = 0.043). Table 22 presents the Tukey multiple comparisons results for gradient. The table shows that time gaps while following HGVs on upgrade sections were greater than those while following on flat sections (p-value = 0.035). However, time gaps while following HGVs on upgrade and downgrade sections were not significantly different (p-value = 0.173) and neither were time gaps while following HGVs on flat and downgrade sections (p-value = 1.000).

		Value Label	N
Gradient Type	1	upgrade	282
	2	flat	1432
	3	downgrade	225

Table 20: Sample sizes for gradient analysis

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.339(a)	2	2.170	3.151	.043
Intercept	3713.939	1	3713.939	5393.563	.000
GRAD	4.339	2	2.170	3.151	.043
Error	1333.105	1936	.689		
Total	8102.995	1939			
Corrected Total	1337.444	1938			

Table 21: ANOVA output for gradient analysis

Grad Type 1	Grad Type 2	Mean Difference	Standard Error	Signif.	95% Confidence Level	
					Lower Bound	Upper Bound
up	flat	0.134	0.054	0.035	0.008	0.261
	down	0.133	0.074	0.173	-0.041	0.307
flat	up	-0.134	0.054	0.035	-0.261	-0.008
	down	-0.002	0.060	1.000	-0.141	0.138
down	up	-0.133	0.074	0.173	-0.307	0.041
	flat	0.002	0.060	1.000	-0.138	0.141

Table 22: Tukey multiple comparisons results for gradient

A better understanding of the effects of gradient can be achieved by investigating the interaction of gradient with Traffic conditions, gender and age. This will be presented in a subsequent section.

10.3.6 Building the Linear Model

After determining the main factors affecting time gaps while car-following as observed in the current study, an attempt is made to develop a linear model that would enable predicting time gaps given a set of easily measured factors. The model building approach was based on the stepwise procedure commonly employed to decide on variables to include in models, starting with entering simple forms of variables into the model to determine the variables that would account for significant portions of the variation in time gaps. Variables were included if they were significant and if they had noticeable contribution in reducing the variation in time gaps. The list of prospective variables to be used in the model included age, gender, vehicle type, traffic, gradient, speed, relative speed and previous relative speed. The term previous relative speed refers to the relative speed between the lead and following vehicle one second prior to the time of recording the time gap. Thus, if time gap was recorded at time t where t is measured in seconds, relative speed would also be recorded at time t while previous relative speed would be recorded at time t-1.

Driver age was the first variable entered into the model based on a higher value of adjusted R-squared obtained for this variable than any other variable. Using the same criterion (adjusted R-squared), gender was entered next followed by lead vehicle type. Traffic conditions and gradient type were also found to be significant and important as independent variables. Relative speed along with relative speed in the previous second (previous relative speed) were two quantitative variables that were found to significantly reduce the variation in time gaps. Speed was found to have very little effect in reducing the variation in time gaps and hence was not included in the model.

In the next step, several interactions were entered into the model, starting with two factor interactions. After determining the main two-factor interactions that accounted for significant portions of variations in time gaps, various three-factor interactions were explored to determine the feasibility of their inclusion in the model. This was followed with investigating several four-factor and five-factor interactions. Many lower level interactions that were found to be important in earlier steps were rendered unimportant later when higher level interactions were explored since the information portrayed by the lower level interactions were included in the higher level ones. In exploring the various interactions for inclusion in the model, the aim was to attain a model with a high value of adjusted R-squared while at the same time obtaining a model that is simple to use. Thus, interactions that do not significantly contribute to reducing the variation in time gaps or do not portray unique information unaccounted for by other interactions were omitted. In addition to exploring the various interactions, higher power terms of the quantitative variables included in the model were also investigated. The model building procedure exhausted all possible interactions as well as second and third power terms of the quantitative variables. This procedure of exploring variables, their interactions and higher power terms for inclusion in the model resulted in a model that included age, gender, lead vehicle type, traffic conditions, gradient, relative speed and previous relative speed in addition to 2 interactions; Traffic X Gender X Age X Vehicle type X Gradient and Relative speed X Previous relative speed X Vehicle type. The lack of fit test carried out on the model resulted in a p-value of 0.216, indicating that a linear model is appropriate for the data. The results of this test are presented in table 23. The random trend observed in the plot of predicted values vs. residuals, shown in figure 25, further emphasizes the appropriateness of a linear model for the data set. The R-Squared value for this model was 0.348. The form of this model is presented in table 24 while the ANOVA output from the model is presented in table 25. In the model, RS denotes relative speed measured in kilometres per hour while PRS denotes relative speed in the previous second (previous relative speed), also measured in kilometres per hour.

Source	sum of squares	df	mean square	F	Sig
Lack of Fit	1201.561	2846	0.422	1.175	0.216
Pure Error	21.197	59	0.359		

Table 23: Output from the lack of fit test

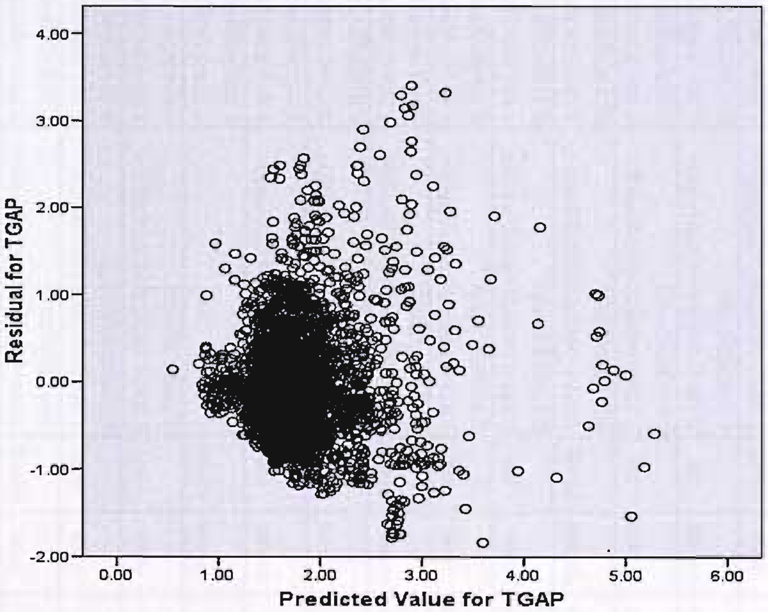

Figure 25: Plot of predicted values vs. residuals

Traffic	Gender	Age	HGV			Car	Van
			Up	Flat	Down		
Light	male	young	1.045-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.52-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.069-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	0.938-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	1.751-0.042(RS)+0.072(PRS)+0.007(RS)(PRS)
Light	male	mid	1.464-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.411-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.391-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.303-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	1.192-0.042(RS)+0.072(PRS)+0.007(RS)(PRS)
Light	male	old	2.020-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.83-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.117-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	2.202-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	1.831-0.042(RS)+0.072(PRS)+0.007(RS)(PRS)
Light	female	young		1.746-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.584-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.675-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	1.946-0.042(RS)+0.072(PRS)+0.007(RS)(PRS)
Light	female	mid	1.827-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.512-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.861-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.488-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	1.879-0.042(RS)+0.072(PRS)+0.007(RS)(PRS)
Light	female	old	4.689-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	2.714-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)		1.761-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	2.969-0.042(RS)+0.072(PRS)+0.007(RS)(PRS)
Moderate	male	young	1.348-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.774-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.425-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.562-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	1.615-0.042(RS)+0.072(PRS)+0.007(RS)(PRS)
Moderate	male	mid	1.571-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.511-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.723-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.554-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	1.351-0.042(RS)+0.072(PRS)+0.007(RS)(PRS)
Moderate	male	old	2.237-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.871-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.694-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	2.023-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	1.781-0.042(RS)+0.072(PRS)+0.007(RS)(PRS)
Moderate	female	young	1.562-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.625-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.843-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.387-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	1.519-0.042(RS)+0.072(PRS)+0.007(RS)(PRS)
Moderate	female	mid	2.255-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.592-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.867-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.713-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	1.778-0.042(RS)+0.072(PRS)+0.007(RS)(PRS)
Moderate	female	old	3.120-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	2.396-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	2.810-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	2.326-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	2.955-0.042(RS)+0.072(PRS)+0.007(RS)(PRS)
Heavy	male	young	1.936-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.819-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.891-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.883-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	1.556-0.042(RS)+0.072(PRS)+0.007(RS)(PRS)
Heavy	male	mid	1.439-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.364-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)		1.123-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	1.012-0.042(RS)+0.072(PRS)+0.007(RS)(PRS)
Heavy	male	old	1.673-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.891-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.683-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.986-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	
Heavy	female	young	1.538-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.764-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.724-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.832-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	
Heavy	female	mid	1.649-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	2.024-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.535-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.311-0.042(RS)+0.072(PRS)+0.009(RS)(PRS)	
Heavy	female	old	1.619-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.598-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)	1.575-0.042(RS)+0.072(PRS)+0.018(RS)(PRS)		

Table 24: Final form of the model

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	653.597(a)	86	7.600	18.056	.000
Intercept	2010.290	1	2010.290	4776.000	.000
VTYPE	1.992	1	1.992	4.733	.030
AGE	52.786	2	26.393	62.704	.000
Gender	29.215	1	29.215	69.408	.000
TRAF	3.809	2	1.904	4.525	.011
Grad	3.541	2	1.771	4.207	.015
PRRELSP	12.618	1	12.618	29.978	.000
VTYPE * AGE * Gender * TRAF * Grad	208.004	72	2.889	6.863	.000
RELSP	3.943	1	3.943	9.368	.002
VTYPE * RELSP * PRRELSP	88.887	3	29.629	70.392	.000
Error	1222.758	2905	.421		
Total	11638.928	2992			
Corrected Total	1876.355	2991			

a R Squared = .348 (Adjusted R Squared = .329)

Table 25: ANOVA output from the model

No parameters were provided by the model for 8 categories, 6 of which were in heavy traffic conditions, conditions that were not encountered frequently during the experiments. Although the R-Squared value for the model is relatively low, implying that the majority of the variation in the response variable is not accounted for, this can be explained by the fact that variation in time gaps existed on four levels. Variation in time gaps was observed during each individual following process, from one following process to another for the same driver (as will be shown later), between drivers of the same age/gender group (as will also be shown shortly) and from one age/gender group to another. Thus, it is doubtful that any modelling technique would account for a much higher percentage of variation in time gaps.

Multi-collinearities between the various quantitative predictor variables were investigated, as shown in table 26, with the result that only two variables were highly collinear. Those were relative speed and previous relative speed, which had a correlation of 0.945. However, removing either of these two variables resulted in noticeable decline in the R-Squared value by about 0.05, indicating that accounting for the variation in the response variable would be reduced by about 5%. Thus, both of these variables were retained in the model.

		Relative Speed	Previous relative speed	VT1RSPRS	VT2RSPRS
Relative Speed	Pearson Correlation	1	.945	-.069	-.037
Previous relative speed	Pearson Correlation	.945	1	-.103	-.043
VT1RSPRS	Pearson Correlation	-.069	-.103	1	-.125
VT2RSPRS	Pearson Correlation	-.037	-.043	-.125	1

Table 26: Correlations between the quantitative variables in the model

Studentized deleted residuals were obtained to identify outlying cases. A critical value for the studentized deleted residual was estimated to be 3.45. Hence, any case with a studentized deleted residual exceeding 3.45 would provisionally be tagged as a possible outlying case. In total, 25 cases were identified as possible outlying cases based on this criterion. Cook's distance measure was used to investigate the influences of these outlying cases on the fitting of the model. Table 27 provides descriptive statistics of the Cook's distance measure. The table shows that the maximum value for Cook's distance was 0.01. This indicates that the outlying cases had little effect if any on the fitting of the model, which was expected since the number of outlying cases was small compared to the sample size. Hence, based on the lack of fit test, the plot of predicted values vs. residuals, the minor multi-collinearities observed and the lack of effects of outlying cases, the model can be deemed appropriate for the time gap data obtained.

	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Cook's Distance for TGAP	2991	.00	.01	.0003	.00091	.000
Valid N (listwise)	2991					

Table 27: Descriptive statistics of Cook's distance

Having developed the model to be used for time gap predictions, the normality of error terms can now be investigated to justify the use of the ANOVA technique to develop the linear model. Although the formal Kolmogorov-Smirnov test (the results of which are shown in table 28) indicated that the error terms are not normally distributed, the histogram of the error terms, shown in figure 26, and the normal probability plot of residuals against their expected values under normality, shown in figure 27, strongly support normality of error terms. Since ANOVA models are robust to non-severe departures from normality (Kutner *et al.* 2004, chapter 18), and since the histogram as well as the normal probability plot suggest that departures from normality were very mild, it can be inferred that the condition of normality of error terms is satisfied. This confirms the appropriateness of the ANOVA modelling technique for the analysis.

		Residual for TGAP
N		2992
Normal Parameters	Mean	.0000
	Std. Deviation	.63938
Most Extreme Differences	Absolute	.075
	Positive	.075
	Negative	-.042
Kolmogorov-Smirnov Z		4.108
Asymp. Sig. (2-tailed)		.000

Table 28: Normality test for residuals

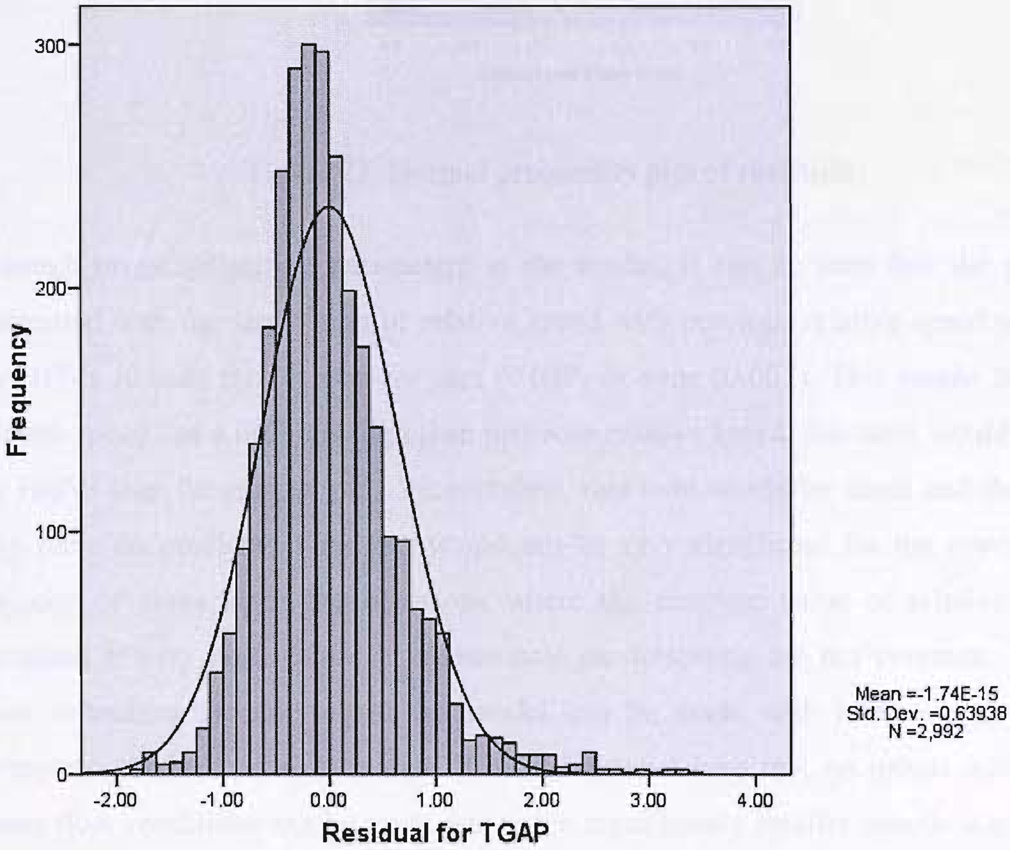

Figure 26: Histogram of residuals

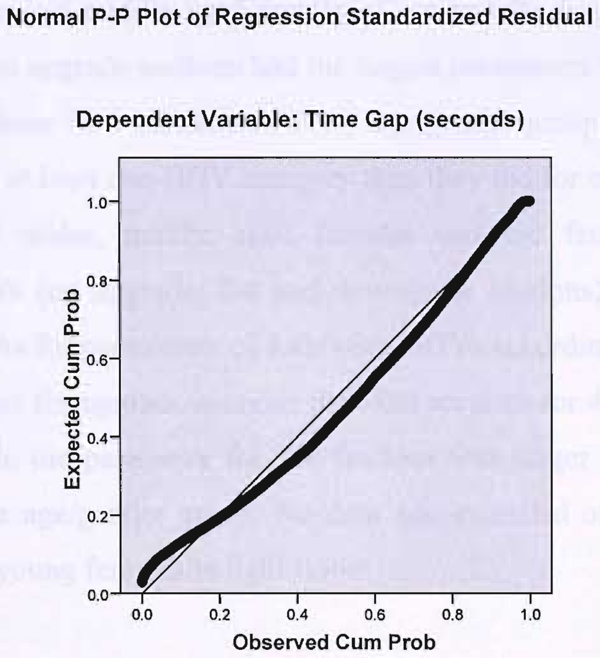

Figure 27: Normal probability plot of residuals

Through investigating the parameters in the model, it can be seen that the parameter associated with the interaction of relative speed with previous relative speed was larger for HGVs (0.018) than it was for cars (0.009) or vans (0.007). This means that unless relative speed has a different sign than previous relative speed, this term would be larger for HGVs than for cars or vans. Nonetheless, this term would be small and the effect it may have on predicted time gap would not be very significant for the overwhelming majority of cases since the occasions where the absolute value of relative speed is sustained at very high values in steady-state car-following are not common. Thus, the most interesting remarks about the model can be made with reference to the main parameter obtained from each cell. It must be noted here that no robust inferences in heavy flow conditions can be made due to the significantly smaller sample size for these conditions compared to those of light and moderate flow conditions. In addition, any remarks made about vans must be treated with caution since the sample size for this type of lead vehicle was relatively small, and the effect of that small sample size would be magnified when investigating several factors simultaneously.

In light flow conditions, the largest parameters were associated with vans for young males, young females and middle aged females. Cars had the largest parameter for old males, while HGVs on upgrade sections had the largest parameters for middle aged males and old females. In these flow conditions, every age/gender group except old males had larger parameters for at least one HGV category than they did for cars. In fact, for young males, middle aged males, middle aged females and old females; all parameters associated with HGVs (on upgrade, flat and downgrade sections) were larger than the parameters for cars. As for parameters of following HGVs according to gradient type, the parameters were larger for upgrade sections than flat sections for 4 age/gender groups in light conditions while the parameter for flat sections was larger than that for upgrade sections for only one age/gender group. No data was recorded of following HGVs on upgrade sections for young females in light flows.

In moderate flow conditions, the largest parameter for each age/gender group was associated with one of the three gradient categories while following HGVs. In fact, young females had larger parameters for HGVs on upgrade, flat and downgrade sections than the parameters of either vans or cars. For young and old female drivers, the lowest parameter was associated with following cars. For middle aged males, the lowest parameter was associated with following vans, which was also the case in light traffic conditions. Similar to observations made in light conditions, the parameters were found to be larger while following HGVs on upgrade sections than those on flat sections for 4 age/gender groups in moderate flows. For the other two groups, parameters associated with following HGVs on flat sections were larger than those of following HGVs on upgrade sections.

The remarks made above about the different lead vehicle types and the different gradient types as obtained from the model are based solely on the values of the parameters and are not results of formal statistical tests. Thus, these remarks do not constitute sound statistical evidence of differences in time gaps according to lead vehicle type or gradient type. In the next section, time gaps in light of these interactions are tested statistically in order to formalize the comparisons made between lead vehicle types and gradient types while accounting for interactions with other factors.

10.3.7 The Effects of Interactions between Factors

To better understand the effects of lead vehicle type on driver behaviour while following, the interaction of lead vehicle type with traffic conditions, gender, age and gradient should be investigated. This interaction was found to be significant and very important. In fact, this interaction was the most significant contributor in the model in accounting for the variation in the response variable. Thus, it is believed that studying the effects of lead vehicle type within the context of this interaction may improve our understanding of the effects of lead vehicle type on drivers' car-following behaviour. Three points must be clarified before investigating this interaction. First, since the sample size for vans is significantly smaller than the sample sizes of HGVs and cars, and since this sample size will be further reduced when looking at several factors simultaneously, comparisons within this interaction will only be made between HGVs and cars as lead vehicles. Second, since the sample size for heavy traffic conditions is small compared to the sample sizes for light and moderate conditions, and since this sample size will be further reduced when studying the interaction, this interaction will be studied only at light and moderate traffic conditions. Third, since the interaction includes gradient, and since all following processes of cars were assumed to take place on flat sections, comparisons will only be made between time gaps while following cars with time gaps while following HGVs on flat sections.

Table 29 shows the results from this interaction. It can be seen from the table that young males and old females followed HGVs at larger time gaps than cars in light traffic conditions. The differences in time gaps while following HGVs and cars in light flow conditions were not significant for all the other groups. In moderate traffic conditions, young male and young female drivers followed HGVs at greater time gaps than cars. The differences were not significant for any of the other groups. However, it must be stressed here that comparisons are only made here between time gaps while following cars in general with time gaps while following HGVs on flat sections. Hence, the fact that time gaps while following HGVs increased on upgrade sections is not accounted for. Therefore, it can be concluded that the results from this interaction are in general agreement with those obtained by studying lead vehicle type separately.

Traffic Conditions	Gender	Age	LV Type	Gradient Type	Mean	Standard Error	95% confidence Interval	
							Lowe Bound	upper bound
Light	male	young	HGV	up	1.037	0.245	0.556	1.518
				flat	1.511	0.066	1.381	1.641
				down	1.061	0.205	0.658	1.463
			car		0.929	0.088	0.757	1.102
		middle age	HGV	up	1.456	0.153	1.156	1.756
				flat	1.403	0.068	1.270	1.535
				down	1.382	0.205	0.980	1.785
			car		1.294	0.073	1.152	1.437
		old	HGV	up	2.011	0.325	1.374	2.648
				flat	1.801	0.119	1.568	2.033
				down	1.109	0.290	0.539	1.678
			car		2.193	0.292	1.621	2.765
	female	young	HGV	up	-	-	-	-
				flat	1.737	0.103	1.534	1.939
				down	1.575	0.291	1.005	2.144
			car		1.666	0.174	1.324	2.007
		middle age	HGV	up	1.818	0.375	1.083	2.553
				flat	1.504	0.098	1.311	1.696
				down	1.852	0.375	1.117	2.586
			car		1.479	0.102	1.279	1.680
		old	HGV	up	4.680	0.188	4.312	5.049
				flat	2.705	0.089	2.532	2.879
				down	-	-	-	-
			car		1.752	0.143	1.472	2.031
Moderate	male	young	HGV	up	1.339	0.088	1.166	1.512
				flat	1.766	0.047	1.674	1.857
				down	1.417	0.109	1.203	1.630
			car		1.553	0.060	1.435	1.671
		middle age	HGV	up	1.562	0.110	1.346	1.778
				flat	1.502	0.043	1.419	1.586
				down	1.714	0.145	1.429	2.000
			car		1.546	0.081	1.387	1.704
		old	HGV	up	2.229	0.162	1.910	2.547
				flat	1.841	0.067	1.711	1.972
				down	1.685	0.149	1.392	1.978
			car		2.014	0.076	1.865	2.162
	female	young	HGV	up	1.553	0.104	1.348	1.757
				flat	1.616	0.053	1.512	1.720
				down	1.834	0.108	1.622	2.047
			car		1.378	0.100	1.181	1.574
		middle age	HGV	up	2.246	0.097	2.055	2.436
				flat	1.584	0.057	1.472	1.695
				down	1.858	0.102	1.659	2.057
			car		1.704	0.078	1.551	1.856
		old	HGV	up	3.111	0.206	2.707	3.514
				flat	2.387	0.060	2.269	2.504
				down	2.800	0.174	2.459	3.142
			car		2.316	0.100	2.120	2.513

Table 29: Results from five-factor interaction

As regards the interaction of gradient type while following HGVs with traffic conditions, gender and age, it can be inferred that in light traffic flows, gradient had did not have any effect on time gaps while following HGVs for young males, middle aged males, young females and middle aged females. In these conditions, though, the time gaps for old males while following HGVs on upgrade sections were similar to those on flat sections but larger than those on downgrade sections. For old females in light flows, time gaps while following HGVs on upgrade sections were larger than those on flat sections. No time gaps of following HGVs on downgrade sections were recorded for this group in light conditions. In moderate traffic flows, there were no differences in time gaps according to gradient type for middle aged male drivers and young female drivers. In these conditions, young males followed HGVs at greater time gaps on flat sections than on upgrade or downgrade sections, with the latter two gradient types not being different from one another for this group. For old male drivers, time gaps while following HGVs were larger on upgrade sections than on flat or downgrade sections. No differences were recorded for this group between following on flat and downgrade sections. For middle aged female drivers, the largest time gaps were observed on upgrade sections followed by downgrade sections, with flat sections having the lowest time gaps while following HGVs. For old female drivers in moderate conditions, time gaps on upgrade and downgrade sections were similar, and both were greater than time gaps of following HGVs on flat sections.

10.3.8 Individual Subjects' Analysis for Lead Vehicle Effects

As a further step to consolidate the results obtained from the analysis regarding the effects of lead vehicle type on driver behaviour, analysis was carried out on an individual subject basis. The results from this analysis are shown in table 30. Of the 30 subjects that took part in the study, lead vehicle type had significant effects on driver behaviour while following for 26 of them. Of the 26 subjects for whom lead vehicle type was significant, 17 followed HGVs at greater time gaps than they followed cars, 6 followed cars at greater time gaps than they followed HGVs and there were no differences in time gaps while following HGVs and cars for 3 subjects. With regard to comparisons of time gaps while following HGVs and vans, 12 subjects followed HGVs at greater time gaps than they followed vans while 7 subjects followed vans at greater time gaps than they followed HGVs, although for two of the 7 subjects the sample size of time gaps while following vans was extremely small compared to that while following HGVs, which raises significant doubt about the results for these two subjects. In addition, there were no differences in time gaps while following HGVs and vans for 3 subjects while there was no data of following vans for 4 subjects.

subject age and gender	lead vehicle effect	largest time gap	middle time gap	smallest time gap	p-value
1: middle age male	significant	van & HGV		car	0.000
2: old female	significant	van & HGV		car	0.000
3: middle age male	significant	car	HGV	van	0.000
4: middle age male	significant	car & HGV		van	0.000
5: middle age female	significant	van		car & HGV	0.000
6: young male	significant	HGV	no vans	car	0.000
7: old female	not significant	no vans			0.500
8: young male	significant	van*	HGV	car	0.000
9: young male	significant	van	HGV	car	0.000
10: middle age female	significant	car	HGV	van	0.000
11: middle age female	significant	van	HGV	car	0.000
12: young female	significant	HGV	car	van	0.001
13: young female	not significant				0.181
14: young male	significant	car	HGV	van	0.000
15: young male	significant	HGV	van	car	0.000
16: old female	significant	van	HGV	car	0.000
17: middle age female	significant	HGV		car & van	0.000
18: middle age male	significant	car	no vans	HGV	0.000
19: middle age male	not significant				0.081
20: young female	significant	HGV		car & van	0.000
21: middle age male	significant	van	car	HGV	0.000
22: old male	significant	HGV	van	car	0.000
23: middle age female	significant	HGV		car & van	0.000
24: old male	significant	car	HGV	van	0.000
25: young male	significant	HGV & van		car	0.000
26: old female	significant	HGV	no vans	car	0.000
27: young female	significant	van*		HGV & car	0.000
28: young female	significant	HGV		car & van	0.000
29: old male	not significant				0.060
30: old male	significant	HGV	car	van	0.000

Table 30: Lead vehicle type effects for individual subjects

It is clear from table 30 that the effects of lead vehicle type on driver behaviour were not uniform for any driver group. In every age/gender group, the effects of lead vehicle type varied from one driver to another. This clearly indicates that no driver group can be considered homogeneous in terms of driver behaviour while following.

10.4 Stability Analysis

The stability of driver behaviour while following may be determined from two aspects of car-following. The first is the variation in headway (time or distance) which portrays information about drivers' abilities to maintain their headways close to the desired headway. The second aspect is the difference in speed between the lead vehicle and the following vehicle (relative speed) which depicts drivers' abilities to maintain relatively constant speed with the lead vehicle, thus maintaining the steady-state phase of car-following. It must be noted here that relative speed is calculated as the lead vehicle's speed minus the following vehicle's speed.

The first approach entails performing statistical tests to compare the variances of time gap distributions. These tests were carried out on data sampled at one reading every 10 seconds. For this approach to be valid, the distribution of time gaps must be normal. Normality of data was studied for each age/gender group separately. The Kolmogorov-Smirnov test was carried out for each group of time gaps as shown in table 31. The results indicate that only for old males did the distribution of time gaps follow the normal distribution. However, when histograms were produced for time gaps of each age/gender group, time gap distributions for two groups (middle aged males and middle aged females) were found to be approximately normal. The departures from normality for these two groups were mild. Figure 28 shows a typical histogram for one of these groups.

		Time Gaps of Young Males	Time Gaps of Young Females	Time Gaps of Middle Aged Males	Time Gaps of Middle Aged Females	Time Gaps of Old Males	Time Gaps of Old Females
N		588	384	600	451	348	302
Normal Parameters	Mean	1.645	1.700	1.485	1.801	1.966	2.465
	Std. Dev.	.7349	.5727	.4815	.5182	.7316	1.2959
Most Extreme Diff.	Absolute	.080	.110	.061	.068	.060	.156
	Positive	.080	.110	.061	.068	.060	.156
	Negative	-.073	-.095	-.031	-.051	-.052	-.106
Kolmogorov-Smirnov Z		1.931	2.158	1.486	1.451	1.113	2.709
Asymp. Sig. (2-tailed)		.001	.000	.024	.030	.168	.000

Table 31: Normality tests for each age/gender group

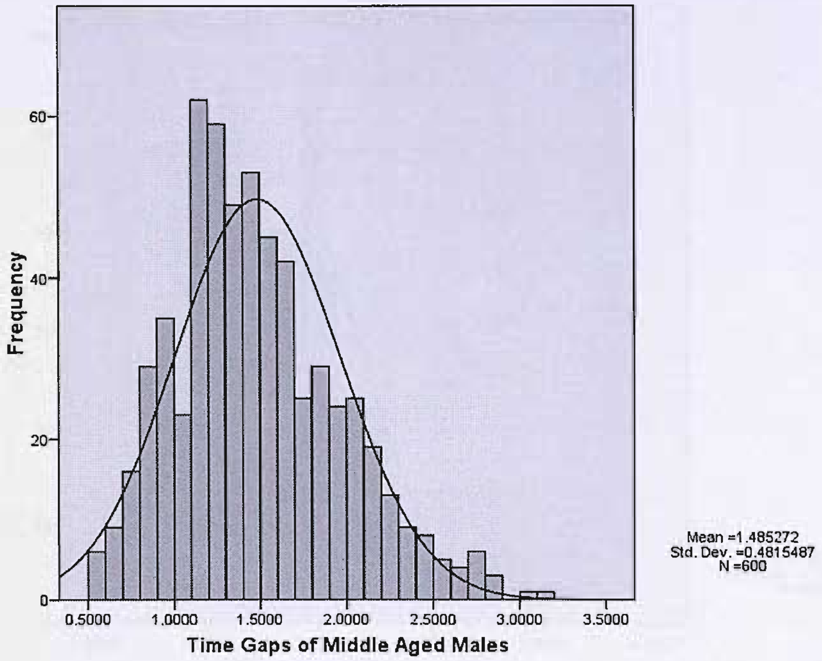

Figure 28: Example of distribution not departing severely from normality

On the other hand, the departures from normality were severe for young males, young females and old females. Figure 29 shows an example of time gap distributions for one of these groups. Thus, results from tests carried out in the first approach have some reservations associated with them since the pre-requisite condition for this test, that time gaps are normally distributed, is not met.

Comparisons between variances were carried out utilizing the F-test. In principal, the F-test for variances statistically examines the deviation of the ratio of two variances from unity. Since the ratio of estimated variances of two normal distributions follows the F-distribution, critical lower and upper bounds can be obtained from the F-distribution, which would serve to establish whether differences between variances exist (Milton and Arnold 1995, Chapter 10). To facilitate presenting the results of these tests, the results are presented in terms of p-values in order to avoid presenting 6 lower and upper critical bounds for each group. All the tests carried out to compare variances were one-tailed tests carried out at the 95% level of significance. Table 32 presents descriptive statistics for each age/gender group, from which the direction of the one-tailed test of interest can be inferred. Table 33 presents the p-values obtained

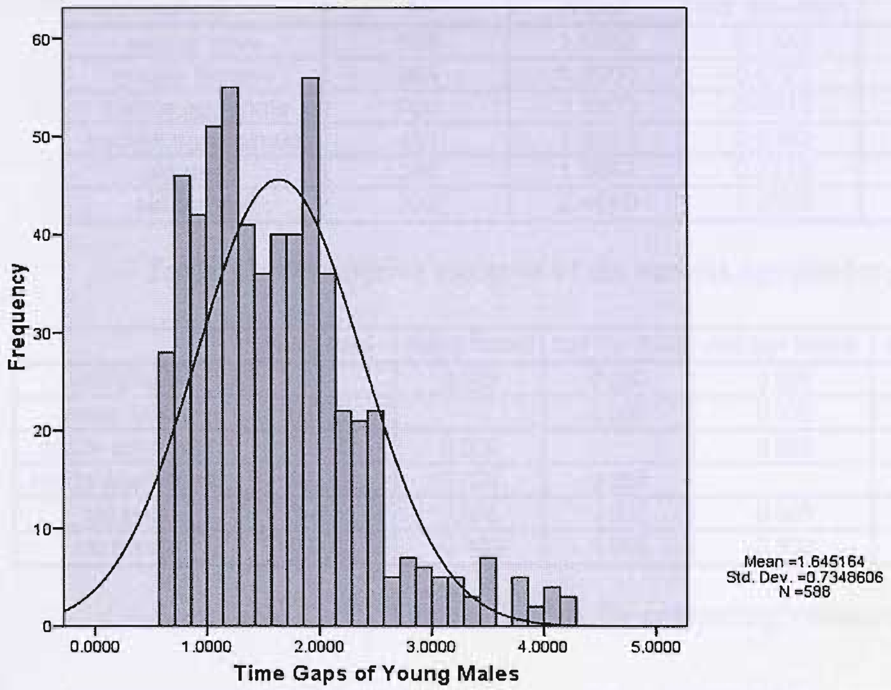

Figure 29: Example of distribution severely departing from normality

from the F-tests. Table 33 illustrates that old females had significantly larger time gap variances than any other group, followed by young and old male drivers, between whom the differences in time gap variances were not significant (p-value = 0.465). The variance of time gaps for middle aged males was smaller than that for young female drivers (p-value = 0.000) but not different from the variance of time gaps for middle aged female drivers (p-value = 0.05). The variance of time gaps for young female drivers was larger than that of middle aged female drivers (p-value = 0.02). Thus, this test results in dividing the 6 different age/gender groups into four driver groups according to variances of time gaps. The first group contains middle aged male drivers and middle aged female drivers, with this group demonstrating the lowest variation in time gaps and thus can be considered the most stable. The second group is that of young female drivers, for whom the variation was relatively low, although not as low as that of the first group. The third group is that of young and old male drivers with relatively high variation in time gaps but less than the variation observed for old female drivers. The old female group had the largest variation in time gaps while following.

Group	N	mean	std. deviation	variance
young male	588	1.6452	0.7349	0.540
young female	384	1.7000	0.5727	0.328
middle age male	600	1.4853	0.4815	0.232
middle age female	451	1.8013	0.5182	0.268
old male	348	1.9664	0.7316	0.535
old female	302	2.4650	1.2959	1.679

Table 32: Descriptive statistics of the various age/gender groups

	young male	young female	mid age male	mid age female	old male	old female
young male		0.000	0.000	0.000	0.465	0.000
young female	0.000		0.000	0.020	0.000	0.000
middle aged male	0.000	0.000		0.050	0.000	0.000
middle aged female	0.000	0.020	0.050		0.000	0.000
old male	0.465	0.000	0.000	0.000		0.000
old female	0.000	0.000	0.000	0.000	0.000	

Table 33: P-values of F-tests for comparing variances

The second aspect of stability analysis utilized figures 30-35 to investigate the variation of distance gap with relative speed during the recorded car-following processes for each age/gender group. Since the variation of distance gaps portrays similar information to that studied earlier through variances of time gaps, the focus here is the variation of relative speed for each age/gender group. A threshold value of relative speed of 2 m/s in absolute value was used to identify unstable observations. In order to ensure that instability as defined by large absolute values of relative speed was mainly attributed to the following driver, observations with absolute values of relative speeds exceeding 2 m/s were identified for each age/gender group and further investigations were carried out to determine whether instability was caused by the lead vehicle or was due to poor performance from the following vehicle's driver. Whether large relative speeds resulted from the lead vehicle or was due to poor driving performance of the instrumented vehicle's driver was deduced from speed profile plots as shown in figures 36 and 37, where figure 36 shows a case where the speed difference was due to disturbances from the lead vehicle while figure 37 illustrates a case where instability was due to the following vehicle's driver. This additional investigation into the cause of instable events will enable assessing driver performance accurately since any point of high relative speed caused by the lead vehicle will not be considered in evaluating driver performance. The analysis here was carried out on data sampled at 1-second frequency, since sampling at seconds. In order to counter the possibility of over-representing unstable events that last for several seconds compared to those that last for shorter duration, the analysis will identify unstable events rather than unstable observations. An unstable event is defined here as an observation point (1 second) or a group of observation points occurring in succession during which relative speed exceeds 2 m/s in absolute value.

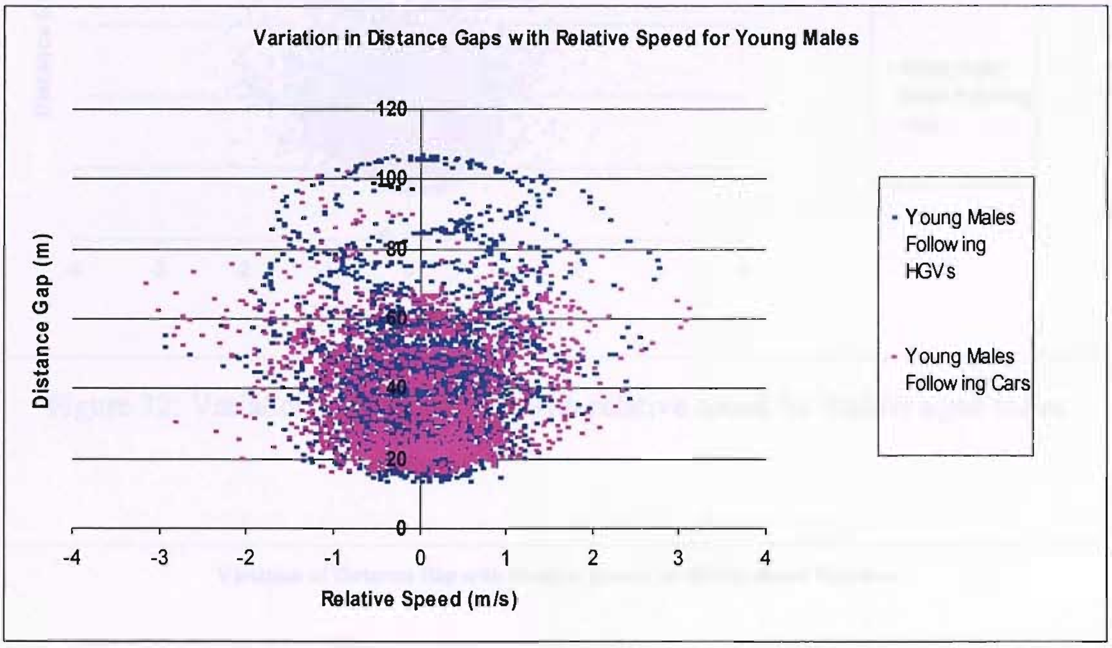

Figure 30: Variation of distance gap with relative speed for young males

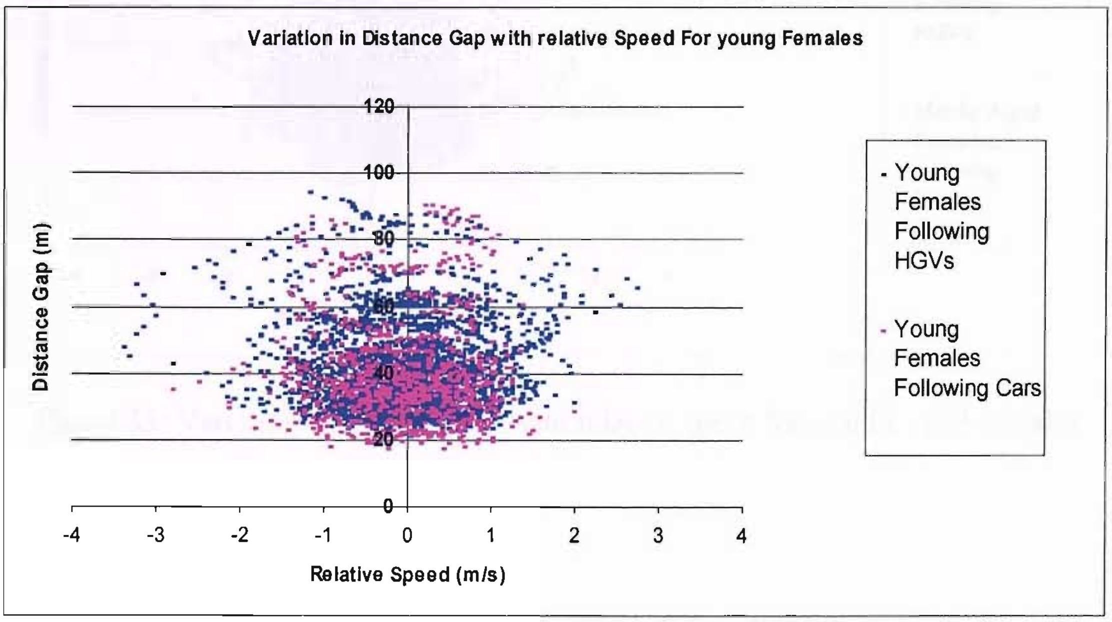

Figure 31: Variation of distance gap with relative speed for young females

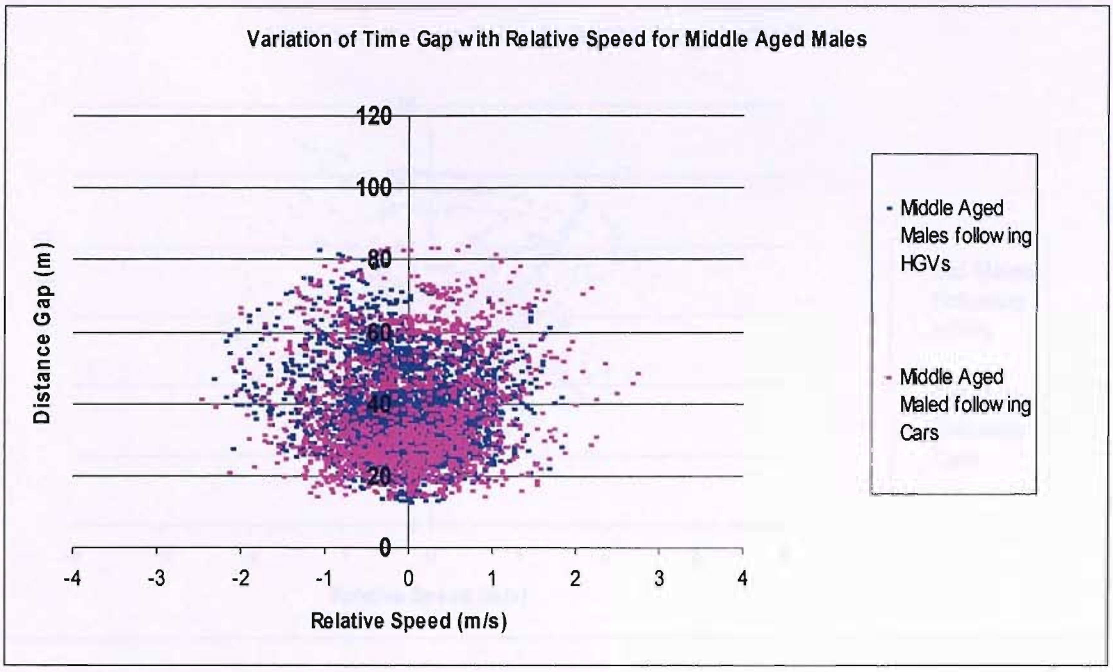

Figure 32: Variation of distance gap with relative speed for middle aged males

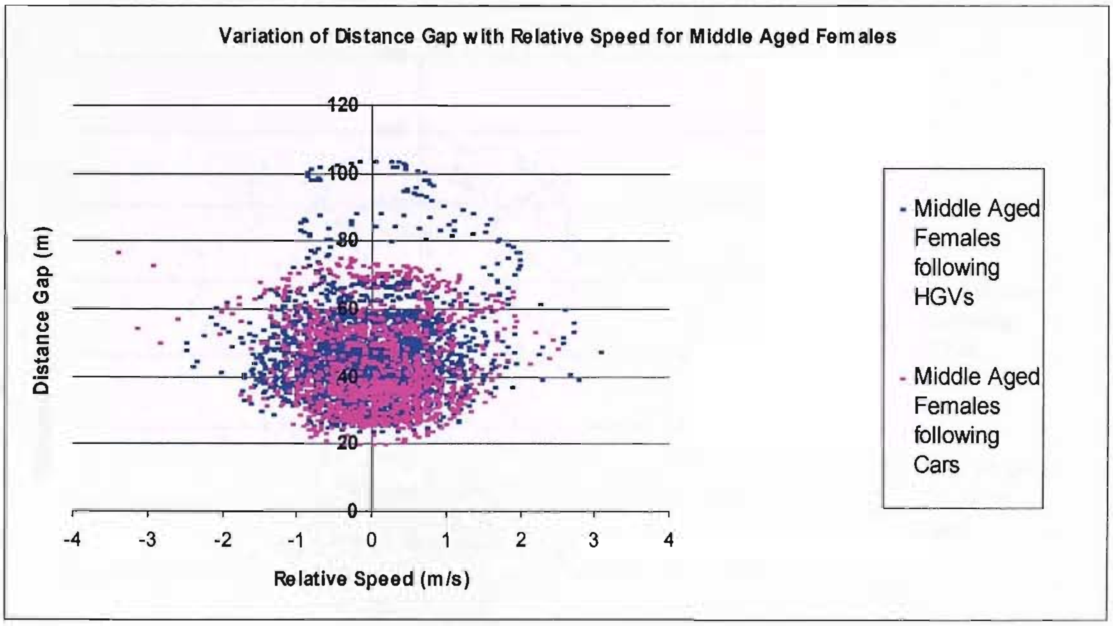

Figure 33: Variation of distance gap with relative speed for middle aged females

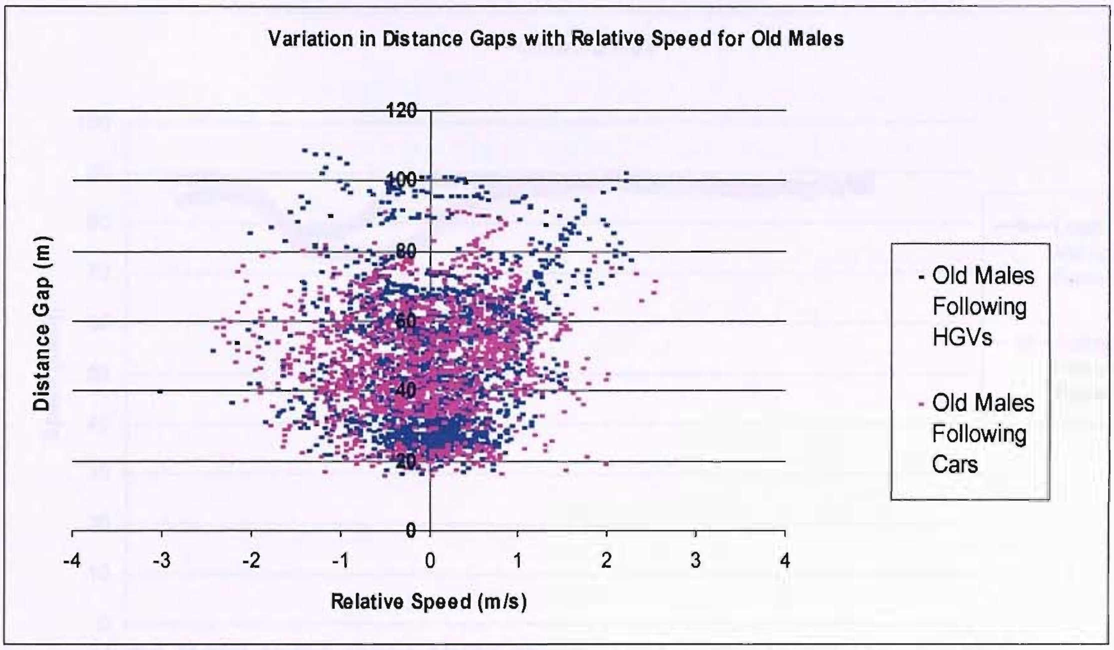

Figure 34: Variation of distance gap with relative speed for old males

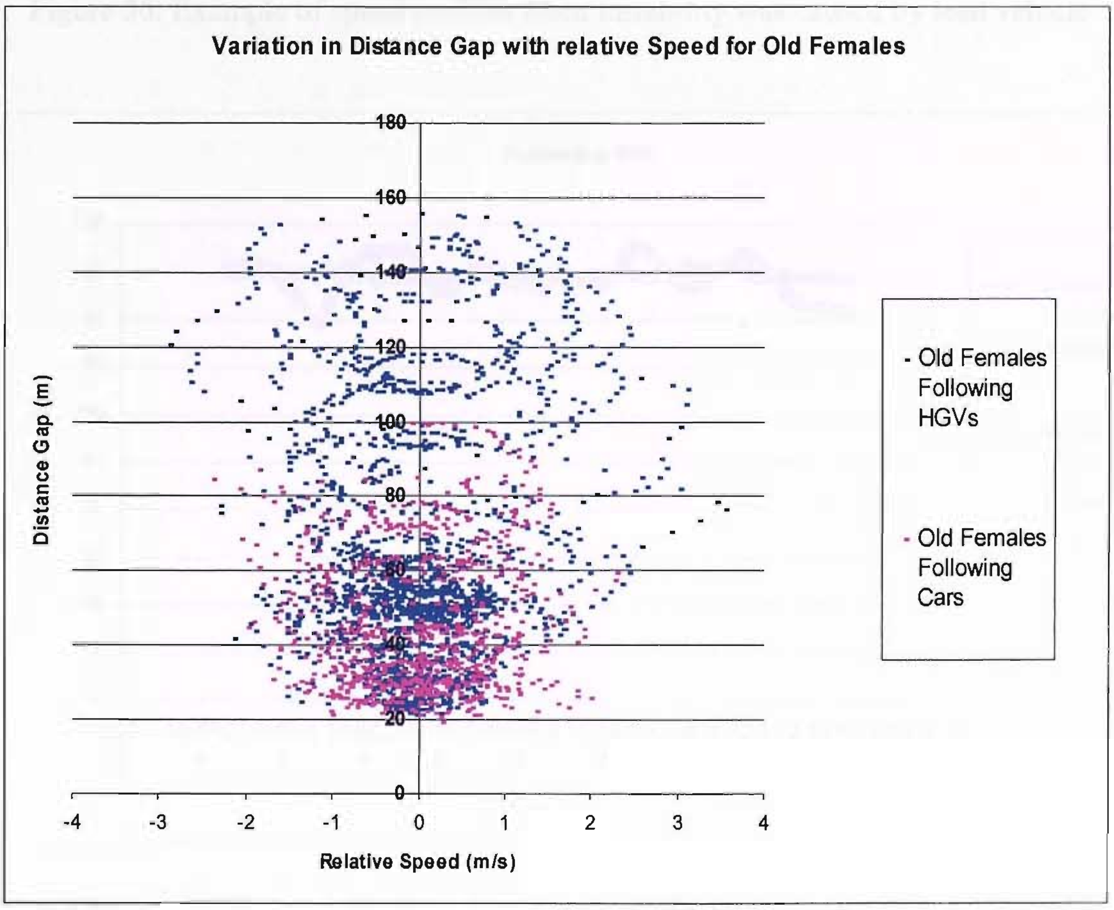

Figure 35: Variation of distance gap with relative speed for old females

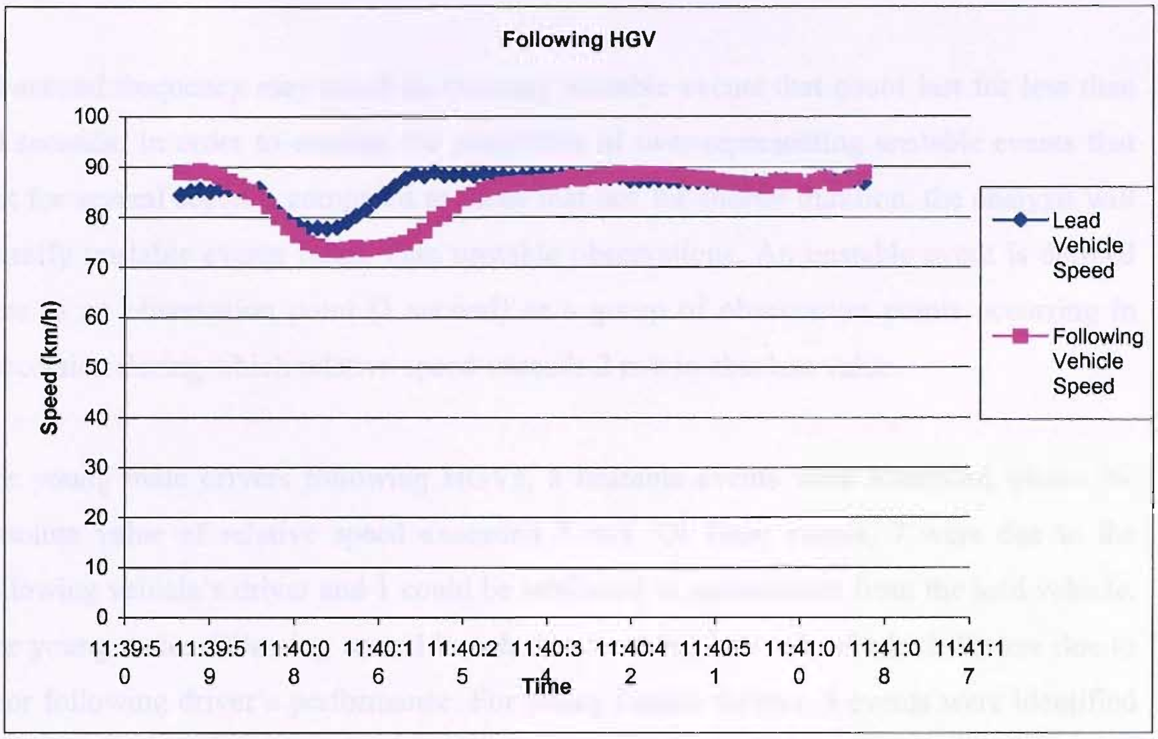

Figure 36: Example of speed profiles when instability was caused by lead vehicle

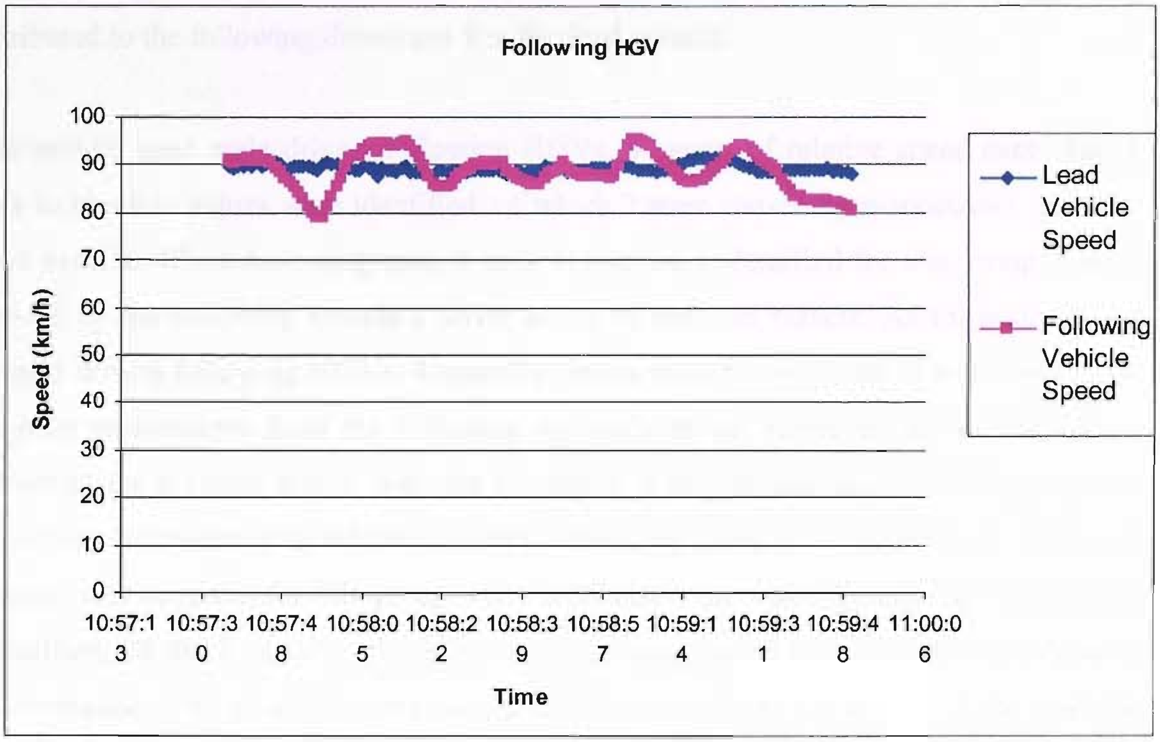

Figure 37: Example of speed profiles when instability was caused by following vehicle

10-second frequency may result in omitting unstable events that could last for less than 10 seconds. In order to counter the possibility of over-representing unstable events that last for several seconds compared to those that last for shorter duration, the analysis will identify unstable events rather than unstable observations. An unstable event is defined here as an observation point (1 second) or a group of observation points occurring in succession during which relative speed exceeds 2 m/s in absolute value.

For young male drivers following HGVs, 8 unstable events were identified where the absolute value of relative speed exceeded 2 m/s. Of these events, 7 were due to the following vehicle's driver and 1 could be attributed to manoeuvres from the lead vehicle. For young males following cars, 14 such events were observed, of which 8 were due to poor following driver's performance. For young female drivers, 5 events were identified while following HGVs and 3 while following cars. Of the 5 observations while following HGVs, 2 could be attributed to the following driver and 3 were due to perturbations from the lead vehicle. Of the 3 unstable events recorded while following cars, 1 event was attributed to the following driver and 2 to the lead vehicle.

For middle aged male drivers following HGVs, 4 events of relative speed exceeding 2 m/s in absolute values were identified, of which 2 were caused by manoeuvres from the lead vehicle. While following cars, 6 such events were identified for this group, with 3 caused by the following vehicle's driver and 3 by the lead vehicle. As for middle aged female drivers following HGVs, 4 unstable events were recorded, all of which were due to poor performance from the following vehicle's driver. However, all 4 events were observed for a single driver, with the remaining 4 drivers belonging to this group not recording any points with relative velocity exceeding 2 m/s in absolute value. A similar pattern was observed for this group while following cars, where 3 unstable events were identified. Of the 3 unstable events observed, 2 were caused by poor following driver's performance, both of which were caused by the same driver for whom all the unstable events while following HGVs were recorded. As for the other event, it was recorded for another driver and was caused by the lead vehicle.

For old male drivers, 7 unstable events were identified while following HGVs and 6 while following cars. Only 2 of the events while following HGVs and another 3 while following cars could be attributed to appreciable changes in lead vehicle's speed, the remaining observations were due to poor performance on the part of the following vehicle's driver. As for old female drivers following HGVs, 8 events were identified with large relative speeds. Although 7 of these events were caused by poor following performance, all of these 7 events were recorded for the same driver. For this group following cars, 4 events were observed with high relative velocities, all of which were caused by speed changes of the lead vehicle.

Thus, it may be inferred from these two aspects of stability analysis that middle aged male drivers, young female drivers and middle aged female drivers display the highest stability while car-following. While the first aspect of stability analysis showed superior car-following performance for middle aged male and female drivers to that of young female drivers, young females displayed the greatest abilities of maintaining constant speeds with lead vehicles. Therefore, middle aged male drivers, young female drivers and middle aged female drivers may be considered to form one group that have superior stability while car-following than the other three groups. Although the first part of stability analysis showed old female drivers to perform much worse than young and old male drivers, the second part of the analysis may be taken to indicate better driver stability of old female drivers compared to that of young and old male drivers. Nonetheless, the overall performance of the latter three groups in terms of car following is inferior to that of middle aged male, young female and middle aged female drivers.

As for stability according to lead vehicle type, an F-test similar to that used above is conducted for each age/gender group between variances while following HGVs and cars. An investigation of the normality of the distribution of time gaps while following each vehicle type had to be carried out for each age gender group. The Kolmogorov-Smirnov test, the results of which are not shown here, indicated that only 3 of the 12 time gap groups actually followed the normal distribution. For 4 other groups, the deviations from normality were very mild. For 5 time gap groups, the deviations from normality were noticeable to severe. Figures 38 and 39 show examples of very mild and severe departures from normality, respectively. Thus, the results here must also be treated with caution since the condition required for carrying out the F-test is not met.

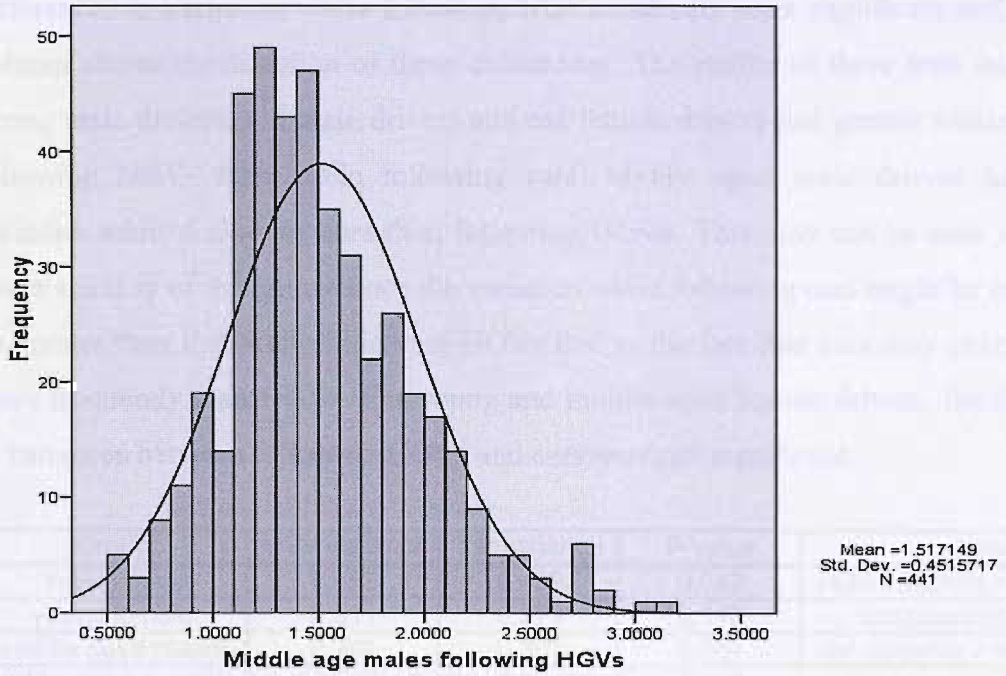

Figure 38: Example of very mild deviation from normality

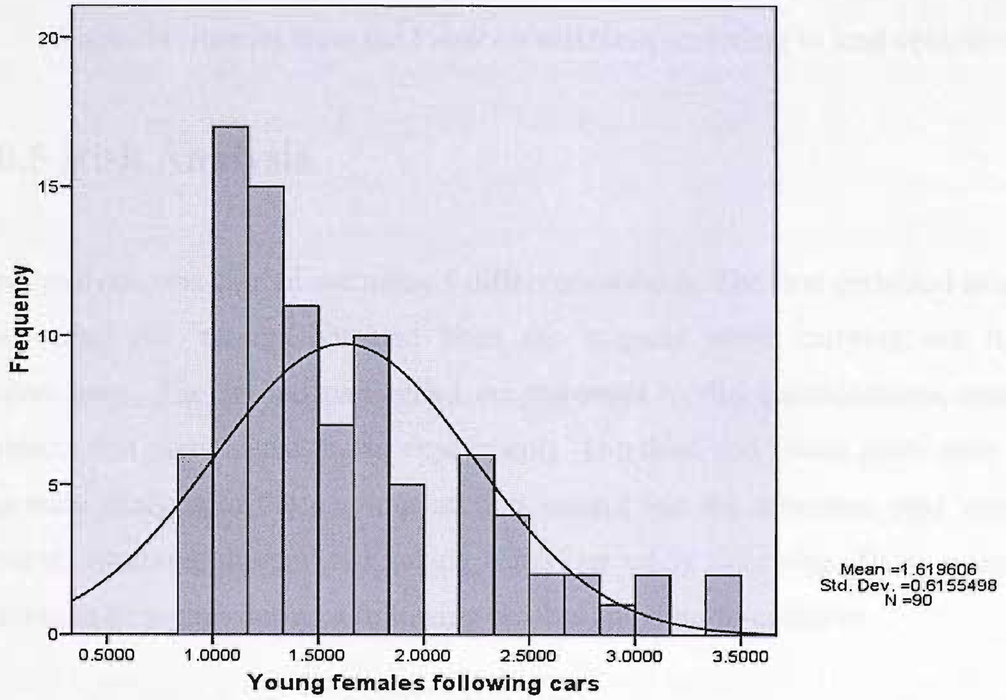

Figure 39: Example of severe deviation from normality

This analysis was carried out on time gap data sampled at one reading every 10 seconds. The results of the F-tests are shown in table 34, where the p-values illustrate whether differences in variances while following HGVs and cars were significant and the result column shows the direction of these differences. The results of these tests indicate that young male drivers, old male drivers and old female drivers had greater variances while following HGVs than while following cars. Middle aged male drivers had greater variation while following cars than following HGVs. This may not be seen to indicate lower stability of this group since the variation while following cars might be expected to be greater than that while following HGVs due to the fact that cars may change speeds more frequently than HGVs. For young and middle aged female drivers, the differences in variances between following HGVs and cars were not significant.

Group	HGV variance	car variance	P-value	result
Young male	0.565	0.452	0.042	HGV variance > car variance
young female	0.311	0.379	0.113	variances not different
middle aged males	0.204	0.301	0.001	car variance > HGV variance
middle aged females	0.253	0.278	0.253	variances not different
old males	0.633	0.378	0.001	HGV variance > car variance
old females	1.906	0.654	0.000	HGV variance > car variance

Table 34: Results from the F-test on variances according to lead vehicle type

10.5 Risk Analysis

This analysis was carried out using 4 different methods. The first pertained to analysis of the verbal risk ratings obtained from the subjects while carrying out the driving experiments. The second part relied on responses to the questionnaires completed by subjects that participated in the experiments. The third and fourth parts were similar to the main analysis of the previous section, except that the measures used were directed towards assessing drivers' risk taking behaviour while following. Those measures were minimum time gaps during a following process and time-to-collision.

In the first part, time gaps associated with each risk rating for different lead vehicle types were isolated. From those, risk ratings obtained at light, moderate and heavy traffic conditions were separated. A further classification was carried out were similar conditions in terms of following vehicle type and type of vehicle in the adjacent lane were obtained. This was done to ensure that the risk ratings obtained corresponded mainly to the lead vehicle type being followed. Once this was accomplished, several sensitivity tests were conducted to test for differences in conditions that could influence risk ratings. The result of these sensitivity tests was that risk ratings while not being followed and with no vehicles in the adjacent lane formed a homogeneous group with risk ratings where the trailing vehicle or the vehicle in the adjacent lane was a car. Another result of these tests was that there were no differences in risk ratings between light and moderate traffic conditions when other factors were controlled. These results allowed for noticeable increase of the sample size on which the analysis is performed.

The sample size for high risk situations was very small. Hence, only comparisons of time gaps corresponding to low and medium risk ratings were conducted. Furthermore, conditions of heavy traffic were scarce and were also removed. This yielded 6 risk rating groups, differing in lead vehicle type and risk rating reported. It must be noted that the sample size of time gaps associated with medium risk while following vans was very small (only 11 cases). Thus, only two vehicle types were investigated at medium risk ratings. Once time gaps were separated according to lead vehicle type and reported risk rating, separate analyses were carried out for low and medium risk ratings, to compare time gaps associated with each based on lead vehicle type.

The results of the analyses performed on the low risk data set are shown in table 35, where the analysis reported no differences in time gap distributions while following HGVs, cars or vans at that risk rating. For the medium risk analysis, the results (shown in table 36) indicate a statistically significant difference between time gaps while following HGVs and cars when the reported risk rating was “medium risk”. The differences between time gap distributions are further illustrated in table 37.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
Corrected Model	1.611(b)	2	.805	1.587	.206	.011	3.174	.335
Intercept	546.137	1	546.137	1076.17	.000	.795	1076.176	1.000
VTYPE	1.611	2	.805	1.587	.206	.011	3.174	.335
Error	140.572	277	.507					
Total	936.008	280						
Corrected Total	142.183	279						

Table 35: ANOVA output for risk rating analysis for low risk situations

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
Corrected Model	2.034(b)	1	2.034	5.519	.020	.044	5.519	.644
Intercept	257.784	1	257.784	699.48	.000	.855	699.486	1.000
VTYPE	2.034	1	2.034	5.519	.020	.044	5.519	.644
Error	43.855	119	.369					
Total	423.160	121						
Corrected Total	45.889	120						

Table 36: ANOVA output for risk rating analysis for medium risk situations

Lead Vehicle Type	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
HGV	1.840	.064	1.714	1.966
car	1.540	.111	1.321	1.759

Table 37: Means and confidence bounds for cars and HGVs for medium risk

The results obtained here do not make for robust evidence that drivers associate higher risk while following HGVs than they do when following other vehicle types. The sample sizes undermine the results obtained. In addition, the method used to reach the conclusion, based on verbal risk ratings, leaves much doubt on the results. This was clear from analysis that was carried out to compare time gap distributions while following the same vehicle type corresponding to low and medium risk ratings. This analysis indicated no differences between time gaps while following HGVs when the reported risk ratings were “low risk” and “medium risk”. Similar results were obtained with cars as lead vehicles. In addition, different risk ratings were reported by the same driver that were associated with similar time gaps. In many situations, higher risk ratings corresponded with greater time gaps while following the same vehicle type by the same driver. Hence, the reported risk ratings may have corresponded to many other factors in addition to lead vehicle type. Thus, contrary to the contention made in Heino *et al.* (1992), it is argued here that the method of verbal risk ratings does not yield reliable results in terms of assessing drivers' risk taking behaviour.

The second stage of the analysis utilized information obtained from the driver behaviour questionnaires completed by subjects taking part in the study. Questionnaires were completed by 33 subjects, 32 who carried out the experiments and one subject for whom the experiment was cancelled. Two questions in the questionnaires were directed towards eliciting drivers' risk perceptions towards HGVs. The first question was: what is your general attitude towards HGVs? The response to this question was either "safer than cars", "same as cars" or "more dangerous than cars". The second was a question in a series of questions relating to drivers' views as to the sources of the effects of HGVs. The statement was: "I allow greater headways when following HGVs on the motorway because they present higher levels of risk compared to cars". The set of possible responses was as follows: strongly disagree, disagree, neutral, agree and strongly agree.

For the first question, 28 out of the 33 respondents (almost 85%) viewed HGVs as being more dangerous than cars. As for the other two responses, 4 subjects (about 12%) viewed HGVs to be safer than cars and one subject (3%) viewed HGVs to be same as cars in terms of safety. For the second question, 10 responded with strongly agree (30.3%), 13 responded with agree (39.4%), 4 responded with neutral (12.1%), 5 responded with disagree (15.2%) and one responded with strongly disagree (3%). In fact, among the 6 different hypothesized sources of HGVs' effects elicited from the questionnaires, presenting higher levels of risk was exceeded only by vision obscuration by HGVs as a source of HGVs' effects.

The third stage of the risk analysis centred on investigating minimum time gaps obtained from each following process. Minimum time gaps were obtained for 348 car-following processes while following HGVs (189), cars (115) and vans (44). ANOVA was again used here with gender, age and vehicle type as the independent variables. The results of the analysis are shown in the ANOVA output in table 38. It can be seen from the table that vehicle type, gender, age and age/gender interactions all had significant effects on minimum time gaps, although the p-value for vehicle type (p-value = 0.035) was not as low as the p-values for the other two factors.

Source	Type III Sum of Squ	df	Mean Square	F	Sig.	Partial Eta Squ	Noncent .Parame	Obs. Power
Corrected Model	26.654	17	1.568	5.506	.000	.221	93.597	1.000
Intercept	451.358	1	451.358	1584.97	.000	.828	1584.97	1.000
GENDER	6.168	1	6.168	21.660	.000	.062	21.660	.996
AGE	10.936	2	5.468	19.201	.000	.104	38.403	1.000
VTYPE	1.929	2	.964	3.386	.035	.020	6.772	.636
GENDER * AGE	2.030	2	1.015	3.563	.029	.021	7.127	.660
GENDER * VTYPE	1.457	2	.729	2.558	.079	.015	5.116	.510
AGE * VTYPE	1.440	4	.360	1.265	.284	.015	5.058	.395
GENDER * AGE * VTYPE	.421	4	.105	.370	.830	.004	1.479	.135
Error	93.975	330	.285					
Total	805.428	348						
Corrected Total	120.629	347						

Table 38: ANOVA results for the minimum time gap analysis

Further investigation into the effects of vehicle type on minimum time gaps utilizing the Tukey multiple comparisons procedure, the results of which are presented in table 39, showed that minimum time gaps while following HGVs were larger than those of following cars at the 95% confidence level. However, minimum time gaps when following vans were not different from those when following HGVs or cars. It must be noted, however, that the sample size for following HGVs was larger than that for following cars (by a factor of about 1.6), and significantly larger than the sample size for following vans (by a factor of almost 4.3).

Vehicle Type 1	Vehicle Type 2	Mean Difference	Standard Error	Signif.	95% Confidence Level	
					Lower Bound	Upper Bound
HGV	car	0.152	0.063	0.043	0.004	0.301
	van	0.114	0.089	0.413	-0.097	0.324
car	HGV	-0.152	0.063	0.043	-0.301	-0.004
	van	-0.039	0.095	0.911	-0.262	0.184
van	HGV	-0.114	0.089	0.413	-0.324	0.097
	car	0.039	0.095	0.911	-0.184	0.262

Table 39: Multiple comparison of minimum time gaps according to vehicle type

As for age and gender effects, table 40 shows that male drivers had significantly lower minimum time gaps than female drivers. There were no differences in minimum time gaps between young and middle aged drivers. Minimum time gaps for old drivers were larger than those of young and middle aged drivers. These results are shown in table 41, where the results of the Tukey multiple comparison procedure are presented.

Driver Gender	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
male	1.273	.047	1.180	1.366
female	1.610	.055	1.502	1.718

Table 40: Effects of gender on minimum time gaps

Age Group 1	Age Group 2	Mean Difference	Standard Error	Signif.	95% Confidence Level	
					Lower Bound	Upper Bound
Young	Mid age	-0.046	0.066	0.772	-0.202	0.111
	old	-0.494	0.073	0.000	-0.666	-0.321
Middle Aged	young	0.046	0.066	0.772	-0.111	0.202
	old	-0.448	0.074	0.000	-0.622	-0.274
Old	young	0.494	0.073	0.000	0.321	0.666
	Mid age	0.448	0.074	0.000	0.274	0.622

Table 41: Multiple comparisons of minimum time gaps according to age

The last stage of the risk analysis entails analyzing another measure associated with risk, time-to-collision (TTC). An ANOVA model was again used to analyze the data with vehicle type, age and gender as independent variables. The sample sizes of TTCs for the various factors are shown in table 42. The analysis results, shown in table 43, reveal that all independent variables had significant effects on TTCs, with all p-values = 0.000. Furthermore, the three-factor interaction was significant. In addition to studying the individual factor's effects, the three-factor interaction will also be further investigated.

		Value Label	N
Gender	1	male	3233
	2	female	1843
Driver Age	1	young	2812
	2	middle age	1965
	3	old	299
Vehicle Type	1	HGV	2952
	2	car	1659
	3	van	465

Table 42: Various factors' sample sizes for TTC analysis

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	196682.590	14	14048.756	32.149	.000
Intercept	3120461.899	1	3120461.899	7140.771	.000
VTYPE	62986.079	2	31493.039	72.068	.000
AGE	7631.373	2	3815.686	8.732	.000
Gender	27615.651	1	27615.651	63.195	.000
VTYPE * AGE * Gender	22780.699	9	2531.189	5.792	.000
Error	2211618.133	5061	436.992		
Total	17544807.61	5076			
Corrected Total	2408300.723	5075			

Table 43: ANOVA output for TTC analysis

Multiple comparisons analysis revealed that the largest TTCs were associated with following HGVs, while there were no differences in TTCs between cars and vans (p-value = 0.889). These results are shown in table 44. This implies greater willingness by drivers to accept risk while following cars and vans as compared to following HGVs. As for age, multiple comparisons showed the smallest TTCs to be associated with young drivers while the largest TTCs were observed for old drivers, as can be seen from the p-values in table 45. It may be inferred from this table that young drivers are more likely to adopt risky driving behaviour compared to middle aged and old drivers. Table 46 shows that male drivers had smaller values of TTCs while following than female drivers. This indicates that male drivers adopt riskier driving behaviour than female drivers.

Vehicle Type 1	Vehicle Type 2	Mean Difference	Standard Error	Signif.	95% Confidence Level	
					Lower Bound	Upper Bound
HGV	car	10.022	0.641	0.000	8.518	11.526
	van	10.528	1.043	0.000	8.083	12.973
car	HGV	-10.022	0.641	0.000	-11.526	-8.518
	van	0.507	1.097	0.889	-2.065	3.078
van	HGV	-10.528	1.043	0.000	-12.973	-8.083
	car	-0.507	1.097	0.889	-3.078	2.065

Table 44: TTC multiple comparisons output for vehicle type

Age Group 1	Age Group 2	Mean Difference	Standard Error	Signif.	95% Confidence Level	
					Lower Bound	Upper Bound
Young	Mid age	-1.945	0.615	0.004	-3.386	-0.504
	old	-10.720	1.272	0.000	-13.702	-7.739
Middle Aged	young	1.945	0.615	0.004	0.504	3.386
	old	-8.776	1.298	0.000	-11.818	-5.733
Old	young	10.720	1.272	0.000	7.739	13.702
	Mid age	8.776	1.298	0.000	5.733	11.818

Table 45: TTC multiple comparisons output for age

Gender	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
male	49.382	.503	48.396	50.368
female	59.025	.816	57.425	60.625

Table 46: Effects of gender on TTC

Investigating the three-factor interaction provides a clearer picture of the effects of lead vehicle type on TTCs. These results are displayed in table 47. For young male, middle aged male and young female drivers, TTCs while following HGVs were significantly greater than TTCs while following cars and vans. There were no differences in TTCs between cars and vans for these three age/gender groups. For middle aged females, there were no differences in TTCs according to lead vehicle type. For old female drivers, there were no differences in TTCs while following HGVs and vans. TTCs while following HGVs and vans for this age/gender group were larger than TTCs while following cars. For old males, the number of TTC observations under 100 seconds did not allow for estimation of means, and hence no comparisons are made for this age/gender group.

Gender	Driver Age	Vehicle Type	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
Male	young	HGV	56.900	.628	55.609	58.132
		car	46.374	.744	44.915	47.833
		van	43.806	1.505	40.856	46.756
	middle age	HGV	58.525	.800	56.957	60.094
		car	45.828	1.116	43.640	48.015
		van	44.860	2.002	40.934	48.785
	old	HGV	-	-	-	-
		car	-	-	-	-
		van	-	-	-	-
Female	young	HGV	61.273	1.007	59.299	63.247
		car	51.758	1.432	48.950	54.566
		van	53.089	2.367	48.449	57.729
	middle age	HGV	58.129	.902	56.360	59.897
		car	57.342	1.426	54.547	60.137
		van	55.904	2.499	51.006	60.802
	old	HGV	67.746	1.505	64.796	70.696
		car	54.662	2.191	50.366	58.959
		van	71.323	5.397	60.742	81.905

Table 47: Effects of three-factor interactions on TTC

10.6 Constancy of Time Headway Analysis

In this part of the analysis, a widely accepted view in the literature that time headway is constant for the individual driver is tested. This hypothesis of constant time headway for the individual driver is vital in microscopic simulation models and in-vehicle technologies. The data gathered in this study provided an opportunity to test this view. This analysis was conducted on four levels starting at a low detailed level, while increasing the details as the analysis progressed.

The first level of the analysis consisted of comparing time gap distributions from each following process with time gap distributions for all other following processes while following the same lead vehicle type for each individual driver. The types of lead vehicles investigated were HGVs and cars. The results showed that for each driver following each lead vehicle type, time gaps were significantly different from one following process to another. In the majority of cases, the p-value was 0+, which indicates vastly differing time gaps from one following process to another.

The second level of the analysis involved introducing the aggregated time gaps from all following processes of the same vehicle type for each driver into the analysis. The results indicated that for each driver, there was at least one following process for which time gaps were significantly different from the aggregated distribution of time gaps for the lead vehicle type investigated. In the majority of cases, there were several following processes for which time gaps were significantly different from the overall time gap distributions. Three examples are presented in tables 48-50, where the results from homogeneity tests are shown. Several additional examples are provided in Appendix C.

The third part of the analysis consisted of investigating whether the differences followed a specific pattern in terms of the order of the following process, which may indicate that these differences are related to drivers' increased familiarity with the instrumented vehicle as the experiment progressed. Consistently decreasing or increasing time gaps would indicate such effects. The results showed that for most drivers, the differences did not follow any pattern and appeared to be random. Figures 40-42 present three examples of these patterns, few more examples are presented in appendix C.

Car following process	N	Subset				
		1	2	3	4	5
following process 5	31	1.2465				
following process 4	33		1.7596			
following process 3	93		1.8353			
all following processes	235			2.2511		
following process 1	35				2.8809	
following process 2	43					3.7395
Sig.		1.000	.994	1.000	1.000	1.000

Table 48: Differences in time gaps between following processes (example 1)

HGV following process	N	Subset					
		1	2	3	4	5	6
following process 7	48	.6505					
following process 8	86	.7043	.7043				
following process 5	68		.7462	.7462			
following process 6	135			.7993			
following process 4	56				.9370		
all following processes	756				.9470		
following process 3	131					1.0339	
following process 2	131					1.1118	
following process 1	101						1.3063
Sig.		.531	.823	.550	1.000	.086	1.000

Table 49: Differences in time gaps between following processes (example 2)

HGV following process	N	Subset				
		1	2	3	4	5
following process 6	89	1.1431				
following process 1	98	1.1440				
following process 2	121		1.2178			
all following processes	601			1.2884		
following process 4	46			1.3283	1.3283	
following process 5	131				1.3750	
following process 3	116					1.4821
Sig.		1.000	1.000	.562	.364	1.000

Table 50: Differences in time gaps between following processes (example 3)

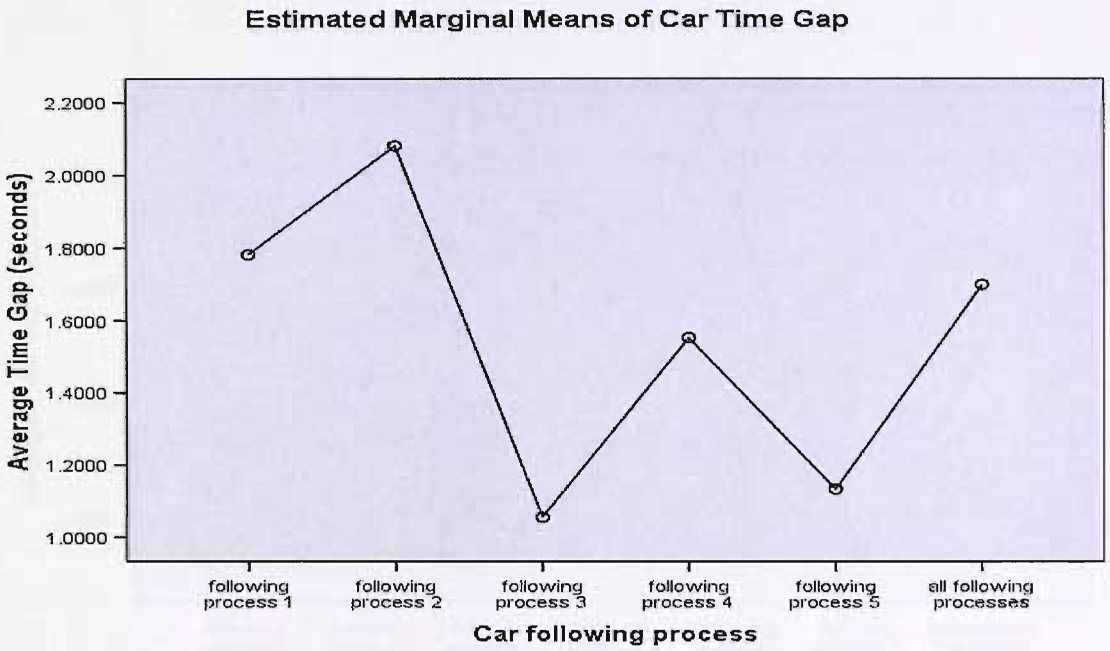

Figure 40: Randomness of variation in time gaps (example 1)

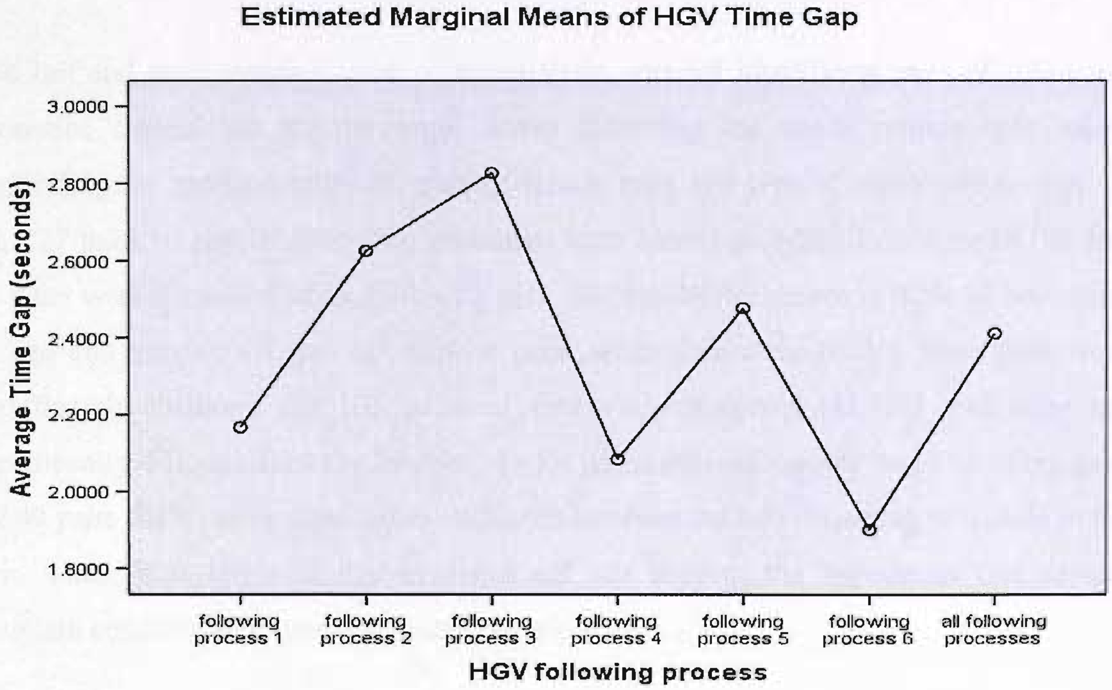

Figure 41: Randomness of variation in time gaps (example 2)

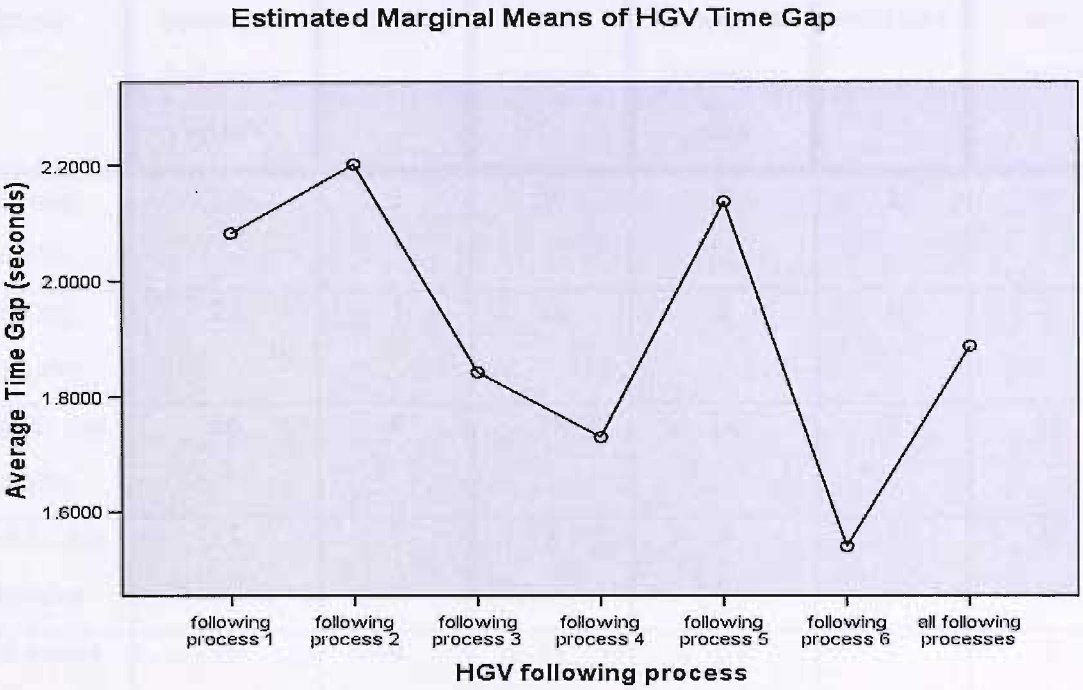

Figure 42: Randomness of variation in time gaps (example 3)

The last and most detailed level of the analysis entailed identifying pairs of following processes carried out by the same driver following the same vehicle type while controlling for traffic conditions, trailing vehicle type and type of motorway section. In all, 127 pairs of similar following processes were identified while following HGVs and 44 pairs were identified while following cars. The results are shown in table 51 according to age and gender. Of the 127 similar pairs while following HGVs, time gaps were significantly different for 103 pairs of following processes (81.1%) and were not significantly different for only 24 pairs. As for when the lead vehicle was a car, time gaps for 40 pairs (91%) were significantly different between the two following processes in the pair. Thus, it is apparent that evidence did not support the hypothesis that drivers maintain constant time gaps while car-following.

Age/gender group	# of processes following HGVs	Time gap constant	Time gap not constant	# of processes following cars	Time gap constant	Time gap not constant
Young males	32	2	30	9	1	8
Young females	23	5	18	2	0	2
Middle age males	36	8	28	14	1	13
Middle age females	11	3	8	9	1	8
Old males	15	4	11	5	1	4
Old females	10	2	8	5	0	5

Table 51: Constancy of time gaps according to vehicle type, age and gender

It must be noted that the analysis for this part were carried out on data sampled at one reading per second. This was done since the comparisons here were made between pairs of following processes, unlike previous analysis were time gaps were aggregated from numerous following processes. Thus, reducing the data to one reading every 10 seconds would have resulted in a vast number of following processes being misrepresented. In addition, the comparisons in tables 47-49 were presented in terms of average time gaps per following process. It is doubtful that reducing the data to one reading every 10 seconds would affect the results significantly in this part of the analysis.

10.7 Analysis of Questionnaire Responses

This part of the analysis is concerned with eliciting the effects of HGVs from the surveys completed by drivers partaking in the study as well as identifying groups of drivers that could be considered aggressive in order to correlate driver behaviour as monitored in the experiments with driver aggressiveness. Prior to analyzing the questionnaires, a noteworthy result from the questionnaires with significant implications regarding the applicability and feasibility of the results obtained here relates to the frequency of encountering situations where the driver is following an HGV. Of the 33 subjects completing the questionnaires, 4 indicated being in such situations "fairly often" while 15 indicated "occasionally" encountering such situations. 13 of the remaining 14 subjects stated that they "rarely" find themselves in such situations while one driver indicated never being faced with such conditions.

10.7.1 The Effects of HGVs

In total, 33 subjects completed the questionnaires. Of those, 30 subjects were the ones for whom data was used in the analysis. Another 2 subjects completed the experiment in rainy conditions, and hence their data was eliminated from the analysis. A further subject completed the questionnaire but was unable to complete the experiment due to failure of some of the systems in the instrumented vehicle. The questionnaire was made up of 6 parts. The analysis here focuses on parts II, III and IV only, since these parts were more relevant in terms of driver behaviour while following HGVs.

Of the 33 subjects completing the questionnaires, 18 subject (54.5%) indicated that they increase their headways while following HGVs either fairly often (14) or often (4). Two subjects indicated that they "occasionally" increase their headways while following HGVs, 11 responded that they "rarely" increase their headways and 2 responded that they "never" increase their headways while following HGVs. When the responses of the questionnaires were compared to subjects' measured driver behaviour in terms of time gaps while following cars and HGVs, questionnaire responses did not match the measured driver behaviour for 15 of the 30 subjects who carried out the driving experiments. As regards the awareness level when in the vicinity of HGVs, the majority of drivers indicated that they increased their awareness level either "often" (7) or "fairly often" (18), while 5 subjects replied that they "occasionally" increase their awareness level when in the vicinity of HGVs. The remaining 3 subjects indicated that they "rarely" increase their awareness level. The next item to be elicited from this part of the questionnaire was whether the effects of HGVs were more pronounced during inclement weather and/or poor lighting conditions. This was done by asking drivers to respond to a statement that they allowed greater headways when following HGVs in night time and/or wet conditions than they did in dry, daytime conditions. Of all the questions in the questionnaire, this question had the most unanimous agreement. 15 subjects indicated increasing headways in such conditions "often", 16 subjects indicated doing so "fairly often" and the remaining 2 indicated doing so "occasionally". As for the effects of being followed by HGVs, most drivers indicated that they felt the need to increase their awareness level when being followed by an HGV as compared to being followed by a car. Of the 33 responses, 11 indicated increasing awareness level when followed by HGVs "often", 16 indicated doing so "fairly often" and 4 subjects did so "occasionally". One subject indicated "rarely" increasing awareness level when trailed by HGVs and another indicated "never" doing so.

With regard to the effects of HGVs during different road, traffic and environmental conditions, most drivers indicated following HGVs at greater headways than following cars in wet conditions. In the sample, 13 subjects responded with "often", 9 responded with "fairly often", 5 responded with "occasionally", another 5 responded with "rarely" and one subject responded with "never". This implied that differences in driver behaviour while following HGVs and cars manifest most in wet conditions. Nearly similar responses were obtained regarding the effects of HGVs on driver behaviour in night time driving. When responding to the statement of driving at greater headways while following HGVs at night time conditions compared to following cars at these conditions, 7 responded with "often", 13 with "fairly often", 5 responded with "occasionally", another 5 with “rarely” and one subject responded with “never”. Drivers’ responses to comparing following HGVs to following cars in congested conditions indicated that the majority of drivers increase their headways while following HGVs in congested conditions compared to following cars in these conditions. This was apparent from the responses, where 6 drivers indicated doing so “often” and 14 indicated doing so “fairly often”. Of the remaining 13 subjects, 6 indicated that they “occasionally” follow HGVs at greater headways in congested conditions, while another 6 indicated doing so “rarely”. One subject responded with “never” increasing headway while following HGVs in these conditions. The last two questions of this part related to HGVs’ effects at upgrade and downgrade sections, where drivers indicated greater effects of HGVs at downgrade sections compared to upgrade sections. This again was not completely in line with the results obtained from the field data.

The last part of the questionnaire analyzed here pertains to drivers’ view as to the sources of the effects of HGVs. For this part, responses were converted to a measure by assigning weights to the various responses. Responding with “strongly agree” to a question regarding the effects of a particular source of HGVs’ effects contributed a weight of 5 points to that source, “agree” with 4 points, “neutral” with 3 points, “disagree” with 2 points and “strongly disagree” with a single point. This resulted in vision obscuration being the most significant source of HGVs’ effects, as perceived by drivers who completed the questionnaires. The psychological effects imposed by HGVs on following drivers and making driven vehicle visible to HGV’s driver were equally significant as sources of HGVs’ effects and were exceeded only by vision obscuration as a source of HGVs’ effects. The next highest source of HGVs’ effects is that “HGVs are driven at low speeds” followed by “excessive vibration of HGVs’ loads due to wind turbulences”. The source receiving the lowest rating was “HGVs exhaust pollution”, to which most drivers associated a response of disagree or strongly disagree.

10.7.2 Identifying Aggressive Drivers and their Driving Behaviours

The first part of the questionnaire was used to investigate the presence of relationships between drivers' aggressiveness and their observed car-following behaviour during the experiments. In doing so, drivers' aggressiveness was elicited from the frequency of exceeding the speed limit by 10 MPH or more, the tendency to follow slower moving vehicles in the fast lane closely to pressure them into moving to another lane and the frequency of following other vehicles at headways of 1 second or less. A driver was marked as showing aggressive driver behaviour in the driving experiments if the average time gap for that driver while following HGVs and cars was contained in the lower one-third of the overall distribution of time gaps obtained in the study. Time gap boundaries were established to identify the lower one-third of the overall time gap distributions while following HGVs and cars. The overall average time gap obtained from the experiments while following HGVs was 1.8489 seconds and the standard deviation was 0.8226 seconds. The overall average time gap while following cars was 1.6739 seconds and the standard deviation was 0.6793 seconds. The boundary condition was estimated as the overall average time gap for a specific lead vehicle type minus half a standard deviation. Drivers for whom the average time gap while following HGVs or cars was lower than the boundary value were marked as displaying aggressive behaviour in the experiments.

Of the 30 subjects that participated in the driving experiments, 15 indicated exceeding the speed limit by 10 MPH or more either "fairly often" or "often". Of these 15 drivers, 7 had average time gaps while following HGVs and cars that were among the lower one-third of the overall distribution of time gaps observed in the study. However, for 5 drivers who indicated exceeding the speed limit frequently, the average time gaps observed during the experiments were greater than the overall average time gaps observed for both lead vehicle types. The other 3 drivers who indicated exceeding the speed limit frequently had average time gaps that were slightly lower than the overall average time gaps, but their average time gaps were not among the lower one-third of the overall distribution. This may imply that frequency of exceeding the speed limit may not be a good indicator of drivers' aggressiveness, at least in terms of headways adopted while following.

Another part of the questionnaire that was used to elicit drivers' aggressiveness was a question pertaining to the frequency of following at headways of 1 second or less on the motorway. Only two of the subjects taking part in the study indicated doing so "fairly often" and none indicated doing so "often". While neither of the two drivers had an average time gap that was close to 1 second, one of them had average time gaps while following HGVs and cars that were among the lower one-third of the overall distribution of time gaps. On the other hand, 4 out of the 30 subjects had average time gaps while following HGVs and cars that were lower than or close to 1 second, which meant that their average time gaps while following were among the lower 15th percentile of the overall time gaps distribution. Of these 4 drivers, 2 indicated maintaining headways of 1 second or less "occasionally" while one subject indicated "never" maintaining time headways of 1 second or less and another indicated "rarely" doing so. A similar conclusion to that obtained when drivers' aggressiveness was drawn out from the frequency of exceeding the speed limit can be inferred here, although the number of subjects identified as aggressive based on this measure was significantly smaller.

Another question that could be used to assess drivers' aggressiveness dealt with the frequency of following slow vehicles closely on the fast lane to pressure their drivers into moving to a slower lane. Only one subject indicated doing so "fairly often", for whom the average time gaps while following HGVs and cars were the lowest observed among all other subjects. Of the other 3 drivers who maintained time gaps of less than or around 1 second, one indicated following slow drivers closely on the fast lane "occasionally", while one driver indicated "rarely" doing so and another indicated "never" undertaking such aggressive behaviour. It can therefore be concluded that as with the previous two measures of drivers' aggressiveness, this measure cannot provide reliable results in identifying aggressive drivers. Thus, of the three questions geared towards eliciting some measure of drivers' aggressiveness, none yielded reliable results that consistently conformed to what was observed in the driving experiments. This confirms what was stated earlier that drivers' stated behaviour in questionnaires may not match their displayed behaviours whilst driving on the road.

When the three items from the questionnaires mentioned above were used collectively to elicit drivers' aggressiveness by associating weights to each response in order to obtain aggressiveness scores for each subject, this resulted in five of the 30 subjects being identified as aggressive drivers. Of those five subjects, 4 had average following time gaps that were among the lower one-third of the overall time gap distribution. On the other hand, five other subjects had average time gaps that were among the lower one-third of the overall time gap distributions, none of whom was identified as an aggressive driver based on their responses to the questionnaires. This may lead to one of two conclusions; either a direct relationship does not exist between drivers' aggressiveness and driver behaviour, or drivers' aggressiveness cannot be elicited accurately based on drivers' responses to questionnaires. Since a number of previous studies showed driver behaviour to be strongly linked with drivers' aggressiveness, (Ulleberg and Rundmo 2003, Owsley *et al.* 2003 and Cassidy and Windover 1998), it is more likely that the second conclusion is the more appropriate one.

Chapter 11

Discussion

This chapter discusses the results obtained in chapter 10 in light of the objectives set forth for this study. The 10 objectives that were outlined in the introduction have all been achieved. The results concerning some of the objectives conformed to expectations and literature, while other results differed from previous expectations or from what is stated in the literature. The large data base accumulated allowed for these objectives to be fulfilled. A discussion of the results and their implications is presented in this chapter. The results relating to the effects of HGVs on driver behaviour constitute the main focus of this chapter, since implications of these results form the main aim of the current study. Other results pertaining to general aspects of driver behaviour while car-following as well as the effects of drivers' characteristics on driver behaviour are also touched upon.

This chapter is divided into 7 sections, covering the various objectives of the study. The first section addresses what has been learned regarding the effects of HGVs on driver behaviour, the sources of these effects and the variation of these effects according to other driver and roadway factors. The second section addresses the variation of driver behaviour while car-following according to 2 driver characteristics, age and gender. Following that is a section discussing driver stability while car-following according to age and gender. The fourth section addresses an issue that have not been addressed in the literature, that of the effects of trailing vehicle type on driver behaviour while following. Following that is a section dealing with an important finding of the current study regarding the widely accepted view that time headway is constant for the individual driver. The penultimate section of this chapter reviews the model building procedure implemented in chapter 10, which aimed at producing a model that can predict time gaps based on a set of easily measured variables. The final section of this chapter presents a brief discussion on the applicability of results obtained here as well as providing provisions for future studies on driver behaviour.

11.1 The Effects of HGVs on Driver Behaviour while Following

11.1.1 Presence of HGVs' Effects

It can be inferred from the results that drivers in general follow HGVs at greater headways than they follow cars. However, this finding cannot be generalized on all drivers of differing characteristics, as illustrated by analysing multi-factor interactions. This may give rise to an argument that the effects of HGVs on driver behaviour are not consistent and could be questioned. Nevertheless, since this effect persisted for two age/gender groups in light flow conditions and for another two age/gender groups in moderate flow conditions, and since comparisons among the interactions were made between time gaps while following cars with time gaps while following HGVs on flat sections which were found to be lower than time gaps of following HGVs on upgrade sections, the results from analyzing the multi-factor interactions cannot be seen to be in disagreement with the general trend observed while analyzing the effects of lead vehicle type separately. This finding was supported by the generally larger parameters obtained for time gaps while following HGVs compared to those while following cars as shown in the developed model. This finding was also supported by the individual analysis, where the number of drivers following HGVs at larger time gaps than cars far exceeded the number of drivers with greater time gaps while following cars. Thus, it can be stated with confidence that the effects of HGVs on driver behaviour are those of increasing drivers' headways while following.

This finding conforms to findings from Yoo and Green (1999) and Peeta *et al.* (2004 and 2005). The finding here is also in line with headway observations reported in Hoogendoorn and Bovy (2001A), Ozaki (1993) and in one part of Mannering *et al.* (1993). The sound methodology and vast amount of data gathered in this study provide strong support for the conclusions regarding HGVs' effects on driver behaviour while car-following. The conclusion in Parker (1996) that time gaps while following HGVs were smaller than those while following cars was in contradiction with the finding here. This could be explained by the fact that the Parker (1996) study was confined to roadwork sites. In addition, the methodology used in Parker (1996), where video cameras were used to obtain data, lays some doubt on the results obtained.

The implications of this finding are multi-faceted. First, this finding emphasizes what has been stated in the literature (Peeta *et al.* 2005, Parker 1996 and Grenzeback *et al.* 1990) that the effects of HGVs on capacity surpass those resulting from HGVs' size and performance characteristics. When accounting for the effects of HGVs on capacity, their impact on driver behaviour must also be considered to allow for accurate assessment of capacity reductions due to HGVs. Second, this finding stresses the importance of incorporating the effects of HGVs on driver behaviour into microscopic simulation models, if these models strive to emulate real traffic conditions. Third, this finding accentuates the importance of adjusting car-following algorithms used in new in-vehicle technologies to make these technologies more in compliance with actual driver behaviour.

11.1.2 Sources of HGVs' Effects

Comparison of time gaps while following HGVs with time gaps while following another vehicle type which obscures following drivers' vision, vans, revealed that the sources of HGVs effects are not confined to them obscuring the vision of the following vehicle's driver. If the effects of HGVs resulted exclusively from vision obscuration, one would expect headways while following HGVs to be similar to those while following vans. The analysis of the effects of lead vehicle type clearly showed that time gaps while following HGVs were greater than those of following vans. This was supported by the analysis carried out on each driver individually. Further support for this finding was provided from the linear model, where it could be seen that the parameters associated with following HGVs were generally larger than those associated with following vans. Hence, the overall trend clearly indicates that drivers maintain greater headways while following HGVs than they do while following vans.

This does not imply in any way that vision obscuration is not a source of the effects of HGVs. To the contrary, this study confirmed that vision obscuration is a main source of the effects of HGVs on driver behaviour. The conclusion that vision obscuration is a source of HGVs' effects was inferred from questionnaire responses, where drivers who completed the questionnaires regarded vision obscuration as the principal source of HGVs' effects on driver behaviour. The argument made here, however, is that there are other sources that contribute to the effects of HGVs on driver behaviour while following, resulting in an increase in time headways while following HGVs. One of the sources of the effects of HGVs that was inferred in this study is following drivers' desire to make their vehicles visible to HGVs' drivers as they followed HGVs. Maintaining greater headways while following HGVs, and thus allowing the HGV driver to notice their presence, ensures that HGVs' drivers account for the vehicle behind in any decisions they make.

Another source of the effects of HGVs which the current study strongly supported is that the distinctive appearance of HGVs, with their large sizes and masses, imposes a psychological impact on drivers following HGVs. This forces drivers following HGVs to increase their headways to allow themselves a greater margin of safety, which would increase the likelihood of taking evasive action to avoid colliding with HGVs in the event these HGVs were to decelerate abruptly. This source of the effects of HGVs was confirmed by the risk analysis, which was conducted using four different methods. The differences in time gap distributions associated with risk ratings of "medium risk" while following HGVs and those distributions while following cars imply that drivers' risk perceptions towards HGVs were different from their perceptions towards cars. These differences indicate that drivers perceive HGVs to pose greater risk than cars. As the method of verbal rating does not necessarily yield reliable results, as was mentioned in chapter 10, other methods to assess drivers' risk behaviour were implemented. Drivers' responses to questionnaires indicated that HGVs impose a psychological impact on drivers, and that these psychological impacts form a source of HGVs' effects. Minimum time gaps observed in each following process also collaborated with this finding, since the minimum time gaps observed during following processes where cars were lead vehicles were significantly less than those where HGVs were lead vehicles. Moreover, time-to-collision confirmed the findings obtained from the previous three methods, while also indicating that drivers viewed HGVs to be more risky than vans as well. Consequently, it can be deduced that drivers perceive HGVs to be riskier than cars, and hence chose to follow them at greater headways. This finding is in agreement with arguments made in Mussa and Price (2004), Magarula and Mussa (2003), Al-Kaisy *et al.* (2002), Parker (1996), Mannering *et al.* (1993) and Krammes and Crowley (1986), although none of these studies actually tested the hypothesis of psychological effects imposed by HGVs.

Other sources of the effects of HGVs were also elicited from the questionnaires, although these sources were not rated as highly as those of vision obscuration, psychological effects and making following vehicle visible to HGV's driver. The two additional sources of the effects of HGVs were that HGVs are driven at low speeds and the excessive vibration of HGVs due to wind turbulences. These sources along with the desire to make the following vehicle visible to the HGV's driver were not tested in the field, however, and were solely based on subjects' responses to questionnaires.

11.1.3 Variation of HGVs' Effects with Age, Gender and Gradient

The main finding from this study is that drivers increase their headways while following HGVs compared to following cars. However, the effects of HGVs on driver behaviour are not uniform for the entire driving population. Investigating the interactions of some factors with lead vehicle type revealed that the driving behaviour of certain driver groups is affected less by HGVs than that of other groups. Young males followed HGVs at greater time gaps than they followed cars in light and moderate traffic conditions. Young female drivers followed HGVs at greater time gaps than cars in moderate traffic conditions. Similarly, old female drivers followed HGVs at greater time gaps than they followed cars in light conditions. In addition, time gaps while following HGVs on upgrade sections were found to be larger than time gaps while following cars for middle aged and old female drivers in moderate traffic conditions. Thus, it may be argued that young male drivers, young female drivers and old female drivers are more susceptible to being affected by HGVs while car-following.

While the effects of HGVs on driver behaviour cannot be generalized for all driver groups, the trends shown by certain driver groups regarding the effects of lead vehicle type on driver behaviour cannot be generalized for all drivers belonging to that group. The individual analysis showed that the effects of lead vehicle type on driver behaviour while following were not uniform for any driver group. Thus, what was inferred from analyzing the multi-factor interaction regarding the effects of HGVs according to age/gender group can merely be considered a general trend that does not necessarily (and in all likelihood does not) apply to all members of that group.

The effects of HGVs on driver behaviour also varied according to roadway gradient. Although the differences between time gaps while following HGVs on upgrade and downgrade sections were not found to be significant, time gaps while following HGVs on upgrade sections were larger than those on flat sections. This was in line with findings from Webster and Elefteriadou (1999) and Elefteriadou et *al.* (1996). This may be related to one of the sources of HGVs' effects mentioned earlier, that of HGVs being driven at low speeds. As HGVs' speeds are reduced even further on upgrade sections, the further reduction in speed may result in a further increase of drivers' headways while following HGVs. Another possible explanation for this increase in time gaps on upgrade sections is that drivers might be more inclined to overtake HGVs on upgrade sections, when their speeds are further reduced. This effect might have been imprinted as a part of drivers' normal driving behaviour. Although drivers were instructed not to change lanes, they reverted to what had become part of their normal driving, exhibited as an increase in headways while following HGVs on upgrade sections.

As was the case with other factors investigated earlier, the increase in HGVs' effects on upgrade sections was not uniform for all driver groups. Although the overall effect of gradient was that time gaps increased while following HGVs on upgrade sections, for four age/gender driver groups in light traffic flows (young males, middle aged males, young females and middle aged females) and two driver groups in moderate flow conditions (middle aged males and young females), there were no differences in time gaps while following HGVs according to gradient type. Additionally, time gaps on flat sections were larger than those on upgrade sections for young males in moderate traffic conditions. Nonetheless, support for results obtained about gradient effects is reinforced by the fact that for old male and female drivers in light conditions and for old males, middle aged females and old females in moderate traffic conditions, time gaps while following HGVs on upgrade sections were greater than those on flat sections. The results obtained from analyzing the interactions may explain the somewhat high, although significant p-value of 0.035 observed for differences in time gaps between upgrade and flat sections. Results obtained from analyzing the interactions were further emphasized by investigating the parameters in the model associated with following HGVs on upgrade and flat sections. Although the general trend from the model parameters support the conclusion of greater time gaps on upgrade sections than on flat sections, the parameters associated with flat sections were greater than those associated with upgrade sections for a significant number of traffic/gender/age groups. Therefore, the main argument made in this regard is that the effects of HGVs are magnified on upgrade sections but not to a large extent.

11.2 The Effects of Driver Characteristics

The effects of gender were found to be significant in this study. Male drivers were found to follow at smaller time gaps than female drivers. This finding provides certainty for the effects of a driver characteristic that had previously lacked such certainty. Although many earlier studies have reached the conclusion inferred here regarding driver gender (Wang *et al.* 2004 and Evans and Wasielewski 1983), there are other studies that found no difference in driver behaviour related to this driver characteristic (Boyce and Geller 2002, Taieb-Maimon and Shinar 2001 and Sayer *et al.* 2000).

For age, the result that conformed to expectations was that old drivers follow at larger headways than young and middle aged drivers. This was in agreement with Boyce and Geller (2002), Sayer *et al* (2000), Evans and Wasielewski (1983), Dingus *et al* (1997) and Taieb-Maimon and Shinar (2001). This implies that setting an age threshold of 55 years old to distinguish old drivers from middle aged ones did not affect the previously observed result of older drivers following at greater headways than young and middle aged drivers. Therefore, an argument can be made that any differences in driver behaviour between drivers aged 55-60 and those over 60 may be very mild if not negligible.

The differences in time gaps were not found to be significant between young and middle aged drivers. This was not consistent with results from Boyce and Geller (2002) and Sayer *et al* (2000). Comparisons could not be made between results obtained here and those obtained from Evans and Wasielewski (1983), Dingus *et al* (1997) and Taieb-Maimon and Shinar (2001) since in these studies results were disclosed in terms of comparisons between driver behaviour of younger and older drivers, without specifically touching on driver behaviour of middle aged drivers. The general trend on the effects of age persisted irrespective of lead vehicle type.

The discrepancy between results obtained here and those obtained earlier regarding differences in following behaviour between young and middle aged drivers might be due to sampling biases in recruiting young drivers, where all but one young driver were full time university students. In addition, only young drivers with no previous history of violations, having a minimum driving experience of 3 years and aged 21-25 were allowed to participate in the experiment. Hence, the sample of young drivers included in this study is not representative of the entire spectrum of the young driver population. Although it might be tempting to attribute the lack of differences in time gaps between young and middle aged drivers to driving experience which may have made middle aged drivers better equipped to judge on the appropriate headway to maintain while car following, it is likely that selecting a more representative sample of young drivers would yield different results than the ones obtained here, which might be in higher conformance with results obtained in the literature.

11.3 Driver Stability

The results showed that middle aged drivers of both genders and young female drivers display the greatest stability in time gaps while car-following, with middle aged male and female drivers performing slightly better than young female drivers with respect to maintaining consistent time gaps while following. Old female drivers were found to display the least stable behaviour while car-following in terms of variation of time gaps, followed by young and old male drivers. These findings, based on comparisons of variances of time gaps, must be treated with caution since the condition required for carrying out the statistical analysis was not fully met. These findings were generally supported when investigating drivers' abilities to maintain relatively constant speeds with their leaders, although some doubt might be laid on the results of this aspect of stability for old female drivers. In addition, young female drivers displayed slightly more stable behaviour when stability was investigated in terms of relative velocity than middle aged male and female drivers. Thus, the conclusion reached here is that middle aged male and female drivers and young female drivers display more stable behaviour while car-following, while young and old male drivers and old female drivers display less stable behaviour while car-following.

As regards driver stability according to lead vehicle type, the three driver groups identified to possess less stable behaviour, namely young males, old males and old females, demonstrated greater stability while following cars than they did while following HGVs. For young and middle aged female drivers, there was no difference in stability of car-following according to lead vehicle type. Middle aged male drivers displayed greater stability while following HGVs compared with following cars. The results concerning stability according to lead vehicle type might be seen to provide further support for the conclusion mentioned above, since the lower speed and acceleration capacities of HGVs would suggest more stable behaviour of their followers compared to cars. Caution must also be exercised regarding stability according to lead vehicle type since the data analyzed was not in complete conformance with requirements of the tests used.

This implies that the results regarding the effects of lead vehicle type obtained for young female, middle aged female and middle aged male drivers have the highest credibility. The high variability in headways for young and old male and old female drivers resulted mainly from the between-driver variation. Each of these three groups showed significant lack of homogeneity among its members.

11.4 The Effects of Trailing Vehicle Type

The hypothesis set forth at the beginning of the study regarding this factor was that drivers increase their headways while being followed by HGVs to allow more space to manoeuvre in case evasive action is required. The analysis carried out on this factor did not support this hypothesis. No specific trends could be established that associate higher or lower time gaps with any trailing vehicle category. Thus, the conclusion reached in this study regarding trailing vehicle type is that driver behaviour, measured by time gaps to the lead vehicle, is not affected by the type of vehicle trailing. Being followed by an HGV does not result in adopting greater headways while car-following.

Although drivers' responses to questionnaires indicated that drivers increase their awareness level when being followed by HGVs, this rise in awareness does not necessarily take the form of greater following headways, as was shown in this study. The increase in awareness level may be in the form of looking at the rear view mirror more frequently, increasing attention, higher stress resulting from the perceived rise in the level of risk or any other aspect of awareness that may not be directly related to following headways. Thus, evidence from the current study did not support the hypothesis that drivers change their headways according to trailing vehicle type. This finding is in line with what is stated in the literature that relative speed and separation distance with the lead vehicle constitute the major cues on which decisions are based while car-following (Chakroborty 2006, Cheng *et al.* 2005, Michaels and Solomon 1962 and Herman and Potts 1961). In so far as drivers' actions while car-following are translated into time gaps to the lead vehicle, the finding from the current study is not in conformance with what is argued by Rakha and Crowther (2002 and 2003), that drivers base their actions on the vehicle immediately behind in addition to the vehicle immediately ahead, vehicles further downstream and traffic control devices.

11.5 Is Time Headway Constant for the Individual Driver?

The results obtained from this study proved that time headway varies for the individual driver from one following process to another. This was proved from analysis carried out on 4 levels, where all the external factors that may have resulted in such variation were controlled for at the 4 different levels. Although this analysis was carried out on data sampled at one second, with the possible consequence that results may have been amplified by correlations between observations, the significant differences between average time gaps from one following process to another as shown in tables 47 - 49 and in the 12 tables in appendix C support the findings inferred from this analysis. This difference from one following process to another is attributed to factors that go beyond the external factors that may alter driver behaviour while following such as driver state, driver fatigue and being under time pressure. What is argued here is that these differences are attributed to the same factors that cause variation in distance and time headways with relative speed in a single car-following process. This would indicate that the variation from one process to another is related to drivers' perception thresholds and their ability to execute their decisions precisely. The variation may also be related to drivers' lack of ability to estimate distance and time gaps accurately.

This finding contradicts the majority of what is stated in the literature in this regard. Numerous studies argued that an individual driver's time headway remains constant, while distance headway varies with speed in a manner that maintains time headway at or around this constant time headway (Kim and Lovell 2005, Taieb-Maimon and Shinar 2001, Cassidy and Windover 1998, van Winsum and Brouwer 1997, van Winsum and Heino 1996 and Heino *et al.* 1992). However, the methodology used here; with the sophisticated data collection apparatus, the relatively large number of subjects and the large quantity of data obtained for each subject substantiate the finding reached in the current study.

This conclusion has many important implications, the most salient of which relates to car-following algorithms utilized in many in-vehicle technologies. Many of these technologies operate with a constant time gap algorithm. Since evidence from the current study has shown that time gap is not constant for the individual driver, this algorithm must be revised to make these technologies more effective as driver aid tools.

11.6 Modelling Drivers' Headways while Following

A linear model was fitted to the data, with time gap as the predictor variable. Although the R-Squared value for the model was low, implying that the majority of variation in time gaps could not be accounted for by the model, this is not seen as an issue that undermines the validity of the model. Variation in time gaps existed on four levels; variation of time gaps in a particular car-following process, variation of time gaps from one following process to another for the individual driver, variation between drivers belonging to the same age/gender group and variation from one age/gender group to another. Thus, it is doubtful that any modelling technique will yield better results in accounting for the variation in time gaps, although an attempt to develop a model using the fuzzy logic technique might prove otherwise. It must be noted that the purpose of developing the linear model was not to produce a model that is used directly for prediction purposes in simulation models or in in-vehicle technologies. Rather, the purpose here was to develop a starting point for models that take various factors into account while predicting headways, including lead vehicle type.

11.7 Applicability of Results and Provisions for Future Studies

Several issues could be identified that may undermine the applicability of the results obtained from the current study. The first issue relates to the overall aim of the study, that of addressing the argument that drivers seldom follow HGVs on motorways and that the results from the study are more applicable to two-lane roads with one lane in each direction. Hence any possible adjustments to car-following models to include the effects of HGVs would be uncalled for. However, through examining responses obtained from questionnaires, more than half the sample (19 out of 33) indicated encountering situations where they are forced to follow HGVs for a significant duration on the motorway either occasionally or fairly often. Moreover, the fact that there were 41 non-instructed following processes of following HGVs in this study refutes this argument.

The second issue undermining applicability of results is raised by the argument that drivers carried out the experiments while complying with specific instructions not change lanes, which means that they are forced to follow even when the surrounding conditions provide them with the opportunity to overtake. However, the aim in designing the experiment was to duplicate situations were drivers are forced to follow, situations where the surrounding conditions do not permit lane change manoeuvres to be executed instantaneously. Since these conditions could not be duplicated naturally, this remains one of the limitations of the current study since the conditions that force drivers to be involved in car-following had to be assumed even if the actual conditions severely differed from those that would result in normal car-following processes.

The most serious issue undermining applicability of results is the difference in time gaps between following processes executed upon the request of the experimenter and following processes taking place due to natural driving styles of subjects or prevailing conditions. The differences in these time gaps were explained in chapter 10. In so far as differences in driver behaviour according to lead vehicle type, age, gender, trailing vehicle type and gradient are concerned, which along with driver stability and risk taking behaviour constitute the major aim of the study, the fact that the experimental design and conditions were consistent for each level of each factor renders the issue of whether following processes were executed forcefully or voluntarily irrelevant. Since the aim was comparing various levels of each factor, and since any limitation associated with the experimental design was not biased towards any certain level of a specific factor, the inferences made regarding the general effects of the factors being studied can be considered valid. Therefore, the issue of whether the results are transferable due to differences in forced vs. voluntary following is more applicable to parameters obtained for the model. The relevance of this issue is further diminished when the statement made earlier that the aim of building the model was to establish a starting point rather than producing a final model to be used in applications is taken into considerations. Despite the fact that the model was built from data which could be judged with great certainty to represent car-following data, it is recommended that another study is carried out where the design of the experiment does not call for any instructions to be given to the subject. Such design will eliminate any possible effects that may have stemmed from drivers conforming to any instructions. Such study will serve to determine the transferability of the results obtained here as well as validating the model produced in this study.

In light of what has been learned from this study, future studies must take into account the possibility that drivers may not display normal driving behaviour if they are obliged to conform to certain instructions laid down by the experimenter. A possible experimental design that may overcome such methodological deficiency is to allow the subject to carry out the experiment unaccompanied where the subject is asked to follow a specific path. Ensuring an appreciable number of following processes may be done by requesting that the subject conforms to the speed limit or by placing restrictions on using the fast lane. This may yet lead to a significantly reduced number of following processes of HGVs and vans compared to what had been obtained in this study. However, any numbers obtained would have more validity associated with them with regard to being representative of actual driving behaviour.

Another provision for future research is to strive to attain a sample of subjects as representative of the driving population as possible. The current study suffered from sampling biases for the young population. A sample representing a wider spectrum of this group may well have led to different results. In addition, it would be advisable to recruit a significantly larger number of subjects than the target number of subject to offset possible technical errors, weather conditions or cancellations.

The current study clearly found that driver behaviour as elicited from questionnaires does not match behaviour displayed in the field. This was the case for 15 of the 30 subjects taking part in the study concerning the effects of HGVs on their driver behaviour. Thus, it is suggested that any results pertaining to driver behaviour obtained solely from questionnaires be treated with the due caution they deserve.

Chapter 12

Conclusions and Future Work

12.1 Conclusions

Car-following is a process with prominent significance in traffic flow theory. It forms the basis for one of the most powerful research tools available, microscopic simulation models. It is also a fundamental component of many of the new in-vehicle technologies that are developed to ensure safer and more efficient operations on the roads. In order to further our understanding of traffic flow theory and improve microscopic simulation models and in-vehicle technologies, many of the factors that affect car-following and driver behaviour while car-following must be investigated accurately and comprehensively. A factor that influences driver behaviour while car-following for which very limited research was dedicated is addressed in the current study. This factor is lead vehicle type, with the emphasis in this study on the effects of HGVs as lead vehicles on drivers' car-following behaviour. In addition to studying the effects of HGVs on driver behaviour while following, several other factors that were also believed to influence car-following behaviour were addressed, along with investigating certain aspects of car-following.

Accurate monitoring of car-following requires a tool that realizes the nature of the process, which progresses over an extended period of time. Utilizing instrumented vehicles for research focusing on driver behaviour while following provides great validity for the results obtained, since driver behaviour in such research is measured comprehensively and realistically. The TRG's instrumented vehicle was used in this study to compile a data base on driver behaviour while car-following on the motorway. The highly sophisticated systems fitted to the TRG's instrumented vehicle vastly improved data measuring capabilities as well as accuracies of measurements. This tool allowed for various factors that influence car-following to be investigated. The methodology employed in this study; with the highly advanced data collection tools, diverse sample of subjects participating in the study and the real environment in which the experiments took place, provide great validity for the results obtained. Various other tools have been employed to collect data on driver behaviour while following, such as video cameras, loop detectors, simulators, questionnaires and even instrumented vehicles on test tracks. However, studies that utilized these tools suffer from methodological deficiencies as a result of the data collection tools used. The methodology employed here avoided many of the limitations associated with these studies.

The main conclusion from this study is that drivers in general follow HGVs at greater time headways than they follow cars or vans. Although this conclusion cannot be generalized for the entire driving population, it held for several driver groups, which indicates that the general effects of HGVs on driver behaviour while following are those of increasing headways. This implies that the underlying assumptions in microscopic simulation models and in-vehicle technologies that drivers maintain the same headway irrespective of lead vehicle type are not warranted and must be revised. It must be recognized, however, that the effects of HGVs on drivers' following behaviour were not uniform for all drivers. Some driver groups were affected more by HGVs as lead vehicles than others. Furthermore, these effects varied between members of the same age/gender group.

Roadway gradient type was also found to affect driver behaviour while following HGVs. The effects of HGVs on driver behaviour were found to magnify on upgrade sections, were headways were observed to increase compared to those of following HGVs on flat sections. This effect was also found not to be uniform for all drivers, although the general tendency supported the existence of such trend.

Another finding from the current study is that male drivers follow at smaller headways than female drivers, irrespective of lead vehicle type. With regard to age, this study confirmed that old drivers of both genders drive at larger headways than middle aged or young drivers. However, an unexpected finding from the current study is that middle aged drivers adopt similar headways to young drivers while car-following, although this finding was undermined by the biases in selecting drivers to represent the young driver population.

As regards driver stability, the current study concluded that middle aged male drivers, young female drivers and middle aged female drivers generally displayed the highest stability. Young and old male drivers were not as stable as these groups. However, the variation in their headways was not as large as that of old female drivers. Young male, old male and old female drivers showed greater stability while following cars compared to following HGVs. For young female drivers as well as middle aged female drivers, stability was not affected by the lead vehicle type. The reliability of these results could be questioned, however, due the requirement for carrying out the tests that yielded such results not being fully satisfied.

The conclusions from this study also confirmed two of the hypothesized sources of HGVs' effects on driver behaviour. This was done with actual field data in addition to responses from questionnaires. These two sources are vision obscuration of HGVs and the psychological effects they impose on following vehicles' drivers. This implies that HGVs cannot be treated like any other vehicle that obscures following drivers' vision, since the effects of HGVs stem from other sources in addition to vision obscuration. An additional source of HGVs' effects on following drivers' behaviour is that while following HGVs, drivers attempt to make their vehicles visible to the HGV's driver. This source, however, was elicited exclusively from questionnaire responses and was not investigated by any other means, although drivers suggested that this was as robust a source of HGVs' effects as psychological effects were.

The current study found no evidence to associate trailing vehicle type with adopting greater or smaller headways. It is argued in this study that this is due to drivers attaining most of the stimuli that affect their measured driving behaviour from the vehicle immediately in front, which plays the prominent role in this regard, and vehicles further downstream from the vehicle immediately in front. The effects of trailing vehicle type on driver behaviour are marginal and may manifest in forms other than increasing or decreasing headways.

A key finding from the current study is that time headway does not remain constant for the individual driver; it changes from one process to another. This contradicted a concept that has received wide spread support in the literature. The argument made here is that differences in headways from one process to another are caused by the same factors that cause the variation of headways with relative speed in a spiral fashion during a single following process. More specifically, these differences in headways from one process to another result from drivers' perception thresholds, their lack of accuracy in estimating time and distance headway at all times and their lack of ability to implement decisions precisely.

A model was developed in this study to predict time headway based on a set of predictor variables that can easily be measured. Although the model accounted for little over one-third of the variation in time gaps in the data base, the presence of variations in time gaps on several levels makes it doubtful that any modelling technique can result in a model that can account for the majority of variation in headways.

12.2 Study Limitations

As with any research, the results obtained from this study had various limitations. The limitations associated with the current study can be summarised in the following:

- The results were obtained from drivers coming from one region in the UK. Conducting this study with drivers from other regions may yield different results.
- The results for young drivers are only valid for drivers belonging to this group who do not have any penalty points on their driving licenses currently. In

addition, no drivers below the age of 21 were allowed to take part in the study. Moreover, the results from this group may have been skewed by the fact all but one of the young subjects were full time university students. Similarly, results from the middle aged and old groups are only pertinent to drivers from these groups who have not accumulated more than 3 penalty points on their driving licenses, although none of the subjects belonging to this group that have indicated willingness to partake in the study had more than 3 penalty points on their licenses.

- The results are applicable to drivers who had at least three years of driving experience in the UK. Although this condition applied to all drivers participating in the study, it was more relevant to young drivers.
- The results obtained regarding the effects of vans as lead vehicles cannot be as robust as results pertaining to other vehicle types due to large differences in sample sizes.
- The results obtained here are only applicable to driver behaviour while driving on motorways.
- The presence of an experimenter during the execution of the experiments may have resulted in drivers altering their normal driving behaviour, although this effect is reduced when the fact that the experimenter was present with all subjects while following all vehicle types is considered.
- Results obtained in this study were based on data from following processes were drivers were instructed refrain from changing lanes while engaged in an instructed following process even if conditions allowed them to do so. Although it is doubtful that this limitation had any effects on the main findings of the study relating to the effects of lead vehicle type or driver characteristics, this limitation may have affected the parameters of the developed model.
- Subjects carried out the experiments while driving a vehicle that might be different from vehicles they normally drive, although this may have had little effect if any on differences in driver behaviour while following the three lead vehicle types.

- More validity for the results may be achieved by utilizing a larger number of subjects in the study. A greater understanding of the variations of HGVs' effects with drivers' age and gender can be achieved by utilizing a larger number of subjects in each age/gender group, with emphasis on including more drivers in the older age groups.
- Traffic conditions were not accounted for accurately. While it is doubtful that such accurate quantitative account of traffic conditions will alter the results significantly, greater validity for the results might be attained when such quantitative account of traffic conditions is exercised.
- The day-to-day variation in driver behaviour is not accounted for. It is unknown whether similar driver behaviour will be displayed by any subject if the experiment is repeated on a different day.

12.3 Future Research

This study presents a starting point for various possible future research studies relating to car-following in general, and the effects of lead vehicle type in particular. Possible future research to follow on from this study can be divided into two groups, research based on the results of the current study and research to confirm some of the findings from this study. Several possible research projects can be conducted to follow on from the results obtained here. Since this study proved that HGVs as lead vehicles influence driver behaviour while following, research should be carried out where the effects of lead vehicle type, and particularly those of HGVs, on driver behaviour are incorporated into microscopic simulation models to determine whether inclusion of these effects enhances the outputs of these models, making them in higher conformance with actual traffic data. Another possible research in this regard entails collecting similar data to the one compiled from the current study and attempting to model this data using a different modelling technique, such as nonlinear regression or some artificial intelligence method such as fuzzy logic or neural networks. This attempt would be aimed at determining the most appropriate technique to model headway data. Yet another possible research may entail using data that was collected for few subjects in the current study from the eye monitoring system of the instrumented vehicle to investigate the presence of eye glance patterns while following HGVs, cars and vans. Finally, since the majority of drivers indicated that the effects of HGVs are greatly magnified in wet conditions and/or night time driving, research similar to the one carried out here may be conducted in rainy conditions and/or night time. Such research might prove to be highly significant in the area of traffic safety.

The other set of possible future research studies entails confirming and/or strengthening the findings obtained in the current study by overcoming some of the limitations associated with it. This can be done by carrying out similar research but with a larger number of subjects in each age/gender group, which may provide more information regarding the variation in driver behaviour of each group. Another possible research entails collecting data similar to that collected here but with a more even spread in sample sizes of headways according to lead vehicle type. A possible study that may avoid one of the main limitations of the current study entails designing the experiment such that the driver carries out the experiment unaccompanied and without conforming to any instructions that may affect his/her normal driving behaviour. Yet another prospective research that may help validate the results is to carry out similar research but with traffic flow measured quantitatively. Another research that may help validate results obtained here would be to use repeat experiments for individual subjects to determine whether different results can be obtained by accounting for day-to-day variation in driving behaviour. Moreover, as the results from the current study are only applicable to motorways, a possible future research would be to carry out similar research on other road types, whether urban or rural. A brief study may also be conducted where the instrumented vehicle is driven for a significantly longer period before the data collection part of the experiment to determine whether a longer familiarization period affects driver behaviour while driving the instrumented vehicle. The current study may also be repeated by eliminating the limitations resulting from presence of an experimenter and driving a new vehicle by instrumenting drivers' own vehicles for a certain period, and compiling a data base which would be highly representative of drivers' normal driving behaviour.

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Appendix A: Preliminary Questionnaire

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Driver Questionnaire

This questionnaire is part of a research project regarding driver behaviour. The aim of this questionnaire is to gather general information on driver behaviour as well as to recruit drivers to participate in the next stage of this project, in which participants will be required to drive a vehicle out on the road and complete a more detailed questionnaire. Participants in the driving studies **will be paid £20 each** for their involvement.

Completing this questionnaire does not assure inclusion in the research project, as the number of participants required and the available funding are limited. Drivers will be selected to fit predetermined profiles relating to the required characteristics to form several groups of specific characteristics. A wide range of driver characteristics is sought after; meaning that inclusion in the project relies heavily on the timing of responses. Early postage of the questionnaire increases your chances of being included in the project. Those correctly completing and returning this questionnaire by 15th of February 2006 will be entered into **a prize draw to win a GPS Navigator**.

Completing this questionnaire should take less than 10 minutes. Please complete the questionnaire and post it using the freepost envelope provided (no stamp required).

I. About You

1. Gender:

Male

Female

2. Which age category do you fall into?

17-20

21-25

26-30

31-35

36-40

41-45

46-50

51-55

56-60

61-65

over 65

3. What is your employment status? (please tick appropriate box)

Employed full time (30 hours a week or more)

Employed part time (less than 30 hours a week)

Self employed

On training Scheme

Unemployed

Full time student

Retired from paid work

Full time house husband/wife

Not in work (disabled)

Receiving state benefits

II. About Commuting

4. What is the method of transport you use most? (please tick appropriate box)

☐ Driving own vehicle ☐ Public Transport

☐ Cycling ☐ Walking

☐ Other:

5. Do you hold a valid UK driving license?

☐ Yes ☐ No

If Yes, please answer all the remaining questions. If No, please go to section IV.

6. How long have you held a UK driving license?

__________________ Years

7. What is your approximate current annual mileage? (please tick one box only)

☐ Less than 5,000 miles ☐ 5,000-10,000 miles

☐ 10,000-15,000 miles ☐ 15,000-20,000 miles

☐ More than 20,000 miles

8. What percentage of your annual mileage is done on the motorway? (please tick one box only)

☐ Less than 25% ☐ 25% to 50%

☐ 50% to 75% ☐ more than 75%

III. About Your Driving History

9. How many current penalty points do you have on your driving license? (please tick one box only)

☐ None ☐ 3 ☐ more than 3

10. Have you been involved in a car accident as a driver in the last 5 years?

☐ Yes ☐ No

11. Have you been banned from driving in the last 10 years?

☐ Yes ☐ No

12. Have you been convicted of Driving Under the Influence or Driving While Intoxicated offences (offence codes DR10, DR20, DR30, DR40, DR50, DR80 or DR90) in the last 5 years?

☐ Yes ☐ No

IV. About Your Attitudes Towards Drivers' Behaviour

Please indicate your attitude towards each of the following statements by ticking the appropriate box.

13. The posted national speed limits on motorways and dual carriageways (70 MPH for cars) are unrealistically low and are difficult for drivers to stick to. (please tick one box only)

Strongly disagree	Disagree	Neutral	Agree	Strongly agree

14. When driving on the motorway with freely flowing traffic, drivers should follow the car in front with a space of eight car lengths or more to ensure safe driving. (An average car length is about 4 metres). (please tick one box only)

Strongly disagree	Disagree	Neutral	Agree	Strongly agree

15. When following heavy vehicles, drivers should increase their following distances compared with following cars since heavy vehicles present more safety hazards than cars. (please tick one box only)

Strongly disagree	Disagree	Neutral	Agree	Strongly agree

16. Heavy vehicles only present more safety hazards to other drivers during night time driving and/or in wet conditions. (please tick one box only)

Strongly disagree	Disagree	Neutral	Agree	Strongly agree

17. Heavy vehicles should be prohibited from using heavily congested motorways during morning and evening rush hour periods. (please tick one box only)

Strongly disagree	Disagree	Neutral	Agree	Strongly agree

18. Would you like to participate in this research project as a test driver?

Yes	No

Please provide your contact details below. These details will only be used to contact you in the event you were selected for participation in the research project and for inclusion in the prize draw.

Contact Details:

Name:

E-mail Address:

Address:

Post Code:

Contact Telephone Number:

Thank you for completing the questionnaire. Please post the completed questionnaire to the address shown on the freepost envelope provided.

The information provided will **only** be used for research purposes, and will remain confidential. The research is conducted by the University of Southampton's Transportation Research Group.

If you have any queries, please contact:

Mahdi Shehab
Transportation Research Group
School of Civil Engineering and the Environment
University of Southampton
E-mail Address: mshehab@soton.ac.uk
Contact Telephone Numbers:
02380 593871
02380 592192
07919 577792

Appendix B: Driver Behaviour Questionnaire

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Driver Behaviour Questionnaire

This questionnaire is part of a research project about driver behaviour. The aim of this questionnaire is to gather information about the attitudes and general driving behaviour of the subjects that are included in the driving part of the research project.

The information provided in this questionnaire will be used for research purposes only. For each of the following statements, please tick the box that best describes your attitude towards that statement.

I. General Driving Behaviour:

1- I exceed the speed limit by 10 mph or more while driving on motorways.

Never Rarely Occasionally Fairly often Often

2- I drive at the same speed during wet conditions as I do in dry conditions.

Never Rarely Occasionally Fairly often Often

3- I follow slower vehicles on the fast lane very closely to pressure them into moving to a slower lane.

Never Rarely Occasionally Fairly often Often

4- While driving on the motorway, I follow other vehicles at a headway of 1 second or less (about 30 m or less) while driving at speeds of 70 MPH or more.

Never Rarely Occasionally Fairly often Often

5- While driving on the motorway, I follow other vehicles at a headway of at least 2 seconds (at least 60 m) while driving at speeds of 70 MPH or more.

Never Rarely Occasionally Fairly often Often

6- How often do you find yourself following other cars on the motorway for 30 seconds or more?

Never Rarely Occasionally Fairly often Often

7- How often do you find yourself following HGVs on the motorway for 30 seconds or more?

Never Rarely Occasionally Fairly often Often

8- Please rank the lanes you use most while driving on the motorway.

____ Inside lane (slow lane) ____ Middle lane ____ outside lane (fast lane)

II. Attitudes towards HGVs

9- I increase my following distance when I am following an HGV as opposed to following a car on the motorway.

Never Rarely Occasionally Fairly often Often

10- I increase my awareness level while driving in the vicinity of HGVs on the motorway.

Never Rarely Occasionally Fairly often Often

11- While driving on the motorway, I allow greater distances when following HGVs in night time and/or wet conditions compared to following HGVs in dry, day time conditions.

Never Rarely Occasionally Fairly often Often

12- When being followed by an HGV on the motorway, I feel the need to be more aware of how close the HGV is following me compared to when I am followed by a passenger vehicle.

Never Rarely Occasionally Fairly often Often

13- What is your general attitude towards HGVs?

Safer than cars same as cars more dangerous than cars

III. HGVs' Effects at Different Driving Conditions

14- While driving in wet conditions on the motorway, I allow greater following distances while following HGVs compared to following other vehicles.

Never Rarely Occasionally Fairly often Often

15- During night time driving on the motorway, I allow greater headways while following HGVs than I do while following other vehicles.

Never	Rarely	Occasionally	Fairly often	Often

16- In congested motorway traffic, I follow HGVs at greater headways than I follow other vehicles.

Never	Rarely	Occasionally	Fairly often	Often

17- I follow HGVs at longer distances when driving on an uphill section of the motorway than I do on a flat motorway section.

Never	Rarely	Occasionally	Fairly often	Often

18- When driving on a downhill section of the motorway, I follow HGVs at longer distances than I follow other vehicles.

Never	Rarely	Occasionally	Fairly often	Often

IV. Sources of HGV Effects

19- I allow greater headways when following HGVs on the motorway because they obscure my vision.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree

20- I allow greater headways when following HGVs on the motorway because of their exhaust pollution.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree

21- I allow greater headways when following HGVs on the motorway because they are usually driven at low speeds.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree

22- I allow greater headways when following HGVs on the motorway because they may not be aware of my presence.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree

23- I allow greater headways when following HGVs on the motorway due to the excessive vibration of these vehicles caused by turbulences from the wind.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree

24- I allow greater headways when following HGVs on the motorway because they present higher levels of risk compared to cars.

Strongly disagree	Disagree	Neutral	Agree	Strongly agree

V. Written Comments

25- Are there any specific aspects of HGVs that may influence your driving style and/or following headway? Please explain.

26- Do you have any other comments?

VI. Preferred Headways

27- Which picture best describes your following distance behind other passenger vehicles while driving on the motorway at speeds of 65 MPH or more?

Picture 1A   Picture 2A   Picture 3A   Picture 4A   Picture 5A

28- Which picture best describes your following distance behind HGVs while driving on the motorway at speeds of 65 MPH or more?

Picture 1B   Picture 2B   Picture 3B   Picture 4B   Picture 5B

29- Which picture represents the following distance you would like other motorists to adopt while following passenger vehicles on the motorway at speeds of 65 MPH or more?

Picture 1A   Picture 2A   Picture 3A   Picture 4A   Picture 5A

30- Which picture represents the following distance you would like other motorists to adopt while following HGVs on the motorway at speeds of 65 MPH or more?

Picture 1B   Picture 2B   Picture 3B   Picture 4B   Picture 5B

Thank you for taking part in this research study. All the information provided will be used for research purposes only.

Name: ______________________________

Date: ________________________

Picture 1A

Picture 2A

Picture 3A

Picture 4A

Picture 5A

Picture 1B

Picture 2B

Picture 3B

Picture 4B

Picture 5B

Appendix C: Extra Tables and Graphs for Non-Constancy of Time Headway

HGV following process	N	Subset				
		1	2	3	4	5
following process 1	26	1.524838				
following process 4	175		2.320516			
following process 3	120		2.446437	2.446437		
all following processes	401			2.769204		
following process 2	50				4.458873	
following process 5	30					4.939954
Sig.		1.000	.958	.249	1.000	1.000

Table C-1: Differences in time gaps between following processes (example 4)

HGV following process	N	Subset			
		1	2	3	4
following process 6	78	1.901109			
following process 4	65	2.083466	2.083466		
following process 1	32		2.167110		
all following processes	435			2.411258	
following process 5	40			2.476200	
following process 2	125			2.625639	2.625639
following process 3	95				2.827213
Sig.		.248	.941	.100	.148

Table C-2: Differences in time gaps between following processes (example 5)

HGV following process	N	Subset				
		1	2	3	4	5
following process 1	96	1.913454				
following process 2	64		2.140543			
following process 7	52		2.209132			
all following processes	448			2.448720		
following process 5	77			2.476287		
following process 4	70				2.714510	
following process 6	40				2.876013	
following process 3	49					3.382352
Sig.		1.000	.972	1.000	.249	1.000

Table C-3: Differences in time gaps between following processes (example 6)

HGV following process	N	Subset			
		1	2	3	4
following process 6	148	.730208			
following process 4	90	.815301			
following process 5	45		1.009902		
all following processes	654		1.083063	1.083063	
following process 2	135			1.140431	
following process 3	130				1.385980
following process 1	106				1.389567
Sig.		.242	.426	.711	1.000

Table C-4: Differences in time gaps between following processes (example 7)

HGV following process	N	Subset					
		1	2	3	4	5	6
following process 9	31	1.7904					
following process 10	45	2.1741	2.1741				
following process 8	61	2.1770	2.1770				
following process 4	36		2.7118				
following process 6	75			3.4854			
following process 7	29			3.8778	3.8778		
all following processes	683			4.0313	4.0313		
following process 1	54				4.1947	4.1947	
following process 3	116					4.6864	
following process 5	107					4.7715	
following process 2	129						5.5432
Sig.		.706	.217	.198	.894	.137	1.000

Table C-5: Differences in time gaps between following processes (example 8)

HGV following process	N	Subset				
		1	2	3	4	5
following process 1	109	.925807				
following process 4	76		1.022882			
following process 3	55		1.057539	1.057539		
following process 6	91		1.076587	1.076587	1.076587	
all following processes	586			1.112658	1.112658	
following process 2	116				1.136109	
following process 5	139					1.334124
Sig.		1.000	.399	.366	.272	1.000

Table C-6: Differences in time gaps between following processes (example 9)

Car following process	N	Subset		
		1	2	3
following process 3	55	1.422045		
following process 1	137		1.587367	
all following processes	247		1.681443	
following process 2	55			2.175174
Sig.		1.000	.248	1.000

Table C-7: Differences in time gaps between following processes (example 10)

Car following process	N	Subset			
		1	2	3	4
following process 5	86	.801554			
following process 2	102	.867870	.867870		
following process 1	86		.911819	.911819	
all following processes	458			.962097	
following process 4	121			.987238	
following process 3	63				1.354153
Sig.		.196	.649	.095	1.000

Table C-8: Differences in time gaps between following processes (example 11)

Car following process	N	Subset			
		1	2	3	4
following process 5	92	1.038038			
following process 6	29	1.223642			
all following processes	381		1.512586		
following process 4	132		1.516655		
following process 3	37			1.763254	
following process 1	50			1.898386	1.898386
following process 2	41				2.072001
Sig.		.096	1.000	.431	.147

Table C-9: Differences in time gaps between following processes (example 12)

Car following process	N	Subset			
		1	2	3	4
following process 3	26	1.055591			
following process 5	26	1.133120			
following process 4	44		1.551736		
all following processes	275		1.698301	1.698301	
following process 1	102			1.780952	
following process 2	77				2.080424
Sig.		.902	.357	.875	1.000

Table C-10: Differences in time gaps between following processes (example 13)

Car following process	N	Subset		
		1	2	3
following process 4	116	1.150660		
all following processes	379		1.319592	
following process 1	176		1.363105	
following process 3	57			1.441137
following process 2	30			1.486586
Sig.		1.000	.510	.465

Table C-11: Differences in time gaps between following processes (example 14)

Car following process	N	Subset		
		1	2	3
following process 3	46	1.415645		
following process 1	48		1.586320	
all following processes	142		1.591272	
following process 2	48			1.764535
Sig.		1.000	1.000	1.000

Table C-12: Differences in time gaps between following processes (example 15)

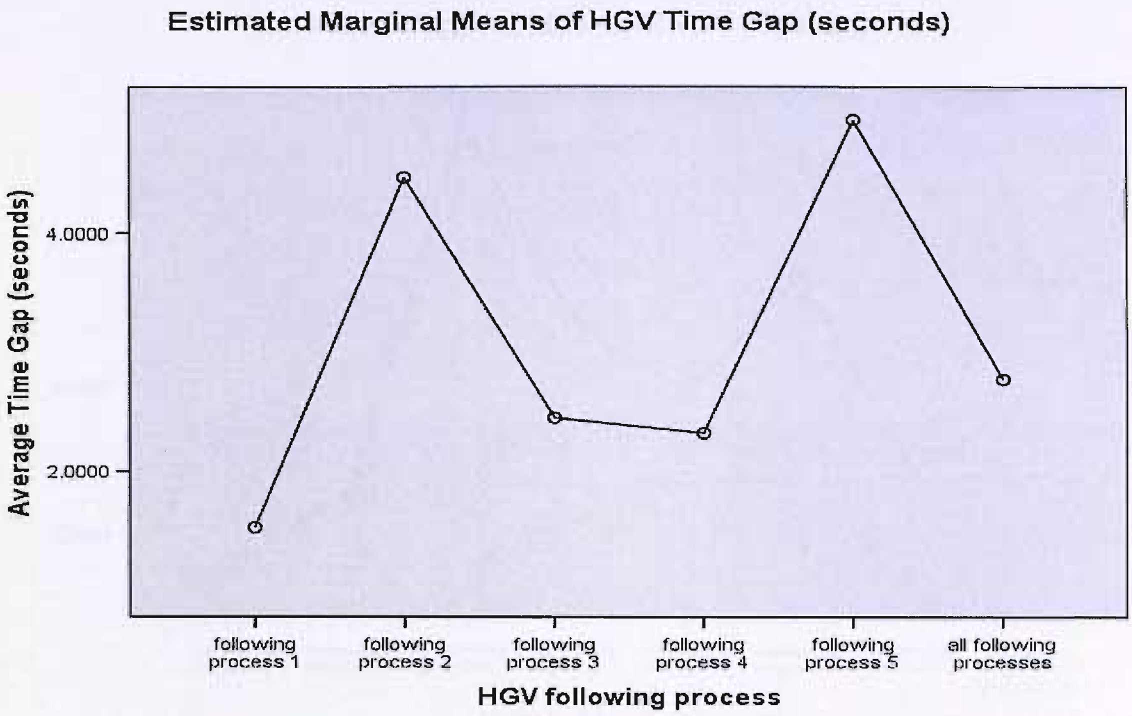

Figure C-1: Randomness of variation in time gaps (example 4)

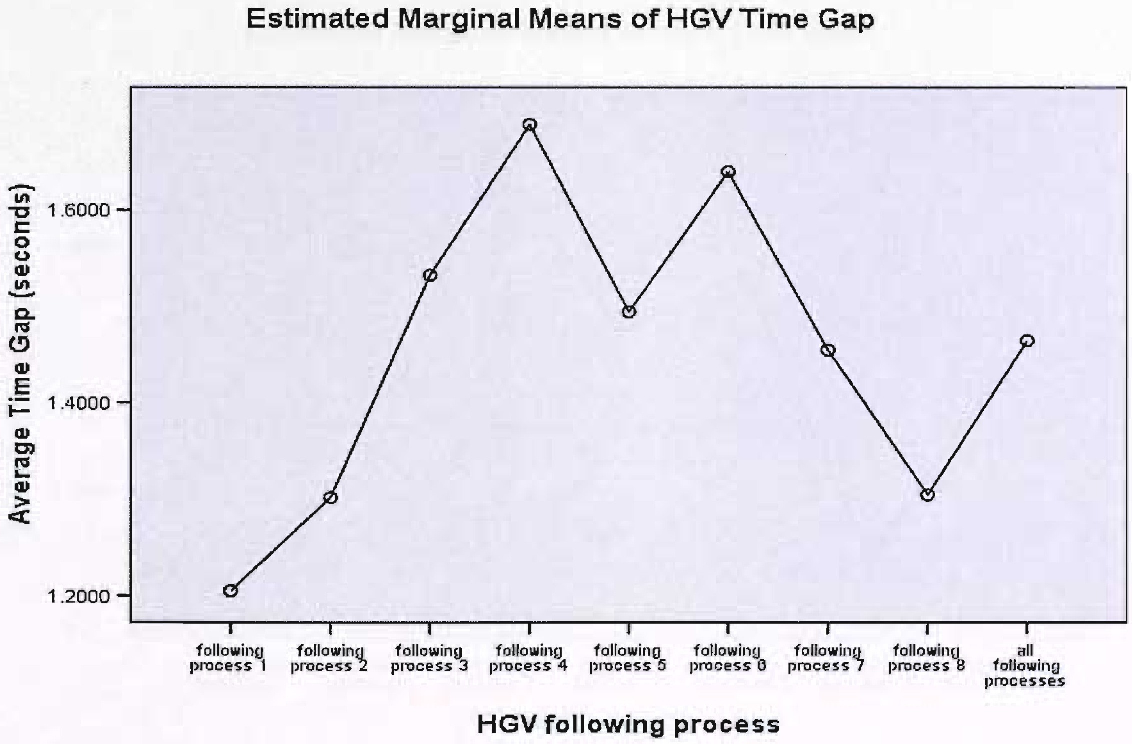

Figure C-2: Randomness of variation in time gaps (example 5)

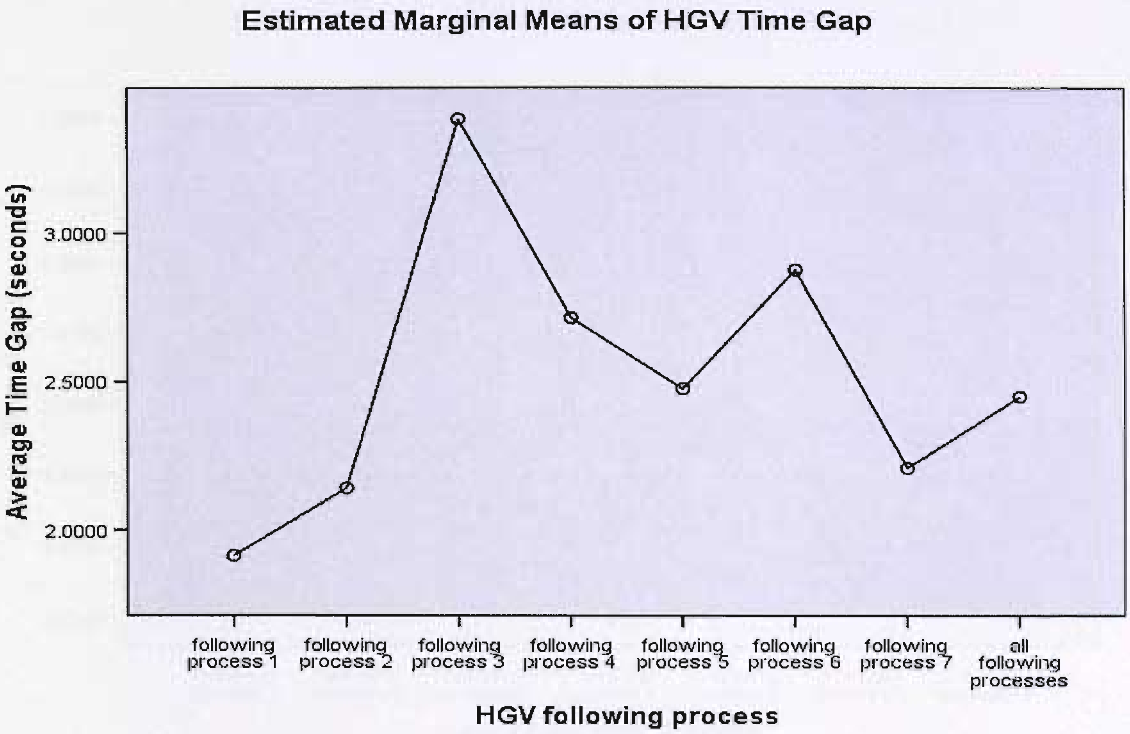

Figure C-3: Randomness of variation in time gaps (example 6)

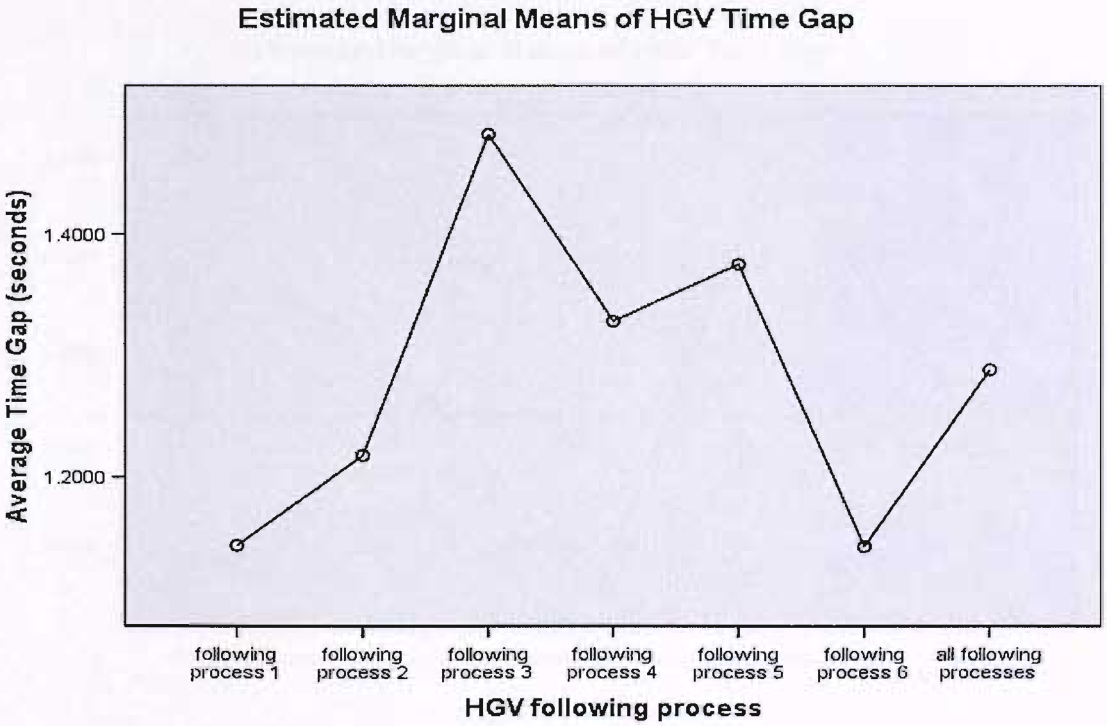

Figure C-4: Randomness of variation in time gaps (example 7)

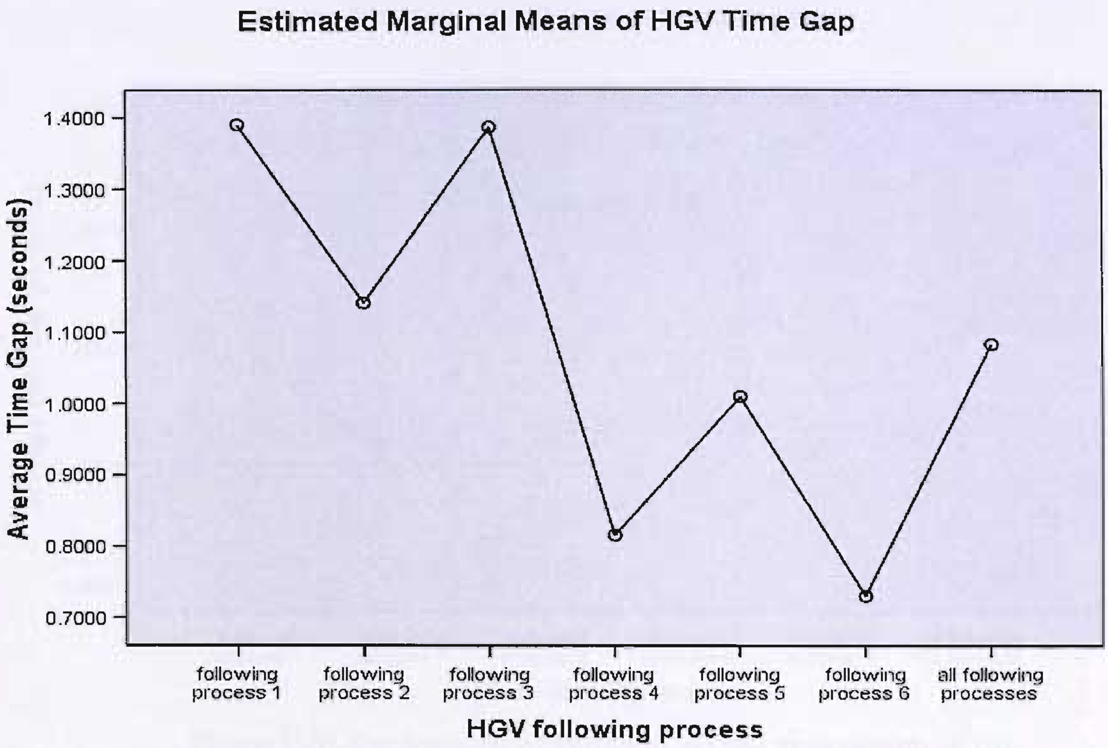

Figure C-5: Randomness of variation in time gaps (example 8)

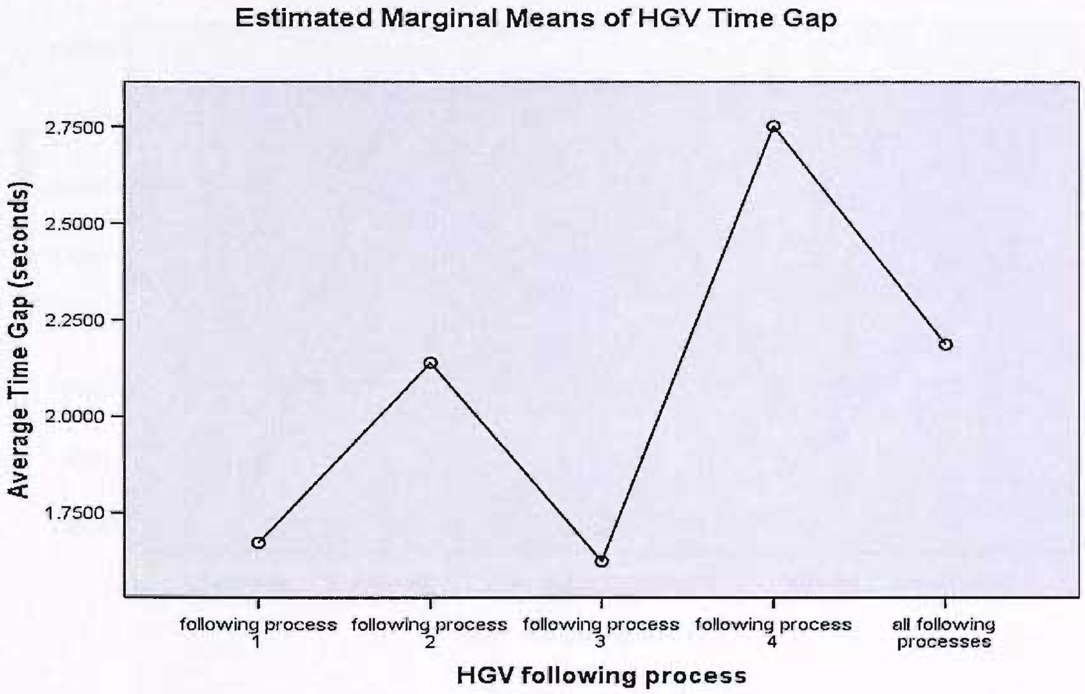

Figure C-6: Randomness of variation in time gaps (example 9)

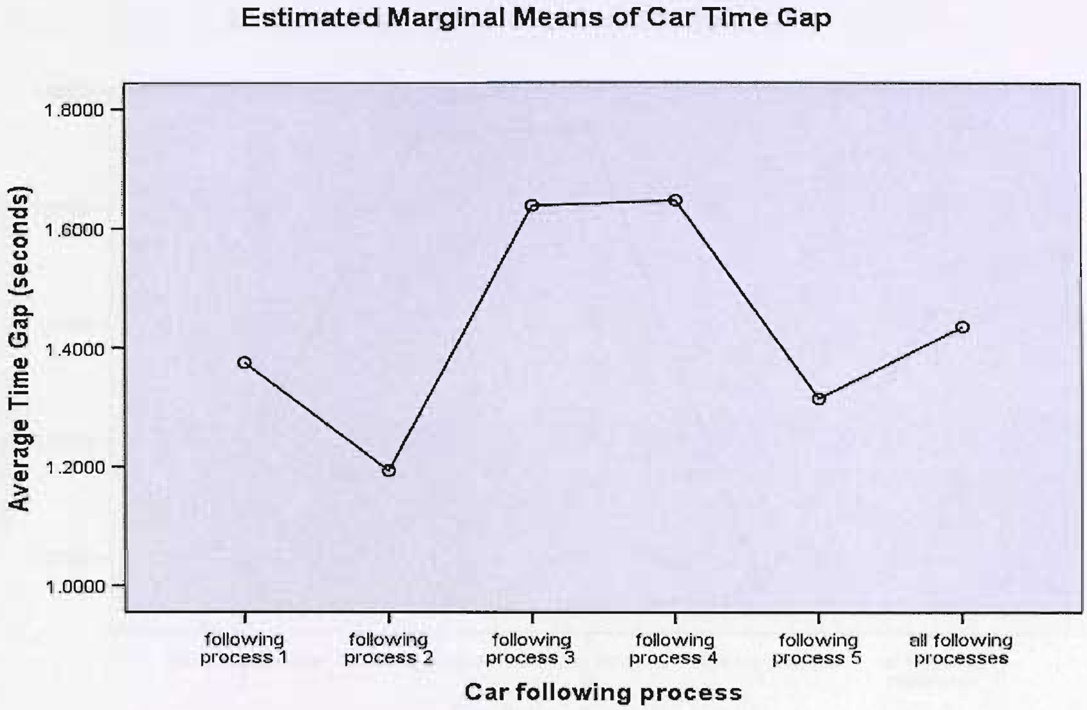

Figure C-7: Randomness of variation in time gaps (example 10)

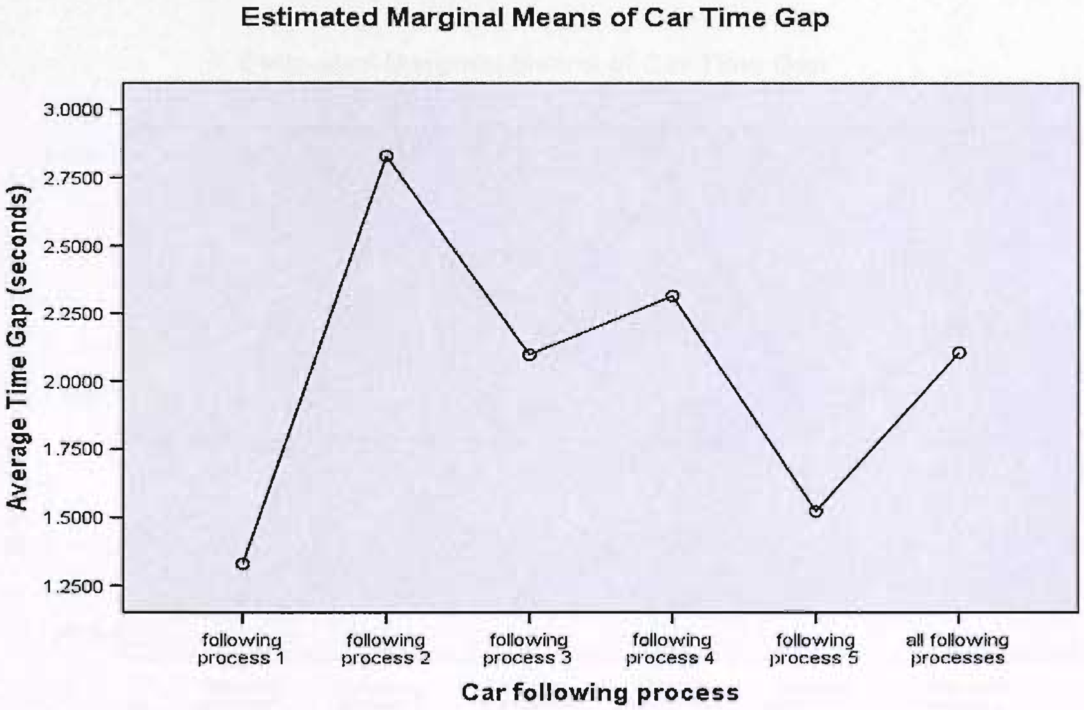

Figure C-8: Randomness of variation in time gaps (example 11)

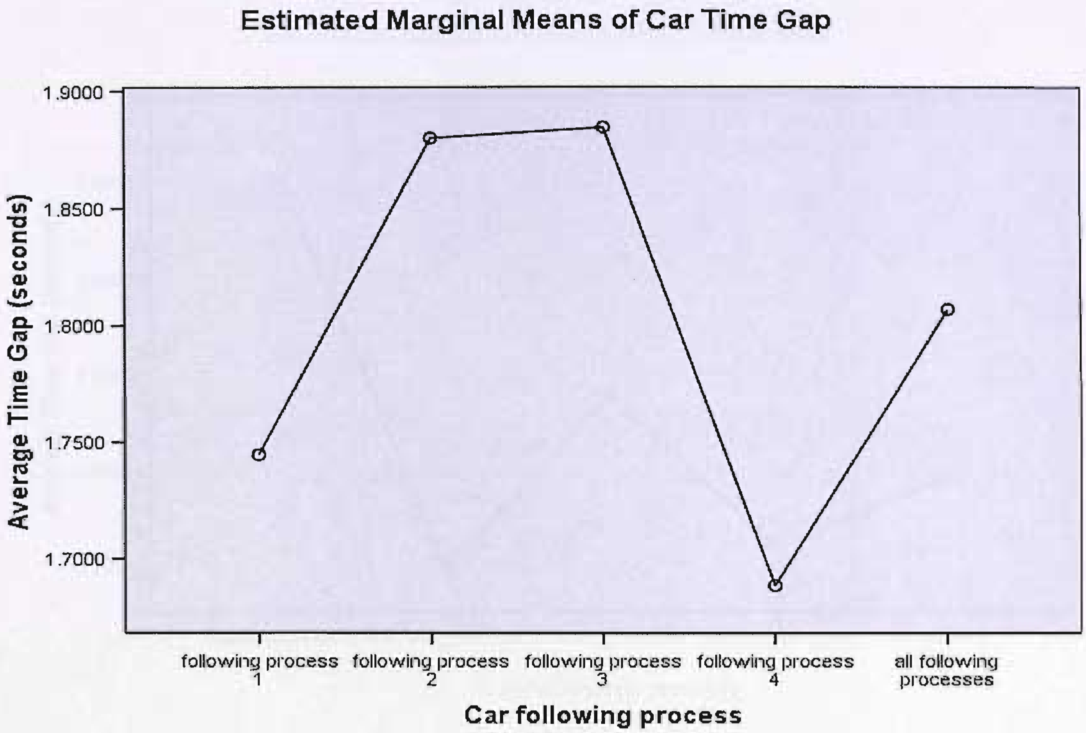

Figure C-9: Randomness of variation in time gaps (example 12)

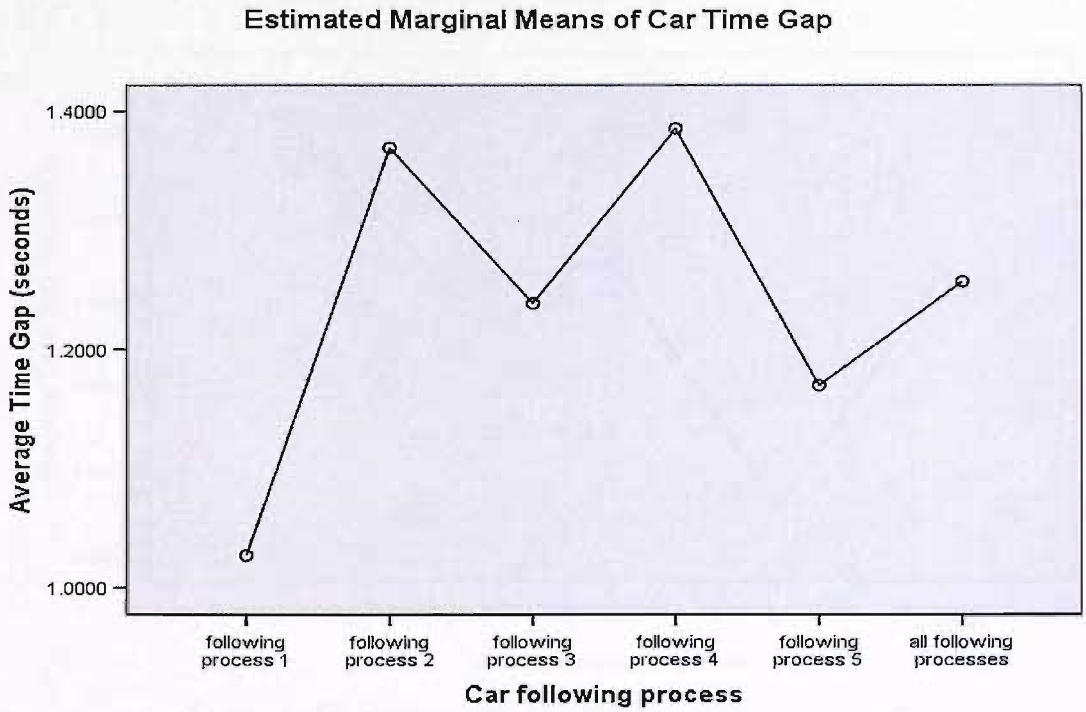

Figure C-10: Randomness of variation in time gaps (example 13)

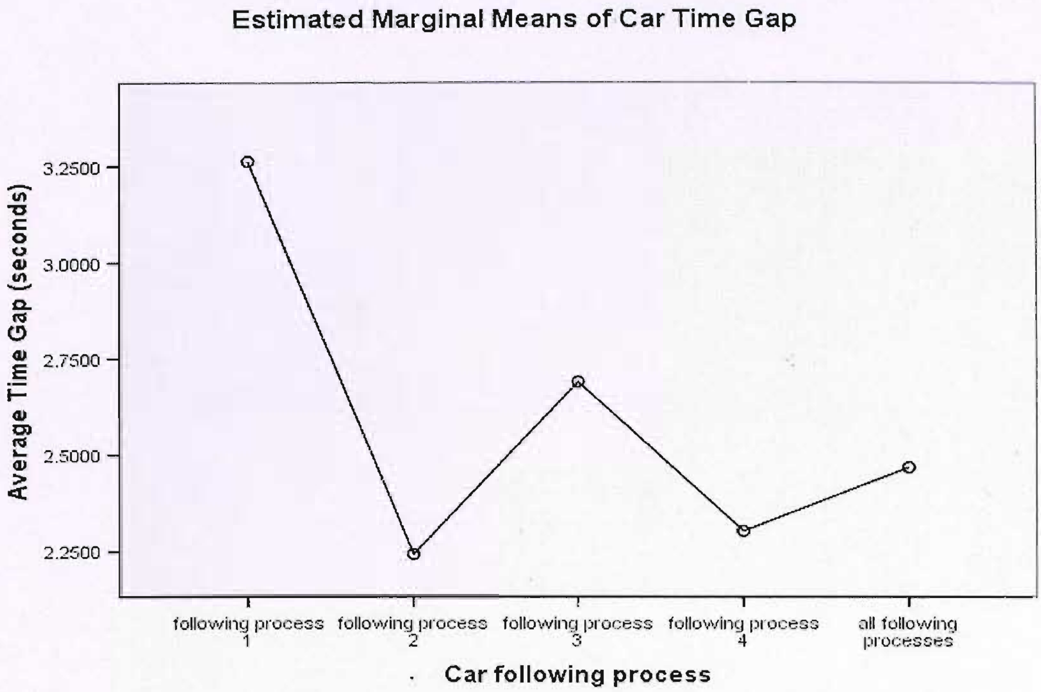

Figure C-11: Randomness of variation in time gaps (example 14)

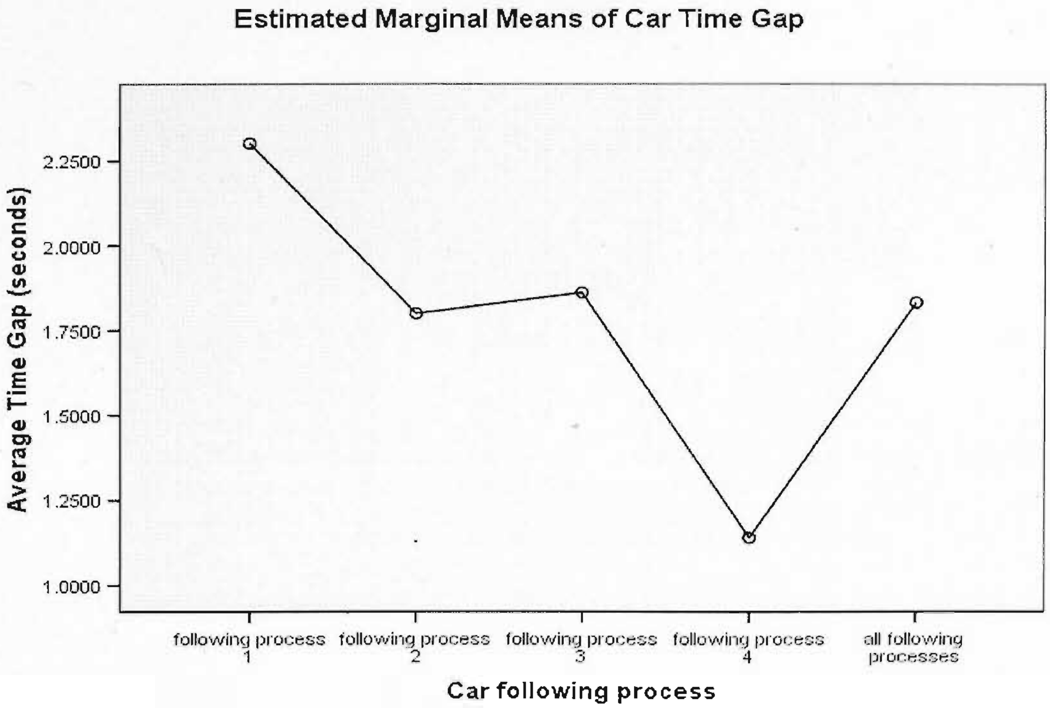

Figure C-12: Randomness of variation in time gaps (example 15)