Revealing the Safety of the Road Environment from Driver Responses: Investigation of Driver Behaviour under Specific Road and Traffic Situations

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Statement of Original Authorship

"The work contained in this thesis has not been previously submitted for a degree or diploma at any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made".

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Abstract

This thesis develops an empirical approach to investigate a driver's perception of safety and behavioural response when faced with specific road and traffic situations. The roundabout was selected as a context for empirical inquiry. We reviewed the literature on driver's perception of safety, driving behaviour and the safety properties of the roundabout. A conceptual framework was proposed within which the effects of attributes describing road and traffic situations can be empirically measured. The stated-preference technique was used to investigate how attributes of roundabouts and characteristics of drivers influence their perception of safety and/or behavioural response. A statistical design was used to reduce the number of combinations of attribute levels to a practical size and to ensure the main effects of attributes can be observed and the effects of correlation among attributes can be minimised. The experimentally designed road and traffic scenarios were visualised using a video image system and developed in a computerised survey instrument. A faced-to-face survey of a sample of Sydney drivers provides the data used in model estimation.

The computerised survey instrument automatically recorded the time that respondents allocated on each evaluated scenario and how they made use of detailed information provided in interactive windows. These allowed us to investigate how respondents assigned time and attention in a survey. We identified three distinctive stages in the response process. At the beginning of the survey, respondents learnt the task and spent a longer time on each evaluation situation. After becoming familiarised with the survey task and developing a response strategy, they allocated a reduced but relatively constant amount of time on each evaluation situation. In the last stage, it appeared that respondents became fatigued or somewhat lost interest in the survey, thus a further reduced response time on each evaluation situation was observed.

The thesis has two major contributions. The first is to investigate preference equality and response consistency associated with the design and implementation of a stated preference experiment. Two formats of the survey instrument, a *Picture and Word* format and a *Picture Only* format, were implemented in a two-wave survey. An important aspect of survey design is the extent that the medium used to present

information (eg picture or word descriptions) acts as a source of response bias, and the likelihood of response consistency over time (eg in two surveys). We found that data evaluated with the *Picture and Word* format were statistically equal to the data evaluated with the *Picture Only* format, suggesting that bias caused by the medium used for presenting information is not significant for this study. Data obtained at the first wave of the survey are statistically equal to data obtained at the second wave of the survey, suggesting that respondent's preferences are relatively stable over time. The behavioural response variance in data obtained in the first wave of the survey was consistently larger than that in the second wave of the survey, suggesting that response consistency improves in a repeated survey. These findings not only support the appropriateness of using stated-preference data for eliciting driver's perception of safety and behavioural response in this study, but also add to our knowledge of the appeal of the stated-preference technique in general.

The second major contribution of the thesis is to investigate drivers' perception of safety and behavioural response at specific road and traffic situations. Ordered probit (logit) models were estimated to investigate how attributes of roundabouts and characteristics of drivers influence the perception of safety. An important output is an *indicator of perceived safety (IPS)*. We found that attributes describing a roundabout and its traffic situation in addition to the characteristics of drivers have a significant influence on the perception of safety. The *IPS* is very sensitive to the change in the levels of attributes such as the size of a roundabout, the number of circulating lanes, visibility to other traffic, size of a potentially conflicting vehicle, general traffic level at a roundabout, presence of a pedestrian and the speed of vehicles, suggesting that these attributes are important determinants of a driver's perception of safety. Given a road and traffic situation, the *IPS* varies among different drivers, suggesting the heterogeneity property of the perception of safety between drivers with different socio-economic characteristics and driving experience.

To investigate behavioural response at specific roundabouts under specific traffic situations, we estimated multinomial logit and mixed logit models. The mixed logit model permits us to account for heterogeneity in preference parameters and to examine choice set correlation and correlation between alternatives. We found that correlation between some pairs of attributes was statistically significant. However, once individual heterogeneity in means was taken into account, the correlation was negligible, suggesting that correlation could be spurious due to a failure to account for unobserved heterogeneity. Estimation results suggest that drivers tend to select a less cautious behavioural response when facing a perceptually safer driving environment. The simulated probabilities based on estimated models suggest that attributes describing a roundabout and its traffic situation have a significant influence on driver's behavioural response. Obstructed visibility, relatively fast speed of a potentially conflicting vehicle, presence of a potentially conflicting pedestrian, a large-sized potentially conflicting vehicle, busy traffic at a roundabout and multi-circulating lanes contribute to a driver's choice of *stopping* or *slowing down* before a roundabout. On the other hand, light traffic at a roundabout, a small-sized potentially conflicting vehicle, relatively slow speed of a potentially conflicting vehicle, a small-sized roundabout and a driver in a hurry contribute to his or her choice of *not slowing down* response before a roundabout. A driver's socio-economic characteristics and driving experience also has a significant influence on their behavioural response. Relatively inexperienced drivers (less than 5 year driving experience) and more experienced drivers (more than 15 year driving experience) are less likely to *stop* or *slow down* before a roundabout. Drivers involved in an accident in the last two years are less likely to *stop* or *slow down* when approaching a roundabout. Low-income drivers (less than $30,000) are more likely to *stop* or *slow down* before a roundabout. Commuter drivers are less likely to *stop or slow down* when approaching a roundabout. Young drivers (25 years or younger) are more likely to *stop* or *slow down* when approaching a roundabout, but male young drivers are less likely to *stop* or *slow down* before a roundabout.

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Chapter One
Introduction

1.1 Understanding Road Safety

Road safety is a social, economic and public health issue worldwide. Traffic accidents cause at least 500,000 deaths every year. They will kill or disable more people than war, tuberculosis or HIV by 2020. In Australia, road accidents have claimed 164,191 lives since 1925 (FORS 1998, ATSB 2000a). Since the age distribution of road accident victims is tilted towards the young, the reduction in length of life and hence loss of productivity is substantial compared with more frequent causes of death such as cancer and diseases which are mostly associated with old age. The records of Australian road crash deaths commenced in 1925, from which road fatalities followed an increasing trend until 1970, when the road toll reached its peak of 3,798. Since then, the trend has reversed. By 1999, only 1,759 fatalities were observed, less than half of those in 1970 (see figure 1-1 for road fatality trend in Australia). The turnaround of the trend in Australian road fatalities is especially evident when compared with increases of vehicle ownership and population. Whereas there were 7.96 road fatalities per 10,000 registered vehicles and 30.4 fatalities per 100,000 of population in 1970, these rates have decreased to 1.51 and 9.28 respectively in 1998.

In economic terms, costs of road crashes are spiralling although the death toll is reducing. In 1988, estimated costs of road crashes in Australia were $8,669 million (in 1999 dollars). Crash costs have increased to $14,980 million in 1996 (in 1999 dollars) (see BTE 2000). These costs accounted for about 3 percent of Gross Domestic Product or $818 per head per year (calculation based on Australian Year Book 1999). These figures were derived by putting a dollar value on the crash-related personal injury (loss of salary and other output, medical costs, coronial, funeral, legal and prison costs), property damage (vehicle repairs, unavailability of vehicles, towing, public and private property damage), and other public costs (police, legal system, insurance system and travel delays), although valuations of human life are controversial.

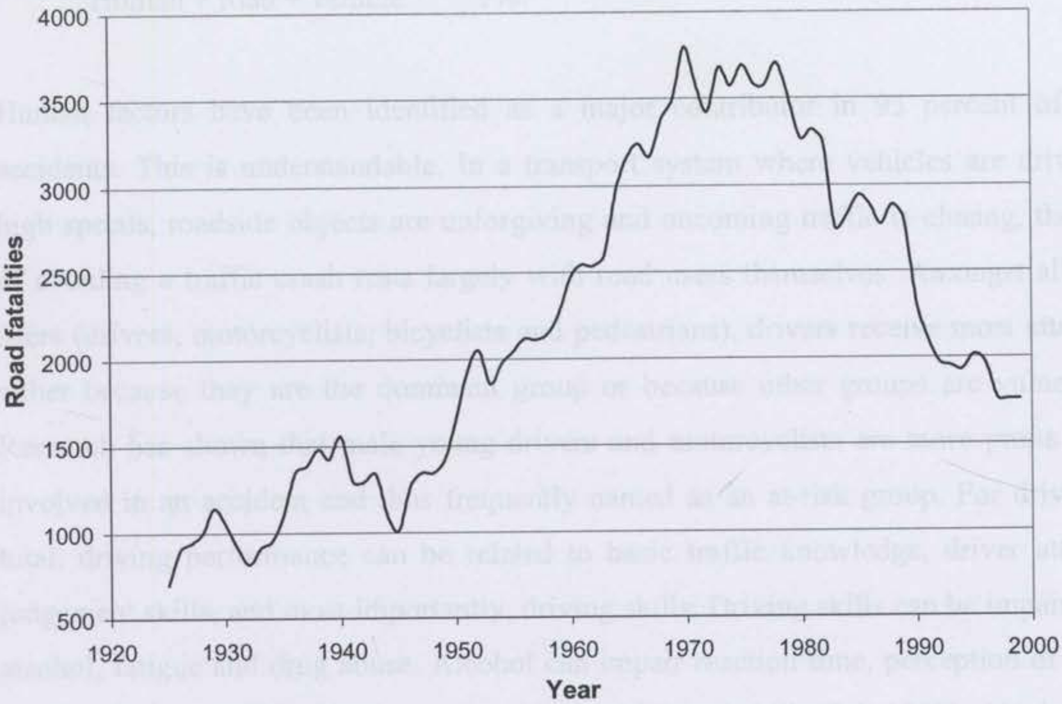


Figure 1-1 Road fatality trend in Australia: 1925-1999

Data Sources: FORS (1998) and ATSB (2000a)

Road accidents were caused by a variety of factors divided into three broad categories: road user, vehicle and road. Systematically, Haddon (1980) developed a matrix of events that considered driver, road and vehicle and how each of these contributed to a crash with respect to time phases, namely pre-crash, in-crash and post-crash. Measures for the pre-crash phase are focused on reducing the frequency of crash occurrence while those for the in-crash and post-crash phases put most effort on alleviating the severity of injury either through driver/passenger protection or well-being for crash victims. Studies showed that the road user, the road and the vehicle interacted as contributors to road crashes. Road accidents represent failures of the system as a whole rather than of its isolated components. In particular, Lay (1990) gives the breakdown as:

Human factors alone	65%
Human + road	25%
Human + vehicle	5%
Road factors alone	2%
Vehicle factors alone	2%

Human + road + vehicle 1%

Human factors have been identified as a major contributor in 95 percent of road accidents. This is understandable. In a transport system where vehicles are driven at high speeds, roadside objects are unforgiving and oncoming traffic is closing, the task of avoiding a traffic crash rests largely with road users themselves. Amongst all road users (drivers, motorcyclists, bicyclists and pedestrians), drivers receive most attention either because they are the dominant group or because other groups are vulnerable. Research has shown that male young drivers and motorcyclists are more prone to be involved in an accident and thus frequently named as an at-risk group. For drivers in total, driving performance can be related to basic traffic knowledge, driver attitude, judgement skills, and most importantly, driving skills. Driving skills can be impaired by alcohol, fatigue and drug abuse. Alcohol can impair reaction time, perception of speed and distance, cognitive functioning, attention and motor skills (Job 1999). Alcohol was estimated to contribute to 28 percent of fatal crashes in New South Wales (NSW) (RTA 1994). Herbert (1980a) even suggested that nearly half of drivers and riders who died on Australian roads were over legal blood alcohol limits. In the drink driving campaign, random breath testing (RBT) was progressively introduced nationwide from 1976 (Victoria in 1976, Northern Territory in 1980, South Australia in 1981, NSW and the Australian Capital Territory in 1982, Tasmania in 1983, Queensland and Western Australia in 1988). With the introduction of RBT, drivers perceived that their chances of being caught had increased. This perception acted as a deterrent which has reduced the number of alcohol related crashes. Henstridge et al (1997) examined the long-term effects of RBT in four Australian states: NSW, Tasmania, Western Australia and Queensland. They found RBT had a substantial initial impact in reducing fatal, single vehicle night-time and all serious accidents. These initial impacts were gradually decaying with time but would not disappear, i.e. there were long-term effects. In particular, they found the initial impact of RBT reduced fatal accidents by 48 percent, single vehicle night-time accidents by 26 percent and all serious accidents by 19 percent in NSW. This initial impact was decaying to 5 percent of original impact in 4.5 months for fatal accidents, 10 years for single-vehicle night-time accidents and 15 months for all serious accidents. In the first year of the introduction of RBT, 204 fatal, 686 single-vehicle night time and 522 all serious accidents were prevented. In the long term, RBT prevented 6742 all serious accidents, 1487 fatal accidents and 3246 single-vehicle night time accidents in a ten year period between 1982 and 1992.

Another important aspect of modifying driver behaviour is compulsory wearing of seat belts and motor cycle helmets. By 1973, legislation had been passed in all Australian States and Territories for compulsory wearing of fitted seat belts in motor vehicles and for the wearing of protective helmets by motor cycle riders and their pillion passengers. The introduction of compulsory seat-belt wearing and helmet wearing for motorcyclists have resulted in a dramatic reduction in deaths. For example, Henderson and Freedman (1974) examined the effects of mandatory seat belt use in NSW. They found the number of deaths over time is some 20 percent below the number to be expected from previously well-established trends. Herbert (1980b) called the seat-belt "the most successful road safety device in Australian history". His claim was supported by giving evidence that there was a 25 percent annual reduction in deaths for vehicle occupants as a result of seat-belt wearing. Seat-belts did not reduce the number of crashes, but injury patterns and the severity of injuries, particularly to the head, chest and spine was reduced (Burke 1973). Adams (1981) presented evidence that the introduction of seat-belt wearing laws in Australian states was followed by a reduction in the number of deaths and injuries of car occupants, but at the same time by an increase in deaths and injuries among nonoccupants. He arrived at a striking conclusion that seat-belt legislation protected car occupants from consequences of bad driving that was encouraging bad driving.

The road environment and the vehicle have also been conclusively identified as a major contributing factor in 28 percent and 8 percent of road crashes. While road and vehicle elements are much less common than human factors in crashes, many road crashes can be analogised as a chain of events where the crash can be avoided if one link is broken. Removal of a pertinent environment and vehicle based link means that the crash will not take place or the impact will be lessened. Sabey (1976) suggested that 15 percent of injury accidents could be avoided through measures applied to the road, and 25 percent through measures applied to the vehicle.

Safety of the road can be enhanced by road engineering and traffic management. A safer road is one of the prime objectives of road design and construction. A road environment should be inherently safe and tolerant of human error. More importantly, road and traffic engineering countermeasures can act, in many cases, to assist or influence the behaviour of the dominant factor, namely the driver. Engineering measures for safety may involve road geometric design, intersection design, cross section design, access control, traffic guidance, warning and control devices, surface skid resistance, roadside furniture, lighting and delineation. In Australia, the safety of the road environment has been significantly improved through Commonwealth, state and local government programs. One such program is the road safety audit, a standardised procedure approved by Standards Australia and Austroads, the national association of road transport and traffic authorities in Australasia. The road safety audit follows a formal procedure to examine an existing or future road or traffic project, or any project which interacts with road users, in which an independent, qualified examiner reports on the project's accident potential and safety performance (Austroads 1993a). A road safety audit is conducted regardless of the size or nature of a project in five stages: the feasibility stage, the draft design stage, the detailed design stage, the pre-opening stage and on an existing road. The road safety audit therefore can identify safety problems for road users and ensure that measures to eliminate or reduce the problems are considered fully in order to reduce the likelihood of accidents and severity of accidents.

While proactive attention should be given to high standards in road design and traffic management devices, inevitably some areas with older design standards or where there are other unforeseen circumstances, can be identified as "black spots" or "hazardous road locations". One of the largest safety enhancement programs in Australia was the Commonwealth Black Spot Program. Under the black spot program, the Government spends $36 million a year to treat around 400 sites throughout Australia as part of a road safety strategy to reduce the road toll through cost-efficient, safety-oriented projects (ATSB 2000b). The Bureau of Transport and Communication Economics evaluated the black spot program and demonstrated significant benefits both in economic terms and in reducing road crashes. Up to 1994, the program delivered net benefits to the Australian community of at least $800 million, generating benefits of around $4 for each dollar of expenditure. Road crashes at treated sites have been significantly reduced by 46 percent for injury crashes, 61 percent for seriously injured and fatal crashes and 30 percent for Property Damage Only (PDO) crashes (BTCE 1995:172). In addition, State and Local Government road safety programs count. For example, road environment safety programs were initiated in 1996 in NSW with the objective to reduce crashes and casualties by improving the road environment and management of traffic (RTA 1996a). At the local government level, the Institute of Municipal Engineering Australia (NSW division) announced its Community Road Safety Program (IMEA 1993), which was aimed at all Councils in NSW.

Automobile engineering has also contributed to improved traffic safety. From 1 January 1970, Australian Design Rules (ADRs) were introduced to set out the design standards for vehicle safety and emissions. It became mandatory to fit seat belts in new passenger vehicles. This requirement has been progressively extended to other motor vehicles, retractable belts, and anchorage for child restraints. The ADRs have also been the mechanism for implementing a host of other mandatory safety requirements. These include requirements for improved vehicle brakes, tyres, lights, indicators, head restraints, increased vehicle impact resistance and increased bus-roll-over strength. Other new enhancements were also claimed beneficial of road safety including airbags, antilock braking system, speed limiters for heavy vehicles and crashworthiness improvements.

1.2 Outline of Research Issues

In the broad domain of road safety issues, this thesis highlights the interaction between the driver and the road. Specifically, it addresses how the driver processes the information from the road environment, formulates the perception of safety (or risk) of the road environment, and how perception of safety may influence their driving behaviour. The perception of safety is an important aspect in developing road safety measures. A driver's perception of safety is an important influence of driving behaviour and performance. Importantly, perception of safety, if well understood and reasonably estimated, can serve as a supplementary measurement of road environment safety. In the road safety literature, it is still the mainstream position that casualty statistics provide the only reliable measure of the safety or danger of a road. For example, in identification of the safety problem of the road (eg black spots), three broad categories of methods in use are crash numbers, exposure-based crash rates and on-site investigation of crashes immediately after their occurrence (BTCE 1995). All methods rely on actual occurrence and the severity of crashes. For eligibility of sites to be treated in the Commonwealth Black Spot program, individual sites (eg intersection, mid-block or short road sections) must have "a history of at least three casualty crashes in any one year, or three casualty crashes over a three year period, four over a four year period" (ATSB 2000b). The safety or danger of a road is measured by its casualty record – the consequences of real accidents. It draws a clear line between actual danger and perceived danger. Funds are prepared to spend on roads with fatality or causality accidents above a criterion. If a road does not have a fatality rate significantly above a criterion, it is not eligible for measures to reduce the danger. These selection criteria have received much criticism and public outrage. Adams (1995:10) in his book *Risk* criticised: "All up and down the country there are people living alongside roads that they perceive to be dangerous, but which have good accident records. They are told in effect that if you don't have blood on the road to prove it, your road is officially, objectively, safe, and your anxiety is subjective and emotional." In NSW, the StaySafe Committee, a state parliamentary committee, is to review traffic safety after the death of a seven-year-old school child by a road accident at an intersection outside a primary school (SMH 2000). The School Parent Community fought a fruitless campaign for 13 years to establish a safer road environment. However they were told by traffic authorities that there were not sufficient serious accidents or fatalities for them to change anything. They would need a "body" before road safety measures could be applied. The fatal accident led to community outrage. "They have their body count now. Let's not kill more kids". Community outrage has put more and more pressure on authorities to change current policies and practices.

Can the perception of safety be included in the assessment of safety of the road environment? In the road safety literature, it appears the major reason for exclusion was that risk perception is highly subjective and not measurable. "Physical scientists tend to be suspicious of phenomena whose existence cannot be verified by objective replicable measurement". "The view that there is a distinction to be made between real, actual, measurable risk that obeys the formal laws of statistical theory and subjective risk inaccurately perceived by non-experts is still the mainstream position in most of the research literature on safety and risk management" (Adams 1995).

In fact, "anything that exists, exists in some quality and can therefore be measured" (cited in Adams 1995). In this thesis, we select roundabouts with different geometrical and traffic features as an empirical research context, and measure a driver's perception of safety when faced with specific roundabout and traffic situations. The stated preference (SP) technique is selected as an appropriate methodology in recognition that the perception of safety is highly subjective and thus cannot be observed in real situations. The SP method involves the elicitation of individual's preferences and/or choices to different hypothetical situations. SP surveys thus can produce data consistent with utility maximisation theory so that general econometric models can be specified and effects of factors can be estimated. The SP method has gained popularity in a number of disciplines such as transport, marketing and environmental valuation. While the advantages of the SP method are evident in many situations (eg, estimating demand for new products with new attributes, enriching explanatory variables exhibiting little variability and/or highly collinearity in the marketplace, as an alternative to observational data which is too expensive and/or incompatible to model assumptions, see Louviere et al 2000 for a detailed discussion), its weaknesses are also well recognised. One frequently raised issue is the incongruity of what respondents say they would do and what they actually did. More recently, there is evidence that survey instrument design, survey length and task complexity have effects on data quality and response consistency (see Louviere and Hensher 2000). In this thesis, in addition to a focus on the measurement of safety perception, we design survey instrument to collect information about a survey response behaviour, comparing data equality and response consistency from different formats of the instrument. Specifically, this thesis will address the following research issues:

(1) Using roundabouts with different specifications and traffic characteristics as an empirical context, identification of a set of attributes that potentially influence driver's perception of safety and/or their driving behavioural response.
(2) Conducting a statistical design to estimates the effects of the attributes with minimised effects amongst attribute level variables and manageable sample size.
(3) Development of a computerised survey instrument using video-captured pictorial traffic situation and detailed word information, to facilitate respondents' understanding the questions and automate the data processing.
(4) Investigation of response behaviour. Testing preference equality and response consistency with an original and a repeated survey and different formats of the

survey instrument.

(5) Establishment of a relationship between the perception of safety and attributes describing a roundabout and traffic situation.

(6) Development of an indicator of perceived safety for a number of typical roundabouts for different driver segments.

(7) Estimation of the effects of attributes of a roundabout and traffic situation on driver' behavioural response. Identification of a relationship between driver's perception of safety and behavioural response under specific road and traffic situations.

1.3 Structure of the Thesis

This thesis is organised into eleven chapters. This chapter serves as a general introduction. In chapter two, we review the existing literature about driver's perception of safety and its implications for driving behaviour. It was found that a driver's perception of safety is derived from the driving environment and has a substantial influence on driving behaviour and task performance. We develop a conceptual framework to empirically investigate a driver's perception of safety and behavioural response at specific road and traffic situations, and to examine the preference equality and response consistency due to the SP survey design and implementation strategy.

Chapter three provides an overview of the safety dimension of roundabouts. In comparison to other forms of intersection control, roundabouts have been found to be a safer intersection treatment. The improved safety at roundabouts can be attributed to their geometric characteristics, operational features and human behaviour factors.

In chapter four, we develop the empirical framework for investigating the driver's perception of safety and behavioural response. We identify a set of road and traffic attributes whose effects on driver's perception of safety and behaviour need to be examined. We also define driver's socio-economic characteristics, driving experience, accident and traffic offence history and driving attitude to be contextually captured in the SP survey. The methodologies for modelling driver's perception of safety and behavioural responses are proposed.

In chapter five, we develop a statistical design to reduce the combination of attribute levels to a practical size while at the same time minimising the effects of correlation amongst attribute level variables and ensuring that the main effects of attributes are presented. The statistical design produces 27 road and traffic scenarios. In chapter six, we report the process of development and implementation of the survey. At the early stage of research, we realised that visualisation of experimentally designed road and traffic scenarios is an important step in survey development. A video image-based system is used to visualise road and traffic situations. A computerised survey instrument is developed in two formats, a *Picture and Word* format and a *Picture Only* format, and a face-to-face interview is conducted on a sample of Sydney drivers, each interviewed twice in two consecutive months.

In chapter seven, we present the process of coding, processing and preliminary analysis of the survey data sets. Effects-codes and dummy-codes schemes are used for coding attributes and driver contextual variables. A descriptive analysis of respondents' socio-demographic characteristics is conducted. The relative importance of variables influencing a driver's perception of safety and driving behaviour is investigated, using the Classification and Regression Tree approach.

In chapter eight, we test the effects of the repeated survey and different survey formats on response consistency. A test scheme combining the log-likelihood ratio test and the role of the scale parameter is used. The scale parameter is estimated using an artificial manipulation of data by pooling two data sources and specifying the Nested Logit Model. Test results indicate that choice consistency can always be improved by a repeated survey, but there is no conclusive difference in choice consistency between a *Picture Only* format and a *Picture and Word* format.

Chapters nine and ten address the driver's perception of safety and behavioural response. In chapter nine, we establish a functional relationship between a driver's perception of safety and attributes of the road and traffic environment, using the ordered probit (logit) model. An indicator of perceived safety is developed based on estimated probabilities from the ordered probit model. In chapter ten, we develop and construct a driver behaviour model where driver's behavioural response at specific road and traffic situations is connected to attributes describing the road and traffic situations. We also demonstrate the relationship between a driver's perception of safety and behavioural response. Addition to restrictive multinomial logit model, we relax the assumption of independent and identical distribution by specifying a mixed logit model.

Chapter eleven presents the conclusions of the thesis. Appendixes I-VI set out two formats of the survey instrument, as well as detailed estimation results for ordered probit (logit) and mixed logit models.

Chapter Two

Perception of Safety and Traffic Behaviour: A Review of the Literature and Development of A Conceptual Framework for Empirical Inquiry

In chapter 2, we review the existing literature on driver's perception of safety and its relationship with driving behaviour. It is found that perception of safety is derived from a driving environment best described by the road geometry, the traffic situation, driver physiological and psychological state and the driver's vehicle condition etc. A driver's perception of safety has a significant influence on his or her driving behaviour and task performance. However, questions arise as how to measure the perception of safety. Early studies suggested that perception of safety (or risk) is reflected to varying degrees in the electrical changes of the skin, and developed the electrodermal activity method to record variation in risk perception. The empirical findings of these studies greatly contributed to formulating two well-known driver behaviour models: the zero-risk model (Naatanen and Summala 1974) and the risk homeostasis theory (Wilde 1982a, 1982b). These models suggested that in a long run improved road safety can only be achieved by increasing road users' desire to be safe, but not by providing road users more opportunity to be safe with safer roads and/or more crashworthy cars. On the other hand, driver performance models suggested that driving tasks could be represented by an interaction between driver capabilities and road environmental demands. The safer roads can lower the environmental demands thus improve the road safety.

This chapter is organised into seven sections. In the following section, we demonstrate how a perception of safety is formulated in a driving task. In section 2.2, we discuss the issues of measurement of risk in traffic safety. Section 2.3 reviews some of representative studies of measurement of the perception of safety. We review driver behaviour models in section 2.4 and the relationship between driver performance and environment demands in section 2.5. We develop a conceptual framework in section 2.6, within which we can empirically investigate drivers' perception of safety and behavioural response at specific road and traffic situations. The last section concludes the chapter with a summary.

2.1 Driver's Perception of Safety is Derived from the Driving Environment

Driving can be described by three essential tasks - navigation, guidance and control (Ogden 1996). Navigation refers to trip planning and route following, guidance involves following the road and maintaining a safe path in response to traffic conditions, and control means steering and speed control. These tasks require the driver to receive inputs from a driving environment, process them, make predictions about alternative actions, decide which are the most appropriate, execute the actions, observe their effects through feedback and process of new information (Lay 1990). Essential in performing these tasks is the driver's ability to make relatively accurate estimates of the safety of the driving environment. This process can be explained by a driving task model.

Within the framework of the driving task, it is possible to examine the process of formulation of the perception of the driving environment, and its functions in driving behaviour. Figure 2-1 gives a grossly oversimplified representation of the driving task developed by Michaels (1961) and Ran et al (1998). By following through this diagram

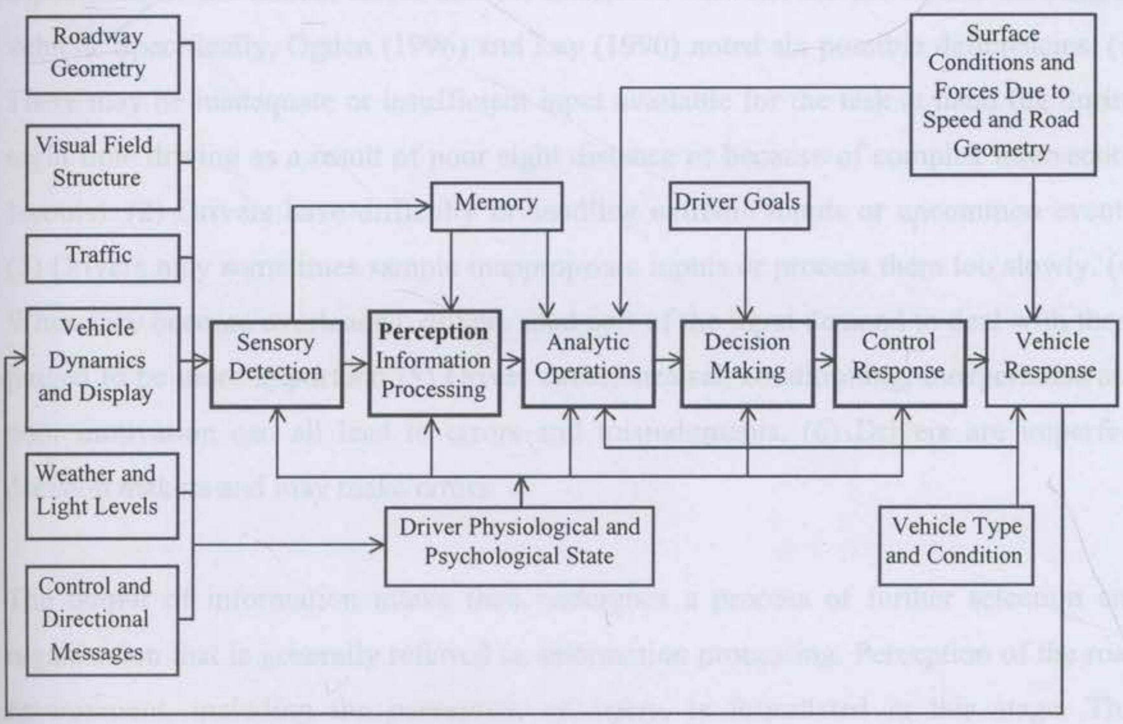


Figure 2-1 A driving task model
Source: Adapted from Ran et al (1998)

it may be possible to develop an appreciation of the complexity of human behaviour required by the driving task. The first task of the driver in the framework is sensory detection, the process of seeing and hearing the driving environment. It is believed that the driver receives information in a selective fashion and thus information irrelevant to the driving task is filtered out. Once the driver has detected these inputs, s/he uses the memory of past experience and acquired knowledge to process the significance of these inputs. Perception is formulated based on information from the driving environment. The driver then makes a decision about the appropriate course of action to follow, and takes maneuvering action such as applying the brakes to slow down, steering to follow the route etc. Finally the vehicle will respond to the driver's maneuvering as a feedback. It is a continuous process in which the driver receives information from the vehicle reaction and the driving environment, and makes the driving decision.

This model links a driver's perception of the road environment to the maneuvering actions. It highlights the importance of *information inputs*. Information from the road environment is received by the driver in an elemental yet selective fashion. In most situations, drivers can handle the demands appropriately, although there are potential problems inherent in the process of information intake, arising from both the capabilities of the human driver and the interfaces between the driver and the road or vehicle. Specifically, Ogden (1996) and Lay (1990) noted six possible deficiencies. (1) There may be inadequate or insufficient input available for the task at hand (eg during night time driving as a result of poor sight distance or because of complex intersection layouts). (2) Drivers have difficulty in handling extreme inputs or uncommon events. (3) Drivers may sometimes sample inappropriate inputs or process them too slowly. (4) When they become overloaded, drivers shed part of the input demand to deal with those judged to be more important. (5) Driver stress, arousal, conditioning, inexperience and poor motivation can all lead to errors and misjudgments. (6) Drivers are imperfect decision makers and may make errors.

The output of information intake then undergoes a process of further selection and organisation that is generally referred as information processing. Perception of the road environment, including the *perception of safety*, is formulated in this stage. This perception is the first transformation of environmental stimulation into meaningful human information. Fildes and Jarvis (1994:55) have defined the concept of perception in three dimensions:

(1) Perception is often used to refer to the relatively automatic sensory processes of an individual interacting with his or her environment. In this sense, it is the first stage of the psychological process that occurs between a human being stimulated and subsequently responding. This is referred to as the *sensory perceptual phase* of driving.

(2) Perception has also been used to describe the deliberate and conscious thought processes involved in human response, involving an individual's beliefs, motivations and desires. In this sense, perception involves higher order decision making processes where the social consequences of an action can influence the ultimate response. This is referred to as the *cognitive perceptual phase*.

(3) Driver behaviour can involve both of these perceptual constructs. While sensory perception will determine from the outset what information is available to a human operator in a particular stimulus situation, the internal states or social forces can nevertheless influence the form of the ultimate response to that situation.

Thus, the more closely the perception describes the road environment as it really is, the more accurate will be the outcome of the subsequent operations performed on the perception. The determinants of perception are complex. It depends on firstly the nature of the information coming in but secondarily and very importantly upon the individual's emotional state and personal characteristics. The factors influencing perception include:

Road environment factors:

(1) Roadway geometry (eg horizontal and vertical curves), road-side furniture, traffic control devices, land use, road type, speed limit, intersection type and delineation.

(2) Visual field structure, illumination, visibility (sight distance), conspicuity, legibility, comprehensibility, and credibility of traffic signs.

(3) Traffic characteristics include traffic flow, composition, movements, typical vehicle speeds and speed variation.

(4) Weather condition and night-time lightning levels.

(5) Road surface conditions, skid resistance and drainage.

Driver and vehicle factors:

(1) Driver experience and goals.

(2) Driver physiological and psychological state, personal characteristics (age, sex, commuter status), attitude, time pressure and mood.

(3) Vehicle type and conditions, control and directional messages, vehicle dynamics and display.

2.2 Measurements of Safety

Driver's perception of safety in a driving environment is an important determinant of driving behaviour and task performance. The question arises as how to measure the perception of safety. Safety and risk are two sides of the same coin. In the safety literature, measurement of safety generally comes out of the measurement of risk, which has produced a number of terms including objective risk, subjective risk and acceptable risk.

Objective risk, sometimes simply referred as risk, is generally considered the real thing. Haight (1986) provides a widely accepted definition of objective risk as the *probability* of an event's occurrence multiplied by the *magnitude* (ie cost) of the event if it does occur. As a probability in the sense of statistical theory, risk obeys all the formal laws of combining probabilities. If risk exists, it exists as a probability that can be measured. This perspective leads to the concept that the progress in measurement of risk lies in refining their methods of measurement and collecting more data on both the probabilities of adverse events and their magnitude. It supports the idea that actual traffic risk is best estimated by direct observation of what happens in a traffic system. It is the mainstream position that casualty statistics provide the only reliable measurement of risk or safety. However, there are criticisms. Adams (1995) noted that measuring the actual risk is frustrated in that risk is culturally constructed. That is, both the adverse nature of particular events and their probabilities are inherently subjective. Besides, both event probabilities and costs present insuperable quantification problems.

Subjective risk is also referred to as perceived risk or perception of risk, the opposite of perception of safety. Subjective risk is traditionally considered an individual's imperfectly informed estimate of real risk. Because of its subjective nature, measurement of the subjective risk has been a challenge to researchers and practitioners. Perceived risk is conceptually independent but empirically has been shown to be a component of perceived task difficulty (Macdonald 1985). Subjective risk recognises the relationship between the perception of risk and the behaviour. Risk is the probability times cost of some future events. The future is uncertain and inescapably subjective. It does not exist except in the minds of people attempting to anticipate it. People's anticipations are largely formed by projecting past experience into the future. Their behaviour is guided by their anticipations. If people anticipate harm they take avoiding action. Dangerous and safe situations per se do not exist, but only safe and dangerous behaviour in certain situations. A dangerous road does not imply that certain constructional properties of the road are dangerous in themselves, but that on this road an unusual amount of dangerous behaviour is to be observed, thus the road only becomes dangerous or safe through behaviour (Klebelsberg 1994).

Acceptable risk is also referred to as the target level of risk. It is a level of risk that society wishes to take in exchange for a level of mobility. Driving is twelve times more risky than taking train (Savage 2000). People choose to drive because they accept the potential risk in driving. Humans value the ability to travel and to ship their goods, and have been prepared to endure the inherent risks. However, there are long-running arguments in the risk literature about what risks and levels of risk are acceptable. At one extreme are those who argue that one death is too many, and at the other those who interpret the prevailing accident rate as a measure of the level of risk that society as a whole voluntarily takes and finds acceptable. In between are those who advocate, not specifically, for less risk (Adams 1995). Their striving to reduce risk for the general population implies that the danger they perceive is greater than the risk they consider acceptable.

The definitions of three types of risk make it clear that any measurements of risk are elusive. Risk analyst frequently uses the number of deaths as a measurement of objective risk, either because it is the most accurate recorded statistic or it represents the ultimate loss. However, deaths are sufficiently infrequent and their causes sufficiently diverse. Any analysis of the causes of accidents often leads to the conclusion that they are stochastic or probabilistic phenomenon. In the case of fatal accidents, the probability is very low. For example, there were 2017 road accident deaths on Australian roads in 1995. These deaths were spread over a population of 18.1 million, 11.0 million registered vehicles and 166.5 billion vehicle kilometers travelled (FORS 1996). Based on these statistics, there is a very small chance of fatal accident occurrence even at the worst black spots. This leads to the paradoxical result that there are "not enough accidental deaths" to produce a pattern that can serve as a reliable guide to the effectiveness of specific safety prevention measures.

As a consequence, risk analysts seek other measurements of risk such as accident rate for injury and property damage, in ascending order of numbers but in descending order of severity compared to fatal accidents. The main accident and injury data sources are police reports, hospital and insurance company statistics. However, none are complete as they all suffer from under-reporting. For example, Rosman and Knuiman (1994) compared police data and hospital data and showed that much information in police accident records, particularly on accident severity and causes, is inaccurate. Attempts to match crash occurrence and injury using the two sources of data invariably resulted in significant numbers of hospitalisations reported on police forms not appearing in hospital records, and significant numbers of crash victims admitted to hospitals for which police had no crash record. Many small accidents can be handled by the conflicting parties. If the damage is small, not even the insurance companies are informed.

When accident rates are used in the evaluation of countermeasures at specific locations, there are two possible sources of bias: regression to mean effects and accident migration. Regression to mean is a statistical phenomenon which occurs when two variables (such as the number of crashes that occur during two periods of time at a particular site) are associated with less than perfect correlation (BTCE 1995). The number of road accidents on any particular part of road network fluctuate up and down over time. After a particularly bad spell they usually come down. After a particularly good spell they usually go up. Parts of the network that have experienced bad spells are defined as accident black spots thus get priority treatment (see chapter one). When they are treated, the numbers of accidents usually go down – but they probably would have gone down anyway. The regression to mean effect can be as small as five percent and as large as 60 percent at sites with observed crash frequencies considered appropriate for a remedial treatment (BTCE 1995, Wright and Boyle 1987).

Another source of bias is the accident migration effect. Accident migration refers to a tendency for accidents at treated black spots to decrease, with the increased number of crashes in the neighborhood of the back spot. That is, there is an apparent migration of crashes from the treated site to surrounding sites (BTCE 1995, Adams 1995). Crash migration in the spatial sense is one type of migration. Adams discussed the possibility that crash migration could occur temporally. For example, as traffic has grown and perceived danger increased, parents have responded by delaying the age at which they allow their children to cross the road, ride their bikes, or go to school on their own. This has had the effect of delaying the educational experience of coping with traffic directly. When in their teens, children are confounded, but ill prepared, with a much more dangerous world. As a result, crashes migrate to later ages.

Accident rates therefore have limitations, even retrospectively, as measures of risk. If they are low it does not necessarily mean that the risk was not high. It could mean that a high risk was perceived and avoided. Risk assessments are conditional estimates of probability and cost. Past accident rates could serve as prospective measures of objective risk only if we could assume that nothing would ever change, and only if we could assume that we learn nothing from past experience.

Some studies use traffic conflicts as a substitute for accident registration (OECD 1997, Hyden 1987). Conflicts are near accidents occurring far more frequently in traffic and can include the whole range of incidences where the actual accident is just at one end of the scale. Traffic conflict techniques range from the purely subjective – no quantifying measures but using descriptions such as "sudden behaviour" or "evasive action" – to the more objective where conflicts are rated by measurements such as "time to collision" (if no evasive action taken) or "post-encroachment time" (time between one user leaving the potential collision point and the other road user entering the point). At specific locations, normally intersections, observation or video-recording methods are used to estimate the number of vehicles or pedestrians using the area, so that conflict rates can be calculated. An advantage of using conflict techniques is that short term observations produce much higher numbers of conflicts than accidents, and the severity can be rated.

2.3 Early Studies of the Measurement of the Perception of Safety

Although the literature on measuring objective safety in terms of number of accidents or accident rates is extensive, only a small number of studies have attempted to measure the perception of safety (or subjective risk). These studies use the *electrodermal activity* as a measurement of perceived risk in the traffic environment. It is considered that emotionality (eg fear caused by danger on the road) is reflected in different degrees of perspiration and hence changes in the electrical activity of the skin. Therefore, it was assumed that it would be possible to measure perceived risk by looking at changes in the electrodermal activity while driving. In past decades, experiments to relate the perception of risk to electrodermal activity include Hulbert (1957), Michaels (1960), Tayor (1964), Brown and Huffman (1972), Helander and Soderberg (1973) and Heino et al (1994). The results of these studies directly contributed to the development of two well known yet controversial driver behaviour models: the zero-risk model by Naatanen and Summala (1974) and the risk homeostasis theory by Wilde (1982a, 1994). We briefly review four representative electrodermal activity studies.

Hulbert (1957) found a relationship between driver's electrodermal activity and changes in traffic conditions. While subjects drove a car over a prescribed route, electrodermal response, a short lasting phasic change in the electrical activity of the skin was measured. Each time an electrodermal response occurred, an observer in the car filled in a data sheet to describe the traffic situation and the driver's action such as deceleration, overtaking or lane changing at that moment. Results showed that 91 percent of electrodermal responses could be connected with one of four traffic events, ie, actual interruption of the idealised path, possible interruption of the idealised path, actual infringement upon the idealised path and possible infringement upon the idealised path.

Michaels (1960) related electrodermal responses to those traffic events that caused the overt change in speed or lateral movement. A number of traffic events were defined including turning, overtaking and crossing manoeuvres. It was observed whether traffic events were accompanied with an electrodermal response. It was found that 85 percent of the recorded traffic events generated a measurable electrodermal response. The events that caused the greatest electrodermal responses were turning manoeuvres and crossing manoeuvres. Events inducing the smallest electrodermal responses were those relating to fixed objects in the environment such as parked cars.

Taylor (1964) related electrodermal activity to traffic behaviour and accident rates. In the experiment, subjects drove on a prescribed route that consisted of heterogeneous road sections. In each section the accident rate was specified as the average number of personal injury accidents occurring in daylight per vehicle mile. It was found that the number of electrodermal responses per mile correlated positively with the accident rate and negatively with the driver's average speed driven. The electrodermal activity per time unit was constant over different road sections. That is, the frequency of electrodermal responses per minutes was invariant over the road sections.

Heino et al (1994) examined the relationship between electrodermal activity and traffic events as well as the relationship between electrodermal activity and the verbal estimate of risk. They defined a number of traffic events such as a red traffic light, a pedestrian crossing and overtaking. In the experiment, each subject drove along the experimental route, consisting of several different road sections. The electrodermal activity was measured continuously with an electrodermal activity amplifier. The verbal risk was defined on a seven-point rating scale with a rating of 0 indicating no risk perceived and rating 6 indicating unacceptable risk perceived. The unaccepted risk perceived was described by a traffic situation where an accident could be avoided but only at the greatest effort. Subjects were required to give verbal risk estimates each 30 seconds or whenever they experienced a change in the perception of risk. It is found that electrodermal activity did not necessarily reflect the risk perceived by the automobile driver. Firstly, it was found that 50 percent of the electrodermal responses could not clearly be related to traffic events. Furthermore, the relationship between electrodermal responses and deceleration suggests that the motor activity associated with deceleration could have played a role in the electrodermal activity elicitation. In particular, traffic events are associated with major bodily movements (eg changing traffic lane) elicited both large deceleration and relatively large electrodermal responses. Electrodermal activity seems very sensitive to many kinds of stimulation, including motor behaviour. As a result, it is not very specific to changes in the perceived level of risk. A comparison of the verbal risk estimates with the electrodermal responses further reinforced that electrodermal activity did not necessarily reflect the perceived level of risk.

The overall findings of studies of electrodermal activity can be summarised as follows. The number of electrodermal activities per kilometre varied with road section with different road safety records, suggesting that electrodermal activity can to a certain degree reflect the changes in the road environment and thus the perceived level of risk. The electrodermal activity per kilometre is negatively correlated with the speed driven, indicating that drivers chose a higher speed when the perceived level of risk is low. The number of electrodermal activities per minute did not vary with road section. Driving can be interpreted as a self-pacing task. The drivers chose a speed and an attention level so that the perceived level of risk is maintained at a constant level over time regardless of the driving environment. However, it was found that the use of electrodermal activity as a measure of perceived risk is highly problematical, mainly because of the low specificity of the electrodermal responses for changes in the perceived level of risk. Electrodermal activity seems highly sensible to various sorts of internal and external influences, and therefore not very specific to changes in perceived risk. In particular, a rise in the perceived level of risk will cause the electrodermal responses, but an electrodermal response does not necessarily indicate a rise in the perceived level of risk.

It is possible to use driving simulators to elicit driver's perceived risk. A driving simulator usually consists of video projected images and a fixed vehicle capsule or a complete car with basic controls and instrumentation having the capability of auditory feedback and some vibration through the wheels. The image is generated by a computer program which can provide real life simulation of driving in a number of full colour geometric environments, with the ability to introduce adverse conditions such as fog, rain, snow and ice. The computer continuously receives feedback from the driving controls and provides updated images using a complex vehicle handling model. Driving simulators are used in a number of studies for driver behaviour (see Fildes and Jarvis 1994). The driving simulator can be used to measure the perceived risk in a number of pre-designed road environments through a verbal rating method. To the author's knowledge, there has been no empirical study on this aspect of driver behaviour.

2.4 Driver Risk Compensation Behaviour

The early studies of electrodermal activity as a measurement of perceived risk had an important influence on the development of two driver behaviour models: the zero-risk model and the risk homeostasis theory.

Naatanen and Summala (1974) developed a zero-risk model. On the basis of the evidence provided by Hulbert (1957) and Taylor (1964) that electrodermal activity occurred infrequently, Naatanen and Summala developed a position that subjective risk of the driver at most times on the road was equal to zero, contrary to the belief that drivers acted at a certain level of subjective risk which they are willing to tolerate in exchange for the utility derived from such behaviour. They used the term *subjective risk monitor* to describe driver's risk perception. The subjective risk had an inhibiting effect of on a driver's subsequent behaviour. Driver's subjective risk and decision making had important implications on traffic safety. They noted that many countermeasures (eg broadening and straightening of roads) had been found ineffective in reducing accidents because subjective risk was attenuated. Changes in the traffic environment makes driving appear safer. Under such circumstances, the driver can drive faster and overtake other cars more frequently before subjective risk is experienced. If the physical traffic environment is unchanged, increased speed and an increased frequency of overtaking would induce more road crashes (Solomon 1964). They suggested that traffic safety can be improved by enhancing the traffic environment without reducing the subjective risk or through increasing subjective risk. The best result expected is to make the traffic system objectively safer whilst simultaneously increasing the subjective risk (Naatanen and Summala 1974: 257).

Risk Homeostasis Theory proposed by Wilde (1982a, 1982b, 1984, 1994) assumes that drivers tend to maintain a *target level of risk* greater than zero. It is believed that at any moment of time a road user perceives a certain level of subjective risk, which he or she compares with the level of risk he or she desires to accept. If the level of subjective risk perceived is higher or lower than the level of risk desired, the individual will take action in an attempt to eliminate this discrepancy.

There are three types of skills that have their effects upon driver behaviour. (1) Perceptual skills determine the extent to which the subjective risk corresponds to the objective risk. (2) Decisional skills determine the driver's ability to decide what should be done when faced with a traffic situation. And (3), vehicle handling skills determine whether the driver can effectively carry out the driving task. The level of performance attributable to all three types of skills may be improved by driver education, by licensing standards and/or by an ergonomically designed environment, including road geometry, signalisation, controls and displays in vehicle design. However, such improvements are unlikely to have a lasting effect upon the accident rate. A more crashworthy car, a better designed highway, an improvement in vehicle control skills will permit the same accident rate to occur at higher speeds. Hence, drivers will travel faster, or follow more closely (ie increased tailgating), or pay less attention to the driving task.

The *target level of risk* is the only factor that is hypothesised to ultimately determine the accident rate in the population as a whole. The target level of risk is influenced by the expected utility of action alternatives. It is a risk level at which the net benefit from road mobility subject to expected accident loss is maximised. The long-lasting crash reduction per unit of time exposure or per capita would not be achieved by providing road users with more opportunity to be safe (eg safer road and/or more crashworthy cars). Accident rates can only be reduced by increasing a road user's desire to be safe by reducing their target level of risk. Wilde (1982a, 1994) proposed four classes of utility factors and corresponding example tactics to reduce a driver's target level of risk:

(1) Decrease the expected benefit of risky behaviour (eg abolish any financial benefits that truck drivers receive for driving long distances in short periods of time).
(2) Decrease the expected cost of cautious behaviour (eg subsidise public transportation between and within cities; Provide reserved lanes and other privileges for public transit within cities, which would reduce travelling time for their patrons).
(3) Increase the expected benefit of cautious behaviour (eg reduce automobile insurance premiums for accident-free driving).
(4) Increase the expected cost of risky behaviour (eg increase enforcement and

penalties with respect to unsafe driving acts; manufacture cars that are uncomfortable, ie, noisy or vibrating when driven at high speeds).

Wilde (1982a) cited a limited number of studies to support his theory. One of them was conducted by Peltzman (1975) for the presumed safety benefits of vehicle manufacturing standards in the United States. Peltzman arrived at the conclusion that the installation of seat belts for all car seats, an energy-absorbing steering column, a penetration-resistant windshield, dual braking systems and padded instrument panels failed to reduce the total traffic death rate per billion vehicle miles. The study by Adams (1981) was also cited by Wilde to support his theory. Adams compared changes in road death tolls in countries that imposed mandatory seat belt wearing with countries that did not. He found that, following legislation, these changes were less favorable in countries with legislation than in those without, and he arrived at the striking conclusion that this legislation is counterproductive to safety, because protecting car occupants from the consequences of bad driving encourages bad driving. Other studies cited by Wilde to support his theory include the unexpected accident reductions after the change-over from left-hand to right-hand driving direction in Sweden and Iceland (Alexandersson 1972). These findings lead to the conclusion that risk compensation behaviour is either complete or at least significant. Those safety measures provided a better means for safety, but did not increase the public's desire to be safe because road users adjusted their behaviour in such a way that the accident rate showed no measurable deviation from the constancy. On the other hand, drivers overestimated the amount of risk engendered by a drastic measure such as directional change-over. They took cautious action and the accident rates decreased.

The Risk Homeostasis Theory has received much criticism. One of problems is whether there exists a *target level of risk*. Indeed, if we ask drivers how much risk they wish to take, we would expect that most drivers would answer that they do not wish to take any risk in traffic. As Fuller (1994) criticised: "except where speed increases are rewarding, only very special road users, such as homicidal maniacs, putative suicides and demolition engineers ever intentionally opt for a greater chance of collision with obstacles in front of them". Even if the target level of risk exists at all, either Wilde or supporters of the theory did not give a method how to measure it. Evans (1991) argued that the use of the word "theory" to describe the notion of risk homeostasis was without justification because a scientific theory must be capable of being experimentally refuted. Others criticised the risk homeostasis theory either from a theoretical perspective or empirical findings. For example, McKenna (1988) noted that the risk homeostasis theory switches between the individual level and the societal level which is unjustified. Evans (1986) reported empirical findings that contradict the trends that would be predicted by the theory. He concluded that the risk homeostasis theory should be rejected because there is no convincing evidence supporting it and much evidence refuting it. Job (1999) argued that the well established safety benefits which arise from improvements such as divided roads and roundabouts indicate that this theory does not apply in the road safety arena. While improvements to vehicles (ABS brakes) or changes in behaviour in relation to safety (seat-belt use) may result in more risky behaviour, the clear safety benefits of seat-belts in Australian statistics attests to the net benefit and incomplete homeostasis in relation to these countermeasures. Additional criticisms of the risk homeostasis theory can be found in Haight (1986), Knott (1994) and BTCE (1995).

2.5 Driver Behaviour and Road Environment: The Driver Performance Model

Unlike the abovementioned controversial risk compensation models, driver performance models are widely accepted. These models assume that drivers perform their driving tasks according to the demands imposed by road, traffic, the vehicle, other environmental conditions and their own capabilities. These approaches have led to conclusions that improvements in the vehicle and road environment can reduce the system demands and facilitate better performance of the driving task and hence can improve road safety.

Mahalel and Szternfeld (1986) related driver performance to environmental demands. Figure 2-2 illustrates a hypothetical representation of driver performance levels and demands from the road environment on a time axis. The performance level of the driver varies over time because of factors such as lack of concentration, fatigue, drowsiness and illness. The demands of the road environment vary due to factors such as rates of traffic flow, geometric features of the road and the type of road. Usually driver performance is adapted to the demands of the road system, thus the performance level of the driver increases with increased road demands (time 1) and decreases with decreased demands (time 2). A crash may occurs when the level of performance of the driver does not match the demands of the road environment (time 3).

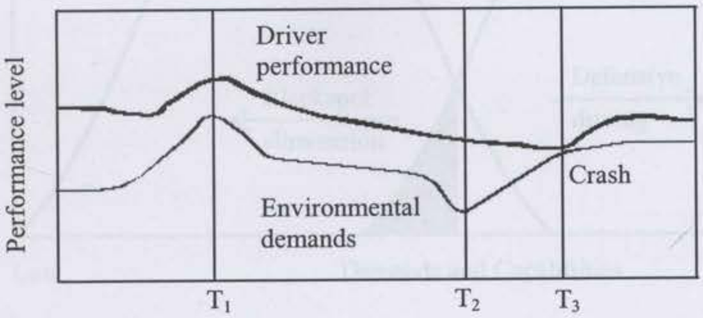


Figure 2-2 Driver performance and environmental demands
Source: Adapted from BTCE (1995)

According to this model of crash causation, engineering improvements in the road network lower the environmental demands. Consequently, the gap between the performance level of the driver and the performance demands of the road environment increases, thus the probability of a crash is reduced (BTCE 1995).

Brown (1982) developed a model relating driver capabilities to system demands as shown in figure 2-3. There are two functions varying over time: one representing the driver's capabilities or skills, the other representing traffic system demands. The precise nature of the two distributions is unknown, but clearly the statistically low probability of individual involvement in road accidents indicates that system demands and driver capabilities are adequately separated by a safety margin most of the time. Both distributions have high and low tails to describe the changes in demands and skills over time and in different parts of the road network. An accident can occur only when the driver's capabilities fail to meet the current demands of the system. Accident prevention will therefore require us to inhibit overlap between the tails of the two distributions, as shown in the shaded parts of figure 2-3. This can be achieved by shifting the curves apart. For example, an ergonomic redesign of the whole traffic system could reduce the demands to a tolerable level. Extensive legislative constraints on road user behaviour could have similar effects. Selection and well-designed training of all drivers could

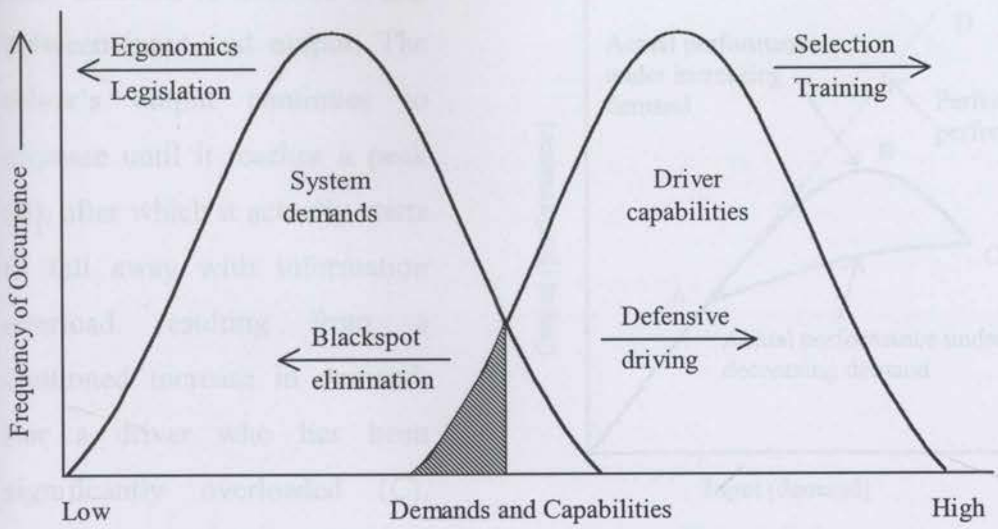


Figure 2-3 System demands and driver capabilities
Source: Brown (1982)

upgrade the general capabilities of the motoring population. Alternatively, one could prevent the distributions overlapping by simply reducing their spread. For example, redesigning accident black spots would reduce certain peak system demands. Inculcating defensive driving skills would reduce periods of low capability.

The main shortcomings of the models proposed by Mahalel and Szternfeld (1986) and Brown (1982) lie in their implication that the environmental demands and driver performance vary independently. Traffic demands and driver performance act in an interactive manner. Driving is a self-paced task. This means that it is the driver who largely determines the degree of difficulty of the task and the level of performance. Thus, both distributions in Brown' model will be a function of the driver's behaviour.

Ogden (1995) showed that when environmental demands are beyond a threshold (ie the driver is overloaded), driver performance is likely to deteriorate. Figure 2-4 plots the rate at which tasks are presented to the driver (rate of input demand) against the rate at which decisions are transmitted (the output of performance). It can be seen that when demand is low, output equals demand, ie all inputs are processed correctly, and all decisions are appropriate. However, as demand increases, there comes a point (*A*) at which the rate of output starts to fall below the rate of demand. Beyond *A*, if demand is increased still further, output also continues to increase for a time, but at a lesser rate than demand, ie there is a gap between input and output. The driver's output continues to increase until it reaches a peak (*B*), after which it actually starts to fall away with information overload resulting from a continued increase in demand. For a driver who has been significantly overloaded (*C*), there is a residual effect on performance even after demand is reduced. This is shown by the lower curve *CA*. The gap between input and output (i.e. between line *AD* and curve *ABC*) may be indicated by an error, input information which is not detected, or information which is selectively and deliberately shed.

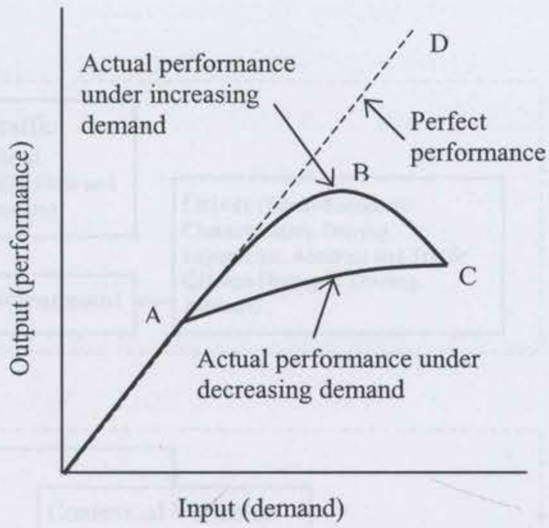


Figure 2-4 Information overload model

Source: Ogden (1995)

The driver performance models recognises that crash rates can be reduced by lowering the demands of the road and/or heightening the capabilities and skills of drivers. These can be achieved through traditional 'Triple E' approaches: Engineering, Education and Enforcement, by supplying a better road system, driver training and legislative constraints on driver behaviour and driver training. These solutions are challenged by behaviour compensation models. An engineering improvement in the road system is inadequate to ensure the expected decrease in crashes. It will have the expected degree of effectiveness only if driver behaviour remains unchanged.

2.6 Development of A Conceptual Framework for Empirical Inquiry

The perception of safety is an important determinant of driver's decision making and traffic behaviour. We develop a conceptual framework within which we can investigate drivers' perception of safety and behavioural response at specific road and traffic situations. Figure 2-5 gives a diagram of conceptual framework consisting three major parts: a research context, a SP framework for empirical inquiry and thesis contributions.

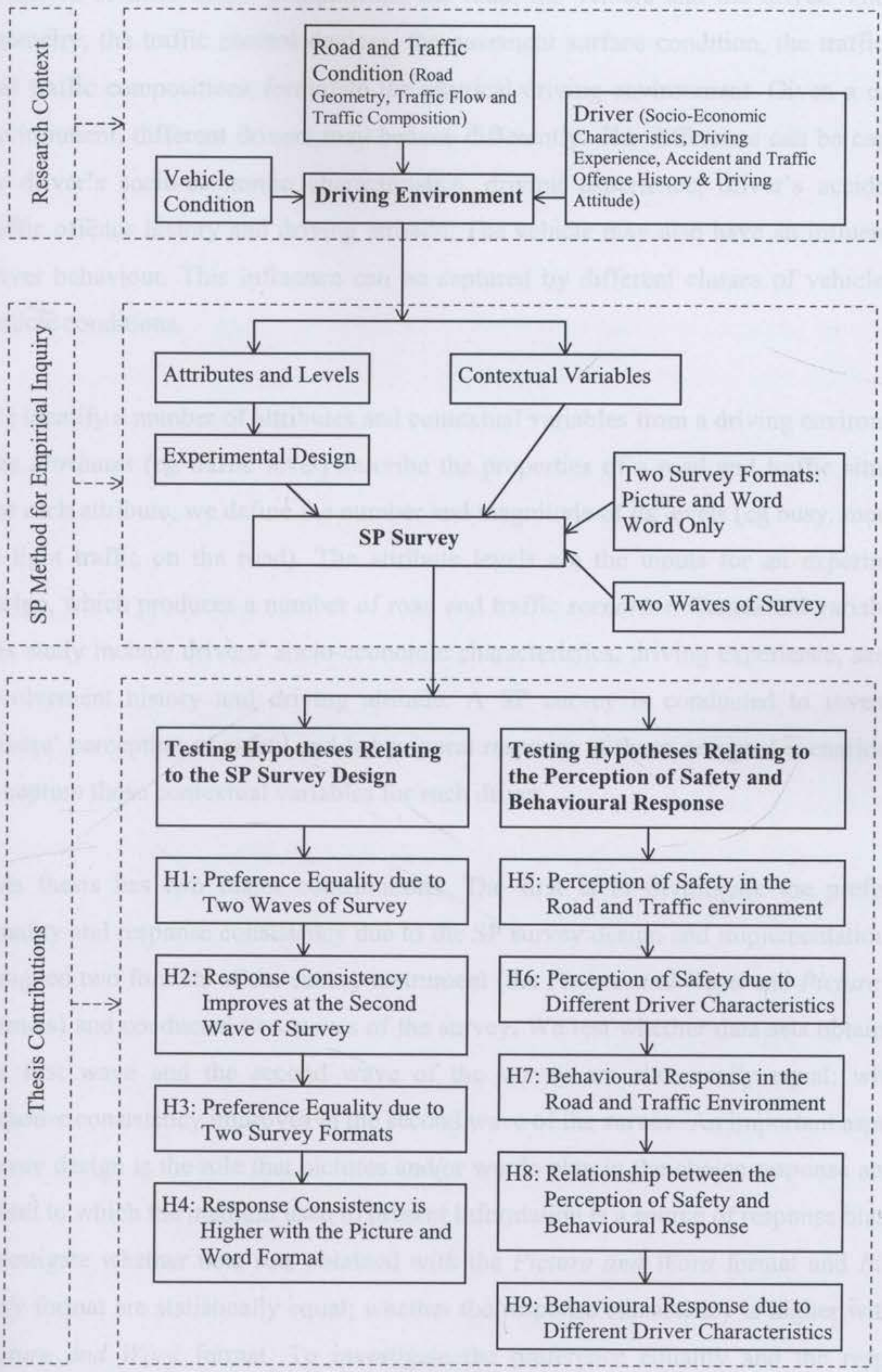


Figure 2-5 Conceptual framework for empirical inquiry

We use a driving environment as the research context. A driving environment is consisted of three major components: the road, the vehicle and the driver. The road geometry, the traffic control devices, the pavement surface condition, the traffic flow and traffic compositions formulate the physical driving environment. Given a driving environment, different drivers may behave differently. The difference can be captured by driver's socio-economic characteristics, driving experience, driver's accident or traffic offence history and driving attitude. The vehicle may also have an influence on driver behaviour. This influence can be captured by different classes of vehicles and vehicle conditions.

We identify a number of attributes and contextual variables from a driving environment. The *attributes* (eg traffic level) describe the properties of a road and traffic situation. For each attribute, we define the number and magnitude of its levels (eg busy, moderate or light traffic on the road). The attribute levels are the inputs for an experimental design, which produces a number of road and traffic *scenarios*. Contextual variables in this study include drivers' socio-economic characteristics, driving experience, accident involvement history and driving attitude. A SP survey is conducted to investigate drivers' perception of safety and behavioural response at these designed scenarios, and to capture those contextual variables for each driver.

This thesis has two major contributions. The first is to investigate the preference equality and response consistency due to the SP survey design and implementation. We designed two formats of the survey instrument (the *Picture and Word* and *Picture Only* formats) and conducted two waves of the survey. We test whether data sets obtained in the first wave and the second wave of the survey are statistically equal; whether response consistency improves in the second wave of the survey. An important aspect of survey design is the role that pictures and/or words play in the choice response and the extent to which the medium used to present information is a source of response bias. We investigate whether data sets obtained with the *Picture and Word* format and *Picture Only* format are statistically equal; whether the response consistency is higher with the *Picture and Word* format. To investigate the preference equality and the response consistency between two data sets, we employ the random utility theory as a theoretical framework and use an "artificial tree" structure to specify the nested logit model for the joint data set and multinomial logit models for each data set (see chapter eight). The relative scale parameter of two data sets and the preference (utility) parameters are estimated. The preference equality of two data sets is defined as the equality of the products of the scale parameter and the utility parameter in statistical sense, and the response consistency is compared by the scale parameter (the inverse of the variance) of the data sets. Four hypotheses have been formulated:

- *Hypothesis 1*: Preference profile obtained at the first wave of the SP survey and the second wave (repeated) survey are statistically equal.
- *Hypothesis 2*: Response consistency improves at the second wave of the survey.
- *Hypothesis 3*: Preference profile evaluated with the *Picture and Word* format and the *Picture Only* format are statistically equal.
- *Hypothesis 4*: The response consistency evaluated with the *Picture and Word* format is greater than that associated with the *Picture Only* format.

The second major contribution of the thesis is to measure drivers' perception of safety and to investigate behavioural response at specific road and traffic situations. When faced with a road and traffic situation, a driver evaluates the safety of the situation. The perception of safety is derived from a set of attributes describing the road and traffic situation. After evaluated the safety of the driving environment, the driver selects a behavioural response that is most appropriate to the safety and mobility of the prevailing road and traffic situation. Five hypotheses have been formulated to investigate driver's perception of safety and behavioural response:

- *Hypothesis 5*: Attributes representing the road and traffic situation have a significant influence on driver's perception of safety.
- *Hypothesis 6*: Given a road and traffic situation, drivers with different socio-economic characteristics, driving experience and attitude tend to have different perceptions of safety.
- *Hypothesis 7*: Attributes associated with the road and traffic situation have a significant influence on driver's behavioural response.
- *Hypothesis 8*: There exists a relationship between the perception of safety and behavioural response. Specifically, drivers tend to select a less cautious behavioural response when facing a safer driving environment.

- *Hypothesis 9*: Driver's socio-economic characteristics and driving experience have a significant influence on their behavioural response.

2.7 Summary

The literature review highlights the need for research on the perception of safety both in terms of the measurement of safety of the road environment and in the development of safety countermeasures. Early studies have used electrodermal activity as a measurement of subjective risk in a belief that driver perception of risk at a traffic situation is reflected in the changes of the electrodermal activity of the skin. Such studies found that the *number of electrodermal activities per vehicle kilometre* varies by road sections with different accident histories, and is negatively correlated with vehicle speed. The *electrodermal activity per minute* does not vary with road sections. The use of electrodermal activity as a measurement of perception of risk is problematic, because electrodermal activity is very sensitive to many influences and therefore not specific to changes in perceived risk. The electrodermal activity is difficult to implement and the results are subject to great variation to the sensibility of the instrument used to measure the electrodermal responses.

We developed a conceptual framework to empirically investigate two broad issues: (1) preference equality and response consistency due to the SP survey design and implementation, and (2) driver's perception of safety and behavioural response at specific road and traffic situations. The stated-preference technique was proposed as the methodology and associated hypotheses were formulated. The stated-preference provides an appropriate approach for investigating the perception of safety. In particular:

- Driver's perception of safety is subjective thus is difficulty to be directly observed in real situations.
- We have complete control over the attributes presented in the situations. This enables a wide range of situations to be investigated, which may not easily be measured when observations of actual behaviour are used.
- The preference data is consistent with random utility theory, thus a number of

econometric models can be specified to estimate the effects of road and traffic attributes. An experimental design minimises the effects of correlation between the variables so that the effects of attributes can be independently identified. This is superior to traditional method where the perceived risk can only be related to different road sections or predefined traffic events.

Chapter Three

Safety of Roundabouts

Roundabouts were selected as the empirical research context for measuring driver's perception of safety. This chapter provides a review of safety and risk exposure at roundabouts. The operational features of roundabouts are discussed in the following section. Section 3.2 briefly reviews the safety of roundabouts by comparing accident rates at roundabouts to other intersection controls, comparing the accident rates before and after roundabout installation, and addressing safety for pedestrians and two-wheel vehicles. Section 3.3 identifies the contributory factors for improved safety at roundabouts while section 3.4 relates the safety of roundabouts to its geometric elements. The chapter concludes with a summary of the safety performance of roundabouts.

3.1 Operational Features of Roundabouts

A roundabout is defined as a channelised intersection at which all traffic moves clockwise around a central traffic island (Austroads 1993b). In the United States, the term modern roundabout has been used to differentiate it from the nonconforming traffic circles. The modern roundabout has two unique operational features:

(1) *Give way at entry*: This requires that vehicles in the circulatory roadway have the right-of-way and all entering vehicles on the approaches have to wait for a gap in the circulating flow. Traffic control (a give way line) at the entry point maintains traffic flow fluidity and high traffic capacity.

(2) *Deflection for entering traffic*: The route for entering traffic is deflected to the left by the central island. No traffic stream gets a straight movement through the intersection.

Historically, the give way at entry is the most important operational feature of roundabouts. It is a criterion to differentiate modern roundabout to old nonconforming traffic circles. The era of modern roundabouts began in the United Kingdom in 1956 when the first give way at entry roundabout was constructed. In 1966, a nationwide give way at entry rule in the UK launched the modern roundabout revolution (see Todd 1991 for a review of history of roundabouts in Britain). Australia and other British-influenced countries soon built modern roundabouts. The give way at entry rule was formally adopted by France by 1983, Norway by 1985, Switzerland by 1987 (Ourston and Bared 1995). As of 1998, there are about 35,000 roundabouts worldwide. France leads the world with an estimated 15,000 modern roundabouts, built at a rate of 1,000 per year during the 1990's (Guichet 1997). In the United States, the first modern roundabout was built in 1990 and by 1997 there were about 50 modern roundabouts. They have become a subject of great interest and attention over the last few years. This interest is partially based on the great success of roundabouts in Australia and Europe. In particular, nonconforming traffic circles generally have one or more of the following features (TRB 1998).

(1) *Entering traffic has right of way*. At higher volumes this locks up the circle.
(2) *Entries were regulated by stop signs or traffic lights*. This reduces fluidity and capacity.
(3) *Entries were tangential to a circle*. This encourages high entering speeds and reduces the safety benefits.
(4) *Pedestrians crossed onto the central island*. This is unsafe for pedestrians and disruptive for drivers.
(5) *The through road cut through the circle*. Capacity, fluidity, and safety benefits are lost by the need to signalise the central intersection.
(6) *Circulating traffic was controlled by a traffic signal or stop sign*. This decreases the fluidity of circulating traffic and can lock up the circle.
(7) *Parking was permitted in the circle*. This reduces the capacity and safety of the circle by adding friction and conflicts.

Roundabouts have been extensively used in Australia as a safe and efficient form of intersection control. Roundabouts have been found satisfactory at a wide range of sites where the intersecting roads have roughly the same classification and purpose. They are especially effective at intersections where traffic volumes on the intersecting roads are such that *Stop* or *Give Way* signs or the *T-junction* rule result in unacceptable delays for the minor road traffic or where there are high proportions of right-turning traffic.

Roundabouts are a frequently used treatment for improvement of the safety and amenity of a local street or residential street network. The geometric elements of roundabouts are frequently cited in this thesis, as illustrated in figure 3-1. The definitions are self-evident from the figure.

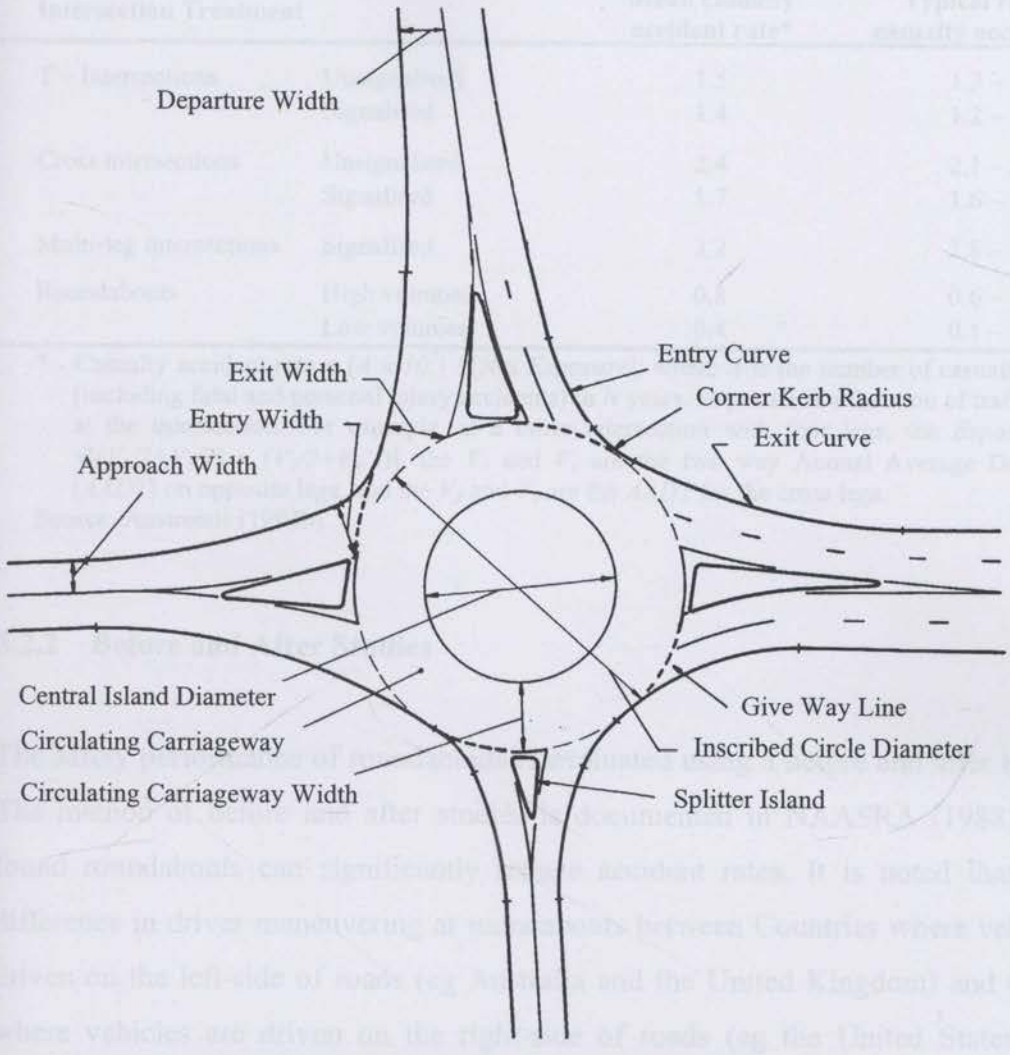


Figure 3-1 The geometric elements of a roundabout
Source: Adapted from Austroads (1993b)

3.2 Safety of Roundabouts

3.2.1 Comparison of the Safety of Roundabouts with Other Intersection Treatments

Roundabouts are recognised as a safe intersection treatment. Austroads (1993b) gives casualty rates at various intersection treatments as shown in table 3-1. Roundabouts have lower casualty accident rates than signalised and unsignalised T-intersections, cross intersections or multi-leg intersections.

Table 3-1 Typical casualty accident rates for urban intersection treatments

Intersection Treatment		Mean casualty accident rate*	Typical range of casualty accident rate
T – Intersections	Unsignalised	1.5	1.3 – 1.7
	Signalised	1.4	1.2 – 1.6
Cross intersections	Unsignalised	2.4	2.1 – 2.7
	Signalised	1.7	1.6 – 1.8
Multi-leg intersections	Signalised	3.2	2.8 – 3.6
Roundabouts	High volumes	0.8	0.6 – 1.1
	Low volumes	0.4	0.1 – 1.0

* - Casualty accident rate = $[A \times 10^7] / [N \times Exposure]$, where A is the number of casualty accidents (including fatal and personal injury accidents) in N years. Exposure is a function of traffic volumes at the intersection. For example, at a cross intersection with four legs, the $Exposure = 2 \times \sqrt{[(V_1/2+V_3/2) \times (V_2/2+V_4/2)]}$, the V_1 and V_3 are the two way Annual Average Daily Traffic (*AADT*) on opposite legs, and the V_2 and V_4 are the *AADT* for the cross legs.

Source: Austroads (1993b)

3.2.2 Before and After Studies

The safety performance of roundabouts is evaluated using a before and after technique. The method of before and after studies is documented in NAASRA (1988). Studies found roundabouts can significantly reduce accident rates. It is noted that there is difference in driver maneuvering at roundabouts between Countries where vehicles are driven on the left-side of roads (eg Australia and the United Kingdom) and Countries where vehicles are driven on the right-side of roads (eg the United States). In the following, we briefly review some of before and after studies, separating into Australian and international studies.

Australian Studies

Miller et al (1981) reported a before and after study of accident change at 52 sites in urban areas in Victoria. These sites were previously cross intersections. The sites were grouped based on traffic volumes. Table 3-2 summarises the changes in casualty accidents after the installation of a roundabout. Accident rates were reduced in all groups of roundabouts. On average, a 68 percent casualty accident reduction was observed.

Table 3-2 Changes in casualty accidents after roundabout installation: Victorian urban area

Group	Change in casualty accidents
Very low traffic volumes, typical of residential streets	100% reduction
Low to moderate traffic volumes, typical of collector roads	74% reduction
Moderate to high traffic volumes, typical of arterial roads	35% reduction
Total	68% reduction

In the 1970's, roundabouts were accepted as a safer intersection control device in an urban area. However, it was believed that they were dangerous on rural roads. Miller et at observed accident occurrence at two rural roundabouts (table 3-3). In fact, there were no casualty accidents occurred in more than two years after roundabout installation. It appears that roundabouts in rural area are at least as safe as those in urban area.

Table 3-3 Change in casualty accidents after roundabout installation: Victorian rural area

	Before roundabout	After roundabout
Total observation years	8	2.25
Total casualty accidents	39 (including 4 fatals)	0
Average casualty accidents per year	4.9	0

O'Brien and Richardson (1985) updated the study conducted by Miller at al (1981) to cover 73 sites in Victoria over a longer period of observation time. The major findings of the study include:

(1) Sites were grouped according to entering traffic volumes. All groups showed a statistically significant reduction in accident rates. The casualty accident rate for all sites decreased by 75.4 percent after roundabout installation.

(2) There was a 32 percent reduction in the property damage accidents after roundabout installation. O'Brien and Richardson noted that this was not conclusive because not all property damage accidents were reported. It appeared that roundabouts have led to a reduction in property damage accidents as well as casualty accidents.

(3) Two roundabouts in a high speed area (with 100 km/h speed limits) had produced very large reductions in casualty accidents. In the three years after the

installation of the roundabout there were no casualty accidents.

(4) There was a 68 percent reduction in pedestrian casualty accidents per year after the roundabout installation for all sites combined. This result was encouraging. However, due to the low number of pedestrian accidents, the reduction was not statistically significant at the 10 percent level.

Richardson (1982) conducted a before and after study at 14 sites in Western Australia. The results indicated a 62 percent reduction at the 5 percent significant level in all types of accidents after roundabouts were installed. Richardson (1990) provided an update of his 1982 study by analysing accident statistics at 48 roundabouts and 45 control sites in the city of Stirling, Western Australia. The study showed that all accidents were reduced by 41 percent and severe injury accidents were reduced by 66 percent. He concluded that roundabouts were very effective in reducing accidents at the busier intersections with the warning that accident rates were likely to increase in some low traffic sites.

Davis (1984) conducted a before and after study of 18 roundabouts in Brisbane, reporting that the injury accidents have been reduced by 57 percent, and total accidents reduced by 40 percent. When taking into account traffic growth, total accidents would be reduced more substantially, up to 55 percent.

Tudge (1990) analysed the before and after accident data at 230 roundabouts and 60 control sites in New South Wales. There was a marked reduction in accidents for all types of accidents at the roundabout sites, compared with an increase for all types of accident at the control sites (table 3-4). For injury accident rates, a reduction of 45.36 percent was observed in the roundabouts, compared with a 56.59 percent increase in the control sites. If these reductions at roundabouts were adjusted for the control sites, the safety benefits of roundabouts would be more evident. Tudge drew the following conclusions from his safety study.

(1) Roundabouts specifically designed to reduce accident problems are more successful in accident reduction than those constructed for other purposes such as speed control or capacity constraint.

(2) The higher the existing accident rate, the greater the reduction in accidents and the more cost-effective the construction of a roundabout.

(3) Some roundabouts tend to increase accidents, especially at those intersections with no recorded accidents before roundabout construction.

Table 3-4 Average annual accident frequencies before and after roundabout construction: New South Wales

Accident type	Roundabouts			Control		
	Before	After	Change (%)	Before	After	Change (%)
Fatal	0.024	0.009	-62.50	0.009	0.022	144.44
Injury	1.045	0.571	-45.36	0.857	1.342	56.59
Damage Only	2.841	1.709	-39.85	2.951	4.034	36.70

Source: Tudge (1990)

Using the accident data from 1990 to 1994, Robinson (1998) investigated accidents at roundabouts in New South Wales. She found a significant proportion of accidents at the roundabouts involved only a single vehicle. Single vehicle accidents accounted for 40 percent of all severe/fatal accidents and 24.5 percent of all injury accidents at the roundabouts. These happened when a vehicle failed to stay on course, either running off the road or into a parked car or other object. This suggested that a significant cause of serious accidents at roundabouts was excessive approach speeds.

International Studies

Three studies of safety of roundabouts in the United States were Ourston and Bared (1995), Flannery and Datta (1996) and TRB (1998). Ourston and Bared (1995) examined five roundabouts constructed during 1990-1993. These are the earliest modern roundabouts in the USA, produced remarkable safety records. Flannery and Datta (1996) compared before and after crash statistics at six roundabouts in the United States, and concluded that in all but one case, the reduction in accidents for roundabout sites was in the range of 60-70 percent. Statistical tests indicated a significant difference in the reduction of frequency and mean of accidents at 95 and 99 percent confidence levels respectively.

The Transportation Research Board reported a survey conducted in 1997 which produced before and after accident statistics for 11 roundabouts in the United States (TRB 1998). Crash frequencies were observed for several years before the roundabout was built, and for a shorter period after roundabout installation. Average annual crash frequencies were calculated, broken down by total crashes, injury crashes, and property damage only (PDO) crashes. Table 3-5 summarises the results for the 11 roundabouts in two categories: large roundabouts with three-lane entries and small to moderate roundabouts with one or two-lane entries and inscribed circle diameters of 37 m or less. For the small to moderate roundabouts, a reduction of 51 percent for total crashes was observed. Injury and PDO crashes were reduced by 73 and 32 percent respectively. For the large roundabouts, total crashes were reduced by 29 percent, injury crashes by 31 percent and PDO crashes by 10 percent.

Table 3-5 Average annual crash frequencies before and after roundabout construction in the USA

Crash type	Small/Moderate (8 sites)	Large (3 sites)	Total (11 sites)
Average annual crashes: Before roundabouts			
Total	4.8	21.5	9.3
Injury	2.0	5.8	3.0
PDO	2.4	15.7	6.0
Average annual crashes: After Roundabouts			
Total	2.4	15.3	5.9
Injury	0.5	4.0	1.5
PDO	1.6	11.3	4.2
Percent change			
Total	-51	-29	-37
Injury	-73	-31	-51
PDO	-32	-10	-29

Source: TRB (1998)

Schoon and Minnen (1994) conducted a study at 181 roundabouts in the Netherlands to determine their safety performance. These roundabouts are converted from stop or give way controls, old nonconforming traffic circles or signalised intersections. The study compared the accident rates at roundabouts with an average period of 5.3 years before roundabouts and an average period of 2 years after roundabouts. It was found that total accidents per year per roundabout dropped from 4.9 to 2.4, and casualty accidents per year per roundabout dropped from 1.3 to 0.37. Roundabouts converted from old nonconforming traffic circles improved safety most significantly, with a decrease of 75 percent in casualty accidents. In contrast, roundabouts converted from signalised intersections were shown to reduce vehicle accidents by only 2.7 percent and to increase the moped and cycle casualties by 4 percent.

France has the world's largest inventory of roundabouts. A study of 83 roundabouts was conducted by the Centre D'Etudes Techniques de L'Equipment de l'Ouest (1986). The results are shown in table 3-6. It was found that the transformation of a traditional intersection into a roundabout resulted in significant safety benefits. The injury accidents per year reduced by 78 percent, and both the number of fatalities and injuries were reduced significantly. Smaller roundabouts had fewer crashes than larger roundabouts, and roundabouts with an oval central island had the highest accident rates. The slope toward the outside of the circle was preferable to the inside slope, because it improves the recognition of the roundabout from an approach. The study did not take into consideration the traffic volumes. If we assume that larger roundabouts carry higher traffic volumes than smaller ones, the statistics would be less favorable for the smaller roundabouts. The study related the better safety performance of the outside slope to the improved visibility of the central island. The fact that no vehicles lost control on the circulating carriageway at the outside sloping roundabout may suggest that the "wrong" slope reinforces the message to slow down.

Table 3-6 Crash frequencies at roundabouts: France

Before and after crash frequencies			
	Before	After	Change (%)
Injury accident per year	0.42	0.31	-78
No. of fatalities per year	0.16	0.02	-88
No of injuries per year	2.78	0.49	-82
Crash frequencies and size of inscribed diameter			
Size of inscribed diameters	Number of roundabouts		Crashes per roundabout
<30 m	13		0.69
30 – 50 m	11		1.54
50 – 70 m	26		1.58
70 – 90 m	16		1.81
>90 m	8		3.80
Oval	9		4.40
Crash frequencies and slope of circulatory roadway			
	Slope to the inside		Slope to the outside
Total crashes per year per roundabout	0.50		0.28
Accidents due to loss of control at entry	0.12		0.06
Accidents due to loss of control or ring	0.09		0.00
Accidents due to refusal of priority an entry	0.14		0.09

Source: TRB (1998)

3.2.3 Safety for Pedestrians and Cyclists

Many studies indicate that roundabouts are relatively safe for pedestrians. This is because pedestrians are able to cross one direction of traffic at a time by staging on the splitter islands. Vehicle speeds are restricted at roundabouts giving additional safety. However, unlike traffic signals, roundabouts do not give positive priority to pedestrians over traffic movements. The record of safety for bicycles and motorcycles has been mixed. Research indicates that cyclists perceived roundabout treatments, particularly on the more heavily trafficked roads where two or more entry and circulating lanes are used, as significantly more stressful to negotiate than other forms of treatment. Allott and Lomax (1991) found that some cyclists even changed their regular journey route to avoid some roundabouts. The studies of safety for pedestrians and two-wheel vehicles at roundabouts are reviewed below.

Jordan (1985) conducted a before and after study at 36 roundabout sites at the Melbourne metropolitan area. The roundabouts were installed between 1980 and 1982. The study found that pedestrian accidents reduced by 12 percent while cyclist accidents increased by 28 percent.

Robinson (1998) analysed accident data between 1990 and 1994 in New South Wales (NSW) and found that cyclists and motorcyclists were over-represented in accidents at roundabouts (see table 3-7). Major conclusions of the study associated with safety of pedestrians, bicyclists and motorcyclists include:

(1) The cyclists were over-represented in injury accidents at roundabouts. Injury accidents involving a cyclist represent 22.3 percent of two-party accidents at roundabouts, compared to 6.8 percent of all reported accidents in NSW.

(2) Motorcyclists were over-represented in injury accidents at roundabouts. Injury accidents involving a motorcyclist account for 16.6 percent of all two-part accidents at roundabouts, compared to 9.8 percent of all reported accidents in NSW.

(3) Pedestrian accident rates at roundabouts were no greater than pedestrian accident rates in all roads of NSW.

(4) The road user movement (RUM) code analysis indicated that accidents at

roundabouts were mainly made up of an entering motorist hitting a circulating bike rider. This suggested that higher approach speed was a major contributory factor to cyclist accidents at roundabouts.

(5) Lane changing, side-swipe or overtaking accidents accounted for 8 percent of all two-party accidents at roundabouts. This proportion is small probably because the vast majority of roundabouts in NSW are single-lane.

Table 3-7 Percentage of accidents involving a cyclist, pedestrian or motorcyclist: New South Wales

Accident Type	Bicycle	Pedestrian	Motorbike	Any of these
Two-party accident at roundabouts (1990-92)				
All accidents	7.9	4.1	6.6	18.4
Injury accidents	22.3	11.5	16.6	50.0
Severe/fatal accidents	22.6	20.2	25.6	66.1
All reported accidents in NSW (1992-94)				
All accidents	2.7	6.4	3.9	13.0
Injury accidents	6.8	16.3	9.8	32.9
Severe/fatal accidents	4.9	20.6	11.9	37.4

Source: Robinson (1998)

In the study of cyclist accidents at roundabouts in the UK, Layfield and Maycock (1986) reported that 50 percent of cyclist accidents involved entering vehicles hitting circulating cyclists and 17 percent involved exiting vehicles hitting circulating cyclists. A literature review by Allott and Lomax (1991) found that cyclist accident rates at roundabouts in the UK were up to 15 times those of cars and were 2 to 3 times greater than cyclist accident rates at traffic signalised intersections.

In France, Alphand et al (1991) showed that annual frequency of two-wheeled vehicle accidents at signalised intersections was 0.23 per year per intersection, in contrast with 0.13 per year per roundabout. It appeared that roundabouts were relatively safe for cyclists in France.

The before and after study performed by Schoon and Minnen (1994) in the Netherlands showed a reduction in pedestrian injuries of 89 percent. Bicycle and motorcycle injuries decreased from 0.55 to 0.31 per year per intersection. The study indicated that roundabouts were relatively safe for both pedestrians and cyclists.

3.3 Contributory Factors for Improved Safety at Roundabouts

Studies of safety performance of roundabouts generally indicated great safety benefits in reduction of injury crashes. Roundabouts are at least as safe for pedestrians as other forms of intersection control. Some studies indicated that roundabouts increase the risk of accidents to cyclists and motorcyclists, although others suggested the same benefits to all groups of road users. The improved safety of roundabouts can be related to a number of geometric, operational and human factors.

Geometric elements: The physical guidance, the limitation of traffic speeds and the separation of the various movements by the splitter islands and the central island reduce conflict points. As shown in figure 3-2, there are 32 conflict points at which drivers are required to cross, merge or diverge from other traffic streams at a cross intersection. At a four-approach roundabout, there are only eight. The entry deflection forces all vehicles to slow down, thus reducing the probability of a crash and the severity of the crash. All vehicles travel at slow speeds, with little speed difference between cars and bicycles, making the operation more congenial and safe. Pedestrian crossings are at locations where vehicles travel at slow speeds.

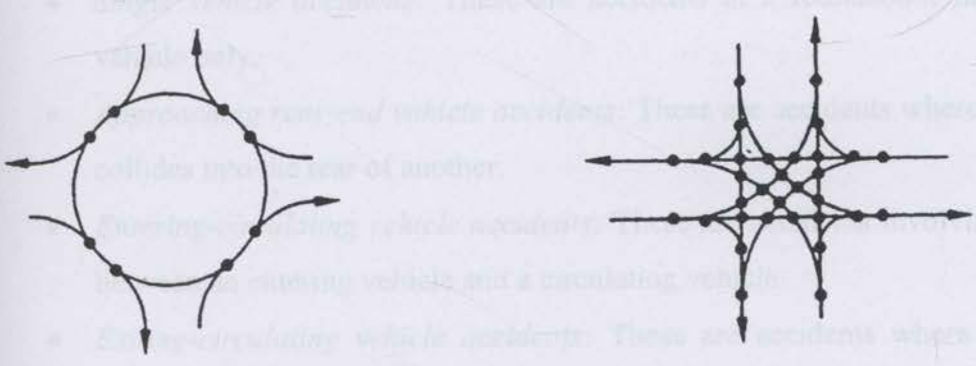


Figure 3-2 Conflict points at a roundabout and at a cross intersection
Source: Troutbeck 1993, Drive on right side of road

Operational elements: One-way operation, give way at entry and the reduced number of conflict points make the decision process for drivers easier. The entering driver, after looking out for pedestrians, only has to look for an acceptable gap to enter into the flow. Weaving only occurs in multiple-lane roundabouts, where it is simplified by the low speeds.

Human elements: Roundabouts generally can reduce delays compared to signalised intersections (Austroads 1993b). The reduced delays decrease the level of frustration and aggressiveness of drivers. In addition, slower speeds make drivers more congenial and aware of their environment. The drivers notices other road users more readily, especially the more vulnerable users. Having to give way to the traffic already in the circulating carriageway and having to slow down induces greater driver courtesy and a higher level of responsibility. This is contrary to an intersection where many drivers are encouraged by a green/yellow light to accelerate to get across the intersection quickly and to "beat the red light".

3.4 Relating the Safety to Roundabout Geometry

Several studies related the accident rates to roundabout geometric elements (Maycock and Hall 1984, Arndt 1994 and Arndt 1998). These studies employed generalised linear regressions and assumed that different types of accidents follow different patterns. Specifically, five types of accidents have been defined in these studies as follows.

- *Single vehicle accidents:* These are accidents at a roundabout involving one vehicle only.
- *Approaching rear-end vehicle accidents:* These are accidents where one vehicle collides into the rear of another.
- *Entering-circulating vehicle accidents:* These are accidents involving collisions between an entering vehicle and a circulating vehicle.
- *Exiting-circulating vehicle accidents:* These are accidents where one vehicle from the inner circulating lane onto the departure leg collides with another vehicle that is continuing to circulate on the outer circulating lane.
- *Side-swipe vehicle accidents:* These are accidents where two vehicles collide in a side-swipe manner whilst travelling on different paths in the same direction, generally involving one cutting lane vehicle colliding with another vehicle remaining on the lane.

These studies used the number of accidents as the dependent variable with traffic volume, vehicle speeds and geometric elements as explanatory variables. The effects of some important explanatory variables are discussed below.

- *Vehicle speeds:* Increasing the approach speed increases the single vehicle accidents and rear-end accidents. The entering-circulating vehicle accidents are predominantly related to the relative speed between entering and circulating vehicles. Minimising the relative speed between entering and circulating vehicles will minimise the entering-circulating vehicle accident rates.
- *Traffic volume:* Traffic volume is an important factor in predicting accident rates. Given the geometry of a roundabout, increasing the traffic volume increases the accident rates.
- *Number of circulating lanes:* Increasing the number of circulating lanes for the same traffic flows will increase the entering-circulating vehicle accident rates. Exiting-circulating and side-swipe vehicle accidents are very rare on single lane roundabouts but occur predominately on multilane roundabouts.
- *Number of approach lanes:* An increase in the number of approach lanes for the same traffic volume will increase approaching rear-end accidents.
- *Inscribed circle island:* Increasing the diameter of a roundabout usually enables provision of better approach geometry to decrease vehicle approach speeds. An increase in roundabout diameter will also provides a reduction in the angle formed between the entering and circulating vehicle paths thus reducing the relative speed between these vehicles and decreasing the entering-circulating vehicle accidents.
- *Entry path curvature:* The entry path curvature is the maximum vehicle path curvature through the roundabout at the entry point and is the inverse of the entry radius. As the entry curvature increases, single vehicle accidents and rear-end accidents increase, while the entering-circulating accidents decrease. This implies that there is an optimum value of entry curvature that produces minimum total accidents.
- *Entry width:* It was found that a large entry width produces higher total accident rates. As the entry width increases, the entering-circulating vehicle accidents increase but the rear-end accidents decrease.
- *Visibility:* For entering-circulating vehicle accidents, sight distance was not a

statistically significant parameter. For single vehicle accidents, accident rates increase as sight distance increases. This result was unexpected, the reason for this result was not identified in studies.

- *Central island:* Central islands of roundabouts should be raised. Roundabouts with a raised central island give a better recognition of the roundabout geometry for approaching drivers. Conversely, depressed islands give a poor recognition of the roundabout. The poor recognition of roundabouts can lead to the sudden speed reduction before the give way line, that in turn increases the rear-end accidents.

3.5 Safety of Roundabouts: A Summary

The following conclusions can be drawn from the review of the existing literature on safety of roundabouts. These conclusions are particular useful in identifying the attributes to be included in our empirical inquiry as discussed in the next chapter.

- Casualty accident rates at roundabouts are lower than those at signalised and unsignalised T-intersections, cross intersections and multi-leg intersections.
- Before and after studies showed that fatal, injury and property damage accident rates can be significantly reduced after roundabout installation.
- Roundabouts are a relatively safe intersection treatment for pedestrians.
- The safety of roundabouts for two-wheel vehicles is not conclusive. Some studies indicated that roundabouts are dangerous for cyclists while others demonstrated that roundabouts are relatively safe for cyclists and motorists as well.
- Improved safety at roundabouts can be attributed to human factors, geometric elements and operational features.
- Regression analysis indicated that accident rates at roundabouts could be successfully related to vehicle speeds, traffic volumes and roundabout geometric elements (eg number of circulating lanes, entry curvature and entry width).

Chapter Four

The Empirical Framework for Investigation of Driver's Perception of Safety and Behavioural Response

Chapter four develops the empirical framework to investigate a driver's perception of safety and behavioural response. The chapter is organised into four sections. The measurement dimensions designed to capture the perception of safety and behavioural responses are defined in section 4.1. The attribute levels are identified in section 4.2. The survey instrument and its implications on response consistency are discussed in section 4.3. The modelling approaches are proposed in the section 4.4. The chapter concluded with a summary.

4.1 Defining the Measurement Dimensions for the Perception of Safety and Behavioural Response

The first consideration for an empirical study is how the perception of safety and behavioural response are measured. The driver's perception of safety is measured on a five-point Likert scale from 1-5. When a roundabout and traffic situation is presented to a driver, s/he is asked to choose only one scale point that best describes his or her perception of safety to the offered situation. The definitions of these scale points are:

1 = Very Unsafe.
2 = Somewhat Unsafe.
3 = Neutral.
4 = Somewhat Safe.
5= Very Safe.

The driver's behavioural response is defined as a discrete choice response out of three predefined options. When a roundabout and traffic situation is presented to a driver, s/he is asked to indicate one alternative that s/he is most likely to do in reality. The three ordered alternatives of behavioural response are:

1. *Slow Down to Stop*

2. *Slow Down and Keep Going*
3. *Not Slow Down and Keep Going*

4.2 Identification of Attributes and Contextual Variables

A large number of factors potentially have a direct or indirect influence on the perception of safety and/or behavioural response. An early consideration in this thesis is to identify those attributes to be included in the experimental design and those to be captured as contextual variables. Attributes describing the roundabout geometry and traffic situation are selected for the experimental design, with driver characteristics, driving experience and attitudes are selected to represent contextual variables. The number and magnitude of attribute levels are determined by the possible situations likely to be faced by drivers in reality. In addition, the number of attribute levels is influenced by the desire to investigate non-linearity of the impact. To identify attributes to be included in the experimental design, we firstly conducted an extensive literature review in road safety in general and safety at roundabouts in particular. The focus groups are used to identifying issues in refining and best presenting attributes. Finally, nine attributes were determined as discussed below.

Attribute 1 - The size of a roundabout: Previous studies suggested that a larger roundabout should be safer. A large roundabout generally has a large central island, which provides greater separation between adjacent conflict areas and makes it easier for entering drivers to determine whether vehicles, already on the circulating carriageway, are exiting or continuing on around the circulating carriageway. A larger central island can also improve driver's recognition of the form of intersection treatment from an approach. Poor recognition of the roundabout central island from an approach leg will not only contribute to accidents between approaching vehicles and circulating vehicles, but also to single vehicle accidents. A smaller central island causes rapidly changing curvature, increasing the driving task. However, a larger roundabout is likely to encourage higher speeds. Large roundabouts generally have higher accident rates than small and moderate ones (see table 3-5 for American evidence and table 3.6 for French evidence).

In traffic engineering, the size of the roundabout is measured by the inscribed diameter consisting of two dimensions, the diameter of the central island and the width of the circulating carriageway. In practice, the size of a roundabout is principally determined by traffic capacity requirements, the need to obtain sufficient deflection to control vehicle speed and the space available. A central island can be as small as 5 m in diameter and preferably 10 m in areas where drivers are likely to be familiar with roundabout operation. A single lane roundabout designed for high speed rural areas where two-way roads intersect, typically has a central island diameter in the range of 20 to 30 m. In engineering design, the width of a carriageway is dependent on the turning radius of the design vehicle. When using one articulated vehicle as the design vehicle, the width of a carriageway can be in the range of 4.6 to 7.6 m for a turning radius of 100 to 105 m. (See Austroads 1993b for specifications of roundabouts). In this study, we investigate the effect of this attribute at three levels, small, medium and large, defined as:

- *Small*: Inscribed circle diameter less than 32.4 m.
- *Medium*: Inscribed circle diameter between 32.4 and 52.2 m.
- *Large*: Inscribed circle diameter larger than 52.2 m.

Attribute 2 - The number of circulating lanes: Studies of safety of the roundabout have indicated that entering-circulating accident rates are higher at two or three lane roundabouts than at single lane roundabouts. Exiting-circulating accidents and side-swipe accidents occur predominantly at multilane roundabouts but are very rare at single lane roundabouts. The relationships between the number of circulating lanes and safety are connected to origin-destination profile. For left turn traffic, supplying one more circulating lane would be safer. But for through and right turn traffic, one more circulating lane requires traffic weaving, making driving maneuvering difficult. If there is more than one entry lane, interaction among drivers at different approach lanes would take place. A useful distinction is made between a dominant lane and sub-dominant lane/s. The right side lane or the lane with the greatest flow is normally the dominant lane, and other entry lane/s are sub-dominant. Drivers at a dominant lane tend to influence the behaviour of drivers in sub-dominant lane/s at an approach (Troutbeck 1989). In this study, we examine the effects of this attribute at two levels:

- *Single lane*: The circulating carriageway is narrow (eg 5 m). Only one vehicle can pass the circulating carriageway each time. There is no traffic weaving on the roundabout.
- *Multilane*: There are two or more lanes on the circulating carriageway. The circulating carriageway can accommodate two or more vehicles side by side. There is traffic weaving on the roundabout.

Attribute 3 - Visibility to other traffic: The driver visibility to the oncoming vehicles at right approach or already on the circulating carriageway is an important factor for both perception of safety and driving behaviour at roundabouts because the operation of roundabouts is based on gap-acceptance. However, previous studies indicated that this attribute does not statistically significantly relate to accident rates at roundabouts (Arndt 1998, Maycock and Hall 1984). Maycock and Hall even found single accident rates increase with the increase of sight distance. They could not explain this unexpected result. However they suggested that the sight distance should not be deliberately reduced.

In traffic engineering, the visibility requirements are satisfied by supplying adequate sight distances through appropriate alignment combinations of vertical and horizontal geometrics. There are three criteria for determining the sight distance at a roundabout. The first criterion requires an approach sight distance at least equal to *Approach Stopping Distance* (ASD), which is a distance required for stopping at a *give way* line from the moment of detecting the roundabout. The ASD is proportional to approaching speed. This criterion requires that the approach road is designed so that the driver has a good view of the splitter island, the central island and desirably the circulating carriageway. The second criterion is *Entering Sight Distance* (ESD), which requires a sight distance to see the approaching traffic entering the roundabout from the immediate right approach, and the circulating traffic that has already entered from the other approaches. This distance represents the product of the entering speed and a travel time equal to the *critical acceptance gap*. On urban local streets, a critical gap value of 4 seconds and an entering speed of 25 km/h provides a sight distance of 28 m. On arterial roads, a distance of 70 m is required based on a critical gap of 5 seconds and an entering speed of 50 km/h (Austroads 1993b). This sight distance is essential for safe operation of roundabouts. The last criterion is *Safe Sight Distance* (SSD). It requires that drivers approaching the roundabout are able to see other entering traffic well before they reach the give way line. An appropriate safe sight distance allows an approaching driver to stop and avoid conflicting with a vehicle driving through the roundabout. This is a desirable criterion. In urban areas, it is not always possible to achieve this distance. In a stated preference study, it is difficult to represent these sight distance requirements in a manner that is comprehensible by respondents. We therefore simplify the problem by offering two levels for this attribute, clear or obstructed visibility to other traffic, as defined below:

- *Clear*: Adequate sight distance is provided. An approaching driver can see vehicles already on the circulating lane and vehicles approaching the roundabout at the right side approach.
- *Obstructed*: Visibility is obstructed by other objects (eg buildings or trees), so that an approaching driver is uncertain whether there is a vehicle approaching on the right side.

Attribute 4 - Size of the vehicle potentially conflicting with the respondent: There is little research evidence on the range of driver reaction when encountering different sized vehicles. To gain some insights, we captured a number of traffic situations using a video recorder and observed driving behavioural responses at roundabout. We found that when a car driver at an approach encountered other cars at their right approach or already on the circulating carriageway, they behaved more consistently by accepting an appropriate gap. When they encountered trucks, most drivers drove more cautiously by accepting a longer headway while others accepted a shorter headway or sometimes accelerated to pass before the truck. Evans (1994) compared driver injury and fatality risk in two-car crashes. The severity of a collision is dependent on both the absolute mass of one vehicle and the relative masses of two colliding vehicles. The lighter the vehicle is, the riskier it is when involved in a collision. When two cars of the same mass crash into each other, their risks are equal. However, when a small car with a mass of 900 kg collides with a large car with a mass of 1800 kg, the injury risk of the small car is as high as 11.6 times that of the large car. We investigate how a car driver evaluates the safety when encountering different size vehicles by specifying vehicle sizes:

- *Small*: Including car, mini-bus (less than 12 seats) and small truck with

Manufactures Vehicles Mass (GVM) less than 4.5 tonnes. This is equivalent to vehicles with a "C" Class Licence (see RTA 1996b).

- *Medium*: Light commercial vehicle and van, medium rigid truck or bus with a GVM less than 8 tonnes.
- *Large*: Heavy rigid truck or bus, heavy articulated vehicle, B-double and road train.

Attribute 5 - Speed of the vehicle potentially conflicting with the driver: Studies have indicated that entering-circulating accidents are related to the relative speed between entering and circulating vehicles. Speed is the most important factor affecting accident risks and consequences. This is directly explained by Newtonian mechanics. The force that a car causes to its counterpart in a crash is proportional to the square of its speed, and the distance that a car needs to stop is proportional to the square of its original speed (Fildes and Lee 1993). The risk of all injury accidents changes by the second power of the relative change in speeds, severe injury accidents by the third power and fatality accidents by the fourth power (Nilsson 1984). In a 60 km/h speed limited area, the risk of involvement in a casualty crash doubles with each 5 km/h increase in travelling speed above 60 km/h (Kloeden et al 1997). We examine the relationship between drivers' safety perception and speed of a conflicting vehicle at three levels:

- *Slow*: The speed of a vehicle is slower than 30 km/h.
- *Moderate*: The speed of a vehicle is between 30 and 45 km/h.
- *Quick*: The speed of a vehicle is faster than 45 km/h.

Attribute 6 - General traffic level at a roundabout: Increasing the traffic volume increases the probability of conflicts between vehicles. Studies indicate that approaching rear-end accidents, entering-circulating accidents, exiting-circulating accidents and side-swipe accidents at roundabouts increase as the traffic volume increases.

Traffic at roundabouts is distinguished as entering traffic flow and circulating traffic flow. A single lane roundabout can accommodate the circulating flow of 0-1700 vehicles per hour and the entry flow of 0-1500 vehicles per hour. A two-lane roundabout can handle the circulating flow of 0-3500 vehicles per hour and the entry flow of 0-3000 vehicles per hour. The circulating flow and entry flow are inversely related (Austroads 1993b). For a very high circulating flow (eg 1700 vehicles per hour at a single-lane roundabout), the entry capacity approaches zero. In a stated preference experiment, offering traffic profiles in terms of traffic volumes is not very meaningful to a respondent. A better way to represent the traffic level at roundabout is the likelihood that a respondent can find an appropriate gap to manoeuvre through the roundabout. We investigate the effects of the traffic situation at a roundabout at three levels:

- *Light*: Traffic at roundabout is light. When a driver approaches the roundabout, s/he generally can find a large gap to unhurriedly manoeuvre through the roundabout.
- *Moderate*: Traffic at the roundabout is moderate. When a driver approaches the roundabout, s/he normally can find an appropriate gap to manoeuvre through the roundabout. Vehicles are not queued at any approaches.
- *Busy*: Traffic at the roundabout is busy. A driver generally has to wait an appropriate gap to manoeuvre through the roundabout. Vehicles are queued at one or more approaches.

Attribute 7 - Presence of a pedestrian who potentially conflicts with a driver's normal driving pattern: Drivers have a strong tendency to slow down when there is a pedestrian trying to cross the road in front of their vehicle. Katz (1973) conducted a very interesting experiment to examine the interaction between driver and pedestrian. He compared the effects of two different pedestrian behaviours upon the behaviour of drivers. In one condition, the pedestrian (a confederate of the experimenter) was instructed to go across the road while pretending not to see the approaching driver. In the other condition, the confederate was told to look at the approaching car and to seek eye contact with its driver. It was found that vehicle speed was significantly higher in the latter circumstance. "Looking behaviour of the pedestrian provides the driver with evidence that the pedestrian is aware of the vehicle, thus increasing the driver's readiness to usurp the right of way". When the pedestrian did not look, the driver was more likely to slow down, "apparently because the driver was forced to accept a larger share of the responsibility for the outcomes of the crossing conflict".

In most situations, drivers are very cautious even if there is no eye contact with a pedestrian. In this study, we investigate the effects of pedestrian on drivers' safety perception and behaviour at two levels:

- *Presence:* There is a pedestrian trying to cross the road in front of the driver.
- *Not presence*: There is no potentially conflicting pedestrian.

Attribute 8 - Speed of respondent's car when approaching the roundabout: Studies have demonstrated that increasing the approach speed increases the single vehicle accidents and rear-end accidents. The relationship of travelling speed and the risk of crash involvement has been discussed previously. Drivers may have different risk perception to the speed of other vehicles and the speed of their own. We investigate this possibility by examining this attribute at three levels: slow, moderate and quick. The definitions are the same as those in Attribute 5.

Attribute 9 - Is the driver in a hurry? When drivers are in a hurry, they may behave quite differently. Wilde (1982) noticed that a driver in a hurry would be expected to have a higher target level of risk because of the high-perceived benefit of risky behaviour. It is possible that this attribute would interact with other attributes. The attribute "in a hurry" may also present other difficulties since it is technically an attribute of the individual, and usually under individual control. We examine the effect of this attribute at two levels.

- *In a hurry*: The driver's schedule is such that s/he is in a hurry
- *Not in a hurry*: The driver's schedule is such that s/he is not in a hurry.

Contextual variables: A set of variables describing a driver's socio-economic status and driving experience may have an influence on their perception of safety or behavioural response. The set of variables captured in the survey are:

- *Gender*.
- *Age*: In nine categories: (1) 16-20 years (under license legislation, individuals under 16 years old are not permitted possessing a driving license, see RTA

1996b); (2) 21-25 years; (3) 26-30 years; (4) 31-35 years; (5) 36-40 years; (6) 41-45 years; (7) 46-50 years; (8) 51-55 years and (9) 56 years or older.

- *Personal annual income before tax*: In seven categories: (1) \$20,000 or less; (2) \$20,001 - \$30,000; (3) \$30,001 - \$40,000; (4) \$40,001 - \$50,000; (5) \$50,001 - \$60,000; (6) \$60,001 - \$80,000; (7) \$80,001 or more.
- *State and suburb*: Where a respondent lives.
- *Licence status*: In seven categories (see RTA 1996b): (1) national heavy vehicle licence; (2) unrestricted gold licence; (3) unrestricted silver licence (4) provisional licence (P plate); (5) learners' licence (L plate); (6) probationary licence (eg traffic offence); (7) other licence (e.g. overseas licence).
- *Years that respondent has been driving.*
- *Accident involvement in the last two years*: In two categories: involved or not. If involved, then we sought details on who was at fault. An accident is defined as any apparently unpremeditated event resulting in death, injury or property damage (\$300 or more) attributable to the movement of a vehicle on a road (RTA 1994).
- *Traffic offence in the last two years*: In two categories: committed or not. If the respondent committed a traffic offence, then we identified how many demerit points were recorded against his/her licence. A traffic offence is defined as driving behaviour that violates traffic laws and is caught by police so that demerit points are recorded against the driver's licence (RTA 1996b).
- *Commuter status.* Commuter driver or not.
- *A description of the vehicle that respondent normally drives*: Including make, model, year of manufacture, number of cylinders and body type. The vehicles are classified into six categories based on collected information using the TRESIS vehicle classification scheme as a reference (ITS Sydney 2000): (1) *small*: ≤4 cylinders; (2) *medium*: 5-7 cylinders; (3) *large*: 8 cylinders; (4) *4WD*: all four wheel drive; (5) *luxury*: all of Mercedes, BMW, Rolls Royce, Jaguar, Audi, Bentley, Lexus, Daimler and Eunos and (6) *light commercial vehicle*.
- *Respondent's self-description of his/her psychological state in most situations when driving*: In five categories: (1) an aggressive driver; (2) an impatient driver; (3) a hesitant driver; (4) a slow driver and (5) a very cautious driver.

Driving attitude: Eight statements describing driving attitude, behaviour and experience on roads are included. Drivers are asked to indicate how often each statement applies to their driving experience in five levels of frequency, ie, *never*, *sometimes* (25% of the time), *often* (50% of the time), *very often* (75% of the time) and *almost always* (100% of the time). These statements are[†],

- *Driving usually makes me feel aggressive.*
- *I tend to overtake other vehicles whenever possible.*
- *When irritated I drive aggressively.*
- *When I try but fail to overtake I am usually frustrated.*
- *Driving a car gives me a sense of power.*
- *In general, I mind being overtaken.*
- *I am not usually patient during the peak hour.*
- *It annoys me to drive behind slow moving vehicles.*

4.3 Survey Instrument and Response Consistency

The combinations of attribute levels represent road and traffic scenarios. These scenarios are presented to drivers in a face-to-face survey to elicit their perception of safety and behavioural response. Some important features of the empirical framework are summarised below:

- *Statistical design*: The nine attributes (five with three levels and four with two levels) generate 3^5*2^4 = 3888 possible scenarios. A statistical design is necessary to reduce the number of scenarios to a practical size while ensuring that the effects of interest (eg main effects and two-way interactions) can be separately identified and evaluated.
- *Visualisation of scenarios*: Road and traffic scenarios should be visible when presented to respondents to ensure their comprehension of the road and traffic situations so that the safety of each situation can be evaluated and appropriate behavioural response determined.

[†] The author would like to acknowledge the help of Professor Ann Brewer in drafting these statements and providing appropriate references.

- *Survey instrument design*: A computerised survey instrument is designed. It has many advantages over traditional "showcards". A visualised road and traffic scenario, a Likert scale for perception of safety and a discrete choice response can be combined in one experimental platform (screen). Other important information (eg definition of attributes) can be added into respondent interactive windows which can be easily retrieved when requested by a respondent. Survey responses can be automatically saved into a data file and directly exported to analysis packages (eg Limdep or SPSS).
- *Survey arrangement*: We develop two formats for the survey instrument. The first is based on picture and a verbal description of each scenario (*Picture and Word* format, see Appendix I and II). The second is based on a visualised scenario only (*Picture Only* format, see Appendix III). We conduct two waves of interviews in two consecutive months. The respondents will be grouped and different combinations of two survey formats will be presented for each group (see table 6-4).

The visualised scenarios and the computerised survey instrument offer an opportunity to investigate some important task-related issues for stated preference surveys. Firstly, the computerised survey instrument can automatically record the time that a respondent spends on each scenario and record how respondents use the detailed information provided in interactive windows. With these survey behaviour details, we can investigate how respondents assign the time and attention as the survey progresses. Secondly, we can examine data equality and response consistency due to two survey formats and two waves of the survey. The survey task-related factors might have a significant influence on responses which might induce different preference parameters under some circumstances. Relatively few studies have investigated this possibility. For example, Louviere et at (1987) compared results from one stated preference survey, in which a proportion of respondents were given descriptions in verbal form while the rest received combinations of verbal and visual descriptions. No significant difference was detected between the two groups' responses. There is evidence that task-related factors may cause significant random component variance differences. For example, Brazell and Louviere (1995) found that respondent choice consistency declined as the survey length increased. Louviere and Hensher (2000) pointed out that research attention should focus on identifying combinations of task-related factors that lead to lower random component variance outcomes. In this thesis, we apply a statistical procedure to test whether the data sets evaluated with *Picture and Word* format and *Picture Only* format are statistically equal, and whether the data sets obtained from the first wave of interviews and the second wave of interviews are statistically equal. We also investigate response consistency due to the different survey formats and repeated surveys.

4.4 A Framework for Modelling Driver's Perception of Safety and Behavioural Response

In chapter two, we showed that a driver's perception of safety is derived from a set of driving environment inputs. We can express the perception of safety as a function:

$$\textit{Perception of Safety} = f(X_1, X_2, X_3, \ldots, X_n) \tag{4-1}$$

where $X_1, X_2, X_3, \ldots, X_n$ are explanatory variables including road and traffic attributes and driver socio-demographic characteristics. Because the perception of safety is measured on a five point ordinal Likert scale, an ordered probability model is appropriate to relate the perception of safety to a broad range of explanatory variables. The estimated parameters provided by the ordered probability model can be used to derive an *Indicator of Perceived Safety (IPS)* for different road and traffic scenarios as a measurement of safety of driving environments.

It is assumed that a driver's behavioural response to a road and traffic situation is a result of trading-off mobility and safety. That is, the behavioural response is the outcome of a process of utility maximisation where expected (opportunity) mobility benefits are traded with the potential accident costs in the meanwhile recognising other constraints such as abiding by the speed limits or giving way to right. It is reasonable to assume that drivers assign a utility index to all possible behavioural options. That utility index is derived from the attributes of the road, the characteristics of traffic and the potential accident costs. The driver is assumed to behave as if he/she is maximising their utility index as represented by the choices of one behavioural option for each situation. The driver's behavioural responses is analysed within the framework of random utility theory. The driver's behavioural responses can be expressed as a function of,

$$Utility(Behavioural\ Responses) = f(Y_1, Y_2, Y_3, \ldots, Y_n) \quad (4\text{-}2)$$

where Y_1, Y_2, Y_3, ..., Y_n are road and traffic attributes. A utility function can be formulated for each behavioural response so that a set of discrete choice models can be specified.

A driver's perception of safety may also have an important influence on their behavioural response. To investigate these possibilities, additional discrete choice models are specified:

$$Utility(Behavioural\ Responses) = f(IPS, Z_1, Z_2, Z_3, \ldots, Z_n) \quad (4\text{-}3)$$

where *IPS* is the *Indicator of Perceived Safety* that will be derived from ordered probability models, Z_1, Z_2, Z_3, ..., Z_n are driver socio-demographic variables.

4.5 Summary

In this chapter, we have set out the measurement dimensions used to capture the driver's perception of safety and their behavioural response. We have identified attributes and their levels, which are the inputs for an experimental design (as discussed in next chapter). A driver's socio-demographic characteristics were also identified for contextual observation in the survey. We considered a number of variations in the survey scheme permitting us to investigate the influence of such variations on the perception of safety and behavioural response. This extends the thesis to contribute to the broader survey literature on the influence of pictures versus words and inter-temporal data capture on response consistency. In the next chapter, we apply statistical design theory to combine the attribute levels into an experiment.

Chapter Five

Experimental Design

In chapter five, we use statistical design theory to combine attribute levels into an experiment. A statistical design is a way of manipulating attributes and their levels to permit rigorous tests of certain hypotheses of interest. The statistical design provides a way of planning in advance exactly which observations to take and how to take them to make the best inferences from the survey data. The statistical design also deals with planning the experiment in such a way that as many other influences (eg correlation) as possible can be ruled out.

A design can be *full factorial*, which contains all possible combinations of attribute levels. Each combination of attribute levels describes a choice situation, often referred to as a *profile*, a *treatment* or a *scenario* in the stated preference literature. Generally, the number of possible combinations for an empirical study will be large. Thus a *fractional factorial design* is normally required. A fractional factorial design contains selected combinations from the full factorial by omitting some assumed unimportant effects. The fractional factorial design introduces aliasing, the correlation between the included effects and the omitted effects. A sound statistical design should reduce the number of combinations to a practical size and minimise the effects of correlation. A statistical design uses attribute levels as the inputs. We have identified attributes and their levels for our empirical study in chapter four, which are summarised in table 5-1.

This chapter is organised as follows. In the next section, we discuss some concepts used in the statistical design and code schemes for approximating the main effects of quantitative and qualitative attributes. In the section 5.2, we consider a full factorial design. The full factorial design produces too many scenarios thus a random sampling strategy is unlike to satisfy its statistical properties. This motivates us to conduct a parsimonious design. In section 5.3, we evaluate a series of fractional factorial designs and finally select a smallest factorial design for estimating main effects only. The last section concludes the chapter with a summary.

Table 5-1 Summary of attribute levels for experimental design

Attributes	Abbreviation	Levels and Codes
Size of the roundabout	ROUND	0 = small 1 = medium 2 = large
The number of circulating lanes	LANE	0 = multilane 1 = single
Visibility to other traffic	VISIB	0 = clear 1 = obstructed
Size of the vehicle potentially conflicting with the driver	SIZE	0 = small (eg car) 1 = medium (eg light commercial) 2 = large (eg truck)
Speed of the vehicle potentially conflicting with the driver	SPEED	0 = quick (eg 60 km/h) 1 = moderate (eg 35 km/h) 2 = slow (eg 15 km/h)
General traffic level	TRAFK	0 = light 1 = moderate 2 = busy
Presence of a pedestrian who potentially conflicts the driver's normal driving	PEDES	0 = not presence 1 = presence
Speed of respondent's car when approaching the roundabout	MYSPD	0 = slow (eg 15 km/h) 1 = moderate (eg 35 km/h) 2 = quick (eg 60 km/h)
The driver's time availability	HURRY	0 = not in a hurry 1 = in a hurry

5.1 Effects, Main Effects, Interactions, Degrees of Freedom and Approximations of Main Effects

The objective of any statistical model is to estimate effects of interest. For example, in the case of Analysis of Variance, the effects of interest are means and variances. In the case of multiple regression models, the effects of interest are regression parameters. By definition, an *effect* is a difference in a treatment mean relative to a comparison, such as the grand (or overall) mean. In the statistical design literature, an effect is a comparison of a mean of an attribute level by the mean of the orthogonal constraints (Louviere et al 2000). A *main effect* is the difference in the mean of each level of a particular attribute and the overall or "grand mean", such that the differences for all levels sum to zero. Because of this constraint, one of the differences is exactly defined once the remaining *L-1* differences are calculated for an *L* level attribute. This constraint gives rise to the concept of *degrees of freedom.* There are *L-1* degrees of freedom for each main effect in an *L* level attribute because one difference is exactly determined. In general, if an attribute has no statistical effect on the response, then the mean of each of its level (marginal mean) will be the same, and exactly equal to the grand mean in theory or statistically equivalent in practice.

Main effects are the primary interests in most SP applications. However, they are not the only effects that may be of interest. In particular, analyst may wish to identify *interaction effects*, both for theoretical reasons (eg to test if they are statistically significant) and for practical consideration (eg to identify confounding effects). An interaction between two attributes will occur if respondent's preference for levels of one attribute depends on the levels of the other attribute. Considering two attributes, the size of the vehicle potentially conflicting with the driver (SIZE) and speed of the vehicle potentially conflicting with the driver (SPEED), if a driver's safety perception on levels of SIZE depends on the levels of SPEED, an interaction between two attributes occurs.

A number of studies have produced evidence that some important interactions exist (eg Norman and Louviere 1974, Norman 1977, Lerman and Louviere 1978 and Louviere et at 2000 for a discussion). Even if analysts are well aware of the importance of some interactions, they generally do not know which ones they are. There is no theoretical or empirical guidance in deciding which interactions should be estimated. In practice, analysts are generally limited to two-way interaction effects as well as main effects. As more attributes are included in a model, it is more likely that most of higher-order interactions will be statistical insignificant or of little interest. Even if they are proved to be significant, it is difficult to interpret the three-way, four-way or higher-order interactions. Indeed, interpretation of such high order interactions is risky in the absence of highly controlled laboratory conditions (Louviere et al 2000).

In many situations, we have to ignore higher-order interactions or do nothing, because the degrees of freedom for interaction effects are many. As an example, we have calculated the degrees of freedom for main effects, two-way and higher-order interaction effects for our empirical study as given below:

- *Main effects*: For each attribute with *L* levels, there are *L-1* degrees of freedom for main effects. In this study, we have nine attributes, five with three levels and four with two levels. We have 5*(3-1) + 4*(2-1) = 14 degrees of freedom for all main effects.

- *Two-way interaction effects*: There is a total of 86 degrees of freedom for two-way interaction effects, as computed in table 5-2. Each level in *L-1* levels of an attribute interacts with each level in *L-1* levels of other attributes, and this generates one degree of freedom. For example, there are four degrees of freedom for two-way interactions between the attribute SIZE (three levels) and the attribute SPEED (three levels). There is no internal interaction for an attribute (eg, no interaction between level 1 of ROUND and level 2 of ROUND).
- *Higher-order interaction effects*: Direct calculation for degrees of freedom for three-way, four-way or higher-order interactions is complex. A simple way is to calculate the total degrees of freedom for three-way and higher-order interaction effects, which are equal to the number of total possible combinations of attribute levels minus the degrees of freedom for main effects and two-way interactions. Our design has nine attributes, five of them with three levels and four with two levels. This will generate $3^5*2^4 = 3888$ possible combinations. Therefore, there are 3888-86-14 = 3788 degrees of freedom for higher-order interaction effects.

Table 5-2 Calculation of degrees of freedom for two-way interaction effects

Attributes		ROUND		LANE	VISIB	SIZE		SPEED		TRAFK		PEDES	MYSPD		HURRY
	L-1 Levels	1	2	1	1	1	2	1	2	1	2	1	1	2	1
ROUND	1														
	2														
LANE	1	1	1												
VISIB	1	1	1	1											
SIZE	1	1	1	1	1										
	2	1	1	1	1										
SPEED	1	1	1	1	1	1	1								
	2	1	1	1	1	1	1								
TRAFK	1	1	1	1	1	1	1	1	1						
	2	1	1	1	1	1	1	1	1						
PEDES	1	1	1	1	1	1	1	1	1	1	1				
MYSPD	1	1	1	1	1	1	1	1	1	1	1	1			
	2	1	1	1	1	1	1	1	1	1	1	1			
HURRY	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
#Interactions		12	12	11	10	8	8	6	6	4	4	3	1	1	0

The effects of an attribute on response (the dependent variable) can take different forms. In general, for a quantitative (continuous) attribute, the main effect can be defined by a polynomial of degree *L-1*, where *L* is the number of levels of the attribute. Formally,

$$Y = \beta_0 + \beta_1 X + \beta_2 X^2 + \ldots + \beta_{L-1} X^{L-1} \quad (5\text{-}1)$$

where *Y* represents the response, and the β_s are the means for *L-1* levels of an attribute. If the attribute has no statistical effect, all (regression) parameters will be exactly equal to zero. The mean of each of its levels (marginal mean) will be the same and equal to β_0, the grand mean. Its effect curve will be a line paralleling to the *X*-axis (curve 1 in figure 5-1). If an attribute has a linear effect on response, the parameters $\beta_2, \beta_3, \ldots, \beta_{L-1}$ will be statistically insignificant. Its effect curve will be a line with the grand mean β_0 and gradient β_1 (curve 2 in figure 5-1). If this is the case, exactly two levels of the attribute will capture its main effect. The effect of an attribute can be quadratic or cubic. We can capture the quadratic effect of an attribute with at least three levels (curve 3 in figure 5-1). Similarly, for capturing a cubic effect of an attribute, we must specify at least four levels for that attribute (curve 4 in figure 5-1). Curves 1, 2, 3 and 4 can be mathematically expressed as:

$$\begin{aligned}
&\text{Curve 1:} && Y = \beta_0 \\
&\text{Curve 2:} && Y = \beta_0 + \beta_1 X \\
&\text{Curve 3:} && Y = \beta_0 + \beta_1 X + \beta_2 X^2 \\
&\text{Curve 4:} && Y = \beta_0 + \beta_1 X + \beta_2 X^2 + \beta_3 X^3 \quad (5\text{-}2)
\end{aligned}$$

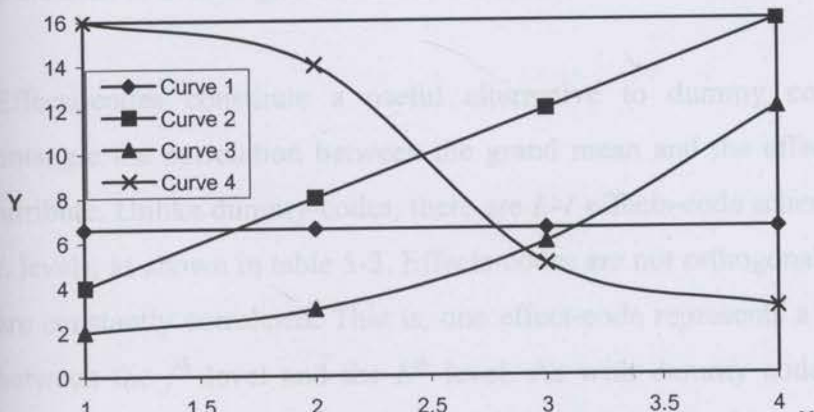


Figure 5-1 Possible functional forms for main effects

In the case of qualitative (discrete) attribute, we can choose code-schemes from dummy-codes or effects-codes. Dummy-codes are widely used because of their simplicity in interpretation of estimation results for a model. If an attribute has L levels, we can define the main effect using L-1 dummy variables by following several steps (Louviere et al 2000):

(1) Create a dummy variable, D_1, such that if the scenario contains the first level selected, $D_1=1$, otherwise, $D_1=0$.
(2) Create a second dummy variable, D_2, such that if the scenario contains the second level selected, $D_2=1$, otherwise, $D_2=0$.
(3) Continuing this process until L-1 dummies are created, ie, $D_1, D_2, ..., D_{L-1}$.

The main effect of the attribute then is expressed as:

$$Y_{ij} = \beta_0 + \beta_1 D_{i1} + \beta_2 D_{i2} + ... + \beta_{L-1} D_{iL-1} \qquad (5\text{-}3)$$

where Y_{ij} represents the response of individual i to scenario j with the attribute described by dummy variables $D_1, D_2, ..., D_{L-1}$. The mean of the L^{th} level is exactly equal to β_0, and β_1, β_2 and β_{L-1} are the means of each level of the attribute. Thus, the L^{th} effect is perfectly correlated with the intercept or grand mean. For a statistical model, we can estimate one grand mean for all included attributes. If we have two or more qualitative attributes in the model, we would not find each of L^{th} effects, because each of them is correlated to overall grand mean in the model.

Effects-codes constitute a useful alternative to dummy codes. Effects-codes can untangle the correlation between the grand mean and the effect of the L^{th} level of an attribute. Unlike dummy-codes, there are L-1 effects-code schemes for an attribute with L levels, as shown in table 5-3. Effects-codes are not orthogonal with one another. They are constantly correlated. That is, one effect-code represents a non-orthogonal contrast between the j^{th} level and the L^{th} level. As with dummy codes, the main effect of a qualitative attribute is defined by L-1 effects-coded variables that represent L-1 of its levels. Using the effects-code scheme 1 in the table 5-3, we can create effects-coded variables as follows (Louviere et al 2000):

(1) Create an effects-coded variable, D_1, such that if the scenario contains the first level selected, $D_1=1$, if the scenario contains the L^{th} level selected, $D_1=-1$, otherwise, $D_1=0$.

(2) Create a second effects-coded variable, D_2, such that if the scenario contains the second level selected, $D_2=1$, if the scenario contains the L^{th} level selected, $D_2=-1$, otherwise, $D_2=0$.

(3) Continue this process until $L-1$ effects-coded variables are created, i.e. $D_1, D_2, \ldots, D_{L-1}$.

Table 5-3 Effects-codes for as many as five attribute levels

#Levels	Levels	Effects-Codes 1	Effects-Codes 2	Effects-Codes 3	Effects-Codes 4
2	1	+1			
	2	-1			
3	1	+1	0		
	2	0	+1		
	3	-1	-1		
4	1	+1	0	0	
	2	0	+1	0	
	3	0	0	+1	
	4	-1	-1	-1	
5	1	+1	0	0	0
	2	0	+1	0	0
	3	0	0	+1	0
	4	0	0	0	+1
	5	-1	-1	-1	-1

Source: Louviere et al (2000)

The main effect of the attribute then can be expressed as:

$$Y_{ij} = \beta_0 + \beta_1 D_{i1} + \beta_2 D_{i2} + \ldots + \beta_{L-1} D_{iL-1} \quad (5\text{-}4)$$

where Y_{ij} represents the response of individual i to scenario j with the attribute described by effects-coded variables $D_1, D_2, \ldots, D_{L-1}$. Under this coding scheme, the mean of the L^{th} level is equal to $(-1) * (\beta_1 + \beta_2 + \ldots + \beta_{L-1})$ and $\beta_1, \beta_2, \ldots, \beta_{L-1}$ are the means of the remaining $L-1$ attribute levels. The effect of the L^{th} level is not correlated with grand mean, enabling us to independently identify the effect of each level of all qualitative attributes in the model.

5.2 Full Factorial Design

The full factorial design is firstly considered because it contains all possible combinations of attribute levels, enabling us to independently estimate the statistical effect of each attribute level on respondent's perception of safety and behavioural response. The full factorial design generates 3888 combinations. It is impractical to ask each respondent to evaluate all 3888 scenarios. We have to seek sampling strategies so that all designed scenarios can be evaluated by respondents and statistical properties of the full factorial design can be retained.

One such strategy is random sampling. That is, we offer the respondents a set of randomly sampled scenarios from the full factorial. We can offer all respondents the same number of scenarios, or this number can be varied among respondents. If we offer all respondents a fixed number of scenarios, we can divide the full factorial into subsets or blocks, and randomly assign a respondent to a block. This procedure requires an assumption about respondents' homogeneity of preference, or alternatively a way to account for heterogeneity of preference (Louviere et al 2000).

The question is how many scenarios we would offer to a respondent. Random sampling theory guarantees that if we take large enough samples from the complete factorial, we would closely approximate the statistical properties of the full factorial itself. This suggests there is a requirement that at least a minimal number of scenarios are selected and offered to every respondent. On the other hand, the literature in statistical design suggests there is an upper survey length limit of how many scenarios respondents would complete in respect to optimising trade-offs between response rates and data quality. However, there is no theory or empirical evidence to inform "best practice" in the sense of helping to determine the "optimum" number of scenarios or treatments for particular applications. It has to be judged on a case by case basis according to the nature and complexity of the survey.

In a study of length effects in conjoint choice experiments and surveys, Brazell and Louviere (1995) reviewed the state of practice on how many choice sets have been used in choice tasks. They noted that general consensus in the choice modelling literature was that choice surveys should be kept short and simple. A medium conjoint task could involve sixteen profiles with eight attributes, each having three levels. A typical choice-based conjoint task was somewhat smaller than this. In practice, there is considerable variation in the number of choice-sets offered to respondents. For example, Louviere et al (1993) reported that as few as four sets and as many as 64 sets had been employed in different studies. More recently, Louviere et al (2000) has concluded that:

(1) Many experiments have employed at least 32 profiles successfully.
(2) As the number of attributes increases, task complexity increases because of the number of things to which respondents must attend.
(3) As the complexity of levels increases, task complexity increases because of cognitive effort involved in comprehending and attending to information.

In order to estimate all the possible effects, each scenario requires a minimum of one observation. Bunch and Batsell (1991) suggested that a minimum of six respondents per scenario is required to satisfy large sample statistical properties. In our empirical context, a single random sample of 32 scenarios represents 0.82% of the 3888 attribute level mixes, which is unlikely to represent the statistical properties of the full factorial. If we assign each respondent to a block with 32 scenarios, we need 122 respondents to ensure each scenario is observed once. If we require that each scenario be evaluated by six respondents, we need at least 732 respondents. This is impractical given the time and cost constraints.

5.3 Fractional Factorial Design

Random sampling from the full factorial requires many respondents and thus is expensive. It also leaves much to chance, and is unlikely to represent the statistical properties of the full factorial. This motivates us to seek alternative design strategies to ensure that effects of interest can be identified and estimated relatively efficiently for a manageable sample size. Fractional factorial designs are used for reducing the total combination of attribute levels.

Fractional designs are ways to systematically select subsets of treatment combinations from the full factorials such that the effects of primary interest can be estimated. In general, all fractional designs involve some loss of statistical information, and the information loss can be large. That is, all fractions require assumptions about non-significance of higher-order interactions. The study results from linear models (Dawes and Corrigan 1974, Louviere et al 2000) have suggested that:

(1) Main effects typically account for 70%-90% of explained variance.
(2) Two-way interactions typically account for 5% to 15% of explained variance.
(3) Higher-order interactions account for the remaining explained variance.

Therefore, even if higher-order interactions are statistically significant, they rarely account for a great deal of explained variance. Now, we are willing to ignore some higher-order interactions, either because of their limited explanatory power or we have no choice. Fractional designs provide parsimonious statistical models for the potential response surface rather than the full factorial that involves all possible effects. Such models can be derived from theory, hypothesis, empirical evidence, curve-fitting and other sources. The possible statistical design schemes include (Pearmain et al 1991, Louviere et al 2000):

(1) Fractional factorial design for estimating main effects and all two-way interaction effects, assuming all three-way and higher-order interactions are negligible.
(2) Fractional factorial design for estimating main effects and some two-way interaction effects. We can choose to estimate the two-way interactions for the selected attributes, or we can directly select some two-way interactions to be estimated, while assuming all unselected two-way, three-way or higher-order interactions are negligible.
(3) A combination of two fractional factorial designs. The first is a smallest design for estimating main effects independently. The second is an endpoint design for estimating bilinear components of all two-way interactions (and main effects). The combined design then is used to estimating main effects and bilinear components of all two-way interactions.
(4) Fractional factorial design for estimating main effects only, independent of two-

way interactions. We assume all interactions are negligible. Otherwise, even if some two-way interactions are significant, their effects do not distort measurement of the main effects.

(5) Fractional factorial design for estimating main effects only, assuming all interactions are negligible.

Five schemes will produce designs with different sizes, in the order from larger to smaller. Generally speaking, the larger the design, the more statistical information is available to inform model specification and make inferences about process, ceteris paribus. The need for statistical information to understand process is typically traded-off for practical parsimony in many academic and commercial applications of choice experiments.

5.3.1 A Design for Estimating Main Effects and All Two-Way Interaction Effects

The first design strategy is a statistical design for estimating all main effects plus all two-way interaction effects. When we specified such a design, we could not find one that is parsimonious. That is, all 3888 combinations had to be included to independently estimate main effects and all two-way interactions. This is financially impractical.

5.3.2 An Endpoint Design for Estimating Main Effects and Some Two-Way Interaction Effects

In practice, we are required to ignore some two-way interactions. Fortunately, not all such interactions will be statistically significant. Endpoint designs provide a useful way of allowing for a particular set of two-way intersections to in included. They have been shown to be theoretically justified and practical in some circumstances (Louviere et al 2000).

A prerequisite for the endpoint design is that the directionality of respondent's preferences on attributes is known a priori. If attribute levels are monotonically related to responses, additive models will fit and predict data well within the domain of attribute levels encompassed by the experiment. In this case, the interaction effects will have specific properties that can be used for a statistical design. The important property is that most of the variance explained by interactions is captured by linear-by-linear (or bilinear) components. A *bilinear* component is a simple cross-product of two-linear components in a polynomial expansion. Considering two attributes *SIZE* and *SPEED* again, each of them has three levels, their two-way interaction, denoted as *Int(SIZE, SPEED)*, can be exactly fit by expanding the cross-product to include all 2 x 2 polynomial components, i.e.,

$$Int\,(SIZE, SPEED) = SIZE * SPEED + SIZE^2 * SPEED + SIZE * SPEED^2 + SIZE^2 * SPEED^2 \quad (5\text{-}5)$$

The bilinear component of the expansion is the *SIZE * SPEED*, and if both *SIZE* and *SPEED* are monotonically related to the response, most of variance explained by the two-way interactions of two attributes should be captured in the bilinear component. The property of conditional monotone attributes can be used to generate an *endpoint design*, which is based on the extreme levels of each attribute. This design strategy is consistent with the objective of minimising the variance attributable to the unobserved effects. These extreme levels must be identified for each respondent separately. However, unless all attributes are quantitative and/or their preference directions are known a priori for all respondents, extreme levels will not be obvious. In practice, initial interviews and computerised interviewing techniques have been adopted to identify the extremes for each respondent. Hence, identifying extremes is a minor problem with current technology. This design strategy requires the combination of two designs. The first is an endpoint design, which uses a regular fraction of 2^J factorial, where J is the total number of attributes. The endpoint design ensures that all main effects and two-way interactions are independent of one another. The second is a regular fraction of L^J factorial, where L are the attribute levels, where all main effects are independent of each other. The two designs are then combined together. Data from the combined design can guarantee that all main effects and all bilinear effects of two-way interactions are independent of one another. In our empirical study, we have 3^5*2^4 combinations of a full factorial. The smallest design enabling us to estimate *main effects only* contains 27 scenarios (see table 5-3). If levels of all attributes are restricted to their extremes, we obtain 2^9 combinations of the full factorial. There are 9 main effects and 36 two-way interaction effects, totally 45 degrees of freedom in this extreme regime. If we want to estimate all main-effects and two-way interaction effects independently, we have to use

512 scenarios. By the combination of two designs we obtain 539 scenarios, which can be used to estimate 14 main effects and 36 bilinear interactions independently for the original design context. There are two duplicated scenarios between the two designs, which can be eliminated. Sometimes, one may wish to keep these duplications for estimating test-retest reliability.

An endpoint design reduces the number of combinations dramatically. However, it is still impractical to ask each respondent to evaluate all 539 scenarios from the combined design. We still need a sampling strategy. Again, if we use a single random sample of 32 scenarios, a sample represents 5.94% of the 539 attribute level mixes from the combined design, which is still unlikely to represent the statistical properties of the combined design. Even if we may think that we can approximate the statistical properties of the combined design by sampling, a large number of respondents are required. The constraints on time and cost do not permit us to undertake such a survey.

5.3.3 The Smallest Design for Independently Estimating Main Effects Only

Since the design to estimate main effects and all bilinear components of two-way interactions is still too large to be operational, we are motivated to seek a more parsimonious design. We are willing to ignore all two-way and higher-order interactions. This is the smallest design for independently estimating main effects only. As computed previously, we have 14 degrees of freedom of main effects and we have explicitly ignored all two-way and higher–order interactions, which have 3888-14 = 3874 degrees of freedom. Because these interaction effects would account for 10%-30% of explained variance (Louviere et al 2000), it would be miraculous if all of them are statistically insignificant.

If the interaction terms are insignificant, accurate measures of preferences towards each attribute can be obtained. If one or more of these interaction effects are significant, their effects will be loaded onto the main effects. Parameter estimates based on such data will be biased and potentially misleading. The nature and extent of the bias cannot be known in advance because it depends on the unobserved effects. In such a case, the main effects are referred to as confounded or aliased with interaction effects.

The aliasing is the by-product of a fractional design. The *aliasing* of an effect contains one or more omitted effects. For example, in a simple case of an experiment with three attributes A, B and C and each with two levels, the main effects of A is perfectly aliased with the BC interaction. The main effect of B is perfectly aliased with the AC interaction. The main effect of C is perfectly aliased with the AB interaction. The three-way interaction ABC shows no variation because it is perfectly aliased with the intercept or grand mean (see McLean and Anderson 1984). In a larger experiment, it is not so easy to establish such confounding relationships. The main effect of an attribute will be aliased with several interactions of different orders. Configurations of these interactions are well discussed in Street (1996), who suggested that the aliasing structure can be known in advance in a regular fraction. A *regular fraction* is a specific fractional factorial design scheme. It is relatively easy to check if we have selected a regular fraction because all regular fractions contain a row of defining relation. Continuing the previous example, the three-way interaction ABC is the defining relation for a 2^3 design. In this case, all entries of the orthogonal code for the row of a defining relation will be "1". Louviere et al (2000) demonstrated that aliasing structure of an effect in a regular fraction can be known as exact subsets of other effects of the design, therefore, it is easy to determine exactly which effects are aliased with what other effects. That is, included effects are perfectly correlated with one or more omitted effects. In contrast, an aliasing structure for an irregular faction consists of a linear combination of other effects in the design. The aliasing structure is not easy to determine. The included effects are a linear combination of omitted effects or highly correlated with them. The reason for using a regular fraction is obvious.

There are a number of programs which can be used to design regular fractional factorial experiments. The most popular packages include SPEED2.1 (Hague Consulting Group), CONSURV (Intelligent Marketing Systems, Canada), and GAME GENERATOR (Steer, Davies and Gleave of the Great Britain). We used the SPEED2.1 to generate the smallest design for estimating main effects only for our empirical study. SPEED2.1 is a Stated Preference Experiment Editor and Designer (see Bradley 1991), which contains four interactive modules (experiment module, design module, utility module and response module). The user specifies the attributes and levels, and follow the menu-driven instructions to select a particular fractional factorial that has the statistical properties they wish to use. The smallest design for independently estimating *main* *effects only* for this study produces 27 scenarios, as shown in table 5-4. These scenarios are selected in such a way that the resulting main effect columns in our design are orthogonal. The orthogonality ensures that we can efficiently estimate parameters of a linear model that represents the utility function of main effects only. The design codes can be translated into scenarios by replacing each code with its corresponding attribute level to produce the designed road and traffic situations in table 5-5.

5.4 Concluding Comments

This chapter has developed a statistical design to reduce the number of combinations of attribute levels and to ensure the main effects of attributes can be independently observed. We introduced the dummy-code and effects-code schemes and demonstrated how these code schemes can be used to approximate the main effects of an attribute. We considered a full factorial design and an endpoint design, both of which produce too many scenarios so that random sampling is unlikely to approximate the statistical properties of the designs. We finally selected a smaller design that can be used to independently estimate the main effects only for all attributes. The design produced 27 scenarios from which the road and traffic situations were constructed. In the next chapter, we will visualise these roundabout and traffic situations using video-captured traffic situations, design a computerised survey instrument and conduct a survey.

Table 5-4 Experimental design: design codes

Attributes	ROUND	LANE	VISIB	SIZE	SPEED	TRAFK	PEDES	MYSPD	HURRY
Levels	3	2	2	3	3	3	2	3	2
Scenario 1	1	1	0	2	1	2	0	2	0
Scenario 2	1	0	0	2	0	1	1	1	0
Scenario 3	1	1	1	2	2	0	0	0	1
Scenario 4	1	0	1	0	1	2	0	2	0
Scenario 5	1	1	0	0	0	1	0	1	1
Scenario 6	1	1	0	0	2	0	1	0	0
Scenario 7	1	1	0	1	1	2	1	2	1
Scenario 8	1	1	1	1	0	1	0	1	0
Scenario 9	1	0	0	1	2	0	0	0	0
Scenario 10	2	0	1	2	1	1	1	0	1
Scenario 11	2	1	0	2	0	0	0	2	0
Scenario 12	2	1	0	2	2	2	0	1	0
Scenario 13	2	1	0	0	1	1	0	0	0
Scenario 14	2	1	1	0	0	0	1	2	0
Scenario 15	2	0	0	0	2	2	0	1	1
Scenario 16	2	1	0	1	1	1	0	0	0
Scenario 17	2	0	0	1	0	0	0	2	1
Scenario 18	2	1	1	1	2	2	1	1	0
Scenario 19	0	1	0	2	1	0	0	1	0
Scenario 20	0	1	1	2	0	2	0	0	1
Scenario 21	0	0	0	2	2	1	1	2	0
Scenario 22	0	1	0	0	1	0	1	1	1
Scenario 23	0	0	0	0	0	2	0	0	0
Scenario 24	0	1	1	0	2	1	0	2	0
Scenario 25	0	0	1	1	1	0	0	1	0
Scenario 26	0	1	0	1	0	2	1	0	0
Scenario 27	0	1	0	1	2	1	0	2	1

Table 5-5 Experimental design: constructed road and traffic scenarios from design codes.

Attributes	ROUND	LANE	VISIB	SIZE	SPEED	TRAFK	PEDES	MYSPD	HURRY
Levels	3	2	2	3	3	3	2	3	2
Scenario 1	Medium	Single lane	Clear	Large	Moderate	Busy	Not presence	Quick	Not in a hurry
Scenario 2	Medium	Two or more	Clear	Large	Quick	Moderate	Presence	Moderate	Not in a hurry
Scenario 3	Medium	Single lane	Obstructed	Large	Slow	Light	Not presence	Slow	In a hurry
Scenario 4	Medium	Two or more	Obstructed	Small	Moderate	Busy	Not presence	Quick	Not in a hurry
Scenario 5	Medium	Single lane	Clear	Small	Quick	Moderate	Not presence	Moderate	In a hurry
Scenario 6	Medium	Single lane	Clear	Small	Slow	Light	Presence	Slow	Not in a hurry
Scenario 7	Medium	Single lane	Clear	Medium	Moderate	Busy	Presence	Quick	In a hurry
Scenario 8	Medium	Single lane	Obstructed	Medium	Quick	Moderate	Not presence	Moderate	Not in a hurry
Scenario 9	Medium	Two or more	Clear	Medium	Slow	Light	Not presence	Slow	Not in a hurry
Scenario 10	Large	Two or more	Obstructed	Large	Moderate	Moderate	Presence	Slow	In a hurry
Scenario 11	Large	Single lane	Clear	Large	Quick	Light	Not presence	Quick	Not in a hurry
Scenario 12	Large	Single lane	Clear	Large	Slow	Busy	Not presence	Moderate	Not in a hurry
Scenario 13	Large	Single lane	Clear	Small	Moderate	Moderate	Not presence	Slow	Not in a hurry
Scenario 14	Large	Single lane	Obstructed	Small	Quick	Light	Presence	Quick	Not in a hurry
Scenario 15	Large	Two or more	Clear	Small	Slow	Busy	Not presence	Moderate	In a hurry
Scenario 16	Large	Single lane	Clear	Medium	Moderate	Moderate	Not presence	Slow	Not in a hurry
Scenario 17	Large	Two or more	Clear	Medium	Quick	Light	Not presence	Quick	In a hurry
Scenario 18	Large	Single lane	Obstructed	Medium	Slow	Busy	Presence	Moderate	Not in a hurry
Scenario 19	Small	Single lane	Clear	Large	Moderate	Light	Not presence	Moderate	Not in a hurry
Scenario 20	Small	Single lane	Obstructed	Large	Quick	Busy	Not presence	Slow	In a hurry
Scenario 21	Small	Two or more	Clear	Large	Slow	Moderate	Presence	Quick	Not in a hurry
Scenario 22	Small	Single lane	Clear	Small	Moderate	Light	Presence	Moderate	In a hurry
Scenario 23	Small	Two or more	Clear	Small	Quick	Busy	Not presence	Slow	Not in a hurry
Scenario 24	Small	Single lane	Obstructed	Small	Slow	Moderate	Not presence	Quick	Not in a hurry
Scenario 25	Small	Two or more	Obstructed	Medium	Moderate	Light	Not presence	Moderate	Not in a hurry
Scenario 26	Small	Single lane	Clear	Medium	Quick	Busy	Presence	Slow	Not in a hurry
Scenario 27	Small	Single lane	Clear	Medium	Slow	Moderate	Not presence	Quick	In a hurry

Chapter Six
Survey Development, Implementation and Administration

Chapter six develops a survey instrument and conducts a stated-preference survey to elicit a driver's perception of safety and a behavioural response on each of 27 experimentally designed road and traffic scenarios. This chapter is organised into five sections. In the following section, we discuss the necessity of visualising the experimentally designed scenarios and review the possible methods for visualisation. In section 6.2, we describe a video image-based system for visualisation of road scenarios. In section 6.3, we develop the SurveyStar, a computerised survey instrument. In section 6.4, we conduct a pilot survey to test the adequacy of all aspects of the survey. In section 6.5, we set out the implementation and administration procedure for the main survey. The last section concludes the chapter with a summary.

6.1 Visualisation of Road and Traffic Situations

The objective of a stated preference survey is to correctly elicit individual preferences of how they respond to different situations. In developing such a survey, it is important to consider how a stated preference experiment is presented to respondents. The most important issues to consider include preliminary planning of the survey, selection of a survey method and design of the survey instrument. In the preliminary planning stage, we reviewed the existing information and designed a statistical experiment. In the choice of a survey method, we considered a broad range of factors such as survey complexity, sampling and survey costs. Generally, five methods have been used to implement SP surveys: a self-completion survey, a personal interview survey, a telephone interview survey, an intercept survey and an in-depth interview survey. Although the marginal costs of the self-completion surveys are very low and a large sample size can be relatively inexpensively achieved, the most consistent problem has been the high level of non-response (Richardson et al 1995). A complex survey requiring careful explanation and cognitive effort will almost certainly be face to face administered. The telephone survey offers a less expensive data collection method. However, there are limitations of the complexity and the length of the survey which can be successfully completed over the phone. With the increasing amount of direct marketing by telephone, the general public is becoming wary of an unsolicited phone call and therefore it is more and more difficult to get an initial response over the telephone. The intercept survey involves personal interviews with travellers who are stopped by an interviewer asking a series of questions. It is an effective method for origin-destination surveys. Intercept surveys have been conducted in the pilot survey of this study. Our experience indicates that the intercept survey can deliver a satisfactory response rate for a complex survey. In-depth interactive interviews are increasing in popularity in transport studies in recognition of travel as a derived demand. However, the interactive interviews do not provide data in a form that is amenable to the construction of detailed mathematical models of travel behaviour (Richardson et al 1995).

Another important task in survey development is the design of the survey instrument. Most SP surveys were administered using pen and paper, whether using face to face interviews or using self-completion methods. If a self-completion method is used, questionnaire can be posted to respondents. For a face to face interview, SP options are normally presented on "Show Cards". Each card can only contain one option if a ranking is required so that a respondent can spread out a number of cards and arrange them physically in the order of preference. If choice sets are being used, two or more alternatives are presented at a time and the respondent is asked to choose the most preferred. Sometimes, additional support materials and/or visual aids are used to supply the detailed information or to illustrate new products (eg a very fast train as a new transport mode). Computerised interviews have been found particularly helpful in building a customised SP experiment for each respondent (Pearmain et al 1991).

A road and traffic situation is a complex setting where the driver, the vehicle and the road interact in a dynamic and complex pattern to influence the road safety outcome. We have selected the face to face interview as the method of survey administration, because it is almost impossible to develop a verbal based self-completion questionnaire that accurately depicts a road and traffic situation. We realised that a visualisation of road and traffic situations is an indispensable step in developing an acceptable survey instrument for this study. A review of methods for visualisation was undertaken and a video image-based system was tested. We developed SurveyStar, a computerised survey instrument to combine the visualised scenario and other necessary information required in decision making into an integrated survey platform.

6.1.1 A Review of Possible Methods for Visualisation of Road and Traffic Scenarios

Visualisation of a driving environment requires using computer graphics to reproduce the road and traffic situation. We reviewed a broad range of computer packages. Five programs have been identified, each of them is available in our current resources and has potential for visualising a road and traffic situation. We briefly review these programs as follows.

- *AutoCAD R13*: AutoCAD is a full-featured program for computer-aided design (Autodesk 1996). It can draft realistic, accurate two-dimensional drawings and three-dimensional models. In AutoCAD, the images are drawn using basic drawing elements such as line, circle, arc etc. AutoCAD has been widely used in engineering applications.
- *VRML (Virtual Reality Modeling Language) 2.0*: VRML is a computer language that describes three-dimensional objects for the Internet. VRML is different from conventional computer languages (such as Visual C++ or Visual Basic) in two aspects. It does not have a compiler, and it is an internet-dependent utility (McCarthy and Descartes 1998).
- *MediaStudio VE (Video Edition) Version 2.5*: MediaStudio is a set of programs designed to edit, assemble, and create video projects (Ulead Systems 1995). MediaStudio works on existing image sources, which can be sourced a number of ways (eg video-captured images or bitmap format images).
- *ViVAtraffic*: ViVAtraffic is an automatic traffic-monitoring system developed by the Transportation Department, the University of Kaiserslautern (Rudolph 1999). It uses a video camera to capture the traffic situation. The captured images are exported to a computer for monitoring and/or analysing traffic. This system has been applied by road safety researchers (Hupfer 1999).
- *Director 6.0*: Director is an authoring tool for multimedia products (Macromedia 1998). It is an ideal tool for creating web-sites or entertainment titles etc.

A preliminary comparison on these programs ruled out options of using VRML, ViVAtraffic and Director. Two methods were identified to visualise the road and traffic situations for this study, which are discussed below.

6.1.2 Use AutoCAD to Draw the Road and Traffic Situations (AutoCAD Images)

Several basic steps are required for reproducing a driving environment using AutoCAD.

(1) Knowing the geometric measurements of a roundabout. These are basic requirements of any drawing. The exacting measurements of all components (such as central island, splitter island and carriageway) of the roundabout should be known in a three-dimensional profile. In traffic engineering, these measurements are available from an engineering design. In our experimental design, some of measurements are attribute levels (for example, size of the roundabout, the width of carriageway). The other geometric measurements can be obtained from traffic engineering specification manuals or a field survey.

(2) Drawing planar layout. Several methods are available in AutoCAD for producing three-dimensional (3D) images. A method that draws 3D images from two-dimensional (2D) drawings is used. A planar layout is drawn in the XY plane. This layout determines the relative positions of all components of the roundabout, but not their space distribution (height).

(3) Creating 3D surfaces. A 3D surface can be produced using a mesh, or created from a composite solid by combining two or more regular solids (AutoCAD provides box, cone, cylinder, sphere, torus and wedge), or revolving/extruding a 2D drawing.

(4) Rendering 3D images. This includes defining a 3D view point (where you 'see' images), applying materials to different surfaces, applying one or more lights (eg, to simulate sunlight), and finally, rendering 3D images. A sample of rendered roundabout images is given in figure 6-1.

By using AutoCAD images, we have full manipulation and control over combinations of attribute levels. This is important in designing a survey instrument for a controlled SP experiment. The weakness of this method is the low quality of images. More realistic-looking images are desirable for correctly eliciting driver's response at offered scenarios.

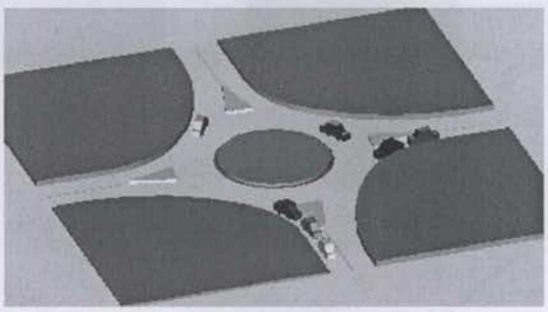


Figure 6-1 A sample of visualised road and traffic situation using AutoCAD

6.2 A Video Image-Based System for Visualising Road and Traffic Situations

6.2.1 The Components of the Video Image System

To obtain the high quality images for experimentally designed road and traffic scenarios, we developed a video image-based system. The system has three major components: a video recorder, an IOMEGA BUZ and a computer, as shown in figure 6-2. The function of each component is described below.

- *A video recorder* is used to record the roundabout and traffic situation in the field. The image sequence is stored in videotape in a format of Analog Signals.
- *An IOMEGA BUZ* system includes a Buz Box, a Buz Card and an Audio/Video cable. The Buz Card is installed into the motherboard of a computer. The video recorder and the computer were connected via the Buz Box through an Audio/Video cable. The Buz Box enables high speed image sequence transfer from the video recorder to Buz Card. The Buz Card is a video capture card where Analog Signals are digitised.
- *A computer* receives and saves the digitised images. The digitised images can be edited by a number of programs (eg MediaStudio) to formulate computer images, which are saved as visualised road and traffic situations.

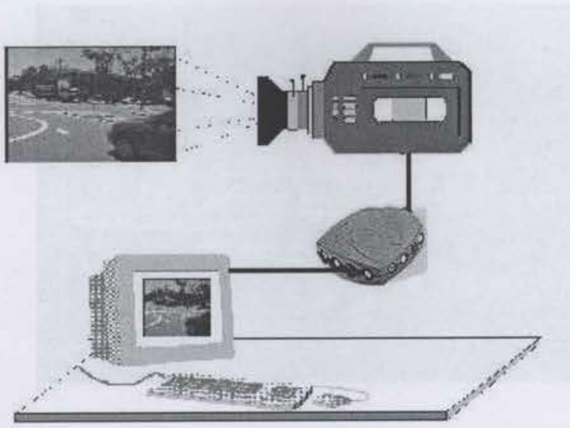


Figure 6-2 The video image-based system

The video image system was successfully tested, and used to visualise a road and traffic situation by several steps as described below.

(1) Selecting a real roundabout to be video-captured. Selected real roundabouts must be similar to experimentally designed road scenarios in terms of attribute levels.

(2) Use the video-recorder to capture a number of traffic situations at the selected roundabout.

(3) Digitising the video images through IOMEGA BUZ. Editing the video image sequence using MediaStudio. Figure 6-3 shows a sample of visualised road and traffic situations.

An image produced by the video image-based system has obvious advantages over an AutoCAD drawing image. By using a video-recorder, we capture a real driving environment. By using MediaStudio, we decompose the captured video sequence into separate frames. We pick up one frame that best describes the scenario we wish to present to respondents. We can edit it to satisfy the requirements of an experimentally designed scenario. In this way, we can manipulate the attribute levels. The major challenge of using the video image system is to find the real roundabouts that are equivalent to our experimentally designed scenarios in all attribute levels. It is a difficult but promising task given there are abundant roundabouts on Sydney roads.

Figure 6-3 A sample of a visualised road and traffic situation

6.2.2 The Fieldwork for Capturing the Road and Traffic Situations

The fieldwork involves two tasks: selection of sites and capture of the road and traffic situations. Our experimental design produced 27 scenarios. For each scenario, we have a set of attributes. The challenge is to find the real road and traffic situations that correspond to experimentally designed scenarios in each of attribute levels. Suppose we are looking for a road and traffic situation for experimentally designed scenario No.1 in table 5-4. The general requirements of this scenario include:

- A medium-sized roundabout with single circulating lane;
- Respondents having clear visibility to other traffic;
- The overall traffic level at the roundabout is busy;
- The respondent is driving a car at a quick speed;
- There is a large-sized truck approaching from an other approach at a medium speed, which may potentially conflict with the respondent;
- There is no pedestrian and the respondent is not in a hurry.

At this stage we should consider how to present each of these attributes to respondents. Ideally, if we use an *animated* sequence of images, all these attributes (except *whether or not a respondent is in a hurry*) can be exhibited directly. This requires that all levels of the attributes describing the experimentally designed road and traffic scenario take place at the same time when we capture it. It would be very difficult to find such a situation. Alternatively, we can use a *static* picture. It is simpler because we can edit static pictures to make up one scenario looking as if all required levels of the attributes take place together.

Static pictures can represent the following attributes: size of the roundabout; the number of circulating lanes; visibility to other traffic; size of vehicles; and presence of pedestrians. However, they cannot convey information relating to the following attributes: speed of vehicles and respondent's time availability (in a hurry or not). The vehicle speed can only be represented with an animating sequence of images. Static pictures can partially represent the general traffic level at a roundabout. However, due to the limitation of the video recorder we used, only a few vehicles appeared in the focus scope of the video recorder even if traffic at the roundabout was busy. The captured picture generally indicates a traffic situation that looks not as busy as the real situation. For those attributes that cannot be represented in a static picture, we have to find an alternative method to express them. A word description for each attribute has been used. The word description is presented in a table in the *Picture and Word* format, and is provided in interactive windows in the *Picture Only* format.

To look for appropriate sites, we visited more than 70 roundabouts around the Sydney metropolitan area between October 20 and November 24, 1999. We selected 20 roundabouts as sites to record road and traffic situations. The locations of these sites are given in table 6-1. At each location, about 10-minutes of road and traffic situations were recorded from different roundabout approaches.

Table 6-1 The locations of sites for capturing road and traffic situations

Site ID	Suburb	Crossing Street (Including/St/Rd/Ave/Pde/Etc)				
		St1	St2	St3	St4	St5
1	Alexandria	Sydney Park	Euston	Huntley	Sydney Park	
2	Kingsford	Anzac	Rainbow	Anzac	Bunnerong	Gardeners
3	Eastlakes	King	Maloney	King	Maloney	
4	Eastlakes	Westcott	Chipman	Westcott	Chipman	
5	Miranda	The Boulevarde	Kiora	Porthacking	The Boulevarde	Kiora
6	Homebush	Underwood	Homebush Bay	Underwood	Homebush Bay	
7	North Strathfield	Correys	Tenterfield	Gracemere	Mackkenzie	
8	Camperdown	Missenden	Carillon	Missenden	Carillon	
9	Stanmore	Harrow	Liberty	London	Liberty	

Site ID	Suburb	Crossing Street (Including/St/Rd/Ave/Pde/Etc)				
		St1	St2	St3	St4	St5
10	Stanmore	Kingston	Trade	Liberty	Trade	
11	Lewisham	Grosvenor	Longport	Smith	Carlton	
12	Petersham	Audley	Trafalgar	Audley	Trafalgar	
13	Petersham	Brighton	Palace	Brighton	Palace	
14	Petersham	Railway	Brighton	Railway	Brighton	
15	Rosebury	Dalmeny	Harcourt	Dalmeny	Harcourt	
16	Eastlakes	Evans	Barber	Evans		
17	Pagewood	Heffron	Banks	Heffron	Banks	
18	Ashbury	Holden	Seaview	Armstrong	Holden	
19	Ashbury	Hanks	Armstrong	Hanks	Queen	
20	Ashbury	Griffiths	Queen	Griffiths	Queen	

6.2.3 Image Processing

Image processing involves converting Analog Signals stored in a videotape into a computer recognisable format (eg GIF, BMP, JPG or TIF). This process is accomplished in three steps, using the video image system as illustrated in figure 6-2.

- *Video Capture*: This is a process of capturing "live video" outputted from a video recorder. Video recorder and computer are connected via Buz Card, where analog signals are digitised. Captured digital video is displayed on the monitor and is saved into a file. The program MGI VideoWave SE Plus (Iomega Corporation 1998) is used as support software for this video capture.
- *Video Decomposition*: We use MediaStudio to decompose captured video file into a sequence of "clips". Each clip is a traffic situation at a moment. The clips can be manually checked one by one to find a desired traffic situation.
- *Image Editing*: Each clip can be saved in Windows Bitmap (BMP) format. MediaStudio Image Editor is used to edit these images. For example, we can add a vehicle or a pedestrian to a desired position.

6.3 Development of A Computerised Survey Instrument - *SurveyStar*

SurveyStar is a computerised survey instrument specifically designed for road safety research. Various versions of the program were produced and evaluated through a series of discussions, pre-pilot and pilot tests. The *focus group* for survey development consisted of five members at the Institute of Transport Studies (ITS): Professor David Hensher and Dr Tu Ton (supervisors of this doctoral research program), Mr Chackrit Duangphastra (PhD student), Professor Ann Brewer and Mr Kirk Bendall. Microsoft Visual Basic 6.0 is selected as the developmental tool. Visual Basic uses the "visualised" method to create the graphical user interface (GUI), which makes it fast and easy to create a windows-based application.

Contents of the survey: The survey collects information about respondents' perception of safety and behavioural response on the experimentally designed road and traffic scenarios. The driver's socio-economic characteristics and driving experience are also contextually observed. The main contents of the survey include:

- *Road and traffic situations*: We constructed one evaluation situation for each scenario. The 27 evaluation situations are presented in a fixed order for all respondents.
- *Respondents' socio-demographic characteristics and driving experience*: These include gender, age, personal annual income, licence status, driving years, accident involvement, traffic offence history and commuter status, as defined in chapter four.
- *Eight statements about respondent's driving attitude, behaviour and experience*, as defined in chapter four.
- *Response behaviour during the survey*: We collect variables measuring the response behaviour during the survey including: the time that a respondent allocates for each evaluation situation; total time that a respondent spends on the entire survey; and the number of times that a respondent activates the interactive windows (to read detailed information) on each evaluation situation and during entire survey.
- *Three formats of the survey instrument*: To test the preference equality and response consistency due to the survey task-related factors, we initially developed three formats of the survey instrument, a *Picture and Word* format, a *Picture Only* format and a *Word Only* format. (The *Word Only* format is abandoned after the pilot survey).

Picture and Word format: The survey instrument in the *Picture and Word* format is presented in Appendix I. An example of an evaluation screen is shown in figure 6-4. Each evaluation screen contains six components, which are described below.

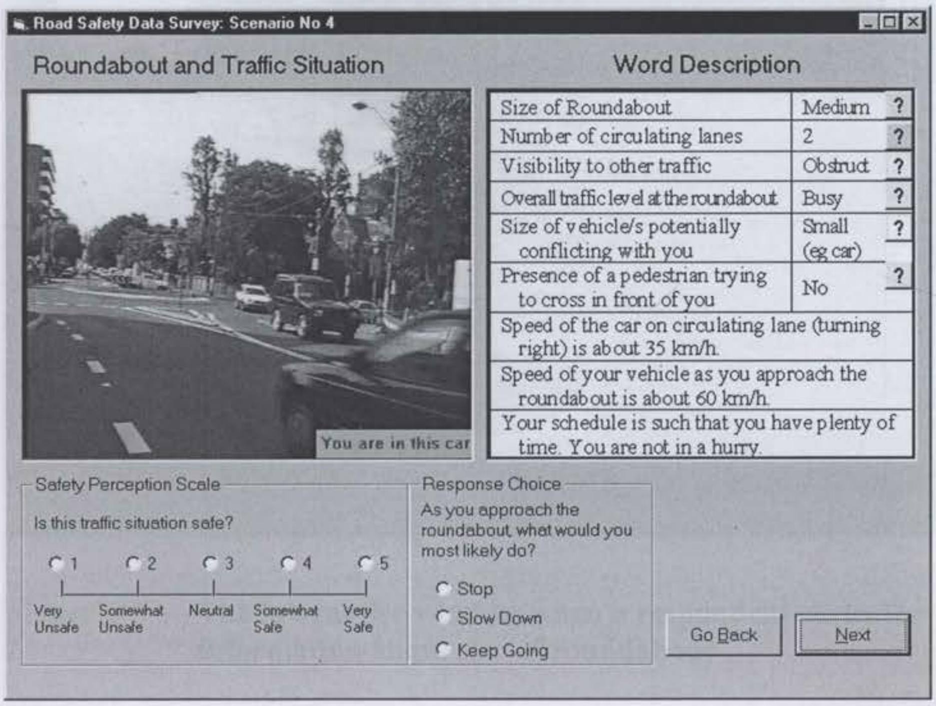


Figure 6-4 An example of evaluation situation screen in the Picture and Word survey format

(1) *A visualised road and traffic situation* provides graphical display of the evaluation situation. A message is added to indicate where the respondent's car is.

(2) *A word description* gives the attributes and levels in association with the evaluated situation in a table format.

(3) *Six Information Buttons*. These buttons are gateways to enter interactive windows. An interactive window provides the definition and detailed information on attribute levels. Sometimes it contains pictures to visually illustrate an attribute level. Figure 6-5 shows an interactive window when a respondent clicks on the Information Button for the "*Size of Roundabout*". More examples of interactive windows are given in Appendix II.

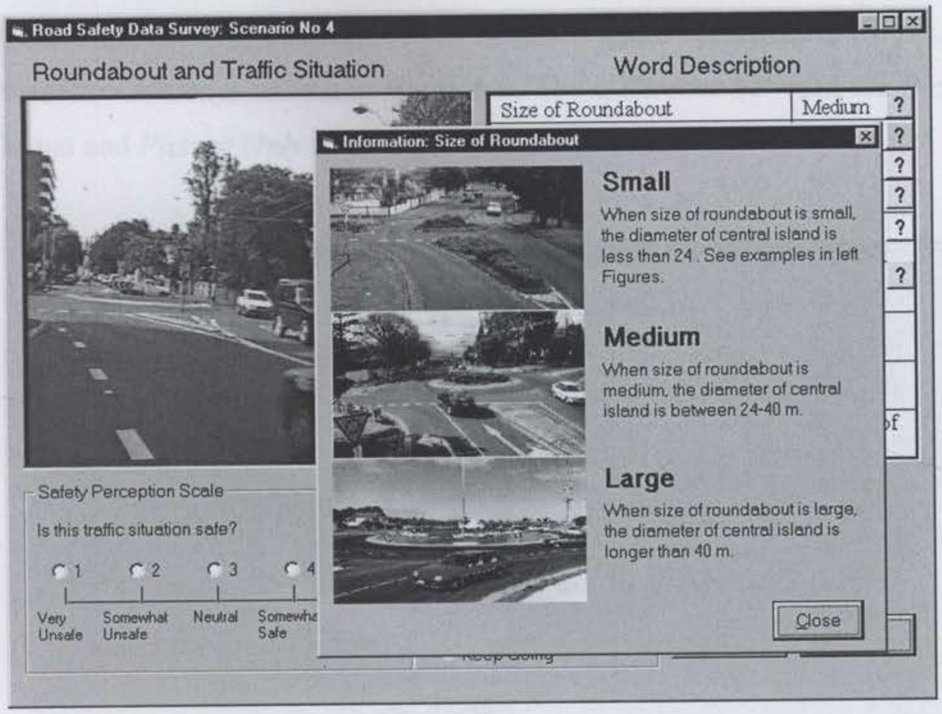


Figure 6-5 The interactive window when a respondent clicks for information about size of roundabout

(4) *A scale panel for the perception of safety*. The perception of safety is measured on a five-point Likert scale from *very unsafe* to *very safe*. A respondent can select one scale only at each evaluation task.

(5) *A choice panel for behavioural response.* For all evaluated road and traffic situations, we have defined a universal choice set with three options: Option one: *Slow Down to Stop* (abbreviated as ST in the utility function), Option two: *Slow Down and Keep Going* (SL), and Option three: *Not Slow Down and Keep Going* (KG). A respondent can choose one option only at each evaluation task.

(6) *"Go Back" and "Next" commands*. By clicking on "Go Back" command, a respondent can go back to previous evaluation situations to check or change their selected scale for the perception of safety and/or the choice for behavioural response. A respondent clicks on command "Next" to proceed to the next evaluation situation. The command "Next" is initially disabled and is enabled only if a respondent has selected a scale for the perception of safety and a choice for the behavioral response. In this way, we obtain all the essential data upon the completion of the survey.

The Picture Only format: The *Picture Only* format is given in Appendix III. An example of an evaluation screen is shown in figure 6-6. The difference between the *Picture and Word* format and *Picture Only* format is explained below.

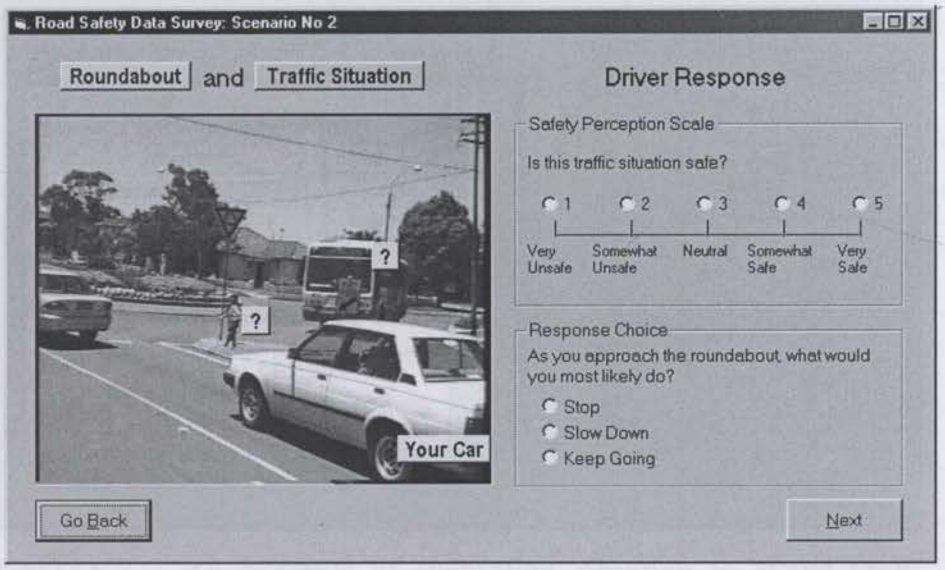


Figure 6-6 An example of evaluation situation in Picture Only survey format

In the *Picture Only* format, the scale panel for the perception of safety, the choice panel for the behavioural response, the "Go Back" and the "Next" commands are exactly the same as those in the *Picture and Word* format. The word description for attribute levels has been omitted. The Information Buttons are relocated in the picture and title areas. Each Information Button is adjacent to the object it refers to, through which a respondent can activate an interactive window. The *Picture and Word* format represents a survey format where missing information is minimised. The *Picture Only* format is a simplified survey instrument. A respondent evaluates a visualised road and traffic situation directly. If respondents need other information, they have to activate interactive windows, where they can obtain further information needed for their safety evaluation and behavioural response. Therefore, the major difference between the two survey formats is the method of information presentation.

The Word Only format: The *Word Only* format was abandoned after the pilot survey. In the pilot survey, this survey instrument has received many complaints about its inadequacy and ambiguity to provide necessary information for decision making. This survey format will not be discussed here. An example of evaluation situation is shown in figure 6-7.

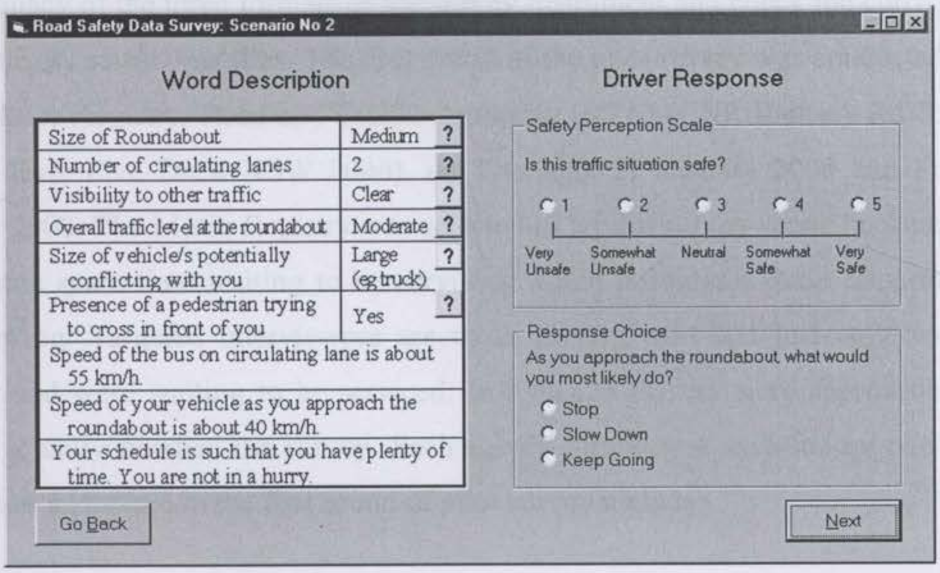


Figure 6-7 An example of evaluation situation in Word Only survey format

An advantage of a computerised survey instrument is its automated data management. For each respondent, the program creates a data file and automatically saves information about the selected scale for the perception of safety, the selected choice for behavioural response, the values of attribute levels, respondents' socio-economic characteristics and their responses for eight statements measuring their driving attitude and experience. The saved data files can be exported into an analysis package (eg Limdep or SPSS) for estimating statistical models.

6.4 Pilot Survey

The objective of the pilot survey is to test the adequacy of all aspects of the survey with a specific intention to test our computerised survey instrument, *SurveyStar*. The pilot survey followed a test-refinement-retest process. Three rounds of pilot survey have been conducted. At each round, some specific issues were tested and problems were identified. The pilot survey process was introduced below.

6.4.1 The First Round of the Pilot Survey

In the first round of the pilot survey, we examine how long a survey normally takes, test the adequacy of the three formats of the survey instrument and check the correctness of automatically saved data files. The first round of the pilot survey was conducted at Five Dock Motor Registry, Road and Traffic Authority (RTA) (CNR Ramsay Rd & Henley Marine Dve, Five Dock NSW 2046), on Thursday 27 January 2000 and Friday 28 January 2000. The Motor Registry was selected as a pilot survey venue because drivers have some spare time waiting to be serviced, which provides a good opportunity for interviewing. Targeted interviewees are those drivers who had just collected a call number and were waiting to be serviced. In total, 23 drivers were approached and 6 drivers actually finished the survey. Each survey format was assessed by two drivers. The issues addressed in the first round of pilot survey include:

How long an interview takes: The purpose of examination of the time requirement is to draft an invitation letter for the survey. Table 6-2 summarises the revealed time from the first round of the pilot survey. The limited sample indicated that 15-25 minutes are required for finishing the survey.

Table 6-2 Average time for a survey in different instruments

Survey Formats	Picture &Word	Picture Only	Word Only
Observed Time 1 (minutes)	16.23	15.78	30.01
Observed Time 2 (minutes)	19.04	15.66	14.52
Average time	17.64	15.72	22.27

Survey formats: The *Picture and Word* format and *Picture Only* format are satisfactory. A visualised road and traffic scenario can provide most information required for decision making. However, we received many complaints about the *Word Only* format. Drivers experienced difficult in making a decision based on the information presented in this survey format. After the first round of the pilot survey, we improved all three survey formats by fixing the inadequacies identified. Especially, more information regarding the road and traffic situation was provided in interactive windows for the *Word Only* format.

The choice set for behavioural response: At the first round of the pilot survey, three options for behavioural response were defined: *Stop*, *Slow Down* and *Keep Going*. Some respondents were confused between *Slow Down* and *Keep Going*. "If I slow down a little then enter the roundabout, does it belong to *Slow Down* or *Keep Going*?" In fact, all vehicles approaching a roundabout have to slow down more or less because of the deflected vehicle path, regardless of the traffic interaction. After the first round of the pilot survey, we clarified three behavioural options by adding an interactive window with detailed definition for each option.

Data file: All automatically saved data files are satisfactory although we detected some inconsistencies in the data formats. The necessary changes were made to correct them.

An invitation letter: An invitation letter was drafted based on the experience of the first round of the pilot survey. The invitation letter addresses the purpose of survey, the background of the interviewer, the security of respondent's personal information and the time that a respondent needs to contribute to the survey. The final version of the invitation letter was given in appendix IV. To increase the credibility of the survey, the invitation letter bears the signature of Professor David Hensher, the Director of the Institute of Transport Studies.

6.4.2 The Second Round of the Pilot Survey

At the second round of the pilot survey, we further examine the appropriateness of three formats of the survey instrument and the choice set for the behavioural response. We also test if it is possible to recruit respondents for the main survey from the intercepted drivers. The second round of the pilot survey was conducted between January 31 and February 05, 2000 at the RTA Five Dock Motor Registry. We completed 12 interviews to test three survey formats. Issues raised in the second round of pilot survey include:

Choice set: The effects of improvements in response options after the first round of the pilot survey were not ideal. The major problem was that respondents did not take time to check these added interactive windows. (The check rate was 11%. The automatically saved data file indicated four checks. If all respondents check all definitions, there should be 36 checks). After the second round of the pilot survey, we redefined three options in the choice set as: Option 1 - *Slow Down to Stop*, Option 2 - *Slow Down and Keep Going* and Option 3 - *Not Slow Down and Keep Going*.

Consideration for recruitment of respondents for the main survey: As stated in chapter two, we wish to examine the preference equality and response consistency due to the repeated survey. That is, we wish to interview each respondent three times using three different survey formats in three months. We expected that it would be difficult to recruit enough respondents who can be interviewed three times. To test whether we could recruit some respondents from intercepted individuals, we added a pop up dialog box after the completion of the pilot survey (see figure 6-8). Our experiment indicated that no individual was willing to be interviewed three times. We have to find alternative methods to recruit respondents.

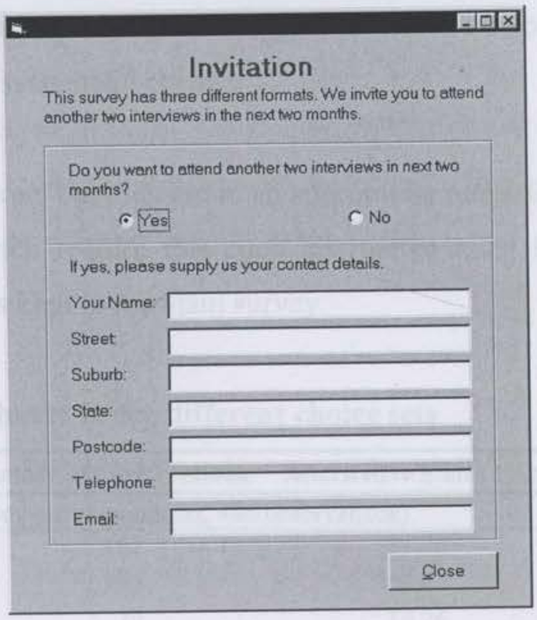


Figure 6-8 An invitation screen

Three formats of the survey instrument: The *Picture and Word* format and *Picture Only* format proved successful. However, the problems with the *Word Only* format remained. After the second round of the pilot survey, we abandoned this survey format.

6.4.3 The Third Round of the Pilot Survey

After we fixed the problems identified at the first and the second rounds of pilot survey, and abandoned the *Word Only* format, we tested all aspects of the survey at the third round of the pilot survey. The third round of the pilot survey was conducted between February 10 to February 15, 2000 at the Five Dock Motor Registry and at some households in the Western Suburbs of Sydney. We conducted 12 interviews, 6 with the *Picture and Word* format and 6 with the *Picture Only* format. Both survey formats are reliable and ready for a main survey. The newly defined choice set is better than the previous one, because three alternatives deliver clear messages. We calculated the alternative shares observed from "old" choice sets (at the first and the second rounds of the pilot survey) and "new" choice set (at the third round of the pilot survey), as shown in table 6-3. The alternative shares were slightly changed. It appeared like a random variation (between individuals) rather than a systematic change.

Alternative shares for three options are not even, but they are in an appropriate range for specifying the discrete choice models (which require that each alternative must be observed at least once). The new choice set is kept in the main survey.

Table 6-3 Comparison of alternative shares in the different choice sets

Choice set	Number of Observations	Alternative Share (%)
The first and second round of pilot survey (18 respondents, 486 observations)		
Stop	152	31.28
Slow Down	255	52.47
Keep going	79	16.26
The third round of pilot survey (12 respondents, 324 observations)		
Slow Down to Stop	94	29.01
Slow Down and Keep Going	167	51.54
Not Slow Down and keep Going	63	19.44

6.5 Survey Implementation and Administration

Sample size and survey arrangement: A survey scheme is carefully planned as given in table 6-4. In this scheme, we would recruit 100 respondents. The essence of sample size considerations is one of trade-offs. Too large a sample means that the survey will be too costly and time consuming. Too small a sample means that results are subject to a large degree of variability (Richardson et at 1995). A small sample size may mean that some effects of interest cannot be observed. Somewhere between these two extremes there exists a sample size which is most cost-effective given the survey objectives and the precision required. In particular, data obtained from 100 respondents should contain appropriate variation in responses, socio-economic characteristics and driving attitudes. The respondents were randomly assigned into four groups, each with 25 respondents. Each respondent would be interviewed twice. The second interview would be conducted 25 or more days after the first to reduce the response correlation between two interviews. Each group was offered one unique combination of survey formats in the first and second round of interviews. In this way, we can examine the preference equality and response consistency due to two survey formats and due to two waves of the main survey.

Table 6-4 General survey plan

Total No. of Respondents	Group: No. of Respondent	First Interview Data set : Survey Format	Second Interview Data set : Survey Format
100	Group A : 25	A1: Picture & Word	A2: Picture & Word
	Group B : 25	B1: Picture & Word	B2: Picture Only
	Group C : 25	C1: Picture Only	C2: Picture Only
	Group D : 25	D1: Picture Only	D2: Picture & Word

Recruitment of respondents: Sampled respondents should be random to reduce bias. However, resources (mainly costs associated with interviewing) are required to recruit and interview drivers in a two-wave survey, which are not available for a PhD study. As a convenient sampling, we selected four groups of people:

- *ITS Staff*: An invitation letter was sent to all staff in the Institute of Transport Studies (ITS) at the University of Sydney. Fifteen letters were sent, and six people participated in the survey. The bias associated with this sample group is that all staff has better knowledge of transport, road safety and transport data surveys.
- *Ashfield Residents*: Ashfield is a suburb in inner west of Sydney. Twenty-eight invitation letters were handed over face-to-face to the selected residents, and additional 36 invitation letters were dropped into resident mailboxes. Forty-eight drivers participated in the survey. Bias associated with this sample group is that all respondents lived in same area.
- *Students*: Fifty invitation letters were sent to selected postgraduate students at the Institute of Transport Studies of the University of Sydney and postgraduate students in the Master of Commerce Program at the University of New South Wales. Twenty-one students participated in the survey. Bias associated with this sampled group is that all respondents are students. There is little variation in age and personal income.
- *Friend Group*: Forty-three friends were contacted. All of them agreed to

participate in the survey. Twenty-three were actually interviewed. Bias associated this sample group is that all respondents have some common characteristics (eg similar age or backgrounds and felt obliged to participate).

Survey administration: A face to face interviews was chosen as the survey method. We sent out 152 invitation letters to potential respondents. In the reply form attached to the invitation letter, respondents were required to give their preferred interview date/time and their contact details. The reply forms were collected after 2-7 days of distribution.

Two waves of interviews were conducted. The first wave of the main survey was conducted between February 28 and April 06, 2000. The *SurveyStar* was installed on a laptop computer, and all interviews were conducted with the laptop computer. At the beginning of each interview, the interviewer demonstrated how to make a response on a computer screen, how to proceed to the next evaluation situation or go back to previous ones. The respondent was then asked to complete the survey in the presence of the interviewer. We conducted 100 interviews at the first wave of the main survey.

The second wave of interviews was conducted between March 27 to May 16, 2000. The interviewer no longer demonstrated how to complete the survey. The respondents generally experienced little difficulty during the second wave of the interview. Among the 100 respondents interviewed at the first wave of the survey, two of them quit at the second wave, leaving 98 interviews at the second wave of the survey.

6.6 Summary

In this chapter, we visualised the experimentally designed roundabout and traffic scenarios using a video image-based system. We developed a computerised survey instrument in three formats: a *Picture and Word* format, a *Picture Only* format and a *Word Only* format. We conducted a pilot survey to test the adequacy of all aspects of the survey and the appropriateness of the survey instrument. Two survey formats were used in the main survey. 100 Sydney drivers participated in the two waves of the face-to-face survey. In the next chapter, we process the survey data and conduct a descriptive analysis.

Chapter Seven
Data Processing and Preliminary Descriptive Analysis

In chapter seven, we process the data obtained at two waves of the main survey and conduct a preliminary descriptive analysis. In section 7.1, we firstly conduct a check for completeness and validity for all responses. In section 7.2, we use effects-codes to represent the effects of attributes and use dummy-codes to represent the effects of driver's socio-economic variables. In section 7.3, we provide an overall description for eight data sets produced from the survey. In section 7.4, we present a descriptive overview of the findings of the survey. In section 7.5, we investigate the relative importance of variables in explaining the drivers' perception of safety and behavioural response, using the Classification and Regression Tree approach. The last section concludes the chapter with a summary.

7.1 Preliminary Data Processing

The first step in data processing is to check the completeness and validity of responses. SurveyStar has been programmed to partially check the completeness of responses. For each scenario, a respondent must choose one safety perception scale as well as one behavioural option before s/he can proceed to the next scenario. From the pilot survey and the marketing research literature, we know some respondents are concerned about privacy in respect of personal information such as income and age. SurveyStar permits the survey to continue even if some questions are unanswered. An overall completeness check for all data was conducted after the survey was finished, and missing values are set to -999.

A validity check was also conducted to establish response consistency. When individuals undertake a survey task, they firstly learn the survey task and develop decision rules. Secondly, when they have familiarised themselves with the survey task, their response consistency increases. Finally, they become fatigued or lose interest in the survey. They may simplify their decision rules or even respond randomly in order to complete the survey (Brazell and Louviere 1995). If this occurs, the response data would contain little useful information. We need to detect these invalid responses before any data processing progresses.

The literature on stated preference analysis suggests that a dominance check should be undertaken (Pearmain et al 1991 and Bradley 1991). For a set of alternatives in a choice set, if one alternative has attribute levels that are either better than or equal to the levels of other alternatives, this alternative dominates others. It is logically expected that respondents would choose this alternative. Including a dominant or dominated alternative gives very little useful information for identifying utility tradeoffs. Therefore it is not a preferred practice. Alternatively, Speed 2.1 (Bradley 1991) uses the utility differences for a dominance check. While this approach does not necessarily include a dominant or dominated alternative in a choice set, it requires specifying a set of hypothetically representative utility coefficients before model estimation. This is not operational for a complex choice situation where there are many attributes and coefficients of some variables can be either positive or negative so that they cannot be decided a priori. For these reasons, we did not conduct such a dominance check.

We used a practical approach to check response validity. Our scenario sequence is designed such that we can confidently assume that the last three choice situations (from scenario 25 to 27) are substantially different enough. We expect respondents would make different responses accordingly. If a respondent gave the same rating on the safety perception scale and the same behavioural choice on these three scenarios, we treat the responses as invalid and exclude the data set for further processing.

A completeness and validity check was conducted with all 198 data sets. Only 1 data set was detected as non-compliant and thus excluded. Table 7-1 summarises the sample size for the first and the second round of the survey, as well as the final valid responses. In total, we recruited 100 respondents. All of them agreed to participate in two survey interviews. These respondents are randomly divided into 4 groups of 25 respondents. In the first round survey, we interviewed all 100 respondents. In the second round survey, 2 respondents (in group D) dropped out. The response completeness and valid check further abandoned one respondent data (in group B). This yielded 97 respondents, whose responses are valid and complete in both the first and second rounds of the survey. Our data analysis and model specification are based on these 97 respondents.

Table 7-1 Sample size at the first and second round of the survey

Group	Group A	Group B	Group C	Group D	Total
The first interview	25	25	25	25	100
The second interview	25	25	25	23	98
Valid responses	25	24	25	23	97

7.2 Coding Designs for Attributes, Socio-Economic Variables and Responses

As most attribute and socio-demographic variables are discrete, coding is a necessary step before any data processing can commence. Two coding schemes are available: effects-codes and dummy-codes (see Chapter five). We use effects-codes to represent the effects of *L-1* levels of qualitative attributes with *L* levels. Two continuous attributes (Speed and MySpd) need not be coded and are entered directly. These attributes are listed in table 7-2. There are totally 12 attributes subjects to effects-code scheme.

Table 7-2 The effects-code scheme for qualitative variables

Variable Name	Description
	Effects-Coded Attributes
	Size of the roundabout (Large, Medium & Small)
RoudL	Large roundabout: 1 if roundabout is large; -1 if roundabout is small; 0 otherwise.
RoudM	Medium roundabout: 1 if roundabout is medium; -1 if roundabout is small; 0 otherwise.
	Number of circulating lanes (Single & Two or more)
Lane1	Single-circulating lane: 1 if the roundabout has one circulating lane; -1 if the roundabout has two or more circulating lanes.
	Size of the vehicle that potentially conflicting with the respondent's car (Large, Medium & Small)
VehLG	Large-sized vehicle: 1 if vehicle is large; -1 if vehicle is small; 0 otherwise.
VehMD	Medium-sized vehicle: 1 if vehicle is medium; -1 if vehicle is small; 0 otherwise.
	Visibility to other traffic (Clear & Obstructed)
Clear	Clear visibility to other traffic: 1 if the visibility is clear; -1 if the visibility is obstructed.
	Overall traffic level at the roundabout (Busy, Moderate & Light)
BusyT	Traffic at the roundabout is busy: 1 if traffic is busy; -1 if traffic is light; 0 otherwise.

Variable Name	Description
ModeT	Traffic at the roundabout is moderate: 1 if traffic is moderate; -1 if traffic is light; 0 otherwise.
	Presence of a pedestrian trying to cross the road in front of the respondent's car (Presence & Non-Presence)
PedsY	The traffic situation that there is a pedestrian trying to cross the road in front of the respondent's car: 1 for presence of a pedestrian; -1 for non-presence of a pedestrian.
	Time availability or time pressure of a respondent (In a hurry & Not in a hurry)
Hurry	Respondent's time schedule is such that s/he is in a hurry: 1 if respondent is in a hurry; -1 if respondent is not in a hurry.
	Quantitative Attributes
Speed	The speed of the vehicle that potentially conflicts with the respondent's car, varying between 15-60 km/h.
MySpd	Speed of the respondent's car when it approaches the roundabout, varying between 15-60 km/h.

We use dummy-codes to represent the effects of 49 qualitative socio-demographic variables, which are listed in Table 7-3.

Table 7-3 Dummy codes of socio-demographic variables

Variable Name	Description
	Gender
GendF	1 if respondent is female, 0 otherwise
	Age
Age20	1 if respondent is 16-20 years old, 0 otherwise
Age25	1 if respondent is 21-25 years old, 0 otherwise
Age30	1 if respondent is 26-30 years old, 0 otherwise
Age35	1 if respondent is 31-35 years old, 0 otherwise
Age40	1 if respondent is 36-40 years old, 0 otherwise
Age45	1 if respondent is 41-45 years old, 0 otherwise
Age50	1 if respondent is 46-50 years old, 0 otherwise
Age55	1 if respondent is 51-55 years old, 0 otherwise
Age56	1 if respondent is 56 years or older, 0 otherwise
	Personal annual income (before tax)
Incm2	1 if personal income is less than or equal to $20,000, 0 otherwise
Incm3	1 if personal income is $20,001-30,000, 0 otherwise
Incm4	1 if personal income is $30,001-40,000, 0 otherwise
Incm5	1 if personal income is $40,001-50,000, 0 otherwise

Variable Name	Description
Incm6	1 if personal income is $50,001-60,000, 0 otherwise
Incm8	1 if personal income is $60,001-80,000, 0 otherwise
Incm9	1 if personal income is more than $80,001, 0 otherwise
	State and suburb
StNSW	1 if respondent lives in NSW, 0 otherwise
StOth	1 if respondent lives in a state other than NSW, 0 otherwise
Metro	1 if respondent lives in Metropolitan Area, 0 otherwise
	Drivers' licence status
Lhevy	1 if respondent holds a national heavy vehicle licence, 0 otherwise
Lgold	1 if respondent holds an unrestricted gold licence, 0 otherwise
Lsilv	1 if respondent holds an unrestricted silver licence, 0 otherwise
Lprov	1 if respondent holds a provisional licence (P plate), 0 otherwise
Llner	1 if respondent holds a learners' licence, 0 otherwise
Lprob	1 if respondent holds a probationary licence (e.g., traffic offence), 0 otherwise
Lothe	1 if respondent holds an other licence (e.g., overseas licence), 0 otherwise
	Years that respondent has been driving
DrYrs	Quantitative variable
	Respondent's accident involvement in the last two years
AccNo	1 if respondent was not involved in an accident in the last two years, 0 otherwise
AccYe	1 if respondent was involved in an accident in the last two years, 0 otherwise
AcYeM	1 if respondent was involved in an accident and respondent was at fault, 0 otherwise
AcYeB	1 if respondent was involved in an accident and both respondent and other involved driver were at fault, 0 otherwise
AcYeO	1 if respondent was involved in an accident but other involved driver was at fault, 0 otherwise
	Respondent's traffic offence history
OffNo	1 if respondent did not commit a traffic offence in the last two years, 0 otherwise
OffYe	1 if respondent committed a traffic offence and got a demerit point in the last two years, 0 otherwise
Point	Quantitative variable representing respondent's highest demerit points in the last two years
	Commuter status
ComYe	1 if respondent is a commuter, 0 otherwise
ComNo	1 if respondent is not a commuter, 0 otherwise
	The class of vehicle that the respondent normally drives (Vehicles are classified into 6 categories, as defined in chapter 6)
CarSM	1 if respondent normally drives a small car, 0 otherwise
CarMD	1 if respondent normally drives a medium car, 0 otherwise
CarLG	1 if respondent normally drives a large car, 0 otherwise
CarWD	1 if respondent normally drives a 4WD, 0 otherwise

Variable Name	Description
CarLX	1 if respondent normally drives a luxury car, 0 otherwise
CarLM	1 if respondent normally drives a light commercial vehicle, 0 otherwise
	Respondent's self-description of his/her psychological state in most situations when driving
Paggr	1 if respondent describes his/herself as an aggressive driver, 0 otherwise
Pimpa	1 if respondent describes his/herself as an impatient driver, 0 otherwise
Phesi	1 if respondent describes his/herself as a hesitant driver, 0 otherwise
Pslow	1 if respondent describes his/herself as a slow driver, 0 otherwise
Pcaut	1 if respondent describes his/herself as a very cautious driver, 0 otherwise

We have eight statements about a respondent's driving behaviour and experience. Each statement has five levels. We use 40 dummy-codes to represent these statement levels, shown in table 7-4.

Table 7-4 Dummy-coded variables for statements about driving experience

Variable name	Statements about driving behaviour and experience
	Statement 1: Driving usually makes me feel aggressive
DMFA1	1 if the statement 1 *never* applies to respondent's driving experience, 0 otherwise.
DMFA2	1 if the statement 1 *sometimes (25% of the time)* applies to respondent's driving experience, 0 otherwise.
DMFA3	1 if the statement 1 *often (50% of the time)* applies to respondent's driving experience, 0 otherwise.
DMFA4	1 if the statement 1 *very often (75% of the time)* applies to respondent's driving experience, 0 otherwise.
DMFA5	1 if the statement 1 *almost always (almost 100% of the time)* applies to respondent's driving experience, 0 otherwise.
	Statement 2: I tend to overtake other vehicles whenever possible
TOVP1	1 if the statement 2 *never* applies to respondent's driving experience, 0 otherwise.
TOVP2	1 if the statement 2 *sometimes (25% of the time)* applies to respondent's driving experience, 0 otherwise.
TOVP3	1 if the statement 2 *often (50% of the time)* applies to respondent's driving experience, 0 otherwise.
TOVP4	1 if the statement 2 *very often (75% of the time)* applies to respondent's driving experience, 0 otherwise.
TOVP5	1 if the statement 2 *almost always (almost 100% of the time)* applies to respondent's driving experience, 0 otherwise.
	Statement 3: When irritated I drive aggressively
WIDA1	1 if the statement 3 *never* applies to respondent's driving experience, 0 otherwise.
WIDA2	1 if the statement 3 *sometimes (25% of the time)* applies to respondent's driving experience, 0 otherwise.

Variable name	Statements about driving behaviour and experience
WIDA3	1 if the statement 3 *often (50% of the time)* applies to respondent's driving experience, 0 otherwise.
WIDA4	1 if the statement 3 *very often (75% of the time)* applies to respondent's driving experience, 0 otherwise.
WIDA5	1 if the statement 3 *almost always (almost 100% of the time)* applies to respondent's driving experience, 0 otherwise.
	Statement 4: When I try but fail to overtake I am usually frustrated
TFOF1	1 if the statement 4 *never* applies to respondent's driving experience, 0 otherwise.
TFOF2	1 if the statement 4 *sometimes (25% of the time)* applies to respondent's driving experience, 0 otherwise.
TFOF3	1 if the statement 4 *often (50% of the time)* applies to respondent's driving experience, 0 otherwise.
TFOF4	1 if the statement 4 *very often (75% of the time)* applies to respondent's driving experience, 0 otherwise.
TFOF5	1 if the statement 4 *almost always (almost 100% of the time)* applies to respondent's driving experience, 0 otherwise.
	Statement 5: Driving a car gives me a sense of power
DCGP1	1 if the statement 5 *never* applies to respondent's driving experience, 0 otherwise.
DCGP2	1 if the statement 5 *sometimes (25% of the time)* applies to respondent's driving experience, 0 otherwise.
DCGP3	1 if the statement 5 *often (50% of the time)* applies to respondent's driving experience, 0 otherwise.
DCGP4	1 if the statement 5 *very often (75% of the time)* applies to respondent's driving experience, 0 otherwise.
DCGP5	1 if the statement 5 *almost always (almost 100% of the time)* applies to respondent's driving experience, 0 otherwise.
	Statement 6: In general, I mind being overtaken
GMBO1	1 if the statement 6 *never* applies to respondent's driving experience, 0 otherwise.
GMBO2	1 if the statement 6 *sometimes (25% of the time)* applies to respondent's driving experience, 0 otherwise.
GMBO3	1 if the statement 6 *often (50% of the time)* applies to respondent's driving experience, 0 otherwise.
GMBO4	1 if the statement 6 *very often (75% of the time)* applies to respondent's driving experience, 0 otherwise.
GMBO5	1 if the statement 6 *almost always (almost 100% of the time)* applies to respondent's driving experience, 0 otherwise.
	Statement 7: I am not usually patient during the peak hour
NPPH1	1 if the statement 7 *never* applies to respondent's driving experience, 0 otherwise.
NPPH2	1 if the statement 7 *sometimes (25% of the time)* applies to respondent's driving experience, 0 otherwise.
NPPH3	1 if the statement 7 *often (50% of the time)* applies to respondent's driving experience, 0 otherwise.
NPPH4	1 if the statement 7 *very often (75% of the time)* applies to respondent's driving experience, 0 otherwise.

Variable name	Statements about driving behaviour and experience
NPPH5	1 if the statement 7 *almost always (almost 100% of the time)* applies to respondent's driving experience, 0 otherwise.
	Statement 8: It annoys me to drive behind slow moving vehicles
ABSV1	1 if the statement 8 *never* applies to respondent's driving experience, 0 otherwise.
ABSV2	1 if the statement 8 *sometimes (25% of the time)* applies to respondent's driving experience, 0 otherwise.
ABSV3	1 if the statement 8 *often (50% of the time)* applies to respondent's driving experience, 0 otherwise.
ABSV4	1 if the statement 8 *very often (75% of the time)* applies to respondent's driving experience, 0 otherwise.
ABSV5	1 if the statement 8 *almost always (almost 100% of the time)* applies to respondent's driving experience, 0 otherwise.

The response variables are listed in table 7-5. These include the safety perception rating, driving behavioural choice, time spent on each scenario, time spent on the entire survey, and number of clicks respondents made to seek detailed information on attributes and levels. The rating response suggests the use of an ordered probit (logit) model. We created a variable ChoiceZ, the index for behavioural response, for specifying the discrete choice models in later chapters.

Table 7-5 Response variables

Variable Name	Description
	Respondent's safety perception rating on a scale from 1-5
Rating	0 if the scenario is rated as very unsafe 1 if the scenario is rated as somewhat unsafe 2 if the scenario is rated as neutral 3 if the scenario is rated as somewhat safe 4 if the scenario is rated as very safe
	Respondent's behavioural choice
Choice	1 if Option 1: Slow Down to Stop, is chosen 2 if Option 2: Slow Down and Keep Going, is chosen 3 if Option 3: Not Slow Down and Keep Going, is chosen
	Transformed variable of respondent's behavioural choice
ChoiceZ	Transformed variable of respondent's behavioural choice for specifying a discrete choice model. For a choice set with 3 options, 3 separate data sets are developed. For data set 1, ChoiceZ=1 when option 1 (Slow Down to Stop) was chosen, 0 otherwise. For data set 2, ChoiceZ=1 when option 2 (Slow Down and Keep Going) was chosen, 0 otherwise. For data set 3, ChoiceZ=1 when option 3 (Not Slow

Variable Name	Description
	Down and Keep Going) was chosen, 0 otherwise.
	Time that respondents spend on the survey
Ptime	Quantitative variable representing the time (in seconds) that a respondent spends on evaluating each of scenario
Ttime	Quantitative variable representing total time (in minutes) that a respondent spends on the entire survey
	Numbers of clicks
InfoS	Quantitative variable representing numbers of clicks that a respondent made to seek detailed information or a definition of an attribute level associated with an offered scenario

7.3 Data Description

Eight data sets were produced following the above-mentioned coding-schemes. These data sets are described in table 7-6. Each of the 97 effective respondents was interviewed twice. At each interview, each respondent evaluated all 27 road and traffic situations, giving a total of 5238 evaluation situations if all eight data sets are pooled together.

Table 7-6 Name and description of data sets

Data Name	Description
A1 & A2	Data sets for Group A in the first and second rounds of the survey respectively. There are 25 X 27 = 675 evaluation situations.
B1 & B2	Data sets for Group B in the first and second rounds of the survey respectively. There are 24 X 27 = 648 evaluation situations.
C1 & C2	Data sets for Group C in the first and seconds rounds of the survey respectively. There are 25 X 27 = 675 evaluation situations.
D1 & D2	Data sets for Group D in the first and second rounds of the survey respectively. There are 23 X 27 = 621 evaluation situations.

7.4 Survey Findings: A Descriptive Overview

7.4.1 Socio-Demographic Characteristics

The socio-demographic characteristics of respondents are presented in table 7-7 It is observed that distributions of gender, age, and driver's licence status in the sampled driver are very close to distributions for all drivers. Thus, sapling bias would be not significant. A brief description of the socio-economic characteristics of the sampled individuals is provided below:

- *Gender:* The sample is compared with licences on issue by gender in New South Wales (NSW) in June 1998 (RTA 1998). Both men and women are well represented in the sample. Women are slightly over-sampled.
- *Age:* The sample is compared with licences on issue by age category in NSW in June 1998. A direct comparison is not possible because of the different categories used in the sample and reference source. Drivers in the age group 16-20 years are not represented in the sample, while drivers in the age group 21-30 years are over-sampled. Drivers in the age group 41-50 and age group 51 years or older are under-sampled.
- *Personal income before tax:* The sample is compared with CDATA96 (ABS 1998), the *1996 Census of Population and Housing* collected by the Australian Bureau of Statistics. No direct comparison to CDATA96 is possible because not all individuals hold a driver licence. Individuals with annual income $20,000 or less are under-represented in the sample, while individuals in all other income categories are over-represented.
- *State and suburb:* All respondents live in the Sydney metropolitan area, although two respondents have a home address other than in NSW.
- *Driver's licence status:* Drivers with an unrestricted gold licence, unrestricted silver licence, provisional licence and learner's licence are well represented in the sample. Drivers holding a probationary licence or other licence (eg overseas license) are not represented. Only one driver with a national heavy vehicle licence is observed.
- *Driving experience:* 40.21% of sampled drivers have less than 5-year driving

experience, while 16.59% of sampled drivers have more than 30-year driving experience.

- *Accident involvement:* 16.49% of sampled drivers reported they were involved in an accident in the last two years.
- *Traffic offence:* 10.31% of respondents reported that they committed a traffic offence in the last two years.
- *Commuter status:* 52.58% of respondents are commuter drivers.
- *The class of car that respondent normally drives:* 53.61% of sampled drivers normally drive a small car, 23.71% normally drive a medium car and other drivers drive either a large car, a 4WD, a luxury car or a light commercial vehicle.
- *Respondents' self-description of their psychological state in most situations when driving:* No driver describes his/herself as an aggressive driver. More than half of the respondents describe themselves as very cautious or slow drivers.

Table 7-7 Summary of respondent characteristics

Characteristics	Sample	Percentage	Reference
Gender			**RTA(1998)**
Female	45	46.39	43.57
Male	52	53.61	56.43
Age			**RTA(1998)**
16-20 years	0	0	5.93
21-25 years	12	12.37	19.58
26-30 years	23	23.71	
31-35 years	13	13.40	22.15
35-40 years	9	9.28	
41-45 years	7	7.22	20.33
46-50 years	8	8.25	
51-55 years	16	16.49	32.01
56 years or older	9	9.28	
Personal annual income before tax			**CDATA96**
$20,000 or less	28	28.87	58.44
$20,001 - $30,000	21	21.65	11.22
$30,001 - $40,000	18	18.56	17.04
$40,001 - $50,000	11	11.34	5.77
$50,001 - $60,000	10	10.31	2.35
$60,001 - $80,000	5	5.15	2.89

Characteristics	Sample	Percentage	Reference
$80,001 or more	4	4.12	2.28
State and Suburb			
NSW	95	97.94	
Other State	2	2.06	
Metropolitan area	97	100	
Driver's licence status			**RTA(1998)**
National Heavy Vehicle Licence	1	1.03	9.33
Unrestricted Gold Licence	55	57.73	59.03
Unrestricted Silver Licence	18	18.56	25.61
Provisional Licence (P Plate)	13	13.40	2.18
Learners' Licence (L Plate)	9	9.28	3.35
Probationary Licence (Traffic Offence)	0	0	0.51
Other Licence (eg. Overseas Licence)	0	0	-
Driving experience			
0 – 1 years	10	10.31	
2 – 5 years	29	29.90	
6 – 15 years	22	22.68	
16 – 30 years	20	20.62	
31 – 35 years	12	12.37	
More than 35 years	4	4.12	
Accident involvement in last 2 years			
No	81	83.51	
Yes	16	16.49	
If yes, who is at fault?			
Respondent	5	5.15	
Other Driver	7	7.22	
Both Drivers	4	4.12	
Traffic offence in last 2 years			
Yes	10	10.31	
No	87	89.69	
Commuter status			
Commuter Driver	51	52.58	
Not Commuter Driver	46	47.42	
The class of car that respondent normally drives			
A small car	52	53.61	
A medium car	23	23.71	
A large car	2	2.06	
A 4WD	14	14.43	
A luxury car	3	3.09	
A light commercial	3	3.09	

Characteristics	Sample	Percentage	Reference
Respondent's self-description of his/her psychological state in most situations when driving			
An aggressive driver	0	0	
An impatient driver	16	16.49	
A hesitant driver	17	17.53	
A slow driver	28	28.87	
A very cautious driver	36	37.11	

7.4.2 Driving Experiences and Behaviour

Eight statements about driving behaviour and experience were included in the survey. Each statement has five frequency levels measuring how often the statement applies to a respondent's driving experience. Respondents are asked to select one frequency level that best describes their driving behaviour or experience. A *frequency percentage* is attached to each level (never, 25%, 50%, 75% and always). Table 7-8 *gives observed percentages* that each level was chosen by respondents in the categories of men, women and overall. A *frequency indicator* for each statement is also calculated. The frequency indicator is an overall index representing how often a statement is applicable to drivers as a whole. It is calculated as the sum of the product of the frequency percentage and observed percentage. For example, the frequency indicator of the statement 1 for men is calculated as: 63.46 x 0 + 26.92 x 0.25 + 7.69 x 0.50 + 1.92 x 0.75 + 0 x 1.0 = 12.02. We use the frequency indicator and the observed percentage to investigate how these statements apply to driving behaviour and experience.

- *Statement 1: Driving usually makes me feel aggressive.* The overall frequency indicator for this statement is 12.12%. About 62.89% of drivers think that driving never makes them feel aggressive. No driver thinks that driving always makes her/himself feel aggressive. Women are slightly more likely to agree with this statement.
- *Statement 2: I tend to overtake other vehicles whenever possible.* Men are more likely to overtake other vehicles whenever possible than women. About 59.79% of drivers never tend to overtake other vehicles whenever possible. The overall frequency indicator of this statement is 16.75%.
- *Statement 3: When irritated I drive aggressively.* Irritation has little effect on aggressive driving. About 75.26% of drivers state that they never drive

aggressively when irritated. Men are more likely than women to drive aggressively when irritated.

- *Statement 4: When I try but fail to overtake I am usually frustrated.* Overtaking frustration is a frequently occurring phenomenon. The overall frequency is 38.15%. Although drivers are unlikely to overtake other vehicles whenever possible (16.75%, statement 2), they would generally be frustrated when they tried but failed to do so. Men are more likely to be frustrated by an unsuccessful overtaking than women.
- *Statement 5: Driving a car gives me a sense of power.* Drivers rarely think that driving a car gives them a sense of power, especially for men. Women are much more likely than men to connect the sense of power with driving a car.
- *Statement 6: In general, I mind being overtaken.* Drivers state that they mind being overtaken in 28.86% of the time. Women are more likely to mind being overtaken than men. Some thoughtful respondents have suggested that this statement is highly dependent on the driving environment. For example, they would never mind being overtaken on a rural highway but would generally mind being overtaken on a local street.
- *Statement 7: I am not usually patient during the peak hour*. Drivers are generally not patient during the peak hour. Because 97.94% of our sample are Sydney metropolitan-based drivers, we can infer that congestion in Sydney during peak hours is so severe that most drivers occasionally get impatient.
- *Statement 8: It annoys me to drive behind slow driving vehicles.* Reported frequency of annoyance for driving behind a slow moving vehicle is high. It suggests most drivers like to drive at a preferred speed. Men are more likely to be annoyed from following a slow moving vehicle.

It is worth noting the higher reported frequency from women in statements 1, 5 and 6, (feel aggressive when driving, the sense of power when driving and mind being overtaken). Brewer (2000) attributes this phenomenon to a higher propensity in women to report impatience, frustration and anger. She further associated this inclination of higher reporting to firstly women's capability to express their emotions more effectively than men, and secondly, women's different perception of time and balancing work and home commitments.

Table 7-8 Driving behaviour and experience

Statements	Men (% of 52)	Women (% of 45)	Overall (% of 97)
1. Driving usually makes me feel aggressive	(12.02)	(12.22)	(12.12)
Never	63.45	62.22	62.89
Sometimes (25% of the time)	26.92	28.89	27.84
Often (50% of the time)	7.69	6.67	7.22
Very often (75% of the time)	1.92	2.22	2.06
Almost always (almost 100% of the time)	0	0	0
2. I tend to overtake other vehicles whenever possible	(16.83)	(16.67)	(16.75)
Never	63.46	55.56	59.79
Sometimes (25% of the time)	15.38	22.22	18.56
Often (50% of the time)	11.54	22.22	16.49
Very often (75% of the time)	9.62	0	5.15
Almost always (almost 100% of the time)	0	0	0
3. When irritated I drive aggressively	(10.58)	(8.88)	(9.79)
Never	73.08	77.78	75.26
Sometimes (25% of the time)	17.32	13.33	15.46
Often (50% of the time)	3.85	4.44	4.12
Very often (75% of the time)	5.77	4.44	5.15
Almost always (almost 100% of the time)	0	0	0
4. When I try but fail to overtake I am usually frustrated	(39.91)	(36.10)	(38.15)
Never	26.92	17.78	22.68
Sometimes (25% of the time)	17.31	33.33	24.74
Often (50% of the time)	34.62	40.00	37.11
Very often (75% of the time)	11.54	4.44	8.25
Almost always (almost 100% of the time)	9.62	4.44	7.22
5. Driving a car gives me a sense of power	(5.29)	(13.89)	(9.28)
Never	86.54	75.56	81.44
Sometimes (25% of the time)	7.69	4.44	6.19
Often (50% of the time)	3.85	11.11	7.22
Very often (75% of the time)	1.92	6.67	4.12
Almost always (almost 100% of the time)	0	2.22	1.03
6. In general, I mind being overtaken	(26.93)	(31.11)	(28.86)
Never	48.08	40.00	44.33
Sometimes (25% of the time)	17.31	13.33	15.46
Often (50% of the time)	17.31	31.11	23.71
Very often (75% of the time)	13.46	13.33	13.40
Almost always (almost 100% of the time)	3.85	2.22	3.09

Statements	Men (% of 52)	Women (% of 45)	Overall (% of 97)
7. I am not usually patient during the peak hour	(42.31)	(42.22)	(42.27)
Never	11.54	6.67	9.28
Sometimes (25% of the time)	36.54	44.44	40.21
Often (50% of the time)	26.92	28.89	27.84
Very often (75% of the time)	21.15	13.33	17.53
Almost always (almost 100% of the time)	3.85	6.67	5.15
8. It annoys me to drive behind slow moving vehicles	(39.43)	(37.78)	(38.66)
Never	21.15	24.44	22.68
Sometimes (25% of the time)	32.69	26.67	29.90
Often (50% of the time)	23.08	26.67	24.74
Very often (75% of the time)	13.46	17.78	15.46
Almost always (almost 100% of the time)	9.62	4.44	7.22

7.4.3 Investigation of Respondent Behaviour in the Stated Choice Experiment

Respondent behaviour in choice experiment surveys is an important issue because of its implications for empirical research and theory development. A number of studies have addressed these issues suggesting a three-step choice survey completion process (Brazell and Louviere 1995). The first step is response decision-taking. When individuals are asked to participate in a survey, they decide whether or not to participate. Response decision involves a complex interaction amongst the survey characteristics, respondent characteristics and time availability. The second step is an attention level decision. If a respondent decides to participate in and complete the survey, they then decide how much attention and effort to be invested in the survey task. The third step involves undertaking and completing the survey tasks. Before the survey, a respondent may estimate how long it would take to complete the survey, and allocate a fixed amount of time to finish the survey task. At the beginning of the survey, a respondent learns the task and develops a decision strategy/rules. They gradually get familiarised with the task, resulting increased choice efficiency and consistency. Finally, if the survey takes a long time or requires a demanding cognitive effort, respondents may become fatigued or lose interest in the task. They may simplify their decision strategy, or even respond randomly to finish the task and honour their commitment.

This survey completion process has important implications on respondent behaviour. It not only can enlighten us to increase the response rate (step 1), but also to improve the reliability of the response (steps 2 & 3). If the entire process of completing the survey described in step 3 occurs, we expect that respondents would spend longer time on each choice situation at the beginning. As they become familiarised with the survey task, they would spend less time on each choice situation. If they become fatigued or lose interest in the survey and simplify the decision strategy to make the task easier or quicker to complete, we expect a sharp decrease in time spent at each choice situation.

Taking advantage of a computerised survey, we have recorded the time that a respondent invested in evaluating each road and traffic scenario as well as time devoted to the entire survey. We also recorded the number of clicks on the Information Buttons. (Respondents can click the Information Buttons to seek a definition or detailed information on attributes and levels). We investigated respondent behaviour through examining the elapsed time and number of clicks associated with each evaluation scenario as the survey progresses.

The average number of clicks for each scenario, calculated as the total number of clicks divided by the total number of respondents, is summarised in table 7-9 and depicted in figure 7-1 for two survey formats. For the *Picture and Word* format, the number of clicks declined sharply after the third scenario, then stabilised for the remaining evaluation situations. This suggests that respondents need detailed information to learn survey tasks at the beginning of the survey. The overall average number of clicks received by each scenario is 0.39, which suggests respondents have little need for detailed information to support their decision as long as they get familiarised with the survey task. Because each scenario picture is accompanied by a word description about attributes and levels, information missing in this survey format is minimised. Respondent behaviour in clicking for detailed information is quite different for the *Picture Only* format. At the first and the second scenario, respondents make more than the average number clicks per treatment. They are learning the survey task. After they get familiarised with the survey layout, they maintain an average of 1.5 clicks per scenario. This suggests that the survey format of *Picture Only* misses some information needed to make a decision, (compared to the *Picture and Word* format). From the trend of the number of clicks in both survey formats, we find little evidence of respondent fatigue or loss of interest in the survey.

The average time that a respondent spends on each scenario is also calculated, given in table 7-9 and figure 7-2. Respondent behaviour is quite similar between the two survey formats. Three distinctive response stages are noticeable. The first stage involves scenarios 1-4. Respondents spend lesser and lesser time on each response situation as the survey progresses. We can connect this trend to the respondent's learning process. The second stage occurs between scenarios 5-13. Respondents spend relatively stabilised time for each scenario. This suggests that, after experiencing four evaluation scenarios, respondents have familiarised themselves with the task and developed a response strategy. The third stage is from scenarios 14 to 27. A noticeable time reduction for each scenario is observed. Two assumptions can be used to explain this phenomenon. (1) After experience with 13 choice situations, respondents get further familiarised with the survey tasks so that they need less time for each choice situation. (2) Respondents became fatigued or lost interest in the survey, so that they simplified the decision rules, resulting less time needed for each scenario. These assumptions are testable if a specific experiment is designed for this purpose, which is beyond the focus of this study. It is worthy to note that the "learning" process of survey task may have implications on utility parameters. That is, parameter estimates may be different based on data observed from different survey stages. The parameter stability can be formally explored using a technique known as latent class analysis. This is not a focus for this thesis thus parameter stability will not be investigated in the remaining of the thesis.

To further investigate the effects of survey format, we calculated the total number of clicks and total survey time for each respondent, summarised in tables 7-10 and 7-11, and figures 7-3 figure 7-4. The differences in the number of clicks and total survey time for two survey formats are obvious.

Table 7-9 Number of clicks and response time for each choice scenario

Scenario	Format of Picture & Word		Format of Picture Only	
	"Clicks"	Time (S)	"Clicks"	Time
1	4.51	53.82	3.51	54.07
2	0.84	44.55	2.10	49.47
3	0.41	42.08	1.71	44.73
4	0.34	39.04	1.72	39.85
5	0.30	33.89	1.81	34.15
6	0.30	33.58	1.84	34.02
7	0.32	32.35	1.85	32.99
8	0.38	33.35	1.75	33.03
9	0.27	33.54	1.85	32.73
10	0.41	31.37	1.76	33.31
11	0.21	31.07	1.82	33.88
12	0.15	31.47	1.86	34.59
13	0.19	30.43	1.81	33.03
14	0.14	24.34	1.66	27.56
15	0.11	25.80	1.49	27.70
16	0.14	24.59	1.53	26.92
17	0.14	26.22	1.68	28.49
18	0.07	24.98	1.40	27.75
19	0.19	24.39	1.55	28.05
20	0.13	26.72	1.53	27.47
21	0.09	25.08	1.67	26.62
22	0.18	23.53	1.63	25.78
23	0.14	23.08	1.54	25.89
24	0.10	22.98	1.35	24.39
25	0.16	22.06	1.28	23.24
26	0.13	22.85	1.36	24.46
27	0.16	23.04	1.51	25.08
Average	0.39	30.01	1.72	31.82

Table 7-10 Frequency of number of clicks over respondents

Category of Total Clicks	Number of respondents	
	Picture & Words	Picture Only
0-5	6	1
6-10	47	2
11-15	32	1
16-20	8	1
21-25	3	1
26-30	1	0
31-35	0	0
36-40	0	5
41-45	0	18
46-50	0	39
51-55	0	17
56-60	0	10
61+	0	2
Total respondents	97	97

Table 7-11 Frequency of survey time over respondents

Category of Total Time (minutes)	Number of respondents	
	Picture & Words	Picture Only
12-	1	0
12-13	4	2
13-14	5	2
14-15	14	7
15-16	18	15
16-17	21	19
17-18	14	20
18-19	12	16
19-20	5	13
20+	3	3
Total respondents	97	97

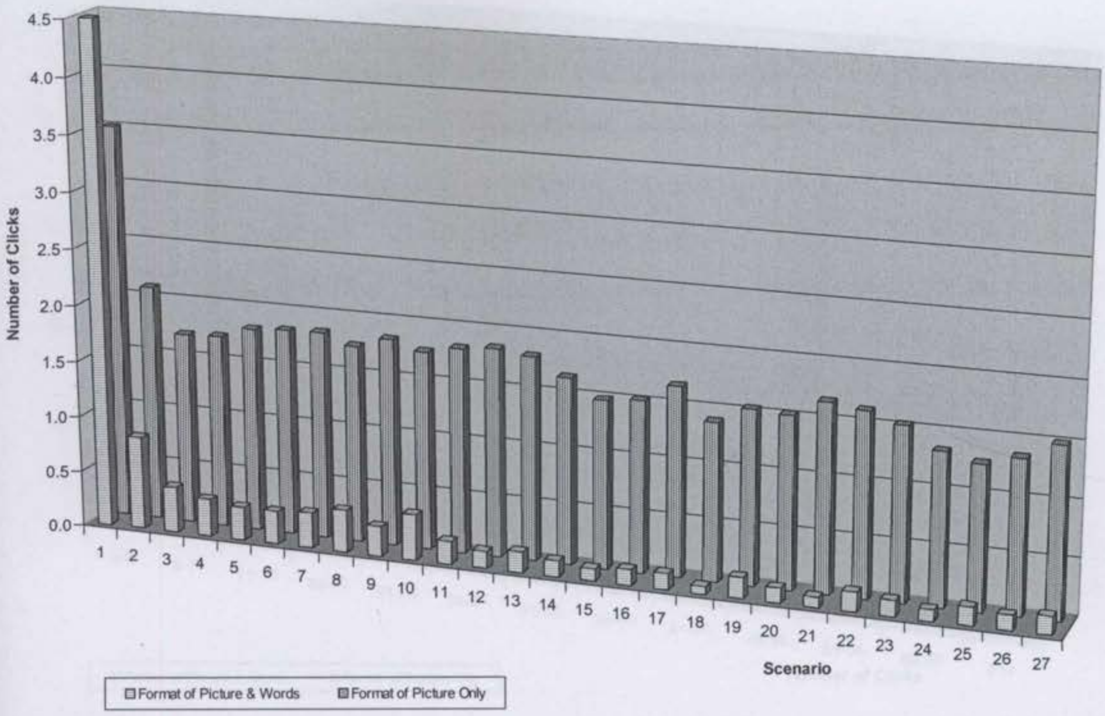


Figure 7-1 Number of clicks at each scenario

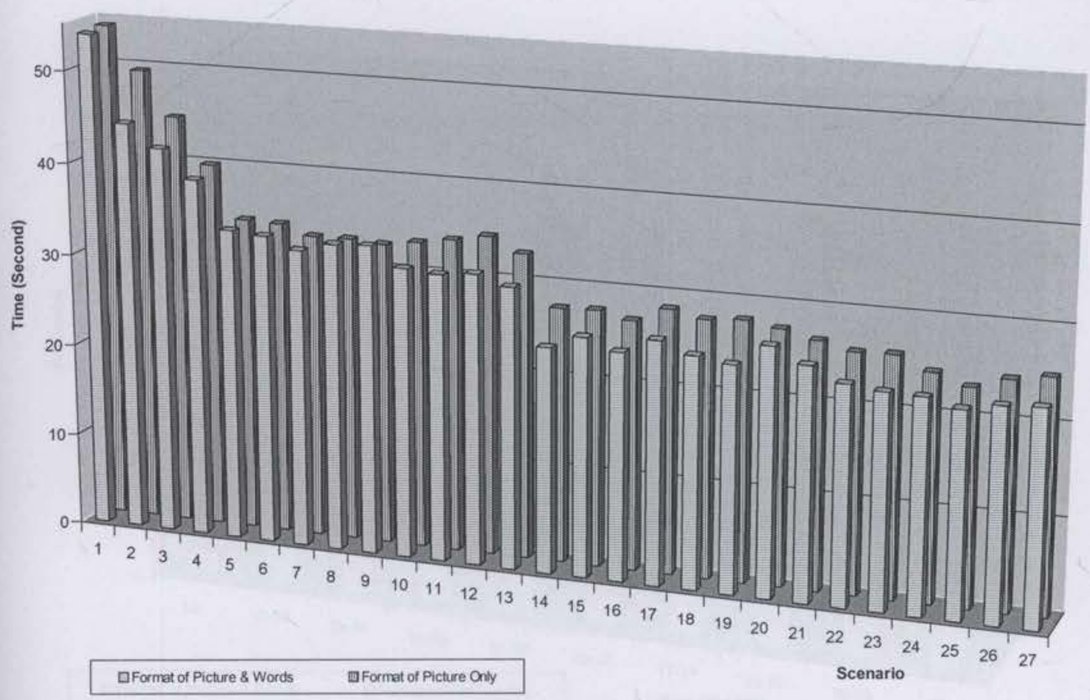


Figure 7-2 Response time (in seconds) on each scenario

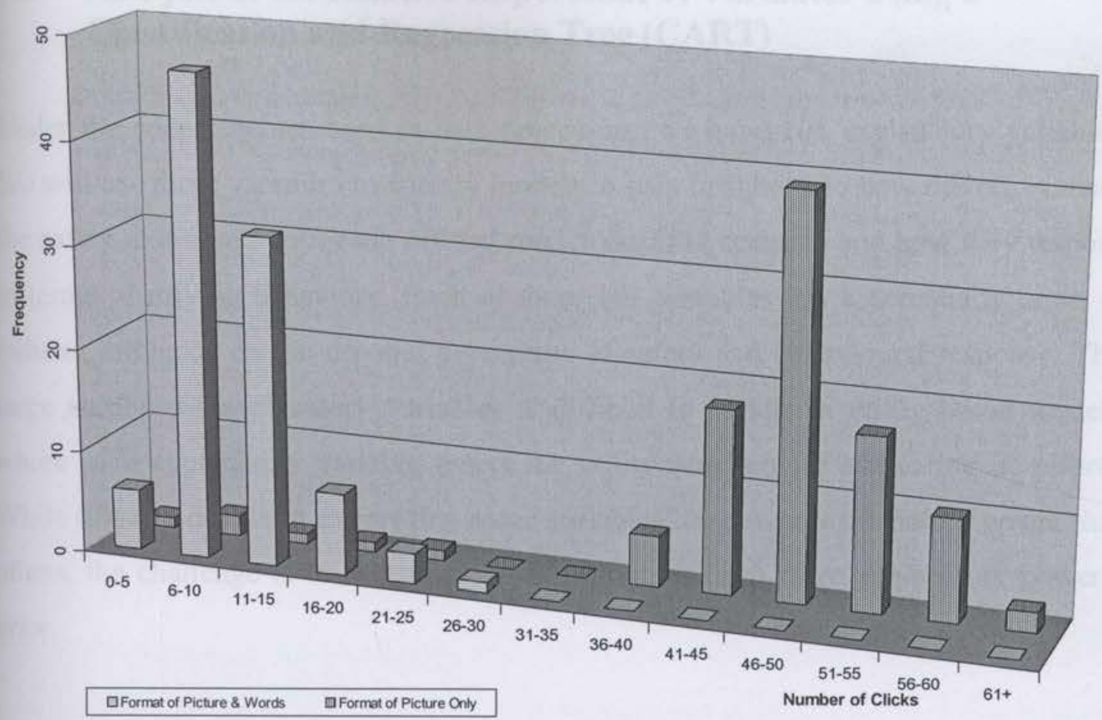


Figure 7-3 Histogram of number of clicks of the survey

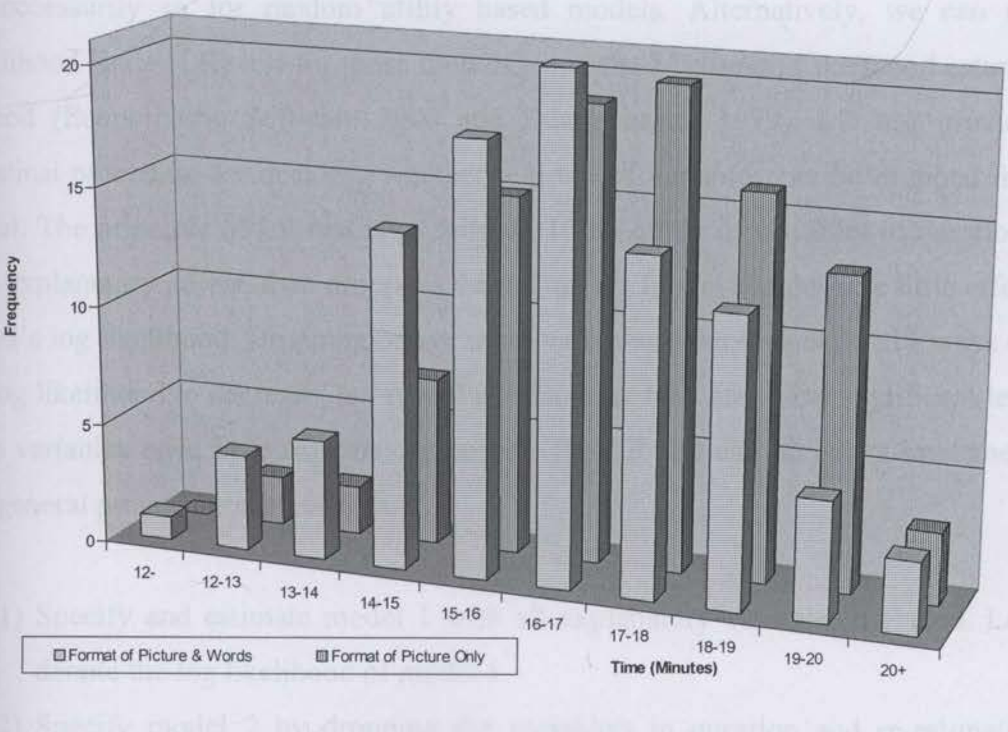


Figure 7-4 Histogram of time (in minutes) of the survey

7.5 Analysis of the Relative Importance of Variables Using a Classification and Regression Tree (CART)

Under the code-schemes used in data processing, we have 101 explanatory variables. We will use these variables to specify models to gain insights into how drivers evaluate the safety associated with each offered road and traffic scenario and how they respond in terms of driving behaviour. Each of these 101 variables has a potentially direct or indirect influence on the drivers' perception of safety and behavioural response. This large number of explanatory variables is difficult to handle in utility based models, where each explanatory variable enters the utility function for estimating its effects. While it is reasonable to expect that some variables have more explanatory power than others, the challenge is to determine which variables have more explanatory power a prior.

A number of statistical procedures can be used for this purpose. For example, stepwise regression can be used to determine whether a variable should be included or excluded in the model (Econometric Software 2000). However, while variables identified by this method as significant or insignificant are applicable to stepwise regression model, this is not necessarily so for random utility based models. Alternatively, we can use a Likelihood Ratio (LR) test for those models using the Maximum Likelihood estimation method (Econometric Software 2000 and Duangphastra 1999). LR test provides a statistical procedure for deciding whether a group of variables can be dropped from a model. The principle of LR test is as follows. If the group of variables in question has little explanatory power, then dropping them from the model should have little effect on model's log likelihood. Dropping one or more variables from a model will always cause the log likelihood to decrease, but it will not decrease by a statistical significant level if these variables have little explanatory power. The LR test can be easily implemented. The general procedure is given below.

(1) Specify and estimate model 1 with all explanatory variables included. Let *L1* denote the log likelihood of model 1.

(2) Specify model 2 by dropping the variable/s in question and re-estimate the model. Let *L2* denote the log likelihood of model 2.

(3) The LR test statistic is calculated as: $LR = 2(L1\text{-}L2)$. The *LR* is always positive.

> The LR test is asymptotically distributed as Chi-squared with degree of freedom equal to the number of variables dropped. An LR value larger than the critical value at a significant level favours model 1, ie, variables being tested should be retained in the model. Otherwise, model 2 is preferred, ie, variables being test should be dropped in model specification.

The *LR* test can be repeated until a preferred model is identified. This method is time consuming. If there is multicollinearity among the variables, it can lead to erroneous model specification. Neither stepwise regression nor the LR test gives an overall rank of explanatory power of all variables. We are therefore motivated to employ a non-parametric procedure known as Classification and Regression Tree (CART) to investigate the relative importance of the variables. CART was developed by Breiman et al. (1984) and later enhanced and implemented by Steinberg and Colla (1998). CART uses a multi-sequential search algorithm to optimise the classification of a phenomenon and presents the results in the form of a decision tree. The technique of CART is not discussed here. Interested readers should refer to Breiman et al. (1984), Steinberg and Colla (1998). Ton and Wang (1999) present a detailed application in transport.

The first step of analysis of the relative importance of variables is to construct a classification tree. Two classification trees are constructed. One uses driver behavioural choice (3 categories) as the target (dependent) variable, and uses all 101 explanatory variables as predictors. The other uses the safety perception scales (5 categories) as the target variable and the same set of explanatory variables as predictors. The constructed tree for driver behaviour is given in figure 7-5. There are two types of nodes: splitting nodes (represented by hexagons) and terminal nodes (represented by quadrilaterals). Splitting nodes are nodes that can be further split to two child nodes. The root node is also a splitting node. Terminal nodes are nodes that cannot be further split into child nodes. Starting from the root node at the top of the tree with 5,238 observations, we can see that the splitting rule is based on whether a driver is in a hurry (HURRY = 0,1) with 1,746 cases (node 2) associated with a driver not in a hurry. The 1,746 cases at node 2 are further split based on the speed of other vehicles that potentially conflict with the driver (SPEED $\leq$ 32.5 km/h). There are 582 cases satisfying SPEED $\leq$ 32.5 kph. These cases are declared as terminal node 1. Terminal node 1 is classified as KG (Option 3: *Not Slow and Keep Going*). Its purity rate, defined as the cases successfully predicted amongst total cases at a terminal node, is 437/582 = 75.09%. We can control when a node is declared as a terminal node and thus control its purity rate by specifying a standard error (S.E.) in the classification tree model. If the standard error is small, a larger tree will be produced which will fit the learning sample better, but not necessarily perform well when a new data set is input for prediction purpose. There are 1,164 cases that do not satisfy SPEED ≤ 32.4 km/h, which are sent to node 3. The tree keeps growing from node 3 to other nodes. Other parts of the tree are partitioned in a binary manner until no further split is found. In total, there are 20 split nodes forming 21 terminal nodes.

Each explanatory variable in the classification tree is assigned a score based on its contribution to predicting the target variable. (The algorithm for calculating this score is quite involved and is computing extensive. Interested readers are referred to Breiman et al 1984 for a detailed discussion). A relative importance score on the scale from 0 (not important at all) to 100 (the most important variable) is a standard output of CART (Steinberg and Colla 1998). Relative importance scores for all 101 variables in explaining respondents' behavioural choice are given in table 7-12. The most important variable is SPEED. This is reasonable from the viewpoint of our own driving experience. Appropriate sight distances (CLEAR), size of the roundabout (ROUDM, ROUDL), respondent's approaching speed (MYSPD) and the size of other vehicles (VEHLG, VEHMD) also have important explanatory power. Twelve variables do not have any explanatory power at all. A further scrutiny of these 12 variables indicates that 8 of them (AGE20, PAGGR, METRO, LOTHE, DMFA5, TOVP5, WIDA5, LPROB) were not observed in the survey. That is, these variables have no variation in the data.

Relative importance scores in explaining a respondent's perception of safety are given in table 7-13. It is noticeable that those variables having important explanatory power for behavioural choice also have relatively important explanatory power for the safety perception rating, although the order of ranking is not exactly the same. This suggests that driving behaviour is closely related with the perception of safety. Those safety measures that modify the perception safety should have an influence on driving behaviour.

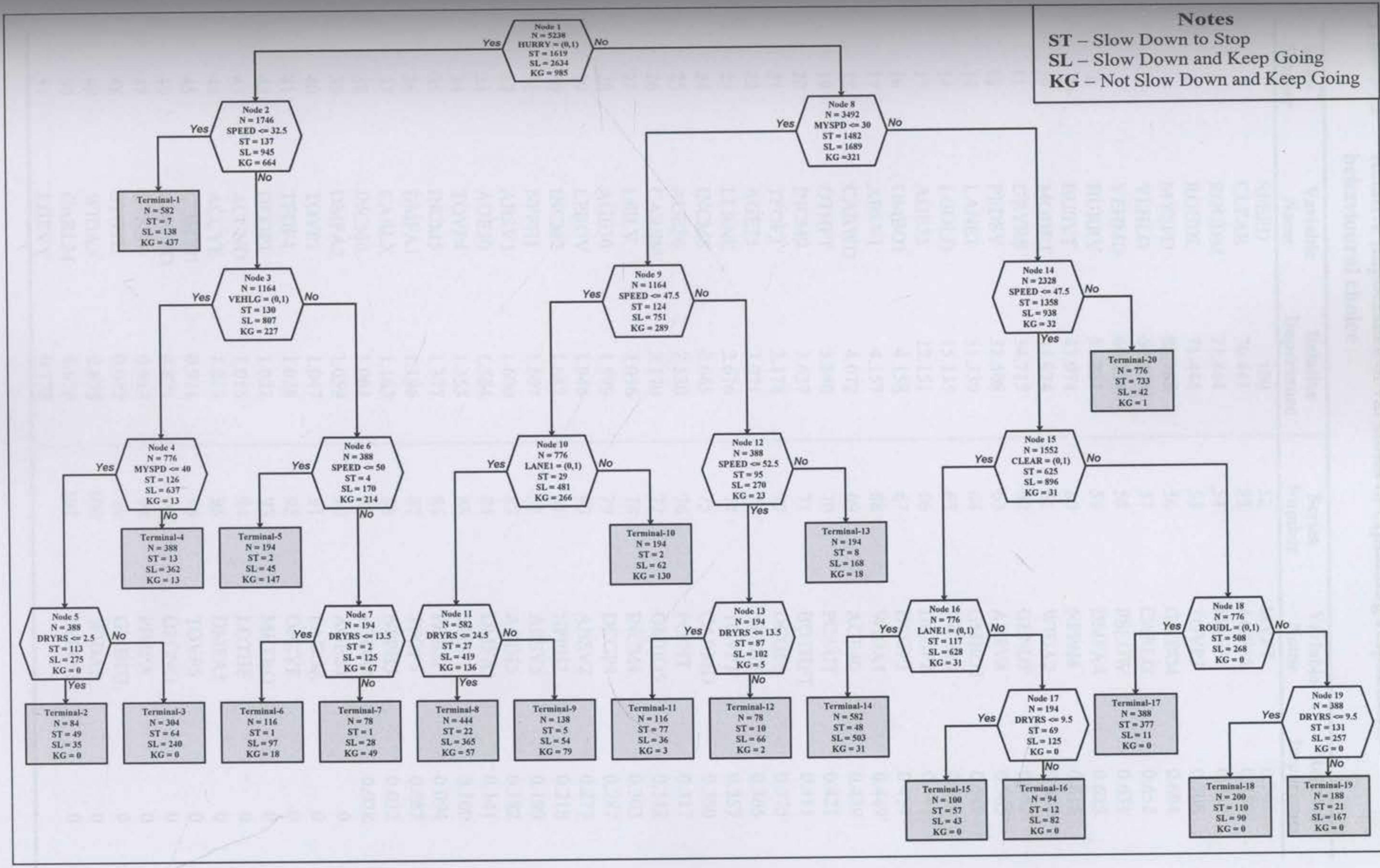


Figure 7-5 Classification tree of respondent behavioural choice

Table 7-12 Relative importance of variables in explaining respondents' behavioural choice

Series Number	Variable Name	Relative Importance	Series Number	Variable Name	Relative Importance
1	SPEED	100	52	MYFT	0.767
2	CLEAR	76.441	53	AGE35	0.750
3	ROUDM	71.444	54	TFOF1	0.747
4	ROUDL	71.444	55	TOVP3	0.708
5	MYSPD	68.785	56	GMBO4	0.694
6	VEHLG	60.204	57	CARLG	0.652
7	VEHMD	60.204	58	PSLOW	0.631
8	HURRY	55.231	59	DMFA4	0.625
9	BUSYT	43.974	60	NPPH4	0.615
10	MODET	43.974	61	WIDA2	0.607
11	DRYRS	34.713	62	GENDF	0.582
12	PEDSY	32.508	63	ABSV4	0.563
13	LANE1	31.339	64	GMBO2	0.549
14	LGOLD	15.135	65	INCM3	0.544
15	AGE55	12.151	66	DCGP2	0.461
16	GMBO1	4.158	67	DCGP3	0.459
17	ABSV1	4.157	68	WIDA1	0.449
18	CARWD	4.072	69	AGE40	0.439
19	OTHFT	3.880	70	PCAUT	0.421
20	INCM9	3.637	71	BOTHFT	0.411
21	TFOF3	3.178	72	DCGP5	0.375
22	AGE25	3.071	73	NPPH3	0.365
23	LLRNE	2.676	74	TOVP2	0.357
24	INCM8	2.665	75	CARMD	0.350
25	AGE56	2.530	76	POINT	0.317
26	CARSM	2.170	77	GMBO5	0.312
27	LSILV	2.036	78	INCM4	0.303
28	AGE30	1.999	79	DCGP4	0.287
29	LPROV	1.946	80	ABSV2	0.277
30	INCM2	1.682	81	NPPH2	0.218
31	NPPH1	1.607	82	ABSV5	0.199
32	ABSV3	1.600	83	AGE45	0.182
33	AGE50	1.584	84	DMFA3	0.141
34	TOVP4	1.355	85	TFOF2	0.100
35	INCM5	1.327	86	PHESI	0.094
36	DMFA1	1.196	87	TFOF5	0.082
37	CARLX	1.163	88	NPPH5	0.032
38	INCM6	1.063	89	WIDA4	0.028
39	DMFA2	1.059	90	AGE20	0
40	TOVP1	1.047	91	PAGGR	0
41	TFOF4	1.028	92	OFCYE	0
42	DCGP1	1.027	93	METRO	0
43	ACCNO	1.015	94	LOTHE	0
44	ACCYE	1.015	95	DMFA5	0
45	COMYE	0.971	96	TOVP5	0
46	COMNO	0.971	97	OFCNO	0
47	STNSW	0.912	98	PIMPA	0
48	STOTH	0.912	99	GMBO3	0
49	WIDA3	0.878	100	WIDA5	0
50	CARLM	0.818	101	LPROB	0
51	LHEVY	0.778			

Table 7-13 Relative importance of variables in explaining respondents' safety perception

Series Number	Variable Name	Relative Importance	Series Number	Variable Name	Relative Importance
1	SPEED	100	52	STNSW	1.811
2	BUSYT	77.549	53	STOTH	1.811
3	MODET	77.549	54	AGE35	1.747
4	ROUDM	66.229	55	CARLX	1.617
5	ROUDL	66.229	56	WIDA3	1.412
6	DRYRS	66.104	57	PCAUT	1.315
7	VEHLG	62.028	58	GENDF	1.256
8	VEHMD	62.028	59	CARMD	1.249
9	CLEAR	55.426	60	TFOF5	1.232
10	MYSPD	49.563	61	CARLG	1.171
11	LGOLD	45.464	62	DCGP2	1.167
12	PEDSY	38.483	63	TFOF4	1.164
13	HURRY	21.764	64	ABSV2	1.069
14	LANE1	20.619	65	DCGP3	1.026
15	AGE55	17.355	66	DMFA1	1.020
16	CARSM	14.863	67	TOVP4	1.018
17	GMBO1	13.598	68	CARLM	0.956
18	INCM8	11.541	69	ABSV4	0.912
19	LLRNE	10.304	70	TOVP2	0.901
20	INCM6	9.922	71	NPPH5	0.835
21	CARWD	9.112	72	GMBO3	0.797
22	AGE25	8.651	73	NPPH2	0.769
23	INCM2	8.112	74	LHEVY	0.749
24	ABSV1	7.991	75	TFOF1	0.699
25	LSILV	7.589	76	POINT	0.589
26	LPROV	6.959	77	NPPH3	0.521
27	INCM9	6.272	78	DMFA3	0.519
28	ABSV3	5.193	79	GMBO5	0.393
29	INCM3	5.159	80	MYFT	0.389
30	AGE30	5.051	81	AGE40	0.358
31	NPPH1	4.660	82	ABSV5	0.315
32	AGE56	4.011	83	INCM4	0.276
33	WIDA2	3.988	84	TFOF2	0.272
34	INCM5	3.976	85	DCGP5	0.268
35	COMYE	3.908	86	DMFA2	0.243
36	COMNO	3.908	87	PHESI	0.221
37	WIDA4	3.296	88	PIMPA	0.219
38	TOVP1	3.186	89	OFCYE	0.133
39	OTHFT	2.840	90	OFCNO	0.133
40	GMBO4	2.726	91	DCGP4	0.127
41	TOVP3	2.435	92	PSLOW	0.061
42	GMBO2	2.358	93	AGE45	0.046
43	WIDA1	2.357	94	LOTHE	0
44	ACCYE	2.158	95	METRO	0
45	ACCNO	2.158	96	PAGGR	0
46	NPPH4	2.018	97	AGE20	0
47	DCGP1	1.997	98	DMFA5	0
48	AGE50	1.990	99	WIDA5	0
49	TFOF3	1.857	100	TOVP5	0
50	BOTHFT	1.837	101	LPROB	0
51	DMFA4	1.824			

7.6 Summary

In this chapter, we processed the data obtained from the survey. We firstly checked the completeness and the validity for all responses. We coded the attributes and respondents' socio-economic variables. We briefly described respondents' socio-economic characteristics. We investigated how respondents assign time and attention when conducting the survey by examining the time that respondents spent on each evaluation situation and the number of clicks that respondents made to read the detailed information provided in interactive windows. We investigated the relative importance of variables in explaining the perception of the safety and the behavioural response. In the next chapter, we will employ a statistical procedure to test the preference equality and response consistency due to the two survey formats and due to two waves of the survey.

Chapter Eight

Effects of the Repeated Survey and Survey Format: Tests of Preference Equality and Choice Consistency

In the chapter six, we detailed the development and implementation of the survey method. The survey was conducted in two waves of interviews using two survey formats. In this chapter, we use a statistical procedure to test the effects of the repeated survey and the two survey formats. Specifically, we test whether data sets obtained in the first and the second round of the survey are statistically equal; whether response consistency has been improved in the second round of the survey. This test is important in understanding response behaviour. One of challenges in designing a survey instrument is to elicit individual preferences and reduce response bias. Response equality can be tested if there are common attributes between data sets. Response consistency between data sets can be compared by estimating the response variances. The smaller the variance, the more consistent the response. As most SP experiments involve a set of choice sets evaluated at one point of time, the ability through a repeated survey to assess the nature of choice consistency is a useful exercise. We also test whether data sets obtained in two survey formats are equal; whether response consistency evaluated with *Picture and Word* format is greater than that with *Picture Only* format. Four hypothesis (*Hypothesis 1-4*) in association with testing the preference equality and response consistency were presented in chapter two.

We use a total of eight different data sets as described in table 8-1, each distinguished by a respondent group, a survey format and a survey wave. These eight data sets are designed to explain the same phenomenon: driver's behavioural choices when facing a specific road and traffic environment scenario. Response variability can arise for many reasons, but of particular interest herein are: variability due to the heterogeneity of respondents; variability due to the repeated survey and variability due to two survey formats. If all data sets are pooled together and these sources of variability are present, they will be confounded. The general structure of potential difference between any two data sets is given in table 8-2.

Table 8-1 A description of eight data sets

Respondent Group: Sample Size	Wave 1 (First Interview) Data set : Survey Format	Wave 2 (Second Interview) Data set : Survey Format
Group A : 25	A1: Picture & Word	A2: Picture & Word
Group B : 24	B1: Picture & Word	B2: Picture Only
Group C : 25	C1: Picture Only	C2: Picture Only
Group D : 23	D1: Picture Only	D2: Picture & Word

Table 8-2 The sources of variability between pairs of data sets

	Data	A1	B1	C1	D1	A2	B2	C2	D2
Wave 1	A1	—							
	B1	G	—						
	C1	F,G	F,G	—					
	D1	F,G	F,G	G	—				
Wave 2	A2	R	R,G	F,R,G	F,R,G	—			
	B2	F,R,G	F,R	R,G	R,G	F,G	—		
	C2	F,R,G	F,R,G	R	R,G	F,G	G	—	
	D2	R,G	R,G	F,R,G	F,R	G	F,G	F,G	—

Variability due to: G – Respondent Group R – Repeated Survey F – Survey Format

This chapter is organised as follows. The following section discusses the statistical procedure used to test the preference equality and response consistency between the data sets. In section 8.2, we present the test results for the repeated survey. The effects of survey formats are tested in section 8.2 and general conclusions are drawn in the last section.

8.1 The Statistical Procedure for Testing the Equality and Choice Consistency between Data Sets

8.1.1 The Theoretical Framework for Testing the Equality of Two Data Sets

The theoretical foundation for modelling individual discrete choice behaviour is random utility theory. It is assumed that an individual compares a set of mutually exclusive alternatives and choose one alternative that produces the highest utility. We therefore choose the random utility theory as a framework to compare the equality and the response consistency between data sets. Equality of data sets is comparable only if there are common attributes amongst all data sets. Suppose we have two data sets, S1 and S2, the utility underlying the choice process of two data sets is (Louviere et al 2000):

$$U_i^{S1} = \alpha_i^{S1} + \beta^{S1} X_i^{S1} + \omega Z_i + \varepsilon_i^{S1}, \quad \forall_i \in C^{S1}$$
$$U_i^{S2} = \alpha_i^{S2} + \beta^{S2} X_i^{S2} + \delta W_i + \varepsilon_i^{S2}, \quad \forall_i \in C^{S2} \tag{8-1}$$

where i is an alternative in a choice sets C, the α's are alternative-specific constants, the X's are attributes common to S1 and S2, the β's are utility parameters for the common attributes, and ω and δ are utility parameters for the unique attributes Z's and W's in data sets S1 and S2 respectively. If we assume that ε's are Independently and Identically Distributed (IID) extreme value type I (EVI), the simple multinomial logit model (MNL) can be derived. (See Hensher and Johnson 1981, Ben-Akiva and Lerman 1985). The MNL model defines the probability that an individual will choose alternative i from choice sets C as follows:

$$P_i^{S1} = \frac{\exp[\lambda^{S1}(\alpha_i^{S1} + \beta^{S1} X_i^{S1} + \omega Z_i)]}{\sum_{j \in C^{S1}} \exp[\lambda^{S1}(\alpha_i^{S1} + \beta^{S1} X_i^{S1} + \omega Z_i)]}$$

$$P_i^{S2} = \frac{\exp[\lambda^{S2}(\alpha_i^{S2} + \beta^{S2} X_i^{S2} + \delta W_i)]}{\sum_{j \in C^{S2}} \exp[\lambda^{S2}(\alpha_i^{S2} + \beta^{S2} X_i^{S2} + \delta W_i)]} \tag{8-2}$$

where the λ's are scale parameters unique to data sets S1 and S2. The scale parameter is inversely related to the variance of the error term for all alternatives and all individuals such that:

$$\lambda^2 = \frac{\pi^2}{6\sigma_\varepsilon^2} \tag{8-3}$$

where σ_ε^2 is the variance of the error distribution. Recognition of the role of the scale parameter in the estimation and interpretation of choice models was fostered by the desire to combine stated preference (SP) and revealed preference data (Hensher et al 1999, Louviere and Hensher 2000). The larger the scale, the smaller the variance. When λ is zero, the MNL model will predict equal probabilities among all alternatives (no predictive power). As λ increases from zero, the model performs better and better. When a scale parameter becomes infinitely large, the model would differentiate among all alternatives (perfectly predictive power). As the scale parameter is inversely related of the scale parameter (Swait and Louviere 1993). The inefficient estimate might be a problem because the standard errors are likely to be underestimated, leading to inflated *t*-statistics. Although the manual method is simple in concept and ease of implementation, we prefer an efficient estimator to identify the relative scale parameter.

An efficient method using an artificial tree structure for specifying nested logit model was proposed by Hensher and Bradley (1993) and Bradley and Daly (1994) to obtain an estimate of the relative scale parameter and utility parameters simultaneously, using the Full Information Maximum Likelihood (FIML) estimation method. Such a tree is shown in figure 8-1, assuming each of S1 and S2 has three alternatives. In the nested logit model, the systematic utility of all alternatives in a sub-nest of the tree is multiplied by the inverse of the *inclusive value* (IV). Readers are referred to Louviere et at (2000) for a detailed discussion of the nested logit model and the calculation of the inclusive value. If we assume that the inclusive values associated with all S2 alternatives are equal, and normalise the S1 inclusive value parameter to one, we can identify and estimate the variance and hence the scale parameter of the S2 data set relative to the S1 data set. In the artificial tree shown in figure 8-1, we set IV parameters in sub-nest S1 to one, and set $IV_{S2Alt1}=IV_{S2Alt2}=IV_{S2Alt3}$. The artificial tree approach for estimating the scale parameter can be easily generalised. For example, we can extend the artificial tree to combine multiple data sources, or estimate the variance of each alternative, simply by manipulating the tree structure and setting IV parameters to be constrained or unconstrained.

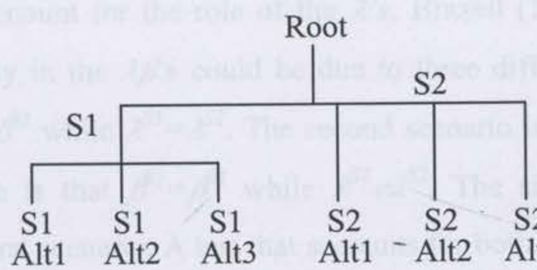


Figure 8-1 Artificial tree structure for identifying relative scale parameter

8.1.3 The Statistical Procedures for Testing Data Equality

Because the scale parameter and utility parameters are confounded, a procedure that examines the equality between data sets must test the equality of the multiplication form of them. Taking equation 8-2, we must test whether $\lambda^{S1}\beta^{S1}=\lambda^{S2}\beta^{S2}$.

to the variance of the error term, it is an ideal parameter for representing choice consistency (Brazell 1999). Equation (8-2) indicates that an equality restriction on common attributes in two data sets means $\lambda^{S1}\beta^{S1}=\lambda^{S2}\beta^{S2}$. At this point, it is appropriate to have a formal definition for *preference equality* and *response consistency* of data sets.

- *Preference equality*: If two or more data sets are statistically equal, the products of the scale parameter and utility parameter for a common attribute are equal in the statistical sense, i.e. $\lambda^{S1}\beta^{S1}=\lambda^{S2}\beta^{S2}$.
- *Response consistency*: The response consistency is represented by the scale parameter λ. The larger the scale parameter, the more consistent the response.

8.1.2 The Methods of Estimating the Scale Parameter

To investigate equality of two data sets, the scale parameter must be identified. However, in an MNL specification of IID, it is not possible to identify a scale parameter within a particular data source, because it is inseparable to the utility parameters in a multiplicative form $(\lambda\beta)$. This requires us to normalise the scale parameter of one data set to one ($\lambda^{S1}=1$), and estimate the relative scale parameter between two data sets ($\lambda = \lambda^{S2}/\lambda^{S1} = \lambda^{S2}$).

Swait and Louviere (1993) proposed a manual method for estimating the relative scale parameter. It involves manually searching across a predefined range of λ values to identify a scale parameter that maximises log likelihood (*LL*) of the MNL model for pooled data sets conditional on the relative scale. A range of λ values is firstly defined within which the log likelihood is expected to be maximised. The lower bound of the range should be larger than 0, and the upper bound must be larger than lower bound. As a rule of thumb, Louviere et al (2000) proposed that λ tends to be in the range $0<\lambda<3$. In any particular pooled data set, it is easy to find an upper bound by trial and error. Starting with a lower bound relative scale (e.g. $\lambda_1 = 0.1$), we estimate the LL_1 with pooled data sets where all rows in data set S2 are multiplied with the relative parameter λ_1. We can try progressively larger values of λ in the defined range using fixed increment grid or Golden Section search. Because the *LL* is concave, there is a unique solution. The value of λ that maximises the *LL* is a consistent but inefficient estimator

Traditionally, researchers would perform a Chow test by computing the likelihood ratio (Brazell 1999). If we denote LL_{S1} and LL_{S2} as the log likelihood of the MNL model for data sets S1 and S2 respectively, the test statistic is $LLR = -2(LL_{S1}-LL_{S2})$, asymptotically χ^2 distributed with 1 degree of freedom. A simple likelihood ratio test accounts for the equality of $\beta^{S1}=\beta^{S2}$, but would fail to account for the role of the λ's. Brazell (1999) demonstrated that the observed inequality in the $\lambda\beta$'s could be due to three different scenarios. The first scenario is that $\beta^{S1}\neq\beta^{S2}$ while $\lambda^{S1}=\lambda^{S2}$. The second scenario is that $\beta^{S1}\neq\beta^{S2}$ and $\lambda^{S1}\neq\lambda^{S2}$. The third scenario is that $\beta^{S1}=\beta^{S2}$ while $\lambda^{S1}\neq\lambda^{S2}$. The simple likelihood test can only account for the first scenario. A test that accounts for both scale and utility parameters was suggested by Swait and Louviere (1993). The null hypothesis of the test is:

$$H_1:\ \beta^{S1}=\beta^{S2} \text{ and } \lambda^{S1}=\lambda^{S2} \qquad (8\text{-}4)$$

They used a two-stage testing procedure. The first stage is to determine whether the β vectors are equal while permitting the scale parameters to differ between data sets, i.e.,

$$H_{1A}:\ \beta^{S1}=\beta^{S2}=\beta \qquad (8\text{-}5)$$

The hypothesis can be tested using the LLR test. The test statistic is,

$$\chi^2_{\alpha,K} = -2[LL_\lambda - (LL_{S1} + LL_{S2})] \qquad (8\text{-}6)$$

where α is the significance level and K is the degrees of freedom, equal to the difference of the sum of parameters of separate models and the number of parameters of a joint model. LL_λ is the log likelihood of the joint model using λ as the relative scale parameter, where λ is estimated using manual method (or FIML method as well). The LL_{S1} and LL_{S2} have been defined previously. If H_{1A} is rejected, H_1 is also rejected. If H_{1A} is retained, we can proceed to the second stage of the hypothesis test to determine if the scale parameters between two data sets are equal. Formally,

$$H_{1B}:\ \lambda^{S1}=\lambda^{S2}=\lambda \qquad (8\text{-}7)$$

The LLR statistic for the hypothesis H_{1B} is:

$$\chi^2_{\alpha,K} = -2[LL_P - LL_R] \tag{8-8}$$

where LL_P is the log likelihood of the simple pooled model with the scale parameters not allowed to differ between two data sets (i.e. naïve pooling). The degree of freedom K is equal to the number of scale parameters estimated in the joint model, (equal to 1 when there are two data sets). The null hypothesis is retained only if both H_{1A} and H_{1B} are retained.

The hypothesis test was implemented by Swait and Louviere in two stages mainly because the technique and commercial software used to simultaneously estimate of the relative scale parameter as well as utility parameters were not available at the time when this test procedure was developed. The procedure can be simplified because we can use the nested logit trick to simultaneously estimate the scale and utility parameters using FIML estimator. Limdep (Econometric Software 2000) permits one to specify the tree structure for multiple data sets, and estimate the *N-1* relative scale parameters and utility parameters of common and data set-specific attributes simultaneously for combining N data sets. The simplified test procedure was introduced in Louviere et al (2000).

(1) Estimate separate MNL models for each data set S1 and S2 as given in equation 8-2. This yields a vector of utility parameters $\lambda^{S1}\alpha^{S1}$, $\lambda^{S1}\beta^{S1}$ and $\lambda^{S1}\omega^{S1}$ with log likelihood function LL^{S1} and number of parameters K^{S1} for data set S1, and a vector of utility parameters $\lambda^{S2}\alpha^{S2}$, $\lambda^{S2}\beta^{S2}$ and $\lambda^{S2}\delta^{S2}$ with log likelihood function LL^{S2} and number of parameters K^{S2} for data set S2.

(2) Estimate the joint MNL model from the pooled data set. This produces a vector of utility parameters α^{S1}, β^{Joint}, ω^{S1}, α^{S2} and δ^{S2} and a relative scale parameter λ simultaneously with the joint log likelihood LL^{Joint}. The number of parameters of the joint model is equal to $(K^{S1}+K^{S2}+1-K^{\beta})$, where K^{β} is the number of common utility parameters between data sets S1 and S2.

(3) Calculate the χ^2 statistic for the hypothesis that the common utility parameters (β^{Joint}) are equal as follows:

$$\chi^2_{\alpha,K} = -2[LL^{Joint} - (LL^{S1} + LL^{S2})] \tag{8-9}$$

The degrees of freedom K is equal to the difference of the sum of parameters of separate models $(K^{S1}+K^{S2})$ and the number of parameters of the joint model $(K^{S1}+K^{S2}+1-K^{\beta})$, which is equal to $(K^{\beta}-1)$.

As previously discussed, this simplified test procedure can be extended to multiple data sets by manipulating the artificial tree structure and the set of IV parameters. We will use this procedure to test our hypotheses 1-4 as proposed in chapter two.

8.2 The Effect of a Repeated Survey

The equality of data sets obtained in the original and repeated surveys can be tested using data sets A1 vs A2 and C1 vs C2, where all context conditions are exactly the same. To test the equality of two data sets, one needs to specify three models: two separate MNL models for each data set and one nested MNL model for the joint data. We firstly test the equality of data sets A1 and A2.

Model A1 and A2: The MNL models for data sets A1 and A2. Each sampled respondent evaluates a traffic setting on an approach to a roundabout and responds by choosing one of the three alternatives: *Slow Down to Stop (ST)*, *Slow Down and Keep Going (SL)* and *Not Slow Down and Keep Going (KG)*. There are three utility functions involving two alternative specific constants (ASC's) and 12 attributes. In addition, 8 driver socio-economic variables are entered into utility functions.

Joint Model A1 & A2: The nested logit (NL) model for the data pooled from A1 and A2. The artificial tree structure is constructed to identify the relative scale parameter (see figure 8-1). The inclusive value in data set A1 is normalised to one, and the inclusive values for three alternatives in data set A2 are set equal. Under this manipulation of the data sets, we can estimate the relative scale parameter $\lambda=\lambda_{A2}/\lambda_{A1}$. The parameters for the 12 attributes are restricted to be equal between the two data sets, while ASC's and parameters for the driver's socio-economic variables are allowed to be unique to each data set.

Table 8-3 Estimates for individual MNL models and joint NL model, test of the equality of data sets: A1 & A2

Variables	Definition	Coefficient	t-Ratio	Coefficient	t-Ratio	Coefficient	t-Ratio
	Model	MNL A1		MNL A2		Joint Nested Logit	
	Attributes common to all models						
ROUDL	Large-sized roundabout	0.2629	1.829	0.2848	1.949	0.2253	2.642
ROUDM	Medium-sized roundabout	-0.3219	-2.596	-0.6527	-4.372	-0.4054	-4.930
LANE1	Single lane	0.1879	1.819	0.2749	2.271	0.1824	2.762
CLEAR	Clear visibility	1.0811	9.804	1.3990	9.982	1.0142	10.951
VEHLG	Large-sized vehicle	1.2516	7.632	1.0524	6.577	0.9203	8.168
VEHMD	Medium-sized vehicle	-0.1605	-1.171	-0.2319	-1.478	-0.1711	-1.972
SPEED	Speed of conflicting vehicle	0.0441	5.317	0.0643	7.470	0.0453	8.091
BUSYT	Busy traffic at roundabout	0.5442	3.470	0.7655	4.708	0.5503	5.612
MODET	Moderate traffic at roundabout	-0.1554	-1.255	-0.1980	-1.372	-0.1359	-1.733
PEDSY	Presence a pedestrian	0.7310	4.624	0.9169	5.399	0.6861	6.640
MYSPD	Speed of respondent's car	0.0174	2.405	0.0138	1.814	0.0127	2.861
HURRY	Respondent is in a hurry	1.0660	8.239	2.2199	9.088	1.2821	11.514
	Socio-economic variables unique to MNL A1						
A_A1ST	ASC for alt 1: slow down to stop	-1.8145	-3.427			-1.9364	-4.535
A_A1SL	ASC for alt 2: slow down and keep going	-1.2128	-2.653			-1.1838	-3.604
GENDF1	Female	0.7318	2.883			0.6999	2.820
DRYRS1	Years of driving experience	0.0234	1.860			0.0238	1.875
ILOW1	Low personal income	0.3226	1.143			0.3039	1.099
IHIGH1	High personal income	-0.4395	-1.576			-0.4463	-1.588
PCAUT1	A very cautious driver	0.1128	0.497			0.1081	0.488
COMYE1	Commuter driver	-0.1128	-0.639			-0.1145	-0.649
AGEY1	Young driver	0.2830	0.661			0.2766	0.657
AGEM1	Medium-aged driver	-0.4011	-1.654			-0.4078	-1.668

Table 8-3 **Estimates for individual MNL models and joint NL model, test of the equality of data sets: A1 & A2 (continued)**

Variables	Definition	Coefficient	t-Ratio	Coefficient	t-Ratio	Coefficient	t-Ratio
	Model	MNL A1		MNL A2		Joint Nested Logit	
		Socio-economic variables unique to MNL A2					
A_A2ST	ASC for alt 1: slow down to stop			-2.8277	-4.944	-1.8104	-4.921
A_A2SL	ASC for alt 2: slow down and keep going			-1.7199	-3.725	-1.2548	-4.273
GENDF2	Female			0.5639	2.199	0.4106	2.198
DRYRS2	Years of driving experience			0.0349	2.392	0.0238	2.329
ILOW2	Low personal income			0.6051	2.094	0.4423	2.105
IHIGH2	High personal income			0.1424	0.425	0.0974	0.416
PCAUT2	A very cautious driver			0.1392	0.605	0.1015	0.613
COMYE2	Commuter driver			-0.0421	-0.222	-0.0290	-0.216
AGEY2	Young driver			0.0672	0.154	0.0505	0.162
AGEM2	Medium-aged driver			-0.0478	-0.172	-0.0344	-0.178
		Model parameters					
	LL		-529.5949		-451.7961		-991.1358
	#Parameters		22		22		33
		Scales and variances					
	Data Sets	λ	$\sigma^2 = \pi^2/6\lambda^2$	S.E.	t-Ratio	P	
	A1	1.0000	1.6449	fixed	fixed	fixed	
	A2	1.4095	0.8280	0.1413	9.976	0.000	
		LLR Test					
	LLR: $-2(LL_j-LL_i)$		df	$\chi^2(0.05,df)$	P		
	19.4896		11	19.6752	0.0529		

Table 8-4 Estimates for individual MNL models and joint NL model, test of the equality of data sets: C1 & C2

Variables	Definition	Coefficient	t-Ratio	Coefficient	t-Ratio	Coefficient	t-Ratio
	Model	MNL C1		MNL C2		Joint Nested Logit	
	Attributes common to all models						
ROUDL	Large-sized roundabout	0.2845	2.068	0.4973	3.140	0.3668	3.763
ROUDM	Medium-sized roundabout	-0.6667	-4.722	-0.8730	-5.467	-0.7110	-6.842
LANE1	Single lane	0.2379	2.095	0.1232	0.982	0.1679	2.121
CLEAR	Clear visibility	1.2993	10.464	1.5988	10.780	1.3422	12.165
VEHLG	Large-sized vehicle	1.2930	8.115	1.0669	6.489	1.1058	9.094
VEHMD	Medium-sized vehicle	-0.1634	-1.063	-0.0668	-0.412	-0.1065	-1.022
SPEED	Speed of conflicting vehicle	0.0462	5.711	0.0607	6.764	0.0494	8.240
BUSYT	Busy traffic at roundabout	0.7168	4.624	0.5973	3.571	0.6052	5.525
MODET	Moderate traffic at roundabout	-0.2091	-1.533	-0.2616	-1.793	-0.2147	-2.306
PEDSY	Presence a pedestrian	0.7485	4.776	0.6556	4.115	0.6655	6.122
MYSPD	Speed of respondent's car	0.0272	3.785	-0.0080	-1.004	0.0096	1.900
HURRY	Respondent is in a hurry	1.2904	8.491	2.2155	9.433	1.5715	11.647
	Socio-economic variables unique to MNL C1						
A_C1ST	ASC for alt 1: slow down to stop	-1.6699	-2.860			-1.4469	-2.789
A_C1SL	ASC for alt 2: slow down and keep going	-1.1552	-2.460			-0.7480	-1.987
GENDF1	Female	-0.0581	-0.240			-0.0539	-0.228
DRYRS1	Years of driving experience	0.0185	1.584			0.0189	1.603
ILOW1	Low personal income	0.0231	0.092			0.0127	0.052
IHIGH1	High personal income	0.6563	2.228			0.6724	2.254
PCAUT1	A very cautious driver	0.1245	0.467			0.1206	0.463
COMYE1	Commuter driver	-0.2262	-1.149			-0.2249	-1.141
AGEY1	Young driver	-0.5082	-0.898			-0.4882	-0.889
AGEM1	Medium-aged driver	0.1247	0.388			0.1268	0.390

Table 8-4 Estimates for individual MNL models and joint NL model, test of the equality of data sets: C1 & C2 (continued)

Variables	Definition	Coefficient	t-Ratio	Coefficient	t-Ratio	Coefficient	t-Ratio
	Model	MNL A1		MNL A2		Joint Nested Logit	
	Socio-economic variables unique to MNL C2						
A_C2ST	ASC for alt 1: slow down to stop			-0.9765	-1.552	-0.9730	-2.043
A_C2SL	ASC for alt 2: slow down and keep going			-0.3016	-0.608	-0.6312	-1.778
GENDF2	Female			-0.0144	-0.055	-0.0170	-0.074
DRYRS2	Years of driving experience			0.0424	3.242	0.0355	3.132
ILOW2	Low personal income			0.8733	3.011	0.7818	2.947
IHIGH2	High personal income			0.1663	0.534	0.1376	0.514
PCAUT2	A very cautious driver			-0.5966	-2.042	-0.5393	-2.046
COMYE2	Commuter driver			0.2040	0.981	0.1741	0.961
AGEY2	Young driver			0.0226	0.035	0.0328	0.057
AGEM2	Medium-aged driver			0.4451	1.287	0.3739	1.254
	Model parameters						
	LL		-498.2643		-434.2850		-946.3896
	#Parameters		22		22		33
	Scales and variances						
	Data Sets	λ	$\sigma^2 = \pi^2/6\lambda^2$	S.E.	t-Ratio	P	
	C1	1.0000	1.6449	fixed	fixed	fixed	
	C2	1.1352	1.2764	0.1111	10.215	0.000	
	LLR Test						
	LLR: $-2(LL_j-LL_i)$		df	$\chi^2(0.05,df)$	P		
	27.6806		11	19.6752	0.0036		

The estimation results for the individual and joint models as well as the LLR test are summarised in table 8-3. The relative scale parameter is 1.4095, suggesting that the variance in data set A2 is much smaller. The LLR statistic is 19.4896. The χ^2 critical value for the $\alpha=0.05$ significance level with 11 degrees of freedom is 19.6752, which suggests that we should retain the null hypothesis of parameter homogeneity for the common attributes.

Although the hypothesis is retained, we see that the LLR statistic is quite close to the χ^2 critical value. This motivates us to test another pair of data sets: C1 vs C2. All context conditions between C1 and C2 are the same. The same test procedure was used. The estimation results and LLR test are summarised in table 8-4. Again, the variance in the repeated survey has decreased. However, the LLR test suggests that the hypothesis of parameter homogeneity of common attributes between two data sets is rejected.

To investigate the reasons for the rejection of the null hypothesis, we graphed the common parameters for the MNL models, as shown in figure 8-2. The line represents the scale parameter, which always passes through the origin point and is located in the quadrants I and III. Each point represents one common attribute with an X value equal to the parameter from data set C1 and a Y value equal to the parameter from data set C2. Most parameter points are around the scale line. The distance between each parameter point and the scale line represents the utility changes in the repeated survey relative to the original survey. The closer an attribute point is to the scale line, the smaller the utility changes. It is worth noting that parameter points in quadrants I, II, III and IV should be interpreted differently.

Quadrant I: The parameter of an attribute in both the MNL C1 and MNL C2 models is positive. If the parameter point is above the scale line, the associated attribute has a stronger effect in data set C2 than in data set C1. On the other hand, if the parameter point is beneath the scale line, the associated attribute has a weaker effect in data set C2 than in data set C1. In the second round of the survey, attributes HURRY, CLEAR and ROUDL have greater positive effects while VEHLG, PEDSY, BUSYT and LANE1 have less positive effects on a driver' decision whether to stop, slow down or keep going.

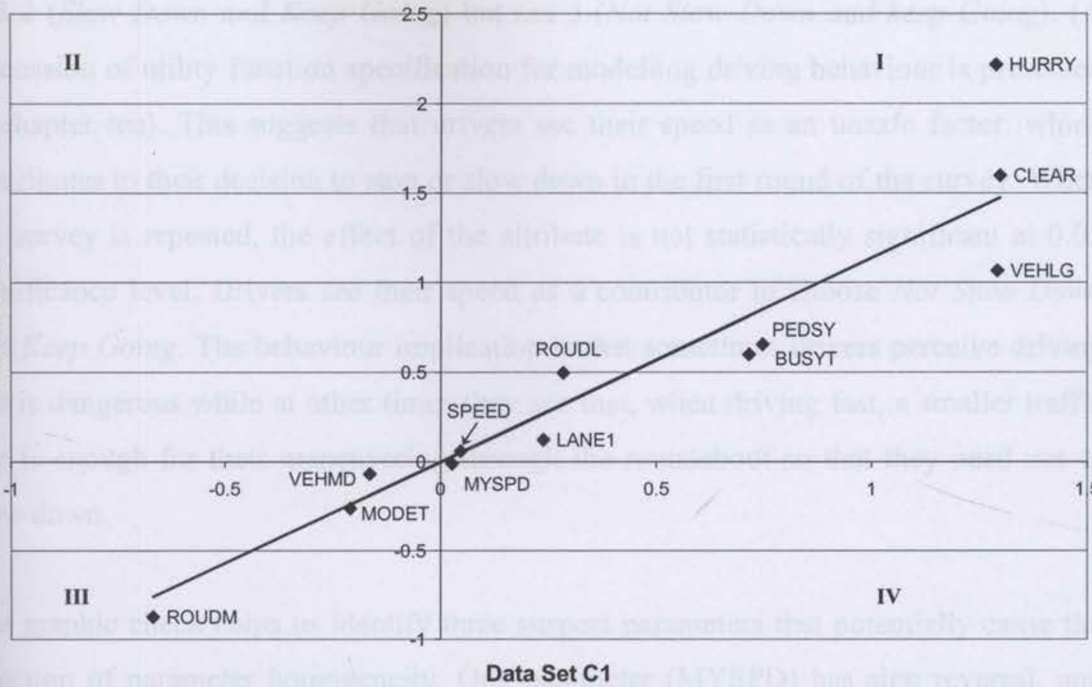


Figure 8-2 Common parameter comparison between MNL model C1 and C2

Quadrant II: The parameter of an attribute in data set C1 is negative while in data set C2 it is positive. The sign incomparability in the two data sets indicates that the effect of the associated attribute on driving behaviour has been reversed. There is no parameter point observed in quadrant II.

Quadrant III: The parameter of an attribute in both the MNL C1 and MNL C2 is negative. If the parameter point is above the scale line, the associated attribute has a weaker negative effect in data set C2 than in data set C1. On the other hand, if the parameter point is beneath the scale line, the associated attribute has a stronger negative effect in data set C2 than in data set C1. In the second round of the survey, the attribute VEHMD has a less negative effect while ROUDM has a more negative effect on driver's behavioural response.

Quadrant IV: The parameter of an attribute in data set C1 is positive while in data set C2 it is negative. MYSPD is the only attribute exhibiting the sign reversal between the two data sets. (MYSPD represents the speed of respondent's car when approaching the roundabout). MYSPD enters the utility function of alternative 1 (*Slow Down to Stop*) and 2 (*Slow Down and Keep Going*) but not 3 (*Not Slow Down and keep Going*). (A discussion of utility function specification for modelling driving behaviour is presented in chapter ten). This suggests that drivers see their speed as an unsafe factor, which contributes to their decision to stop or slow down in the first round of the survey. When the survey is repeated, the effect of the attribute is not statistically significant at 0.05 significance level. Drivers see their speed as a contributor to choose *Not Slow Down and Keep Going*. The behaviour implication is that sometimes drivers perceive driving fast is dangerous while at other times they see that, when driving fast, a smaller traffic gap is enough for their maneuvering through the roundabout so that they need not to slow down.

The graphic check helps us identify three suspect parameters that potentially cause the rejection of parameter homogeneity. One parameter (MYSPD) has sign reversal, and two (HURRY and VEHLG) have a large utility shift in the two data sets. To investigate this possibility, we re-estimated the NL model that allows three parameters to be data set-specific. The LLR test result is given in table 8-5, which suggests we should retain the assumption of parameter homogeneity in the remaining nine attributes at the 0.05 significance level.

Table 8-5 Retest the equality of data sets: C1 & C2

Model	MNL C1	MNL C2	Joint Nested Logit
		Model parameters	
Log likelihood	-498.2643	-434.2850	-934.2981
No. of Parameters	22	22	36
		LLR Test	
LLR: $-2(LL_j-LL_i)$	df	$\chi^2(0.05,df)$	P
3.4976	8	15.5073	0.8994

8.4 Testing the Effect of Survey Format

The hypotheses in association with two survey formats can be tested on a number of pairs of data as long as the survey formats are different in the two data sets. Referring to table 8-1, if we use A1 as base case (Picture and Word format), we can select one data set from B2, C1, C2 and D1 as the comparison case. Table 8-2 makes it clear that variability of A1 and B2 is resulted from the confounded effects from three sources:

respondent group, repeated survey and survey format. In the same manner, the variability between A1 and C1, between A1 and C2 and between A1 and D1 is confounded with two or three effects. The objective is to select these data sets so that we can untangle the confoundment to test the effects of survey format only.

The first step is to differentiate the effect of a repeated survey. This is straightforward by choose two data sets from the same survey round. Referring to table 8-1 again, if we use the Picture and Word format as the base case, there are eight pairs of data sets from same round of the survey and with different survey format: A1 vs C1, A1 vs D1, B1 vs C1, B1 vs D1, A2 vs B2, A2 vs C2, D2 vs B2 and D2 vs C2.

The variability between any pair of above mentioned data sets is confounded with two effects: respondent group and survey format. To test the effect of survey format, we have to conduct a formal statistical test to untangle the effect of respondent group. Because respondents were assigned into four groups in a random manner, we expect choice variability between respondent groups are not significant, (given the sample size is large). Table 8-6 sets out the general considerations for testing heterogeneity among respondent groups. The choice consistency between Group A and B is testable through data sets A1 and B1. All conditions between two data sets are exactly same except that the survey was conducted with different respondent groups. (I.e., survey format between A1 and B1 is the same and they were conducted in the same round of the survey, the only difference is that they are conducted by respondent group A and B respectively, refer to table 8-1). Similar, the choice consistency between Group B and C, between Group C and D as well as between Group A and D is also testable. However, the choice consistency between Group A and C is not testable. As shown in table 8-1, the difference between A1 and C1 as well as between A2 and C2 is confounded with the effect of group heterogeneity and the effect of survey format. Similarly, the choice consistency between Group B and D is not testable. Strictly speaking, the choice consistency is not transferable, because of the possible error accumulation. For example, even if we demonstrate that choice consistency between Group A and B is same and between B and C is so, we still cannot say that choice consistency between A and C is same.

Table 8-6 Test homogeneity between respondent groups

Survey Group	Group A	Group B	Group C	Group D
Group A	—			
Group B	A=B? Testable (A1vs B1)	—		
Group C	A=C? Not-testable	B=C? Testable (B2 vs C2)	—	
Group D	A=D? Testable (A2 vs D2)	B=D? Not-testable	C=D? Testable (C1 vs D1)	—

We now test the effect of group heterogeneity through four pairs of data sets: A1 vs B1, B2 vs C2, C1 vs D1 and A2 vs D2. The procedure described in section 8-2 and implemented in section 8-3 for testing the effect of repeated survey is again used. The test results are summarised in table 8-7. In testing the equality between A1 and B1, we specified two individual MNL models, each for data set A1 and B1, and one NL model for the joint data set. Log likelihood for the MNL A1 is –529.5959, with 22 parameters. Log likelihood for the MNL B1 is –484.0952, with 22 parameters. Log likelihood for joint NL model is –1024.2060, with 33 parameters. Based on these parameters, an LLR test was conducted. The LLR statistic is 1.0298. The χ^2 critical value at the α=0.05 significance level with 11 degrees of freedom is 19.6752, suggesting that we should retain the null hypothesis of parameter homogeneity for the common attributes. The relative scale parameter between B1 and A1 was also estimated from the NL model, equal to 1.1405. Test results for other three pairs of data sets are interpreted in similar manner. In summary, the hypothesis of parameter homogeneity for all four pairs of data sets is retained. The scale parameter of Group B to A is larger than 1, indicating that response variance in Group B is smaller than in Group A. Other relative scale parameters are smaller than 1, suggesting the variance in data sets on comparison is larger than the base case.

After the parameter homogeneity among respondent groups is tested, four pairs of data sets can be identified appropriate to test the effect of survey format: A2 vs B2, B1 vs C1, D2 vs C2 and A1 vs D1. The difference in choice consistency between any pair of data sets is due to two sources: respondent group and survey format. The effect of respondent group is known, equal to the relative scale parameter between two groups as given in table 8-7. The assumption is that the relative scale parameter between two groups in the first round of the survey is equal to that in the second round of the survey. For example, the relative scale parameter between B1 and A1 in the first wave due to respondent group is 1.1405. We assume that scale is kept constant in the second wave. In this way, the difference between A2 and B2 is composed of two components: due to respondent group with the relative scale 1.1405, and due to survey format whose relative scale is to be estimated. To untangle the effect of respondent group, we multiplied each row in the data set B2 by 1.1405, the relative scale parameter of respondent Group B to A. The statistical procedure described in section 8-2 is then employed to test the equality and estimate the scale parameter between A2 and B2. The relative scale parameter of B2 to A2 is obtained from the different survey formats only. Other three pairs of data sets follow the same procedure.

The test results for the four pairs of data sets are summarised in table 8-8. In testing the equality between A2 and B2, we specified two individual MNL models, each for data set A2 and B2, and one NL model for the joint data set, where each row from data set B2 was multiplied by 1.1405, the relative scale due to respondent group. Log likelihood for the MNL A2 is –451.7961, with 22 parameters. Log likelihood for the MNL B2 is –427.1717, with 22 parameters. Log likelihood for joint NL model is –878.9678, with 33 parameters. An LLR test was then conducted. The LLR statistic is 5.0288. The χ^2 critical value at the α=0.05 significance level with 11 degrees of freedom is 19.6752, suggesting that we should retain the null hypothesis of parameter homogeneity for the common attributes. The relative scale parameter between B2 and A2 was also estimated from the NL model, equal to 0.8684, resulted from the different survey format only. Test results for other three pairs of data sets are explained in similar manner.

The hypothesis of parameter homogeneity is retained for all cases, suggesting that the data sets obtained in two survey formats are fundamentally equal. This is not surprising because two formats of the survey instrument are designed to explain the same phenomenon, driver's behavioural response faced with a road and traffic situation. We obtained a mixed result for choice consistency, which is discussed below:

Table 8-7 Test the response consistency between respondent groups

Group A : B (Data Set A1 versus B1, Picture and Word format)				
Model parameters				
Model	MNL A1	MNL B1	Joint NL	
Log likelihood	-529.5959	-484.0952	-1014.2060	
No. of Parameters	22	22	33	
Scale and variance				
Data Sets	λ	$\sigma^2 = \pi^2/6\lambda^2$	t-Ratio	P
A1 (Base)	1.0000	1.6449	fixed	fixed
B1	1.1405	1.2646	9.825	0.0000
LLR Test				
	LLR statistic	df	$\chi^2(0.05,df)$	P
	1.0298	11	19.6752	0.9999
Group B : C (Data Set B2 versus C2, Picture Only format)				
Model parameters				
Model	MNL B2	MNL C2	Joint NL	
Log likelihood	-426.8695	-434.3811	-865.6180	
No. of Parameters	22	22	33	
Scale and variance				
Data Sets	λ	$\sigma^2 = \pi^2/6\lambda^2$	t-Ratio	P
B2 (Base)	1.0000	1.6449	Fixed	fixed
C2	0.9912	1.6743	9.1333	0.0000
LLR Test				
	LLR statistic	df	$\chi^2(0.05,df)$	P
	8.7348	11	19.6752	0.6464
Group C : D (Data Set D1 versus C1, Picture Only format)				
Model parameters				
Model	MNL D1	MNL C1	Joint NL	
Log likelihood	-436.7344	-500.6675	-940.8730	
No. of Parameters	22	22	33	
Scale and variance				
Data Sets	λ	$\sigma^2 = \pi^2/6\lambda^2$	t-Ratio	P
D1 (Base)	1.0000	1.6449	Fixed	fixed
C1	0.9486	1.8280	10.251	0.0000
LLR Test				
	LLR statistic	df	$\chi^2(0.05,df)$	P
	6.9422	11	19.6752	0.8037
Group A : D (Data Set A2 versus D2, Picture and Word format)				
Model parameters				
Model	MNL A2	MNL D2	Joint NL	
Log likelihood	-451.7961	-413.3046	-874.3654	
No. of Parameters	22	22	33	
Scale and variance				
Data Sets	λ	$\sigma^2 = \pi^2/6\lambda^2$	t-Ratio	P
A2 (Base)	1.0000	1.6449	fixed	fixed
D2	0.9413	1.8565	9.811	0.0000
LLR Test				
	LLR statistic	df	$\chi^2(0.05,df)$	P
	18.5294	11	19.6752	0.0701

Table 8-8 Test the response consistency of survey formats

Picture & Word : Picture Only (Data Set A2 versus B2)				
Model parameters				
Model	MNL A2	MNL B2	Joint NL	
Log likelihood	-451.7961	-427.1717	-878.9678	
No. of Parameters	22	22	33	
Scale and variance				
Data Sets	λ	$\sigma^2 = \pi^2/6\lambda^2$	t-Ratio	P
A2 (Base)	1.0000	1.6449	fixed	fixed
B2	0.8684	2.1813	10.458	0.0000
LLR Test				
	LLR statistic	df	$\chi^2(0.05,df)$	P
	5.0288	11	19.6752	0.9298
Picture & Word : Picture Only (Data Set B1 versus C1)				
Model parameters				
Model	MNL B1	MNL C1	Joint NL	
Log likelihood	-484.0952	-498.3595	-985.2055	
No. of Parameters	22	22	33	
Scale and variance				
Data Sets	λ	$\sigma^2 = \pi^2/6\lambda^2$	t-Ratio	P
B1 (Base)	1.0000	1.6449	fixed	fixed
C1	1.0582	1.4690	9.671	0.0000
LLR Test				
	LLR statistic	df	$\chi^2(0.05,df)$	P
	5.6920	11	19.6752	0.8931
Picture & Word : Picture Only (Data Set D2 versus C2)				
Model parameters				
Model	MNL D2	MNL C2	Joint NL	
Log likelihood	-413.3046	-434.2850	-852.1184	
No. of Parameters	22	22	33	
Scale and variance				
Data Sets	λ	$\sigma^2 = \pi^2/6\lambda^2$	t-Ratio	P
D2 (Base)	1.0000	1.6449	fixed	fixed
C2	1.0937	1.3752	8.832	0.0000
LLR Test				
	LLR statistic	df	$\chi^2(0.05,df)$	P
	9.0576	11	19.6752	0.6166
Picture & Word : Picture Only (Data Set A1 versus D1)				
Model parameters				
Model	MNL A1	MNL D1	Joint NL	
Log likelihood	-529.5949	-437.6930	-970.1548	
No. of Parameters	22	22	33	
Scale and variance				
Data Sets	λ	$\sigma^2 = \pi^2/6\lambda^2$	t-Ratio	P
A1 (Base)	1.0000	1.6449	fixed	fixed
D1	1.3410	0.9147	9.078	0.0000
LLR Test				
	LLR statistic	df	$\chi^2(0.05,df)$	P
	5.7338	11	19.6752	0.8905

(1) From the data sets A2 vs B2, we see the response variance associated with the Picture Only format is larger than that with the Picture & Word format. This corresponds with our expectation. The result suggest that a word description of road and traffic situation is an important part of survey instrument. It gives the respondent more information on actual setting, so that there is less information assigned to the unobserved effect.

(2) The test result from data sets A1 vs D1 indicates that the variance associated with Picture Only format is much smaller. The Picture Only format is a simplified survey instrument where the word description of road and traffic situation is omitted. The test results suggest response consistency has been improved by simplified survey instrument.

(3) From data sets B1 vs C1 and D2 vs C2, we see the relative scale parameters associated with the Picture Only format is slightly larger, indicating that the choice variance evaluated with the Picture Only format is slightly smaller. The test results suggest that there is no much difference in response consistency associated with two survey formats. The function of a word description can be ignored.

In summary, the hypothesis tests suggest that data sets associated with two survey formats are statistically equal. The simplified survey format in Picture Only format may decrease or increase the choice consistency. No formal conclusion is drawn with the mixed results.

8.4 Concluding Remarks

The scale parameters and variances for all data sets where A1 (in *Picture and Word* format) is set as the base case are presented in table 8-9 and in figure 8-3, from which we see a general structure of choice consistency when all sources of choice variability are confounded. The choice consistency exhibited in the four repeated surveys (A2, B2 C2 and D2, as shown in quadrangle in figure 8-3) is quite similar. It strongly suggests that response consistency can be improved by a repeated survey, no matter which survey format was used. The response consistency is stabilised in the repeated survey, although the survey was conducted by different groups of respondent using different survey formats.

Table 8-9 The scale parameters and variances in all data sets

Data Sets	λs	Variance	S.E.	Asymp.t.	P
A1 (Base)	1.0000	1.645	fixed	fixed	fixed
B1	1.1405	1.265	0.1161	9.825	0.000
C1	1.1933	1.155	0.1144	10.433	0.000
D1	1.3411	0.915	0.1477	9.078	0.000
A2	1.4095	0.828	0.1413	9.976	0.000
B2	1.3935	0.847	0.1516	9.190	0.000
C2	1.4033	0.835	0.1453	9.657	0.000
D2	1.3644	0.884	0.1535	8.886	0.000

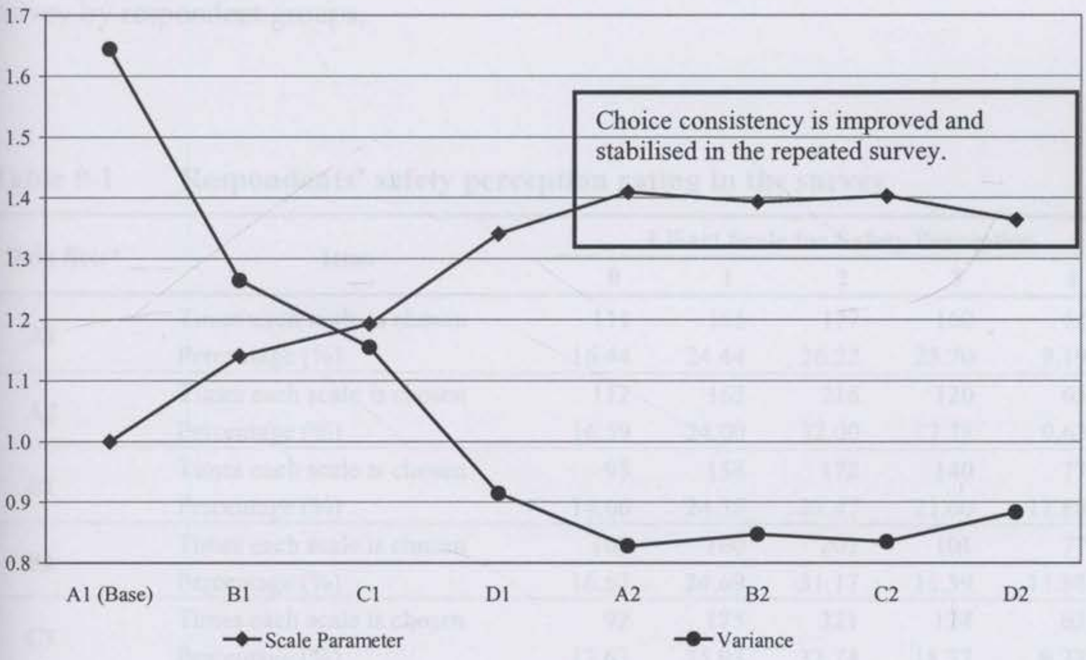


Figure 8-3 Scale parameters and variances for all data sets

Chapter Nine

Measurement of Safety Perception of the Road Environment: Development of an Indicator of Perceived Safety

9.1 An Empirical Framework for Measurement of Driver's Perception of Safety in the Road Environment

We have designed 27 road and traffic scenarios. We invited 97 respondents, and each of them has evaluated all of these road and traffic scenarios and indicated their perception of safety for each scenario. The safety perception is measured on a 5-point Likert scale, which is ordered to represent *very unsafe*, *somewhat unsafe*, *neutral*, *somewhat safe* and *very safe* from 0 to 4 respectively. Table 9-1 summarises the number and percentage of times that each of these safety perception scales was chosen in the first and second survey by respondent groups.

Table 9-1 Respondents' safety perception rating in the survey

Data Sets*	Item	Likert Scale for Safety Perception				
		0	1	2	3	4
A1	Times each scale is chosen	111	165	177	160	62
	Percentage (%)	16.44	24.44	26.22	23.70	9.19
A2	Times each scale is chosen	112	162	216	120	65
	Percentage (%)	16.59	24.00	32.00	17.78	9.63
B1	Times each scale is chosen	95	158	178	140	77
	Percentage (%)	14.66	24.38	27.47	21.60	11.88
B2	Times each scale is chosen	108	160	202	101	77
	Percentage (%)	16.67	24.69	31.17	15.59	11.88
C1	Times each scale is chosen	92	175	221	124	63
	Percentage (%)	13.63	25.93	32.74	18.37	9.33
C2	Times each scale is chosen	83	169	190	158	75
	Percentage (%)	12.30	25.04	28.15	23.41	11.11
D1	Times each scale is chosen	115	163	182	104	57
	Percentage (%)	18.52	26.25	29.31	16.75	9.18
D2	Times each scale is chosen	112	155	176	130	48
	Percentage (%)	18.04	24.96	28.34	20.93	7.73
Overall	Times each scale is chosen	828	1307	1542	1037	524
Survey	Percentage (%)	15.81	24.95	29.44	19.80	10.00

* See Chapter 7 for definition

Our objective in this chapter is to measure the drivers' safety perception associated with each offered scenario and develop an indicator of perceived safety. Specifically, we will investigate: (1) which of the experimentally designed attributes have a significant influence on drivers' perception of safety? (2) in what manner does each of these attributes influence the perception of safety? (3) how do the drivers differ in their perception of safety in a given road and traffic situation? and (4), what is the relationship between driver characteristics and their perception of safety?

We need an empirical framework to investigate the driver's perception of safety. The perception of safety is measured on a 5-point Likert scale using a perceptual response of drivers. If we apply ordinary linear regression to examine the relationship between a choice response and experimentally design attributes, we must assume that the safety perception scale is both continuous and an interval scale. A number of theoretical studies have questioned the validity of the linearity assumption of such a response scale (e.g. Hensher 1989, Winship and Mare 1984). If the linear assumption is violated, ordinary least square regression may give misleading results. On the other hand, the unordered multinomial logit or probit models would fail to account for the ordinal nature of the dependent variable. An appropriate approach that both recognises the non-linearity and accommodates the ordinal property of the ordered choice response scale is the ordered response model.

Ordered response models can take the form of ordered probit or ordered logit. The difference between probit and logit is the assumption on the distribution of random term. If a standard normal distribution is assumed, the ordered probit model is specified. If a standard logistic distribution is assumed, the ordered logit model is used. The ordered model allows us to use ordinal dependent variables in such a way that explicitly recognises their ordinality and avoids arbitrary assumptions about their scale. The essence of the approach is an assumed probability distribution of the continuous variable that underlies the observed ordinal dependant variable (Hensher 2000a). The underlying continuous variable is mapped into categories that define the points on the observed response scale as thresholds. These categories are ordered but separated by unknown distances. For example, we cannot say that the difference between responses 1 and 2 is identical to the difference between responses 2 and 3 or between 3 and 4. The ordered model also takes into account the ceiling and the floor restrictions on ordinal variables, whereas a linear regression model does not.

9.2 Specification of an Ordered Probability Model and Test of the Normality Assumption

In specifying an ordered probit model for drivers' perception of safety, we assume that the 5-point response scale is a non-strict monotonic transformation of an unobserved interval variable. Because perceptions of safety are ordered from very unsafe to very safe, the ordered probit model is an appropriate specification. The ordered probit model was originally developed by McKelvey and Zavoina (1975), and further discussed in Liao (1994). Formally,

$$y_i^* = \beta' x_i + \varepsilon_i \tag{9-1}$$

The ordered probit model is used to express a respondent's preference on the ordinal ranking of y_i^*. β' is a vector of coefficients to be estimated. x_i is a vector of attributes. y_i^* is unobservable but is assumed to represent the underlying tendency of an observed phenomenon. What we can observe is,

$$\begin{aligned} y_i &= 0 \text{ if } y_i^* \le \mu_0 \\ &= 1 \text{ if } \mu_0 \le y_i^* \le \mu_1 \\ &= 2 \text{ if } \mu_1 \le y_i^* \le \mu_2 \\ &\;\;\ldots\ldots \\ &= J \text{ if } \mu_{J-1} \le y_i^* \end{aligned} \tag{9-2}$$

where y_i is observed in J ordered categories, and the μs are threshold parameters to be estimated together with β's. There are strict assumptions on the error term ε: (1) they are independent among response categories. (2) they are identically distributed. and (3) they follow the standard normal distribution.

In a particular empirical study, these assumptions may be violated. For example, variances of ε's may vary across individuals having different socio-economic characteristics, which lead to a different model specification. A number of authors have demonstrated that parameter estimates are generally inconsistent if the statistical assumptions on the unobserved terms in the ordered probit model do not hold (Glewwe 1997, Johnson 1996). In these cases, we have to relax some or all restrictions. If we wish to keep the ordered property of the dependent variable, a heteroskedastic ordered probit model would be an appropriate specification. Otherwise, we can specify more sophisticated models such as heteroskedastic extreme value (HEV) model, covariance heterogeneity logit (CovHet) model, random parameter logit (RPL, also referred to as mixed logit model), latent class heteroscedastic MNL model and multinomial probit (MNP) model. The latest theoretical developments and practical applications of these models are documented in Louviere et al (2000). These models generally discard the information on order and use an unordered specification of the choice outcomes. A random parameter model is estimated for driver behavioural response in this empirical study and is presented in chapter ten.

The normality assumption for ordered probit model is testable. Bera et al (1984) developed a simple Lagrange Multiplier (LM) test. Glewwe (1997) extended the LM test to the standard ordered probit model and the ordered probit model where censoring is present in the dependent variable. Glewwe examined the LM test method using a Monte Carlo experiment. A similar approach was also adopted in Johnson (1996). We use a Lagrange Multiplier to test the underlying assumption of the ordered probit model. The LM test procedure is programmed using Econometric Software (2000). The null hypothesis is an ordered probit model with homoskedasticity, i.e., the unobserved error term follows a standard normal distribution. The alternative hypothesis is an ordered probit model with multiplicative heteroskedasticity, i.e., variance of unobserved error term is a function of z_i, a set of explanatory variables. Formally,

$$\text{var}(\varepsilon_i) = \sigma^2 = [\exp(\gamma' z_i)]^2 \qquad (9\text{-}3)$$

The general Lagrange Multiplier statistic (Econometric Software 2000) for a test of hypothesis $\boldsymbol{H_0}$ is:

$$LM = g_0' [H_0]^{-1} g_0 \qquad (9\text{-}4)$$

where $\boldsymbol{g}$ is the gradient of the log likelihood function. $\boldsymbol{H}$ is $\boldsymbol{N}$ times a consistent estimator of the expected value of the Hessian of the log-likelihood. $\boldsymbol{H_0}$ and $\boldsymbol{g_0}$ indicate that these matrices are to be computed at the parameter estimates obtained under the restrictions of the null hypothesis.

It is trivial to infer the log-likelihood function for ordered probit model,

$$\ln L = \sum_i \sum_j Q_{ij} \ln\left\{ \Phi\left[\frac{\mu_j - \beta' x_i}{\exp(\gamma' z_i)^2} \right] - \Phi\left[\frac{\mu_{j-1} - \beta' x_i}{\exp(\gamma' z_i)^2} \right] \right\} \quad (9-5)$$

where $Q_{ij} = 1$ if $\mu_{j-1} < y_i \leq \mu_j$, 0 otherwise.

The parameter vector to be simultaneously estimated is,

$$\theta = [\beta_1, \cdots, \beta_K, \gamma_1, \cdots, \gamma_L, \mu_1, \cdots, \mu_{J-1}]$$

Then LM test statistic for the ordered probit model, evaluated under the constrained hypothesis is,

$$LM = \left(\frac{\partial \ln L}{\partial \theta} |_{H_0} \right) \left[-E \frac{\partial^2 \ln L}{\partial \theta \partial \theta} |_{H_0} \right]^{-1} \left(\frac{\partial \ln L}{\partial \theta} |_{H_0} \right) \quad (9-6)$$

The LM test is asymptotically distributed as Chi-squared with degrees of freedom equal to the number of constraints. An LM value larger than the critical value at a significant level favours ordered heteoskedastic probit model as the correct specification. Otherwise, we accept ordered probit model as the correct specification.

9.3 Development and Evaluation of Simple Ordered Probit Model for Driver's Perception of Safety

A simple ordered probit model is firstly specified without consideration of potential heteroskedasticity. The dependent variable is the drivers' safety perception scale. the possible explanatory variables include all 12 effects-coded attribute variables from the experimental design. Detailed definitions of attribute variables were given in table 7-2 in chapter seven. A brief description of these variables is given in table 9-2 for the convenience of readers.

Table 9-2 Specification of simple ordered probit model

Variable	Description
	Dependent Variable
RATING	Safety perception rating on 5-point scale
	Independent Variables
ONE	Constant
ROUDL	Effects-coded variable for large-sized roundabout
ROUDM	Effects-coded variable for medium-sized roundabout
LANE1	Effects-coded variable for single circulating lane roundabout
CLEAR	Effects-coded variable for clear visibility to other traffic
VEHLG	Effects-coded variable for a large-sized vehicle that potentially conflicts with the respondent's car
VEHMD	Effects-coded variable for a medium-sized vehicle that potentially conflicts with the respondent's car
SPEED	Quantitative variable representing the speed of the vehicle that potentially conflicts with the respondent's car
BUSYT	Effects-coded variable for the situation where traffic at the roundabout is busy
MODET	Effects-coded variable for the situation where traffic at the roundabout is moderate
PEDSY	Effects-coded variable for the traffic situation where there is a pedestrian trying to cross the road in front of the respondent's car
MYSPD	Quantitative variable representing the speed of the respondent's car
HURRY	Effects-coded variable representing a respondent's time schedule is such that s/he is in a hurry

Four models are estimated sequentially as described below, using the Maximum Likelihood Estimation method. Final model estimates for models 3 and 4 are given in table 9-3 and detailed estimation outputs are given in Appendix V (Model 1-4).

Model 1: Some selected two-way interactions including interactions between HURRY and other attributes have been tested in the model. All two-way interactions are statistically insignificant. This can be traced to our experimental design, where we chose not to independently estimate two-way interactions, thus observed data could not provide information to estimate them It is also highly possible that these two-way interactions are really insignificant and account for only a small potion of explained variance. All 12 explanatory variables are included in the model. Estimation results suggest two explanatory variables (ROUDM and HURRY) are statistically insignificant. Simple excluding these insignificant variables from the model is not a good practice. We need to employ the Likelihood Ratio (LR) test to examine whether the variables should be excluded. The LR test was discussed in chapter seven.

Model 2: HURRY is firstly excluded in the model because it is the least statistically significant. Estimation results indicate that coefficients and significant level of other variables are almost unchanged in comparison to model 1. This suggests that the variable HURRY has little correlation with the other variables. LR statistic based on log likelihood functions of model 1 and model 2 is 0.1926. The χ^2 distribution with 1 degree of freedom at 5% significant level is 3.841 (=1.96^2). The test result accepts that model 2 is a better specification than model 1. That is, the variable HURRY should be dropped from the model.

Model 3: Estimation of model 2 indicates that ROUDM is still statistically insignificant. ROUDM is excluded and the model is re-estimated. All remaining variables are highly significant in model 3. The LR test is again conducted to examine whether we should exclude ROUDM from the model. Two LR tests are available at this stage. One is based on estimation results of models 2 and 3. The LR statistic is 0.954 which is less than $\chi^2(0.95,1)=3.841$. The other LR test is based on estimation results of model 1 and model 3. The LR statistic is 1.146. The χ^2 distribution with 2 degrees of freedom at 5% of significant level is 4.605. Both tests suggest model 3 is a better specification than model 1 or model 2.

Model 4: Ordered logit specification of model 3. Estimation results indicate that the two models are quite similar. Liao (1994) suggested that one can go from one set of estimates to the other. For example, if one multiplies a probit estimate by a factor, one gets an approximate value of the corresponding logit estimate. This factor is $\pi/\sqrt{3}=1.814$ (Aldrich and Nelson 1984). However, Amemiya (1981) proposed a scale difference of 1.6 by trial and error. In our case, the ratios of coefficient of logit to that of probit concentrate on 1.814 ± 0.04. Given the similarity between the two models, either model will give identical substantive conclusions.

Table 9-3 Estimation results of simple ordered probit (logit) models: driver's safety perception

Variable	Coefficient	t-Ratio	Significance
Model		**Model 3 (Probit)**	
	Index function for probability		
ONE	5.8432	70.605	0.0000
ROUDL	-0.5190	-24.638	0.0000
LANE1	0.2232	12.468	0.0000
CLEAR	1.3259	63.202	0.0000
VEHLG	-0.6855	-28.620	0.0000
VEHMD	0.2740	11.540	0.0000
SPEED	-0.0743	-53.532	0.0000
BUSYT	-0.4383	-18.532	0.0000
MODET	0.1439	6.092	0.0000
PEDSY	-0.7527	-38.790	0.0000
MYSPD	-0.0384	-35.147	0.0000
	Threshold parameters for index		
μ 1	1.8046	44.127	0.000
μ 2	3.6032	76.007	0.000
μ 3	5.0114	90.234	0.000
	Model performance		
Log likelihood			-4759.348
Restricted log likelihood			-8113.318
Chi-squared			6707.940
Degrees of freedom			10
Significance level			0.0000
Number of observations			5238
Model		**Model 4 (Logit)**	
	Index function for probability		
ONE	10.5945	54.289	0.0000
ROUDL	-0.9500	-24.050	0.0000
LANE1	0.3997	12.746	0.0000
CLEAR	2.4020	49.955	0.0000
VEHLG	-1.2363	-27.769	0.0000
VEHMD	0.4863	11.409	0.0000
SPEED	-0.1350	-46.295	0.0000
BUSYT	-0.8080	-19.058	0.0000
MODET	0.2613	6.252	0.0000
PEDSY	-1.3447	-36.029	0.0000
MYSPD	-0.0695	-32.258	0.0000
	Threshold parameters for index		
μ 1	3.2615	38.344	0.0000
μ 2	6.5297	55.984	0.0000
μ 3	9.0204	63.743	0.0000
	Model performance		
Log likelihood			-4715.339
Restricted log likelihood			-8113.318
Chi-squared			6795.957
Degrees of freedom			10
Significance level			0.0000
Number of observations			5238

Model 3 is our preferred specification in investigating driver's perception of safety without consideration of heteroskedasticity. An overall evaluation of this model is appropriate at this stage. Model appreciation is conducted in terms of individual coefficient estimates, goodness of fit, pseudo R-squared, prediction success and the role of threshold parameters.

Individual coefficient estimates: Ten explanatory variables plus one constant are included in the model. For each of these variables, a set of estimates including coefficient (β), standard error (*S.E.*), t-ratio (t) and significant level (α) are reported. Reported coefficient estimates are asymptotically unbiased and efficient estimates of effects of attributes. The t-ratio is used for testing the null hypothesis that a coefficient is not statistically significantly different from zero, i.e., the corresponding variable has no effect on the dependent variable. Significant level α is the probability value for the hypothesis test based on the standard normal distribution. All coefficients in our model are highly statistically significant.

Goodness of fit: Goodness of fit describes the significance of the overall relationship between the explanatory variables and the dependent variable. This is again addressed by the log likelihood ratio. The output of model estimation includes the restricted log likelihood $LL(0)$ of the null model, in which the coefficients for all regressors are taken as zero, and the log likelihood $LL(1)$ function for fitted model. Log likelihood ratio $LR = 2[LL(1)-LL(0)]$ is calculated which follows the χ^2 distribution with the degrees of freedom equal to the number of explanatory variables. The LR test indicates that the model is highly significant at the 100% confidence level.

Pseudo R-squared: Pseudo R-squared is an alternative method to measure the overall goodness of fit. R-squared has a particularly attractive interpretation in regression analysis as the proportion of the variance in the dependent variable that is explained by exogenous variables. There is no way of knowing the variance of the dependent variable on its underlying interval scale for an ordered probit model. A method of calculating pseudo R-squared has been proposed by the McKelvey and Zavoina (1975), which is given in equation 9-7.

$$\hat{R}^2 = \sum_{i=1}^{N} \hat{y}_i^2 / (\sum_{i=1}^{N} \hat{y}_i^2 + N) \qquad (9-7)$$

The numerator component in the formula is the Chi-squared statistic for the fitted model (Aldrich and Nelson 1984), and N is total sample size. Thus pseudo R-squared is easily obtained, because the value of Chi-squared is obtainable from the output of the model estimation. The estimated pseudo R-squared is 0.5615 for model 3. This should be considered as extremely good fit. Hensher and Johnson (1981) pointed out that values of pseudo R-squared between 0.2 and 0.4 for multinomial logit model are a good fit so that analysts should not be looking for values in excess of 0.9 that is often the case where the R-squared is used in ordinary regression.

Prediction success: Prediction success is another way to investigate the goodness of fit of the model. The notion of prediction success was first introduced by McFadden (1979) and developed by Hensher and Johnson (1981). The principle of prediction success compares actual outcomes with outcomes predicted on the basis of the model. Following the notation developed in Hensher and Johnson (1981, 51-55), we calculated the prediction success table of model 3 as is given in table 9-4. Cases appearing on the diagonals of the matrix correspond to successful prediction, while off-diagonal entries represent unsuccessful prediction. Comparison of predicted total to actual total for each perception scale gives a rough idea how well the model performs. Percent correct indicates the proportion successfully predicted for each scale. We also provide the Success Index for each perception scale, which denotes the fraction by which the percent correct exceeds what would be expected on the basis of chance alone. An overall prediction success index is also calculated, which is 0.3654. (The formulas for calculation of the overall success index are illustrated in *Appendix V - formulas for calculation of success index table*). The overall prediction success index is comparable to pseudo R-squared because it is normalised in the range of 0 and 1 in its algorithm.

Table 9-4 Prediction success table of drivers' safety perception scale

Perception Scale	Predicted Perception Scale					Observed	Observed
	1	2	3	4	5	Total	Share
1	438	380	7	1	2	828	15.808
2	139	896	258	14	0	1307	24.952
3	3	254	1016	249	20	1542	29.439
4	1	19	257	615	145	1037	19.798
5	1	3	14	285	221	524	10.004
Predicted Total	582	1552	1552	1164	388	5238	100.000
Predicted Share	11.111	29.630	29.630	22.222	7.407	100.000	
Percent Correct	75.258	57.732	65.464	52.835	56.959	60.825	
Success Index	0.641	0.281	0.358	0.306	0.496	**0.3654**	

The role of threshold parameters: Threshold parameters are estimated together with coefficients. These thresholds are free parameters used to separate the adjacent categories and provide the ranking, therefore there is no significance to the unit distance between the set of observed values of categories y_i in equation (9-2). In order for all the probabilities that an observed categories y_i falls into a category j to be positive, we have $\mu_0<\mu_1<\mu_2<...<\mu_{J-1}$. The first threshold is normalised to zero because the scale is arbitrary and can start or finish with any value. The number of thresholds is always one smaller than the number of categories. There will be J-2=3 threshold parameters to be estimated under this normalisation for this study (*J=5 categories*). All threshold parameters are highly significant with a high and positive t-ratio, which indicates that the five categories of the safety perception scale in the response are indeed ordered (Liao 1994).

9.4 Accommodation of Heterogeneity in Perception of Safety among Drivers

So far, we have developed a preferred ordered probit based on assumption of no individual heterogeneity with respect to the perception of safety in a given road and traffic situation. It is possible that different drivers have different perceptions of safety in a given road environment. The heterogeneity can be originated from many sources including driver's characteristics, driving experience and accident history. For example, women may perceive a higher risk than men at a sharp bend. Experienced drivers are more likely to detect the potential danger than the inexperienced. Young drivers may see less risk than old drivers on a motorway. Heterogeneity in safety perception among drivers can be accommodated in the ordered probit model by specifying a variance function for the random term ε in equation 9-1. This specification is referred to as the heteroskedastic ordered probit model. Before specifying a heteroskedastic probit model, we need to select a set of variables that can explain the variance of the random term ε. These variables can be selected from driver's socio-demographic characteristics (table 7-3), and dummy variables derived from statements about driving experience and behaviour (table 7-4). In totally, there are 90 such variables. Each of them has potential direct or indirect influence on the variance of the random term. We cannot include all 90 variables. Some will have little explanatory power, and others maybe ill-conditioned causing problem in estimation. The process of selecting variables to set the variance function of the unobserved term is briefly described below.

(1) The starting point for specifying the variance function is the relative importance of variables that we have developed in chapter seven (table 7-13) using the CART approach. We firstly dropped eight variables whose relative importance score is 0 (no explanatory at all). All quantitative variables in table 7-3 and table 7-4 are included in the variance function. For those qualitative variables with *L* levels, only *L-1* dummy-coded variables are included We also included some interaction variables (e.g. AGE20 x GENDM) to measure the effects of the interaction between young and male drivers. However, the model was inestimable because variance matrix of estimates was singular. This indicates that some variables in the variance function are ill-conditioned.

(2) We again employ the relative importance of variables (table 7-13) and drop more variables whose relative importance score is low. We also dropped some less frequently observed variables (e.g. LHEVY, drivers holding a national heavy vehicle licence, only one observation in 97 respondents). The model is still not estimable because of singular variance matrix. The specification searches were undertaken many times, following different assumptions and analytical intuition.

(3) After many trials, we created new variables to combine some detailed categorised variables into broader categories. For example, we originally have nine age categories. We transformed these nine age categories into three broad categories, AGEY, AGEM and AGEO, to represent young-aged, middle-aged and old-aged driver groups respectively. The category variables for personal

income follow the similar treatment. Finally, we concentrated on 12 variables as shown in table 9-5.

Table 9-5 Specification of variance function of the heteroskedastic ordered probit model

Variable	Description
GENDF	Dummy variable for female respondent
AGEY	Transformed dummy variable representing the age group16-25 years old by combining AGE20 and AGE25
AGEM*	Transformed dummy variable representing the age group 26-50 years old by combining AGE30, AGE35, AGE40, AGE45 and AGE50
ILOW*	Transformed dummy variable representing the annual income group $30,000 or lesser by combining INCM2 and INCM3
IMID	Transformed dummy variable representing the annual income group between $30,001 - $50,000 by combining INCM4 and INCM5
RESTR	Transformed dummy variable representing that respondent holds a restrictive drivers licence, by combining LPROV, LLRNE, LPROB and LOTHE
DRYRS	Quantitative variable representing years that respondent has been driving
COMYE	Dummy variable for commuter driver
ACCNO	Dummy variable indicating that respondent was not involved in an accident in the last two years
OFCNO*	Dummy variable indicating that respondent did not commit a traffic offence in the last two years
CARSM	Dummy variable indicating that respondent normally drives a small car (no. of cylinders <= 4)
PCAUT	Dummy variable indicating that a respondent describes her/himself as a very cautious driver in most situations when driving

* – these variables are excluded in the final model because their effects are insignificant.

The process of specification search suggests that we should be careful in designing categories for respondent' socio-economic variables such as income and age. If too many categories are given, it is highly possible that we cannot observe their effects because of insignificance of coefficients, or, at the worst the model is inestimable because of a singular covariance matrix. On the other hand, if too few categories are given, we cannot estimate the quadratic and cubic effects. Models 5 and 6 are our final specifications for the heteroskedastic ordered probit/logit models, whose estimation results are given in table 9-6 and detailed in the Appendix V (Model 5-6).

Model 5: The heteroskedastic ordered probit model. The variance function includes nine respondent's socio-demographic variables. The effects of three variables (AGEM, ILOW and OFCNO) in table 9-5 are insignificant and thus eliminated from the final specification. A Lagrange Multiplier (LM) test is conducted to test the appropriateness of the heteroskedastic specification. The reported LM statistic is 71.014. The critical value of Chi-squared with nine degree of freedom at the 5% significance level is 16.919, suggesting that the heteroskedastic probit model is the preferred specification. The pseudo R-squared is 0.5642, which suggests that overall goodness of fit of heteroskedastic specification is slightly better than that of the simple ordered probit model (0.5615). However, its overall success index is lower than that of the simple ordered specification (0.3637 vs 0.3654), which suggests that a better model in the statistical sense is not necessarily better from a behaviour perspective.

Model 6: The heteroskedastic ordered logit specification of model 5. Ratios of coefficients between the logit and probit specification for variables in the index function and threshold parameters are around 1.814. However, there is no such regularity for ratios of coefficients of variables in the variance function.

Table 9-6 Estimation results of heteroskedastic ordered probit (logit) models: driver's safety perception

Variable	Coefficient	t-Ratio	Significanc	Coefficient	t-Ratio	Significanc
Model		**Model 5**			**Model 6**	
			Index function for probability			
ONE	6.1892	15.811	0.0000	11.6797	12.753	0.0000
ROUDL	-0.5504	-13.598	0.0000	-1.0528	-11.512	0.0000
LANE1	0.2362	9.949	0.0000	0.4418	9.171	0.0000
CLEAR	1.4129	15.848	0.0000	2.6661	12.745	0.0000
VEHLG	-0.7291	-14.622	0.0000	-1.3784	-12.105	0.0000
VEHMD	0.2879	9.790	0.0000	0.5412	8.892	0.0000
SPEED	-0.0790	-15.678	0.0000	-0.1495	-12.680	0.0000
BUSYT	-0.4637	-12.097	0.0000	-0.8951	-10.725	0.0000
MODET	0.1471	5.628	0.0000	0.2794	5.573	0.0000
PEDSY	-0.7991	-15.199	0.0000	-1.4942	-12.376	0.0000
MYSPD	-0.0405	-14.742	0.0000	-0.0765	-12.158	0.0000
			Variance function			
GENDF	0.1052	3.671	0.0002	0.1006	2.933	0.0034
AGEY	-0.0975	-1.984	0.0472	-0.0607	-1.027	0.3044
IMID	-0.1002	-3.503	0.0005	-0.0877	-2.423	0.0154
RESTR	0.1275	3.295	0.0010	0.2099	4.401	0.0000
DRYRS	0.0041	3.009	0.0026	0.0075	4.451	0.0000
COMYE	-0.0747	-2.801	0.0051	-0.0441	-1.248	0.2121
ACCNO	0.0721	1.663	0.0964	0.0175	0.361	0.7180
CARSM	-0.0632	-2.138	0.0325	-0.0473	-1.282	0.1999
PCAUT	-0.0907	-3.241	0.0012	-0.0887	-2.552	0.0107
			Threshold parameters for index			
μ 1	1.9244	15.279	0.0000	3.6234	12.443	0.0000
μ 2	3.8407	15.800	0.0000	7.2514	12.737	0.0000
μ 3	5.3374	16.063	0.0000	10.0280	12.859	0.0000
Number of observations		5238			5238	

9.5 Inferring Driver's Perception of Safety from the Ordered Probit Analysis

9.5.1 The Methods of Interpreting Ordered Probit (Logit) Models

The simple and heteroskedastic ordered probit models establish a general relationship between drivers' perception of safety and the attributes of the road and traffic situation as well as drivers' personal characteristics. Estimated parameters *(β_k, γ_l, μ_j)* are useful in interpreting driver's perception of safety in a number of ways.

The signs and magnitude of parameter estimates: A brief look at the signs (+ & -) of coefficients in the index function for probability gives a direct interpretation of how the road and traffic attributes would influence a driver's perception of safety. A negative sign of the estimate indicates that the probability of a higher order response (e.g. scale four rather than scales 0-3) decreases with the increased value of x_k (or x_k =1 for effects-coded variables), holding other *x*s constant. For example, as the level of SPEED increases, the probability that the traffic situation is rated as *very safe* instead of other categories (*somewhat safe, neutral, somewhat unsafe* and *very unsafe*) will decrease. Conversely to interpreting a negative parameter, a positive sign of a coefficient indicates that the probability of the higher order response increases with the increased level of x_k (or x_k=1 for effects-coded variables), keeping all other influences unchanged. A comparison of the magnitude of coefficients gives the relative importance of variables that affect respondents' perception of safety. This comparison is valid only when the variables are measured on the same scale or can be converted to the same scale (Achen 1982). For example, SPEED and MYSPD are comparable because they are measured in the same measurement unit. Coefficients between two dummy- or effects-coded variables are also comparable. Interpretation based on signs and magnitude of coefficients is vague. We do not know how much the probability of a response falling into a particular category increases (or decreases) given an increased level of x_k or what is the functional form of such an effect. However it is the easiest way of interpreting an estimated model.

Effects of an attribute in shifting the odds of safety perception categories: Estimated β_k

is also useful in investigating the effect of x_k in shifting the odds of responding to category *j, j=0, 1,2,......J*. As an example, we examine the effect of an effects-coded variable, VEHMD. This variable represents the size of the vehicle that potentially conflicts with a respondent's car. Because logit models lead themselves more easily to interpretation in terms of odds, we use the logit estimates from model 6. The logit estimate of VEHMD is 0.5412. Exponentiation gives 1.718, which is the estimated effect on odds. When VEHMD =1, the odds that a road and traffic scenario is rated as *very safe* instead of other categories is 1.718 times as high as when VEHMD=0. Interpreting of odds is a flexible and useful option for making sense of a logit model with ordered responses. However, this interpretation is *illusive* when the number of ordered categories is more than three.

Predicted probability given a set of explanatory variables: Another interpretation of the estimated ordered model is to predict probabilities given a set of values in the explanatory variables. For the ordered probit model, the probability that a response falls into category *j, j=0, 1,2,......J*, is (Liao 1994),

$$prob(y=0) = \Phi\left\{\frac{-\sum_{k=1}^{K}\beta_k x_k}{[\exp(\gamma' z_i)]^2}\right\}$$

$$prob(y=1) = \Phi\left\{\frac{\mu_2-\sum_{k=1}^{K}\beta_k x_k}{[\exp(\gamma' z_i)]^2}\right\} - \Phi\left\{\frac{-\sum_{k=1}^{K}\beta_k x_k}{[\exp(\gamma' z_i)]^2}\right\}$$

$$prob(y=2) = \Phi\left\{\frac{\mu_3-\sum_{k=1}^{K}\beta_k x_k}{[\exp(\gamma' z_i)]^2}\right\} - \Phi\left\{\frac{\mu_2-\sum_{k=1}^{K}\beta_k x_k}{[\exp(\gamma' z_i)]^2}\right\} \qquad (9\text{-}8)$$

$$\cdots\cdots\cdots$$

$$prob(y=J) = 1-\Phi\left\{\frac{\mu_{J-1}-\sum_{k=1}^{K}\beta_k x_k}{[\exp(\gamma' z_i)]^2}\right\}$$

where $\Phi(\bullet)$ represents the cumulative standard normal density function. The second term in every line except the first and last line in equation 9-8 is the corresponding cumulative standard normal distribution probability from the line above. We identify the probability of event j by taking the difference between two adjacent cumulative probabilities with the exception of the first and the last category because $prob(y \le 0) = prob(y=0)$ and $prob(y \le J) = 1$. We have five response categories. We estimated three threshold parameters because the first is normalised to 0. The five response probabilities are the area of five partitioned regions under a normal curve, as shown in figure 9-1. The cut-off point for the first and second region is the normalised threshold (0) minus the influence of attributes (βxs) divided by their variance. The cut-off point for the second and third region is the estimated μ_1 minus the influence of attributes, divided by the variance. The other two cut-off points are calculated in a similar manner.

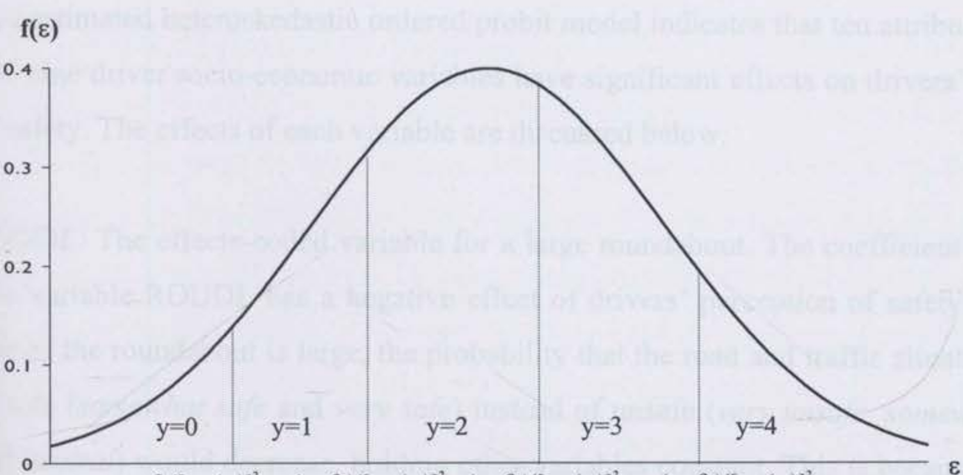


Figure 9-1 Probabilities in the heteroskedastic ordered probit model

Marginal effects of the probability of response categories: We can also use the estimated model to investigate the marginal effects on the probability of an event. We express the marginal effect of an event probability in the ordered probit model as the partial derivative of the probability with respect to an attribute x_k. In general, we have,

$$\frac{\partial prob(y=j)}{\partial x_k} = \left[\phi\left(\frac{\mu_{j-1} - \sum_{k=1}^{K} \beta_k x_k}{[\exp(\gamma' z_i)]^2} \right) - \phi\left(\frac{\mu_j - \sum_{k=1}^{K} \beta_k x_k}{[\exp(\gamma' z_i)]^2} \right) \right] \beta_k \qquad (9-9)$$

where $\phi(\bullet)$ represents the standard normal probability density function. Marginal effects in an ordered probit (logit) model are quite complex because there is no meaningful conditional mean functional to manipulate (Econometric Software 2000). They represent the effects of changes in the covariates on the category probabilities.

9.5.2 Interpretation of the Perception of Safety in Terms of the Attributes of the Road and Traffic Scenario and Driver Characteristics

The estimated heteroskedastic ordered probit model indicates that ten attribute variables and nine driver socio-economic variables have significant effects on drivers' perception of safety. The effects of each variable are discussed below:

ROUDL: The effects-coded variable for a large roundabout. The coefficient is -0.5504. The variable ROUDL has a negative effect of drivers' perception of safety. When the size of the roundabout is large, the probability that the road and traffic situation is rated as safe (*somewhat safe* and *very safe*) instead of unsafe (*very unsafe, somewhat unsafe* and *neutral*) would decrease, holding other variables constant. This is because at a large roundabout, the traffic pattern is generally complex. Large roundabouts are usually built at locations where traffic is heavy. The increased traffic volume increases the chance of traffic conflicting. Drivers are also more likely to drive at a higher speed as they approach a large roundabout.

LANE1: The effects-coded variable for single circulating lane roundabout has a positive effect on driver's perception of safety. Operation at the single circulating lane roundabout is relatively simple, compared with a two or three circulating lane roundabout, where traffic weaving and lane changing are generally required, greatly increasing maneuvering demands.

CLEAR: Effects-coded variable for clear visibility to other traffic when approaching the roundabout. It has positive effects on safety perception. CLEAR has the largest positive coefficient among attribute variables. The clear visibility is essential for the safe operation of roundabouts. The sight distance is the most important factor influencing clear visibility. The visibility can deteriorate due to poor weather conditions (e.g. fog, raining), or poor road lightning.

VEHLG and *VEHMD*: Effects-coded variables for large- and medium-sized vehicle that potentially conflicts with a respondent's car. VEHLG has a negative effect while VEHMD has a positive effect on the perception of safety. VEHLG and VEHMD are the first and second levels of the attribute of the size of potentially conflicting vehicles, which has three levels. The advantage of using effects-codes is that we can identify the effects of the third level. If we define VEHSM representing the small-sized roundabout, we have:

$$\beta_{VEHSM} = (-1) \times (\beta_{VEHLG} + \beta_{VEHMD}) = (-1)*(-0.7291 + 0.2879) = 0.4412.$$

Table 9-7 shows the predicted probabilities of safety perception at three levels of the vehicle size attribute, while keeping other attribute and driver's socio-demographic variables fixed. When VEHLG=1, respondents are more likely to rate the road and traffic situation as very unsafe. This propensity declines when VEHMD=1 and further declines when VEHSM=1. If we use a dummy-code scheme, we would be unable to detect the effects of VEHSM. The predicted probabilities in table 9-7 are calculated using equation 9-8. It is worthy to note that five predicted probabilities across the safety perception categories at each investigated situation should sum to 1. The equality serves as a useful check for verifying the calculations.

Table 9-7 Predicted probabilities of safety perception: the size of the potentially conflicting vehicle

Variable	Prob(y=0)	Prob(y=1)	Prob(y=2)	Prob(y=3)	Prob(y=4)	Sum
VEHLG=1	0.6663	0.2756	0.0547	0.0032	0.0002	1.0000
VEHMD=1	0.4312	0.4022	0.1489	0.0163	0.0014	1.0000
VEHSM=1	0.3958	0.4139	0.1683	0.0202	0.0019	1.0000

SPEED and *MYSPD*: SPEED is the quantitative variable representing the speed of the vehicle that potentially conflicts with a respondent's car. MYSPD is the quantitative variable representing the speed of the respondent's car. Both attributes have negative effects on a drivers' perception of safety. They are measured in the same unit so their effects are comparable. The ratio of the SPEED and MYSPD coefficients is 1.95. This indicates that the effect of SPEED is 1.95 times as large as that of MYSPD. Drivers may see that other vehicles approaching at the speed of 45 km/h is unsafe, but possibly think it is safe when his/her car is driven at the same speed. This interpretation is similar to interpreting the *rate of substitution* in consumer behaviour studies. However, rate of substitution is behaviourally meaningless because drivers cannot reduce the speed of other vehicles in trading-off an increased speed of their vehicle, so we do not interpret the coefficients in this way.

The quantitative variable, SPEED, is convenient in investigating how the predicted probabilities of safety perception categories change as the level of SPEED increases (or decreases). Table 9-8 summarises the predicted probabilities when SPEED is set to 10, 20, 30, 40 and 50 km/h, while holding other variables constant. As the level of SPEED increases, the probability that the road and traffic situation is rated as *very unsafe* increases, while the probabilities of other categories decrease.

Table 9-8 Predicted probabilities of safety perception: the speed of the potentially conflicting vehicle

Variable	Prob(y=0)	Prob(y=1)	Prob(y=2)	Prob(y=3)	Prob(y=4)	Sum
SPEED=10	0.2989	0.4314	0.2297	0.0359	0.0042	1.0000
SPEED=20	0.4764	0.3840	0.1264	0.0123	0.0009	1.0000
SPEED=30	0.6587	0.2807	0.0569	0.0034	0.0002	1.0000
SPEED=40	0.8098	0.1684	0.0210	0.0008	0.0000	1.0000
SPEED=50	0.9108	0.0828	0.0063	0.0001	0.0000	1.0000

BUSYT and *MODET*: Effects-coded variables where traffic at the roundabout is busy and moderate respectively. BUSYT has a negative effect while MODET has a positive effect on the perception of safety. BUSYT and MODET are the first and second levels of the attribute representing the overall traffic at the roundabout, which has three levels. The third level of the attribute indicates the situation that traffic at the roundabout is light. If we use LIGHT representing the third level, then its effect is:

$$\beta_{LIGHT} = (-1) \times (\beta_{BUSYT} + \beta_{MODET}) = (-1)*(-0.4637 + 0.1471) = 0.3166.$$

PEDSY: Effects-coded variable representing the situation where there is a pedestrian trying to cross the road in front of a respondent's car. PEDSY has the highest negative effect among all attribute variables. This suggests that respondents connect a strong unsafe perception to the presence of a pedestrian who may conflict with their driving.

The estimated coefficients can be used to investigate the relative importance of attributes to driver's perception of safety, as shown in figure 9-2. An obstructed visibility has the largest negative effect on the perception of safety. Other importance variables negatively influencing the perception of safety include presence of a conflicting pedestrian, increased speed of conflicting vehicle and a large roundabout etc. On the other hand, drivers perceive a clear visibility, a decreased speed of conflicting vehicle and a small roundabout as safe factors.

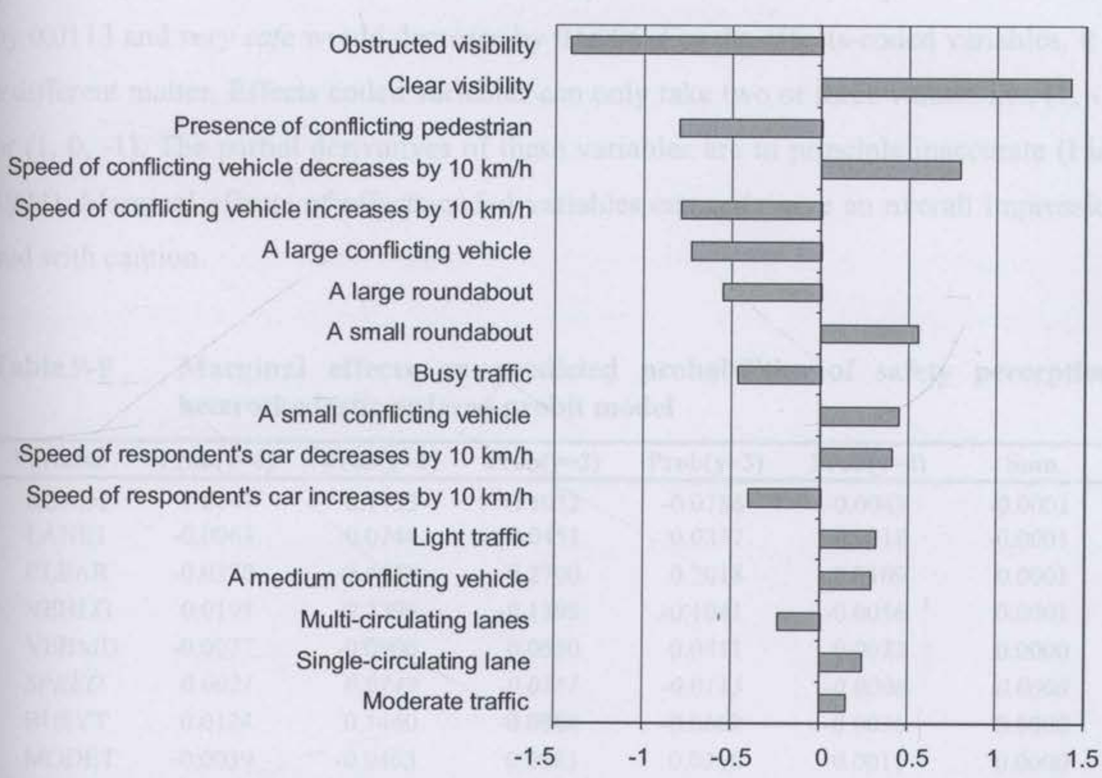


Figure 9-2 Relative importance of attributes influencing driver's perception of safety

Other socio-demographic characteristics: Nine socio-demographic variables entered the model. These influence the probabilities of the perception of safety through the variance function. If the variance is small, a lesser differentiation in choice among the safety perception categories would be observed, and vise versa.

Finally, the marginal effects of the attribute variables are given in table 9-9. Investigating marginal effects in an ordered probit model represents a useful approach to look at the changes in the event probabilities. However, we should note the difference between continuous and effects-coded variables.

For the continuous variables, the marginal effect represents the change in predicted probabilities in safety perception categories given a unit change in an attribute level. For example, given a unit increase in SPEED, the probability that the road and traffic scenario is rated as *very unsafe* would increase by 0.0021, *somewhat unsafe* would increase by 0.0249, *neutral* would decrease by 0.0151, *somewhat safe* would decrease by 0.0113 and *very safe* would decrease by 0.0006. For the effects-coded variables, it is a different matter. Effects coded variables can only take two or three values, i.e., (1, -1) or (1, 0, -1). The partial derivatives of these variables are in principle inaccurate (Liao 1994). Marginal effects of effects-coded variables can only give an overall impression and with caution.

Table 9-9 Marginal effects on predicted probabilities of safety perception: heteroskedastic ordered probit model

Variable	Prob(y=0)	Prob(y=1)	Prob(y=2)	Prob(y=3)	Prob(y=4)	Sum
ROUDL	0.0147	0.1733	-0.1052	-0.0786	-0.0043	-0.0001
LANE1	-0.0063	-0.0744	0.0451	0.0337	0.0018	-0.0001
CLEAR	-0.0378	-0.4448	0.2700	0.2018	0.0109	0.0001
VEHLG	0.0195	0.2296	-0.1393	-0.1041	-0.0056	0.0001
VEHMD	-0.0077	-0.0906	0.0550	0.0411	0.0022	0.0000
SPEED	*0.0021*	*0.0249*	*-0.0151*	*-0.0113*	*-0.0006*	*0.0000*
BUSYT	0.0124	0.1460	-0.0886	-0.0662	-0.0036	0.0000
MODET	-0.0039	-0.0463	0.0281	0.0210	0.0011	0.0000
PEDSY	0.0214	0.2516	-0.1527	-0.1141	-0.0062	0.0000
MYSPD	0.0011	0.0128	-0.0077	-0.0058	-0.0003	0.0001

9.6 Development of an Indicator of Perceived Safety

Respondents evaluated the safety of 27 road and traffic scenarios. Respondents' choices on ordered categories can be viewed as discrete realisations of unmeasured continuous variables. Based on their choices, we analysed the perception of safety in the road and traffic scenarios using the method of ordered probability analysis as presented in previous sections. The aim of this section is to develop a set of *indicators of perceived safety* (IPS) for the various road and traffic situations. The conceptualisation of using ordered probability analysis to develop the quality index is not new. Hensher (1989) estimated an ordered probit model to derive the predicted relative satisfaction indicators to capture the image-enhancement of Sydney bus services. We use a similar notation to develop the IPS, based on respondents' safety perceptions on each specific scenario. The IPS serves as a general indication of safety properties of the road and traffic environment. The IPS for experimentally designed scenarios 1-27 will also be used as an explanatory variable to investigate the relationship between driver's safety perception and driving behaviour in chapter ten.

We start at a road and traffic scenario. The scenario has a set of attributes, x_k, which are observed. A respondent was asked to evaluate the safety of the scenario and gave a response of safety perception scale, y_i. We established the relationship between y_i and x_k using the ordered probit model (model 5) and estimated a set of β_k. The estimated β_k is the *theoretical contribution* of x_k to safety perception y_i, which can be directly translated as a change in the explanatory variable into a change in the dependent variable (Achen 1982:69). If the estimate β_k is positioned in a particular measurement space X, $X = x_1$. x_2, ... x_k, its effects are $\beta_k x_k$ termed *level contribution* (Achen 1982:72). The sum of all level contributions ($\sum\beta_k x_k$) represents the overall safety perception in that measurement space. The thresholds μs are eigenvalues that determine which ordered category the overall safety perception falls into.

The sum of level contributions can be negative or positive. Because we intend to use IPS as an overall safety indication of road and traffic scenario, it would be inconvenient to interpret a negative indicator. As we previously discussed, the threshold parameters (μs) that separate the adjacent safety perception categories are free parameters. Their scale is arbitrary and can start and finish with any value. Therefore, we normalised level contributions into a new scale to make all values positive. These rescaled overall safety perception values are the indicators of perceived safety (IPS) for road and traffic scenarios.

We investigate the driver's perception of safety at 13 typical road and traffic situations as given in table 9-10. The situation 1 represents a safer scenario, from which an attribute level is changed one at a time so that the latter situation is a little un-safer than the previous one. Table 9-10 summarises the IPS for these typical situations, which clearly demonstrate how driver's perception of safety changes as the attribute of road or traffic changes. Theoretically, each respondent has a specific set of IPS because each respondent has a unique set of socio-economic variables. We derived the IPS for all drivers as well as other six typical driver segments: female commuter, female non-commute, male commuter, male non-commuter, female young, and male young. Female-commuter and female non-commuter have a lower than average safety indicators. Other segments have a higher than average indicators. The male young have the highest IPS, suggesting that male young drivers see the road and traffic situations much safer than an average driver does. Graph is more intuitively appealing than table to look at the IPS. Figure 9-3 shows the IPS for different driver segments at the road and traffic situation 7 (table 9-10 and table 9-11). Figure 9-4 shows the IPS for different drivers segments at all 13 typical road and traffic situations. Table 10-12 gives the derived IPS for 27 experimentally designed scenarios, where we can see that scenario 6 is the safest and scenario 14 is the most unsafe.

Table 9-10 Typical road and traffic situations under investigation

Scenario	Size of the roundabout	Number of circulating lanes	Visibility to other traffic	Size of other conflicting vehicle	Speed of other conflicting vehicle	Traffic at the roundabout	Presence of a pedestrian	Speed of the respondent's car
Situation1	Small	Single	Clear	Small	20	Light	Non Presence	***20***
Situation2	Small	Single	Clear	Small	20	Light	Non Presence	***40***
Situation3	Small	Single	Clear	Small	20	Light	Non Presence	***60***
Situation4	Small	Single	Clear	Small	20	Light	***Presence***	60
Situation5	Small	Single	Clear	Small	20	***Moderate***	Presence	60
Situation6	Small	Single	Clear	Small	20	***Busy***	Presence	60
Situation7	Small	Single	Clear	Small	***40***	Busy	Presence	60
Situation8	Small	Single	Clear	Small	***60***	Busy	Presence	60
Situation9	Small	Single	Clear	***Medium***	60	Busy	Presence	60
Situation10	Small	Single	Clear	***Large***	60	Busy	Presence	60
Situation11	Small	Single	***Obstructed***	Large	60	Busy	Presence	60
Situation12	Small	***Two or More***	Obstructed	Large	60	Busy	Presence	60
Situation13	***Large***	Two or More	Obstructed	Large	60	Busy	Presence	60

Table 9-11 Indicator of perceived safety (IPS): all drivers and six driver segments

Scenario	All Drivers	Female Commuter	Female Non-Commuter	Male Commuter	Male Non-Commuter	Female Young	Male Young
Situation1	13.560	12.932	11.142	15.964	13.754	14.727	18.179
Situation2	12.750	12.160	10.476	15.010	12.932	13.848	17.093
Situation3	11.940	11.387	9.811	14.057	12.110	12.968	16.007
Situation4	10.341	9.862	8.497	12.174	10.488	11.231	13.863
Situation5	10.171	9.701	8.357	11.974	10.316	11.047	13.636
Situation6	9.560	9.118	7.855	11.255	9.697	10.383	12.816
Situation7	7.980	7.611	6.557	9.395	8.094	8.667	10.698
Situation8	6.400	6.104	5.259	7.534	6.491	6.951	8.580
Situation9	6.246	5.957	5.133	7.354	6.336	6.784	8.374
Situation10	5.229	4.987	4.296	6.156	5.304	5.679	7.010
Situation11	2.402	2.291	1.974	2.828	2.436	2.609	3.220
Situation12	1.929	1.840	1.585	2.271	1.957	2.095	2.586
Situation13	0.828	0.790	0.680	0.975	0.840	0.899	1.110

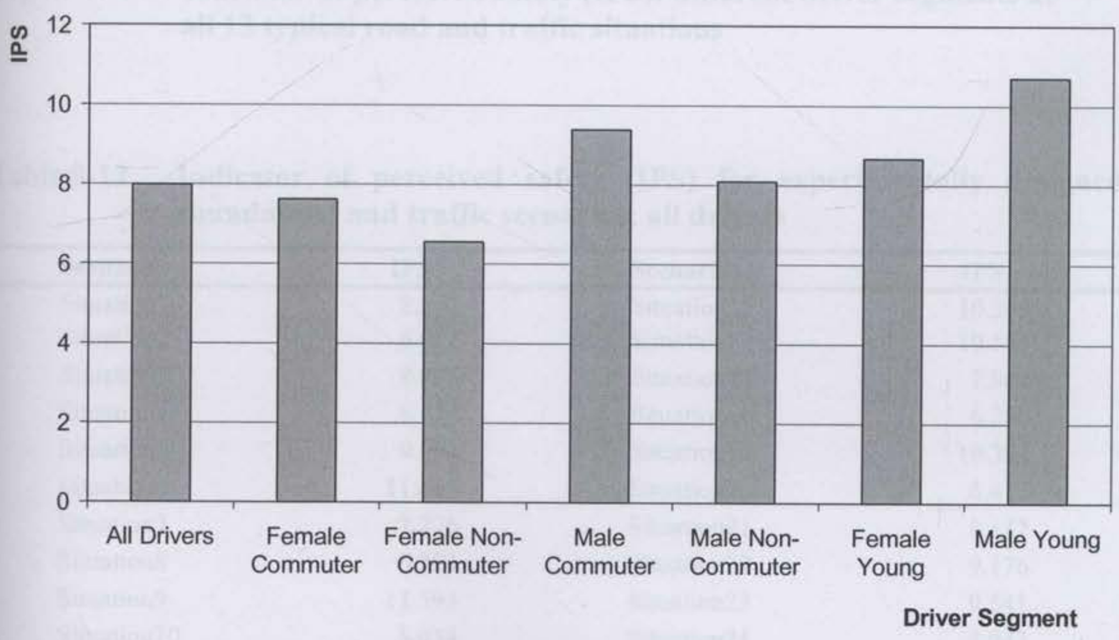


Figure 9-3 Indicator of perceived safety: different driver segments at road and traffic situation 7

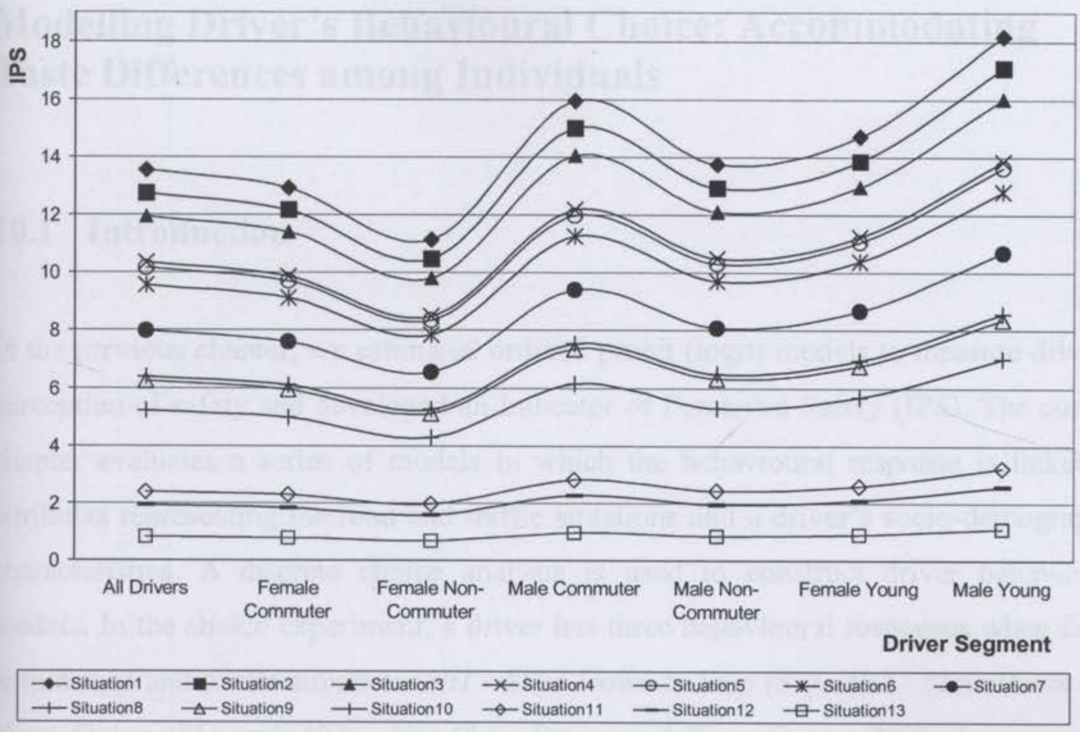


Figure 9-4 Indicator of perceived safety (IPS): different driver segments at all 13 typical road and traffic situations

Table 9-12 Indicator of perceived safety (IPS) for experimentally designed roundabout and traffic scenarios: all drivers

Scenario	IPS	Scenario	IPS
Situation1	8.252	Situation15	10.395
Situation2	6.022	Situation16	10.555
Situation3	9.406	Situation17	7.842
Situation4	6.124	Situation18	6.288
Situation5	9.264	Situation19	10.394
Situation6	**11.805**	Situation20	6.411
Situation7	7.276	Situation21	8.132
Situation8	6.284	Situation22	9.176
Situation9	11.593	Situation23	9.541
Situation10	5.034	Situation24	8.943
Situation11	7.297	Situation25	7.322
Situation12	10.092	Situation26	8.656
Situation13	10.314	Situation27	10.827
Situation14	**4.042**		

Chapter Ten

Modelling Driver's Behavioural Choice: Accommodating Taste Differences among Individuals

10.1 Introduction

In the previous chapter, we estimated ordered probit (logit) models to measure drivers' perception of safety and developed an Indicator of Perceived Safety (IPS). The current chapter evaluates a series of models in which the behavioural response is linked to attributes representing the road and traffic situations and a driver's socio-demographic characteristics. A discrete choice analysis is used to construct driver behavioural models. In the choice experiment, a driver has three behavioural responses when faced with a road and traffic situation: *Alt1 - Slow Down to Stop (ST)*, *Alt2 - Slow Down and Keep Going (SL)* and *Alt3 - Not Slow Down and Keep Going (KG)*. An important question in the modelling of driver behaviour is the role that the road and traffic attributes play in influencing the probability that drivers will choose a specific behavioural alternative. A driver's behavioural response is a result of a trading-off between safety and mobility. When a driver chooses one behavioural option, s/he also chooses a level of mobility and a level of safety or risk associated with it. It is assumed that the driver assigns an index to all possible behavioural options. The index is derived from the attributes of the road and the characteristics of traffic. The driver can maximise the index with respect to the underlying behavioural paradigm by choosing one specific behavioural option in each situation. This process of decision making and behavioural response can be modelled using the random utility approach, which assumes that an individual compares a set of mutually exclusive alternatives and chooses one alternative that produces the highest utility.

If we denote U_{njt} as the utility of the j^{th} alternative for the n^{th} individual at time period t, a utility function is generally expressed as (Louviere et al 2000, Ben-Akiva and Lerman 1985, Hensher and Johnson 1981):

$$U_{njt} = V_{njt} + \varepsilon_{njt} \quad (10\text{-}1)$$

The utility value is partitioned into two components: a systematic component V_{njt} and a random component ε_{njt}. The systematic component is the part of utility contributed by the attributes, $V_{njt} = \Sigma\beta'_n X_{njt}$, where the β's are utility (preference) parameters and the X's are attributes. The preference parameter associated with V_{njt} are assumed to be the same for all individuals (in the multinomial logit model) or varied around a mean following a distribution (in the mixed logit model). This part of utility is observable by the analyst. The random component is the utility contributed by attributes unobserved by the analyst. The random component arises because the analyst cannot 'peep into the head' of each individual and fully observe all influencing factors and the complete decision rules (Hensher and Johnson 1981). If we assume that an individual chooses an alternative with the highest utility, and ε_{njt} follows the extreme value type I (EVI) distribution (also referred as Weibull, Gumbel and double exponential), the multinomial logit (MNL) model can be derived (Hensher and Johnson 1981, Louviere et al 2000). Specifically,

$$P_i = \frac{\exp(V_i)}{\sum_{j=1}^{J} \exp(V_j)} \qquad (10 - 2)$$

where P_i is the probability that an individual chooses alternative i from a choice set with $j=1,2,...,J$ alternatives. The MNL model has three unique properties. (1) The assumption of *Independence from Irrelevant Alternatives (IIA)* holds. This implies that the ratio of the probabilities of choosing one alternative over another (given that both alternatives have a non-zero probability of choice) is unaffected by the presence or absence of any additional alternatives in the choice set (Louviere et al 2000). (2) The coefficient β's are fixed over the individuals. (3) Because the random components ε's are assumed *Independently and Identically Distributed (IID)*, the individual choice is independent across the alternatives and between the choice sets. The MNL model can be estimated using the maximum likelihood method, which is a consistent, asymptotically efficient estimator. The log-likelihood function of the MNL model is globally concave (McFadden 1981), suggesting that as long as an estimation is found, it is unique.

In our experiment, each individual evaluated a group of 27 road and traffic situations at a time. A number of behavioural phenomena can arise under these conditions: (1)

choice set correlation can exist due to repeated choices made by an individual, and (2) the three behavioural alternatives can be correlated for a given choice situation. If the correlation is significant, the MNL model can lead to biased utility parameters. An appropriate specification is the mixed logit (ML) model.

Mixed logit models allow the utility parameter β's associated with an observed attribute to vary randomly over the sampled individuals. Each random parameter can be specified as normal, lognormal or nonstochastic (i.e. no variance). The moments of such a distribution can be estimated. The ML model can accommodate the choice set correlation and/or correlation between response alternatives. Thus, the ML model does not exhibit the *independence from irrelevant alternatives* (IIA) properties. This chapter estimates ML and MNL models to investigate driver behavioural responses. The specification and estimation of the mixed logit model is discussed in section 10.2. In section 10.3, we evaluate a series of driver's behavioural response models by linking the behavioural responses to attributes of the roundabout and traffic situations and the characteristics of the drivers. In section 10.4, we infer the behavioural responses from the estimated models. The last section concludes the chapter with a summary.

10.2 Specification and Estimation of the Mixed Logit Model

Mixed logit was developed relatively recently with a small but growing number of applications. Because of its flexibility in model specification, it has taken different forms and has been referred to by various nomenclatures. The earliest applications include Boyd and Mellman (1980) and Cardell and Dunbar (1980). They used aggregate share data and assumed that the coefficients of the explanatory variables do not vary over individuals, thus the integration is calculated for only "one individual" (see comments in Revelt and Train 1997). When the coefficients of explanatory variables are allowed to vary over individuals, *random parameters logit* or *random coefficients logit* has been used (e.g. Ben-Akiva and Lerman 1985, Train 1998, Bhat 1996, Econometrics Software 2000). *Error components logit* was used in Brownstone and Train (1999) which reflects the fact that the random term of the utility can be decomposed into several components and these components can be specified to provide realistic and flexible substitution patterns. Ben-Akiva and Bolduc (1999) used the term "*multinomial* *probit with a logit kernel*" to describe the situation that the individual-specific parameters are normally distributed. *Mixed logit* generalised all situations where the choice probability is specified as a mixture of logits with a specified mixing distribution (Revelt and Train 1997, McFadden and Train 1998). Because of this generality, the term mixed logit reflects any interpretation of a mixture of IID logit and a free distribution in the additive component of the random errors.

Model Specification: Continuing from equation (10-1), the vector of coefficients β_n is unobserved for each individual n and varies over individuals following a distribution with a density function of $f(\beta_n|\theta^*)$, where θ^* are the true parameters of this distribution. Conditional on β_n, the probability that individual n chooses alternative i in choice situation t takes the multinomial logit form. That is,

$$L_{nit}(\beta_n) = \frac{e^{\beta_n' x_{nit}}}{\sum_j e^{\beta_n' x_{njt}}} \qquad (10-3)$$

The unconditional probability is the integral of the conditional probability over all possible values of β_n, which is dependent on distribution parameters θ^* (Train 1998),

$$Q_{nit}(\theta^*) = \int L_{nit}(\beta_n) f(\beta_n \mid \theta^*) d\beta_n = \int \frac{e^{\beta_n' x_{nit}}}{\sum_j e^{\beta_n' x_{njt}}} f(\beta_n \mid \theta^*) d\beta_n \qquad (10-4)$$

For maximum likelihood estimation, we need the probability of each individual's sequence of observed choices. We denote $i(n,t)$ as the alternative that is chosen by individual n at the choice situation or time period t. Conditional on β_n, the probability that individual n makes the observed choice sequence is the product of the multinomial logits,

$$S_n(\beta_n) = \prod_t L_{ni(n,t)t}(\beta_n) \qquad (10-5)$$

The unconditional probability for the chosen sequence is the integral of the conditional probability over all possible values of β_n, which is again dependent on distribution parameters θ^*,

$$P_n(\theta^*) = \int S_n(\beta_n) f(\beta_n \mid \theta^*) d\beta_n \tag{10-6}$$

The coefficient β_n is a vector of parameters associated with person n. These parameters represent individual tastes, unobservable for each individual. These tastes vary over individuals following a distribution. The θ^* are the moments of the density function of this distribution representing the mean and covariance of β_n.

Model estimation: One of objectives of estimating a mixed logit model is to estimate θ^*. (Other objectives include estimating the elements of the correlation matrix and individual heterogeneity in the mean for random parameters. See estimation results of model 4 and model 5 in the next section). The log likelihood function for equation (10-6) is $LL(\theta) = \sum_n lnP_n(\theta)$. Maximum likelihood estimation involves calculation of the multiple dimensions of the integral, which does not exist in a closed form. The dimension of the integral increases with the number of coefficients allowed random in the model. Ben-Akiva et al (1993) estimated a mixed logit model using a Gaussian quadrature to evaluate the integral. As the dimension of integrals gets larger, the Gaussian quadrature becomes impossible to implement. Simulated maximum likelihood (SML) estimation methods have been derived to estimate the mixed logit model. For example, Lee (1992) and Hajivassiliou and Ruud (1994) derived the asymptotic distribution of the maximum simulated likelihood estimator based on smooth probability simulators with the number of repetitions increasing with sample size. Bhat (1996) and Revelt and Train (1997) discussed the SML methods for estimation of mixed logit models. Most recently, Econometric Software (2000) implemented the SML estimation method, providing analysts with a mixed logit model capability without complex computing.

In SML estimation, the integrals are approximated by a simulator sampling from multivariate normal probabilities and then averaging. The GHK (Geweke, Hajivassiliou, Keane) methodology is used to approximate the multivariate normal cumulative density function (CDF) (Greene 1997). The technique produces quick and accurate approximations up to the 20-fold integrals, although the accuracy declines with increased dimensions of the integral. Almost all recent applications of mixed logits have used SML as the estimation methods (eg, Hensher 2000b, Brownstone and Train 1999, Train, 1998, Louviere et al 2000, Revelt and Train 1997). A simplified simulation process is described below (Algers et al 1998):

(1) Set the starting values for the parameters of interest. For example, set the mean b and variance σ for a normally distributed coefficient β. Generally, we use the parameter estimation of standard logit as the starting values.
(2) Draw an individually specific coefficient β_n from the specified distribution for each individual. This coefficient is kept constant for the individual over all of his/her responses. The random coefficients are distributed as $\beta \sim N(b, \sigma)$.
(3) Use observed data and the obtained random coefficient to evaluate the log-likelihood function $LL_r(\theta)$ as if the random coefficients are fixed.
(4) Repeat the draw and evaluate the log-likelihood function for each draw (step 2 & 3) for R times. Compute the average log-likelihood, which is simulated log-likelihood value.

$$SLL(\theta) = \sum_{r=1}^{R} LL_r(\theta) / R \qquad (10-7)$$

(5) Reset the parameters of b and σ and repeat step (2) to step (4) until a maximal value of simulated log likelihood is found. The value of b and σ are simulated maximum likelihood estimates of β.

The SML is an unbiased estimator of $P_n(\theta)$ whose variance decreases as R increases. It is smooth (twice-differentiable) which helps in the numerical search for the maximum of the simulated log-likelihood function. It is strictly positive for the finite R draws such that the log of the simulated probability is always defined (Revelt and Train 1997). McFadden and Train (1998) established the following results for the SML estimator:

(1) Under mild regularity conditions, any discrete choice model derived from random utility maximisation has choice probabilities that can be approximated as close as one pleases by a mixed logit model. In fact, when the random taste

weights are all set to the mean (ie fixed), the exact MNL model is produced (Hensher 2000b).

(2) A mixed logit model with normally distributed coefficients can approximate a multinomial probit (MNP) model as closely as one pleases. If a mixed logit model is specified in which all alternative specific constants are random, all utility parameters are not random and free correlation in the covariance matrix is allowed, the exact MNP model is produced. This implies that a mixed logit can be used whenever the MNP is appropriate. Also, this means that the mixed logit model can provide an alternative method for estimating the MNP model, using simulation instead of direct integration (Econometric Software 2000). This is especially attractive if the dimensionality of the mixed distribution is less than the number of alternatives (eg there are 59 alternatives and seven random parameters in Train 1998). The mixed logit simulator has an advantage over the MNP model simply because the simulation is over fewer dimensions.

Halton sequence: Estimation of the mixed logit model generally requires a large number of draws to assure reasonably low simulation error in the estimated parameters. The large number of draws means a long computer run-time. (Estimation of mixed logit model is quite time consuming. For an estimation task with 5000 observations and 12 random parameters using 500 random draws, the estimation takes about 80 hours on a Pentium 133 RAM 32 MB computer, or takes about 5 hours at a Work Station with RAM 256 MB). Procedures have been proposed for taking intelligent draws from a distribution rather than random ones (Sloan and Wozniakowski 1998). One such procedure is Halton sequence draws. A Halton draw procedure is detailed in Train (1999). Empirical investigations have found that Halton sequences for the mixed logit estimation are vastly superior to random draws. Hensher (2000b) concluded that a Halton draw number as small as 50 produces a very good model fit. Bhat (1999) found that the simulation error in the estimated parameters was lower using 100 Halton numbers than 1000 random numbers. In particular, the estimation error with 125 Halton draws was half as large as with 1000 random draws and smaller than with 2000 random draws. Train (1999) confirmed Bhat's results and illustrated two possible reasons for improvements: (1) Halton numbers are designed to give fairly even coverage over the domain of the mixing distribution. With more evenly spread draws for each observation, the simulated probabilities vary less over observations, relative to those calculated with random draws. In fact, if random draws are used, the estimation results are always different when a model runs twice with exactly the same specification in two runs. Although the difference is not large, it causes much inconvenience in model interpretation. If we use the Halton sequence instead, the estimation results are exactly the same over two runs. (2) With Halton sequences, draws for one observation tend to fill in the spaces left empty by the previous observations. The simulated probabilities thus become negatively correlated over observations which reduces the variance in the log-likelihood function. We use Halton draws in our model estimation.

Correlation: The Mixed Logit models accommodate correlations between alternatives as well as correlations between choice sets. The variation of β_n can explain any possible correlation in utility over repeated choices and between alternatives. In particular, the coefficient vector for each individual β_n can be expressed as the sum of the population mean b and individual deviation μ_n, representing the individual tastes relative to the average tastes in the population. Continuing on equation (10-1), utility is $U_{njt} = b'x_{njt} + \mu'_n W x_{njt} + \varepsilon_{njt}$. We estimate b but cannot observe μ_n for each individual. Thus, the unobserved portion of utility is $\mu'_n W x_{njt} + \varepsilon_{njt}$. *Because this portion of utility is used by an individual for all choice situations, it introduces choice set correlation, and the correlation among alternatives in a choice set.* To investigate the various correlation patterns, we can specify $\beta_n \sim N(b,\Omega)$ for general Ω. The coefficient vector is expressed as $\beta_n = b+L\mu_n$ where L is a lower triangular factor in *Cholesky matrix* for Ω, so that $LL'=\Omega$, and μ_n is a vector of independent standard normal deviates. In this way, we can estimate both b and L.

Distribution of coefficients: The mixed logit model permits analysts to nominate a number of coefficients (including alternative specific constants) as random parameters with the mean estimated together with the standard deviation. The selected random parameters are specified to follow either a normal or lognormal distribution, although it is possible to use other distributions (e.g. uniform and triangular distributions). There is no formal guide for the selection of a distribution assumption. However, each distribution has unique properties that help us determine which distribution to use. A normal distribution may produce both positive and negative values across the parameter distribution. A lognormal distribution contains one sign but typically produces a very thick tail that is behaviourally implausible for evaluation (Hensher 2000b). For a random parameter, the coefficient vector can be expressed as $\beta_n = b + W\mu_n$, where b is a vector of means representing the average taste among the population, W is a vector of diagonal elements in the Cholesky matrix whose values represent standard deviations, μ_n is a vector of independent standard normal deviates. If n is an element in β following a normal distribution, this coefficient can be expressed as $\beta_n = b_n + \eta_n\mu_n$, where b_n and η_n are parameters to be estimated, representing the mean and standard deviation of β_n. On the other hand, if k is an element in β following a lognormal distribution, the coefficient can be expressed as $\beta_k = exp(b_k + \eta_k\mu_k)$, where b_k and η_k are parameters to be estimated, representing the mean and standard deviation of $ln(\beta_k)$. The median, mean, and standard deviation of β_k are $exp(b_k)$, $exp(b_k+(\eta_k^2/2))$, and $exp(b_k+(\eta_k^2/2))*(\sqrt{[exp(\eta_k^2)-1]})$ respectively.

Preference heterogeneity: In a mixed logit model, a random parameter can be simply varying around a mean that is the same for all individuals. This specification cannot capture the variation in parameters that is related to observed characteristics of individuals. In multinomial logit models, the variations in parameters can be captured through the interaction of individual characteristics with attributes of the alternatives. In the mixed logit, the mean of parameters can be related to a number of contextual variables (eg income and age), such that,

$$\beta_n = b_n + \delta_n W_n + \eta_n \mu_n \qquad (10\text{-}8)$$

where W_n is a vector of choice invariant characteristics that produce individual heterogeneity in the means of the randomly distributed coefficients, the δ_n is a vector of coefficients for W_n (also referred to as "deep" coefficients), and other symbols are defined previously.

In summary, advantages of using the mixed logit specification include:

(1) The mixed logit model accommodates preference heterogeneity by introducing random coefficients. The mean and the standard deviation can be estimated. The heterogeneity in the mean can be refined by making it a function of observed individual contextual variables (invariant of choices).

(2) The model does not exhibit the IIA property. By decomposing the random term into two parts, one part has a general distribution over alternatives and individuals, and the remaining part is assumed IID Extreme Value I, the mixed logit disentangles IID from IIA (Hensher 2000b).

(3) The model accounts for various correlation patterns. This provides a way of investigating choice set correlation of the repeated choices, a common feature of stated choice experiments.

10.3 Driver's Behavioural Responses to Road and Traffic Attributes

10.3.1 Specification of the Behavioural Response Model

Random utility models are used for modelling driver behavioural responses. The utility derived by individual *n* choosing option *j* in choice situation *t* takes a general form as described in equation 10-1. The utility functions for three alternatives of behavioural responses are given in equation 10-9. Variables entering into each utility function include two alternative-specific constants and twelve attributes.

*U(ST) = RoudL*RoudL + VehLG*VehLG + Speed*Speed + BusyT*BusyT + PedsY*PedsY + MySpd*MySpd*

*U(SL) = A_SL + RoudL*RoudL + RoudM*RoudM + Lane1*Lane1 + Clear*Clear + VehLG*VehLG + VehMD*VehMD + Speed*Speed + BusyT*BusyT + ModeT*ModeT + PedsY*PedsY + MySpd*MySpd + Hurry*Hurry*

*U(KG) = A_KG + RoudM*RoudM + Lane1*Lane1 + Clear*Clear + VehMD*VehMD + ModeT*ModeT + Hurry*Hurry*

(10-9)

where *U(ST), U(SL) and U(KG)* are utilities respectively for *Alt1- Slow Down to Stop*, *Alt2 - Slow Down and Keep Going* and *Alt3 - Not Slow Down but Keep Going*. *A_SL* and *A_KG* are alternative specific constants associated with alternative 2 and 3 respectively. The coefficients of attributes take the same name as their attributes (e.g. in *RoudL*RoudL*, the first *RoudL* represents the coefficient and the second represents the attribute). All attributes have been defined in chapter six. Since three alternatives in a choice situation share the same set of attributes, each attribute can only be included in the utility functions for two alternatives. (Inclusion of an attribute in the utility functions for all alternatives leads to singularity of the variance matrix of the estimates, so that the model is not estimable. This specification of utility function requires caution in parameter interpretation).

Data used to estimate the driver behavioural response models have been described in chapter six. Each of 94 respondents provides 27 choice situations to yield 5238 observations. Five behavioural response models are specified as described in table 10-1.

Table 10-1 Behavioural response models

Model	Utility Parameters	Correlation among Alternatives	Correlation among Repeated Choice	Preference Heterogeneity
Model 1	Not-random	No	No	No
Model 2	*Random*	No	No	No
Model 3	*Random*	*Yes*	No	No
Model 4	*Random*	*Yes*	*Yes*	No
Model 5	*Random*	*Yes*	*Yes*	*Yes*

Notes:

- *Model 1 - The multinomial logit model*. All utility parameters are fixed.
- *Model 2 - The simple mixed logit model*. Some utility parameters are allowed to be random.
- *Model 3 - The mixed logit model with correlation between alternatives*. Some utility parameters are allowed to be random. The correlation between alternatives in the choice set is estimated.
- *Model 4 - The mixed logit model with choice set correlation and correlation between alternatives*. Some utility parameters are allowed to be random. The choice set correlation together with the correlation between alternatives in a choice set is estimated.
- *Model 5 - The mixed logit model with heterogeneity in mean, choice set correlation and correlation between alternatives*. Some utility parameters are allowed to be random. The choice set correlation together with the correlation between alternatives in choice sets is estimated. The heterogeneity in the means of utility parameters is refined by a function of contextual variables. The associated parameters for heterogeneity are estimated.

10.3.2 Statistical Measures for Assessment of Discrete Choice Models

Five driver behavioural models differ in assumptions and complexity. In a statistical sense, model 5 is the best model in that it is the least restrictive and accounts for choice set and alternative correlation as well as heterogeneity of mean. However, a model best in a statistical sense is not necessarily the best in a behavioural sense. Analyst judgement about overall model validity should also exercise an influence in selecting the preferred model. Nevertheless, there are a number of statistical measures of model validity that can assist assessment of an empirically estimated individual choice model, as discussed below.

Statistical significance of utility parameters (βs): Statistical significance involves testing whether a particular parameter β is significantly different from zero. The maximum likelihood (or simulated ML) estimation procedure calculates asymptotic standard errors for the preference parameter βs and employs these to test the statistical significance of individual preference parameters using the asymptotic t-test. Typically analysts will seek out mean utility parameters which have sufficiently small standard errors to ensure that the mean estimate is a good representation of the influence of the particular attribute in explaining the level of relative utility associated with each alternative.

Overall goodness of fit: Under the maximum likelihood estimation method, the overall goodness of fit can be assessed using the log likelihood function at the mean of the estimated utility parameters. The procedure, known as the *likelihood ratio* (LR) test, has the null hypothesis that the probability of an individual choosing an alternative is independent of the value of the parameters in the utility functions in the model. If this hypothesis is retained, the utility parameters are not statistically significantly different from zero. The generalised likelihood ratio criterion is:

$$LR = 2[LL(\beta) - LL(0)] \quad (10\text{-}10)$$

where LR is the likelihood ratio, $LL(0)$ is the maximum of the likelihood function with utility parameters (βs) constrained to zero, $LL(\beta)$ is the maximum of the likelihood function for unconstrained utility parameters. The *LR* is approximately χ^2 distributed with *N* degrees of freedom, where *N* is the number of parameters in the model. For a specific model, the null hypothesis is almost always rejected. Thus, the ability of the *LR* test to assess the overall significance of the model is limited. The usefulness of the *LR* test is to determine whether the subsets of the parameters are significant (ie should or should not be kept in the model) in a comparison of different model specifications.

Pseudo R^2: Louviere et al (2000) provides a likelihood ratio index as a pseudo R-squared to measure the overall goodness-of-fit of the choice models as follows:

$$R^2 = 1 - [L(\beta) / \sum_{q-1}^{Q} (J_q - 1) - K] \Big/ [L(0) / \sum_{q=1}^{Q} (J_q - 1)] \qquad (10\text{-}11)$$

where $L(\beta)$ is the maximised value of the log-likelihood; The $L(0)$ is the value of the log-likelihood evaluated with alternative specific constants only, such that the probability of choosing an alternative is exactly equal to the observed aggregate share of that alternative in the sample; J_q is the number of alternatives faced by individual *q*. The *K* is the degrees of freedom in the model. J_q and *K* are introduced to improve the pseudo R^2 by adjusting it for degrees of freedom. The higher the explanatory power of the attributes *Xs*, the larger is $L(\beta)$ in comparison to $L(0)$, and the larger the pseudo R^2. A pseudo R^2 between 0.2 and 0.4 is considered to be indicative of an extremely good model fit that is equivalent to 0.7 to 0.9 for R-squared in ordinary (linear) least squares regression models (Louviere et al 2000).

10.3.3 Estimation Results for Behavioural Response Models

Model 1 - The multinomial logit model: The estimation results are shown in table 10-2 (also see Appendix VI - Model 1 for Limdep estimation output). Some selected two-way interactions were tested and found statistically insignificant. The overall model performance is summarised below:

Table 10-2 Estimation results: multinomial logit model

Variables	Definition	Coefficient	t-Ratio	Significance
A_SL	Alternative specific constant	0.9630	17.62	0.00
A_KG	Alternative specific constant	1.5776	10.41	0.00
ROUDL	Large-sized roundabout	0.3548	6.79	0.00
ROUDM	Medium-sized roundabout	-0.5253	-10.67	0.00
LANE1	Single lane	0.1857	4.65	0.00
CLEAR	Clear visibility	1.3161	29.26	0.00
VEHLG	Large-sized vehicle	1.1670	19.98	0.00
VEHMD	Medium-sized vehicle	-0.1490	-2.79	0.01
SPEED	Speed of conflicting vehicle	5.1429	17.31	0.00
BUSYT	Busy traffic at roundabout	0.6236	10.84	0.00
MODET	Moderate traffic at roundabout	-0.2469	-5.16	0.00
PEDSY	Presence a pedestrian	0.7735	13.25	0.00
MYSPD	Speed of respondent's car	1.0708	4.04	0.00
HURRY	Respondent is in a hurry	1.5125	25.88	0.00
	Log-likelihood = 3869.835			
	Pseudo R^2 = 0.277			
	Degrees of freedom = 14			
	Number of observations = 5238			

- The model estimation indicates that all coefficients are significant at 5 percent level.
- The *LR* test indicates that the model is significant at the 0.000 level evaluated with χ^2 distribution with 14 degrees of freedom.
- The pseudo R^2 is 0.277.

Model 2 - The simple mixed logit model: The parameters ROUDL, ROUDM, CLEAR, VEHLG, SPEED, BUSYT, MODET, PEDSY and HURRY are specified random following the standard normal distribution, while LANE1, VEHMD, MYSPD and two alternative specific constants are not random. (This is a result of specification searches). The estimation results are summarised in table 10-3 and are detailed in Appendix VI - Model2. The output of model estimation includes the coefficients for random parameters, the coefficients for nonrandom parameters and the standard deviations for random parameters. The overall model interpretation is given below.

Table 10-3 Estimation results: simple mixed logit model

Variables	Definition	Coefficient	t-Ratio	Significance
	Random parameters in utility functions (all normally distributed)			
ROUDL	Large-sized roundabout	0.3548	6.79	0.00
ROUDM	Medium-sized roundabout	-0.5255	-10.67	0.00
CLEAR	Clear visibility	1.3168	29.20	0.00
VEHLG	Large-sized vehicle	1.1670	19.98	0.00
SPEED	Speed of conflicting vehicle	5.1431	17.31	0.00
BUSYT	Busy traffic at roundabout	0.6235	10.83	0.00
MODET	Moderate traffic at roundabout	-0.2468	-5.16	0.00
PEDSY	Presence a pedestrian	0.7734	13.24	0.00
HURRY	Respondent is in a hurry	1.5131	25.85	0.00
	Nonrandom parameters in utility functions			
A_SL	Alternative specific constant	0.9634	17.61	0.00
A_KG	Alternative specific constant	1.5780	10.41	0.00
LANE1	Single lane	0.1859	4.66	0.00
VEHMD	Medium-sized vehicle	-0.1492	-2.80	0.01
MYSPD	Speed of respondent's car	1.0710	4.04	0.00
	Derived standard deviations of parameters: Normal distributions			
NsROUDL	Large-sized roundabout	0.0017	0.01	0.99
NsROUDM	Medium-sized roundabout	0.0439	0.33	0.74
NsCLEAR	Clear visibility	0.0033	0.03	0.98
NsVEHLG	Large-sized vehicle	0.0123	0.09	0.93
NsSPEED	Speed of conflicting vehicle	0.0128	0.05	0.96
NsBUSYT	Busy traffic at roundabout	0.0087	0.07	0.95
NsMODET	Moderate traffic at roundabout	0.0146	0.10	0.92
NsPEDSY	Presence a pedestrian	0.0153	0.12	0.91
NsHURRY	Respondent is in a hurry	0.0193	0.18	0.86
	Log-likelihood = 3869.747			
	Pseudo R^2 = 0.277			
	Degrees of freedom = 23			
	Number of observations = 15714			

- All random and nonrandom parameters in utility functions are significant at the 5 percent level.
- None of standard deviations for random parameters are statistically significant, suggesting the parameters might be nonrandom. This is why the coefficients are quite similar to those in the multinomial logit model.
- The *LR* test indicates that the model is significance at the 0.000 level evaluated at χ^2 distribution with 23 degrees of freedom.
- The pseudo R^2 is 0.277.

The estimation result of the mixed logit model permits us to evaluate the variation of a parameter. Both the means and standard deviations of random parameters are estimated. The values of the 5th percentile and the 95th percentile are calculated as given in table 10-4. Because the standard deviations are not statistically significant, the variations are quite small.

Table 10-4 Mean, 5 percentile and 95 percentile values for random parameters: the simple mixed logit model

Variable	Definition	5 percentile	Mean	95 percentile
ROUDL	Large-sized roundabout	0.3520	*0.3548*	0.3576
ROUDM	Medium-sized roundabout	-0.5977	*-0.5255*	-0.4533
CLEAR	Clear visibility	1.3114	*1.3168*	1.3222
VEHLG	Large-sized vehicle	1.1468	*1.167*	1.1872
SPEED	Speed of conflicting vehicle	5.1220	*5.1431*	5.1642
BUSYT	Busy traffic at roundabout	0.6092	*0.6235*	0.6378
MODET	Moderate traffic at roundabout	-0.2708	*-0.2468*	-0.2228
PEDSY	Presence a pedestrian	0.7482	*0.7734*	0.7986
HURRY	Respondent is in a hurry	1.4814	*1.5131*	1.5448

Model 3 - The mixed logit model with correlation between alternatives: Model 3 considers the possible correlation between three alternatives. The parameters specified as random or nonrandom are exactly the same as model 2. The model is not estimable with a lack of convergence. The possible reasons are set out with discussion of model 4.

Model 4 - The mixed logit model with choice set correlation and correlation between alternatives: Model 4 considers two patterns of possible correlation, the correlation between choice alternatives and the correlation due to the repeatedly evaluated choice situations. The parameters specified as random or nonrandom are exactly the same as model 2. The output of model estimation includes means for random and nonrandom parameters, standard deviations for random parameters, a Cholesky matrix, a correlation matrix and a covariance matrix for random parameters. The estimation results are summarised in table 10-5, 10-6 and 10-7 and are detailed in Appendix VI – Model 4. The model performance is summarised below.

Table 10-5 Estimation results: model 4

Variables	Definition	Coefficient	t-Ratio	Significance
	Random parameters in utility functions			
ROUDL	Large-sized roundabout	0.3012	1.59	0.11
ROUDM	Medium-sized roundabout	-0.7262	-3.97	0.00
CLEAR	Clear visibility	1.3122	11.68	0.00
VEHLG	Large-sized vehicle	1.2049	6.16	0.00
SPEED	Speed of conflicting vehicle	4.9580	5.00	0.00
BUSYT	Busy traffic at roundabout	0.6877	3.69	0.00
MODET	Moderate traffic at roundabout	-0.1704	-0.88	0.38
PEDSY	Presence a pedestrian	0.7367	4.04	0.00
HURRY	Respondent is in a hurry	1.4490	7.80	0.00
	Nonrandom parameters in utility functions			
A_SL	Alternative specific constant	0.9970	9.86	0.00
A_KG	Alternative specific constant	1.7953	5.21	0.00
LANE1	Single lane	0.1913	2.24	0.03
VEHMD	Medium-sized vehicle	-0.1685	-1.00	0.32
MYSPD	Speed of respondent's car	1.2887	1.94	0.05
	Derived standard deviations of parameters: Normal distributions			
sdROUDL	Large-sized roundabout	0.0006	0.85	0.40
sdROUDM	Medium-sized roundabout	0.5010	***1450.51***	0.00
sdCLEAR	Clear visibility	0.3544	5.06	0.00
sdVEHLG	Large-sized vehicle	0.0579	0.25	0.80
sdSPEED	Speed of conflicting vehicle	1.2200	1.16	0.25
sdBUSYT	Busy traffic at roundabout	0.3776	0.85	0.39
sdMODET	Moderate traffic at roundabout	0.2279	0.86	0.39
sdPEDSY	Presence a pedestrian	0.1254	0.57	0.57
sdHURRY	Respondent is in a hurry	0.3148	0.53	0.60

Log-likelihood = 3820.574
Pseudo R^2 = 0.283
Degrees of freedom = 52
Number of observations = 15714

Table 10-6 Cholesky matrix for random parameters: model 4

	ROUDL	ROUDM	CLEAR	VEHLG	SPEED	BUSYT	MODET	PEDSY	HURRY
ROUDL	0.0006								
	(0.85)*								
ROUDM	**-0.3545**	**0.3540**							
	(-2.09)	**(2.09)**							
CLEAR	**-0.1448**	**-0.1448**	**0.2893**						
	(-1.69)	**(-1.69)**	**(1.68)**						
VEHLG	-0.0464	0.0244	0.0244	0.0024					
	(-0.19)	(0.10)	(0.10)	(0.00)					
SPEED	-0.8933	0.5684	-0.2066	0.5684	0.0400				
	(-0.91)	(0.73)	(-0.15)	(0.73)	(0.02)				
BUSYT	0.3108	-0.1509	-0.0008	-0.0184	-0.1509	0.0105			
	(0.94)	(-0.43)	(0.00)	(-0.02)	(-0.43)	(0.01)			
MODET	0.1912	-0.0240	-0.1123	0.0088	-0.0395	-0.0240	0.0001		
	(0.57)	(-0.07)	(-0.24)	(0.01)	(-0.04)	(-0.07)	(0.01)		
PEDSY	0.0738	-0.0496	0.0163	-0.0131	-0.0465	0.0192	-0.0496	0.0491	
	(0.25)	(-0.12)	(0.03)	(-0.03)	(-0.05)	(0.02)	(-0.12)	(0.12)	
HURRY	-0.2548	0.0112	0.1775	0.0458	0.0075	0.0121	-0.0007	0.0112	0.0101
	(-0.75)	(0.02)	(0.26)	(0.06)	(0.01)	(0.01)	(0.00)	(0.02)	(0.01)

* - t-Ratio in the brackets

Table 10-7 Correlation matrix for random parameters: model 4

	ROUDL	ROUDM	CLEAR	VEHLG	SPEED	BUSYT	MODET	PEDSY	HURRY
ROUDL	1								
ROUDM	**-0.7076**	1							
CLEAR	**-0.4085**	**0.0004**	1						
VEHLG	-0.8016	0.8652	0.4994	1					
SPEED	-0.7322	0.8473	-0.0294	0.7313	1				
BUSYT	0.8230	-0.8648	-0.1747	-0.8312	-0.8243	1			
MODET	0.8387	-0.6679	-0.7019	-0.9230	-0.5675	0.7978	1		
PEDSY	0.5882	-0.6955	0.0274	-0.5877	-0.6976	0.7993	0.5148	1	
HURRY	-0.8095	0.5978	0.7765	0.9077	0.5823	-0.6971	-0.9631	-0.4201	1

- The coefficients for two random parameters (ROUDL, MODET) and one nonrandom parameter (VEHMD) are statistically insignificant at the 10 percent level.
- Two standard deviations of parameter distributions (ROUDM, CLEAR) are statistically significant. Especially, the t-ratio for ROUDM is very large (1450.51), seemingly abnormal. This is a warning signal of mis-specification of the model. Usually we would exclude this attribute as a random parameter.

However, one lower element in the Cholesky matrix associated with it (ROUDM: ROUDL in table 10-7) is statistically significant. We kept it to investigate the correlation pattern.

- Three lower factors in the Cholesky matrix are statistically significant (ROUDM : ROUDL, CLEAR : ROUDL and CLEAR : ROUDM), suggesting presence of correlation between these attributes. Two diagonal values in the Cholesky matrix (NsROUDM, NsCLEAR) are statistically significant at the 10 percent level, confirming that the standard deviations of these random parameter distributions are significant. The factors in the Cholesky matrix are used to investigate whether the correlation and standard deviation are statistically significant. These factors have no meaning in themselves and should not be used for behavioural interpretation (see Train 1998).
- The correlation matrix (table 10-8) however can be used for behavioural interpretation. Three lower factors in the correlation matrix are statistically significant (ROUDM : ROUDL, CLEAR : ROUDL and CLEAR : ROUDM). The correlation between ROUDM and ROUDL is negative, suggesting that drivers who consider a medium-sized roundabout as a safe factor tend to think a large-sized roundabout as an unsafe factor (see figure 10-1: Negative Correlation). The correlation between CLEAR and ROUDL is negative, having a similar interpretation. The correlation between CLEAR and ROUDM is positive, suggesting that drivers who think that a clear visibility is a safer factor tend to consider a medium-sized roundabout as a safe factor as well (figure 10-1: positive correlation).

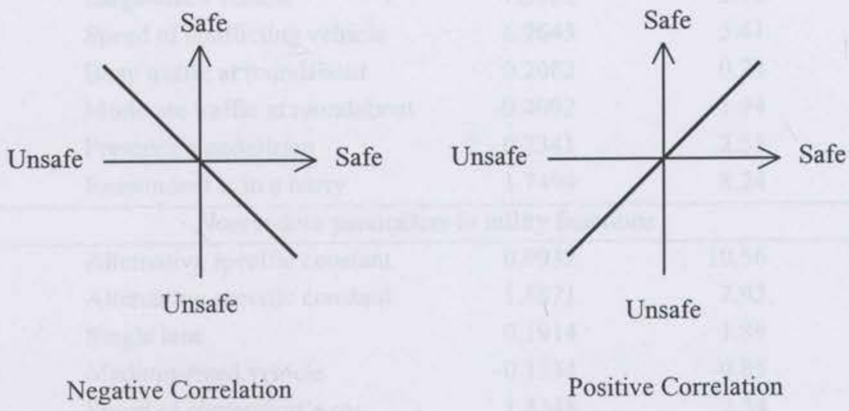


Figure 10-1 Behavioural interpretation of correlation

- The factors in the correlation matrix are confounded with choice set correlation due to repeated choices and the correlation between alternatives. If choice set correlation is presented but ignored (model 3), the mixed logit model tends to be difficult to estimate.
- The *LR* test indicates that the model is significant at the 0.000 level evaluated at χ^2 distribution with 52 degrees of freedom.
- The pseudo R^2 is 0.283.

Model 5 - The mixed logit model with the heterogeneity in mean, choice set correlation and correlation between alternatives. Model 5 considers the possibility that the mean of the random parameters may vary across the individuals by including a set of individual variables. The model also estimates choice set correlation and the correlation between alternatives. The output of model estimation includes means for random and nonrandom parameters, standard deviations for random parameters, heterogeneity in mean for random parameters, a Cholesky matrix, a correlation matrix and a covariance matrix for random parameters. The estimation results are summarised in table 10-8. 10-9 and 10-10 and are detailed in Appendix VI – Model 5. The model performance is summarised as follows.

Table 10-8 Estimation results: model 5

Variables	Definition	Coefficient	t-Ratio	Significance
	Random parameters in utility functions			
ROUDL	Large-sized roundabout	0.8840	3.51	0.00
ROUDM	Medium-sized roundabout	-0.1287	-0.58	0.56
CLEAR	Clear visibility	1.4115	7.45	0.00
VEHLG	Large-sized vehicle	1.3682	3.52	0.00
SPEED	Speed of conflicting vehicle	6.9643	5.41	0.00
BUSYT	Busy traffic at roundabout	0.2082	0.73	0.47
MODET	Moderate traffic at roundabout	-0.4092	-1.94	0.05
PEDSY	Presence a pedestrian	0.7341	2.53	0.01
HURRY	Respondent is in a hurry	1.7498	8.24	0.00
	Nonrandom parameters in utility functions			
A_SL	Alternative specific constant	0.9932	10.56	0.00
A_KG	Alternative specific constant	1.8871	7.92	0.00
LANE1	Single lane	0.1914	1.89	0.06
VEHMD	Medium-sized vehicle	-0.1534	-0.85	0.39
MYSPD	Speed of respondent's car	1.4348	2.34	0.02
	Derived standard deviations of parameters: Normal distributions			
SdROUDL	Large-sized roundabout	0.0001	0.11	0.91
SdROUDM	Medium-sized roundabout	0.2938	1008.98	0.00

SdCLEAR	Clear visibility	0.3075	1.43	0.15
SdVEHLG	Large-sized vehicle	0.2452	0.43	0.67
SdSPEED	Speed of conflicting vehicle	0.6628	0.24	0.81
SdBUSYT	Busy traffic at roundabout	0.1462	0.19	0.85
SdMODET	Moderate traffic at roundabout	0.0665	0.14	0.89
SdPEDSY	Presence a pedestrian	0.1184	0.24	0.81
SdHURRY	Respondent is in a hurry	0.1255	0.19	0.85

Log-likelihood = 3733.738
Pseudo R^2 = 0.299
Degrees of freedom = 60
Number of observations = 15714

Table 10-9 Heterogeneity in mean for model 5: (Parameter: Variable)

Variables	Coefficient	t-Ratio	Significance
ROUDL:DRYRS	***-0.0282***	***-3.57***	***0.00***
ROUDM:DRYRS	***-0.0282***	***-3.57***	***0.00***
CLEAR:DRYRS	-0.0036	-0.38	0.70
VEHLG:DRYRS	-0.0058	-0.40	0.69
SPEED:DRYRS	***-0.0913***	***-2.23***	***0.03***
BUSYT:DRYRS	***0.0226***	***2.36***	***0.02***
MODET:DRYRS	0.0116	0.95	0.34
PEDSY:DRYRS	0.0005	0.05	0.96
HURRY:DRYRS	-0.0151	-1.64	0.10

DRYRS – The years that respondent has been driving

Table 10-10 Cholesky matrix for random parameters: model 5

	ROUDL	ROUDM	CLEAR	VEHLG	SPEED	BUSYT	MODET	PEDSY	HURRY
ROUDL	0.0001								
	(0.11)*								
ROUDM	0.2079	0.2077							
	(0.71)	(0.71)							
CLEAR	0.0696	0.1741	0.2437						
	(0.16)	(0.80)	(0.83)						
VEHLG	0.1741	0.0042	-0.1726	0.0054					
	(0.80)	(0.01)	(-0.23)	(0.01)	()				
SPEED	0.0042	-0.0601	0.5439	-0.1432	0.3455				
	(0.01)	(-0.09)	(0.24)	(-0.02)	(0.07)				
BUSYT	-0.0601	-0.0067	-0.0856	0.0623	0.0801	0.0098			
	(-0.09)	(-0.01)	(-0.11)	(0.02)	(0.04)	(0.01)			
MODET	-0.0067	-0.0035	0.0530	0.0103	-0.0009	-0.0325	0.0197		
	(-0.01)	(-0.01)	(0.08)	(0.01)	(0.00)	(-0.02)	(0.02)		
PEDSY	-0.0035	0.0698	-0.0651	0.0181	0.0229	0.0253	-0.0574	0.0104	
	(-0.01)	(0.15)	(-0.09)	(0.01)	(0.01)	(0.01)	(-0.06)	(0.01)	
HURRY	0.0698	0.0000	-0.0909	-0.0069	-0.0311	-0.0053	0.0326	0.0146	0.0172
	(0.15)	(0.00)	(-0.13)	(0.00)	(-0.02)	(0.00)	(0.03)	(0.01)	(0.01)

* - t-Ratio in brackets

- A specification search is conducted to look for the variables that produce heterogeneity in means of the randomly distributed coefficients. *The years that respondent has been driving* (DRYRS) is the only variable that produces individual heterogeneity in the means.
- The coefficients of DRYRS as normally distributed parameters ROUDL, ROUDM, SPEED and BUSYT are statistically significant (see table 10-10). The effects of DRYRS are additive to the means of random parameters. Table 10-11 gives an example how the means of normally distributed parameters vary when individual driving experience is set to five and ten years.

Table 10-11 Effects of driving experience in mean heterogeneity

Attribute	Mean *(b)*	Coefficient *(δ)*	Effects	
			DRYRS = 5	DRYRS = 10
ROUDL	0.8840	-0.0282	0.7430	0.6020
ROUDM	-0.1287	-0.0282	-0.2697	-0.4107
SPEED	6.9643	-0.0913	6.5078	6.0513
BUSYT	0.2082	0.0226	0.3212	0.4342

- None of factors in the Cholesky matrix (table 10-11) are statistically significant. This suggests that once individual heterogeneity in the mean is taken into account, the choice set correlation and correlation between alternatives are negligible. This result is consistent with findings in Daniels and Hensher (2000b), who suggested that the choice set correlation may be spurious due to the failure to account for unobserved heterogeneity.
- The *LR* test indicates that the model is statistically significant at the 0.000 level evaluated with χ^2 distribution of 60 degrees of freedom.
- The pseudo R^2 is 0.299.

10.3.4 A Comparison of Driver Behavioural Response Models

A summary of model performance is given in table 10-12. When the pseudo R^2 is used as the assessment criterion, model 5 is the best model. A likelihood ratio test that uses model 1 as the base model suggests that model 2 should be rejected, and models 4 and 5 might be retained. Because model 5 is superior to the model 4, the model 4 is easily rejected. (Model 5 has a greater pseudo R^2 and can accommodate the heterogeneity in the means for random parameters). We select model 5 as our preferred model to connect behavioural responses and attributes of the roundabout.

Table 10-12 A summary of driver behavioural response models

Criteria		Model 1	Model 2	Model 4	Model 5
Pseudo R^2		0.277	0.276	0.283	0.299
Log-likelihood		-3869.835	-3869.747	-3820.574	-3733.738
Restricted log-likelihood		-5754.531	-5754.531	-5754.531	-5754.531
Degrees of freedom		14	23	52	60
Overall goodness of fit		0.000	0.000	0.000	0.000
		Likelihood ratio test			
LR statistic	Base model		0.176	98.522	272.194
Degrees of freedom			9	38	46
Critical value			16.919	53.384	62.830

10.3.5 Investigating the Relationship between Behavioural Response and the Safety Perception as well as Characteristics of Drivers

We specify models to investigate the relationship between behavioural response and the perception of safety as well as the socio-economic characteristics of drivers. A specification search identifies a set of individual characteristics having an influence on behavioural response using the utility functions as below:

$$U(ST) = DrYrs*DrYrz + AccYe*AccYe + ILow*ILow + AgeM*AgeM$$
$$U(SL) = A\_SL + IPS*IPS + DrYrs*DrYrs + AccYe*AccYe + ILow*ILow + AgeY*AgeY + AgeM*AgeM + ComYe*ComYe + YoungM*YoungM$$
$$U(KG) = A\_KG + IPS*IPS + AgeY*AgeY + ComYe*ComYe + YoungM*YoungM \quad (10\text{-}12)$$

These utility functions follow the same format as equation 10-8. The IPS represents the *Indicators of Perceived Safety* for each scenario developed in chapter nine (see table 10-12). The definition of variables in the utility function is given in chapter six and is summarised in table 10-13. Two models are specified. Model 6 is a multinomial logit model, and model 7 is a simple mixed logit model. The estimation of models 6 and model 7 is summarised in table 10-13 and is detailed in Appendix VI – model 6 and model 7. A *LR* test suggests that model 7 can be rejected. Model 6 is our preferred model to link behavioural response to the perception of safety as well as the characteristics of drivers. Both model 6 and model 7 are intermediate models for identifying potential significant socio-economic variables to be included in the final model (see equation 10-13). Using these models for behavioural interpretation is misleading. It is noted that ASCs in these models are negative. This would be intuitively interpreted as a negative utility of "keep going" relative to "stop", everything else held constant. However, as models 6 and 7 are intermediate models, this would not necessarily so if all attributes and driver's socio-economic variables were considered.

Table 10-13 Estimation results: model 6 and model 7

Variables	Definition	Model 6: MNL model		Model 7: Mixed Logit model	
		Coeff.	t-ratio	Coeff.	t-ratio
Parameters in utility functions					
A_SL	Alternative specific constants	-7.1501	-33.55	-7.1876	-31.75
A_KG	Alternative specific constants	-8.3238	-34.27	-8.3610	-32.87
IPS	Indicator of perceived safety	9.6417	35.71	9.6910	33.65
DRYRS	The years that respondent has been driving	-0.2444	-6.73	-0.2443	-6.73
ACCYE	Respondent involved in an accident in the last 2 years	-0.1593	-1.66	-0.1594	-1.66
ILOW	Respondent's annual income is below $30,000	0.2226	2.78	0.2230	2.78
AGEY	Respondent is 25 years old or younger	-0.4394	-2.91	-0.4254	-2.71
AGEM	Respondent is between 26-50 years old	0.1750	2.00	0.1755	2.00
COMYE	Commuter driver	0.1579	1.96	0.1590	1.97
YOUNGM	Male young driver	0.2128	0.96	0.2158	0.95
Derived standard deviations of random parameters: normal distribution					
NsIPS	Indicator of perceived safety			0.0064	0.03
NsDRYRS	The years that respondent has been driving			0.0020	0.04
NsACCYE	Respondent involved in an accident in the last 2 years			0.0181	0.07
NsILOW	Respondent's annual income is below $30,000			0.0004	0.00
NsAGEY	Respondent is 25 years old or younger			0.4612	0.96
NsAGEM	Respondent is between 26-50 years old			0.0256	0.15
NsCOMYE	Commuter driver			0.0013	0.01
NsYOUNGM	Male young driver			0.1096	0.13
Model performance					
Log likelihood function		-4129.885		-4129.699	
Pseudo R^2		0.228		0.228	
Degrees of freedom		10		18	
Number of observations		5238		15714	

10.3.6 Driver Behavioural Response Related to Both Attributes of Roundabouts and Characteristics of Drivers

Separate models have been estimated to investigate the relationships between behavioural response and attributes representing the roundabout and traffic situations (model 1-5), and the relationships between behavioural response and respondent's socio-economic characteristics (model 6-7). These models are useful to identify the significant attributes and driver characteristic variables and to investigate the various patterns of correlation. We specify the final models that relate the behavioural responses to both attributes and drivers' characteristics. These models have the following utility functions:

$$U(ST) = RoudL*RoudL + VehLG*VehLG + Speed*Speedz + BusyT*BusyT + PedsY*PedsY + MySpd*MySpdz + DrYrs*DrYrz + AccYe*AccYe + ILow*ILow + AgeM*AgeM$$

$$U(SL) = A\_SL + RoudL*RoudL + RoudM*RoudM + Lane1*Lane1 + Clear*Clear + VehLG*VehLG + VehMD*VehMD + Speed*Speedz + BusyT*BusyT + ModeT*ModeT + PedsY*PedsY + MySpd*MySpdz + Hurry*Hurry + DrYrs*DrYrz + AccYe*AccYe + ILow*ILow + AgeY*AgeY + AgeM*AgeM + ComYe*ComYe + YoungM*YoungM$$

$$U(KG) = A\_KG + RoudM*RoudM + Lane1*Lane1 + Clear*Clear + VehMD*VehMD + ModeT*ModeT + Hurry*Hurry + AgeY*AgeY + ComYe*ComYe + YoungM*YoungM \quad (10\text{-}13)$$

All attributes and driver's socio-economic characteristics have been defined previously. Two models were estimated. The estimated results for MNL model 8 are summarised in table 10-14. All coefficients except male young drivers (YOUNGM) are statistically significant at the 10 percent level. After an extensive specification search, the ML model 9 was estimated (table 10-15), allowing choice set correlation and correlation between alternatives for four random attributes (ROUDL, ROUDM, MODET and HURRY). None of elements in the Cholesky matrix is significant, suggesting the correlation is not significant. None of standard deviations for the normally distributed parameters are statistically significant at the 5 percent level, suggesting MNL model might be an appropriate specification. An *LR* test also favours model 8. The model 8 is selected as our preferred model for behavioural interpretation as presented in the next section.

Table 10-14 Estimation results: model 8 (MNL)

Variables	Definition	Coefficient	t-Ratio	Significanc
A_SL	Alternative specific constant	0.931	13.16	0.00
A_KG	Alternative specific constant	1.387	6.83	0.00
ROUDL	Large-sized roundabout	0.365	6.83	0.00
ROUDM	Medium-sized roundabout	-0.526	-10.66	0.00
LANE1	Single lane	0.188	4.70	0.00
CLEAR	Clear visibility	1.329	29.30	0.00
VEHLG	Large-sized vehicle	1.212	20.24	0.00
VEHMD	Medium-sized vehicle	-0.150	-2.80	0.01
SPEED	Speed of conflicting vehicle	5.368	17.51	0.00
BUSYT	Busy traffic at roundabout	0.643	10.98	0.00
MODET	Moderate traffic at roundabout	-0.250	-5.19	0.00
PEDSY	Presence a pedestrian	0.793	13.34	0.00
MYSPD	Speed of respondent's car	1.124	4.15	0.00
HURRY	Respondent is in a hurry	1.526	25.94	0.00
DRYRS	The years that respondent has been driving	-0.304	-7.51	0.00
ACCYE	Respondent involved in an accident in the last 2 years	-0.197	-1.83	0.07
ILOW	Respondent's annual income is below $30,000	0.270	3.04	0.00
AGEY	Respondent is 25 years old or younger	-0.397	-2.74	0.01
AGEM	Respondent is between 26-50 years old	0.216	2.24	0.02
COMYE	Commuter driver	0.145	1.86	0.06
YOUNGM	Male young driver	0.196	0.92	0.36

Log-likelihood = -3776.984
Pseudo R^2 = 0.293
Degrees of freedom = 21
Number of observations = 5238

Table 10-15 Estimation results: model 9 (ML)

Variables	Definition	Coefficient	t-Ratio	Significance
	Random parameters in utility functions (normally distributed)			
ROUDL	Large-sized roundabout	0.373	2.63	0.01
ROUDM	Medium-sized roundabout	-0.545	-3.94	0.00
MODET	Moderate traffic at roundabout	-0.249	-1.99	0.05
HURRY	Respondent is in a hurry	1.542	12.39	0.00
	Nonrandom parameters in utility functions			
A_SL	Alternative specific constant	0.955	13.47	0.00
A_KG	Alternative specific constant	1.426	4.44	0.00
LANE1	Single lane	0.192	2.53	0.01
CLEAR	Clear visibility	1.348	20.60	0.00
VEHLG	Large-sized vehicle	1.212	9.71	0.00
VEHMD	Medium-sized vehicle	-0.158	-1.16	0.25
SPEED	Speed of conflicting vehicle	5.399	8.33	0.00
BUSYT	Busy traffic at roundabout	0.643	5.03	0.00
PEDSY	Presence a pedestrian	0.796	8.09	0.00
MYSPD	Speed of respondent's car	1.143	1.95	0.05

DRYRS	The years that respondent has been driving	-0.303	-6.04	0.00
ACCYE	Respondent involved in an accident in the last 2 years	-0.196	-1.20	0.23
ILOW	Respondent's annual income is below $30,000	0.269	2.48	0.01
AGEY	Respondent is 25 years old or younger	-0.375	-2.30	0.02
AGEM	Respondent is between 26-50 years old	0.213	1.78	0.07
COMYE	Commuter driver	0.141	2.00	0.05
YOUNGM	Male young driver	0.187	0.65	0.51
Diagonal values in Cholesky matrix				
NsROUDL		0.104	0.24	0.81
NsROUDM		0.205	0.10	0.92
NsMODET		0.000	0.00	1.00
NsHURRY		0.002	0.00	1.00
Below values in Cholesky matrix				
ROUDM : ROUDL		-0.293	-0.20	0.84
MODET : ROUDL		0.060	0.33	0.74
MODET : ROUDM		0.060	0.33	0.74
HURRY : ROUDL		-0.083	-0.55	0.58
HURRY : ROUDM		-0.083	-0.55	0.58
HURRY : MODET		-0.001	0.00	1.00
Standard deviations of parameter distribution				
sdROUDL		0.104	0.24	0.81
sdROUDM		0.357	1.77	0.08
sdMODET		0.085	0.33	0.74
sdHURRY		0.118	0.50	0.62

Log-likelihood = -3772.289
Pseudo R^2 = 0.294
Degrees of freedom = 29
Number of observations = 15714

10.4 Interpretations of Drivers' Behavioural Response

The estimated utility models provide a very flexible tool to assess the behavioural response in terms of attributes representing road and traffic situations and the characteristics of drivers. The discrete choice models can be used to predict the likelihood of an individual's choice of a particular response option for a specific road and traffic situation. A *simulation technique* developed recently in Econometric Software (2000) is applied for this purpose. (See Greene and Hensher 2000 for implementation of simulation in Limdep, and Hensher and Greene 2000 for the first simulation application). We define a *base scenario* and systematically change the levels of attributes to evaluate the changes in the simulated probabilities. A series of simulations are conducted, with results reported below and detailed in Appendix VI - Simulations. The base scenario is defined in table 10-16.

Table 10-16 The base scenario for simulation evaluation

Attributes	Abbreviation	Level
Size of the roundabout	ROUND	Medium
The number of circulating lanes	LANE	Single
Visibility to other traffic	VISIB	Clear
Size of vehicle/s potentially conflicting with the driver	SIZE	Medium
Speed of vehicle/s potentially conflicting with the driver	SPEED	30 km/h
General traffic level	TRAFK	Moderate
Presence of a potentially conflicting pedestrian	PEDES	Not presence
Speed of respondent's car when approaching the roundabout	MYSPD	30 km/h
The driver's time availability	HURRY	Not in a hurry
The years that respondent has been driving	DRYRS	10 years
Respondent involved in an accident in the last 2 years	ACCYE	No
Respondent's annual income is below $30,000	ILOW	Yes
Respondent's age category	AGE	Between 26-50
Commuter driver	COMYE	Yes
Male young driver	YOUNGM	No

Simulation 1: The size of roundabout (table 10-17)

The base scenario is a medium-sized roundabout. At a small roundabout, the probability of a driver choosing *Alt1 - slow down to Stop* decreases by 22.085, choosing *Alt2 - slow down and keep going* increases by 8.823 percent, and choosing *Alt3 - not slow down and keep going* increases by 13.362 percent, keeping other attribute levels unchanged. A driver perceives that a small roundabout is safer than a medium roundabout, ceteris paribus. At a large roundabout, the probabilities of choosing *Alt1* and *Alt3* decrease, and choosing *Alt2* increases. A driver is inclined to slow down at a large sized roundabout. A pairwise comparison of a small roundabout with a large roundabout suggests that a driver perceive it is safer to maneuvering through a small roundabout than a large one.

Table 10-17 Simulated probabilities: size of roundabout

Choice	Base (medium)	Small roundabout		Large roundabout	
	Probabilities	Probabilities	Changes	Probabilities	Changes
Alt1-ST	38.025	15.940	-22.085	28.474	-9.551
Alt2-SL	43.815	52.639	8.823	55.543	11.728
Alt3-KG	18.159	31.421	13.262	15.983	-2.176

Simulation 2: The number of circulating lanes (table 10-18)

At a multilane roundabout, the probability of a driver choosing *Alt1 - slow down to Stop* increases by 9.181 percent, choosing *Alt2 - slow down and keep going* decreases by 6.491 percent, and choosing *Alt3 - not slow down and keep going* decreases by 2.690

percent. A driver tends to perceive that a single lane roundabout is safer than a multilane roundabout.

Table 10-18 Simulated probabilities: number of circulating lanes

Choice	Base (single lane)	Two or more lanes	
	Probabilities	Probabilities	Changes
Alt1-ST	38.025	47.207	9.181
Alt2-SL	43.815	37.324	-6.491
Alt3-KG	18.159	15.469	-2.690

Simulation 3: Visibility to other traffic (table 10-19)

A driver's behavioural response is very sensitive to this attribute. When the visibility to other traffic is obstructed, the probability of a driver choosing *Alt1* increases by as high as 51.726 percent, choosing *Alt2* decreases by 36.570 percent, and choosing *Alt3* decreases by 15.156 percent. A driver tends to perceive that obstructed visibility is very unsafe.

Table 10-19 Simulated probabilities: visibility to other traffic

Choice	Base (clear)	Obstructed visibility	
	Probabilities	Probabilities	Changes
Alt1-ST	38.025	89.751	51.726
Alt2-SL	43.815	7.246	-36.570
Alt3-KG	18.159	3.003	-15.156

Simulation 4: Size of potentially conflicting vehicle (table 10-20)

When a driver encounters a small-sized vehicle, the probability of choosing *Alt1* decreases by 16.852 percent, choosing *Alt2* decreases by 10.862 percent, and choosing *Alt3* increases by 27.714 percent. When a driver encounters a large-sized vehicle, the probability of choosing *Alt1* increases by 1.905 percent, choosing *Alt2* increases by 9.657 percent, and choosing *Alt3* decreases by 11.561 percent. A driver tends to think that interaction with a small vehicle is safer than with a large one.

Table 10-20 Simulated probabilities: size of potentially conflicting vehicle

Choice	Base (medium)	Small vehicle		Large vehicle	
	Probabilities	Probabilities	Changes	Probabilities	Changes
Alt1-ST	38.025	21.174	-16.852	39.930	1.905
Alt2-SL	43.815	32.953	-10.862	53.472	9.657
Alt3-KG	18.159	45.873	27.714	6.598	-11.561

Simulation 5: Speed of potentially conflicting vehicle (table 10-21)

As the speed of a conflicting vehicle increases, the probability of a driver choosing *Alt1* increases, choosing *Alt2* increases and choosing *Alt3* decreases. A quicker speed of a potentially conflicting vehicle is perceived as unsafe.

Table 10-21 Simulated probabilities: speed of potentially conflicting vehicle

Choice	Base (30 km/h)	15 km/h	45 km/h	60 km/h
	Probabilities	Probabilities	Probabilities	Probabilities
Alt1-ST	38.025	31.049 (-6.976)	42.270 (4.245)	44.490 (6.465)
Alt2-SL	43.815	35.777 (-8.038)	48.707 (4.891)	51.265 (7.449)
Alt2-KG	18.159	33.174 (15.014)	9.023 (-9.136)	4.245 (-13.914)

* - Changes compared with base scenario in brackets

Simulation 6: General traffic level at the roundabout (table 10-22)

The effects of this attribute are not linear. When traffic at a roundabout is light, the probability of a driver choosing *Alt1* decreases by 15.267 percent, choosing *Alt2* decreases by 0.617 percent and choosing *Alt3* increases by 15.884 percent. When traffic at a roundabout is busy, the probability of a driver choosing *Alt1* decreases by 2.327 percent, choosing *Alt2* increases by 8.979 percent and choosing *Alt3* decreases by 6.652 percent. A driver tends to think that a light traffic is safer.

Table 10-22 Simulated probabilities: general traffic level

Choice	Base (moderate)	Light traffic		Busy traffic	
	Probabilities	Probabilities	Changes	Probabilities	Changes
Alt1-ST	38.025	22.759	-15.267	35.698	-2.327
Alt2-SL	43.815	43.199	-0.617	52.794	8.979
Alt3-KG	18.159	34.043	15.884	11.507	-6.652

Simulation 7: Presence of a potentially conflicting pedestrian (table 10-23)

In the presence of a potentially conflicting pedestrian, the probability of a driver choosing the *Alt1* increases by 6.420 percent, choosing *Alt2* increases by 7.397 percent and choosing *Alt3* decreases by 13.817 percent. A driver tends to think that the presence of a potentially conflicting pedestrian is unsafe.

Table 10-23 Simulated probabilities: presence of a potentially conflicting pedestrian

Choice	Base (not presence)	Presence	
	Probabilities	Probabilities	Changes
Alt1-ST	38.025	44.445	6.420
Alt2-SL	43.815	51.212	7.397
Alt3-KG	18.159	4.343	-13.817

Simulation 8: Speed of respondent's car (table 10-24)

As the speed of the respondent's car increases, the probability of a driver choosing *Alt1* increases, choosing *Alt2* increases and choosing *Alt3* decreases.

Table 10-24 Simulated probabilities: speed of respondent's car

Choice	Base (30 km/h)	15 km/h	45 km/h	60 km/h
	Probabilities	Probabilities	Probabilities	Probabilities
Alt1-ST	38.025	36.798 (-1.227)	39.128 (1.103)	40.110 (2.085)
Alt2-SL	43.815	42.401 (-1.414)	45.086 (1.270)	46.218 (2.403)
Alt2-KG	18.159	20.801 (2.642)	15.786 (-2.373)	13.672 (-4.488)

* - Changes in probabilities compared with base scenario in brackets

Simulation 9: Driver's time availability (table 10-25)

When a driver is in a hurry, the probability of his/her choice of *Alt1* decreases by 35.207 percent, choice of *Alt2* increases by 24.891 percent and choosing *Alt3* increases by 10.316 percent.

Table 10-25 Simulated probabilities: driver's time availability

Choice	Base (not in a hurry)	In a hurry	
	Probabilities	Probabilities	Changes
Alt1-ST	38.025	2.828	-35.207
Alt2-SL	43.815	68.706	24.891
Alt3-KG	18.159	28.475	10.316

Simulation 10: Years that respondent's has been driving (table 10-26)

The effects of driving experience are not linear. Both relatively inexperienced drivers (5-year driving history) and relatively experienced drivers (15-year driving history) tend to be less likely to *slow down to stop (Alt1)*, and more likely to *slow down and keep going (Alt2)* or *not slowdown and keep going (Alt3)*.

Table 10-26 Simulated probabilities: years that respondent has been driving

Choice	Base (10 years)	5 years		15 years	
	Probabilities	Probabilities	Changes	Probabilities	Changes
Alt1-ST	38.025	2.936	-35.089	2.692	-35.333
Alt2-SL	43.815	71.583	27.768	65.635	21.819
Alt3-KG	18.159	25.480	7.321	31.673	13.514

Simulation 11: Respondent's accident history (table 10-27)

Drivers involved in an accident in the last two years are less likely to *slow down to stop (Alt1)* or *slow down and keep going (Alt2)*, and more likely to *not slowdown and keep going (Alt3)*.

Table 10-27 Simulated probabilities: respondent's accident history

Choice	Base (not involved in an accident in the last two years)	Involved in an accident in the last two years	
	Probabilities	Probabilities	Changes
Alt1-ST	38.025	36.578	-1.448
Alt2-SL	43.815	42.147	-1.668
Alt3-KG	18.159	21.275	3.116

Simulation 12: Respondent's annual income (table 10-28)

Drivers with higher annual income (≥$30,000) are less likely to *slow down to stop (Alt1)* or *slow down and keep going (Alt2)*, and more likely to *not slowdown and keep going (Alt3)*. (We have seven income categories in the survey. However, dummy variables representing these detailed income categories are not statistically significant in the model due to limited observations. Thus, we combined them into two broad categories. The estimated results can only provide a rough effect pattern).

Table 10-28 Simulated probabilities: annual income

Choice	Base (≤$30,000)	≥$30,000	
	Probabilities	Probabilities	Changes
Alt1-ST	38.025	35.997	-2.028
Alt2-SL	43.815	41.478	-2.337
Alt3-KG	18.159	22.524	4.365

Simulation 13: Respondent's age (table 10-29)

Young drivers (25 years or younger) are more likely to *slow down to stop (Alt1)* and less likely to *slow down and keep going (Alt2)*. The senior drivers (51 years or older) is less likely to *slow down to stop (Alt1)* or *slow down and keep going (Alt2)*, and more likely to *not slowdown and keep going (Alt3)*. (We have nine age categories in the survey. We combined them into three broad categories for significant estimates. The estimated results can only provide a rough effect pattern).

Table 10-29 Simulated probabilities: age

Choice	Base (26-50 years)	25 years or younger		51 years or older	
	Probabilities	Probabilities	Changes	Probabilities	Changes
Alt1-ST	38.025	46.004	7.978	36.427	-1.599
Alt2-SL	43.815	35.650	-8.165	41.973	-1.842
Alt3-KG	18.159	18.346	0.187	21.600	3.441

Simulation 14: Commuter driver status (table 10-30)

The non-commuter drivers are more likely to *slow down to stop (Alt1)* and less likely to *slow down and keep going (Alt2)* or *not slow down and keep going (Alt3)*.

Table 10-30 Simulated probabilities: commuter driver status

Choice	Base (Commuter driver)	Non-commuter driver	
	Probabilities	Probabilities	Changes
Alt1-ST	38.025	41.508	3.482
Alt2-SL	43.815	41.353	-2.462
Alt3-KG	18.159	17.139	-1.020

Simulation 15: Male young drivers (table 10-31)

In the specification searches, several interaction variables were included. One of these is an interaction variable between young drivers and male drivers. Although it is statistically insignificant, we estimated its effects to give an idea of the behavioural response of male young drivers. The male young drivers are more likely to *slow down to stop (Alt1)* and less likely to *slow down and keep going (Alt2)* or *not slow down and keep going (Alt3)*. This result contradicts the general belief that male young drives are more likely to behave incautiously compared with other drivers.

Table 10-31 Simulated probabilities: male young drivers

Choice	Base (other drivers)	Male young drivers	
	Probabilities	Probabilities	Changes
Alt1-ST	38.025	33.537	-4.489
Alt2-SL	43.815	46.989	3.173
Alt3-KG	18.159	19.475	1.315

The simulation results allow us to evaluate the relative importance of attributes in contributing to driver's behavioural choice. Figure 10-2 shows the determinant power of each single attribute level on drivers' choice of *Alt1- slow down to stop*. An obstructed visibility is the most important attribute contributing to a driver's choice of *slow down to stop*. This suggests that a driver perceives that an obstructed visibility is very unsafe. Other attributes that contribute to drivers' choice of *slowing down to stop* include: a multilane roundabout, relatively quick speed of a potentially conflicting vehicle (45 - 60 km/h), presence of a potentially conflicting pedestrian, relatively quick speed of respondent's car (45 - 60 km/h), and a large-sized potentially conflicting vehicle. On the other hand, a drivers' tight schedule (in a hurry) is the most important attribute influencing non-choice of *slowing down to stop*. Whether or not a driver is in a hurry does not statistically significantly influence the perception of safety (see chapter nine, table 9-3 model1). This suggests that a driver might choose a less cautious behavioural response (eg *not slow down and keep going*) even if he or she perceived an unsafe driving environment. Other attributes that contribute to a driver's non-choice of *slowing down to stop* include: a small roundabout, a small potentially conflicting vehicle, light traffic at a roundabout and relatively slow speed of a potentially conflicting vehicle.

Figure 10-3 shows the determinant power of each attribute on a driver's choice of *Alt2- slow down and keep going*. The attributes that contribute to a driver's choice of *slowing down and keep going* include: a tight time schedule (in a hurry), a large roundabout, a large-sized potentially conflicting vehicle, busy traffic at a roundabout, a small roundabout, relatively quick speed of a potentially conflicting vehicle or respondent's car and presence of a potentially conflicting pedestrian. Interestingly, a driver tends to *slow down to stop* at either a large roundabout or a small roundabout. The attributes that contribute to a driver's non-choice to *slow down and keep going* include: obstructed visibility, a small potentially conflicting vehicle, relatively slow speed of a potentially conflicting vehicle or respondent's car and light traffic at a roundabout.

Figure 10-4 shows the determinant power of each attribute on a driver's choice of *Alt3- not slow down and keep going*. The attributes that contribute to a driver's choice to *not slow down and keep going* include: a small potentially conflicting vehicle, light traffic at a roundabout, relatively slow speed of a potentially conflicting vehicle or respondent's car, a small roundabout and a driver in a hurry. The attributes that contribute to a driver's non-choice to *not slow down and keep going* include: obstructed visibility, relatively quick speed of a potentially conflicting vehicle or respondent's car, presence of a potentially conflicting vehicle, a large potentially conflicting vehicle, busy traffic at a roundabout, a multilane roundabout and a large roundabout.

The above evaluation provides a way to investigate the "safe attributes" and "unsafe attributes" as perceived by drivers. If we apply two criteria for "safe attributes": (1) attributes that contribute to a driver's non-choice of alternative 1 - *slow down to stop*, AND (2) attributes that contribute to a driver's choice of alternative 3 - *not slow down and keep going*, we obtain the following list of "safe attributes":

- Light traffic at a roundabout
- A small-sized potentially conflicting vehicle
- Relatively slow speed of a potentially conflicting vehicle (eg 15 km/h)
- A small-sized roundabout
- A driver in a hurry
- A relatively slow speed of respondent's car (eg 15 km/h)

If we apply two criteria for "unsafe attributes": (1) attributes that contribute to a driver's choice of alternative 1 - *slow down to stop*, AND (2) attributes that contribute to a driver's non-choice of alternative 3 - *not slow down and keep going*, we obtain the following list of "unsafe attributes":

- Obstructed visibility
- Relatively quick speed of a potentially conflicting vehicle (eg 45 - 60 km/h)
- Presence of a potentially conflicting pedestrian
- A large-sized potentially conflicting vehicle
- Busy traffic at a roundabout
- A relatively quick speed of respondent's car (eg 45 - 60 km/h)
- A multilane roundabout

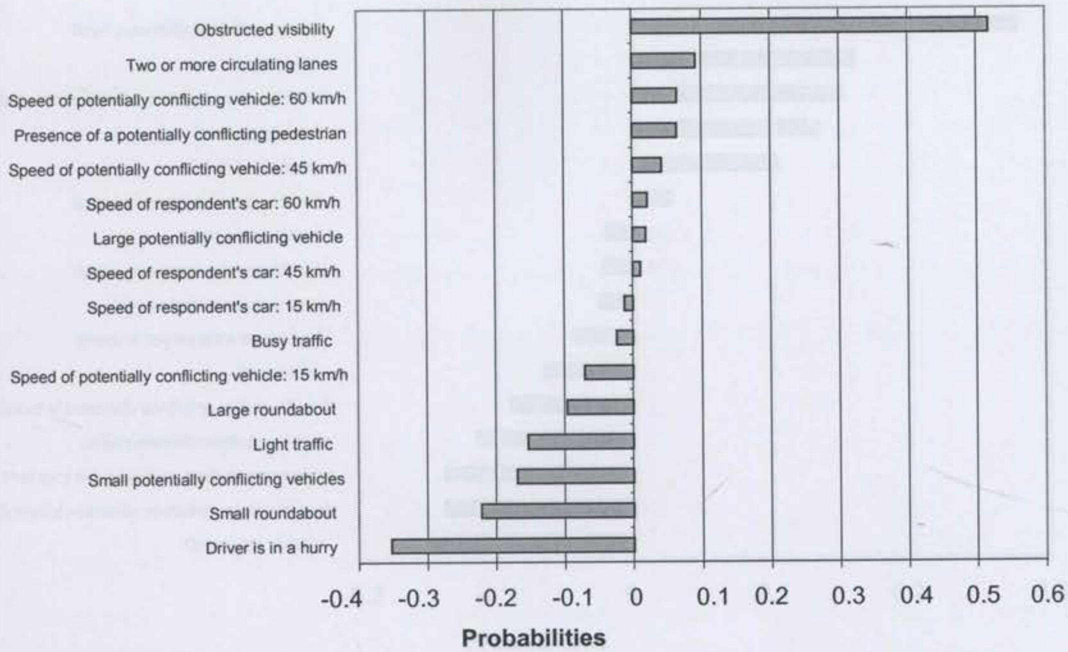


Figure 10-2 Relative importance of attributes in determining driver's choice of Alternative 1 - *Slow Down to Stop*

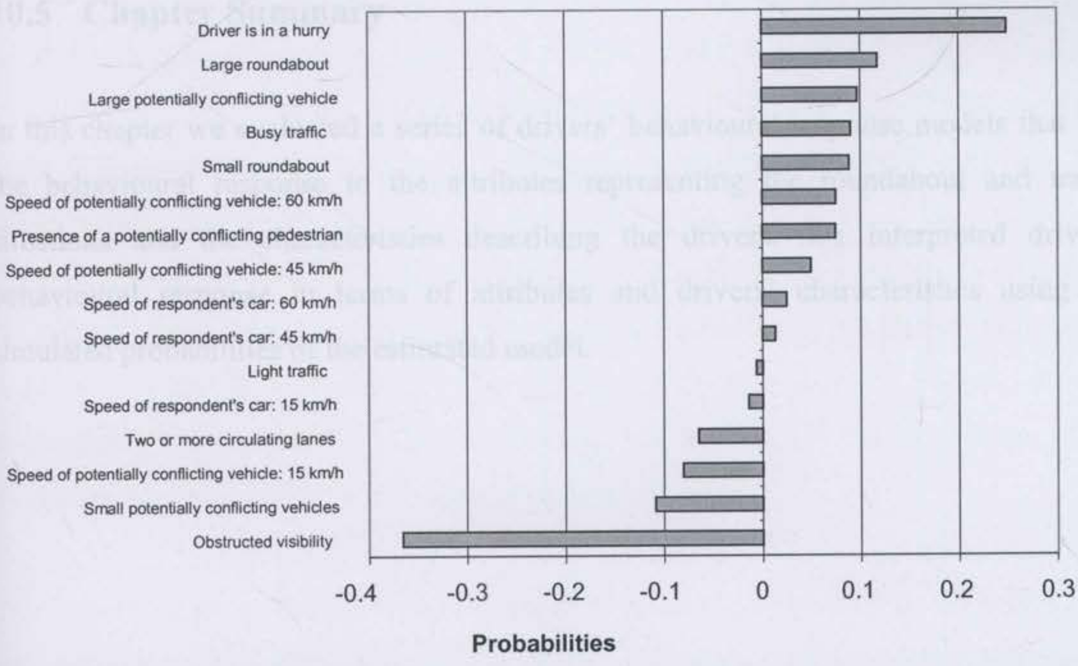


Figure 10-3 Relative importance of attributes in determining driver's choice of Alternative 2 - *Slow Down and Keep Going*

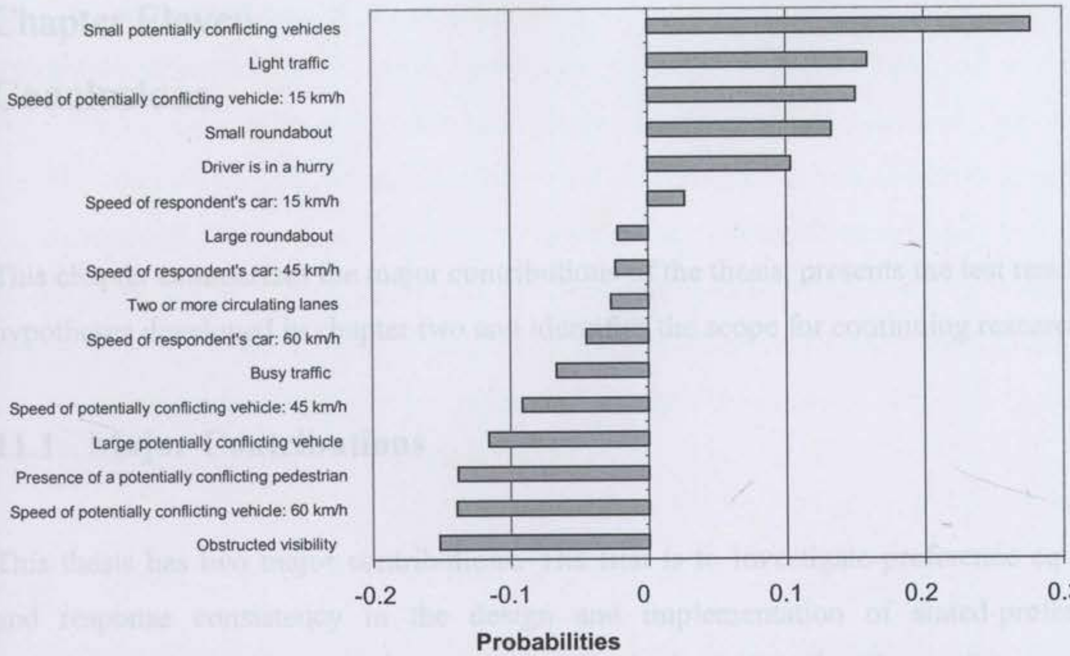


Figure 10-4 Relative importance of attributes in determining driver's choice of Alternative 3 - *Not Slow Down and Keep Going*

10.5 Chapter Summary

In this chapter we evaluated a series of drivers' behavioural response models that link the behavioural response to the attributes representing the roundabout and traffic situations and the characteristics describing the drivers. We interpreted drivers' behavioural response in terms of attributes and drivers' characteristics using the simulated probabilities of the estimated model.

Chapter Eleven
Conclusions

This chapter summarises the major contributions of the thesis, presents the test results of hypotheses developed in chapter two and identifies the scope for continuing research.

11.1 Major Contributions

This thesis has two major contributions. The first is to investigate preference equality and response consistency in the design and implementation of stated-preference surveys. An important aspect of survey design is the extent that the medium used to present information (eg picture or word descriptions) acts as a source of response bias, and the likelihood of response consistency over time (eg in two surveys). We found that data evaluated with the *Picture and Word* format were statistically indistinguishable to the data evaluated with the *Picture Only* format, suggesting that bias caused by the medium used for presenting information is not significant for this study. Data obtained at the first wave of the survey (data sets A1, B1 C1 and D1 in table 7-6) are statistically equal to data obtained at the second wave of the survey (data sets A2, B2, C2 and D2 in table 7-6), suggesting that respondent's preferences are relatively stable over time. The behavioural response variance in data obtained in the first wave of the survey was consistently larger than that in the second wave of the survey, suggesting that response consistency improves in a subsequent wave of a repeated survey. These findings not only support the appropriateness of using stated-preference data for eliciting driver's perception of safety and behavioural response, but also add to our knowledge of the appeal of the stated-preference technique in general.

The second major contribution is to develop a method to measure a driver's perceived safety (producing an index of perceived safety - IPS) and investigate driver behavioural response in the road environment. The measurement of the perception of safety is an ongoing research challenge. The use of accident statistics as a preferred measure of safety has its inherent limitations (eg low accident rates do not mean low risk). The use of electrodermal activity, for example, is problematical because of the low specificity of the electrodermal responses for changes in perceived risk. This study has employed an alternative approach, the stated preference method, and developed an empirical approach to investigate a driver's perception of safety and behavioural response at specific road and traffic situations. The stated preference method overcomes many of the deficiencies in the use of accident statistics or the electrodermal response technique. Relating the perception of safety and behavioural response to attributes of a road and traffic situation, this study has identified the contribution of each attribute to the development of an *indicator of perceived safety* (IPS) and a driver's choice of behavioural response in a road environment.

11.2 Findings from Controlled Experiment

We selected the roundabout as an empirical research context and reviewed the safety performance of roundabouts. The roundabout is a relatively safe intersection control device. We identified a number of attributes describing a roundabout and its traffic situation and defined the contextual variables in association with a driver's socio-demographic characteristics. A statistical design was developed to ensure that the effects of interest can be identified and estimated relatively efficiently for a manageable sample size. A full factorial design produces too many scenarios and a random sampling from full factorial design is unlikely to approximate the statistical properties of the design. We selected a fractional design that can be used to independently estimate the main effects of all attributes. The design produced 27 hypothetical roundabout and traffic situations.

We used a video image-based system to visualise the experimentally designed road and traffic situations. A visualised scenario improved the survey instrument by reducing the cognitive burden required in response. A computerised survey instrument was designed to implement a face to face survey. The computerised survey instrument automatically recorded the time that respondents allocated to each evaluated scenario and how they made use of detailed information provided in interactive windows. These allowed us to investigate how respondents assigned time and attention in a survey. We identified three distinctive stages in the response process. At the beginning of the survey, respondents learnt the task and spent a longer time on each evaluation situation. After becoming familiarised with the survey task and developing a response strategy, they allocated a reduced but relatively constant amount of time on each evaluation situation. In the last stage, it appeared that respondents became fatigued or somewhat lost interest in the survey, thus a further reduced response time on each evaluation situation was observed.

We introduced dummy-code and effects-code schemes and demonstrated how these code schemes can be used to approximate the main effects of an attribute. Dummy-codes have advantages in their simplicity in interpretation of the estimation results for a model. The effects-codes constitute an appealing alternative to dummy-codes. The effects-codes can untangle the correlation between the grand mean and the effect of the L^{th} level of an attribute, enabling us to estimate the effect of each level of an attribute.

11.3 Preference Equality and Response Consistency

We used random utility theory as a theoretical framework to compare preference equality and response consistency between two data sets obtained from different survey formats and/or different survey waves. The preference equality and response consistency is comparable only if there are common attributes between two data sets. For any two data sets, we specified two multinomial logit models for each data set and one nested logit model for the joint data set, and estimated the preference (utility) parameters β and scale parameters λ. If two data sets are equal in the preference profile, the products of the utility parameter and the scale parameter for a common attribute ($\beta\lambda$) are equal in the statistical sense. Because the scale parameter is inversely related to the variance of the error term, we use the scale parameter to represent response consistency. The larger the scale parameter, the greater the response consistency (ie lower variance). The conclusions in association with hypotheses 1-4 formulated in chapter two are:

Hypothesis 1 - Preference Equality between Two Waves of the Survey: Two tests have been undertaken to test the hypothesis of preference equality between the two waves of the survey. The first test suggests that the hypothesis can be retained. The test is based on data set A1 - *Picture and Word* format at the first wave of the survey and data set A2 - *Picture and Word* format at the second wave of the survey. The test result indicates that the parameters of common attributes are homogenous between the two waves of the survey. The second test initially rejected the parameter homogeneity in common attributes. The test is based on C1 - *Picture Only* format at the first wave of the survey and C2 - *Picture Only* format at the second wave of the survey. A graphical examination (figure 8-2) identified three suspect attributes that lead to the rejection of the hypothesis. A re-test suggests that partial parameter homogeneity in common attributes can be retained. The two tests suggest that:

Conclusion 1: *Preference profiles obtained at the first wave of the SP survey and the second (repeated) wave are statistically equal for at least a partial set of common parameters.*

Hypothesis 2 – Response Consistency between Two Waves of the Survey: The relative scale parameter between data set A2 (at the second wave of the survey) and data set A1 (at the first wave of the survey) is 1.4095. The relative scale parameter between data set C2 (at the second wave of the survey) and data set C1 (at the first wave of the survey) is 1.1352. The two tests suggest that the variance of the random term (inverse of the scale parameter) is substantially reduced in the second wave of the survey. The conclusion is:

Conclusion 2: *Response consistency improves at the second wave of the survey. The variance of the random term is always reduced by a repeated survey.*

Hypothesis 3 – Preference Equality between Two Survey Formats: Four tests have been undertaken to test the hypothesis of preference equality between two formats of the survey instrument. These tests are: A2 (*Picture and Word* format) versus B2 (*Picture Only* format), B1 (*Picture and Word* format) versus C1 (*Picture Only* format), D2 (*Picture and Word* format) versus C2 (*Picture Only* format), A1 (*Picture and Word* format) versus D1 (*Picture Only* format). All tests indicate that we can retain the hypothesis of parameter homogeneity in data sets evaluated with the two different survey formats. The conclusion is:

Conclusion 3: *Preference profiles evaluated with the Picture and Word format and the Picture Only format are statistically equal.*

Hypothesis 4 – Response Consistency between Two Survey Formats: Mixed results have been obtained in the four tests. The test based on data sets A2 and B2 suggests that the *Picture and Word* format produces greater response consistency. However, the other three tests demonstrate the opposite directional result. The conclusion is:

Conclusion 4: *There is no conclusive evidence to suggest that the response consistency evaluated with the Picture and Word format is greater than that with the Picture Only format.*

11.4 The Perception of Safety

Ordered probability models are estimated to link the driver's perception of safety to attributes describing roundabout geometry and the traffic situation. Main findings are:

- *Size of roundabout*: Drivers tend to see a small-sized roundabout as safer than a large roundabout. This may be because the traffic pattern at a large roundabout is generally complex requiring drivers to attend to more things than at a small roundabout.
- *Number of circulating lanes*: Drivers tend to perceive higher safety at a single lane roundabout than at a multilane roundabout. Operation at the single lane roundabout is relatively simple. At a multilane roundabout, drivers are required to cross, merge or diverge from different traffic streams. Traffic weaving and lane changing at a roundabout greatly increase the demands of the driving task.
- *Visibility to other traffic*: An obstructed visibility to other traffic can greatly reduce the perceived safety at a roundabout. The visibility is the most important attribute influencing a driver's perception of safety (see figure 9-2). An appropriate visibility is essential for the safe operation of the roundabout.
- *Size of potentially conflicting vehicle*: When interacting with other vehicles, drivers tend to think that a small vehicle is safer than a medium or large vehicle. This is reasonable because risk when colliding with a large vehicle is much higher than with a small vehicle.
- *Speed of respondent's car and speed of the vehicle potentially conflicting with the respondent*: Speed is an important factor affecting accident risk and

consequence. Both attributes have negative effects on a driver's perception of safety.

- *General traffic level at roundabout*: Drivers tend to think light traffic is safer than busy traffic at a roundabout. This is reasonable because the increased traffic volume increases the chance of traffic conflicting. As the traffic volume at a roundabout increases beyond its capacity, vehicles are queued at one or more approaches, which may induce drivers to accept an unsafe gap.
- *Presence of a potentially conflicting pedestrian*: When there is a pedestrian trying to cross the road in front of a car, a driver's perceived safety is greatly reduced.
- *Respondent's time availability*: The effect of this attribute is not statistically significant. This means that a driver's perception of safety of a road and traffic situation is unchanged whether or not he or she is in a hurry.

Five attributes that have the greatest *negative* influence on the perception of safety are ranked as: *(1) obstructed visibility; (2) presence of a potentially conflicting pedestrian, (3) increased speed of a potentially conflicting vehicle; (4) a large-sized potentially conflicting vehicle; and (5) a large-sized roundabout.* The five attributes that have the strongest *positive* influences on the perception of safety are ranked as: *(1) clear visibility; (2) decreased speed of a potentially conflicting vehicle; (3) a small roundabout; (4) a small potentially conflicting vehicle; and (5) decreased speed of a respondent's car.* The results from the ordered probit model for the perception of safety support the conclusion that:

Conclusion 5: *Attributes representing the road and traffic situation have a significant influence on a driver's perception of safety.*

A driver's socio-demographic characteristics have a significant influence on the perception of safety. We developed an *Index of Perceived Safety (IPS)* for a number of typical roundabout and traffic situations. The *IPS* is sensitive to the levels of socio-economic characteristics. For a given roundabout and traffic situation, the *IPS* varies between different driver segments. The male young driver has the highest *IPS*, while the female non-commuter driver has the lowest *IPS.* Female young drivers and male commuter drivers have a higher than average *IPS*, and female commuter drivers have a lower than average *IPS*. This supports the conclusion that:

Conclusion 6: *Given a road and traffic situation, drivers with different socio-economic characteristic, driving experience and driving attitude have different perceptions of safety.*

11.5 Driver's Behavioural Response

We estimated multinomial logit and mixed logit models to investigate a driver's behavioural response. The mixed logit model permits us to account for heterogeneity in preference parameters and to examine choice set correlation and correlation between alternatives. We found that correlation between some pairs of attributes was statistically significant. However, once individual heterogeneity in mean estimates was taken into account, the correlation was negligible, suggesting that correlation could be spurious due to a failure to account for unobserved heterogeneity. A simulation technique was used to investigate the influence of attributes describing the road and traffic situation. The effects of an attribute are best demonstrated by looking at the changes in the probabilities that a driver would choose the behavioural options at different attribute levels, while keeping other attribute levels fixed as defined in table 11-1.

Table 11-1 The fixed attribute levels (base scenario) for simulation evaluation

Attributes	Abbreviation	Level
Size of the roundabout	ROUND	Medium
The number of circulating lanes	LANE	Single
Visibility to other traffic	VISIB	Clear
Size of vehicle/s potentially conflicting with the driver	SIZE	Medium
Speed of vehicle/s potentially conflicting with the driver	SPEED	30 km/h
General traffic level	TRAFK	Moderate
Presence of a potentially conflicting pedestrian	PEDES	Not presence
Speed of respondent's car when approaching the roundabout	MYSPD	30 km/h
The driver's time availability	HURRY	Not in a hurry
The years that respondent has been driving	DRYRS	10 years
Respondent involved in an accident in the last 2 years	ACCYE	No
Respondent's annual income is below $30,000	ILOW	Yes
Respondent's age category	AGE	Between 26-50
Commuter driver	COMYE	Yes
Male young driver	YOUNGM	No

- *Size of roundabout*: When facing a small roundabout, the probability that a driver chooses *Alt1 - slow down to stop* is 0.16; *Alt2 – slow down and keep going* is 0.53; and *Alt3 – not slow down and keep going* is 0.31. When facing a medium roundabout, the probability of choosing *Alt1* increases, while probabilities of choosing *Alt2* and *Alt3* decrease. When facing a large roundabout, probabilities of choosing *Alt1* and *Alt3* decrease, and probability of choosing *Alt2* increases greatly (see figure 11-1). The pattern of the changes of the probabilities in behavioural responses at different attribute levels suggests that the effects of this attribute on behavioural response are not linear. Drivers are more likely to choose *Alt1* and *Alt2* but less likely to choose *Alt3* at a small roundabout than at a large roundabout, suggesting that a small roundabout is safer than a large roundabout.

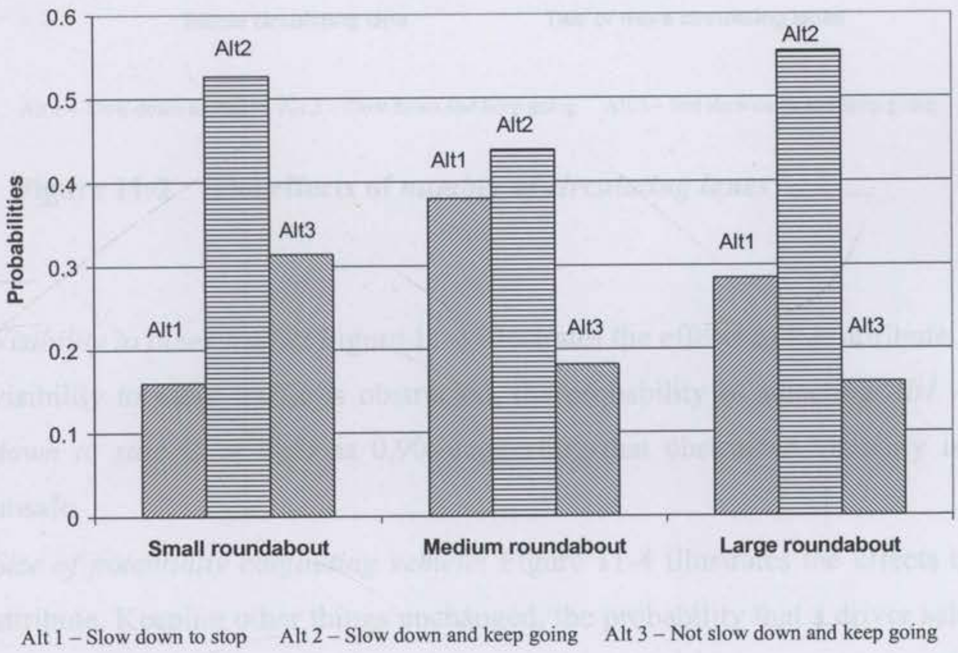
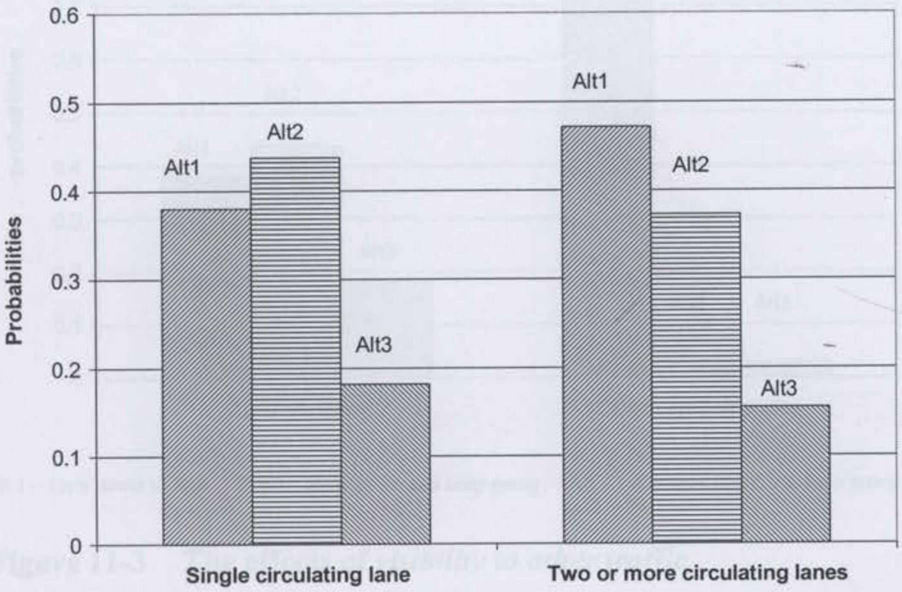


Figure 11-1 The effects of *size of roundabout*

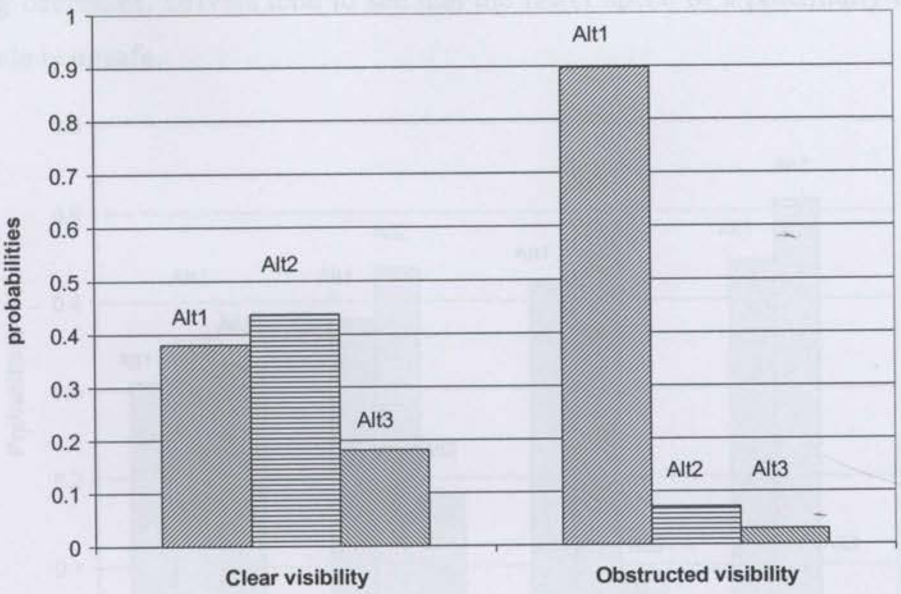
- *Number of circulating lanes*: Figure 11-2 illustrates the effects of this attribute on driver's behavioural response. The probability of selecting *Alt1 – slow down to stop* is higher at a multilane roundabout than at a single lane roundabout, suggesting that a single circulating lane roundabout is safer than a multilane roundabout. This is because the operation of a single lane roundabout is relatively simple. At a multilane roundabout, drivers are required to cross, merge or diverge from different traffic streams. Traffic weaving and lane changing at a roundabout greatly increase the demands of the driving task.



Alt 1 – Slow down to stop Alt 2 – Slow down and keep going Alt 3 – Not slow down and keep going

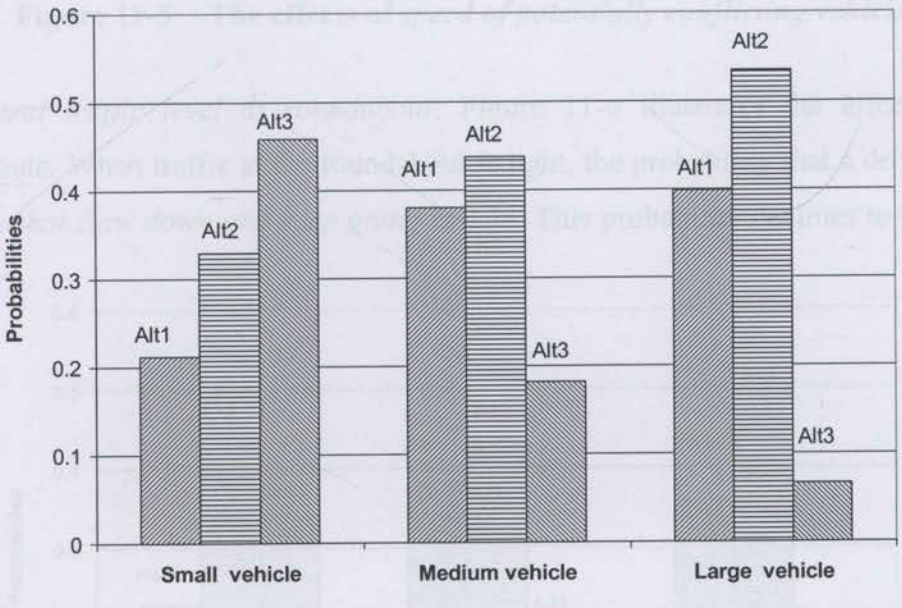
Figure 11-2 The effects of *number of circulating lanes*

- *Visibility to other traffic*: Figure 11-3 illustrates the effects of this attribute. If the visibility to other traffic is obstructed, the probability of selecting *Alt1 - slow down to stop* is as high as 0.90, suggesting that obstructed visibility is very unsafe.
- *Size of potentially conflicting vehicle*: Figure 11-4 illustrates the effects of this attribute. Keeping other things unchanged, the probability that a driver selecting *Alt3 – not slow down and keep going,* is high when encountering a small-sized potentially conflicting vehicle. This probability declines when encountering a medium or a large-sized potentially conflicting vehicle. A small-sized vehicle is safer than a medium-sized vehicle, and a medium-sized vehicle is safer than a large-sized vehicle.



Alt 1 – Slow down to stop Alt 2 – Slow down and keep going Alt 3 – Not slow down and keep going

Figure 11-3 The effects of *visibility to other traffic*



Alt 1 – Slow down to stop Alt 2 – Slow down and keep going Alt 3 – Not slow down and keep going

Figure 11-4 The effects of *size of potentially conflicting vehicle*

- *Speed of the potentially conflicting vehicle:* The effects of this attribute on behavioural response are almost linear (see figure 11-5). As the speed increases, the probabilities of selecting *Alt1 – slow down to stop* and *Alt2 – slow down and keep going* increase, while the probability of selecting *Alt3 – not slow down and keep* *going* decreases. Drivers tend to see that the faster speed of a potentially conflicting vehicle is unsafe.

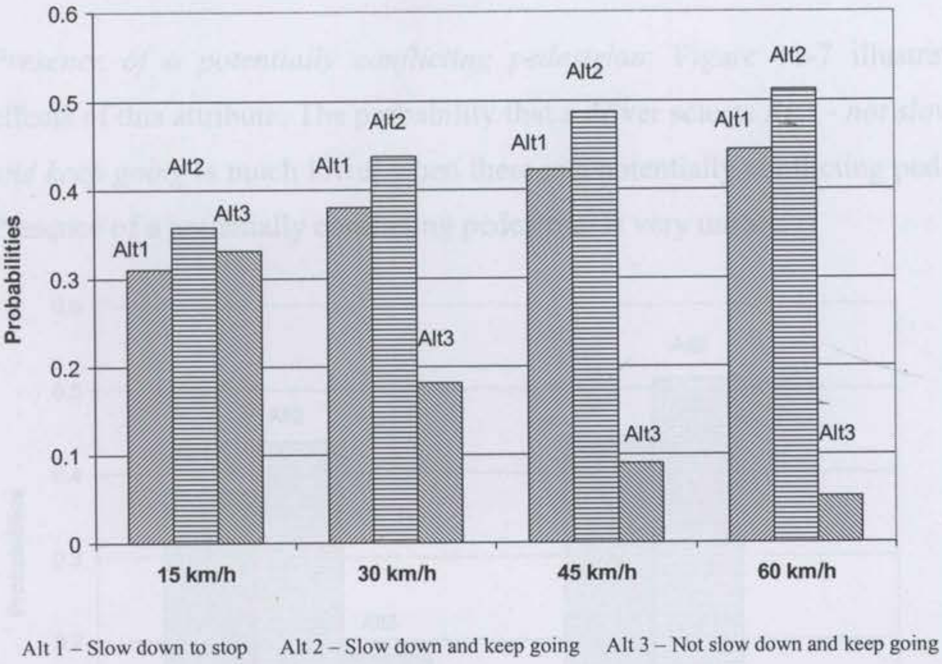


Figure 11-5 The effects of *speed of potentially conflicting vehicle*

General traffic level at roundabout: Figure 11-6 illustrates the effects of this attribute. When traffic at the roundabout is light, the probability that a driver selects *Alt3 - not slow down and keep going* is 0.34. This probability declines to 0.18 when

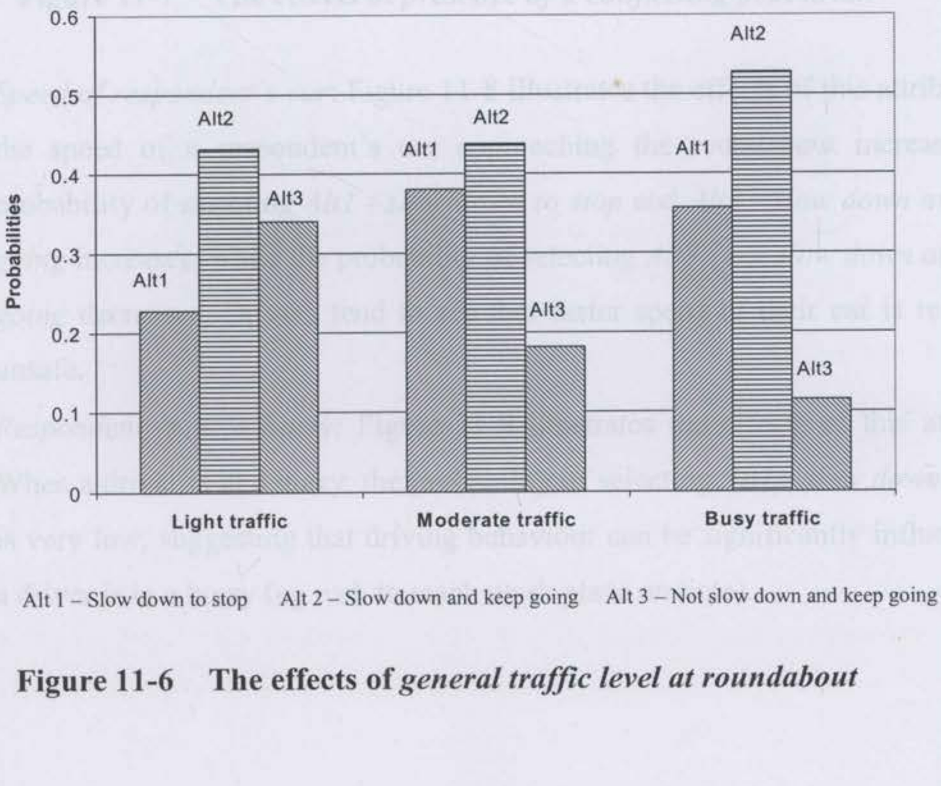


Figure 11-6 The effects of *general traffic level at roundabout*

traffic is moderate, and further declines to 0.12 when traffic is busy. Drivers tend to see light traffic as safer than busy traffic.

- *Presence of a potentially conflicting pedestrian*: Figure 11-7 illustrates the effects of this attribute. The probability that a driver selects *Alt3 - not slow down and keep going* is much lower when there is a potentially conflicting pedestrian. Presence of a potentially conflicting pedestrian is very unsafe.

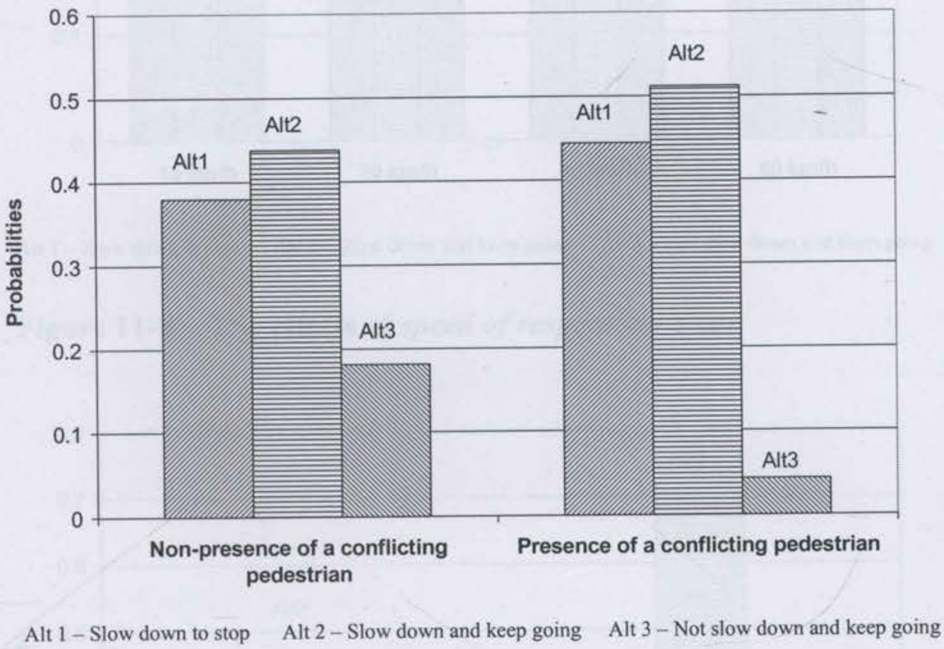
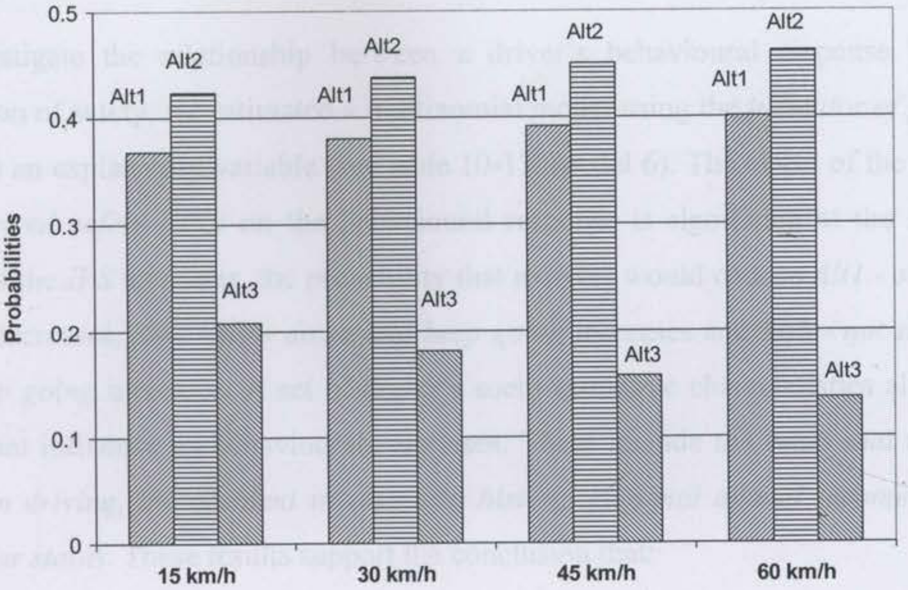


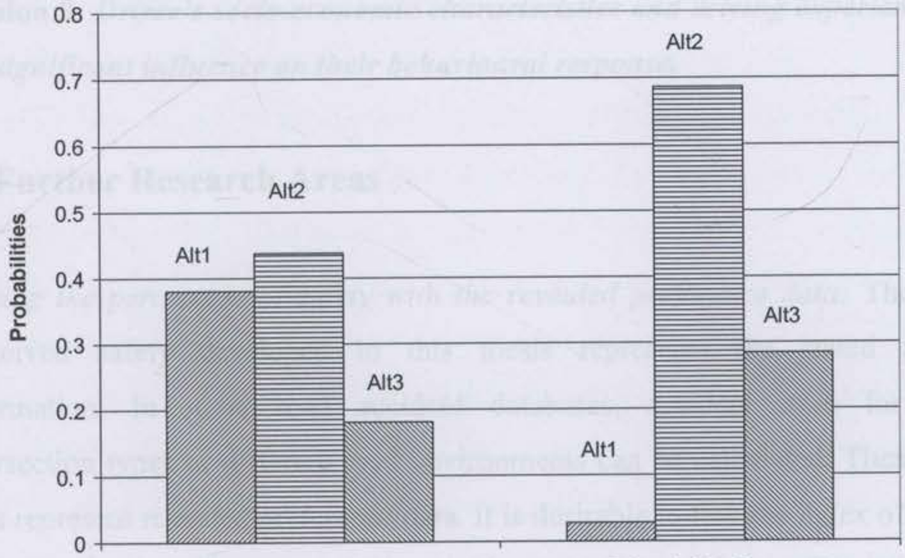
Figure 11-7 The effects of *presence of a conflicting pedestrian*

- *Speed of respondent's car*: Figure 11-8 illustrates the effects of this attribute. As the speed of a respondent's car approaching the roundabout increases, the probability of selecting *Alt1 - slow down to stop* and *Alt2 - slow down and keep going* increases, while the probability of selecting *Alt3 - not slow down and keep going* decreases. Drivers tend to see that faster speed of their car is relatively unsafe.
- *Respondent is in a hurry*: Figure 11-9 illustrates the effects of this attribute. When a driver is in a hurry, the probability of selecting *Alt1 - slow down to stop* is very low, suggesting that driving behaviour can be significantly influenced if a driver is in a hurry (eg rush to reach work place on time).



Alt 1 – Slow down to stop Alt 2 – Slow down and keep going Alt 3 – Not slow down and keep going

Figure 11-8 The effects of *speed of respondent's car*



Alt 1 – Slow down to stop Alt 2 – Slow down and keep going Alt 3 – Not slow down and keep going

Figure 11-9 The effects of *respondent's time availability*

The effects of these attributes on behavioural response support the conclusion that:

Conclusion 7: ***Attributes associated with the road and traffic situation have a significant influence on driver's behavioural response.***

To investigate the relationship between a driver's behavioural response and their perception of safety, we estimated a multinomial model using the *indicator of perceived safety* as an explanatory variable (see table 10-13, model 6). The effect of the *indicator of perceived safety (IPS)* on the behavioural response is significant at the 5 percent level. As the *IPS* increases, the probability that a driver would choose *Alt1 - slow down to stop* decreases, *Alt2 - slow down and keep going* increases and *Alt3 - not slow down and keep going* increases. A set of driver's socio-economic characteristics also have a significant influence on behavioural responses. These include *the years that the driver has been driving, the accident involvement history, personal annual income, age* and *commuter status*. These results support the conclusion that:

Conclusion 8: *There exists a relationship between the perception of safety and behavioural response. Specifically, drivers tend to select a less cautious behavioural response when facing a perceived safer driving environment.*

Conclusion 9: *Driver's socio-economic characteristics and driving experience have a significant influence on their behavioural response.*

11.6 Further Research Areas

(1) *Linking the perception of safety with the revealed preference data:* The index of perceived safety developed in this thesis represents the stated preference information. In some road accident databases, accident rates for different intersection types or different road environments can be calculated. These accident rates represent revealed preference data. It is desirable to link the index of perceived safety to actual accident rates. This would provide a test of the safety index as well as relative comprehensive information for evaluation of the safety of the road environment. This requires an accident database enabling the accident rates be derived for each roundabout type. Such a database is not available at this stage. Further research is recommended in this direction.

(2) *Presenting road traffic scenarios:* The stated-preference technique relies on experimental design to construct a set of hypothetical scenarios to elicit individual preference. It requires that information needed in evaluation and response is

appropriately presented. A "Show Card" based on texts and tables describing attributes is a prevalent format of the survey instrument for its simplicity in design and implementation. A visualised scenario using video-captured real traffic is used to represent a complex phenomenon - a road and traffic situation. The visualised scenario is more appealing to present information such as size of roundabout, the number of circulating lanes, size of a potentially conflicting vehicle. However, it has limitations for presenting information about speed of a vehicle, the general traffic level at a roundabout and visibility to other traffic. (Hence the current survey instrument used a word description to provide additional information about these attributes in a table format and an interactive window). Two possible improvements are proposed. The first is to use animated video-sequences. The speed of a vehicle can be appropriately presented with an animated image sequence. The general traffic level at a roundabout can be captured with a video-recorder with wider camera scope. Another promising method is to use computer graphics. For example, every attribute can be appropriately presented using animated 3D graphics (such as Crystal Animation). Other influences such as the weather condition can also be implemented with 3D animation.

(3) *Incorporating observed driver behaviour data:* The stated-preference technique relies on people's statement about what they would do when faced with a hypothetical scenario. The reliability of a model depends on how consistent it is with what they say they would do in an experiment (stated-preference - SP data) and what they actually do in reality (revealed preference - RP data). The reliability of a model can be improved by combining the SP data with RP data. The technique for incorporating of SP data and RP data for a discrete choice model is available (see Louviere et al 2000). The challenge is to observe driver behaviour at real traffic situations with appropriate variation in attribute levels. A video-image system is proposed to capture driver behaviour at an investigation site, with these sequences analysed frame by frame. (A video-image in a period of one second can de decomposed into 24 frames). It should be noted however that drivers may behave differently when they realise that they are observed, requiring careful consideration in selecting the location of the video-recorder.

(4) *Extending the investigated scenarios to all road and traffic situations*: We have derived an *Indicator of Perceived Safety (IPS)* and proposed that it can be used as a supplementary measure of the safety of the road environment. The IPS is based on

different physical and traffic conditions of roundabouts. In the road transport system, there are many kinds of traffic control devices or driving environments where we may wish to investigate a driver's perception of safety. Typical situations include comparing the perception of safety between different treatment schemes for a "black spot", or comparing the perception of safety between a designed treatment scheme and the status quo. This requires us to extend the evaluation situations beyond the roundabout. The stated preference method provides a rich and flexible way of incorporating any road and traffic situation. If we compare two treatment schemes (eg treated or not treated), a binary choice model can be specified. If we wish to compare a set of choice schemes, other choice models can be used.

(5) *Linking the behavioural response to the likelihood of an accident*: Many analysts prefer to use accident statistics as the most important criterion to measure the safety of the road. The implication for this study is to link a behavioural response at a road and traffic situation to the likelihood of accident occurrence. This firstly requires a technique to record a small change of driving behaviour. The most appropriate measurement of driving behaviour may be driver's speed behaviour (eg accelerating, slowing down or stopping). The second requirement is an accident database where driving behaviour immediately before an accident is included. However, it might be difficult to identify driving behaviour before an accident.

(6) *Limitations of current methodology*: While the stated-preference technique provides a theoretically sound and practically operational framework for measurement of drivers' perception of safety and behavioural response at a road environment, its limitations are noted. One consideration is identification of appropriate attributes for experimental design. Interactions between some attributes may be significant. For example, there may be significant interaction between "in a hurry" to other attributes. An examination of these interactions requires a large sample. If these interactions are significant, the estimated utility parameters may be biased. The behavioural interpretation would be misleading.

(7) *Further research directions*: As a summary, two important research areas are recommended. One involves using hierarchical stated-response design to accommodate interactions between attributes (Hensher 1989). Another is to calibrate index of safety developed from stated-preference data with revealed road safety data.

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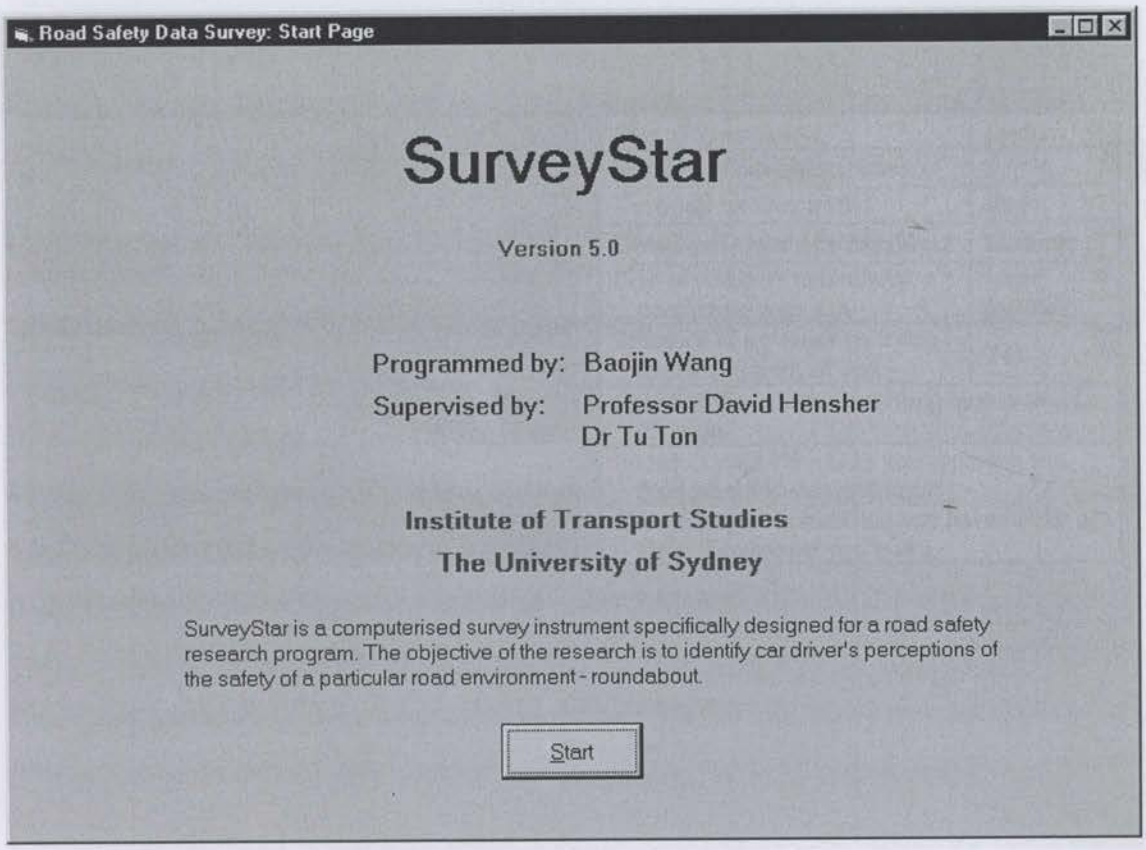
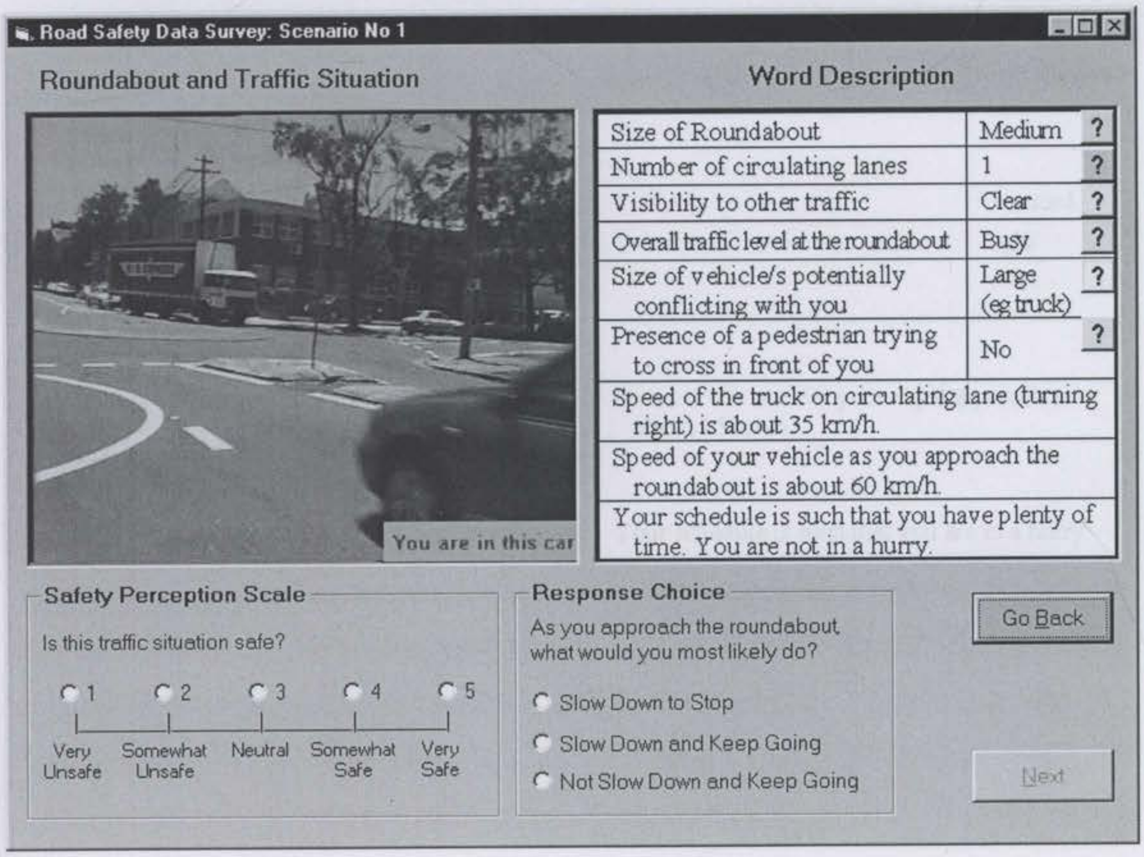
Appendix I

Survey Instrument - Picture and Word format

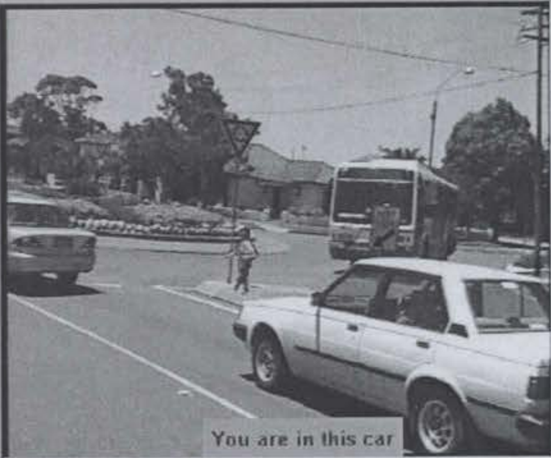
Evaluation Screens


Road Safety Data Survey: Start Page
SurveyStar
Version 5.0
Programmed by: Baojin Wang
Supervised by: Professor David Hensher
Dr Tu Ton
Institute of Transport Studies
The University of Sydney
SurveyStar is a computerised survey instrument specifically designed for a road safety research program. The objective of the research is to identify car driver's perceptions of the safety of a particular road environment - roundabout.
Start


Road Safety Data Survey: Scenario No 1
Roundabout and Traffic Situation
Word Description
You are in this car
Size of Roundabout | Medium
Number of circulating lanes | 1
Visibility to other traffic | Clear
Overall traffic level at the roundabout | Busy
Size of vehicle/s potentially conflicting with you | Large (eg truck)
Presence of a pedestrian trying to cross in front of you | No
Speed of the truck on circulating lane (turning right) is about 35 km/h.
Speed of your vehicle as you approach the roundabout is about 60 km/h.
Your schedule is such that you have plenty of time. You are not in a hurry.
Safety Perception Scale
Is this traffic situation safe?
1 2 3 4 5
Very Unsafe
Somewhat Unsafe
Neutral
Somewhat Safe
Very Safe
Response Choice
As you approach the roundabout, what would you most likely do?
Slow Down to Stop
Slow Down and Keep Going
Not Slow Down and Keep Going
Go Back
Next

Road Safety Data Survey: Scenario No 2

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Medium	?
Number of circulating lanes	2	?
Visibility to other traffic	Clear	?
Overall traffic level at the roundabout	Moderate	?
Size of vehicle/s potentially conflicting with you	Large (eg truck)	?
Presence of a pedestrian trying to cross in front of you	Yes	?
Speed of the bus on circulating lane is about 55 km/h.		
Speed of your vehicle as you approach the roundabout is about 40 km/h.		
Your schedule is such that you have plenty of time. You are not in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

1	2	3	4	5
Very Unsafe	Somewhat Unsafe	Neutral	Somewhat Safe	Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

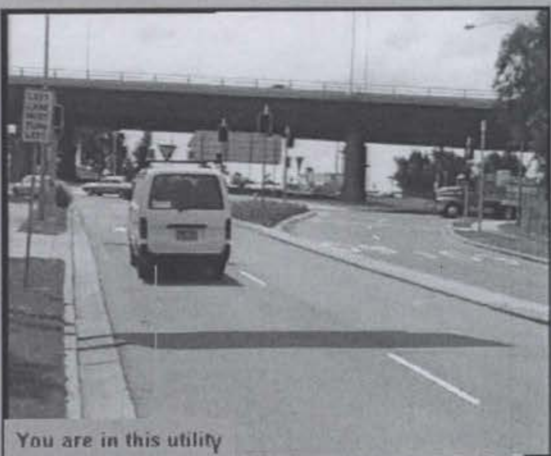
- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

Next

Road Safety Data Survey: Scenario No 3

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Medium	?
Number of circulating lanes	1	?
Visibility to other traffic	Obstructed	?
Overall traffic level at the roundabout	Light	?
Size of vehicle/s potentially conflicting with you	Large (eg truck)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of the truck at your right approach is about 15 km/h.		
Speed of your vehicle as you approach the roundabout is about 20 km/h.		
Your schedule is such that you are in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

1	2	3	4	5
Very Unsafe	Somewhat Unsafe	Neutral	Somewhat Safe	Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

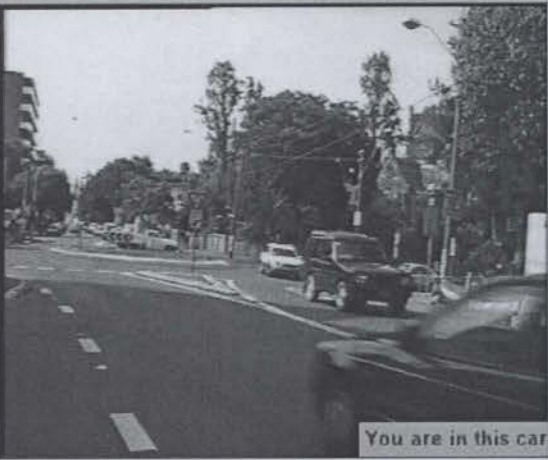
- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

Next

Road Safety Data Survey: Scenario No 4

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Medium	?
Number of circulating lanes	2	?
Visibility to other traffic	Obstructed	?
Overall traffic level at the roundabout	Busy	?
Size of vehicle/s potentially conflicting with you	Small (eg car)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of the car on circulating lane (turning right) is about 35 km/h.		
Speed of your vehicle as you approach the roundabout is about 60 km/h.		
Your schedule is such that you have plenty of time. You are not in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

1	2	3	4	5
Very Unsafe	Somewhat Unsafe	Neutral	Somewhat Safe	Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

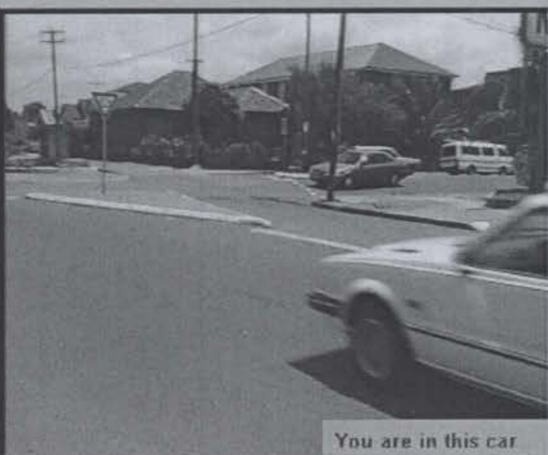
- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

Next

Road Safety Data Survey: Scenario No 5

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Medium	?
Number of circulating lanes	1	?
Visibility to other traffic	Clear	?
Overall traffic level at the roundabout	Moderate	?
Size of vehicle/s potentially conflicting with you	Small (eg Car)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of the car at your right approach is about 55 km/h.		
Speed of your vehicle as you approach the roundabout is about 40 km/h.		
Your schedule is such that you are in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

1	2	3	4	5
Very Unsafe	Somewhat Unsafe	Neutral	Somewhat Safe	Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

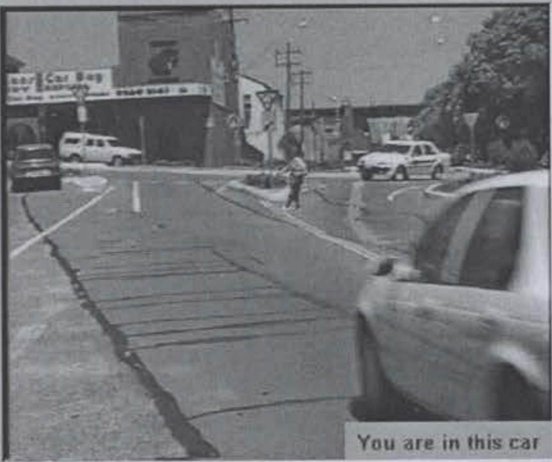
- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

Next

Road Safety Data Survey: Scenario No 6

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Medium	?
Number of circulating lanes	1	?
Visibility to other traffic	Clear	?
Overall traffic level at the roundabout	Light	?
Size of vehicle/s potentially conflicting with you	Small (eg Car)	?
Presence of a pedestrian trying to cross in front of you	Yes	?
Speed of the car on circulating lane is about 15 km/h.		
Speed of your vehicle as you approach the roundabout is about 20 km/h.		
Your schedule is such that you have plenty of time. You are not in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

1	2	3	4	5
Very Unsafe	Somewhat Unsafe	Neutral	Somewhat Safe	Very Safe

Response Choice

As you approach the roundabout what would you most likely do?

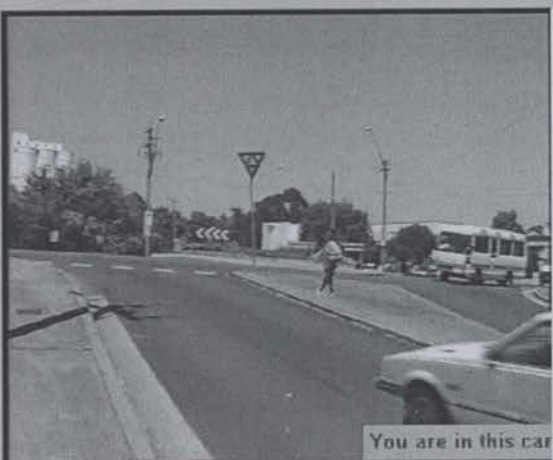
- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

Next

Road Safety Data Survey: Scenario No 7

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Medium	?
Number of circulating lanes	1	?
Visibility to other traffic	Clear	?
Overall traffic level at the roundabout	Busy	?
Size of vehicle/s potentially conflicting with you	Medium (egMedium Bus)	?
Presence of a pedestrian trying to cross in front of you	Yes	?
Speed of the medium-sized bus on circulating lane is about 40 km/h.		
Speed of your vehicle as you approach the roundabout is about 60 km/h.		
Your schedule is such that you are in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

1	2	3	4	5
Very Unsafe	Somewhat Unsafe	Neutral	Somewhat Safe	Very Safe

Response Choice

As you approach the roundabout what would you most likely do?

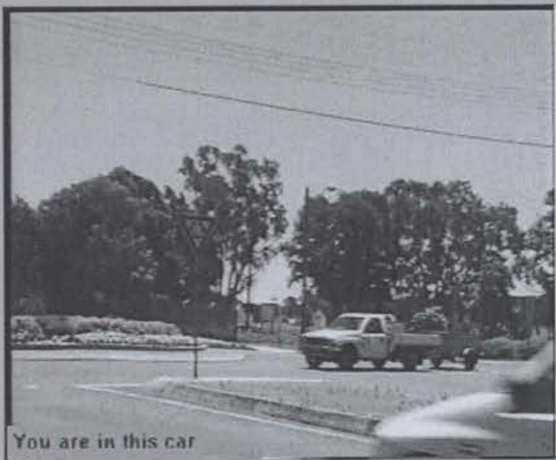
- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

Next

Road Safety Data Survey: Scenario No 8

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Medium	?
Number of circulating lanes	1	?
Visibility to other traffic	Obstructed	?
Overall traffic level at the roundabout	Moderate	?
Size of vehicle/s potentially conflicting with you	Medium (eg Medium Truck)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of the medium-sized truck on circulating lane is about 55 km/h.		
Speed of your vehicle as you approach the roundabout is about 40 km/h.		
Your schedule is such that you have plenty of time. You are not in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

1	2	3	4	5
Very Unsafe	Somewhat Unsafe	Neutral	Somewhat Safe	Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

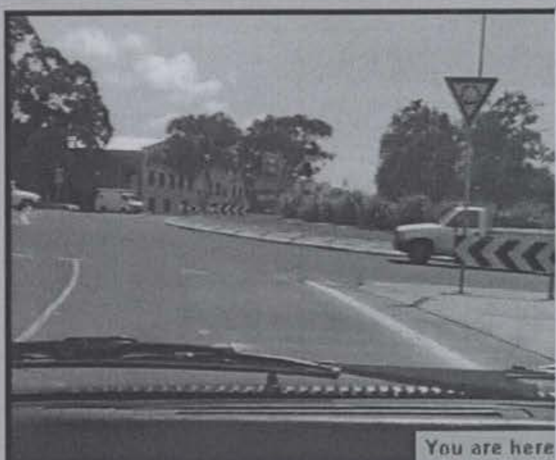
- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

Next

Road Safety Data Survey: Scenario No 9

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Medium	?
Number of circulating lanes	2	?
Visibility to other traffic	Clear	?
Overall traffic level at the roundabout	Light	?
Size of vehicle/s potentially conflicting with you	Medium (eg Medium Truck)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of the medium-sized truck on circulating lane is about 30 km/h.		
Speed of your vehicle as you approach the roundabout is about 20 km/h.		
Your schedule is such that you have plenty of time. You are not in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

1	2	3	4	5
Very Unsafe	Somewhat Unsafe	Neutral	Somewhat Safe	Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

Next

Road Safety Data Survey: Scenario No 10

Roundabout and Traffic Situation

Word Description

Size of Roundabout	Large	?
Number of circulating lanes	2	?
Visibility to other traffic	Obstructed	?
Overall traffic level at the roundabout	Moderate	?
Size of vehicle/s potentially conflicting with you	Large (eg Truck)	?
Presence of a pedestrian trying to cross in front of you	Yes	?
Speed of the truck on circulating lane (turning right) is about 35 km/h.		
Speed of your vehicle as you approach the roundabout is about 20 km/h.		
Your schedule is such that you are in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

1 Very Unsafe — 2 Somewhat Unsafe — 3 Neutral — 4 Somewhat Safe — 5 Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

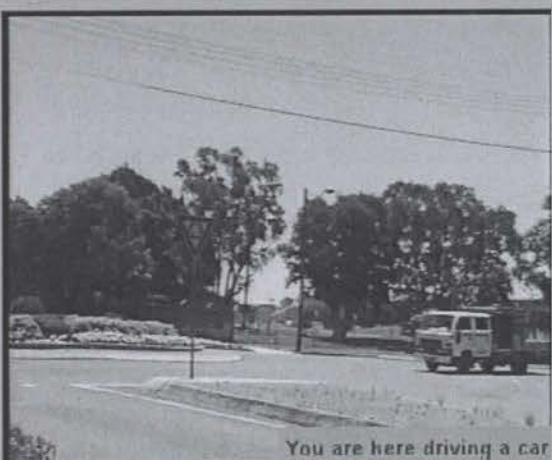
- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

Next

Road Safety Data Survey: Scenario No 11

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Large	?
Number of circulating lanes	1	?
Visibility to other traffic	Clear	?
Overall traffic level at the roundabout	Light	?
Size of vehicle/s potentially conflicting with you	Large (eg Truck)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of the truck at your right approach is about 50 km/h.		
Speed of your vehicle as you approach the roundabout is about 60 km/h.		
Your schedule is such that you have plenty of time. You are not in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

1 Very Unsafe — 2 Somewhat Unsafe — 3 Neutral — 4 Somewhat Safe — 5 Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

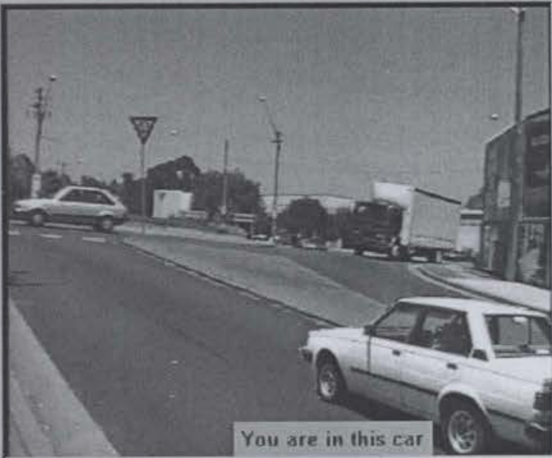
- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

Next

Road Safety Data Survey: Scenario No 12

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Large	?
Number of circulating lanes	1	?
Visibility to other traffic	Clear	?
Overall traffic level at the roundabout	Busy	?
Size of vehicle/s potentially conflicting with you	Large (eg Truck)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of the truck on circulating lane is about 15 km/h.		
Speed of your vehicle as you approach the roundabout is about 40 km/h.		
Your schedule is such that you have plenty of time. You are not in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

( ) 1 Very Unsafe ( ) 2 Somewhat Unsafe ( ) 3 Neutral ( ) 4 Somewhat Safe ( ) 5 Very Safe

Response Choice

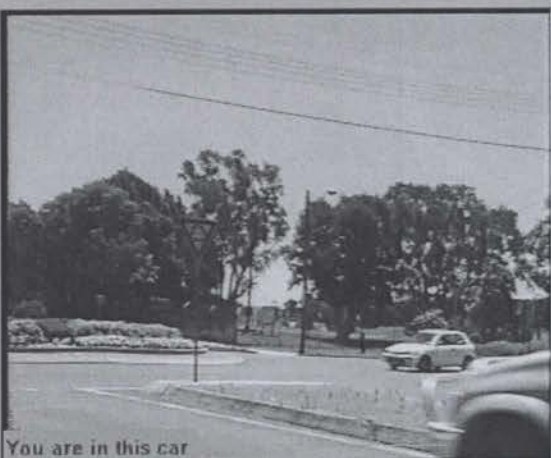
As you approach the roundabout, what would you most likely do?

( ) Slow Down to Stop
( ) Slow Down and Keep Going
( ) Not Slow Down and Keep Going

[Go Back] [Next]

Road Safety Data Survey: Scenario No 13

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Large	?
Number of circulating lanes	1	?
Visibility to other traffic	Clear	?
Overall traffic level at the roundabout	Moderate	?
Size of vehicle/s potentially conflicting with you	Small (eg Car)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of the car at your right approach is about 45 km/h.		
Speed of your vehicle as you approach the roundabout is about 20 km/h.		
Your schedule is such that you have plenty of time. You are not in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

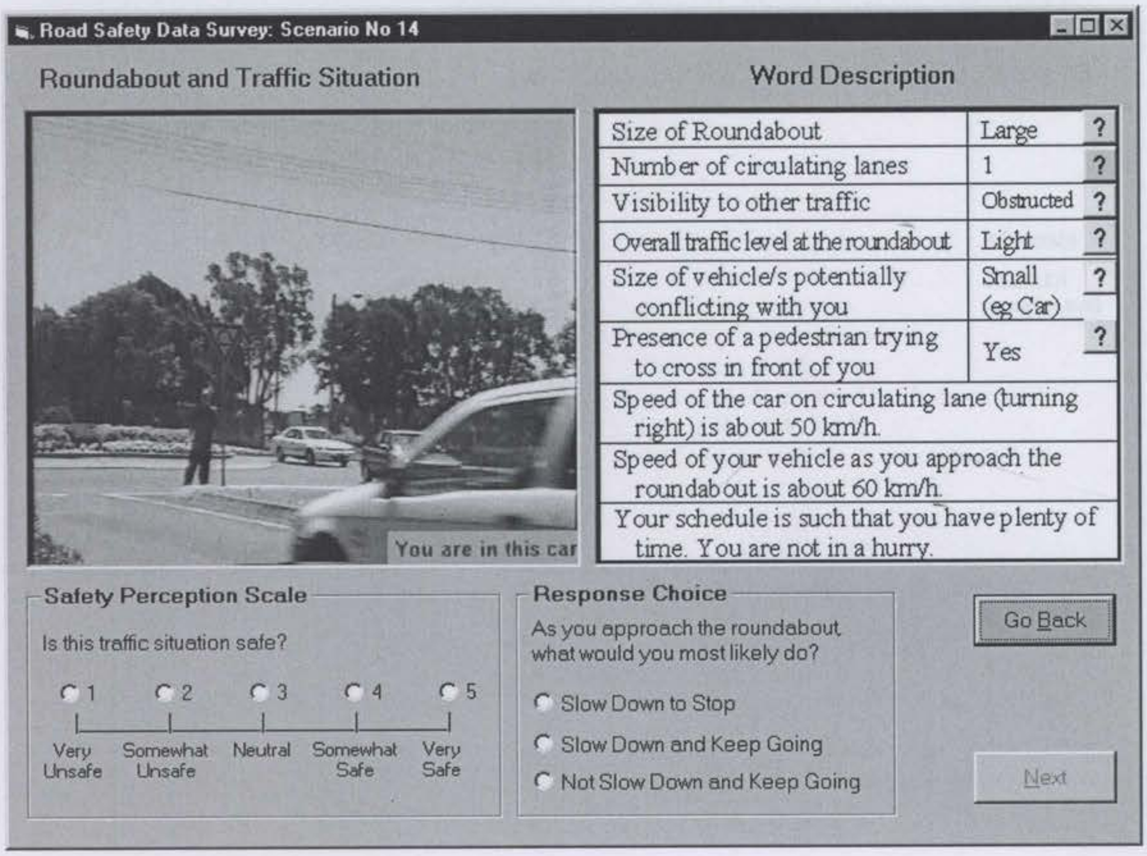
( ) 1 Very Unsafe ( ) 2 Somewhat Unsafe ( ) 3 Neutral ( ) 4 Somewhat Safe ( ) 5 Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

( ) Slow Down to Stop
( ) Slow Down and Keep Going
( ) Not Slow Down and Keep Going

[Go Back] [Next]



Road Safety Data Survey: Scenario No 14

Roundabout and Traffic Situation

You are in this car

Word Description

Size of Roundabout	Large
Number of circulating lanes	1
Visibility to other traffic	Obstructed
Overall traffic level at the roundabout	Light
Size of vehicle/s potentially conflicting with you	Small (eg Car)
Presence of a pedestrian trying to cross in front of you	Yes
Speed of the car on circulating lane (turning right) is about 50 km/h.	
Speed of your vehicle as you approach the roundabout is about 60 km/h.	
Your schedule is such that you have plenty of time. You are not in a hurry.	

Safety Perception Scale

Is this traffic situation safe?

1 Very Unsafe — 2 Somewhat Unsafe — 3 Neutral — 4 Somewhat Safe — 5 Very Safe

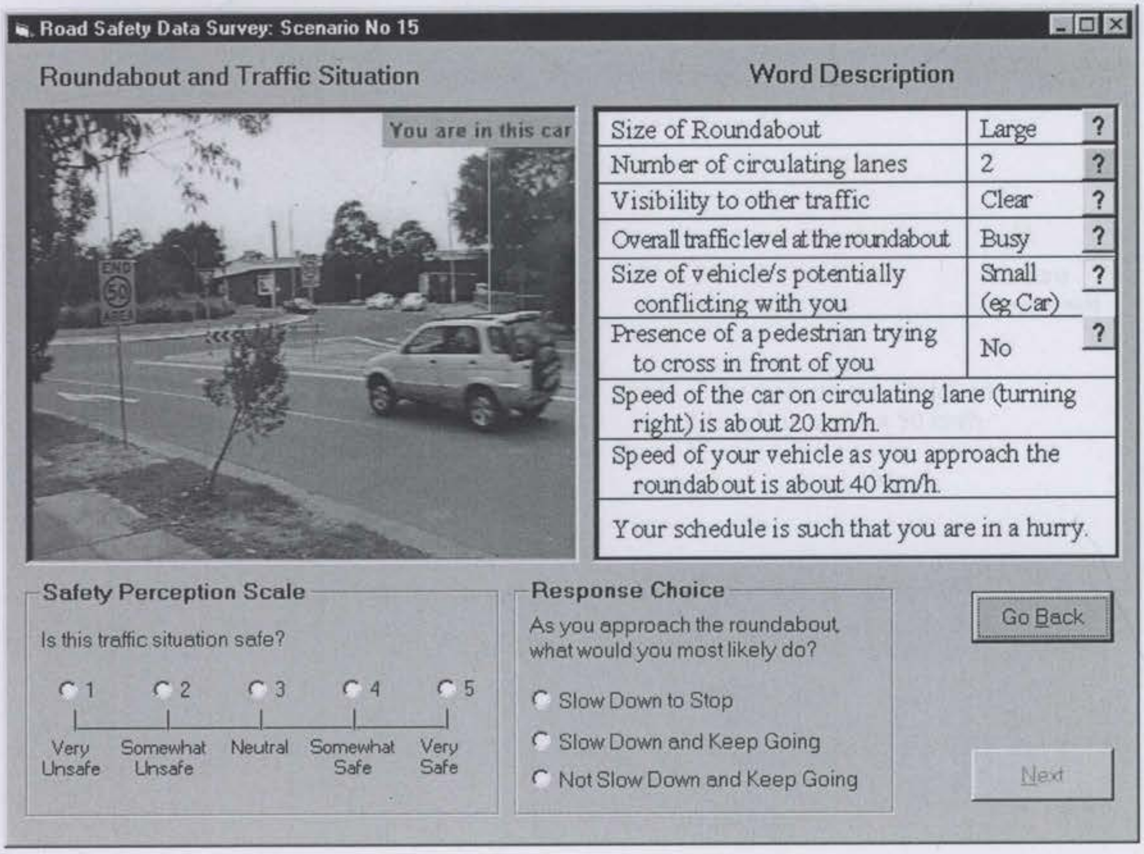
Response Choice

As you approach the roundabout, what would you most likely do?

- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

Next



Road Safety Data Survey: Scenario No 15

Roundabout and Traffic Situation

You are in this car

Word Description

Size of Roundabout	Large
Number of circulating lanes	2
Visibility to other traffic	Clear
Overall traffic level at the roundabout	Busy
Size of vehicle/s potentially conflicting with you	Small (eg Car)
Presence of a pedestrian trying to cross in front of you	No
Speed of the car on circulating lane (turning right) is about 20 km/h.	
Speed of your vehicle as you approach the roundabout is about 40 km/h.	
Your schedule is such that you are in a hurry.	

Safety Perception Scale

Is this traffic situation safe?

1 Very Unsafe — 2 Somewhat Unsafe — 3 Neutral — 4 Somewhat Safe — 5 Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

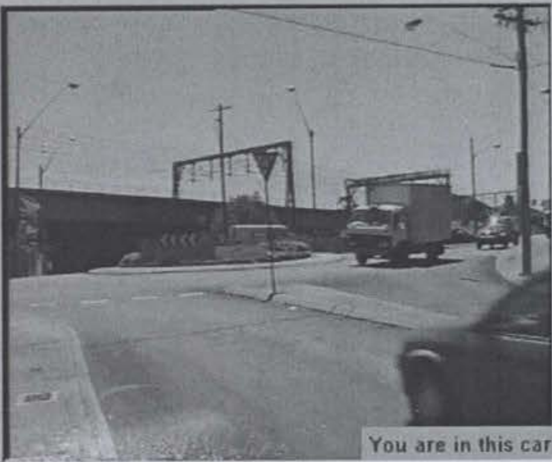
- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

Next

Road Safety Data Survey: Scenario No 16

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Large	?
Number of circulating lanes	1	?
Visibility to other traffic	Clear	?
Overall traffic level at the roundabout	Moderate	?
Size of vehicle/s potentially conflicting with you	Medium (eg medium truck)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of medium-sized truck on circulating lane is about 40 km/h.		
Speed of your vehicle as you approach the roundabout is about 20 km/h.		
Your schedule is such that you have plenty of time. You are not busy.		

Safety Perception Scale

Is this traffic situation safe?

1 Very Unsafe — 2 Somewhat Unsafe — 3 Neutral — 4 Somewhat Safe — 5 Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

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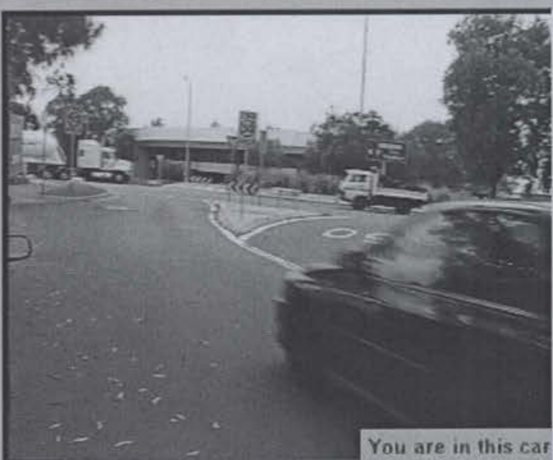
Road Safety Data Survey: Scenario No 17

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Large	?
Number of circulating lanes	2	?
Visibility to other traffic	Clear	?
Overall traffic level at the roundabout	Light	?
Size of vehicle/s potentially conflicting with you	Medium (eg medium truck)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of the medium-sized truck on circulating lane is about 50 km/h.		
Speed of your vehicle as you approach the roundabout is about 60 km/h.		
Your schedule is such that you are in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

1 Very Unsafe — 2 Somewhat Unsafe — 3 Neutral — 4 Somewhat Safe — 5 Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

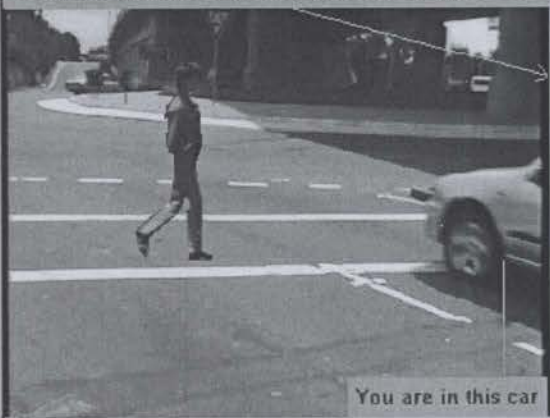
Go Back

Next

Road Safety Data Survey: Scenario No 18

Roundabout and Traffic Situation

A middle sized truck is coming from this approach



Word Description

Size of Roundabout	Large	?
Number of circulating lanes	1	?
Visibility to other traffic	Obstructed	?
Overall traffic level at the roundabout	Busy	?
Size of vehicle/s potentially conflicting with you	Medium (eg medium truck)	?
Presence of a pedestrian trying to cross in front of you	Yes	?
Speed of the medium-sized truck at your right approach is about 20 km/h.		
Speed of your vehicle as you approach the roundabout is about 40 km/h.		
Your schedule is such that you have plenty of time. You are not busy.		

Safety Perception Scale

Is this traffic situation safe?

1 Very Unsafe — 2 Somewhat Unsafe — 3 Neutral — 4 Somewhat Safe — 5 Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

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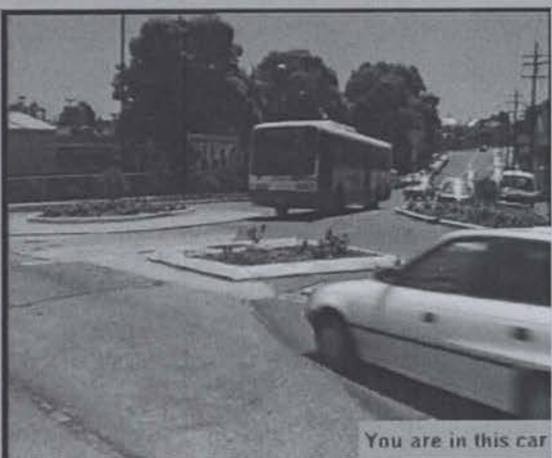
Road Safety Data Survey: Scenario No 19

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Small	?
Number of circulating lanes	1	?
Visibility to other traffic	Clear	?
Overall traffic level at the roundabout	Light	?
Size of vehicle/s potentially conflicting with you	Large (eg Bus)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of the bus on circulating lane is about 35 km/h.		
Speed of your vehicle as you approach the roundabout is about 40 km/h.		
Your schedule is such that you have plenty of time. You are not busy.		

Safety Perception Scale

Is this traffic situation safe?

1 Very Unsafe — 2 Somewhat Unsafe — 3 Neutral — 4 Somewhat Safe — 5 Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

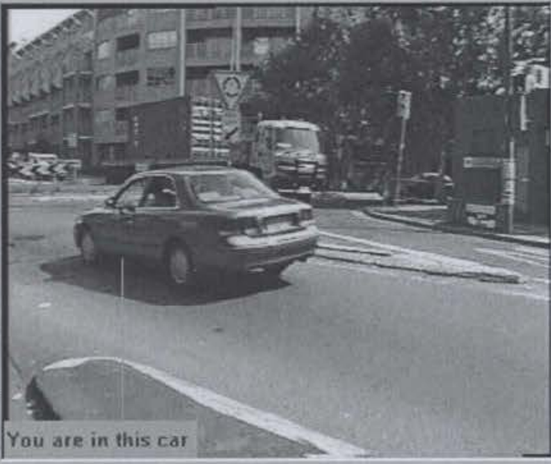
- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

Next

Road Safety Data Survey: Scenario No 20

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Small	?
Number of circulating lanes	1	?
Visibility to other traffic	Obstructed	?
Overall traffic level at the roundabout	Busy	?
Size of vehicle/s potentially conflicting with you	Large (eg large truck)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of the truck on circulating lane is about 50 km/h.		
Speed of your vehicle as you approach the roundabout is about 20 km/h.		
Your schedule is such that you are in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

1	2	3	4	5
Very Unsafe	Somewhat Unsafe	Neutral	Somewhat Safe	Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

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Road Safety Data Survey: Scenario No 21

Roundabout and Traffic Situation

Word Description

Size of Roundabout	Small	?
Number of circulating lanes	2	?
Visibility to other traffic	Clear	?
Overall traffic level at the roundabout	Moderate	?
Size of vehicle/s potentially conflicting with you	Large (eg Bus)	?
Presence of a pedestrian trying to cross in front of you	Yes	?
Speed of the bus on circulating lane is about 25 km/h.		
Speed of your vehicle as you approach the roundabout is about 60 km/h.		
Your schedule is such that you have plenty of time. You are not busy.		

Safety Perception Scale

Is this traffic situation safe?

1	2	3	4	5
Very Unsafe	Somewhat Unsafe	Neutral	Somewhat Safe	Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

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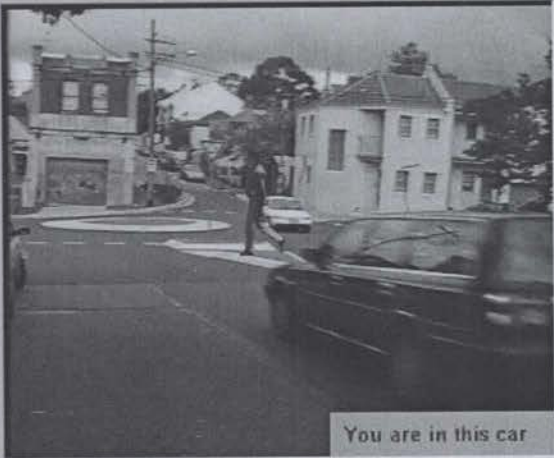
Road Safety Data Survey: Scenario No 22

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Small	?
Number of circulating lanes	1	?
Visibility to other traffic	Clear	?
Overall traffic level at the roundabout	Light	?
Size of vehicle/s potentially conflicting with you	Small (eg Car)	?
Presence of a pedestrian trying to cross in front of you	Yes	?
Speed of the car on circulating lane is about 45 km/h.		
Speed of your vehicle as you approach the roundabout is about 40 km/h.		
Your schedule is such that you are in a hurry.		

Safety Perception Scale

Is this traffic situation safe?

1 Very Unsafe · 2 Somewhat Unsafe · 3 Neutral · 4 Somewhat Safe · 5 Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

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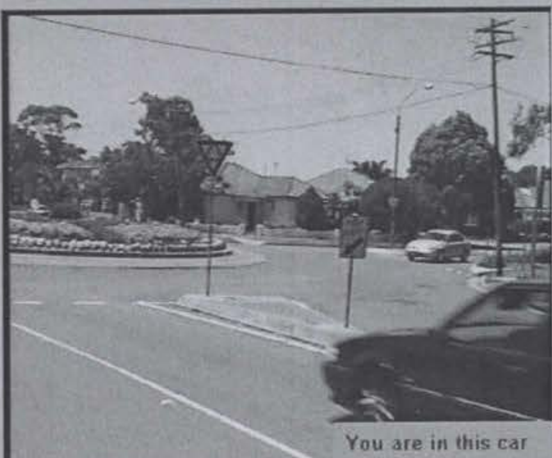
Road Safety Data Survey: Scenario No 23

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Small	?
Number of circulating lanes	2	?
Visibility to other traffic	Clear	?
Overall traffic level at the roundabout	Busy	?
Size of vehicle/s potentially conflicting with you	Small (eg Car)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of the car at your right approach is about 55 km/h.		
Speed of your vehicle as you approach the roundabout is about 20 km/h.		
Your schedule is such that you have plenty of time. You are not busy.		

Safety Perception Scale

Is this traffic situation safe?

1 Very Unsafe · 2 Somewhat Unsafe · 3 Neutral · 4 Somewhat Safe · 5 Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

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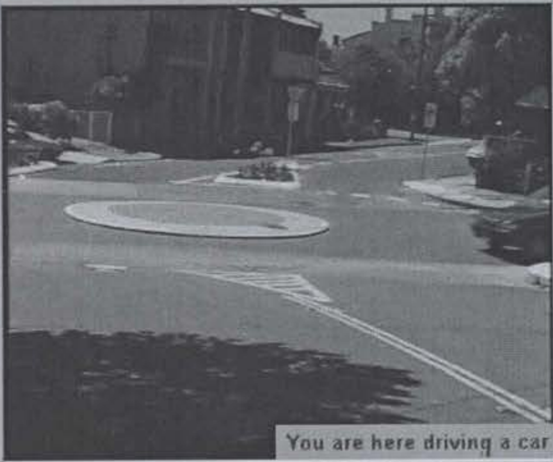
Road Safety Data Survey: Scenario No 24

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Small	?
Number of circulating lanes	1	?
Visibility to other traffic	Obstructed	?
Overall traffic level at the roundabout	Moderate	?
Size of vehicle/s potentially conflicting with you	Small (eg Car)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of the car at your right approach is about 20 km/h.		
Speed of your vehicle as you approach the roundabout is about 60 km/h.		
Your schedule is such that you have plenty of time. You are not busy.		

Safety Perception Scale

Is this traffic situation safe?

1	2	3	4	5
Very Unsafe	Somewhat Unsafe	Neutral	Somewhat Safe	Very Safe

Response Choice

As you approach the roundabout, what would you most likely do?

- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

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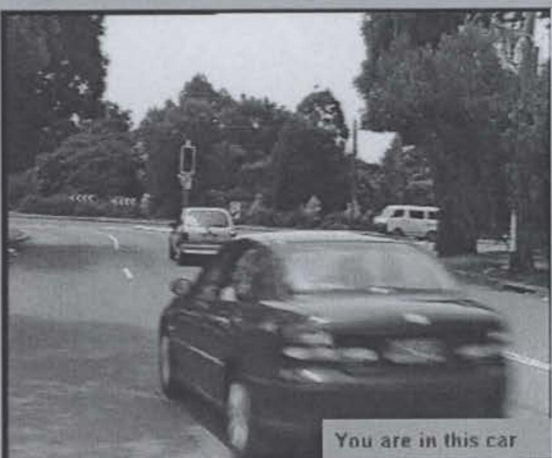
Road Safety Data Survey: Scenario No 25

Roundabout and Traffic Situation



Word Description

Size of Roundabout	Small	?
Number of circulating lanes	2	?
Visibility to other traffic	Obstructed	?
Overall traffic level at the roundabout	Light	?
Size of vehicle/s potentially conflicting with you	Medium (eg medium bus)	?
Presence of a pedestrian trying to cross in front of you	No	?
Speed of the medium-sized bus at your right approach is about 45 km/h.		
Speed of your vehicle as you approach the roundabout is about 40 km/h.		
Your schedule is such that you have plenty of time. You are not busy.		

Safety Perception Scale

Is this traffic situation safe?

1	2	3	4	5
Very Unsafe	Somewhat Unsafe	Neutral	Somewhat Safe	Very Safe

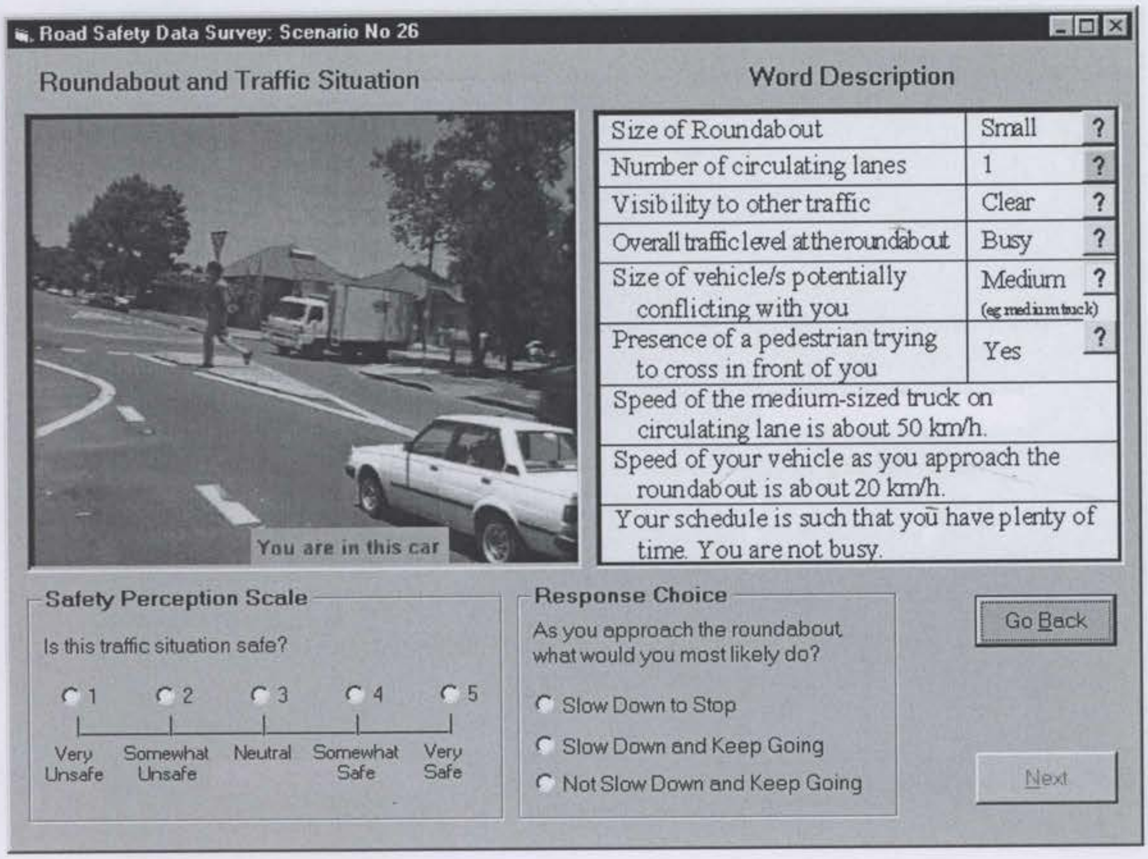
Response Choice

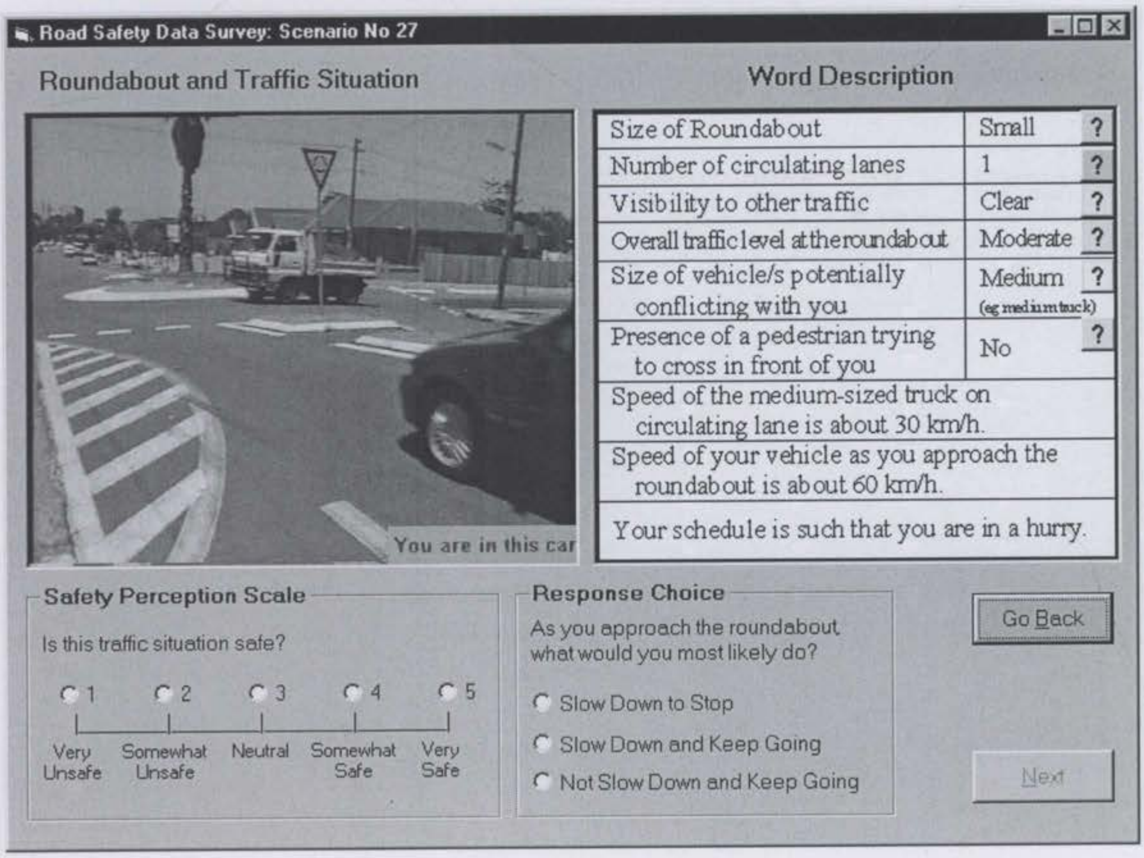
As you approach the roundabout, what would you most likely do?

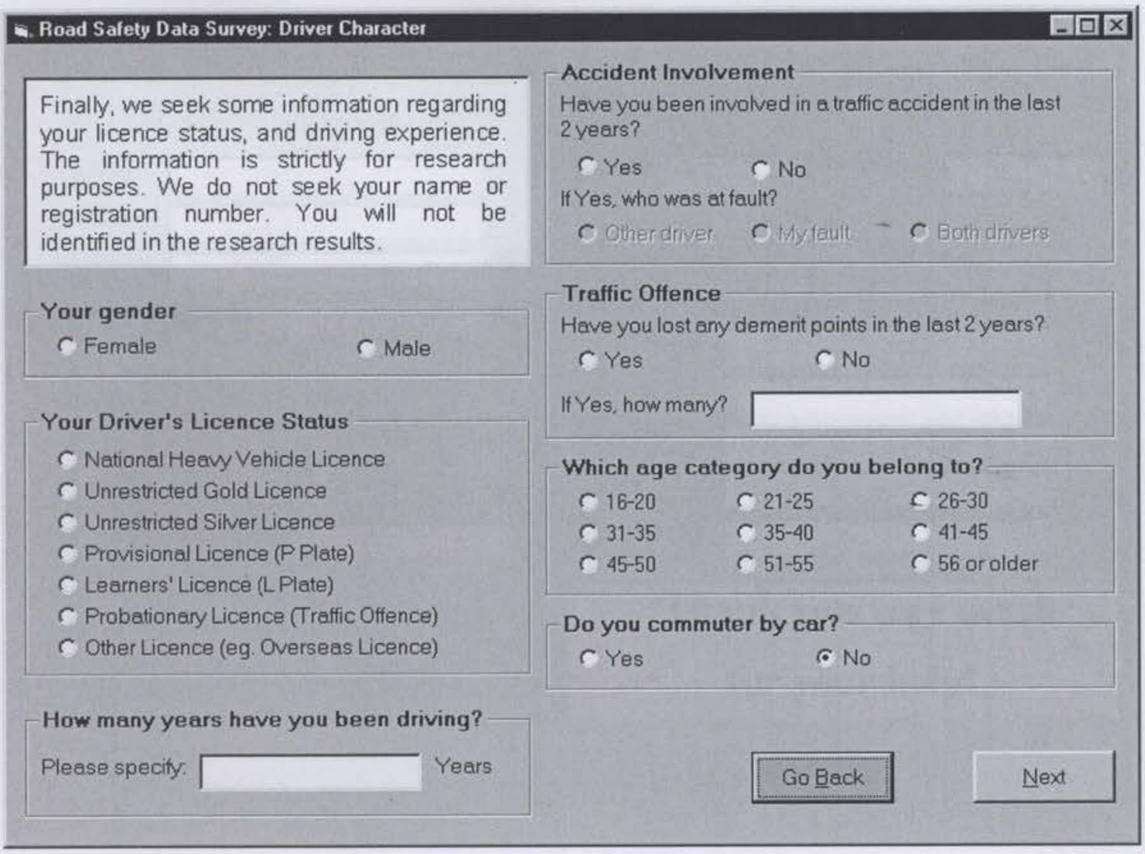
- Slow Down to Stop
- Slow Down and Keep Going
- Not Slow Down and Keep Going

Go Back

Next


Road Safety Data Survey: Scenario No 26
Roundabout and Traffic Situation
Word Description
Size of Roundabout
Small
Number of circulating lanes
1
Visibility to other traffic
Clear
Overall traffic level at the roundabout
Busy
Size of vehicle/s potentially conflicting with you
Medium (eg medium truck)
Presence of a pedestrian trying to cross in front of you
Yes
Speed of the medium-sized truck on circulating lane is about 50 km/h.
Speed of your vehicle as you approach the roundabout is about 20 km/h.
Your schedule is such that you have plenty of time. You are not busy.
You are in this car
Safety Perception Scale
Is this traffic situation safe?
1
2
3
4
5
Very Unsafe
Somewhat Unsafe
Neutral
Somewhat Safe
Very Safe
Response Choice
As you approach the roundabout what would you most likely do?
Slow Down to Stop
Slow Down and Keep Going
Not Slow Down and Keep Going
Go Back
Next


Road Safety Data Survey: Scenario No 27
Roundabout and Traffic Situation
Word Description
Size of Roundabout
Small
Number of circulating lanes
1
Visibility to other traffic
Clear
Overall traffic level at the roundabout
Moderate
Size of vehicle/s potentially conflicting with you
Medium (eg medium truck)
Presence of a pedestrian trying to cross in front of you
No
Speed of the medium-sized truck on circulating lane is about 30 km/h.
Speed of your vehicle as you approach the roundabout is about 60 km/h.
Your schedule is such that you are in a hurry.
You are in this car
Safety Perception Scale
Is this traffic situation safe?
1
2
3
4
5
Very Unsafe
Somewhat Unsafe
Neutral
Somewhat Safe
Very Safe
Response Choice
As you approach the roundabout what would you most likely do?
Slow Down to Stop
Slow Down and Keep Going
Not Slow Down and Keep Going
Go Back
Next



Road Safety Data Survey: Driver Character

Finally, we seek some information regarding your licence status, and driving experience. The information is strictly for research purposes. We do not seek your name or registration number. You will not be identified in the research results.

Your gender
- Female
- Male

Your Driver's Licence Status
- National Heavy Vehicle Licence
- Unrestricted Gold Licence
- Unrestricted Silver Licence
- Provisional Licence (P Plate)
- Learners' Licence (L Plate)
- Probationary Licence (Traffic Offence)
- Other Licence (eg. Overseas Licence)

How many years have you been driving?
Please specify: ______ Years

Accident Involvement
Have you been involved in a traffic accident in the last 2 years?
- Yes
- No

If Yes, who was at fault?
- Other driver
- My fault
- Both drivers

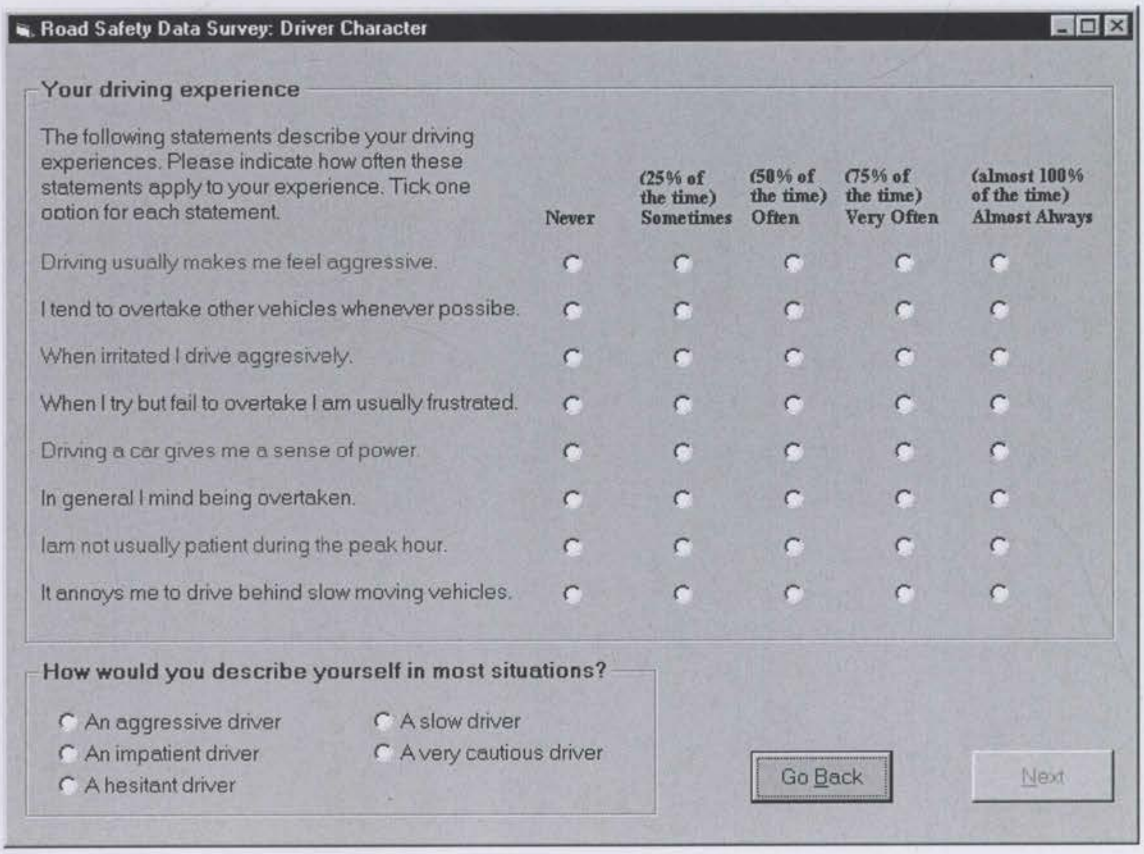
Traffic Offence
Have you lost any demerit points in the last 2 years?
- Yes
- No

If Yes, how many? ______

Which age category do you belong to?
- 16-20
- 21-25
- 26-30
- 31-35
- 35-40
- 41-45
- 45-50
- 51-55
- 56 or older

Do you commuter by car?
- Yes
- No

Go Back | Next



Road Safety Data Survey: Driver Character

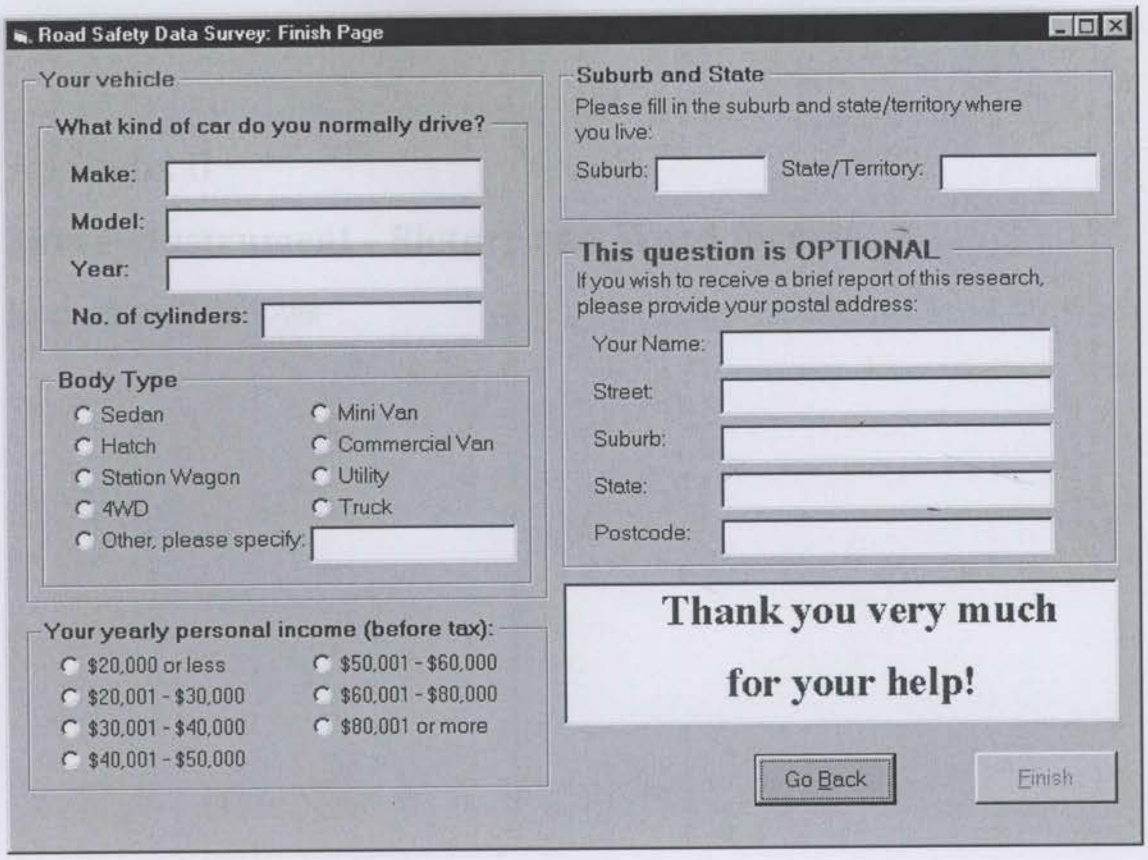
Your driving experience

The following statements describe your driving experiences. Please indicate how often these statements apply to your experience. Tick one option for each statement.

	Never	(25% of the time) Sometimes	(50% of the time) Often	(75% of the time) Very Often	(almost 100% of the time) Almost Always
Driving usually makes me feel aggressive.	○	○	○	○	○
I tend to overtake other vehicles whenever possibe.	○	○	○	○	○
When irritated I drive aggresively.	○	○	○	○	○
When I try but fail to overtake I am usually frustrated.	○	○	○	○	○
Driving a car gives me a sense of power.	○	○	○	○	○
In general I mind being overtaken.	○	○	○	○	○
Iam not usually patient during the peak hour.	○	○	○	○	○
It annoys me to drive behind slow moving vehicles.	○	○	○	○	○

How would you describe yourself in most situations?
- An aggressive driver
- An impatient driver
- A hesitant driver
- A slow driver
- A very cautious driver

Go Back | Next



Road Safety Data Survey: Finish Page

Your vehicle

What kind of car do you normally drive?

Make:

Model:

Year:

No. of cylinders:

Body Type

- Sedan
- Hatch
- Station Wagon
- 4WD
- Mini Van
- Commercial Van
- Utility
- Truck
- Other, please specify:

Your yearly personal income (before tax):

- $20,000 or less
- $20,001 - $30,000
- $30,001 - $40,000
- $40,001 - $50,000
- $50,001 - $60,000
- $60,001 - $80,000
- $80,001 or more

Suburb and State

Please fill in the suburb and state/territory where you live:

Suburb: State/Territory:

This question is OPTIONAL

If you wish to receive a brief report of this research, please provide your postal address:

Your Name:

Street:

Suburb:

State:

Postcode:

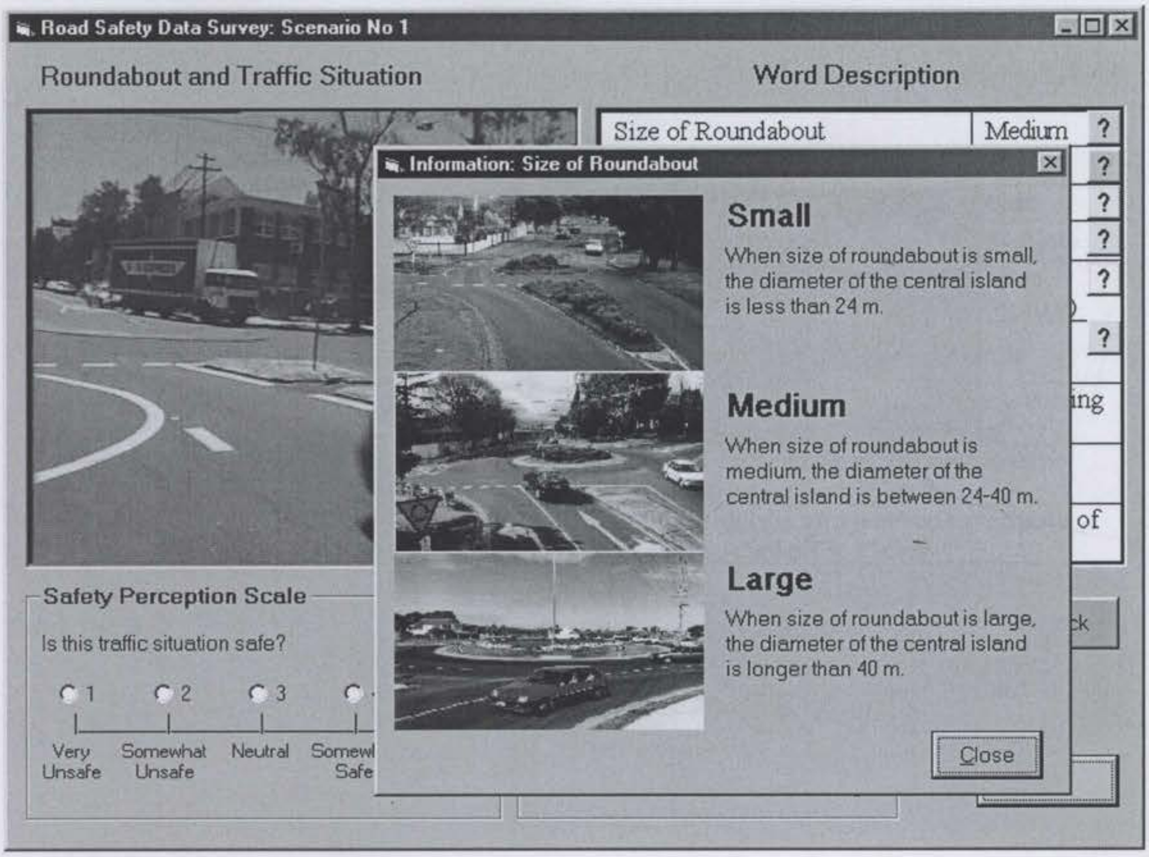
Thank you very much for your help!

Go Back Finish

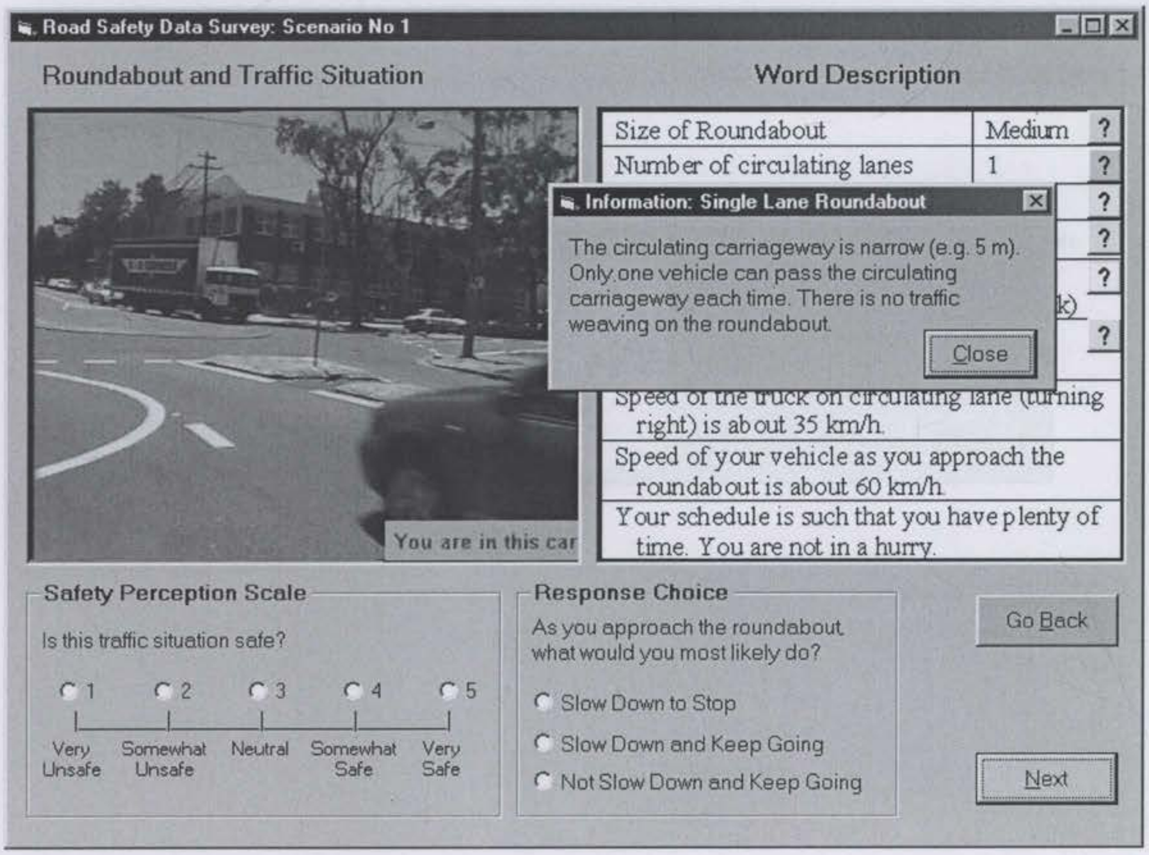
Appendix II

Survey Instrument - Picture and Word format

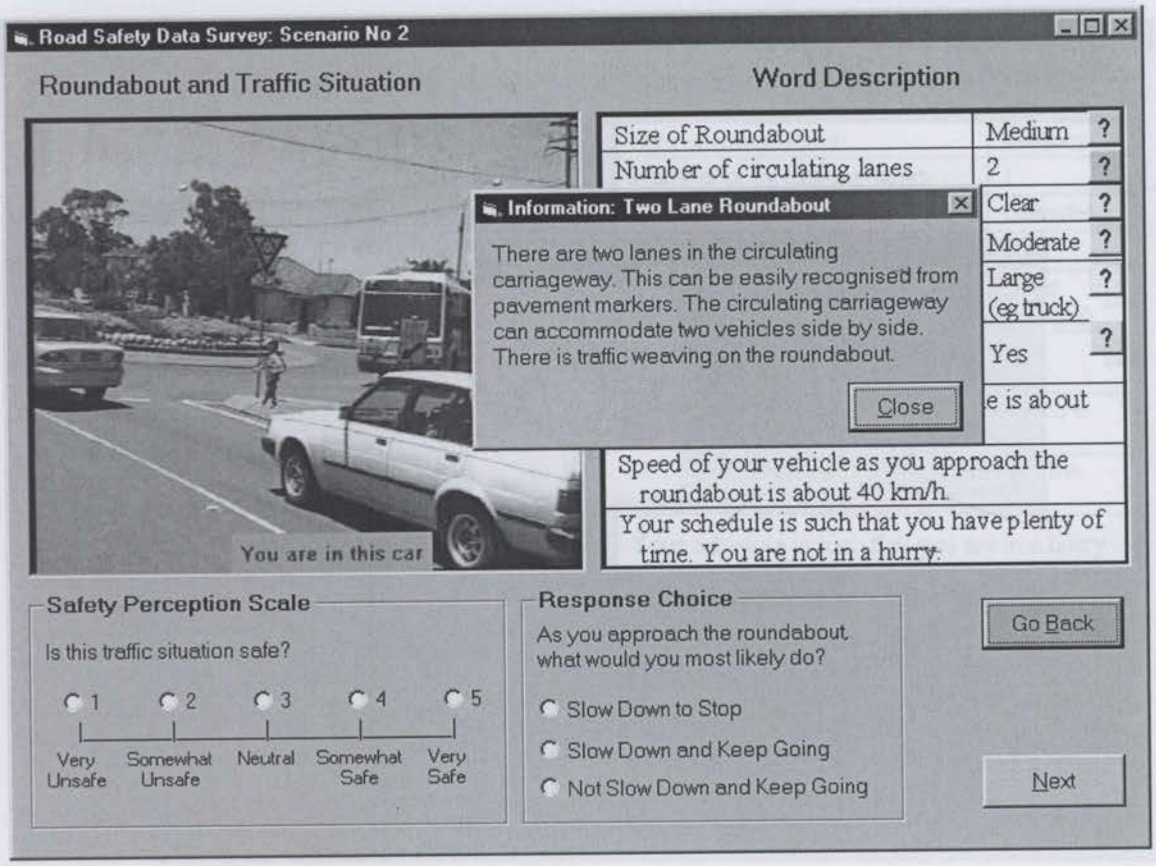
Interactive Windows



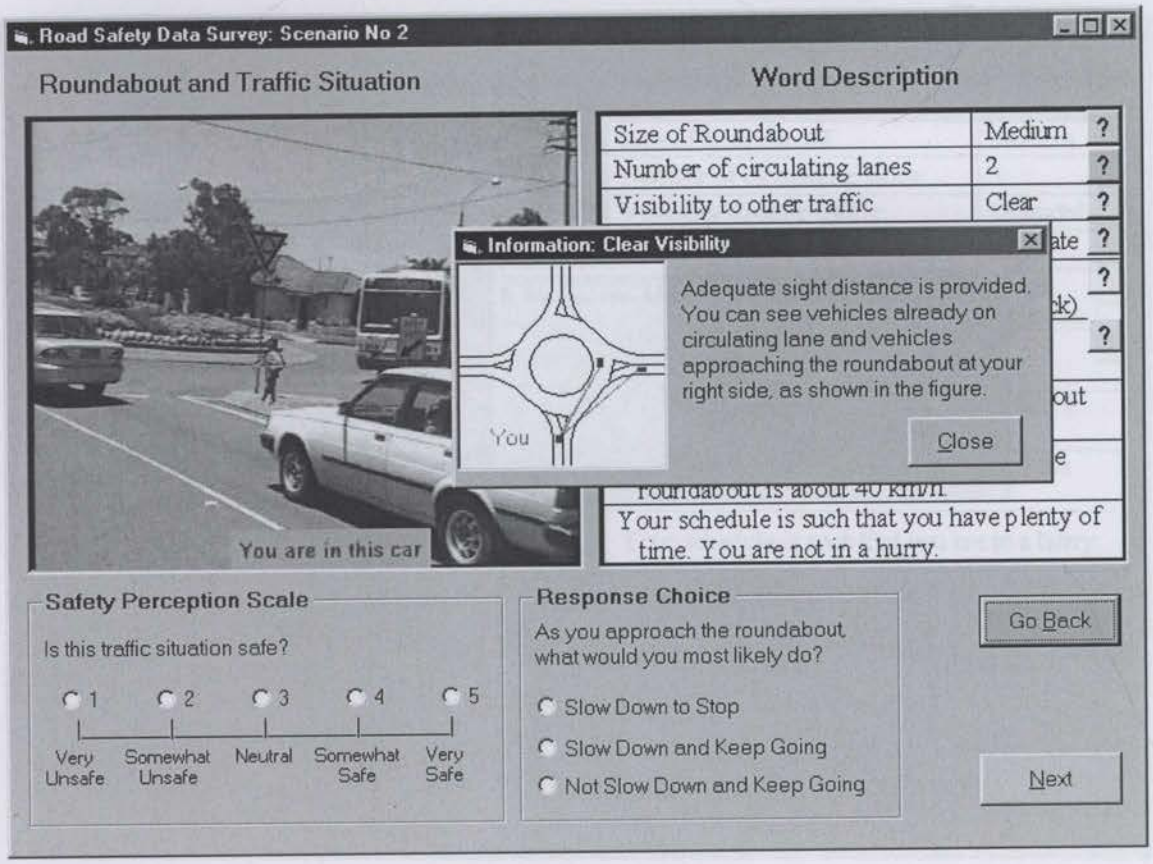
Interactive Window: Size of roundabout



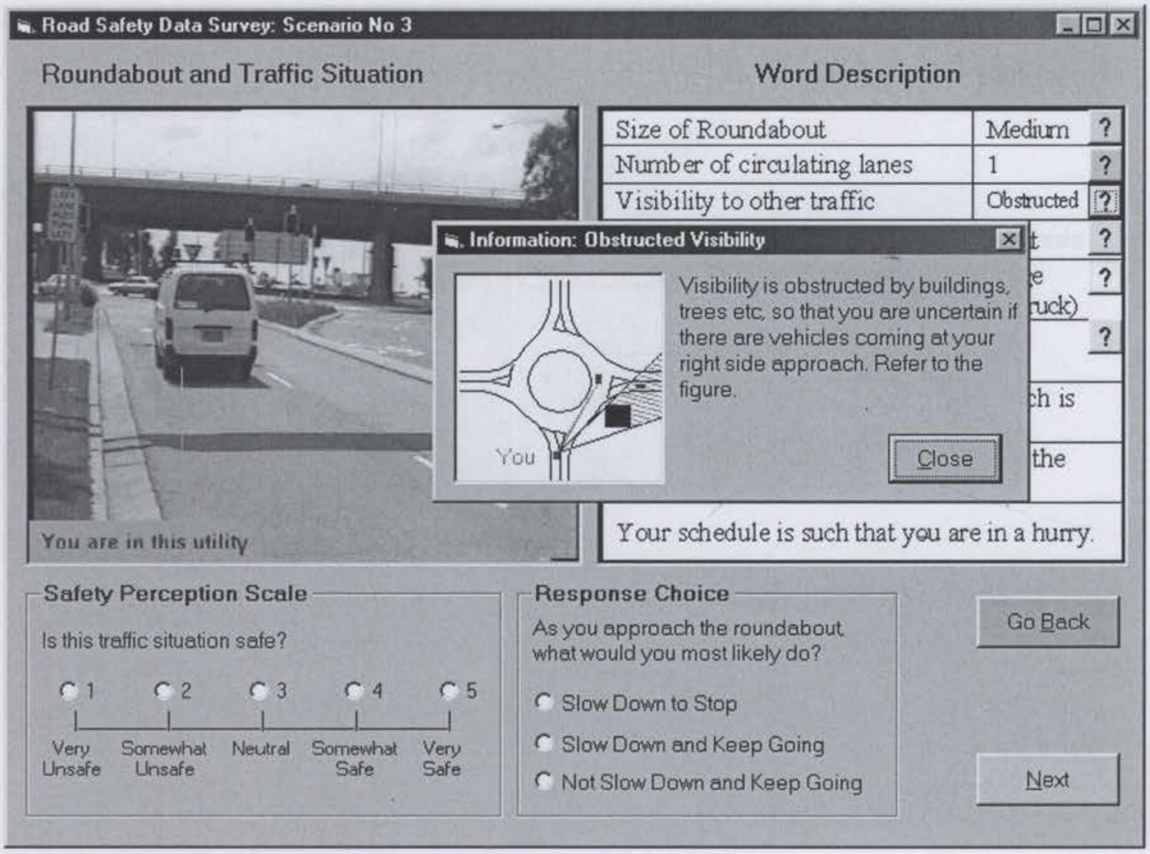
Interactive Window: Single lane roundabout



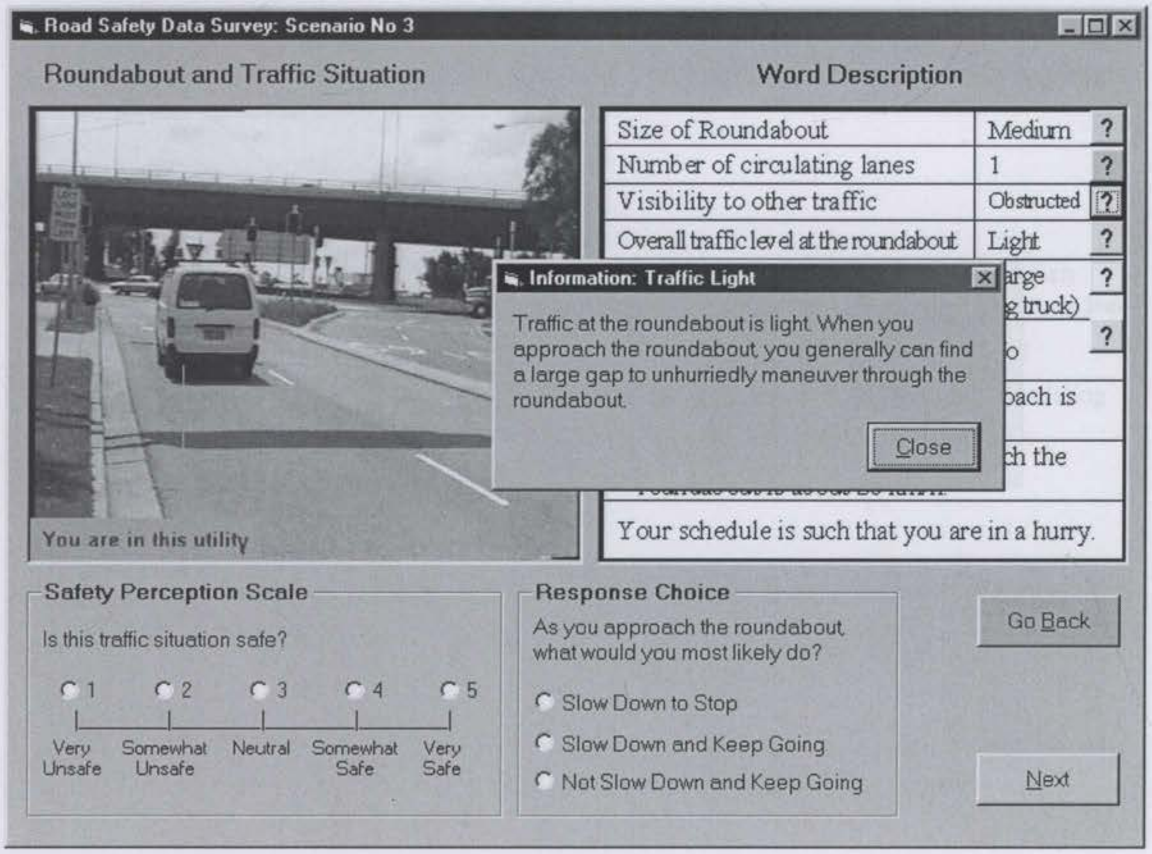
Interactive Window: Two lane roundabout



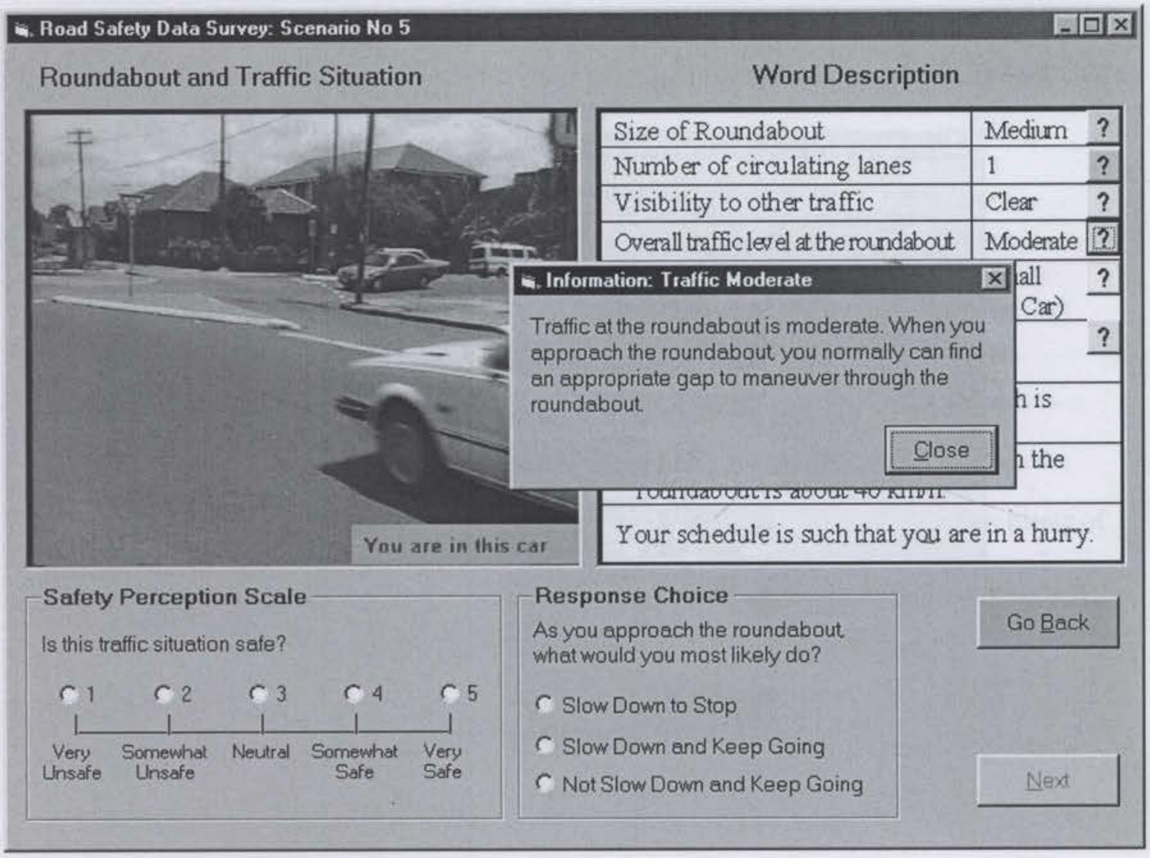
Interactive Window: Clear visibility to other traffic



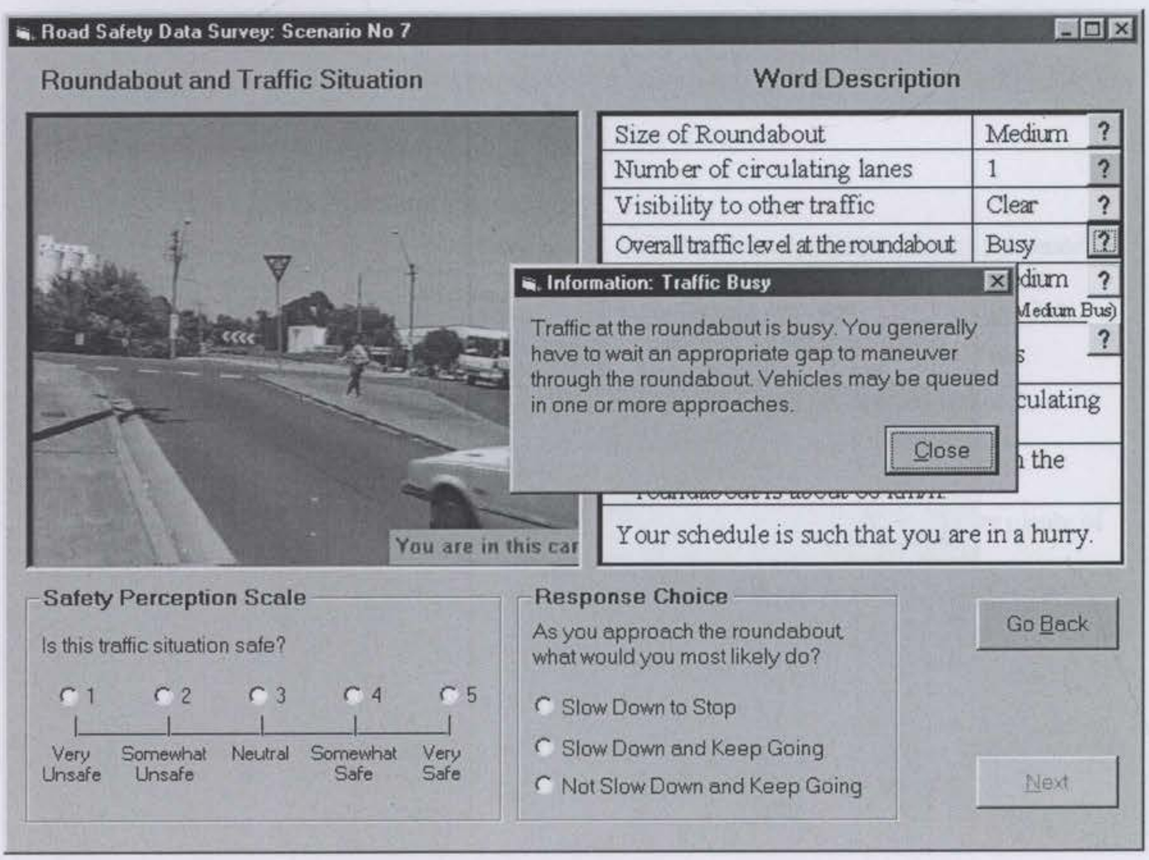
Interactive Window: Obstructed visibility to other traffic



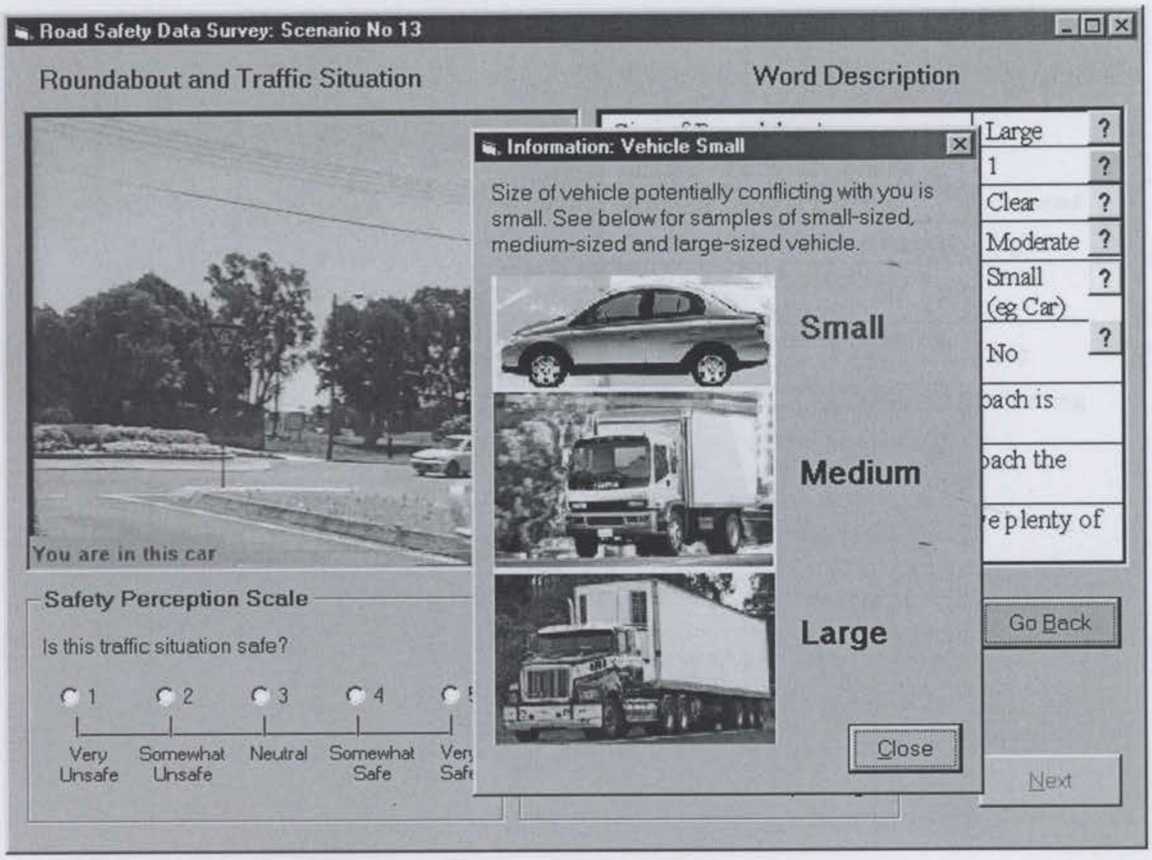
Interactive Window: Light traffic at roundabout



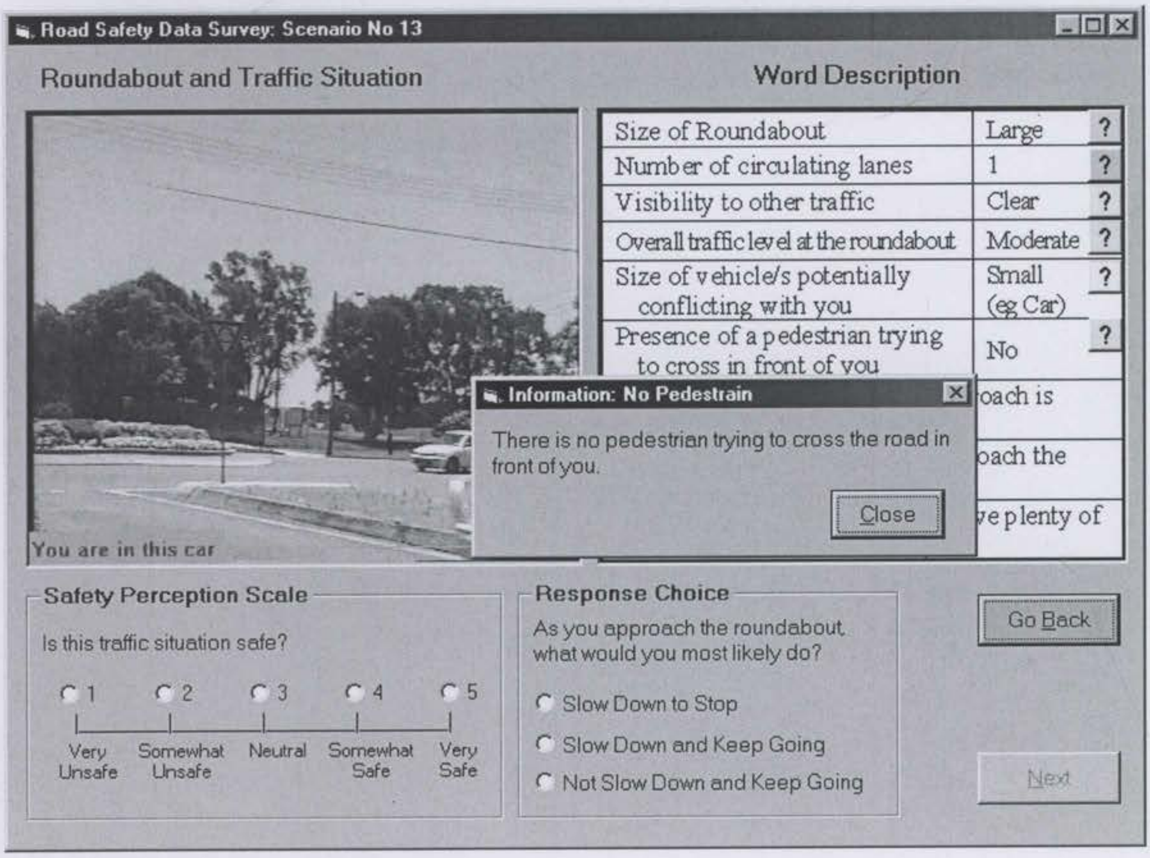
Interactive Window: Moderate traffic at roundabout



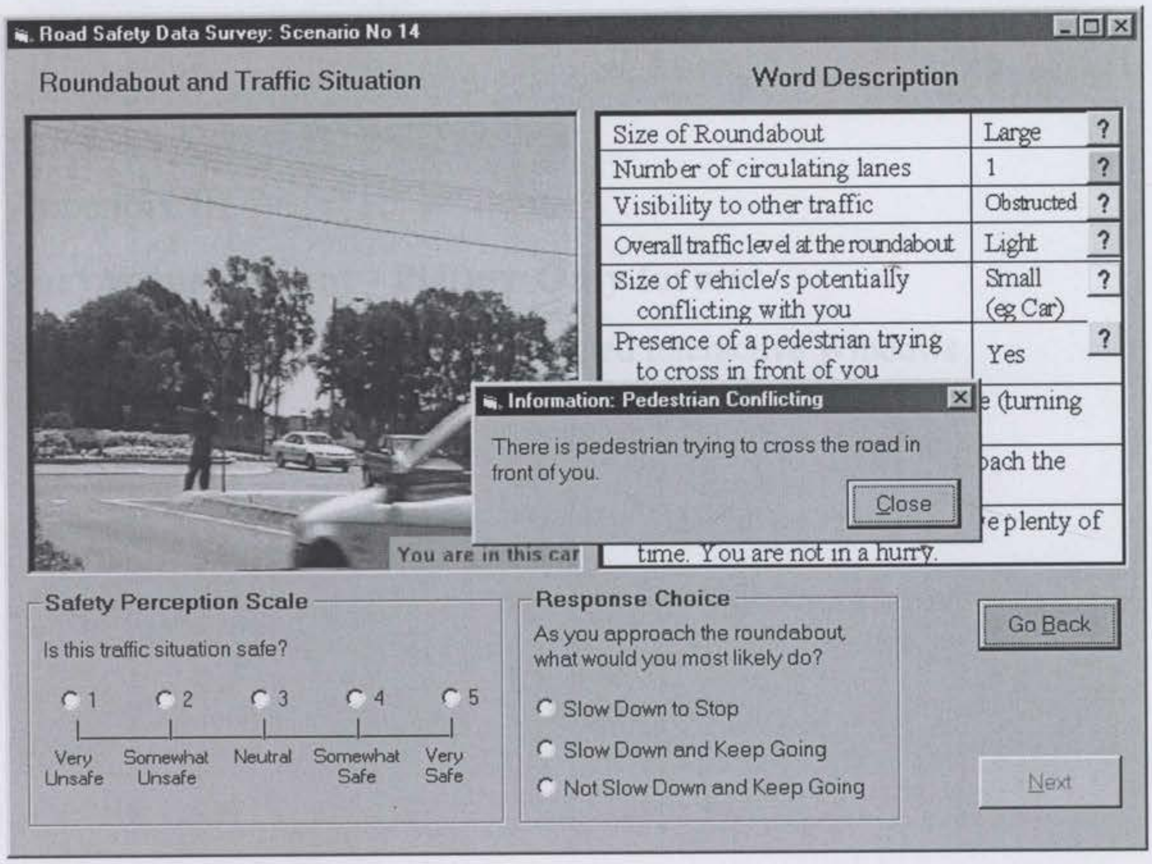
Interactive Window: Busy traffic at roundabout



Interactive Window: Size of potentially conflicting vehicle



Interactive Window: No pedestrian

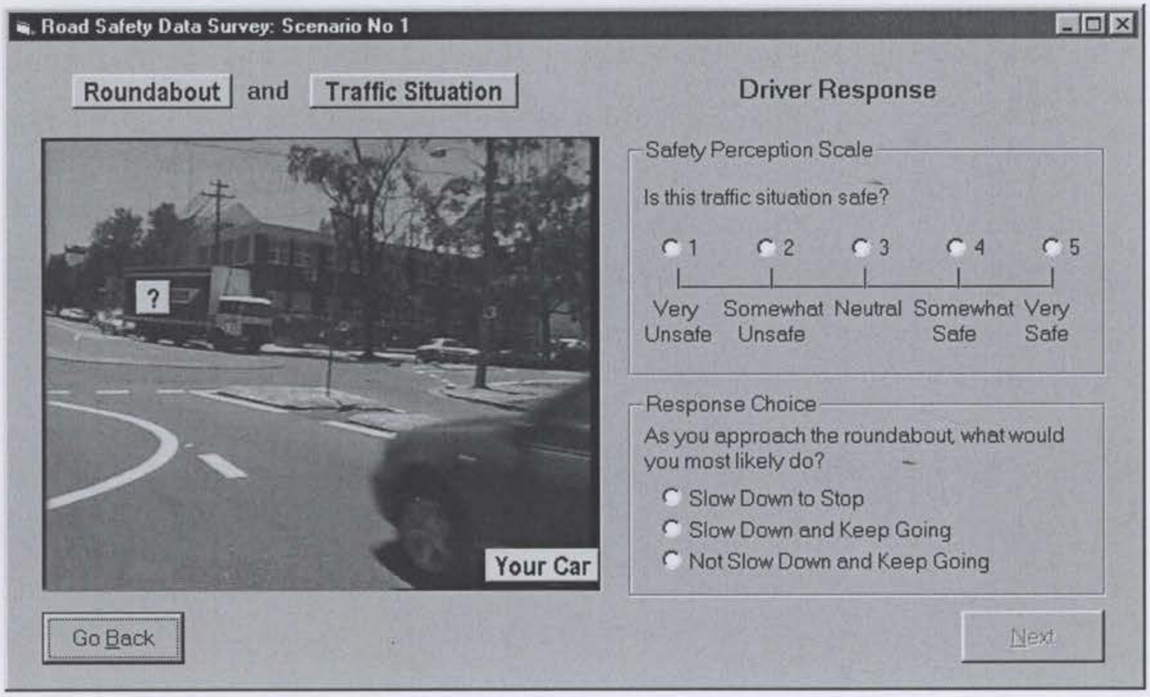


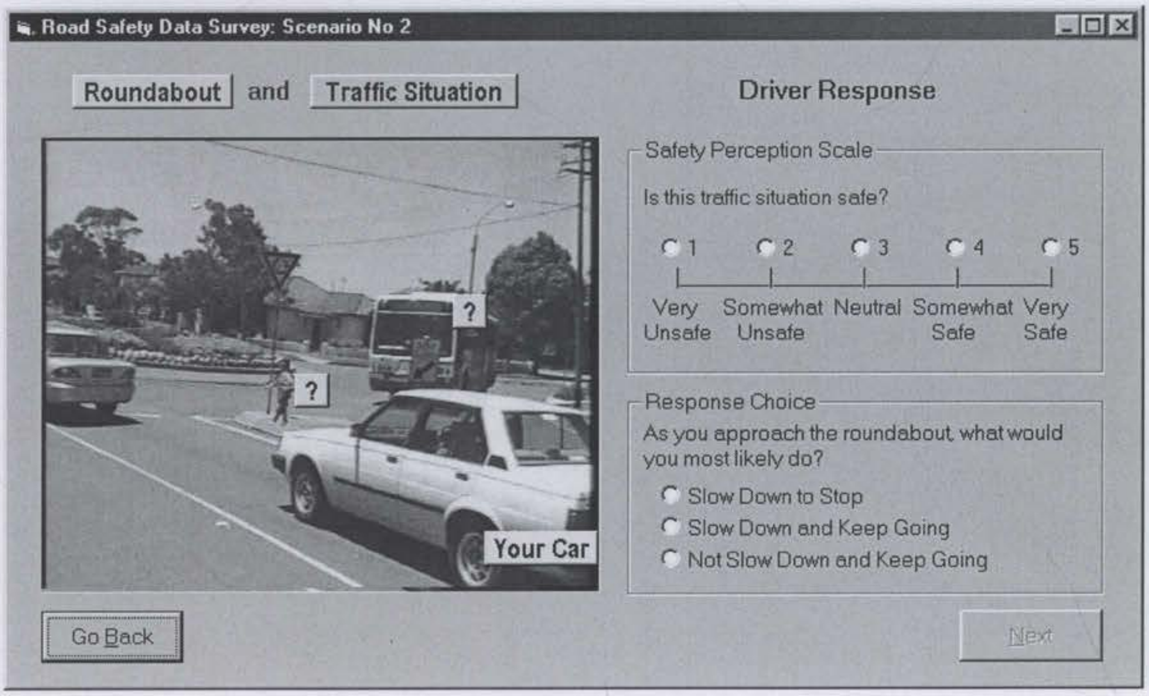
Interactive Window: Presence of a pedestrian trying to cross in front of the driver

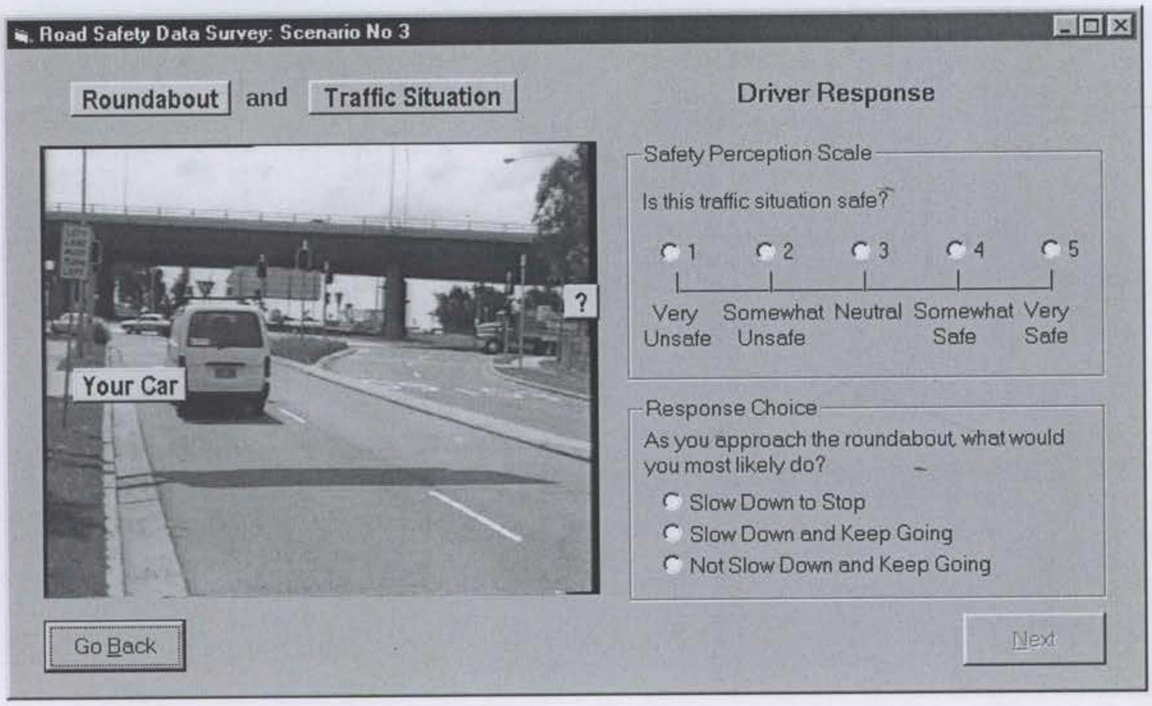
Appendix III

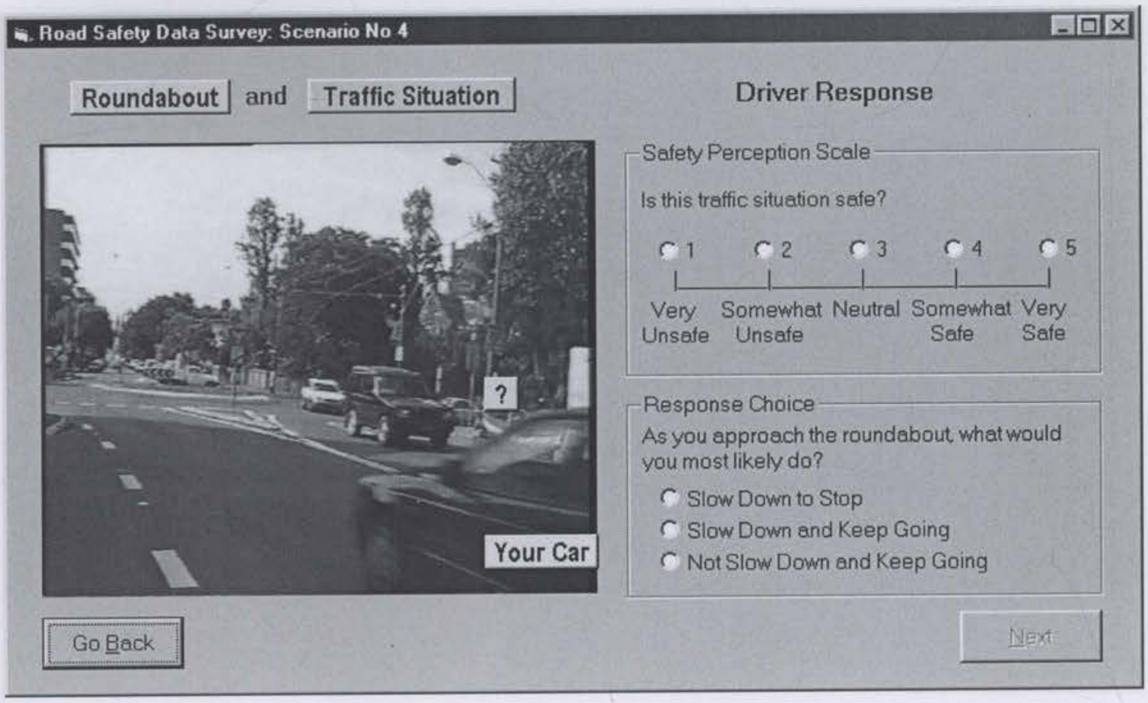
Survey Instrument - Picture Only format

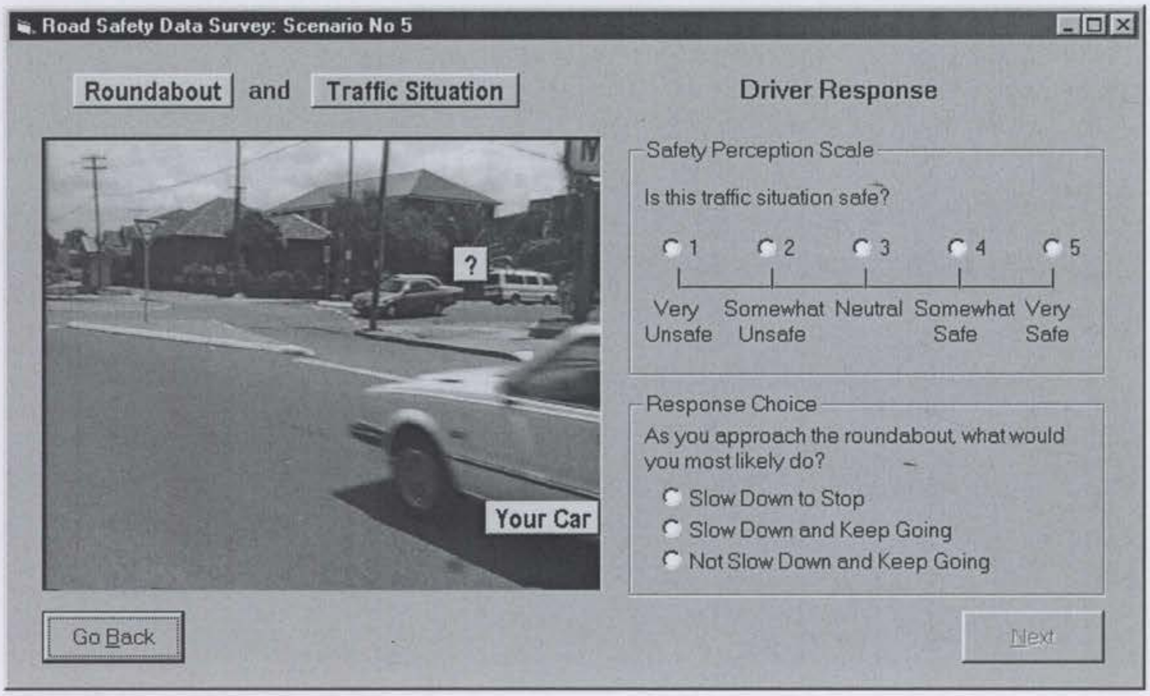
Selected Evaluation Screens and Selected Interactive Windows

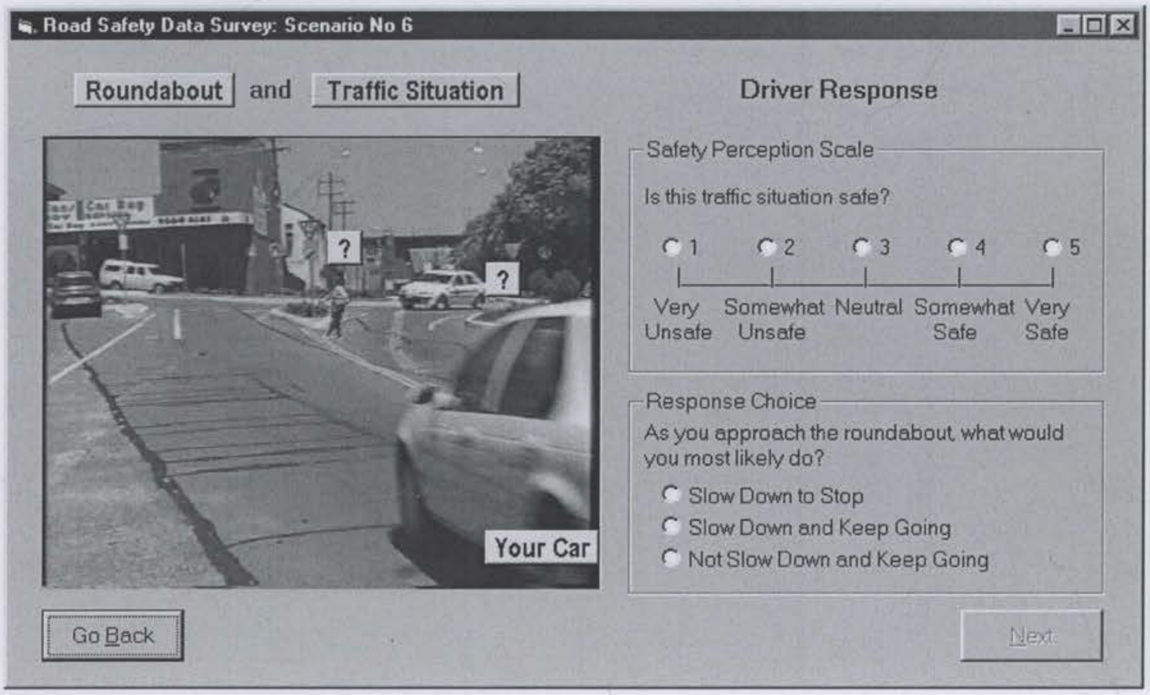

Road Safety Data Survey: Scenario No 1
Roundabout
and
Traffic Situation
?
Your Car
Driver Response
Safety Perception Scale
Is this traffic situation safe?
1 2 3 4 5
Very Unsafe
Somewhat Unsafe
Neutral
Somewhat Safe
Very Safe
Response Choice
As you approach the roundabout, what would you most likely do?
Slow Down to Stop
Slow Down and Keep Going
Not Slow Down and Keep Going
Go Back
Next

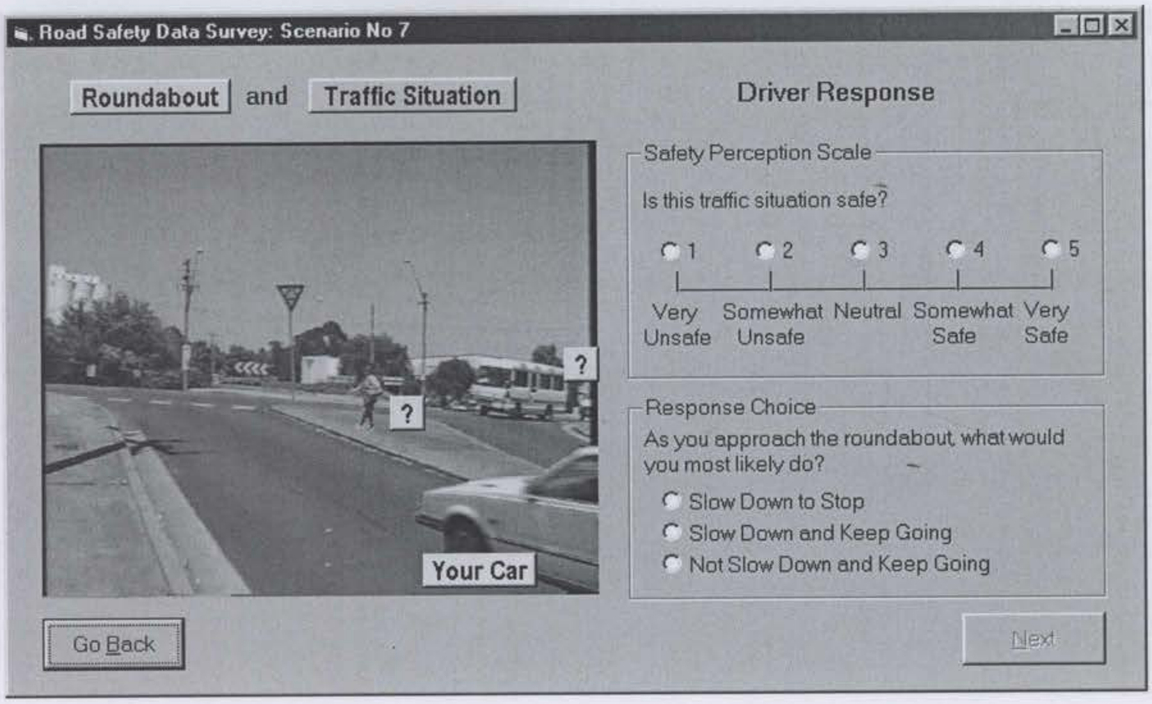

Road Safety Data Survey: Scenario No 2
Roundabout
and
Traffic Situation
?
?
Your Car
Driver Response
Safety Perception Scale
Is this traffic situation safe?
1 2 3 4 5
Very Unsafe
Somewhat Unsafe
Neutral
Somewhat Safe
Very Safe
Response Choice
As you approach the roundabout, what would you most likely do?
Slow Down to Stop
Slow Down and Keep Going
Not Slow Down and Keep Going
Go Back
Next

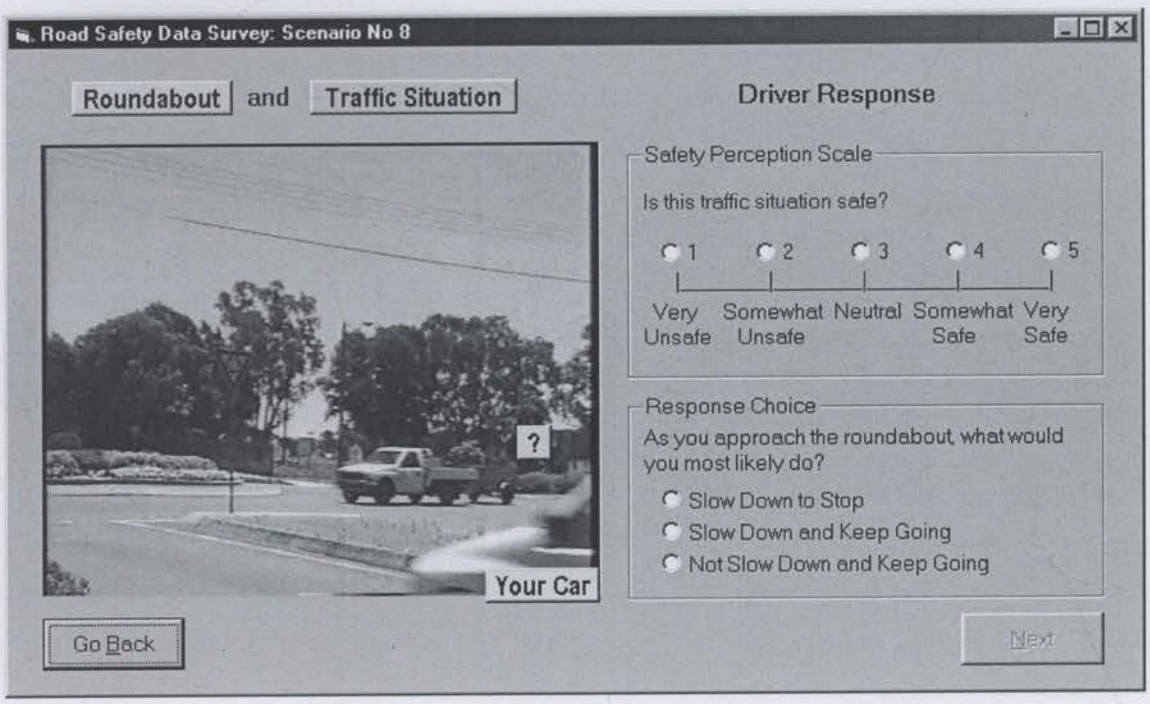

Road Safety Data Survey: Scenario No 3
Roundabout
and
Traffic Situation
Driver Response
Your Car
?
Safety Perception Scale
Is this traffic situation safe?
1
2
3
4
5
Very Unsafe
Somewhat Unsafe
Neutral
Somewhat Safe
Very Safe
Response Choice
As you approach the roundabout, what would you most likely do?
Slow Down to Stop
Slow Down and Keep Going
Not Slow Down and Keep Going
Go Back
Next

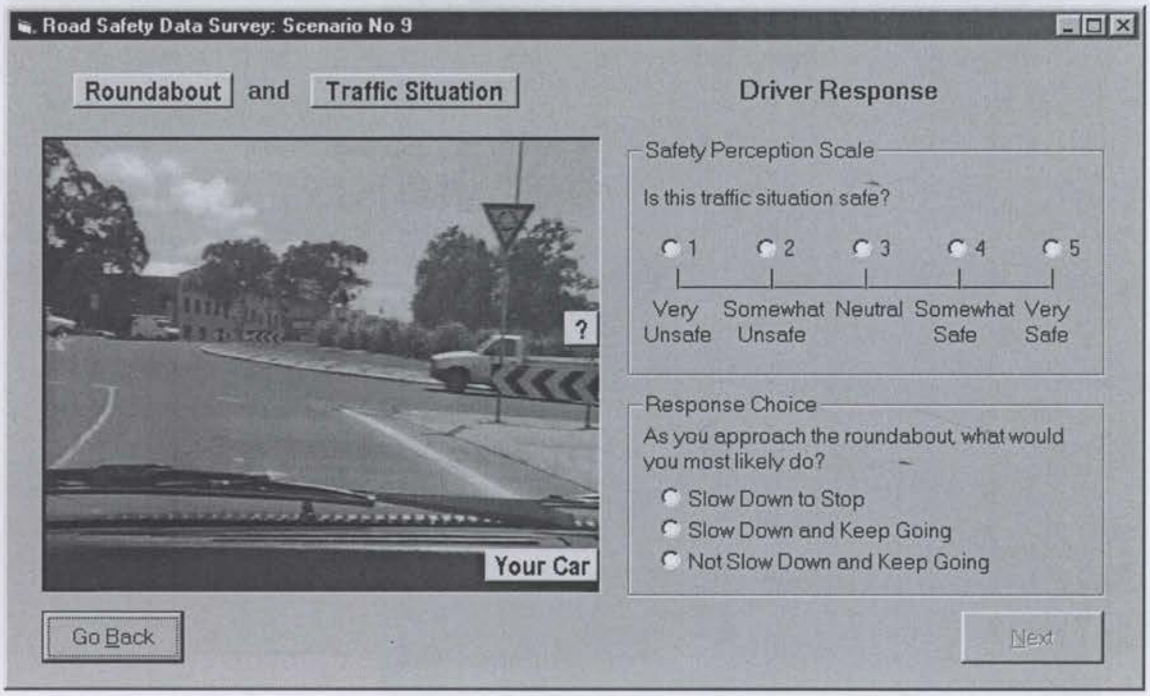

Road Safety Data Survey: Scenario No 4
Roundabout
and
Traffic Situation
Driver Response
?
Your Car
Safety Perception Scale
Is this traffic situation safe?
1
2
3
4
5
Very Unsafe
Somewhat Unsafe
Neutral
Somewhat Safe
Very Safe
Response Choice
As you approach the roundabout, what would you most likely do?
Slow Down to Stop
Slow Down and Keep Going
Not Slow Down and Keep Going
Go Back
Next

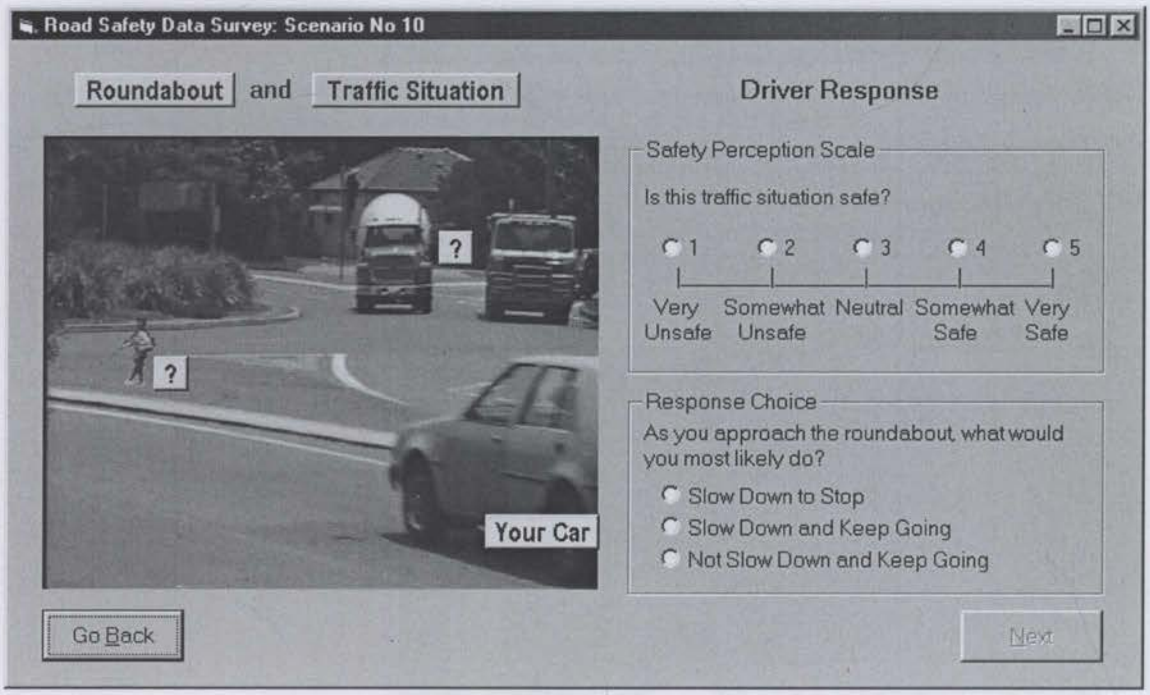

Road Safety Data Survey: Scenario No 5
Roundabout
and
Traffic Situation
Driver Response
?
Your Car
Safety Perception Scale
Is this traffic situation safe?
1
2
3
4
5
Very Unsafe
Somewhat Unsafe
Neutral
Somewhat Safe
Very Safe
Response Choice
As you approach the roundabout, what would you most likely do?
Slow Down to Stop
Slow Down and Keep Going
Not Slow Down and Keep Going
Go Back
Next

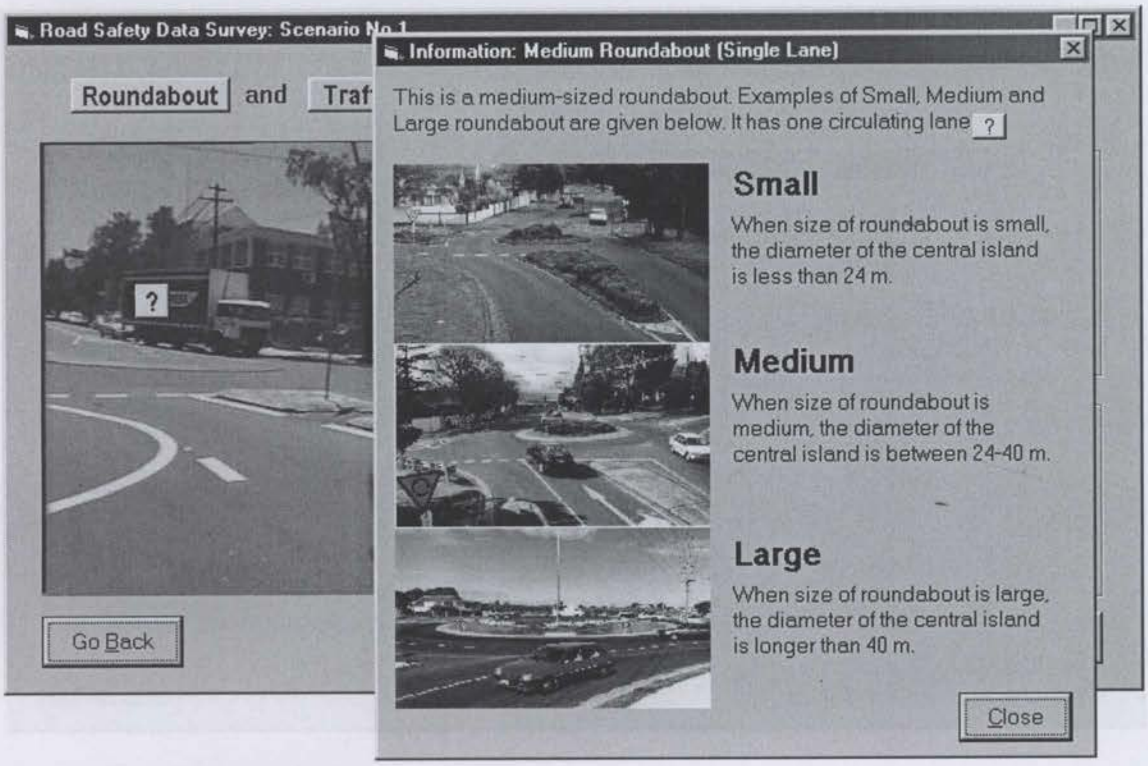

Road Safety Data Survey: Scenario No 6
Roundabout
and
Traffic Situation
Driver Response
?
?
Your Car
Safety Perception Scale
Is this traffic situation safe?
1
2
3
4
5
Very Unsafe
Somewhat Unsafe
Neutral
Somewhat Safe
Very Safe
Response Choice
As you approach the roundabout, what would you most likely do?
Slow Down to Stop
Slow Down and Keep Going
Not Slow Down and Keep Going
Go Back
Next


Road Safety Data Survey: Scenario No 7
Roundabout
and
Traffic Situation
Driver Response
Safety Perception Scale
Is this traffic situation safe?
1
2
3
4
5
Very Unsafe
Somewhat Unsafe
Neutral
Somewhat Safe
Very Safe
Response Choice
As you approach the roundabout, what would you most likely do?
Slow Down to Stop
Slow Down and Keep Going
Not Slow Down and Keep Going
?
?
Your Car
Go Back
Next

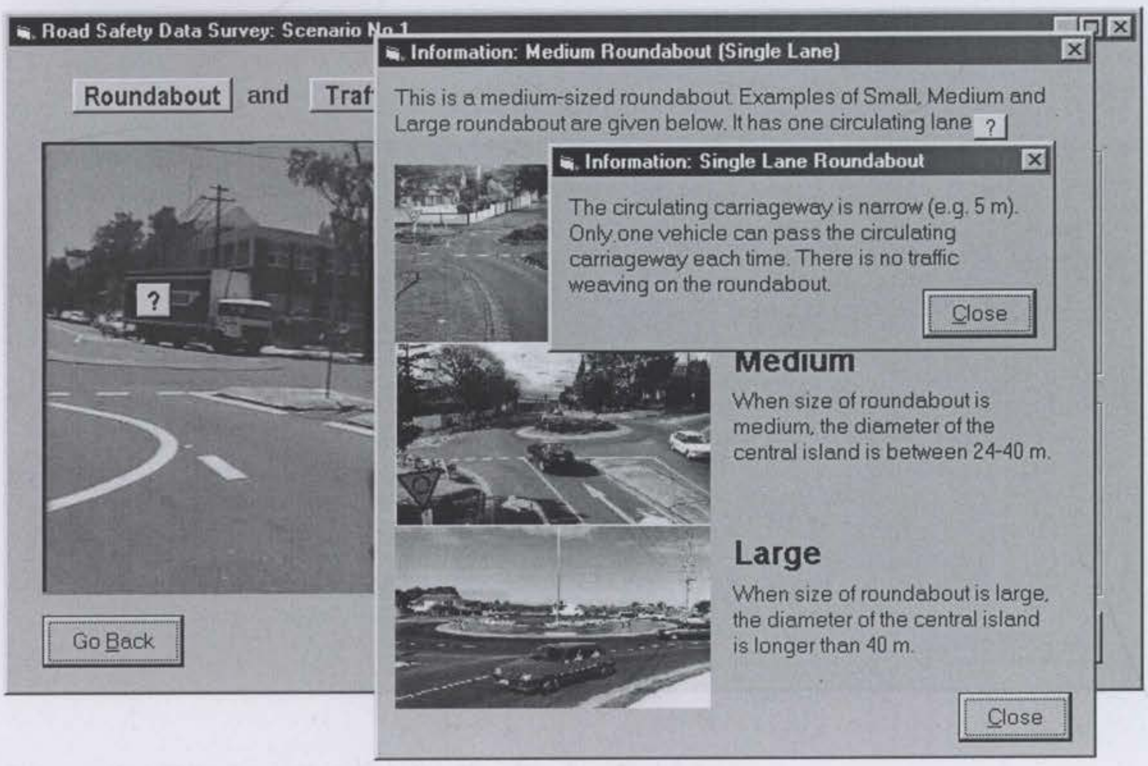

Road Safety Data Survey: Scenario No 8
Roundabout
and
Traffic Situation
Driver Response
Safety Perception Scale
Is this traffic situation safe?
1
2
3
4
5
Very Unsafe
Somewhat Unsafe
Neutral
Somewhat Safe
Very Safe
Response Choice
As you approach the roundabout, what would you most likely do?
Slow Down to Stop
Slow Down and Keep Going
Not Slow Down and Keep Going
?
Your Car
Go Back
Next


Road Safety Data Survey: Scenario No 9
Roundabout
and
Traffic Situation
Driver Response
Safety Perception Scale
Is this traffic situation safe?
1
2
3
4
5
Very Unsafe
Somewhat Unsafe
Neutral
Somewhat Safe
Very Safe
Response Choice
As you approach the roundabout, what would you most likely do?
Slow Down to Stop
Slow Down and Keep Going
Not Slow Down and Keep Going
?
Your Car
Go Back
Next

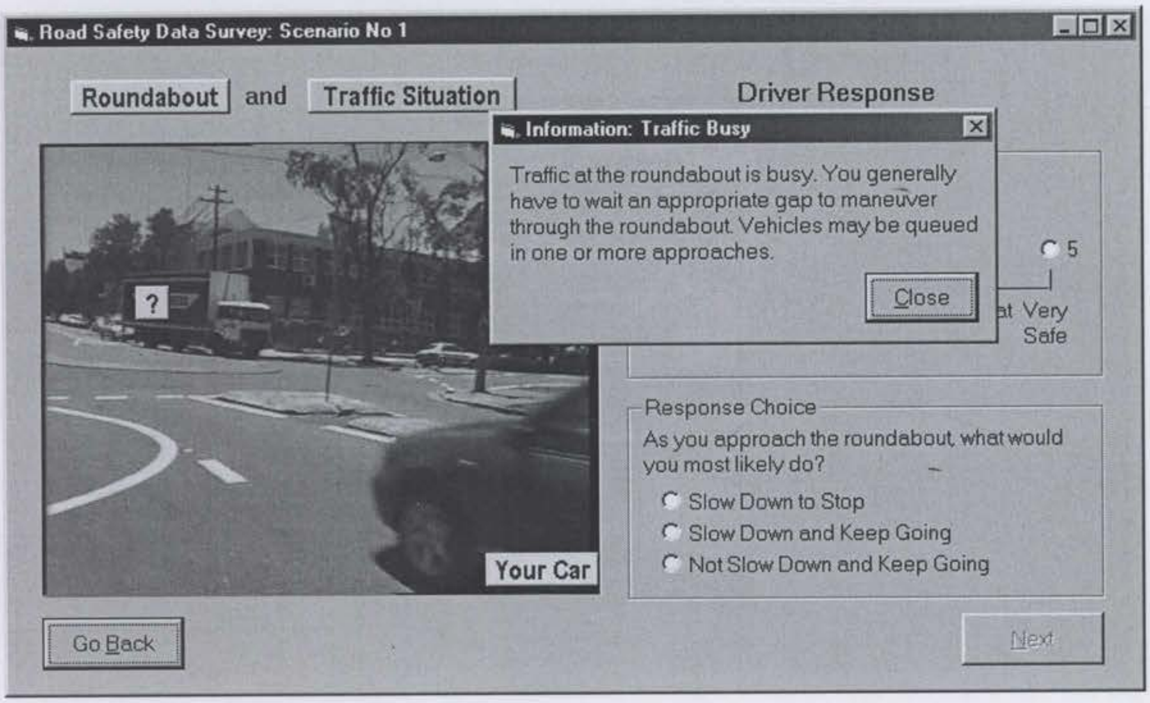

Road Safety Data Survey: Scenario No 10
Roundabout
and
Traffic Situation
Driver Response
Safety Perception Scale
Is this traffic situation safe?
1
2
3
4
5
Very Unsafe
Somewhat Unsafe
Neutral
Somewhat Safe
Very Safe
Response Choice
As you approach the roundabout, what would you most likely do?
Slow Down to Stop
Slow Down and Keep Going
Not Slow Down and Keep Going
?
?
Your Car
Go Back
Next



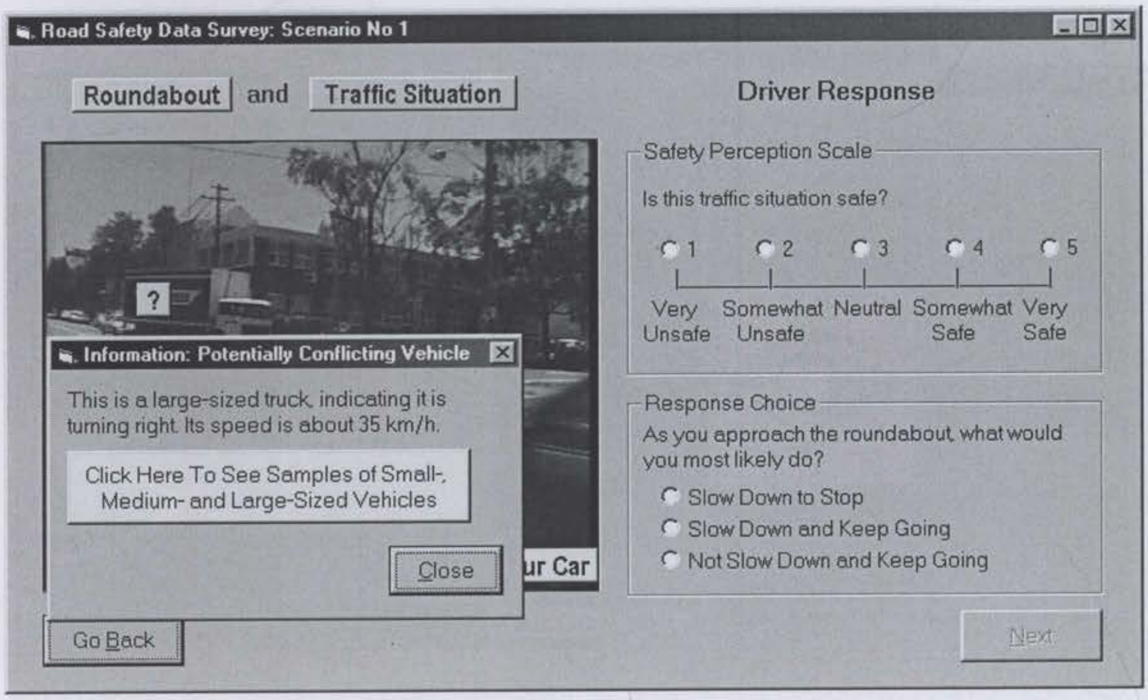
Interactive Window: Size of Roundabout



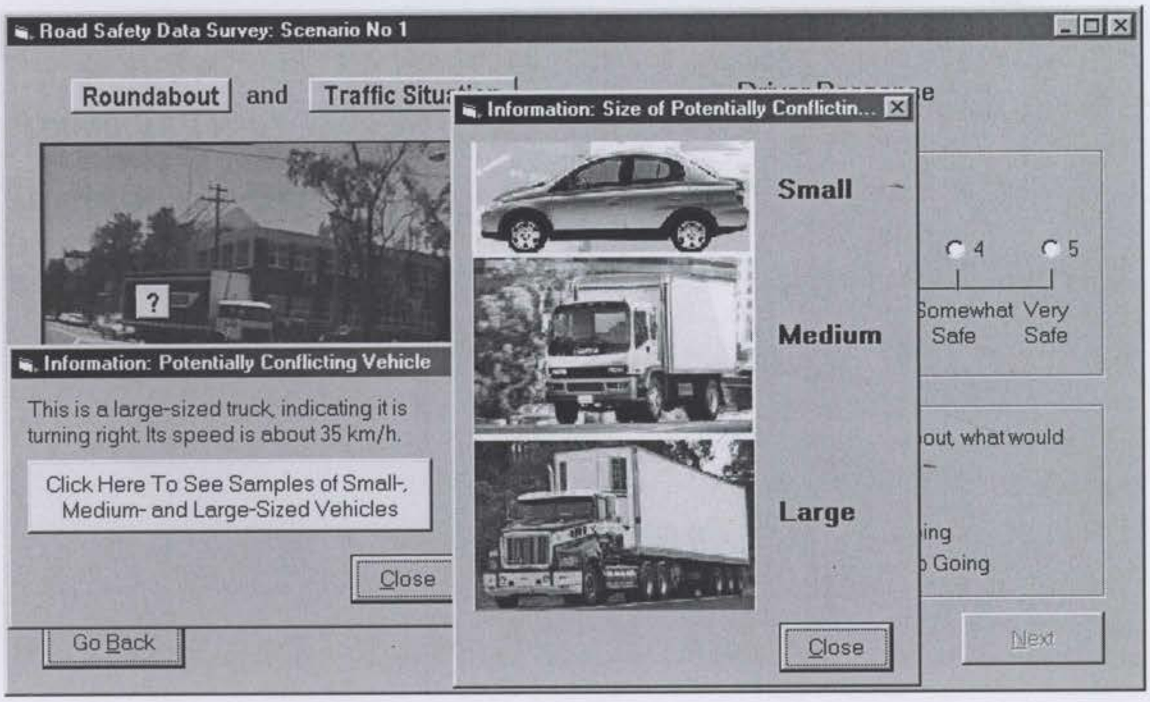
Interactive Window: Number of Circulating Lanes



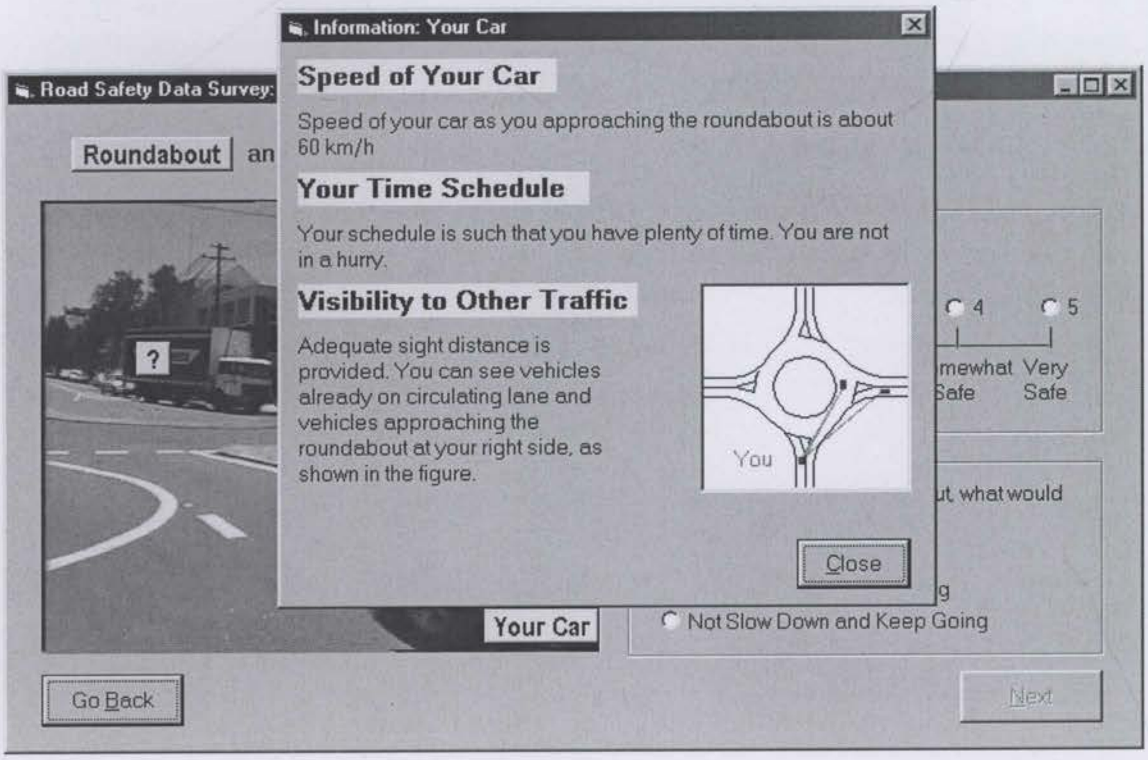
Interactive Window: Traffic Level



Interactive Window: Potentially Conflicting Vehicle



Interactive Window: Size of Vehicle



Interactive Window: Respondent's Car

Appendix IV

Invitation Letter

February 18, 2000

Dear Driver,

Invitation to a Road Safety Survey

I wish to invite you to participate in a survey, which is a vital component of a PhD research program. The objective of the research is to identify car driver's perceptions of the safety of a particular road environment - roundabout. The Institute of Transport Studies, the Australian Key Centre of Transport Management at the University of Sydney, supports this survey.

The survey consists of two face-to-face interviews. Interviews are conducted by our PhD student, Mr. Baojin Wang. Each interview will take 15-20 minutes. The first interview will be conducted between March 1 to March 31. The second interview can be conducted 25 or more days after the first interview.

The survey has been fully computerised. It is very interesting and simple. At each interview, you will evaluate a number of computer graphics of roundabouts and traffic situations. For each situation, you simply "click" a Button to give your safety rating and intended behaviour.

To assist us in the conduct of these interviews it is important that you fill in the attached reply form and return it to Mr. Baojin Wang as soon as possible. After receiving your reply, he would contact you to make an appointment for the interview.

Thank you for your assistance.

Yours sincerely,

Professor David A. Hensher
Director

INSTITUTE OF TRANSPORT STUDIES
The Australian Key Centre in Transport Management

Sydney
Institute of Transport Studies, C37
The University of Sydney
NSW 2006, Australia
144 Burren St, Newtown 2042
Phone +61 2 9351 0071
Fax +61 2 9351 0088
Email itsinfo@its.usyd.edu.au
http://www.its.usyd.edu.au

Monash
Department of Civil Engineering
Monash University
Clayton VIC 3168, Australia
Phone +61 3 9905 9627
Fax +61 3 9905 4944
Email itsinfo@eng.monash.edu.au

Reply

I will participate in the survey. Here are my contact details and preferred dates & time for interview.

My Contacts Details

Name		Telephone	
Street		Mobile	
Suburb		Fax	
Postcode		Email	

My Preferred Date & Time for Interviews

Interview	Date	Time
The first interview		
The second interview*		

* The second interview must be 25 or more days after the first interview.

Please return this reply to:

Office:
Mr. Baojin Wang
Institute of Transport Studies
The University of Sydney
144 Burren St, Newtown NSW 2042
Phone: 9351 0079; Fax: 9351 0088
Email: wangb@its.usyd.edu.au

OR

Home:
Mr. Baojin Wang
Unit 10, 102 Bland St
Ashfield NSW 2131
Phone: 9799 3580

Please cut here and keep below part as your record. Thank you.

Appointment Record

I have two appointments with Mr. Baojin Wang for the road safety data survey.

Appointed Interviews

Interview	Date	Time
The first interview		
The second Interview		

If you want to change above date and/or time, Mr. Baojin Wang can be contacted at:

Office:
Institute of Transport Studies
The University of Sydney
144 Burren St, Newtown NSW 2042
Phone: 9351 0079; Fax: 9351 0088
Email: wangb@its.usyd.edu.au

OR

Home:
Unit 10, 102 Bland St
Ashfield NSW 2131
Phone: 9799 3580

Appendix V
Estimation Results of Models for Driver's Perception of Safety

Model 1: Ordered Probit Model

Model Specification

```
Ordered      ;Lhs=RatingZ
             ;Rhs=One,RoudL,RoudM,Lane1,Clear,VehLG,VehMD,Speed,BusyT,
                   ModeT,PedsY,MySpd,Hurry
             ;Marginal Effects$
```

Estimation Results

```
+---------------------------------------------+
| Ordered Probit Model                      - |
| Maximum Likelihood Estimates                |
| Dependent variable               RATINGZ    |
| Weighting variable                   ONE    |
| Number of observations              5238    |
| Iterations completed                  25    |
| Log likelihood function        -4758.775    |
| Restricted log likelihood      -8113.318    |
| Chi-squared                     6709.086    |
| Degrees of freedom                    12    |
| Significance level              .0000000    |
|   Cell frequencies for outcomes             |
|  Y Count Freq  Y Count Freq  Y Count Freq   |
|  0   828 .158  1  1307 .249  2  1542 .294   |
|  3  1037 .197  4   524 .100                 |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
	Index function for probability				
Constant	5.848125049	.84798598E-01	68.965	.0000	
ROUDL	-.5312569593	.24393896E-01	-21.778	.0000	.00000000
ROUDM	.2218567270E-01	.23684717E-01	.937	.3489	.00000000
LANE1	.2222146259	.18024551E-01	12.328	.0000	.33333333
CLEAR	1.327054899	.21006567E-01	63.173	.0000	.33333333
VEHLG	-.6847818119	.24105605E-01	-28.408	.0000	.00000000
VEHMD	.2750357406	.23775103E-01	11.568	.0000	.00000000
SPEED	-.7430727619E-01	.13965529E-02	-53.208	.0000	37.592593
BUSYT	-.4377922087	.23752634E-01	-18.431	.0000	.00000000
MODET	.1449075240	.23689303E-01	6.117	.0000	.00000000
PEDSY	-.7539462303	.19793332E-01	-38.091	.0000	-.33333333
MYSPD	-.3851506665E-01	.11174971E-02	-34.465	.0000	40.000000
HURRY	.7504145504E-02	.17851204E-01	.420	.6742	-.33333333
	Threshold parameters for index				
Mu(1)	1.802636929	.41294597E-01	43.653	.0000	
Mu(2)	3.601584366	.47822282E-01	75.312	.0000	
Mu(3)	5.009615103	.55593961E-01	90.111	.0000	

(Note: E+nn or E-nn means multiply by 10 to + or -nn power.)

Marginal Effects

Marginal Effects for OrdProbt

Variable	RATING=0	RATING=1	RATING=2	RATING=3
ONE	-.1737	-1.9088	1.1091	.9173

ROUDL	.0158	.1734	-.1007	-.0833
ROUDM	-.0007	-.0072	.0042	.0035
LANE1	-.0066	-.0725	.0421	.0349
CLEAR	-.0394	-.4331	.2517	.2081
VEHLG	.0203	.2235	-.1299	-.1074
VEHMD	-.0082	-.0898	.0522	.0431
SPEED	.0022	.0243	-.0141	-.0117
BUSYT	.0130	.1429	-.0830	-.0687
MODET	-.0043	-.0473	.0275	.0227
PEDSY	.0224	.2461	-.1430	-.1183
MYSPD	.0011	.0126	-.0073	-.0060
HURRY	-.0002	-.0024	.0014	.0012

Marginal Effects for	
Variable	RATING=4
ONE	.0561
ROUDL	-.0051
ROUDM	.0002
LANE1	.0021
CLEAR	.0127
VEHLG	-.0066
VEHMD	.0026
SPEED	-.0007
BUSYT	-.0042
MODET	.0014
PEDSY	-.0072
MYSPD	-.0004
HURRY	.0001

Cross Tabulation

Frequencies of actual & predicted outcomes
Predicted outcome has maximum probability.

	Predicted					
Actual	0	1	2	3	4	Total
0	438	380	7	1	2	828
1	139	896	258	14	0	1307
2	3	254	1016	249	20	1542
3	1	19	257	615	145	1037
4	1	3	14	285	221	524
Total	582	1552	1552	1164	388	5238

Model 2: Ordered Probit Model - Re-specification of Model1 by Dropping HURRY

Model Specification

```
Ordered     ;Lhs=RatingZ
            ;Rhs=One,RoudL,RoudM,Lane1,Clear,VehLG,VehMD,Speed,BusyT,
                     ModeT,PedsY,MySpd
            ;Marginal Effects$
```

Estimation Results

```
+---------------------------------------------+
| Ordered Probit Model                        |
| Maximum Likelihood Estimates                |
```

```
| Dependent variable              RATINGZ    |
| Weighting variable                  ONE    |
| Number of observations             5238    |
| Iterations completed                 24    |
| Log likelihood function       -4758.871    |
| Restricted log likelihood     -8113.318    |
| Chi-squared                    6708.893    |
| Degrees of freedom                   11    |
| Significance level             .0000000    |
|    Cell frequencies for outcomes           |
|  Y Count Freq  Y Count Freq  Y Count Freq  |
|  0   828 .158  1  1307 .249  2  1542 .294  |
|  3  1037 .197  4   524 .100                |
+--------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
	Index function for probability				
Constant	5.841982346	.82740765E-01	70.606	.0000	
ROUDL	-.5309170441	.24239769E-01	-21.903	.0000	.00000000
ROUDM	.2232095447E-01	.23505871E-01	.950	.3423	.00000000
LANE1	.2224394811	.17976430E-01	12.374	.0000	.33333333
CLEAR	1.326545838	.20995388E-01	63.183	.0000	.33333333
VEHLG	-.6852746655	.24087958E-01	-28.449	.0000	.00000000
VEHMD	.2750439360	.23765787E-01	11.573	.0000	.00000000
SPEED	-.7426476467E-01	.13879788E-02	-53.506	.0000	37.592593
BUSYT	-.4378530638	.23713582E-01	-18.464	.0000	.00000000
MODET	.1442714259	.23651735E-01	6.100	.0000	.00000000
PEDSY	-.7535111376	.19556204E-01	-38.531	.0000	-.33333333
MYSPD	-.3847362038E-01	.11006661E-02	-34.955	.0000	40.000000
	Threshold parameters for index				
Mu(1)	1.802105197	.41260062E-01	43.677	.0000	
Mu(2)	3.599655697	.47516813E-01	75.755	.0000	
Mu(3)	5.008677035	.55597650E-01	90.088	.0000	

(Note: E+nn or E-nn means multiply by 10 to + or -nn power.)

Marginal Effects

Marginal Effects for OrdProbt

Variable	RATING=0	RATING=1	RATING=2	RATING=3
ONE	-.1737	-1.9066	1.1063	.9179
ROUDL	.0158	.1733	-.1005	-.0834
ROUDM	-.0007	-.0073	.0042	.0035
LANE1	-.0066	-.0726	.0421	.0350
CLEAR	-.0395	-.4329	.2512	.2084
VEHLG	.0204	.2237	-.1298	-.1077
VEHMD	-.0082	-.0898	.0521	.0432
SPEED	.0022	.0242	-.0141	-.0117
BUSYT	.0130	.1429	-.0829	-.0688
MODET	-.0043	-.0471	.0273	.0227
PEDSY	.0224	.2459	-.1427	-.1184
MYSPD	.0011	.0126	-.0073	-.0060

Marginal Effects for

Variable	RATING=4
ONE	.0561
ROUDL	-.0051
ROUDM	.0002
LANE1	.0021

CLEAR	.0127
VEHLG	-.0066
VEHMD	.0026
SPEED	-.0007
BUSYT	-.0042
MODET	.0014
PEDSY	-.0072
MYSPD	-.0004

Cross Tabulation

```
Frequencies of actual & predicted outcomes
Predicted outcome has maximum probability.
```

	Predicted					
Actual	0	1	2	3	4	Total
0	332	486	7	1	2	828
1	51	984	258	14	0	1307
2	3	254	1016	249	20	1542
3	1	19	257	615	145	1037
4	1	3	14	285	221	524
Total	388	1746	1552	1164	388	5238

Model 3: Ordered Probit Model - Re-specification of Model 2 by Dropping ROUDM

Model Specification

```
Ordered     ;Lhs=RatingZ
            ;Rhs=One,RoudL,Lane1,Clear,VehLG,VehMD,Speed,BusyT,
                      ModeT,PedsY,MySpd
            ;Marginal Effects$
```

Estimation Results

```
+---------------------------------------------+
| Ordered Probit Model                        |
| Maximum Likelihood Estimates                |
| Dependent variable               RATINGZ    |
| Weighting variable                   ONE    |
| Number of observations              5238    |
| Iterations completed                  21    |
| Log likelihood function        -4759.348    |
| Restricted log likelihood      -8113.318    |
| Chi-squared                     6707.940    |
| Degrees of freedom                    10    |
| Significance level              .0000000    |
|   Cell frequencies for outcomes             |
|  Y Count Freq  Y Count Freq  Y Count Freq   |
|  0   828 .158  1  1307 .249  2  1542 .294   |
|  3  1037 .197  4   524 .100                 |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
	Index function for probability				
Constant	5.843241609	.82759666E-01	70.605	.0000	
ROUDL	-.5189774690	.21064134E-01	-24.638	.0000	.00000000
LANE1	.2232428521	.17904680E-01	12.468	.0000	.33333333
CLEAR	1.325873050	.20978402E-01	63.202	.0000	.33333333
VEHLG	-.6854926424	.23951372E-01	-28.620	.0000	.00000000

VEHMD	.2739613637	.23739505E-01	11.540	.0000	.00000000
SPEED	-.7426067579E-01	.13872226E-02	-53.532	.0000	37.592593
BUSYT	-.4382976935	.23650324E-01	-18.532	.0000	.00000000
MODET	.1438708137	.23616640E-01	6.092	.0000	.00000000
PEDSY	-.7526969107	.19404505E-01	-38.790	.0000	-.33333333
MYSPD	-.3844219098E-01	.10937607E-02	-35.147	.0000	40.000000
	Threshold parameters for index				
Mu(1)	1.804557570	.40894896E-01	44.127	.0000	
Mu(2)	3.603231945	.47406863E-01	76.007	.0000	
Mu(3)	5.011385799	.55537397E-01	90.234	.0000	

(Note: E+nn or E-nn means multiply by 10 to + or -nn power.)

Marginal Effects

Marginal Effects for OrdProbt

Variable	RATING=0	RATING=1	RATING=2	RATING=3
ONE	-.1728	-1.9080	1.1080	.9167
ROUDL	.0153	.1695	-.0984	-.0814
LANE1	-.0066	-.0729	.0423	.0350
CLEAR	-.0392	-.4329	.2514	.2080
VEHLG	.0203	.2238	-.1300	-.1075
VEHMD	-.0081	-.0895	.0519	.0430
SPEED	.0022	.0242	-.0141	-.0117
BUSYT	.0130	.1431	-.0831	-.0688
MODET	-.0043	-.0470	.0273	.0226
PEDSY	.0223	.2458	-.1427	-.1181
MYSPD	.0011	.0126	-.0073	-.0060

Marginal Effects for

Variable	RATING=4
ONE	.0561
ROUDL	-.0050
LANE1	.0021
CLEAR	.0127
VEHLG	-.0066
VEHMD	.0026
SPEED	-.0007
BUSYT	-.0042
MODET	.0014
PEDSY	-.0072
MYSPD	-.0004

Cross Tabulation

Frequencies of actual & predicted outcomes
Predicted outcome has maximum probability.

	Predicted					
Actual	0	1	2	3	4	Total
0	438	380	7	1	2	828
1	139	896	258	14	0	1307
2	3	254	1016	249	20	1542
3	1	19	257	615	145	1037
4	1	3	14	285	221	524
Total	582	1552	1552	1164	388	5238

Model 4: Ordered Logit Model - The Logit Specification of Model 3

Model Specification

```
Ordered     ;Lhs=RatingZ
            ;Rhs=One,RoudL,Lane1,Clear,VehLG,VehMD,Speed,BusyT,
                        ModeT,PedsY,MySpd
            ;Marginal Effects
            ;Logit$
```

Estimation Results

```
+---------------------------------------------+
| Ordered Probit Model                        |
| Maximum Likelihood Estimates                |
| Dependent variable               RATINGZ    |
| Weighting variable                   ONE    |
| Number of observations              5238    |
| Iterations completed                  24    |
| Log likelihood function        -4715.339    |
| Restricted log likelihood      -8113.318    |
| Chi-squared                     6795.957    |
| Degrees of freedom                    10    |
| Significance level              .0000000    |
|    Cell frequencies for outcomes            |
|  Y Count Freq  Y Count Freq  Y Count Freq   |
|  0   828 .158  1  1307 .249  2  1542 .294   |
|  3  1037 .197  4   524 .100                 |
| Logistic Probability Model                  |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
	Index function for probability				
Constant	10.59454172	.19515030	54.289	.0000	
ROUDL	-.9499949044	.39501235E-01	-24.050	.0000	.00000000
LANE1	.3997176794	.31360007E-01	12.746	.0000	.33333333
CLEAR	2.402002234	.48083608E-01	49.955	.0000	.33333333
VEHLG	-1.236266419	.44519532E-01	-27.769	.0000	.00000000
VEHMD	.4863455730	.42627458E-01	11.409	.0000	.00000000
SPEED	-.1350235239	.29165778E-02	-46.295	.0000	37.592593
BUSYT	-.8079569834	.42395082E-01	-19.058	.0000	.00000000
MODET	.2613267491	.41801218E-01	6.252	.0000	.00000000
PEDSY	-1.344735613	.37323936E-01	-36.029	.0000	-.33333333
MYSPD	-.6946628082E-01	.21534395E-02	-32.258	.0000	40.000000
	Threshold parameters for index				
Mu(1)	3.261499228	.85059577E-01	38.344	.0000	
Mu(2)	6.529747903	.11663522	55.984	.0000	
Mu(3)	9.020400196	.14151267	63.743	.0000	

(Note: E+nn or E-nn means multiply by 10 to + or -nn power.)

Marginal Effects

Marginal Effects for OrdLogit

Variable	RATING=0	RATING=1	RATING=2	RATING=3
ONE	-.1663	-2.0466	1.4101	.7249
ROUDL	.0149	.1835	-.1264	-.0650
LANE1	-.0063	-.0772	.0532	.0274
CLEAR	-.0377	-.4640	.3197	.1644
VEHLG	.0194	.2388	-.1645	-.0846
VEHMD	-.0076	-.0940	.0647	.0333

SPEED	.0021	.0261	-.0180	-.0092
BUSYT	.0127	.1561	-.1075	-.0553
MODET	-.0041	-.0505	.0348	.0179
PEDSY	.0211	.2598	-.1790	-.0920
MYSPD	.0011	.0134	-.0092	-.0048

Marginal Effects for	
Variable	RATING=4
ONE	.0779
ROUDL	-.0070
LANE1	.0029
CLEAR	.0177
VEHLG	-.0091
VEHMD	.0036
SPEED	-.0010
BUSYT	-.0059
MODET	.0019
PEDSY	-.0099
MYSPD	-.0005

Cross Tabulation

Frequencies of actual & predicted outcomes
Predicted outcome has maximum probability.

Actual	Predicted 0	1	2	3	4	Total
0	438	380	7	1	2	828
1	139	896	258	14	0	1307
2	3	254	1016	249	20	1542
3	1	19	257	615	145	1037
4	1	3	14	285	221	524
Total	582	1552	1552	1164	388	5238

Model 5: Heteroskedastic Ordered Probit Model

Model Specification

```
Ordered     ;Lhs=RatingZ
            ;Rhs=One,RoudL,Lane1,Clear,VehLG,VehMD,Speed,BusyT,
                      ModeT,PedsY,MySpd
            ;Het
            ;Maxit=200
            ;Rh2=GendF,AgeY,Imid,Restr,DrYrs,ComYe,AccNo,CarSM,Pcaut
            ;Marginal Effects$
```

Estimation Results

Ordered Probit Model	
Maximum Likelihood Estimates	
Dependent variable	RATINGZ
Weighting variable	ONE
Number of observations	5238
Iterations completed	36
Log likelihood function	-4722.056
Restricted log likelihood	-8113.318
Chi-squared	6782.524

```
| Degrees of freedom                       19 |
| Significance level                 .0000000 |
|     Cell frequencies for outcomes           |
|  Y Count Freq  Y Count Freq  Y Count Freq   |
|  0   828 .158  1  1307 .249  2  1542 .294   |
|  3  1037 .197  4   524 .100                 |
| Terms  12 to  20 are for variance.          |
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
	Index function for probability				
Constant	6.189186719	.39145388	15.811	.0000	
ROUDL	-.5503554054	.40473034E-01	-13.598	.0000	.00000000
LANE1	.2361830173	.23739371E-01	9.949	.0000	.33333333
CLEAR	1.412894586	.89152475E-01	15.848	.0000	.33333333
VEHLG	-.7291145286	.49865801E-01	-14.622	.0000	.00000000
VEHMD	.2878910240	.29407467E-01	9.790	.0000	.00000000
SPEED	-.7901511543E-01	.50398519E-02	-15.678	.0000	37.592593
BUSYT	-.4637432112	.38334250E-01	-12.097	.0000	.00000000
MODET	.1471310429	.26143397E-01	5.628	.0000	.00000000
PEDSY	-.7991441713	.52579101E-01	-15.199	.0000	-.33333333
MYSPD	-.4053141456E-01	.27493064E-02	-14.742	.0000	40.000000
	Variance function				
GENDF	.1052400927	.28669412E-01	3.671	.0002	.46391753
AGEY	-.9747729724E-01	.49125091E-01	-1.984	.0472	.12371134
IMID	-.1001745493	.28598503E-01	-3.503	.0005	.29896907
RESTR	.1274933390	.38687658E-01	3.295	.0010	.22680412
DRYRS	.4146708533E-02	.13781670E-02	3.009	.0026	13.731959
COMYE	-.7470254318E-01	.26669225E-01	-2.801	.0051	.52577320
ACCNO	.7207405988E-01	.43350011E-01	1.663	.0964	.83505155
CARSM	-.6316349831E-01	.29544823E-01	-2.138	.0325	.53608247
PCAUT	-.9068442455E-01	.27981071E-01	-3.241	.0012	.37113402
	Threshold parameters for index				
Mu(1)	1.924377410	.12595244	15.279	.0000	
Mu(2)	3.840693267	.24308878	15.800	.0000	
Mu(3)	5.337355536	.33226971	16.063	.0000	

(Note: E+nn or E-nn means multiply by 10 to + or -nn power.)

Marginal Effects

Marginal Effects for OrdProbt

Variable	RATING=0	RATING=1	RATING=2	RATING=3
ONE	-.1655	-1.9486	1.1825	.8838
ROUDL	.0147	.1733	-.1052	-.0786
LANE1	-.0063	-.0744	.0451	.0337
CLEAR	-.0378	-.4448	.2700	.2018
VEHLG	.0195	.2296	-.1393	-.1041
VEHMD	-.0077	-.0906	.0550	.0411
SPEED	.0021	.0249	-.0151	-.0113
BUSYT	.0124	.1460	-.0886	-.0662
MODET	-.0039	-.0463	.0281	.0210
PEDSY	.0214	.2516	-.1527	-.1141
MYSPD	.0011	.0128	-.0077	-.0058
GENDF	.3995	.6348	-2.3638	1.1896
AGEY	-.0355	-.0564	.2102	-.1058
IMID	.0152	.0242	-.0902	.0454
RESTR	.0912	.1449	-.5396	.2716
DRYRS	-.0471	-.0748	.2785	-.1401
COMYE	.0186	.0295	-.1100	.0553
ACCNO	-.0051	-.0081	.0302	-.0152
CARSM	-.0299	-.0476	.1771	-.0891

Marginal Effects for OrdProbt				
Variable	RATING=0	RATING=1	RATING=2	RATING=3
PCAUT	.0095	.0151	-.0562	.0283

Marginal Effects for	
Variable	RATING=4
ONE	.0478
ROUDL	-.0043
LANE1	.0018
CLEAR	.0109
VEHLG	-.0056
VEHMD	.0022
SPEED	-.0006
BUSYT	-.0036
MODET	.0011
PEDSY	-.0062
MYSPD	-.0003
GENDF	.1398
AGEY	-.0124
IMID	.0053
RESTR	.0319
DRYRS	-.0165
COMYE	.0065
ACCNO	-.0018
CARSM	-.0105

Marginal Effects for	
Variable	RATING=4
PCAUT	.0033

Cross Tabulation

Frequencies of actual & predicted outcomes
Predicted outcome has maximum probability.

	Predicted					
Actual	0	1	2	3	4	Total
0	431	387	7	1	2	828
1	139	896	258	14	0	1307
2	4	253	1016	249	20	1542
3	1	19	257	615	145	1037
4	1	3	14	285	221	524
Total	576	1558	1552	1164	388	5238

Model 6: Heteroskedastic Ordered Logit Model

Model Specification

```
Ordered      ;Lhs=RatingZ
             ;Rhs=One,RoudL,Lane1,Clear,VehLG,VehMD,Speed,BusyT,
                        ModeT,PedsY,MySpd
```

```
;Het
;Maxit=200
;Rh2=GendF,AgeY,Imid,Restr,DrYrs,ComYe,AccNo,CarSM,Pcaut
;Marginal Effects
;Logit$
```

Estimation Results

```
+---------------------------------------------+
| Ordered Probit Model                        |
| Maximum Likelihood Estimates                |
| Dependent variable                RATINGZ   |
| Weighting variable                    ONE   |
| Number of observations               5238   |
| Iterations completed                   48   |
| Log likelihood function         -4685.109   |
| Restricted log likelihood       -8113.318   |
| Chi-squared                      6856.419   |
| Degrees of freedom                     19   |
| Significance level               .0000000   |
|      Cell frequencies for outcomes          |
|  Y Count Freq  Y Count Freq  Y Count Freq   |
|  0   828 .158  1  1307 .249  2  1542 .294   |
|  3  1037 .197  4   524 .100                 |
| Logistic Probability Model                  |
| Terms  12 to  20 are for variance.          |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
	Index function for probability				
Constant	11.67973741	.91587062	12.753	.0000	
ROUDL	-1.052825828	.91455728E-01	-11.512	.0000	.00000000
LANE1	.4418418543	.48175569E-01	9.171	.0000	.33333333
CLEAR	2.666046884	.20917886	12.745	.0000	.33333333
VEHLG	-1.378397942	.11387066	-12.105	.0000	.00000000
VEHMD	.5411922030	.60866048E-01	8.892	.0000	.00000000
SPEED	-.1495222446	.11791702E-01	-12.680	.0000	37.592593
BUSYT	-.8950677376	.83459959E-01	-10.725	.0000	.00000000
MODET	.2793675068	.50126209E-01	5.573	.0000	.00000000
PEDSY	-1.494174970	.12073072	-12.376	.0000	-.33333333
MYSPD	-.7651639855E-01	.62937567E-02	-12.158	.0000	40.000000
	Variance function				
GENDF	.1006111093	.34303807E-01	2.933	.0034	.46391753
AGEY	-.6071710105E-01	.59118833E-01	-1.027	.3044	.12371134
IMID	-.8773321594E-01	.36209444E-01	-2.423	.0154	.29896907
RESTR	.2099061463	.47696165E-01	4.401	.0000	.22680412
DRYRS	.7477675837E-02	.16801518E-02	4.451	.0000	13.731959
COMYE	-.4406426813E-01	.35312239E-01	-1.248	.2121	.52577320
ACCNO	.1753572464E-01	.48563769E-01	.361	.7180	.83505155
CARSM	-.4733913617E-01	.36926757E-01	-1.282	.1999	.53608247
PCAUT	-.8873591123E-01	.34765034E-01	-2.552	.0107	.37113402
	Threshold parameters for index				
Mu(1)	3.623370580	.29118875	12.443	.0000	
Mu(2)	7.251423248	.56930196	12.737	.0000	
Mu(3)	10.02800751	.77986473	12.859	.0000	

(Note: E+nn or E-nn means multiply by 10 to + or -nn power.)

Marginal Effects

Marginal Effects for OrdLogit

Variable	RATING=0	RATING=1	RATING=2	RATING=3

ONE	-.1675	-2.0793	1.4838	.6919
ROUDL	.0151	.1874	-.1337	-.0624
LANE1	-.0063	-.0787	.0561	.0262
CLEAR	-.0382	-.4746	.3387	.1579
VEHLG	.0198	.2454	-.1751	-.0817
VEHMD	-.0078	-.0963	.0688	.0321
SPEED	.0021	.0266	-.0190	-.0089
BUSYT	.0128	.1593	-.1137	-.0530
MODET	-.0040	-.0497	.0355	.0165
PEDSY	.0214	.2660	-.1898	-.0885
MYSPD	.0011	.0136	-.0097	-.0045
GENDF	.7593	1.2827	-4.1169	1.6839
AGEY	-.0684	-.1156	.3711	-.1518
IMID	.0287	.0485	-.1557	.0637
RESTR	.1733	.2928	-.9397	.3844
DRYRS	-.0896	-.1514	.4859	-.1987
COMYE	.0352	.0594	-.1908	.0780
ACCNO	-.0097	-.0164	.0527	-.0216
CARSM	-.0582	-.0983	.3155	-.1290

Marginal Effects for OrdLogit

Variable	RATING=0	RATING=1	RATING=2	RATING=3
PCAUT	.0182	.0307	-.0985	.0403

Marginal Effects for

Variable	RATING=4
ONE	.0712
ROUDL	-.0064
LANE1	.0027
CLEAR	.0162
VEHLG	-.0084
VEHMD	.0033
SPEED	.0009
BUSYT	-.0055
MODET	.0017
PEDSY	-.0091
MYSPD	-.0005
GENDF	.3910
AGEY	-.0352
IMID	.0148
RESTR	.0893
DRYRS	-.0462
COMYE	.0181
ACCNO	-.0050
CARSM	-.0300

Marginal Effects for

Variable	RATING=4
PCAUT	.0094

Cross Tabulation

Frequencies of actual & predicted outcomes
Predicted outcome has maximum probability.

```
             Predicted
------ -------------------------  +  -----
Actual      0    1    2    3    4 |  Total
------ -------------------------  +  -----
  0       441  377    7    1    2 |    828
  1       145  890  258   14    0 |   1307
  2         4  253 1016  249   20 |   1542
  3         1   19  257  615  145 |   1037
  4         1    3   14  285  221 |    524
------ -------------------------  +  -----
Total     592 1542 1552 1164  388 |   5238
```

Formulas for Calculation of Success Index Table

The calculation of a prediction success index table starts from a cross tabulation, which is an output from an estimated discrete choice model or ordered probit (logit) model. Table below gives the formulas to calculate a prediction success index table, supposing we have three alternatives denoted as *1, 2* and *3*. Several steps are required as given below:

- From an estimated model, obtain the predicted alternative and observed alternative counts (N_{ij}, $i=1,2,3$ and $j=1, 2, 3$).
- Calculate the observed total for each alternative N_{1Y}, N_{2Y} and N_{3Y} (eg $N_{1Y} = N_{11}+N_{12}+N_{13}$).
- Calculate the total observation, $N_{YY} = N_{1Y}+N_{2Y}+N_{3Y}$.
- Calculate the observed share for each alternative (eg N_{1Y}/N_{YY} for alternative *1*).
- Calculate the predicted total for each alternative N_{Y1}, N_{Y2} and N_{Y3}.
- Calculate the predicted share for each alternative.
- Calculate the *Percent Correct Success Index* for each alternative (eg N_{11}/N_{YY} for alternative *1*).
- Calculate the *Success Index* σ_i for each alternative [eg $\sigma_1 = (N_{11}/N_{Y1})-(N_{Y1}/N_{YY})$ for alternative *1*].
- Calculate the Overall Success Index using following formula:

$$\text{Overall Success Index} = \frac{N_{Y1}}{N_{YY}} \times \sigma_1 + \frac{N_{Y2}}{N_{YY}} \times \sigma_2 + \frac{N_{Y3}}{N_{YY}} \times \sigma_3$$

The prediction success index table

Actual Alternatives	Predicted Alternatives			Observed Total	Observed Share
	1	2	3		
1	N_{11}	N_{12}	N_{13}	N_{1Y}	N_{1Y}/N_{YY}
2	N_{21}	N_{22}	N_{23}	N_{2Y}	N_{2Y}/N_{YY}
3	N_{31}	N_{32}	N_{33}	N_{3Y}	N_{3Y}/N_{YY}
Predicted Total	N_{Y1}	N_{Y2}	N_{Y3}	N_{YY}	1
Predicted Share	N_{Y1}/N_{YY}	N_{Y2}/N_{YY}	N_{Y3}/N_{YY}	1	
Percent Correct Success Index	N_{11}/N_{YY}	N_{22}/N_{YY}	N_{33}/N_{YY}		
Success Index	$(N_{11}/N_{Y1})-(N_{Y1}/N_{YY})$	$(N_{22}/N_{Y2})-(N_{Y2}/N_{YY})$	$(N_{33}/N_{Y3})-(N_{Y3}/N_{YY})$		

Appendix VI
Estimation Results for Driver's Behavioural Response Models

Model 1: Multinomial Logit Model

Model Specification

```
Nlogit ;lhs=choiceZ
      ;Choices=ST,SL,KG
      ;start=logit
      ;Maxit = 200
      ;Model:
      U(SL) = A_SL +
              RoudL*RoudL + RoudM*RoudM + Lane1*Lane1 + Clear*Clear
            + VehLG*VehLG + VehMD*VehMD + Speed*Speedz + BusyT*BusyT
            + ModeT*ModeT + PedsY*PedsY + MySpd*MySpdz + Hurry*Hurry/
      U(ST) =
              RoudL*RoudL + VehLG*VehLG + Speed*Speedz + BusyT*BusyT
            + PedsY*PedsY + MySpd*MySpdz/
      U(KG) = A_KG +
              RoudM*RoudM + Lane1*Lane1 + Clear*Clear  + VehMD*VehMD
            + ModeT*ModeT + Hurry*Hurry
      ;show
      ;Effects:Speedz(*)/MySpdz(*);pwt
      ;Crosstab
      ;Set$
```

Estimation Results

```
+---------------------------------------------+
| Discrete choice (multinomial logit) model   |
| Maximum Likelihood Estimates                |
| Dependent variable                 Choice   |
| Weighting variable                    ONE   |
| Number of observations               5238   |
| Iterations completed                    7   |
| Log likelihood function         -3869.835   |
| Log-L for Choice     model =   -3869.8353   |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd RsqAdj  |
| No coefficients  -5754.5312  .32752 .32662  |
| Constants only   -5357.6126  .27769 .27673  |
| Chi-squared[12]           =   2975.55455    |
| Significance for chi-squared =   1.00000    |
| Response data are given as ind. choice.     |
| Number of obs.=  5238, skipped   0 bad obs. |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
A_SL	.9629594356	.54649673E-01	17.621	.0000
ROUDL	.3547817635	.52266972E-01	6.788	.0000
ROUDM	-.5252787517	.49242882E-01	-10.667	.0000
LANE1	.1856606964	.39884858E-01	4.655	.0000
CLEAR	1.316111664	.44987445E-01	29.255	.0000
VEHLG	1.166995905	.58399212E-01	19.983	.0000
VEHMD	-.1489628414	.53336333E-01	-2.793	.0052
SPEED	5.142933075	.29710241	17.310	.0000
BUSYT	.6235701138	.57549504E-01	10.835	.0000

```
 MODET       -.2468907205  .47826105E-01   -5.162   .0000
 PEDSY        .7734768118  .58393600E-01   13.246   .0000
 MYSPD       1.070834284    .26499132       4.041   .0001
 HURRY       1.512478346   .58448122E-01   25.877   .0000
 A_KG        1.577582817    .15154501      10.410   .0000
 (Note: E+nn or E-nn means multiply by 10 to + or -nn power.)
```

Cross Tabulation

```
+---------------------------------------------------------+
| Cross tabulation of actual vs. predicted choices.       |
| Row indicator is actual, column is predicted.           |
| Predicted total is F(k,j,i)=Sum(i=1,...,N) P(k,j,i).    |
| Column totals may be subject to rounding error.         |
+---------------------------------------------------------+

Matrix Crosstab has  4 rows and  4 columns.
           ST            SL              KG            Total
        +--------------------------------------------------------
ST      |   954.0000     579.0000      86.0000     1619.0000
SL      |   571.0000    1540.0000     523.0000     2634.0000
KG      |    94.0000     515.0000     376.0000      985.0000
Total   |  1619.0000    2634.0000     985.0000     5238.0000
```

Model 2: Simple Mixed Logit Model

Model Specification

```
Nlogit ;lhs=choiceZ
       ;Choices=ST,SL,KG
       ;start=logit
       ;Maxit = 200
       ;Model:
       U(SL) = A_SL +
             RoudL*RoudL + RoudM*RoudM + Lane1*Lane1 + Clear*Clear
           + VehLG*VehLG + VehMD*VehMD + Speed*Speedz + BusyT*BusyT
           + ModeT*ModeT + PedsY*PedsY + MySpd*MySpdz + Hurry*Hurry/
       U(ST) =
             RoudL*RoudL + VehLG*VehLG + Speed*Speedz + BusyT*BusyT
           + PedsY*PedsY + MySpd*MySpdz/
       U(KG) = A_KG +
             RoudM*RoudM + Lane1*Lane1 + Clear*Clear  + VehMD*VehMD
           + ModeT*ModeT + Hurry*Hurry
       ;show
       ;RPL
       ;Fcn =RoudL(N), RoudM(N), Clear(N), VehLG(N), Speed(N), BusyT(N),
           ModeT(N), PedsY(N), Hurry(N)
       ;Halten
       ;Pts = 100
       ;Effects: Speedz(*)/MySpdz(*)
       ;Describe
       ;Crosstab
       ;Set$
```

Estimation Results

```
+-----------------------------------------------+
| Random Parameters Logit Model                 |
| Maximum Likelihood Estimates                  |
```

```
                 | Dependent variable               CHOICEZ        |
                 | Weighting variable                   ONE        |
                 | Number of observations             15714        |
                 | Iterations completed                   4        |
                 | Log likelihood function        -3869.747        |
                 | Restricted log likelihood      -5754.531        |
                 | Chi-squared                     3769.569        |
                 | Degrees of freedom                    23        |
                 | Significance level              .0000000        |
                 | R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj     |
                 | No coefficients  -5754.5312  .32753  .32605     |
                 | Constants only   -5357.6126  .27771  .27612     |
                 | At start values  -3869.8353  .00002 -.00218     |
                 | Response data are given as ind. choice.         |
                 +-------------------------------------------------+

                 +-------------------------------------------------+
                 | Random Parameters Logit Model                   |
                 | Replications for simulated probs. = 100         |
                 | Halton sequences used for simulations           |
                 | Number of obs.=  5238, skipped   0 bad obs.     |
                 +-------------------------------------------------+
+---------+--------------+----------------+--------+---------+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] |
+---------+--------------+----------------+--------+---------+
         Random parameters in utility functions
 ROUDL     .3547800315    .52273124E-01     6.787   .0000
 ROUDM    -.5255073471    .49271406E-01   -10.666   .0000
 CLEAR    1.316755656     .45094008E-01    29.200   .0000
 VEHLG    1.167001005     .58410428E-01    19.979   .0000
 SPEED    5.143067151         .29717943    17.306   .0000
 BUSYT     .6234762455    .57556882E-01    10.832   .0000
 MODET    -.2468214642    .47842946E-01    -5.159   .0000
 PEDSY     .7733951534    .58402246E-01    13.243   .0000
 HURRY    1.513118815     .58535301E-01    25.850   .0000
         Nonrandom parameters in utility functions
 A_SL      .9633615766    .54699964E-01    17.612   .0000
 LANE1     .1859393646    .39910081E-01     4.659   .0000
 VEHMD    -.1491958319    .53358250E-01    -2.796   .0052
 MYSPD    1.070950964         .26502742     4.041   .0001
 A_KG     1.577984617         .15158042    10.410   .0000
         Derived standard deviations of parameter distributions
 NsROUDL  .1688759338E-02     .12064942      .014   .9888
 NsROUDM  .4385874271E-01     .13360657      .328   .7427
 NsCLEAR  .3334431126E-02     .11191855      .030   .9762
 NsVEHLG  .1228641013E-01     .13907085      .088   .9296
 NsSPEED  .1280887408E-01     .26814263      .048   .9619
 NsBUSYT  .8729546058E-02     .13050267      .067   .9467
 NsMODET  .1459076133E-01     .15126016      .096   .9232
 NsPEDSY  .1532196534E-01     .12971988      .118   .9060
 NsHURRY  .1934861375E-01     .10794507      .179   .8577
 (Note: E+nn or E-nn means multiply by 10 to + or -nn power.)
```

Cross Tabulation

```
            +-----------------------------------------------------+
            | Cross tabulation of actual vs. predicted choices.   |
            | Row indicator is actual, column is predicted.       |
            | Predicted total is F(k,j,i)=Sum(i=1,...,N) P(k,j,i).|
            | Column totals may be subject to rounding error.     |
            +-----------------------------------------------------+

Matrix Crosstab has  4 rows and  4 columns.
         ST            SL            KG            Total
```

```
      +-----------------------------------------------------------
ST    |    954.0000       579.0000        86.0000      1619.0000
SL    |    571.0000      1540.0000       523.0000      2634.0000
KG    |     94.0000       515.0000       376.0000       985.0000
Total |   1619.0000      2634.0000       985.0000      5238.0000
```

Model 3: Mixed Logit Model with Correlation between Alternatives

Model Specification

```
Nlogit ;lhs=choiceZ
       ;Choices=ST,SL,KG
       ;start=logit
       ;Maxit = 200
       ;Model:
       U(SL) = A_SL +
               RoudL*RoudL + RoudM*RoudM + Lane1*Lane1 + Clear*Clear
             + VehLG*VehLG + VehMD*VehMD + Speed*Speedz + BusyT*BusyT
             + ModeT*ModeT + PedsY*PedsY + MySpd*MySpdz + Hurry*Hurry/
       U(ST) =
               RoudL*RoudL + VehLG*VehLG + Speed*Speedz + BusyT*BusyT
             + PedsY*PedsY + MySpd*MySpdz/
       U(KG) = A_KG +
               RoudM*RoudM + Lane1*Lane1 + Clear*Clear  + VehMD*VehMD
             + ModeT*ModeT + Hurry*Hurry
       ;show
       ;RPL
       ;Fcn =RoudL(N), RoudM(N), Clear(N), VehLG(N), Speed(N), BusyT(N),
             ModeT(N), PedsY(N), Hurry(N)
       ;Halten
       ;Pts = 100
       ;Cor
       ;Effects: Speedz(*)/MySpdz(*)
       ;Describe
       ;Crosstab
       ;Set$
```

Estimation Results (Model is not estimable)

```
Cannot invert Hessian at start values.
Switching to BFGS (gradient based) method.
Line search does not improve fn. Exit iterations. Status=3
Abnormal exit from iterations. If current results are shown
check convergence values shown below. This may not be a
solution value (especially if initial iterations stopped).
Gradient value: Tolerance= .1000D-05, current value= .4295D+02
Function chg. : Tolerance= .0000D+00, current value= .3789D-01
Parameters chg: Tolerance= .0000D+00, current value= .1276D+02
Smallest abs. parameter change from start value = .1248D+00
Function=  .38698353110D+04, at entry,  .34693276576D+04 at exit
Elapsed time:    3 hours, 34 minutes, 29.18 seconds.
```

Model 4: Mixed Logit Model with Choice Set Correlation and Correlation between Alternatives

Model Specification

```
Nlogit ;lhs=choiceZ
    ;Choices=ST,SL,KG
    ;start=logit
    ;Maxit = 200
    ;Model:
    U(SL) = A_SL +
            RoudL*RoudL + RoudM*RoudM + Lane1*Lane1 + Clear*Clear
          + VehLG*VehLG + VehMD*VehMD + Speed*Speedz + BusyT*BusyT
          + ModeT*ModeT + PedsY*PedsY + MySpd*MySpdz + Hurry*Hurry/
    U(ST) =
            RoudL*RoudL + VehLG*VehLG + Speed*Speedz + BusyT*BusyT
          + PedsY*PedsY + MySpd*MySpdz/
    U(KG) = A_KG +
            RoudM*RoudM + Lane1*Lane1 + Clear*Clear  + VehMD*VehMD
          + ModeT*ModeT + Hurry*Hurry
    ;show
    ;RPL
    ;Fcn =RoudL(N), RoudM(N), Clear(N), VehLG(N), Speed(N), BusyT(N),
         ModeT(N), PedsY(N), Hurry(N)
    ;Halten
    ;Pts = 100
    ;Cor
    ;pds=27
    ;Effects: Speedz(*)/MySpdz(*)
    ;Describe
    ;Crosstab
    ;Set$
```

Estimation Results

```
+---------------------------------------------+
| Random Parameters Logit Model               |
| Maximum Likelihood Estimates                |
| Dependent variable                 CHOICEZ  |
| Weighting variable                     ONE  |
| Number of observations               15714  |
| Iterations completed                    71  |
| Log likelihood function          -3820.574  |
| Restricted log likelihood        -5754.531  |
| Chi-squared                       3867.915  |
| Degrees of freedom                      52  |
| Significance level                .0000000  |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj |
| No coefficients  -5754.5312  .33608  .33276 |
| Constants only   -5357.6126  .28689  .28333 |
| At start values  -3869.8353  .01273  .00780 |
| Response data are given as ind. choice.     |
+---------------------------------------------+

+---------------------------------------------+
| Random Parameters Logit Model               |
| Replications for simulated probs. = 100     |
| Halton sequences used for simulations       |
| ------------------------------------------- |
| RPL model with panel has  194 groups.       |
| Fixed number of obsrvs./group=        27    |
| Random effects model was specified          |
| ------------------------------------------- |
| RPL model has correlated parameters         |
| Hessian was not PD. Using BHHH estimator.   |
| Number of obs.=  5238, skipped   0 bad obs. |
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
	Random parameters in utility functions			
ROUDL	.3011718258	.18911142	1.593	.1113
ROUDM	-.7262025128	.18308108	-3.967	.0001
CLEAR	1.312186143	.11232338	11.682	.0000
VEHLG	1.204868090	.19562873	6.159	.0000
SPEED	4.957961366	.99197963	4.998	.0000
BUSYT	.6876722562	.18623368	3.693	.0002
MODET	-.1704123930	.19398840	-.878	.3797
PEDSY	.7366806208	.18227204	4.042	.0001
HURRY	1.448997065	.18566645	7.804	.0000
	Nonrandom parameters in utility functions			
A_SL	.9969733071	.10113585	9.858	.0000
LANE1	.1913479240	.85373494E-01	2.241	.0250
VEHMD	-.1684761899	.16809738	-1.002	.3162
MYSPD	1.288654343	.66380536	1.941	.0522
A_KG	1.795288221	.34481323	5.207	.0000
	Diagonal values in Cholesky matrix, L.			
NsROUDL	.5995424828E-03	.70649096E-03	.849	.3961
NsROUDM	.3540132329	.16912756	2.093	.0363
NsCLEAR	.2892990547	.17171500	1.685	.0920
NsVEHLG	.2401002847E-02	.48956206	.005	.9961
NsSPEED	.4004369897E-01	2.5545991	.016	.9875
NsBUSYT	.1050898722E-01	1.1671078	.009	.9928
NsMODET	.9107666346E-04	.10297154E-01	.009	.9929
NsPEDSY	.4905112620E-01	.40658137	.121	.9040
NsHURRY	.1012046893E-01	.71738089	.014	.9887
	Below diagonal values in L matrix. V = L*Lt			
ROUD:ROU	-.3545027408	.16922385	-2.095	.0362
CLEA:ROU	-.1447975799	.85849862E-01	-1.687	.0917
CLEA:ROU	-.1447975799	.85849862E-01	-1.687	.0917
VEHL:ROU	-.4637638410E-01	.25050625	-.185	.8531
VEHL:ROU	.2440066503E-01	.23972648	.102	.9189
VEHL:CLE	.2440066503E-01	.23972648	.102	.9189
SPEE:ROU	-.8932950578	.97773108	-.914	.3609
SPEE:ROU	.5683826777	.77563238	.733	.4637
SPEE:CLE	-.2065824740	1.3738463	-.150	.8805
SPEE:VEH	.5683826777	.77563238	.733	.4637
BUSY:ROU	.3107830906	.33042062	.941	.3469
BUSY:ROU	-.1509298466	.35254362	-.428	.6686
BUSY:CLE	-.8084069126E-03	.49178017	-.002	.9987
BUSY:VEH	-.1841872397E-01	.85617700	-.022	.9828
BUSY:SPE	-.1509298466	.35254362	-.428	.6686
MODE:ROU	.1911610701	.33306232	.574	.5660
MODE:ROU	-.2400479198E-01	.33849587	-.071	.9435
MODE:CLE	-.1123287042	.46407469	-.242	.8087
MODE:VEH	.8787277908E-02	.63349547	.014	.9889
MODE:SPE	-.3948207204E-01	.99219897	-.040	.9683
MODE:BUS	-.2400479198E-01	.33849587	-.071	.9435
PEDS:ROU	.7377980429E-01	.29699670	.248	.8038
PEDS:ROU	-.4958040668E-01	.40638692	-.122	.9029
PEDS:CLE	.1631546164E-01	.61295961	.027	.9788
PEDS:VEH	-.1307657236E-01	.42451565	-.031	.9754
PEDS:SPE	-.4650899157E-01	.91691688	-.051	.9595
PEDS:BUS	.1918647119E-01	.98118518	.020	.9844
PEDS:MOD	-.4958040668E-01	.40638692	-.122	.9029
HURR:ROU	-.2548295538	.33858867	-.753	.4517
HURR:ROU	.1115778995E-01	.48784810	.023	.9818
HURR:CLE	.1775229967	.69021859	.257	.7970
HURR:VEH	.4582495383E-01	.83105565	.055	.9560
HURR:SPE	.7505138046E-02	.77286300	.010	.9923
HURR:BUS	.1207612845E-01	1.5144574	.008	.9936

```
HURR:MOD -.7462939000E-03    .64956560      -.001    .9991
HURR:PED  .1115778995E-01    .48784810       .023    .9818
         Standard deviations of parameter distributions
sdROUDL  .5995424828E-03  .70649096E-03      .849    .3961
sdROUDM      .5009965692  .34539379E-03  1450.508   .0000
sdCLEAR      .3544384592  .70013105E-01     5.062   .0000
sdVEHLG  .5785601719E-01    .23276720        .249    .8037
sdSPEED     1.219989186    1.0506701       1.161    .2456
sdBUSYT      .3776189989    .44183791        .855    .3927
sdMODET      .2279228184    .26364485        .865    .3873
sdPEDSY      .1254364539    .22147605        .566    .5711
sdHURRY      .3148119687    .59540266        .529    .5970
(Note: E+nn or E-nn means multiply by 10 to + or -nn power.)
```

Cross Tabulation

```
+-----------------------------------------------------------+
| Cross tabulation of actual vs. predicted choices.         |
| Row indicator is actual, column is predicted.             |
| Predicted total is F(k,j,i)=Sum(i=1,...,N) P(k,j,i).      |
| Column totals may be subject to rounding error.           |
+-----------------------------------------------------------+

Matrix Crosstab has  4 rows and  4 columns.
          ST          SL          KG          Total
       +---------------------------------------------------
ST     |   368.0000    691.0000    561.0000    1619.0000
SL     |   489.0000   1099.0000   1046.0000    2634.0000
KG     |   141.0000    405.0000    439.0000     985.0000
Total  |   998.0000   2194.0000   2046.0000    5238.0000
```

Model 5: Mixed Logit Model with the Heterogeneity in Mean, Choice Set Correlation and Correlation between Alternatives

Model Specification

```
--> Nlogit;lhs=choiceZ
     ;Choices=ST,SL,KG
     ;start=logit
     ;Maxit = 200
     ;Model:
     U(SL) = A_SL +
             RoudL*RoudL + RoudM*RoudM + Lane1*Lane1 + Clear*Clear
           + VehLG*VehLG + VehMD*VehMD + Speed*Speedz + BusyT*BusyT
           + ModeT*ModeT + PedsY*PedsY + MySpd*MySpdz + Hurry*Hurry/
     U(ST) =
             RoudL*RoudL + VehLG*VehLG + Speed*Speedz + BusyT*BusyT
           + PedsY*PedsY + MySpd*MySpdz/
     U(KG) = A_KG +
             RoudM*RoudM + Lane1*Lane1 + Clear*Clear  + VehMD*VehMD
           + ModeT*ModeT + Hurry*Hurry
     ;show
     ;RPL =DrYrs
     ;Fcn =RoudL(N), RoudM(N), Clear(N), VehLG(N), Speed(N), BusyT(N),
           ModeT(N), PedsY(N), Hurry(N)
     ;Halten
     ;Pts = 100
     ;Cor
     ;pds=27
```

```
;Effects: Speedz(*)/MySpdz(*)
;Describe
;Crosstab
;Set$
```

Estimation Results

```
+---------------------------------------------+
| Random Parameters Logit Model               |
| Maximum Likelihood Estimates                |
| Dependent variable               CHOICEZ    |
| Weighting variable                   ONE    |
| Number of observations             15714    |
| Iterations completed                  83    |
| Log likelihood function        -3733.738    |
| Restricted log likelihood      -5754.531    |
| Chi-squared                     4041.586    |
| Degrees of freedom                    60    |
| Significance level              .0000000    |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj |
| No coefficients  -5754.5312  .35117  .34743 |
| Constants only   -5357.6126  .30310  .29908 |
| At start values  -3869.8353  .03517  .02961 |
| Response data are given as ind. choice.     |
+---------------------------------------------+

+---------------------------------------------+
| Random Parameters Logit Model               |
| Replications for simulated probs. = 100     |
| Halton sequences used for simulations       |
| ------------------------------------------- |
| RPL model with panel has  194 groups.       |
| Fixed number of obsrvs./group=     27       |
| Random effects model was specified          |
| ------------------------------------------- |
| RPL model has correlated parameters         |
| Hessian was not PD. Using BHHH estimator.   |
| Number of obs.=  5238, skipped    0 bad obs. |
+---------------------------------------------+
+---------+--------------+----------------+--------+---------+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] |
+---------+--------------+----------------+--------+---------+
         Random parameters in utility functions
 ROUDL       .8839675023       .25203325     3.507   .0005
 ROUDM     -.1287205219       .22076342     -.583   .5598
 CLEAR     1.411458948        .18936939     7.453   .0000
 VEHLG     1.368154421        .38878219     3.519   .0004
 SPEED     6.964272581       1.2877546      5.408   .0000
 BUSYT      .2081776966       .28594405      .728   .4666
 MODET     -.4091597398       .21122915    -1.937   .0527
 PEDSY      .7341385340       .28966463     2.534   .0113
 HURRY     1.749785120        .21224243     8.244   .0000
         Nonrandom parameters in utility functions
 A_SL       .9931826636     .94014371E-01  10.564   .0000
 LANE1      .1913600330       .10101052     1.894   .0582
 VEHMD     -.1533988714       .17955222     -.854   .3929
 MYSPD     1.434797431        .61188828     2.345   .0190
 A_KG      1.887141652        .23828765     7.920   .0000
         Heterogeneity in mean, Parameter:Variable
 ROUD:DRY -.2820712572E-01  .79024531E-02  -3.569   .0004
 ROUD:DRY -.2820712572E-01  .79024531E-02  -3.569   .0004
 CLEA:DRY -.3562715314E-02  .93092940E-02   -.383   .7019
 VEHL:DRY -.5783169708E-02  .14405883E-01   -.401   .6881
 SPEE:DRY -.9128443400E-01  .40864513E-01  -2.234   .0255
```

BUSY:DRY	.2263702143E-01	.96105796E-02	2.355	.0185
MODE:DRY	.1159345726E-01	.12195496E-01	.951	.3418
PEDS:DRY	.5239604487E-03	.11364698E-01	.046	.9632
HURR:DRY	-.1510278993E-01	.91854186E-02	-1.644	.1001
	Diagonal values in Cholesky matrix, L.			
NsROUDL	.5377816746E-04	.47237470E-03	.114	.9094
NsROUDM	.2077073519	.29344017	.708	.4790
NsCLEAR	.2437099649	.29319505	.831	.4058
NsVEHLG	.5449624153E-02	1.0860337	.005	.9960
NsSPEED	.3454663568	5.1253808	.067	.9463
NsBUSYT	.9844770890E-02	1.8084429	.005	.9957
NsMODET	.1970751659E-01	1.0384085	.019	.9849
NsPEDSY	.1038031671E-01	1.3318045	.008	.9938
NsHURRY	.1721812119E-01	1.6211934	.011	.9915
	Below diagonal values in L matrix. V = L*Lt			
ROUD:ROU	.2078556552	.29335697	.709	.4786
CLEA:ROU	.6955969280E-01	.44741445	.155	.8765
CLEA:ROU	.1740763373	.21657279	.804	.4215
VEHL:ROU	.1740763373	.21657279	.804	.4215
VEHL:ROU	.4214803414E-02	.79437565	.005	.9958
VEHL:CLE	-.1726005175	.73869772	-.234	.8153
SPEE:ROU	.4214803414E-02	.79437565	.005	.9958
SPEE:ROU	-.6007295461E-01	.68368007	-.088	.9300
SPEE:CLE	.5438959850	2.2477579	.242	.8088
SPEE:VEH	-.1432460750	7.1904104	-.020	.9841
BUSY:ROU	-.6007295461E-01	.68368007	-.088	.9300
BUSY:ROU	-.6675843883E-02	.49958965	-.013	.9893
BUSY:CLE	-.8563206948E-01	.81083411	-.106	.9159
BUSY:VEH	.6227630656E-01	3.2206515	.019	.9846
BUSY:SPE	.8006776414E-01	2.2058006	.036	.9710
MODE:ROU	-.6675843883E-02	.49958965	-.013	.9893
MODE:ROU	-.3517121343E-02	.47564083	-.007	.9941
MODE:CLE	.5298276057E-01	.65088074	.081	.9351
MODE:VEH	.1030647236E-01	2.0068253	.005	.9959
MODE:SPE	-.9209350331E-03	1.7690212	-.001	.9996
MODE:BUS	-.3250225675E-01	1.4764772	-.022	.9824
PEDS:ROU	-.3517121343E-02	.47564083	-.007	.9941
PEDS:ROU	.6982680496E-01	.45368799	.154	.8777
PEDS:CLE	-.6508168704E-01	.71734924	-.091	.9277
PEDS:VEH	.1811351864E-01	3.0782461	.006	.9953
PEDS:SPE	.2288892326E-01	1.9911349	.011	.9908
PEDS:BUS	.2531292612E-01	1.7010016	.015	.9881
PEDS:MOD	-.5741321941E-01	.91978573	-.062	.9502
HURR:ROU	.6982680496E-01	.45368799	.154	.8777
HURR:ROU	.0000000000	.17214668	.000	1.0000
HURR:CLE	-.9092538010E-01	.71736469	-.127	.8991
HURR:VEH	-.6947634980E-02	2.1790359	-.003	.9975
HURR:SPE	-.3110807339E-01	1.3732562	-.023	.9819
HURR:BUS	-.5283984242E-02	1.8505083	-.003	.9977
HURR:MOD	.3257401025E-01	1.1059293	.029	.9765
HURR:PED	.1457825561E-01	1.4384882	.010	.9919
	Standard deviations of parameter distributions			
sdROUDL	.5377816746E-04	.47237470E-03	.114	.9094
sdROUDM	.2938474391	.29123246E-03	1008.979	.0000
sdCLEAR	.3074665333	.21438636	1.434	.1515
sdVEHLG	.2452365650	.57089390	.430	.6675
sdSPEED	.6628090288	2.7370713	.242	.8087
sdBUSYT	.1461926223	.75725671	.193	.8469
sdMODET	.6645272267E-01	.45987971	.145	.8851
sdPEDSY	.1184084210	.49595890	.239	.8113
sdHURRY	.1255275474	.65497278	.192	.8480

(Note: E+nn or E-nn means multiply by 10 to + or -nn power.)

Cross Tabulation

```
+-------------------------------------------------------+
| Cross tabulation of actual vs. predicted choices.     |
| Row indicator is actual, column is predicted.         |
| Predicted total is F(k,j,i)=Sum(i=1,...,N) P(k,j,i).  |
| Column totals may be subject to rounding error.       |
+-------------------------------------------------------+
Matrix Crosstab has  4 rows and  4 columns.
        ST              SL              KG           Total
       +--------------------------------------------------------
ST     |  493.0000       985.0000       141.0000      1619.0000
SL     |  607.0000      1628.0000       399.0000      2634.0000
KG     |  201.0000       545.0000       239.0000       985.0000
Total  | 1301.0000      3158.0000       779.0000      5238.0000
```

Model 6 Multinomial Logit Model Relating Driver Responses to Indicators of Perceived Safety and Other Driver Characteristics

Model Specification

```
Nlogit ;lhs=choiceZ
       ;Choices=ST,SL,KG
       ;start=logit
       ;Maxit = 200
       ;Model:
       U(SL) = A_SL + IPS*IPSz  + DrYrs*DrYrz + AccYe*AccYe + ILow *ILow
             + AgeY *AgeY + AgeM *AgeM  + ComYe*ComYe +YoungM*MY/
       U(ST) = DrYrs*DrYrz + AccYe*AccYe + ILow *ILow + AgeM *AgeM/
       U(KG) = A_KG + IPS*IPSz + AgeY *AgeY + ComYe*ComYe + YoungM*MY
       ;Effects: IPSz(*)/DrYrz(*);pwt
       ;Crosstab
       ;Set$
```

Estimation Results

```
+---------------------------------------------------------+
| Discrete choice (multinomial logit) model               |
| Maximum Likelihood Estimates                            |
| Dependent variable                         Choice       |
| Weighting variable                            ONE       |
| Number of observations                       5238       |
| Iterations completed                            6       |
| Log likelihood function               -4129.885         |
| Log-L for Choice   model =           -4129.8847         |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj             |
| No coefficients  -5754.5312  .28232  .28164             |
| Constants only   -5357.6126  .22916  .22842             |
| Chi-squared[ 8]            =   2455.45586               |
| Significance for chi-squared =  1.00000                 |
| Response data are given as ind. choice.                 |
| Number of obs.=  5238, skipped   0 bad obs.             |
+---------------------------------------------------------+
+---------+--------------+----------------+--------+---------+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] |
+---------+--------------+----------------+--------+---------+
```

```
 A_SL         -7.150046200    .21314483  -33.545  .0000
 IPS           9.641662160    .27001105   35.708  .0000
 DRYRS        -.2443701088  .36300617E-01   -6.732  .0000
 ACCYE        -.1592629667  .95879315E-01   -1.661  .0967
 ILOW          .2225728403  .80152287E-01    2.777  .0055
 AGEY         -.4394032650    .15125605   -2.905  .0037
 AGEM          .1750281874  .87459924E-01    2.001  .0454
 COMYE         .1579016808  .80406707E-01    1.964  .0496
 YOUNGM        .2128074087    .22189346     .959  .3375
 A_KG         -8.323819899    .24292111  -34.266  .0000
 (Note: E+nn or E-nn means multiply by 10 to + or -nn power.)
```

Cross Tabulation

```
+--------------------------------------------------------+
| Cross tabulation of actual vs. predicted choices.      |
| Row indicator is actual, column is predicted.          |
| Predicted total is F(k,j,i)=Sum(i=1,...,N) P(k,j,i).   |
| Column totals may be subject to rounding error.        |
+--------------------------------------------------------+
```

```
Matrix Crosstab has  4 rows and  4 columns.
            ST            SL            KG           Total
        +--------------------------------------------------------
ST      |   966.0000      488.0000      165.0000     1619.0000
SL      |   596.0000     1495.0000      543.0000     2634.0000
KG      |    57.0000      651.0000      277.0000      985.0000
Total   |  1619.0000     2634.0000      985.0000     5238.0000
```

Model 7 Simple Mixed Logit Model Relating Driver Responses to Indicators of Perceived Safety and Driver Characteristics

Model Specification

```
Nlogit;lhs=choiceZ
      ;Choices=ST,SL,KG
      ;start=logit
      ;Maxit = 200
      ;Model:
      U(SL) = A_SL + IPS*IPSz  + DrYrs*DrYrz + AccYe*AccYe + ILow *ILow
            + AgeY *AgeY + AgeM *AgeM  + ComYe*ComYe +YoungM*MY/
      U(ST) = DrYrs*DrYrz + AccYe*AccYe + ILow *ILow + AgeM *AgeM/
      U(KG) = A_KG + IPS*IPSz + AgeY *AgeY + ComYe*ComYe + YoungM*MY
      ;show
      ;RPL
      ;Fcn = IPS(N),DrYrs(N),AccYe(N),ILow(N),AgeY(N),AgeM(N),
      ComYe(N),YoungM(N)
      ;Halten
      ;Pts = 100
      ;Crosstab
      ;Set$
```

Estimation Results

```
+---------------------------------------------+
| Random Parameters Logit Model               |
| Maximum Likelihood Estimates                |
| Dependent variable               CHOICEZ    |
```

```
| Weighting variable                        ONE     |
| Number of observations                  15714     |
| Iterations completed                       24     |
| Log likelihood function           -4129.699     |
| Restricted log likelihood         -5754.531     |
| Chi-squared                        3249.664     |
| Degrees of freedom                       18     |
| Significance level                .0000000     |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj |
| No coefficients  -5754.5312  .28236  .28112 |
| Constants only   -5357.6126  .22919  .22786 |
| At start values  -4129.8847  .00004 -.00168 |
| Response data are given as ind. choice.        |
+------------------------------------------------+

+------------------------------------------------+
| Random Parameters Logit Model                  |
| Replications for simulated probs. = 100        |
| Halton sequences used for simulations          |
| Number of obs.=  5238, skipped   0 bad obs.    |
+------------------------------------------------+
+---------+--------------+----------------+--------+---------+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] |
+---------+--------------+----------------+--------+---------+
          Random parameters in utility functions
 IPS          9.691015468     .28796972     33.653   .0000
 DRYRS       -.2443089347   .36314625E-01   -6.728   .0000
 ACCYE       -.1594191070   .95940592E-01   -1.662   .0966
 ILOW         .2230047532   .80184642E-01    2.781   .0054
 AGEY        -.4254019130     .15719736     -2.706   .0068
 AGEM         .1754891295   .87527899E-01    2.005   .0450
 COMYE        .1590440322   .80753087E-01    1.970   .0489
 YOUNGM       .2157818061     .22818336      .946    .3443
          Nonrandom parameters in utility functions
 A_SL        -7.187617164     .22635596    -31.754   .0000
 A_KG        -8.360973282     .25436942    -32.869   .0000
          Derived standard deviations of parameter distributions
 NsIPS     .6397110538E-02    .22289659      .029    .9771
 NsDRYRS   .2004206409E-02  .46720491E-01    .043    .9658
 NsACCYE   .1805536039E-01    .24473124      .074    .9412
 NsILOW    .4336275002E-03    .20752312      .002    .9983
 NsAGEY       .4612144521     .48211889      .957    .3387
 NsAGEM    .2557025896E-01    .17137569      .149    .8814
 NsCOMYE   .1282455789E-02    .22410087      .006    .9954
 NsYOUNGM     .1095931917     .84292631      .130    .8966
 (Note: E+nn or E-nn means multiply by 10 to + or -nn power.)
```

Cross tabulation

```
+-----------------------------------------------------+
| Cross tabulation of actual vs. predicted choices.   |
| Row indicator is actual, column is predicted.       |
| Predicted total is F(k,j,i)=Sum(i=1,...,N) P(k,j,i). |
| Column totals may be subject to rounding error.     |
+-----------------------------------------------------+
```

Matrix Crosstab has 4 rows and 4 columns.

	ST	SL	KG	Total
ST	966.0000	488.0000	165.0000	1619.0000
SL	596.0000	1495.0000	543.0000	2634.0000
KG	56.0000	651.0000	277.0000	985.0000
Total	1619.0000	2634.0000	985.0000	5238.0000

Model 8 Final Model that Links the Behavioural Response to Attributes of Road and Traffic Situations and Characteristics of Drivers: MNL Specification

Model Specification

```
Nlogit ;lhs=choiceZ
       ;Choices=ST,SL,KG
       ;start=logit
       ;Maxit = 200
       ;Model:
       U(SL) = A_SL +
               RoudL*RoudL + RoudM*RoudM + Lane1*Lane1 + Clear*Clear
             + VehLG*VehLG + VehMD*VehMD + Speed*Speedz + BusyT*BusyT
             + ModeT*ModeT + PedsY*PedsY + MySpd*MySpdz + Hurry*Hurry
             + DrYrs*DrYrz + AccYe*AccYe + ILow *ILow
             + AgeY *AgeY + AgeM *AgeM  + ComYe*ComYe +YoungM*MY/
       U(ST) =
               RoudL*RoudL + VehLG*VehLG + Speed*Speedz + BusyT*BusyT
             + PedsY*PedsY + MySpd*MySpdz
             + DrYrs*DrYrz + AccYe*AccYe + ILow *ILow + AgeM *AgeM/
       U(KG) = A_KG +
               RoudM*RoudM + Lane1*Lane1 + Clear*Clear  + VehMD*VehMD
             + ModeT*ModeT + Hurry*Hurry
             + AgeY *AgeY + ComYe*ComYe + YoungM*MY
       ;show
       ;Effects: Speedz(*)/MySpdz(*)/DrYrz(*)?;pwt
       ;Crosstab
       ;Set
       ;IVB=IVIPS$
```

Estimation Results

```
+---------------------------------------------+
| Discrete choice (multinomial logit) model   |
| Maximum Likelihood Estimates                |
| Dependent variable               Choice     |
| Weighting variable                  ONE     |
| Number of observations             5238     |
| Iterations completed                  7     |
| Log likelihood function       -3776.984     |
| Log-L for Choice   model =   -3776.9843     |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj |
| No coefficients  -5754.5312  .34365  .34233 |
| Constants only   -5357.6126  .29502  .29361 |
| Chi-squared[19]          =   3161.25658     |
| Significance for chi-squared =  1.00000     |
| Response data are given as ind. choice.     |
| Number of obs.=  5238, skipped   0 bad obs. |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
A_SL	.9310326861	.70749881E-01	13.159	.0000
ROUDL	.3648241447	.53378640E-01	6.835	.0000

```
ROUDM      -.5264300431   .49405531E-01  -10.655   .0000
LANE1       .1883108248   .40067445E-01    4.700   .0000
CLEAR      1.329185523    .45358925E-01   29.304   .0000
VEHLG      1.211601924    .59850504E-01   20.244   .0000
VEHMD      -.1502967525   .53624599E-01   -2.803   .0051
SPEED      5.368339864    .30666664       17.505   .0000
BUSYT       .6426146098   .58551496E-01   10.975   .0000
MODET      -.2495676357   .48086473E-01   -5.190   .0000
PEDSY       .7933407006   .59472485E-01   13.340   .0000
MYSPD      1.124164637    .27094468        4.149   .0000
HURRY      1.525963527    .58822675E-01   25.942   .0000
DRYRS      -.3043128012   .40507480E-01   -7.513   .0000
ACCYE      -.1971632452   .10751776       -1.834   .0667
ILOW        .2701989705   .88756683E-01    3.044   .0023
AGEY       -.3966935186   .14481117       -2.739   .0062
AGEM        .2164574486   .96474859E-01    2.244   .0249
COMYE       .1454619273   .78252197E-01    1.859   .0630
YOUNGM      .1955406571   .21295826         .918   .3585
A_KG       1.386985056    .20296181        6.834   .0000
(Note: E+nn or E-nn means multiply by 10 to + or -nn power.)
```

Cross Tabulation

```
+-----------------------------------------------------------+
| Cross tabulation of actual vs. predicted choices.         |
| Row indicator is actual, column is predicted.             |
| Predicted total is F(k,j,i)=Sum(i=1,...,N) P(k,j,i).      |
| Column totals may be subject to rounding error.           |
+-----------------------------------------------------------+
```

Matrix Crosstab has 4 rows and 4 columns.

	ST	SL	KG	Total
ST	963.0000	580.0000	75.0000	1619.0000
SL	571.0000	1563.0000	500.0000	2634.0000
KG	85.0000	490.0000	410.0000	985.0000
Total	1619.0000	2634.0000	985.0000	5238.0000

Model 9 Final Model that Links the Behavioural Response to Attributes of Road and Traffic Situations and Characteristics of Drivers: ML Specification

Model Specification

```
--> Nlogit;lhs=choiceZ
     ;Choices=ST,SL,KG
     ;start=logit
     ;Maxit = 200
     ;Model:
     U(SL) = A_SL +
          RoudL*RoudL + RoudM*RoudM + Lane1*Lane1 + Clear*Clear
        + VehLG*VehLG + VehMD*VehMD + Speed*Speedz + BusyT*BusyT
        + ModeT*ModeT + PedsY*PedsY + MySpd*MySpdz + Hurry*Hurry
        + DrYrs*DrYrz + AccYe*AccYe + ILow *ILow
        + AgeY *AgeY + AgeM *AgeM  + ComYe*ComYe +YoungM*MY/
     U(ST) =
          RoudL*RoudL + VehLG*VehLG + Speed*Speedz + BusyT*BusyT
        + PedsY*PedsY + MySpd*MySpdz
```

```
        + DrYrs*DrYrz + AccYe*AccYe + ILow *ILow + AgeM *AgeM/
  U(KG) = A_KG +
          RoudM*RoudM + Lane1*Lane1 + Clear*Clear  + VehMD*VehMD
        + ModeT*ModeT + Hurry*Hurry
        + AgeY *AgeY + ComYe*ComYe + YoungM*MY
  ;show
  ;RPL
  ;Fcn =RoudL(N), RoudM(N), ModeT(N), Hurry(N)
  ;Halten
  ;Pts = 100
  ;Cor
  ;pds=27
  ;Effects: Speedz(*)/MySpdz(*)/DrYrz(*)?;pwt
  ;Crosstab
  ;Set$
```

Estimation Results

```
+---------------------------------------------+
| Random Parameters Logit Model               |
| Maximum Likelihood Estimates                |
| Dependent variable               CHOICEZ    |
| Weighting variable                   ONE    |
| Number of observations             15714    |
| Iterations completed                  39    |
| Log likelihood function        -3772.289    |
| Restricted log likelihood      -5754.531    |
| Chi-squared                     3964.484    |
| Degrees of freedom                    29    |
| Significance level              .0000000    |
| R2=1-LogL/LogL*  Log-L fncn  R-sqrd  RsqAdj |
| No coefficients  -5754.5312  .34447  .34265 |
| Constants only   -5357.6126  .29590  .29395 |
| At start values  -3776.9843  .00124 -.00153 |
| Response data are given as ind. choice.     |
+---------------------------------------------+

+---------------------------------------------+
| Random Parameters Logit Model               |
| Replications for simulated probs. = 100     |
| Halton sequences used for simulations       |
| ------------------------------------------- |
| RPL model with panel has  194 groups.       |
| Fixed number of obsrvs./group=        27    |
| Random effects model was specified          |
| ------------------------------------------- |
| RPL model has correlated parameters         |
| Hessian was not PD. Using BHHH estimator.   |
| Number of obs.=  5238, skipped   0 bad obs. |
+---------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]
Random parameters in utility functions				
ROUDL	.3728416463	.14190409	2.627	.0086
ROUDM	-.5450199334	.13817315	-3.944	.0001
MODET	-.2487030083	.12504347	-1.989	.0467
HURRY	1.542348326	.12447411	12.391	.0000
Nonrandom parameters in utility functions				
A_SL	.9551653626	.70897993E-01	13.472	.0000
LANE1	.1915137966	.75564923E-01	2.534	.0113

```
 CLEAR        1.347598312   .65416921E-01   20.600   .0000
 VEHLG        1.211498025       .12474793    9.712   .0000
 VEHMD        -.1580612842      .13606191   -1.162   .2454
 SPEED        5.398929835       .64850493    8.325   .0000
 BUSYT        .6425617931       .12769210    5.032   .0000
 PEDSY        .7955859838   .98350317E-01    8.089   .0000
 MYSPD        1.143265747       .58673898    1.949   .0514
 DRYRS        -.3033851576  .50213750E-01   -6.042   .0000
 ACCYE        -.1962570687      .16312774   -1.203   .2289
 ILOW         .2688455619       .10854282    2.477   .0133
 AGEY         -.3747148549      .16275225   -2.302   .0213
 AGEM         .2131197997       .11951221    1.783   .0745
 COMYE        .1411689237   .70556009E-01    2.001   .0454
 YOUNGM       .1867260567       .28556221     .654   .5132
 A_KG         1.425516640       .32092576    4.442   .0000
          Diagonal values in Cholesky matrix, L.
 NsROUDL      .1042494854       .44147750     .236   .8133
 NsROUDM      .2049934916       1.9770513     .104   .9174
 NsMODET    .4227443314E-03     4.1719630     .000   .9999
 NsHURRY    .1993859939E-02     2.1218859     .001   .9993
          Below diagonal values in L matrix. V = L*Lt
 ROUD:ROU    -.2928553059       1.4519820    -.202   .8402
 MODE:ROU  .6034643969E-01      .18171496     .332   .7398
 MODE:ROU  .6034643969E-01      .18171496     .332   .7398
 HURR:ROU -.8307485069E-01      .15084054    -.551   .5818
 HURR:ROU -.8307485069E-01      .15084054    -.551   .5818
 HURR:MOD -.1142270290E-02      3.8917765     .000   .9998
          Standard deviations of parameter distributions
 sdROUDL      .1042494854       .44147750     .236   .8133
 sdROUDM      .3574724630       .20243958    1.766   .0774
 sdMODET   .8534380047E-01      .26020070     .328   .7429
 sdHURRY      .1175080503       .23550416     .499   .6178
 (Note: E+nn or E-nn means multiply by 10 to + or -nn power.)
```

Correlation Matrix for Random Parameters

Matrix COR.MAT. has 4 rows and 4 columns.

	ROUDL	ROUDM	MODET	HURRY
ROUDL	1.0000	-.8192	.7071	-.7070
ROUDM	-.8192	1.0000	-.1738	.1738
MODET	.7071	-.1738	1.0000	-.9998
HURRY	-.7070	.1738	-.9998	1.0000

Covariance Matrix for Random Parameters

Matrix COV.MAT. has 4 rows and 4 columns.

	ROUDL	ROUDM	MODET	HURRY
ROUDL	.0109	-.0305	.0063	-.0087
ROUDM	-.0305	.1278	-.0053	.0073
MODET	.0063	-.0053	.0073	-.0100
HURRY	-.0087	.0073	-.0100	.0138

Cholesky Matrix for Random Parameters

Matrix Cholesky has 4 rows and 4 columns.

	ROUDL	ROUDM	MODET	HURRY
ROUDL	.1042	.0000000D+00	.0000000D+00	.0000000D+00
ROUDM	-.2929	.2050	.0000000D+00	.0000000D+00
MODET	.0603	.0603	.0004	.0000000D+00
HURRY	-.0831	-.0831	-.0011	.0020

Cross Tabulation

```
+----------------------------------------------------------+
| Cross tabulation of actual vs. predicted choices.        |
| Row indicator is actual, column is predicted.            |
| Predicted total is F(k,j,i)=Sum(i=1,...,N) P(k,j,i).     |
| Column totals may be subject to rounding error.          |
+----------------------------------------------------------+
```

Matrix Crosstab has 4 rows and 4 columns.

	ST	SL	KG	Total
ST	962.0000	582.0000	75.0000	1619.0000
SL	570.0000	1564.0000	500.0000	2634.0000
KG	86.0000	490.0000	409.0000	985.0000
Total	1619.0000	2635.0000	984.0000	5238.0000

Simulations

The Base Scenario

Attribute	Alternatives affected			Change type	Value
ROUDL	ST	SL	KG	Fix at new value	.000
ROUDM	ST	SL	KG	Fix at new value	1.000
LANE1	ST	SL	KG	Fix at new value	1.000
CLEAR	ST	SL	KG	Fix at new value	1.000
VEHLG	ST	SL	KG	Fix at new value	.000
VEHMD	ST	SL	KG	Fix at new value	1.000
SPEEDZ	ST	SL	KG	Fix at new value	.300
BUSYT	ST	SL	KG	Fix at new value	.000
MODET	ST	SL	KG	Fix at new value	1.000
PEDSY	ST	SL	KG	Fix at new value	-1.000
MYSPDZ	ST	SL	KG	Fix at new value	.300
HURRY	ST	SL	KG	Fix at new value	-1.000
DRYRZ	ST	SL	KG	Fix at new value	1.000
ACCYE	ST	SL	KG	Fix at new value	.000
ILOW	ST	SL	KG	Fix at new value	1.000
AGEY	ST	SL	KG	Fix at new value	.000
AGEM	ST	SL	KG	Fix at new value	1.000
COMYE	ST	SL	KG	Fix at new value	1.000
MY	ST	SL	KG	Fix at new value	.000

Simulated Probabilities (shares) for this scenario:

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	30.909	1619	38.025	1992	7.117%	373
SL	50.286	2634	43.815	2295	-6.471%	-339
KG	18.805	985	18.159	951	-.646%	-34
Total	100.000	5238	100.000	5238	.000%	0

Simulation 1: The size of roundabout

- Scenario 1 (Base): Medium-sized roundabout
- Scenario 2: Small-sized roundabout
- Scenario 3: Large-sized roundabout

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 2.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	38.025	1992	15.940	835	-22.085%	-1157
SL	43.815	2295	52.639	2757	8.823%	462
KG	18.159	951	31.421	1646	13.262%	695
Total	100.000	5238	100.000	5238	.000%	0

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.

Scenario for this comparison is scenario 3.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	38.025	1992	28.474	1491	-9.551%	-501
SL	43.815	2295	55.543	2909	11.728%	614
KG	18.159	951	15.983	837	-2.176%	-114
Total	100.000	5238	100.000	5237	.000%	-1

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 2.
Scenario for this comparison is scenario 3.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	15.940	835	28.474	1491	12.534%	656
SL	52.639	2757	55.543	2909	2.904%	152
KG	31.421	1646	15.983	837	-15.438%	-809
Total	100.000	5238	100.000	5237	.000%	-1

Simulation 2: Number of circulating lanes

- Scenario 1 (Base): Single lane
- Scenario 2: Two or more lanes

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 2.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	38.025	1992	47.207	2473	9.181%	481
SL	43.815	2295	37.324	1955	-6.491%	-340
KG	18.159	951	15.469	810	-2.690%	-141
Total	100.000	5238	100.000	5238	.000%	0

Simulation 3: Visibility to other traffic

- Scenario 1 (Base): Clear visibility
- Scenario 2: Obstructed visibility

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 2.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	38.025	1992	89.751	4701	51.726%	2709
SL	43.815	2295	7.246	380	-36.570%	-1915
KG	18.159	951	3.003	157	-15.156%	-794

Total	100.000	5238	100.000	5238	.000%	0

Simulation 4: Size of the potentially conflicting vehicle

- Scenario 1 (Base): Medium
- Scenario 2: Small
- Scenario 3: Large

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 2.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	38.025	1992	21.174	1109	-16.852%	-883
SL	43.815	2295	32.953	1726	-10.862%	-569
KG	18.159	951	45.873	2403	27.714%	1452
Total	100.000	5238	100.000	5238	.000%	0

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 3.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	38.025	1992	39.930	2092	1.905%	100
SL	43.815	2295	53.472	2801	9.657%	506
KG	18.159	951	6.598	346	-11.561%	-605
Total	100.000	5238	100.000	5239	.000%	1

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 2.
Scenario for this comparison is scenario 3.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	21.174	1109	39.930	2092	18.756%	983
SL	32.953	1726	53.472	2801	20.519%	1075
KG	45.873	2403	6.598	346	-39.275%	-2057
Total	100.000	5238	100.000	5239	.000%	1

Simulation 5: Size of the potentially conflicting vehicle

- Scenario 1 (Base): 30 km/h
- Scenario 2: 15 km/h
- Scenario 3: 45 km/h
- Scenario 4: 6- km/h

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 2.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	38.025	1992	31.049	1626	-6.976%	-366
SL	43.815	2295	35.777	1874	-8.038%	-421
KG	18.159	951	33.174	1738	15.014%	787
Total	100.000	5238	100.000	5238	.000%	0

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 3.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	38.025	1992	42.270	2214	4.245%	222
SL	43.815	2295	48.707	2551	4.891%	256
KG	18.159	951	9.023	473	-9.136%	-478
Total	100.000	5238	100.000	5238	.000%	0

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 4.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	38.025	1992	44.490	2330	6.465%	338
SL	43.815	2295	51.265	2685	7.449%	390
KG	18.159	951	4.245	222	-13.914%	-729
Total	100.000	5238	100.000	5237	.000%	-1

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 2.
Scenario for this comparison is scenario 3.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	31.049	1626	42.270	2214	11.221%	588
SL	35.777	1874	48.707	2551	12.930%	677
KG	33.174	1738	9.023	473	-24.151%	-1265
Total	100.000	5238	100.000	5238	.000%	0

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 2.
Scenario for this comparison is scenario 4.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	31.049	1626	44.490	2330	13.441%	704
SL	35.777	1874	51.265	2685	15.488%	811
KG	33.174	1738	4.245	222	-28.929%	-1516
Total	100.000	5238	100.000	5237	.000%	-1

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 3.
Scenario for this comparison is scenario 4.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	42.270	2214	44.490	2330	2.220%	116
SL	48.707	2551	51.265	2685	2.558%	134
KG	9.023	473	4.245	222	-4.778%	-251
Total	100.000	5238	100.000	5237	.000%	-1

Simulation 6: General traffic level at roundabout

- Scenario 1 (Base): Moderate
- Scenario 2: Light
- Scenario 3: Busy

```
Pairwise Comparisons of Specified Scenarios
Base     for this comparison is scenario 1.
Scenario for this comparison is scenario 2.
```

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	38.025	1992	22.759	1192	-15.267%	-800
SL	43.815	2295	43.199	2263	-.617%	-32
KG	18.159	951	34.043	1783	15.884%	832
Total	100.000	5238	100.000	5238	.000%	0

```
Pairwise Comparisons of Specified Scenarios
Base     for this comparison is scenario 1.
Scenario for this comparison is scenario 3.
```

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	38.025	1992	35.698	1870	-2.327%	-122
SL	43.815	2295	52.794	2765	8.979%	470
KG	18.159	951	11.507	603	-6.652%	-348
Total	100.000	5238	100.000	5238	.000%	0

```
Pairwise Comparisons of Specified Scenarios
Base     for this comparison is scenario 2.
Scenario for this comparison is scenario 3.
```

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	22.759	1192	35.698	1870	12.940%	678
SL	43.199	2263	52.794	2765	9.596%	502
KG	34.043	1783	11.507	603	-22.536%	-1180
Total	100.000	5238	100.000	5238	.000%	0

Simulation 7: Presence of a potentially conflicting pedestrian

- Scenario 1 (Base): Not presence
- Scenario 2: Presence

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 2.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	38.025	1992	44.445	2328	6.420%	336
SL	43.815	2295	51.212	2683	7.397%	388
KG	18.159	951	4.343	227	-13.817%	-724
Total	100.000	5238	100.000	5238	.000%	0

Simulation 8: Speed of respondent's car

- Scenario 1 (Base): 30 km/h
- Scenario 2: 15 km/h
- Scenario 3: 45 km/h
- Scenario 4: 60 km/h

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 2.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	38.025	1992	36.798	1927	-1.227%	-65
SL	43.815	2295	42.401	2221	-1.414%	-74
KG	18.159	951	20.801	1090	2.642%	139
Total	100.000	5238	100.000	5238	.000%	0

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 3.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	38.025	1992	39.128	2050	1.103%	58
SL	43.815	2295	45.086	2362	1.270%	67
KG	18.159	951	15.786	827	-2.373%	-124
Total	100.000	5238	100.000	5239	.000%	1

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 4.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	38.025	1992	40.110	2101	2.085%	109
SL	43.815	2295	46.218	2421	2.403%	126
KG	18.159	951	13.672	716	-4.488%	-235
Total	100.000	5238	100.000	5238	.000%	0

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 2.
Scenario for this comparison is scenario 3.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	36.798	1927	39.128	2050	2.330%	123
SL	42.401	2221	45.086	2362	2.685%	141
KG	20.801	1090	15.786	827	-5.015%	-263
Total	100.000	5238	100.000	5239	.000%	1

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 2.
Scenario for this comparison is scenario 4.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	36.798	1927	40.110	2101	3.312%	174
SL	42.401	2221	46.218	2421	3.817%	200
KG	20.801	1090	13.672	716	-7.129%	-374
Total	100.000	5238	100.000	5238	.000%	0

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 3.
Scenario for this comparison is scenario 4.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	39.128	2050	40.110	2101	.983%	51
SL	45.086	2362	46.218	2421	1.132%	59
KG	15.786	827	13.672	716	-2.115%	-111
Total	100.000	5239	100.000	5238	.000%	-1

Simulation 9: Driver's time availability

- Scenario 1 (Base): Not in a hurry
- Scenario 2: In a hurry

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 2.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	38.025	1992	2.818	148	-35.207%	-1844
SL	43.815	2295	68.706	3599	24.891%	1304
KG	18.159	951	28.475	1492	10.316%	541
Total	100.000	5238	100.000	5239	.000%	1

Simulation 10: Year that respondent has been driving

- Scenario 1 (Base): 10 years
- Scenario 2: 5 years
- Scenario 3: 15 years

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 2.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	38.025	1992	2.936	154	-35.089%	-1838
SL	43.815	2295	71.583	3750	27.768%	1455
KG	18.159	951	25.480	1335	7.321%	384
Total	100.000	5238	100.000	5239	.000%	1

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 3.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	38.025	1992	2.692	141	-35.333%	-1851
SL	43.815	2295	65.635	3438	21.819%	1143
KG	18.159	951	31.673	1659	13.514%	708
Total	100.000	5238	100.000	5238	.000%	0

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 2.
Scenario for this comparison is scenario 3.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	2.936	154	2.692	141	-.244%	-13
SL	71.583	3750	65.635	3438	-5.949%	-312
KG	25.480	1335	31.673	1659	6.193%	324
Total	100.000	5239	100.000	5238	.000%	-1

Simulation 11: Respondent involved in an accident in the last two years

- Scenario 1 (Base): Not involved
- Scenario 2: Involved

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 2.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	38.025	1992	36.578	1916	-1.448%	-76
SL	43.815	2295	42.147	2208	-1.668%	-87
KG	18.159	951	21.275	1114	3.116%	163
Total	100.000	5238	100.000	5238	.000%	0

Simulation 12: Respondent' annual income

- Scenario 1 (Base): Below $30,000
- Scenario 2: More than $30,001

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 2.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	38.025	1992	35.997	1886	-2.028%	-106
SL	43.815	2295	41.479	2173	-2.337%	-122
KG	18.159	951	22.524	1180	4.365%	229
Total	100.000	5238	100.000	5239	.000%	1

Simulation 13: Respondent' age

- Scenario 1 (Base): Between 26 and 50 years
- Scenario 2: 25 years or younger
- Scenario 3: 51 years or older

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 2.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	38.025	1992	46.004	2410	7.978%	418
SL	43.815	2295	35.650	1867	-8.165%	-428
KG	18.159	951	18.346	961	.187%	10
Total	100.000	5238	100.000	5238	.000%	0

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 3.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber
ST	38.025	1992	36.427	1908	-1.599%	-84
SL	43.815	2295	41.973	2199	-1.842%	-96
KG	18.159	951	21.600	1131	3.441%	180
Total	100.000	5238	100.000	5238	.000%	0

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 2.
Scenario for this comparison is scenario 3.

Choice	Base %Share	Base Number	Scenario %Share	Scenario Number	Scenario - Base ChgShare	Scenario - Base ChgNumber

ST	46.004	2410	36.427	1908	-9.577%	-502
SL	35.650	1867	41.973	2199	6.323%	332
KG	18.346	961	21.600	1131	3.254%	170
Total	100.000	5238	100.000	5238	.000%	0

Simulation 14: Commuter status

- Scenario 1 (Base): Commuter driver
- Scenario 2: Not commuter driver

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 2.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	38.025	1992	41.508	2174	3.482%	182
SL	43.815	2295	41.353	2166	-2.462%	-129
KG	18.159	951	17.139	898	-1.020%	-53
Total	100.000	5238	100.000	5238	.000%	0

Simulation 15: Male young driver

- Scenario 1 (Base): Not male young driver
- Scenario 2: Male young driver

Pairwise Comparisons of Specified Scenarios
Base for this comparison is scenario 1.
Scenario for this comparison is scenario 2.

Choice	Base		Scenario		Scenario - Base	
	%Share	Number	%Share	Number	ChgShare	ChgNumber
ST	38.025	1992	33.537	1757	-4.489%	-235
SL	43.815	2295	46.989	2461	3.173%	166
KG	18.159	951	19.475	1020	1.315%	69
Total	100.000	5238	100.000	5238	.000%	0