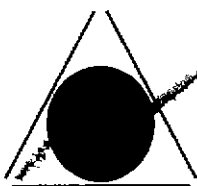


A GIS-Based Analysis Of Demographic, Spatial & Temporal Variations In Crash Rates

Final Report
submitted to
AUSTRALIAN TRANSPORT SAFETY BUREAU
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Transport and Regional Services

Booi H. Kam

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The Transport Research Centre

RMIT
UNIVERSITY

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EXECUTIVE SUMMARY

This study proposes a Geographic Information System (GIS)-based approach to analyse demographic, spatial and temporal variations in crash rates. The concept on which the approach is based stems from the premise that accident occurrence has to be understood as the interaction of three sets of environmental factors: the internal car environment, the external physical environment, and the dynamic traffic environment. As each trip is unique with respect to the three sets of factors, the adoption of this concept suggests that crash risk has to be examined from the perspective of the individual trips. It thus differs from the conventional approach of using an aggregated quotient obtained by dividing the total crash involvement of a particular population group by the combined travel distance of that group. A measure predicated on “number of accidents per trip-km”, instead of the conventional “number of accidents per km”, is put forward.

The implementation of the concept invokes the use of GIS to link data from two different databases – accident reports and travel and activity survey – via their spatial attributes. The GIS algorithm on which the program is based centres on the demarcation of a travel corridor predicated on the travel route of a given trip. Crash records falling within the defined travel corridor and matching the characteristics of the trip and the person making it will be regarded as potential accident hazards to which the person making the trip will be exposed. To demonstrate the use of the proposed disaggregated approach, the crash rates of different population groups residing within the Melbourne Statistical Division was computed separately for weekday and weekend, and for day and night hours according to their age-sex characteristics, the day of travel, and the time of travel. The trip information used for the purpose comes from the Victorian Activity and Travel Survey (VATS) conducted by the Transport Research Centre at RMIT, while the accident records were sourced from CrashStat, an accident database produced by VicRoads.

The results obtained were compared with those generated using the conventional approach. A plot of crash rate against age group shows that the proposed measure produces a polynomial function of a cubic order. It contrasts sharply with that derived using the conventional aggregated approach, which is a U-shape curve with population at either end of the age spectrum (ie, those below 21 and those above 70) having a higher crash rate than those in the middle. The variation of crash rate with respect to age as revealed by the polynomial function suggests that persons in their 20s are among the most vulnerable group in terms of crash risk. The new licensees or

those under 21 and senior citizens above the age of 70 are not the most accident-prone, though their crash rates are also among the highest. This observation is explained as the interactions of a number of behavioural traits which covary with age: driving experience, skills, confidence, self-discipline in terms of the relative ease of being distracted, and the atrophying of physical abilities that affect driving. A second attempt to recompute the crash rates of these population groups on a per trips basis at two different levels of exposure (trips longer than 10 km and those less than 10 km) confirms the omnipresence of the cubic function.

To demonstrate the versatility of the measure, separate exposure indicators were also estimated for persons residing in different parts of Metropolitan Melbourne. The results show that persons whose routine travel and activity spaces fall largely within high accident areas are more at-risk than those having less contact with such black spots. These findings highlight two things: the importance of having an exposure measure which can be aggregated at different levels to produce results of strategic value; and the limitation of an overall risk exposure indicator to summarily represent the crash risk for people residing at different parts of a metropolitan.

Because of the disparate results obtained by using the two approaches, this study warns of the plausible consequence of formulating policy measures designed to impose driving restrictions on some apparently at-risk groups, while ignoring others who seem to be less culpable of a crash involvement. It also points to the noteworthy features of the proposed approach, including:

- a conceptual recognition that each trip is unique in terms of its exposure to crash risk;
- a crash risk measure which is independent of the linearity assumption implicit in the conventional aggregated approach that crash risk increases proportionately with distance travelled; and
- a dataset in which the crash rate for each trip can be estimated and aggregated measures can be computed.

Recent advances in GIS technology and travel survey techniques have greatly facilitated the linking of apparently incompatible databases through their spatial attributes. The proposed exposure concept of using individual trips as the unit of road crash analysis is seen as providing a useful starting point from which other more refined GIS-based methods may evolve.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

This report presents the findings of a research study on the development and use of a Geographic Information System (GIS)-based approach to analyse demographic, spatial and temporal variations in crash rates. The work represents the culmination of a year-long study at the Transport Research Centre at RMIT on attempts to link data from conventional accident reports to data obtained through purpose-designed travel and activity surveys using a GIS platform. The study is motivated by the potential offered by recent advances in GIS technology to cross-reference data from different sources through their spatial attributes. It is felt that one of the problems hampering the development of an "idealised" index of risk exposure, as perceived by Carroll (1971) some 28 years ago, is related to the lack of suitable computational tools to link data from standard accident reports to information found in conventional travel surveys.

In epidemiology, subjects having contacted a disease can usually be studied by tracing their historical level of exposure to the hazards of communicating the disease. Therefore, when studying patients with lung disease, the average number of packs of cigarettes smoked per day over a defined period – such as "pack-years" – is usually sought to derive an index of risk exposure to the disease (see for example Nyberg et al. 1998; Lee et al. 1998; and Howard et al. 1998). In the case of traffic accident crashes, such a deductive process based on information recall to arrive at a similar risk exposure measure would be tantamount to asking persons involved in accidents their driving habits and travel patterns over a defined period in the past. Without going into the issues of data reliability and validity, the retrospective recall of previous smoking habits is evidently less demanding (on the respondents) than the recollection of trips taken over a defined period. In the absence of data on the travel patterns of those directly involved in traffic accidents, the surrogate has been to aggregate accident records by demographics (eg, age and sex) and associate them to aggregated travel data (eg, total travel distance or time spent travelling) pertaining to individuals of similar characteristics to arrive at a crash rate for that population group (Chipman et al. 1992; 1993; Massie, Campbell and Williams 1995; Doherty, Andrey and MacGregor 1998). While intuitively meaningful, the conceptual underpinnings of

using crash rate derived in this manner to express accident risk have been questioned (Mahalel 1986; Janke 1991).

This study contends that many of the criticisms levied at this yardstick would not have prevailed if data relating accidents directly to travel behaviour can be easily collected. Because of data constraints, the current concept of accident risk exposure has been developed based on the manner in which the two disjointed sets of data (ie, accident records and travel patterns) may possibly be linked. This has been achieved at an aggregated level at present. This approach to conceptual development of ideas runs counter to the traditional view of conducting empirical research in which data are collected to test hypotheses generated based on a theoretical construct (see Figure 1). A second problem concerning the current method of computing crash rate relates to the state of available computing technology, which bears a reciprocal relationship to the nature of the data to be collected, ie, the state of computing technology could influence the kind of the data to be collected and coded; likewise the type of data needed could prompt the development of new technology to meet its requirements.

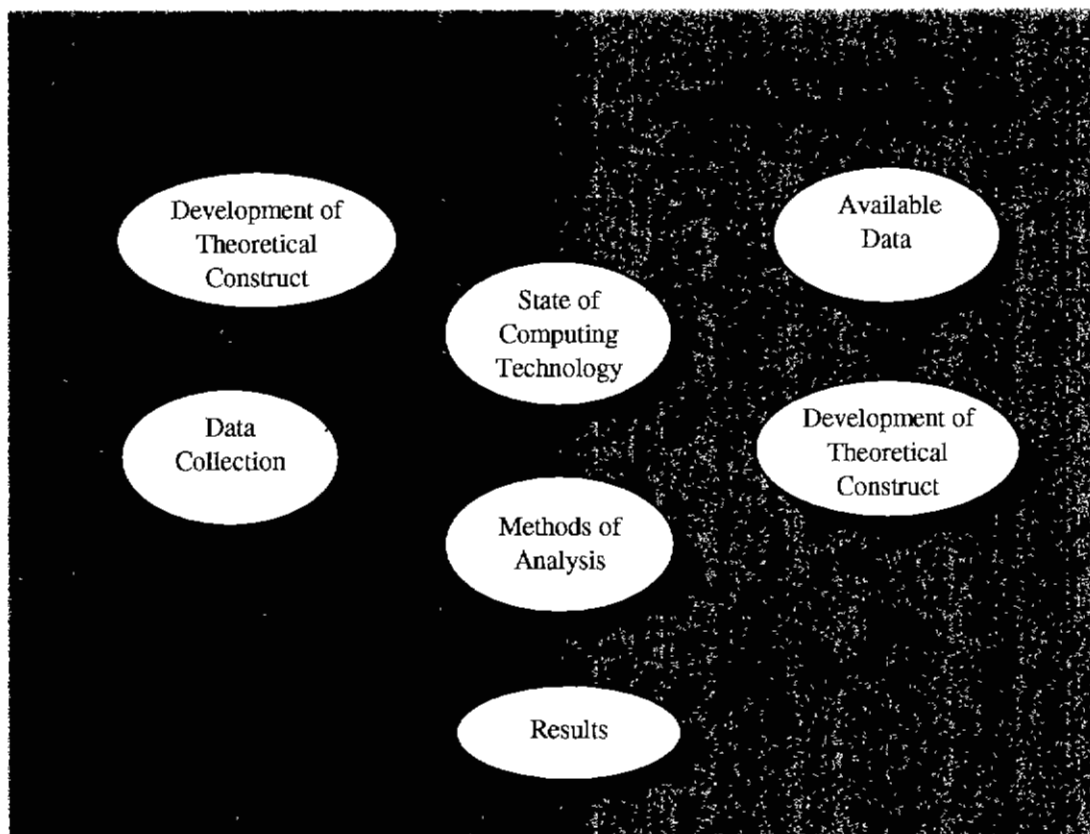


Figure 1

Current Approach to Crash Rate Estimation and Conventional Approach to Empirical Research Compared

A common link between accident records and travel data is the spatial attributes of this information: the locations of the accident sites and the addresses of the trip origins and destinations. One way to connect the two data sets, as such, will be to relate these spatial attributes to one another. To do this, information on these spatial attributes must be present in the requisite data sets and available computing technology must have the capability to do the job. Development in GIS technology over the past decade and the elicitation of origin and destination place by travel surveys in recent years have made possible the development of such a linkage. This research is an attempt to develop that linkage.

1.2 REPORT ORGANISATION

Since the current approach to enumerating crash rate, and hence defining crash risk, is hard-wired to the format of available accident data and travel information, a reconceptualisation of the exposure concept is warranted. This report will begin with a review of the current concept in the next chapter (Chapter 2), focusing on its limitations. A reinterpretation of the exposure concept will then be attempted, centering on overcoming some of the drawbacks inherent in the current notion. A redefinition of crash rate from "accidents per million km" to "accidents per million trip-km" is proposed. This new definition works on the concept of looking at accident risk exposure on a per trip basis. The underlying premise substantiating its development is that once the characteristics of the trip and the environmental conditions surrounding it could be captured, all the factors that can contribute to creating opportunities for accidents can be accounted for. Such traits will include factors pertaining to both the internal car environment as well as the external road environment.

With the re-definition of accident risk exposure in place, Chapter 3 will present the GIS methodology to operationalise the proposed concept. The presentation will commence with a brief overview of the GIS concept of manipulating and relating data from different sources. This will then be followed by an introduction to geocoding origin and destination places in travel surveys in which such information is available. The procedure for matching travel data to accident records via their spatial attributes is then described. As the key to the new exposure concept is the individual trips, the notion of defining a travel corridor to represent the exposure environment is introduced. This is a central piece of the discussion in Chapter 3.

The application of the concept and its implementation via the GIS platform will be illustrated by computing the crash rates of different population groups in Metropolitan Melbourne. Chapter 4 describes the two data sources used to generate these crash rates. The first data set is the Victorian Activity and Travel Survey (VATS) databases, which contain information on travel and out-of-home activities of individuals residing within the Melbourne Metropolitan District (MSD). A year-round, household-based, activity and travel survey, VATS has been conducted by the Transport Research Centre at RMIT since December 1993. To-date, four years of VATS data – VATS94, VATS95, VATS96 and VATS97 – have been released. The accident database from which crash statistics pertaining to Metropolitan Melbourne are distilled is CrashStat. CrashStat is an accident record database produced by VicRoads (1998). The 1998 edition contains road crash statistics in the State of Victoria from 1991 to 1998.

While the GIS technique enables the accident records from the accident database to be superimposed spatially onto the travel corridors, not all accident records found within a defined travel corridor may be "relevant" to the driver making the trip. To identify the sub-set of "relevant" accidents, to which the driver may be exposed, the concept of risk exposure is again invoked. The selection of "relevant" accident records matching the characteristics of the drivers as well as the trip requires special consideration. As such, apart from providing an overview of the two data sources, Chapter 4 also discusses the assumptions, and their conceptual underpinnings, used in matching "appropriate" accident data to individual travel corridors.

Chapter 5 presents the results of the crash rate analysis based on the proposed exposure concept using the GIS technique. By themselves, these results merely provide the crash rates, and hence accident exposure risk, of different population cohorts and will not demonstrate the value of the methodology. To distinguish what the new definition, and the enabling GIS technology, can offer, these results are compared with those obtained via the conventional aggregated approach. Chapter 5 will begin by displaying the outcomes of the crash rate analysis using the conventional approach. This will then be contrasted with those derived using the proposed methodology. The results derived using the travel corridor concept are then interpreted from a behavioural perspective. To ascertain the consistency of the results derived using the new approach, crash rates of persons in different age-sex categories are further computed: first on a per trip basis and second by grouping persons according to their place of residence in addition to age-sex characteristics.

The last chapter (Chapter 6) will reassess the values of the proposed exposure measure and deliberates on its potential for wider application. Based on the results provided by the two methods, ie, the conventional aggregated approach versus the proposed disaggregated travel corridor approach, the merits of the proposed approach are highlighted. Areas of improvement are suggested and directions for further research recommended.

CHAPTER 2

CRASH RISK EXPOSURE: CONCEPTS AND MEASUREMENT

2.1 ACCIDENT RISK EXPOSURE MEASURES: A REVIEW

In characterising exposure to road accidents, it is a common practice to employ accident rate as an indicator of risk. Frantzeskasis (1983), for example, compares highway risk in different countries based on accident rates. Massie, Campbell and Williams (1995), who examine the risk of crash involvement of different groups of drivers, likewise interpret their findings on the basis of crash rates. More recently, Doherty, Andrey and MacGregor (1998) also use accident involvement rates as a yardstick to gauge the situational risks of young drivers under the influence of passengers. In all these studies, accident rates are typically defined as the number of accidents, whether total or restricted to certain types based on severity of injury, divided by total distance travelled. The denominator - total distance travelled - of this quotient, is regarded as an exposure measure, as it represents the number of opportunities for accident (Mahalel 1986).

The sanction given to the distance concept is enshrined in the premise that distance travelled is most directly related to the risk of collision (Carroll 1971; 1973): the longer the distance travelled, the larger the exposure, all else being equal. While total time spent travelling also carries the same connotation, it is, however, less commonly used (Carroll 1971; Hauer 1982; Chipman and MacGregor 1990). The reservation about the use of travel time lies in the paradoxical implication that "driving at high speed reduces the likelihood of a crash by reducing the time at risk" (Chipman et al. 1992, p. 679).

This conventional method of computing accident rate based on distance travelled, however, is not without problems either. For instance, the accident rate for a particular population group, based on the quotient obtained by dividing the total number of accidents involving this population cohort by the total distance travelled by them over a defined period (such as a year), is expected to increase at a constant rate as the distance travelled by people in this cohort increases. For that matter, frequent freeway, or other divided multi-lane roadway, users, who typically accumulate longer travel distances overall, would be expected to have higher accident rates than the infrequent freeway users, all things being equal. Yet, as reported in Janke (1991), data from the California Business, Transportation, and Housing Agency (1985) shows

that non-freeways have 2.75 times more accidents per mile driven than freeways. This observation leads Janke (1991) to conclude that "with constant driver competence and prudence, accidents will tend to rise at a low and decreasing rate as mileage increases beyond a certain point" (p.184). As noted by Mahalel (1986), this implicit linearity assumption is a methodological problem inherent in the use of accident rates.

To further substantiate her argument, Janke (1991) also attempted to empirically test the relationship between accidents and distance travelled. Using data on accident-per-person averages taken over a six-year period for seven annual mileage groups sourced from the California Driver Fact Book, Janke (1991) found that a linear and proportional relationship between accidents and distance travelled failed to provide a conceptually meaningful fit to the data (with a non-zero intercept). Instead, a more complex relationship involving logarithmic and power functions was found to present an intuitively acceptable fit. While Janke's (1991) data were considered poor even for illustrative purpose, it does cast doubt on the dubious linearity assumption underpinning accidents and distance travelled. Incidentally, an earlier work by Burg (1973) also supports Janke's (1991) conclusion. Because of the non-linear relationship between accidents and distance travelled, Janke (1991) argued that the use of accidents per unit distance travelled could exaggerate the apparent risk of low-mileage travellers, such as teenagers and elderly. Other researchers (for example Chipman 1982 and Risk and Shaoul 1982) have also noted the deficiencies associated with the use of distance travelled as an exposure measure. While variants of distance have been considered, including transforming distance to a power function in a multiplicative factor (Quimby et al. 1986) and incorporating hazards on road segments (Risk and Shaoul 1982), the use of distance as an exposure measure continues to prevail. Perhaps, this is due to the problem of finding suitable surrogates. As Mahalel (1986) puts it:

"[t]here appears to be a vicious circle in which, on the one hand, the accepted definition of risk necessitates a linear relationship between accidents and exposure; on the other hand, it is difficult (or even impossible) to find exposure estimates that fulfill this limitation" (p.86).

Carroll (1971), in one of the early studies on risk exposure, has expounded on the ideal of including all possible opportunities for accidents to occur to derive an exposure measure. While such an ideal is yet to be established, Joly, et al. (1993) have cautioned that even if such an idealised index could be formulated, the exposure measure produced may remain an abstract construct, difficult to interpret. This study

recognises that "[t]he relationship between distance and other aspects of exposure, which often vary substantially among drivers, is not a simple one" (Chipman et al. 1993, p. 207). It contends that one of the major obstacles facing the establishment of such an ideal is the problem of having appropriate data which can "better match" accident exposure to driving.

Other than the problems mentioned above, the conventional accident rate derived from dividing number of accidents pertaining to a particular population group by total distance travelled by the same population group suggests that the resulting quotient is an aggregated rate. Statistically, it is possible to derive the variance for such an aggregated measure, as is done in Chipman et al. (1991) and Doherty, Andrey and MacGregor (1998), based on the method suggested by Armitage and Berry (1987). This means that it is possible to infer the intra-group crash risk variability even with this aggregated measure. Conceptually, however, an aggregated risk measure, as such, obscures the effects of many other factors which also create opportunities for accidents to occur.

For the fact that data are aggregated, the accident rate derived, as such, will depend on the level and manner of aggregation. For a given set of data, computing the accident rates for different population groups based on one age classification system (such as 18-22, 23-27, 28-32 and so on predicated on a five year interval) may differ markedly from another way of categorisation (such as 18-21, 22-25, 26-29 using a four-year grouping scheme). If there is a second dimension used in the classification, like time of day (such as when enumerating the accident rate of a specific population group within a defined time period), the number of ways in which the data can be combined will begin to skyrocket. The possible misrepresentation of crash risk based on results generated using different aggregation levels is analogous to the modifiable aerial unit problem when combining spatial units into "homogeneous" traffic analysis zones for transport modelling (Openshaw, 1984). For these reasons, this study will revisit the concept of risk exposure and attempt to define it in a disaggregated sense in order to derive a measure that will ameliorate some of the problems levied at the use of travel distance as an exposure indicator.

2.2 ACCIDENT RISK EXPOSURE: A REINTERPRETATION

In epidemiologic studies of disease, intensity and duration of exposure are considered as two prime risk factors (Chipman et al. 1992). For instance, when studying lung diseases, "pack-years" of cigarettes consumed, which denotes both the intensity and

duration of exposure to cigarette smoking, is used as a risk indicator (see for example Nyberg et al. 1998; Lee et al. 1998; Howard et al. 1998; Tracy et al. 1997 and Freedman et al. 1996). On this premise, distance travelled and time spent travelling, which suggest duration of exposure, have traditionally been enlisted as natural modifiers of crash risk. In studying the etiology of road crashes, however, the concept of exposure is more appropriately viewed from the perspective of a trip. For a given trip, three sets of factors may be regarded as possible contributors to an accident. The first pertains to that of the internal car environment. Factors in this set include the driver characteristics, the condition of the car as well as the presence of the passengers and their behaviour. The second relates to the external physical environment. They include the topography of the route taken, the geometric design of the road, the roadway condition, including lighting and signage, as well as the weather condition. The last set of factors pertains to the dynamic traffic situation and includes the characteristics of the other road users as well as the time of the trip. In this context, the length of the trip, or distance travelled, is but one of the many exposure factors; so too is the time spent travelling. As Janke (1991) rationalises, "the variable that should bear a linear relationship to accident, if any does, is not mileage but exposure to accident risk, of which mileage is only one component" (p.184). Viewed from this perspective, every trip would be unique in terms of accident risk. More importantly, all factors relating to the trip that can contribute to the occurrence of an accident may be perceived as having been summarily captured if accident rates are computed on a disaggregated per trip basis.

In this context, the intensity of exposure may be perceived as the incidence of accident hazards to which a driver would be exposed in the course of a trip. Statistically, the incidence of accident hazards along any travel route could be gauged by the number of accidents occurring within its confine over a defined period of time. For a given travel route with a fixed distance, the greater the number of accident sites encountered, the higher would be the intensity of exposure for any driver travelling along that road. Since the occurrence of accidents would not be uniformly distributed along a road or along different segments of a road, it does not follow that, for a given trip, longer travel distance would necessarily imply greater intensity of exposure. On the contrary, for a given number of accidents along a travel route, the longer the travel distance, the lower would be the accident rate when measured on the basis of per unit distance travelled, all else being equal. From this perspective, the classical criticism of constant accident risk with increasing travel distance levied against the use of distance travelled as a surrogate of accident exposure would no longer apply. For the fact that accident risk is enumerated according to the route of travel for each trip,

accident risk is now measured at a disaggregated level of per trip-km, rather than at the aggregated level of per km travelled.

Carroll (1971), in reviewing a host of definitions used to signify driving exposure, describes accident exposure as "the frequency of traffic events which create the risk of accident". Accepting the number of accidents occurring in a given road section over a period of time as a measure of road hazard, duration of exposure may then be interpreted as the frequency at which a trip encounters an accident spot. The more times a travel route has to traverse a potential accident hazard (ie, a spot where an accident has occurred in a given period of time) in the course of its journey, the longer would be the duration of exposure. Under this definition, a journey along a specific travel route with a given number of accidents would have a constant duration of exposure, regardless of the time taken to traverse the route. This view of exposure duration thus avoids the contradictory logic that the shorter is the travel time, which implies a higher travel speed, the lower will be the risk of exposure, other things remaining constant. Conversely, for a given travel route with a fixed number of accident hazards, the shorter the travel time, which implies a faster travel speed, the greater will be the crash risk when it is measured in terms of number of accidents per trip-hour.

For a given trip, then, the crash rate along a travel route i may simply be mathematically expressed as follows:

$$R_{ijt} = \frac{A_{ijt}}{D_{ijt}} \dots\dots\dots (1)$$

where R_{ijt} = crash rate along route i traversed by person j in time period t (t is a particular period in a day such as from 6:31 am to 9:30 am);

A_{ijt} = total number of accidents occurring within time period t along travel route i involving population group to which person j belongs; and

D_{ijt} = distance travelled or time spent travelling by person j along travel route i within time period t .

While expression (1) is also a quotient similar to the conventional approach of computing accident rate, the difference is that it is expressed in accidents per trip-km

(if the denominator is a distance measure) or per trip-hour (if the denominator is a time measure) rather than accidents per km or per hour. To compute the accident rate of any population cohort in a given time period, the individual accident rates pertaining to trips made by persons fitting the characteristics of the required population cohort and in the stipulated time period may then be aggregated to give the mean for the population group. To make use of this method of estimating crash rate, and hence enumerating accident risk, it requires that a "direct match" be made between accident data and trip information. More specifically, it means that the spatio-temporal attributes of the accidents (ie, the locations and time of occurrence of the accidents) involving people of a particular characteristics have to be "linked" to the trips made by people of similar traits within a "comparable time period".

Unlike the study of cigarette smoking and lung disease, where data on smoking history on persons who have contracted the disease can be retrospectively recalled (see for example Nyberg et al. 1998), travel information on persons involved in accidents cannot be easily collected, even retrospectively. The reason is that the exposure concept predicated on individual trips demands specific details which are harder to remember than number of packs of cigarette smoked per day. Without data to provide a direct match, an alternative would be to devise a method which can make use of available data.

In the field of urban transportation, travel surveys requesting individuals to provide information on the trips they have made are frequently collected. The successive Nationwide Personal Transportation Surveys conducted by the US Department of Transportation since 1969 is one such example and the Victorian Activity and Travel Survey (VATS) conducted by the Transport Research Centre at RMIT in Melbourne is another. The trip details requested by some of these travel surveys, such as VATS, include the addresses of the origins and destinations, which allow the travel route to be traced. On the other hand, many of the accident reports also record the location and time of accidents in addition to the demographic profiles of the persons involved in the accidents. If the travel routes of all persons in a specific demographic group (from a travel survey data file) can be superimposed onto the locations of accident sites involving all people of similar demographic traits (from an accident database), then technically expression (1) can be computed. The issue then is how to link the two sets of data together. The manner in which information from a travel survey can be linked to records of an accident database is the subject of discussion in the next Chapter.

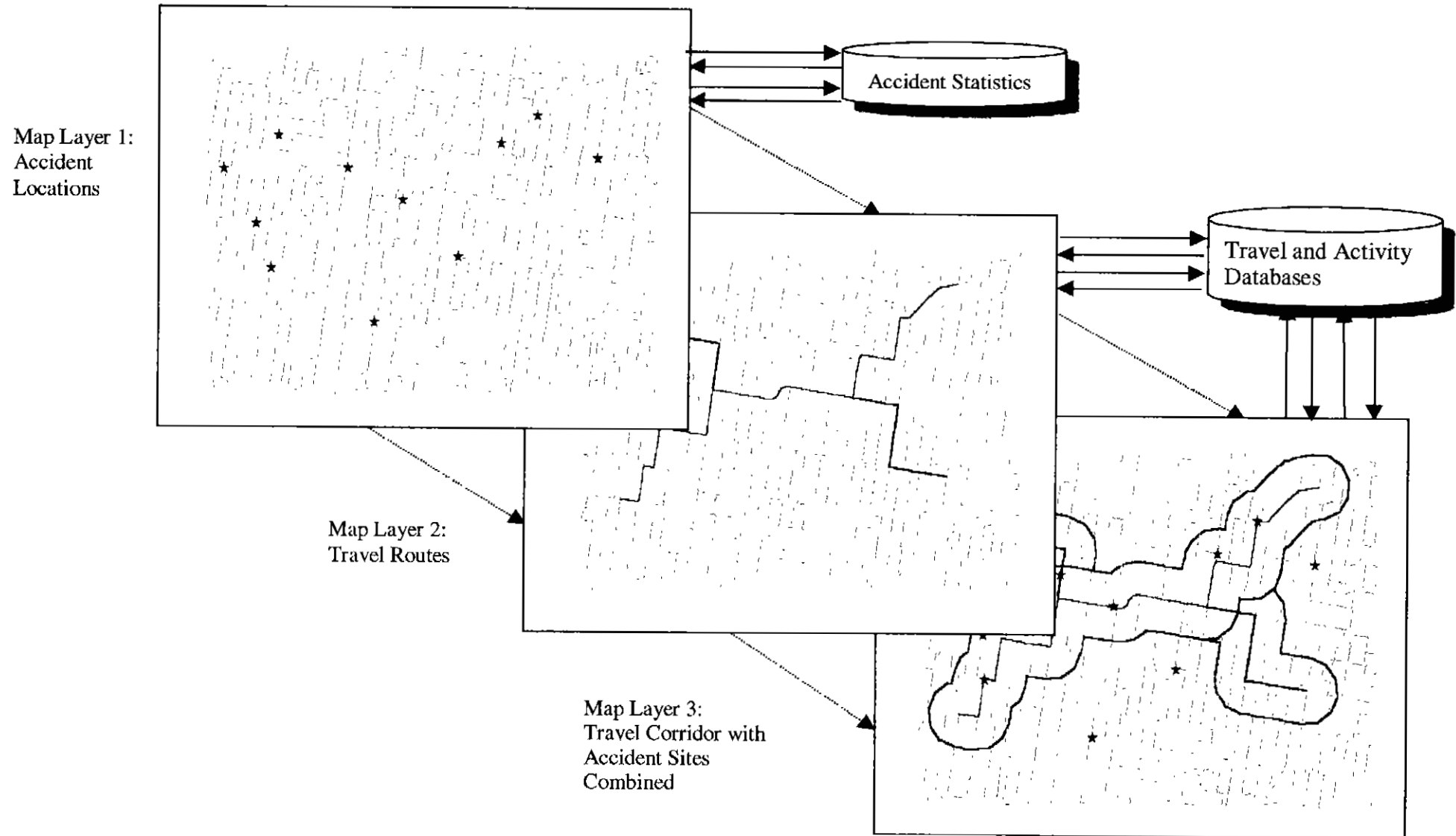
CHAPTER 3

A GIS-BASED APPROACH TO ESTIMATING CRASH RISK

3.1 INTRODUCTION

Enumerating accident risk associated with a given trip based on crash rates invokes the use of a Geographic Information System (GIS) platform. A GIS is a hardware and/or software system designed to capture, store, manipulate, analyze, display and output spatial data in the form of map layers. A GIS database, as such, is essentially a stack of floating map layers. Each layer is connected to a common map base through a coordinate system which permits inter-layer referencing. Through a relational database management system, each map layer could also be linked to a data file or series of files containing information characterizing features on the map layer. This bi-lateral tie allows the databases to be queried either from map features or from information in the database. The GIS paradigm, in brief, is a fundamentally spatial-referenced way of organizing, manipulating and linking information from different sources.

The essence of the GIS approach to estimating risk exposure is to link a map layer of travel routes to a map layer showing accident locations (Figure 2). Attributes contained in the former would include the coordinates of the trip origins and destinations, from which the travel routes and travel distances can be determined. Features included in the latter would encompass the spatial references of the accident locations. The base map will be the street network. Since trip origin and destination information is sourced from a travel data file, other information included in the file, like the socio-demographic profile of the person making the trip, the starting and ending time of trip, mode used and trip purpose, could thus be identified based on information on the travel route layer. Likewise, the demographics of the persons involved in the accident, the time of the accident and other features related to the accident, which are contained in the database housing the accident locations, could also be queried. Overlaying the three map layers onto a GIS platform (such as MapInfo or TransCAD) will allow interlayer-referencing to be made, and hence the exposure (based on distance traveled) of different population groups to road accidents.

**Figure 2**

The GIS Approach to Linking Accident Data to Travel Information: A Conceptual Illustration

3.2 ENUMERATING CRASH RATE BASED ON INDIVIDUAL TRIPS

The derivation of a crash rate or an accident risk exposure measure based on individual trips using two different databases - a travel file containing information on trip characteristics and an accident record file housing road accidents - may be perceived as comprising four major tasks, as shown in Figure 3. The first is to generate the "shortest" travel path between each origin and destination pair using a GIS-based transportation software. The next step is to define a travel corridor centered on the alignment of the shortest travel path. The third is to extract the corresponding accident records, ie, road accidents falling within the boundary of the defined travel corridor made by persons of comparable demographic characteristics, from the accident file. And the last is to compute the crash rate for each of the defined corridors. This can be a ratio of the number of accidents falling within the defined corridor to either the trip distance or the trip time, depending on the choice of exposure measure. Each of these tasks will be described in turn.

3.2.1 Generating Shortest Travel Paths

Data Preparation

In tracing the travel path of an origin-destination pair using a GIS software, the coordinates of the pair have to be identified. However, it is rather unrealistic to expect respondents to a travel survey, which seeks information on trip origin and destination, would be able to provide them. At best, only the street addresses of these places would be given. In normal circumstances, the nearest cross-street or a prominent landmark nearby may be stated. As such, to map the trip origins and destinations from a travel database, a geocoding process has to be conducted first.

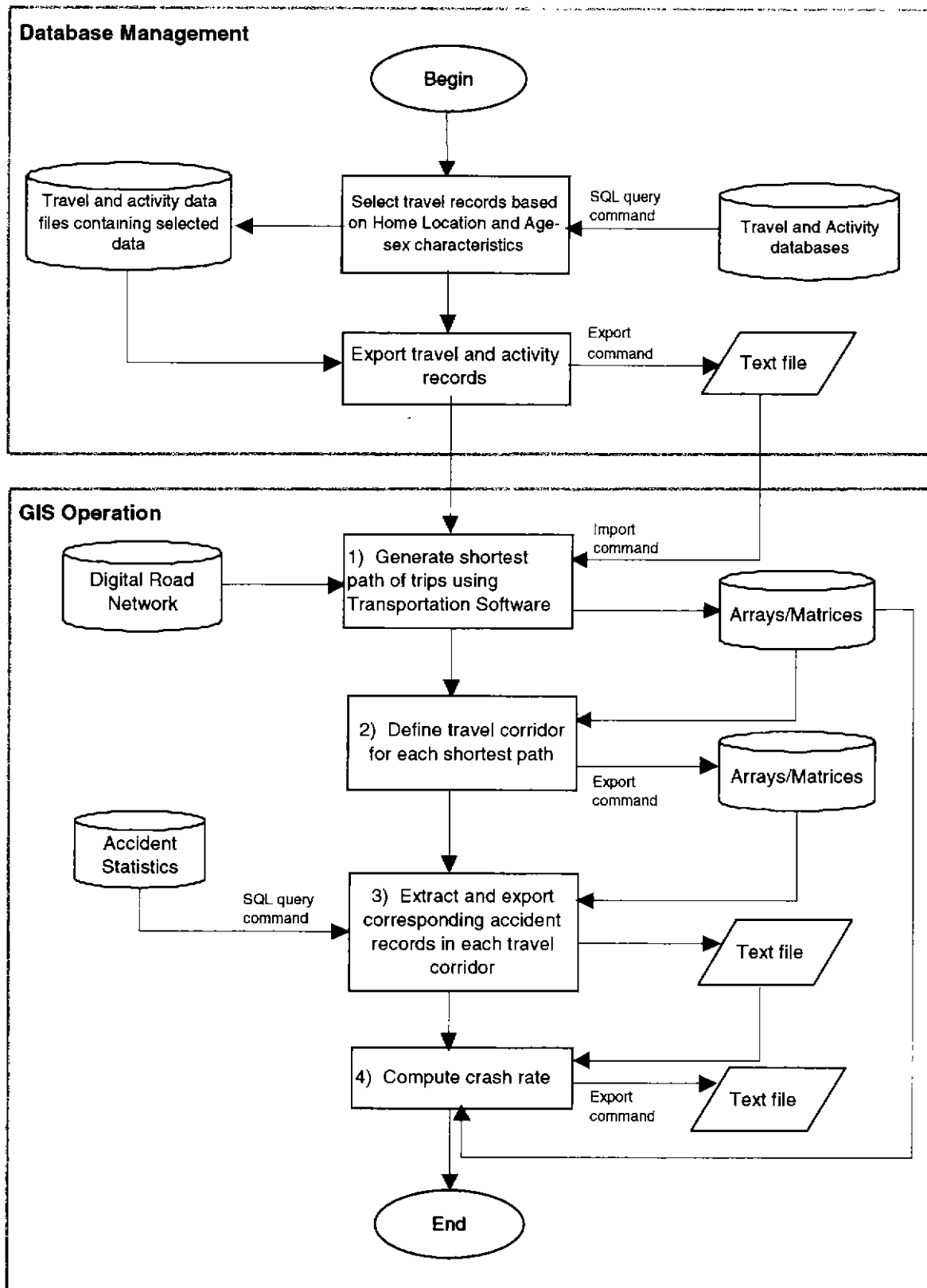


Figure 3

Flow Diagram of the GIS Approach to Estimating Crash Rate

Geocoding of trip origins and destinations can take one of several forms, depending on the level of details given. When the full addresses (ie, inclusive of street number, street name and suburb name or postcode) are given, an exact match of the location can be made to an Address database. The Address database can be created from a digitized street network which is generally available for major cities. It will contain a unique listing of full street address records complete with their coordinates. It is not uncommon to find incorrect suburb or postcode information for a given address. When this occurs, an exact match will not be found. This problem is circumvented by assuming that respondents are unlikely to indicate a suburb far away from the correct suburb. By adopting this assumption, the matching process can be re-attempted by using an increasingly larger boundary, such as including all adjacent suburbs. Undoubtedly, the probability of correctly geocoding an address will diminish as the boundary used in the geocoding process becomes larger. When a match is located, the x-y coordinates of the given address are then extracted from the Address database and attached to the travel file.

If cross-streets instead of full addresses are given, the task then is to first compile a list of unique cross-street addresses supplied by all respondents to avoid unnecessary repetitions in geocoding. A cross-street address consists of two street names and a boundary (e.g. suburb or postcode). Next, a Cross-street database with their coordinates is created, again from a digitized street network file. Geocoding a cross-street address then becomes a matter of searching this cross-street database to find a match between the first and second streets within the appropriate suburb boundary. The coordinates obtained from a cross-street matching will correspond to the centre of the intersection of the two streets.

Because multiple occurrences of a cross-street in various locations are possible, it is necessary to ascertain which cross-street is pertinent. To facilitate checking, the cross-street database has to have a boundary field that qualifies each record. Searching a cross-street in turn must also have boundary information as part of the input. Thus, even if Sydney and Victoria Streets, say, have intersections in several suburbs, overlaying the suburb boundary file will identify the correct location so long as the suburb information is provided along with the cross street names.

Further, multiples may also exist within a single boundary. An example is a "loop" type street where it intersects another street twice, with both intersections likely to be in the same suburb or postcode boundary, as shown in Figure 4. Knowing the number of multiples allows for a randomized approach to selecting a pair of X and Y coordinates among the multiples. It should be pointed out that multiple occurrences

of a cross-street which are in different suburb or postcode boundaries are not considered as multiples.

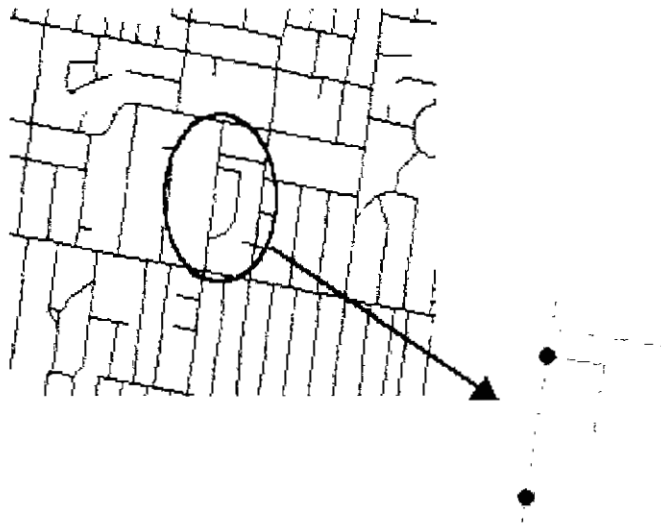


Figure 4
Example of a Multiple Cross Street

The geocoding of cross-streets is also done in successive stages with each subsequent stage employing a larger boundary than the previous. As such, the probability of obtaining a correct geocode decreases as the boundary is extended. For cross-streets, this is aggravated by the random process of selecting a cross-street from its set of multiples, if any.

In travel surveys, respondents may also nominate a landmark as a destination address. Examples of landmarks include the name of a hospital, a shopping centre, a restaurant, a school, a bank, a government office, a park, or a beach. To qualify as a valid address, a landmark has to be uniquely defined and be distinguished from all others with a similar name. A bank, for example, needs to have the branch (usually a suburb) appended to its name.

The geocoding of landmarks may be done by one of several means. First, many landmarks can be geocoded by searching a database of landmarks, such as train and bus stations, schools, child care centers, service stations, shopping centres, restaurants, departmental or discount stores, post office, libraries, police stations, fire

stations, hospitals, places of worship, sports arena, parks/reserves/gardens, banks, art galleries, theatres, cinemas, nightspots, pubs/bars, motels/hotels, caravan parks, rubbish tips, car parks and other places of interest. The commercially available landmarks databases will include both the names of the landmark as well as its geocodes. Alternatively, a landmark file can be compiled by combining information from various sources, such as telephone and street directories.

For each of these landmarks, an equivalent full street or cross-street address is determined manually from published sources (eg, telephone directory), and then the geocoding methods for full street addresses and cross-street addresses (described earlier) is applied to generate the geocodes.

Lastly, addresses provided by respondents are not always complete. Some respondents intentionally omitted street numbers, giving only their suburb or locality - probably for privacy reasons. To geocode these incomplete addresses, either a point along the length of the street would be randomly sampled, if a street name was given, or a point within a suburb could be randomly selected, if suburb was the only information given.

Sampling a point along a street can be achieved by first dividing a long or winding street into a number of short segments, usually at intersections or where the road bends or changes direction. This is followed by randomly selecting a segment among all the segments belonging to the given street within a given area (suburb or postcode). To ensure that longer street segments will have a higher chance of being selected than shorter segments, street segments may be assigned weights according to their lengths. After selecting the road segment, a point along the selected street segment will be randomly sampled. Sampling a point within an area (suburb or postcode) follows the same procedure, with the added step of randomly selecting a street among the streets within the area first. As in geocoding of full street and cross-street addresses, progressively larger boundaries are used when the given street cannot be found within the given suburb boundary.

Tracing the Shortest Path

With the geocodes in place, the map layer for travel routes could then be developed. If information on the travel routes taken is available, a simple path tracing procedure can be employed to sketch the travel route based on the names of the roads traversed. However, in most travel surveys, such information is either far too complex or too difficult to obtain. In the normal situations, no information on the routes used will be provided. Under this situation, the technique of spatial network analysis has to be

invoked to trace the path between an origin-destination pair through a road network. Spatial network analysis is a way of routing and allocating resource flows (eg, finding the shortest travel path between two locations) through a system joined by a set of linear features (eg, roads and freeways). Distance optimization decisions within the system will depend on the nature of the problem, which governs the definition of "best" path. Algorithmically, the search for the "best" path is handled by establishing some attributes in the database to characterize the desirability of traversing each link in the network (Lupien et al. 1987). These attributes include the type, nature and configuration of the network links, the locations and characteristics of barriers to movement, directionality of flows and the positions and conditions of intervening opportunities. Otherwise, the shortest travel path, either by distance or time, is usually the alternative. For this purpose, the shortest path algorithm provided in the Network module of TransCAD (Caliper 1996), a GIS-based transportation software, can be used to trace the travel route between an origin-destination pair.

3.3 DEFINING EXPOSURE CORRIDOR

In a travel database derived from sample survey, it is customary to apply a weighting factor to expand the sample statistic to the population total (Richardson, Ampt and Meyburg 1996). In other words, each trip in the data file, when weighted, is supposed to represent a number of other "similar" trips made by people of comparable socio-demographic and, perhaps, locational characteristics. Since each trip origin and destination can be made very precise by the use of coordinates in a GIS, the shortest path derived between a specific origin-destination pair may thus be interpreted as the travel paths of all trips that the reported trip represents. For purposes of enumerating exposure to road accidents, this would simply mean that all persons making those trips represented by the reported trip will only be exposed to accidents occurring along one specific path. This interpretation, of course, runs the risks of stretching the principle of statistical weighting beyond its original intent. Clearly, if the reported trip is to represent a group of trips made by individuals of comparable characteristics, then it is unreasonable to assume that these trips will all have the same origin and destination coordinates and their travel routes all follow the same path. For this reason, the concept of a "travel corridor" is introduced.

In this research, a travel corridor is defined as all travel paths lying within a given distance (x km) from the identified shortest path as illustrated in Figure 5. The value of x can be altered, depending on the context of the analysis, the configuration of the network and the hierarchy of roads connecting the origin and destination pair.

In short, the key to identifying the possible travel routes between each origin-destination pair is to first trace the shortest path between them and then to define a buffer around the route of the shortest path. All roads and streets falling within the confines of this buffer and linking the origin and destination pair thus form the possible routes which a journey between the confines of the origin and destination pair can take place. In other words, anyone travelling within a radius of x km from the recorded origin to a similar confine of the stated destination would be considered as exposed to the accidents occurring on the roads connecting the defined corridor. Because of the linkage to the travel database, the measurement of exposure can be refined in any manner to restrict the analysis to a specific population group, such as male aged between 18 and 21, and to a specific time period, from 10:30 pm to 2:30 am on a weekend, say, thus imparting greater meaning to the measure derived.

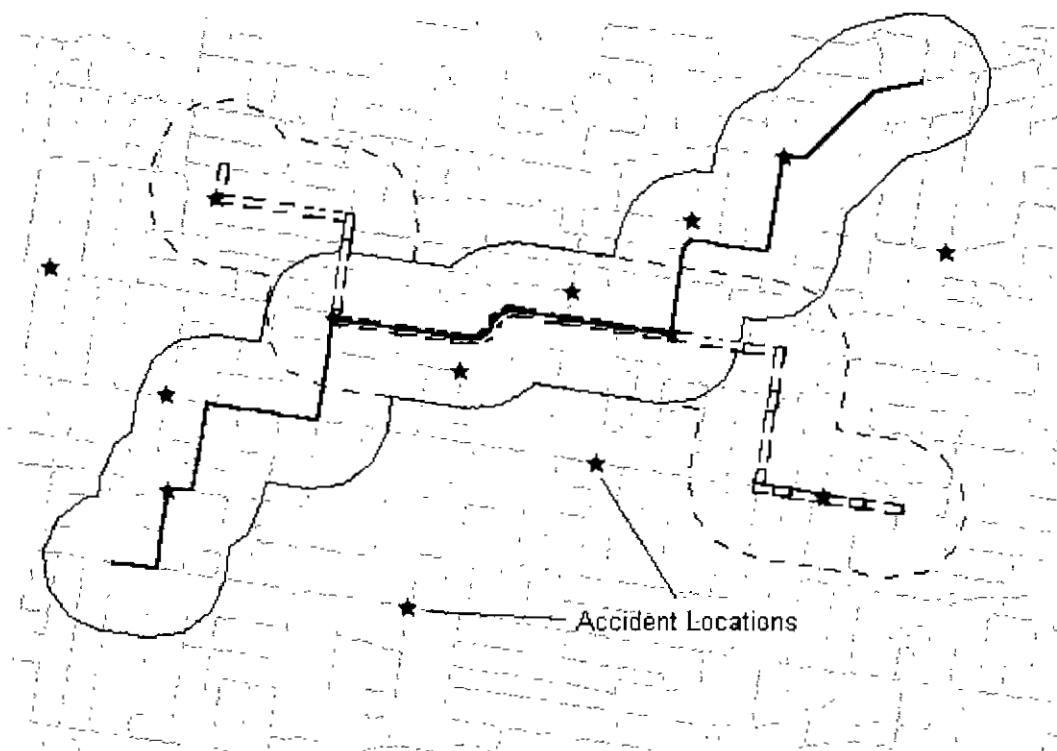


Figure 5

Illustrative Travel Corridors of Shortest Paths between Origin-destination Pairs

3.4 MATCHING ACCIDENT DATA TO TRAVEL ROUTES

3.4.1 Geocoding Accident Locations

Similar to the case of the travel file, precise geographic reference to accident sites, such as site coordinates in terms of longitude and latitude or northings and eastings, are usually not obtainable in accident databases. The locational information generally available in crash statistics include the name(s) of the road(s) on which an accident took place, the nearest intersection or cross-streets, the name(s) of the administrative district(s) or local council(s) within which the accident location falls, and, perhaps, the milestone and distance to the nearest intersection. To create a map layer of accident location, as such, will require that the accident sites be geocoded.

The geocoding process will begin with the generation of locational references for each accident site based on information given in the accident database such as road name, road type, administrative district, and distance from the nearest intersection. These locational references are then matched to a digitized road network file in which coordinates for addresses are given. Again, depending on the level of informational details available, the assignment of geocodes to an accident site can follow one of several alternatives: exact address geocoding, approximate address geocoding, and map grid geocoding. Exact address geocoding is conducted if the location of the accident is identifiable, such as a road intersection or distance from an intersection. Approximate geocoding is used when only the name of the road is given. In this case, a point is randomly selected along the given road. Map grid geocoding is resorted to if the information available pertains to a map grid. Again, a point is randomly selected within the grid to represent the location of the accident.

3.4.2 Extracting Matching Accident Data for Travel Routes

The third phase of the process is to extract the relevant accident records for each of the defined travel corridors. The complexity of this process can vary considerably, depending on the level of disaggregation required of the analysis. If the objective is merely to match the locations of the accidents to the travel routes, then it will simply be a straight forward process of overlaying the accident location map layer onto the travel route map layer. This simple matching, of course, will only ensure that accidents falling within a defined travel corridor are extracted for each origin-destination pair and will not account for the temporal dimension of the accident

occurrence or the characteristics of the persons involved in the accident. If the intention is to derive a more refined measure of exposure that can capture some of these attributes, then the matching process will need to take into consideration the comparability of the two databases with respect to these attributes.

For instance, if the intention is to compute the crash rates of population in different age-sex cohorts during different hours of the day to reflect their innate accident liability, then the spatio-temporal attributes of each accident as well as the socio-demographic characteristics of the persons involved in the accident have to be extracted from the accident database to construct a series of accident layers. Likewise, separate travel route maps will have to be generated, each containing the travel corridors of the population of a specific age-sex group during different time periods. The task, then, will be to overlay each accident layer to its corresponding travel route map onto a common street map to create a GIS database for travel corridors. For each trip, the database will encompass the distance traveled, the time period within which the travel took place, the demographics of the person making the trip, and the number of accidents found within the identified travel corridor for the trip. With that database, the crash rate for each travel corridor can then be computed.

3.5 COMPUTATION OF CRASH RATE

The computation of crash rate for each travel corridor is based on expressions (1). As each sampled trip embedded in a defined travel corridor represents a trip made on a typical day (which can further be refined to a typical weekday or weekend, depending on the day the trip was recorded), they have to be factored up to match the time period defining the crash statistics. Further, since each sampled trip is meant to represent a number of trips made by people of the same socio-demographic characteristics, a weighting factor has to be applied to expand the trip distance or the trip time. Taking all these into consideration, expression (1) should be modified as follows:

$$R_{ijt} = \frac{A_{ijt}}{(D_{ijt} \times 365 \times W_{ijt}) / 1,000,000} \dots\dots\dots (2)$$

where R_{ijt} = crash rate (in number of accidents per million trip-km) along travel corridor i traversed by person j in time period t in a typical day;

A_{ijt} = annual number of accidents occurring within time period t , falling within defined travel corridor i and matching demographic profile of person j making the trip;

D_{ijt} = trip distance traversed in travel corridor i by person j in time period t as defined by length of shortest path; and

W_{ijt} = weighting factor applied to expand trip distance to that traversed by all trips represented by sample trip made by person j in time period t .

Likewise the crash rate in number of accidents per 10,000 trip-hours may be computed thus:

$$R'_{ijt} = \frac{A_{ijt}}{(T_{ijt} \times 365 \times W_{ijt}) / 10,000} \dots\dots\dots (3)$$

where R_{ijt} = crash rate (in number of accidents per 10,000 trip-hours) along travel corridor i traversed by person j in time period t in a typical day; and

T_{ijt} = time taken to traverse travel corridor i by person j in time period t .

The crash rate computed for each travel corridor thus represents the accident exposure rate of all persons (represented by the sampled person) making such a trip. As such, the average crash rate of any particular population cohort can be computed in the usual manner of data analysis.

CHAPTER 4

DATA SOURCES AND ASSUMPTIONS

For the purpose of illustrating the exposure concept proposed in this study, the accident crash rates of car drivers in Metropolitan Melbourne between 1994 and 1997 are enumerated. This Chapter describes the data sets used for the illustration and the assumptions adopted in implementing the exposure concept.

4.1 DATA SOURCES

4.1.1 Travel and Activity Data

The data source from which the travel corridor and the associated travel time and travel distances are derived is the VATS databases produced by the Transport Research Centre at RMIT. Launched in December 1993, VATS has gone on for over five years now and is still continuing. The VATS databases that have been released are VATS94, VATS95, VATS96 and VATS97, which are labeled according to the calendar year within which the travel took place.

VATS is one of the most comprehensive household-based travel and non-home activity databases available in Victoria. Using a self-administered, mail-out/mail-back questionnaire, VATS is conducted year-round. A total of 10,950 households residing within the Melbourne Statistical District (MSD) were sampled each year. As of July 1998, however, this sampling rate has been increased to 16,425 per annum.

Households selected for the survey are asked to fill out a Household Form (see Appendix A) which contains questions seeking information on demographics, and activity and socio-economic status of individual household members. In addition, each member of the household is required to complete a Travel Form (see Appendix B) recording all travel stops made out-of-home on the assigned travel day. Other than detailing the starting and arrival time of trip, stop purpose, mode used and other characteristics associated with each stop, respondents are also requested to provide the address of the stop origin and destination where possible; if not, by the names of the nearest cross-streets.

The detailed travel stop information available enables both travel distance and time spent travelling to be enumerated. From the geocodes of the origin and destination addresses (in terms of northings and eastings) given, the distance for each recorded

trip was derived using the shortest path algorithm in TransCAD (Version 3.0c), a transportation GIS software produced by Caliper (1996). Figure 6 demonstrates the shortest path identified by TransCAD between a home location in the Local Government Area (LGA) of Boroondara and a destination in Melbourne City Centre.

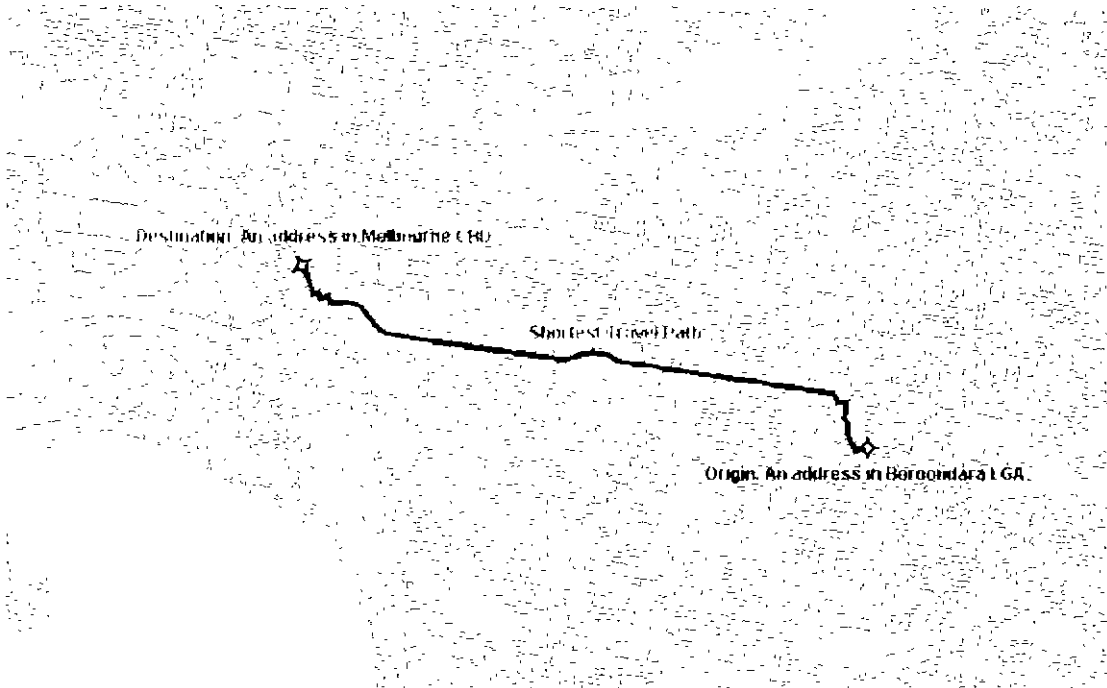


Figure 6

Example of a Shortest Travel Path Traced by TransCAD (Version 3.0)

The distance calculated thus represented the shortest route distance between a given origin and a specified destination.* In the case of the time measure, it was simply the travel time obtained by taking the difference between the arrival and starting times of the trip.

For the purpose of this study, four years of VATS data – VATS94, VATS95, VATS96 and VATS97 – are pooled together. The distance and time measures

* In VATS, respondents are asked to provide the names of up to six of the roads or streets actually used for the journey. It is possible to spatially trace the shortest path between an origin and a destination taking into account the six roads indicated. This would, undoubtedly, be a more realistic measure of the “actual” distance travelled. Craig McPherson, a doctoral student at Melbourne University and previously working at the TRC, has actually developed a software called Roadlink to trace these “shortest” paths as part of his Ph. D. thesis. However, as McPherson’s work is yet to be published, this study will adopt the shortest path algorithm provided in TransCAD.

derived thus represent the total distance travelled and time spent travelling by the respective population groups within the time periods indicated over four years. The results obtained are thus considered more reliable as most conventional time and distance measures are based on figures spanning no more than one year.

4.1.2 Accident Data

The road crash data used for the analysis come from CrashStat (1998 edition), an accident database produced by VicRoads. CrashStat (1998 edition) contains records of all road crashes where at least one person was injured in the State of Victoria from 1991 to early 1998. For fatal accidents, the records included in CrashStat date back to 1987.

The statistical information in CrashStat is compiled from data sourced from the VicRoads Accident database, Australian Bureau of Statistics and the Federal Office of Road Safety. The type of information recorded include:

- Type of accident, such as collision with vehicle, struck pedestrian or animal, or collision with a fixed object;
- Severity of accident: number of vehicles and persons involved and whether it is a fatal accident or serious injury only;
- Road surface condition and type as well as road geometry;
- Light condition: day, dusk/dawn, dark – street lights on or off;
- Atmospheric condition, such as clear or raining;
- Object hit: such as tree, pole, traffic island, guide post, traffic sign, and fire hydrant.
- Speed limit placed on road or road segment;
- Road user characteristics: ie, age and sex;
- Injury level: fatal, serious injury, other injury or no injury;
- Distance from home, the distance given is that between the road user's home post code and post code where the accident occurs;
- Restraint use, such as whether seat belt was in use or child restraint worn or not

- Time of occurrence: date, time and day of week; and
- Accident location identified by name of road, intersection (for intersection accident), kilometrage (for freeways and highways and some major roads where kilometrage posts are erected), and horizontal and vertical grid reference to either the Melway (a popular road directory in Melbourne) or VicRoads Internal Maps.

For the purpose of this exercise, the accident locations are geocoded based on the horizontal and vertical grid reference to Melway.

4.1.3 Invoking the Concept of Accident Exposure: Matching Accident Data to Travel Corridor

A central issue in matching accident records to travel information is "what constitute a representative set of accident records to which the driver traversing a particular corridor may be exposed?" To select the "relevant" accident data for each travel corridor, it is necessary to adopt a number of assumptions which could be rationalised as relating to the accident risk to which a driver is exposed when traversing the travel route. For this exercise, the following assumptions were adopted:

- The width of a travel corridor is defined as ± 0.5 km from the centre line of the travelled road. As explained in Chapter 3, the adoption of a travel corridor, instead of a road, is to account for the possibility that all trips represented by the sampled trip may not be originating from the same geocoded point and ending at the given geocoded destination, which are very precisely defined. A corridor is employed to remove such unrealistic precision implied by the sampled trip. On the other hand, the width of the corridor cannot be unduly large. In deciding the width of the corridor to adopt, the following rules were used:
 - the travel corridor of a trip along a major primary road would not include another parallel primary road; and
 - a trip along a secondary or local road in between two parallel primary roads would not seek one of the primary roads as an alternative travel route, if it is more than a third of the separating distance between the two primary roads.

The buffer width of 0.5 km on either side of the "actual" road used (based on the shortest path traced) is arrived at after examining the distance separating some 250 randomly selected road sections between "parallel" primary arterials in Metropolitan Melbourne. The result of the random check indicates that the average distance separating two primary roads in Metropolitan Melbourne is

about 1.6 km. Adopting a buffer of one km as the exposure corridor (0.5 km on either side of the travel route) for a given trip, as such, seems to meet the above rules well. This adoption thus suggests that if a primary arterial is one of the roads used for a trip, the chance that the driver would be exposed to accidents occurring on a "parallel" primary road is very slim. Further, if a secondary or local road is more than 0.5 km (about a third of the average distance separation between two primary roads) from the nearest primary road, the likelihood that a driver travelling along the secondary or local road would be exposed to accidents occurring on a primary road will also be minimal.

- A driver travelling along a defined travel corridor would be exposed to certain accidents (subject to the constraints of the other assumptions) involving drivers in a comparable age-sex cohort. For this purpose, all drivers aged between 18 (the lowest legal age to possess a driver license) and 20 are presumed to be exposed to all road crashes involving drivers between 18 and 22. Drivers aged between 21 and 68 are regarded to have a reasonable chance of being involved in accidents affecting persons within $\pm$ two years of age from that of the driver. This means that if the driver's age is n , then s/he is expected to be exposed to all road crashes involving drivers aged between $(n - 2)$ and $(n + 2)$. For drivers above the age of 68, the scenario adopted is that they would be exposed to all road crashes involving persons above 67 years old.
- Drivers of a particular gender would only be exposed to traffic accidents pertaining to those of the same sex. This is in recognition that there is a distinct difference between the crash risk of male and female drivers (Massie, Campbell and Williams 1995) and that gender does have an effect on driving behaviour (Massie, Green and Campbell 1997).
- Subject to the constraints of the other assumptions, a trip taken on any weekday (ie, Monday to Friday) is assumed to be exposed to all accidents occurring on a weekday. Likewise, that made on a weekend (ie, Saturday and Sunday) would have the possibility of being linked to road crashes happening on the weekend. An alternative to this would be to link trips made on a particular day to accidents happening on that same day of the week. This option would be most appropriate among persons, such as those not in the work force, with significant day-to-day variations in their trip making patterns. However, from the perspective of those with a routinised daily travel pattern, such as the journey to and from work and trips to day care and school, such a "refined" match is considered insufficient to fully capture the risk of exposure. From the VATS database, it is estimated that

over 50% of the driver trips may be considered as routinised. For this reason, it was decided to adopt the simple weekday-weekend match, rather than a refined day-to-day match.

- Because driving performance has been found to vary with time of day (Lenne, Triggs and Redman 1997), it is also important to differentiate the exposure risks of trips made during different times of the day. In this study, a trip made within each of the following time periods is assumed to be affected by accidents occurring within that same time period: 06:31 – 09:30; 09:31 – 15:30; 15:31 – 18:30; 18:31 – 22:30; 22:31 – 02:30; and 02:30 – 06:30. A trip straddling two or more time periods is assumed to be affected only by accidents in that time period within which the bulk of the travel time falls. The choice of the above six time periods was based on the average traffic profile flowing along the urban road network of Metropolitan Melbourne on a typical weekday (see Figure 7). The first and third periods coincide with the two peak flows and the second, the non-peak. Although there are no more peaks after 18:30, there seems to be vast differences in traffic volumes between 18:31 and 06:30. As such, these hours have been further divided into three periods to distinguish the disparate exposure levels to which drivers travelling after 18:30 are exposed. Lastly, the reason for pegging time periods to traffic profile is in recognition of the relationship between accident occurrence and traffic density.

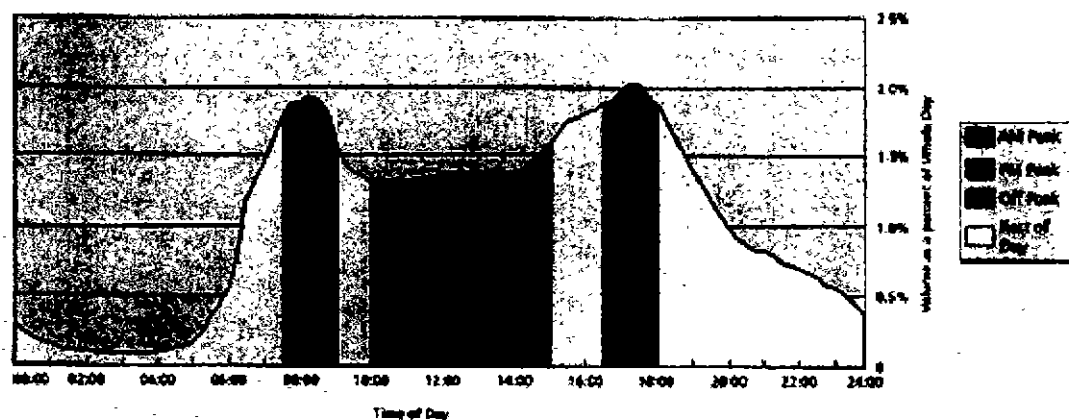


Figure 7

Daily Traffic Profile of a Typical Weekday, Metropolitan Melbourne

Source: VicRoads (1999) Traffic System Performance Monitoring 1997/98, p.13.

CHAPTER 5

CRASH RATES OF MELBOURNIANS

5.1 CRASH RISK BASED ON AGGREGATED TRAVEL DISTANCE AND TRAVEL TIME MEASURES

While the objective of the study is to present and illustrate the concept of enumerating crash risk based on the notion of travel corridor, the presentation would not be complete without comparing the results to those computed using the conventional aggregated approach. This section will present the results of the crash rate analysis using the conventional approach.

Two measures, one based on number of accidents per million km driven and the second on number of accidents per 10,000 hours travelled, were computed separately for men and women for typical weekdays (Monday to Friday) and weekends (Saturday and Sunday) and during daytime (ie. 06:30 to 18:30) and night-hours (18:30 to 04:30). The results of these computations for males and females of different age categories are shown in Figures 8 and 9.

The eight graphs depicted in Figures 8 and 9(a) to (d) all display a U-shape curve. They clearly suggest that both the young and the very old are most accident-prone, irrespective of time of day or day of week. On a typical weekday, male elderly drivers above 70 years of age have a crash rate of about 1.25 accidents per million km travelled, which is about 2.5 times that of their counterparts in the 40-44 cohort when travelling during the day. At night, the differential increases to 3 times. In the case of male drivers under 21, the accident risk is even greater, with a crash rate of almost 2 accidents per million km during day-hours, doubling to over 4 accidents per million km by night.

During weekends, accident rates generally decline for all age groups. Yet, the disparity of crash risk between the two age cohorts at the end of the age continuum and those in the middle remains. Between the young and the elderly, the former has a much higher risk than the latter. During the day, male drivers below 21 years of age average about 0.75 accidents per million km, while their counterparts over 70 have only about 0.4 accidents per million km. The crash rate for female drivers under 21 is over 0.8 accidents per million km driven, whereas that for elderly women drivers over 70 is about 0.52 accidents per million km.

The higher risk of night driving is also evident among weekends. Male drivers under the age of 21, in particular, have a much higher risk than the rest of the population when driving at night. Compared to day driving, the crash risk of this age cohort is 3 times as high, reaching over 2.5 accidents per million km driven. This rate is also twice as high as the next most risky group, female drivers below 21. This group of young women drivers have about 1.25 accidents per million km travelled at night, which is about 50% higher than their daytime rate. Though their crash rate is much lower than the young drivers, elderly drivers over the age of 65, both sexes included, still have a higher crash risk than those in the 30-65 cohort.

Between the two sexes, it may be said that among those younger than 35 years of age, male drivers have a higher crash risk than females. But for those above 35 years old, the reverse is true. The exception to this trend is during the weekend night hours, when men drivers appear to have a higher chance of involving in a road accident than women drivers, age for age.

Changing the measure from accidents per million km travelled to accidents per 10,000 hours of travel time does not seem to materially alter the higher crash risks found among the very young and very old drivers. The U-profile observed earlier persists, as can be seen from Figures 9(a) to 9(d). The danger of night driving is also confirmed, both during weekdays and on weekends. On the whole, men drivers also appear to have a higher crash risk than women drivers.

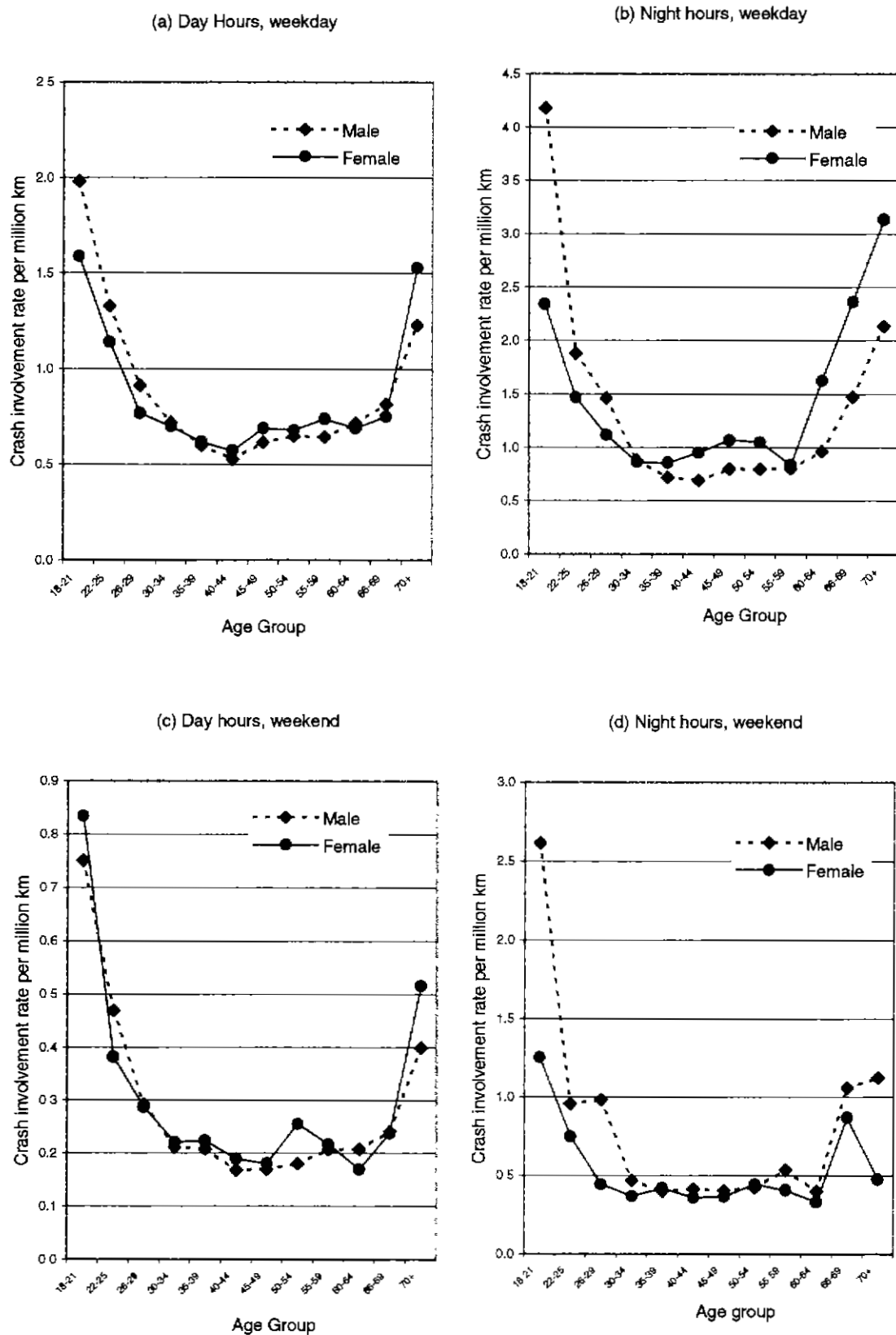


Figure 8

Crash Involvement Rate Per Million Km by Age-Sex Characteristics

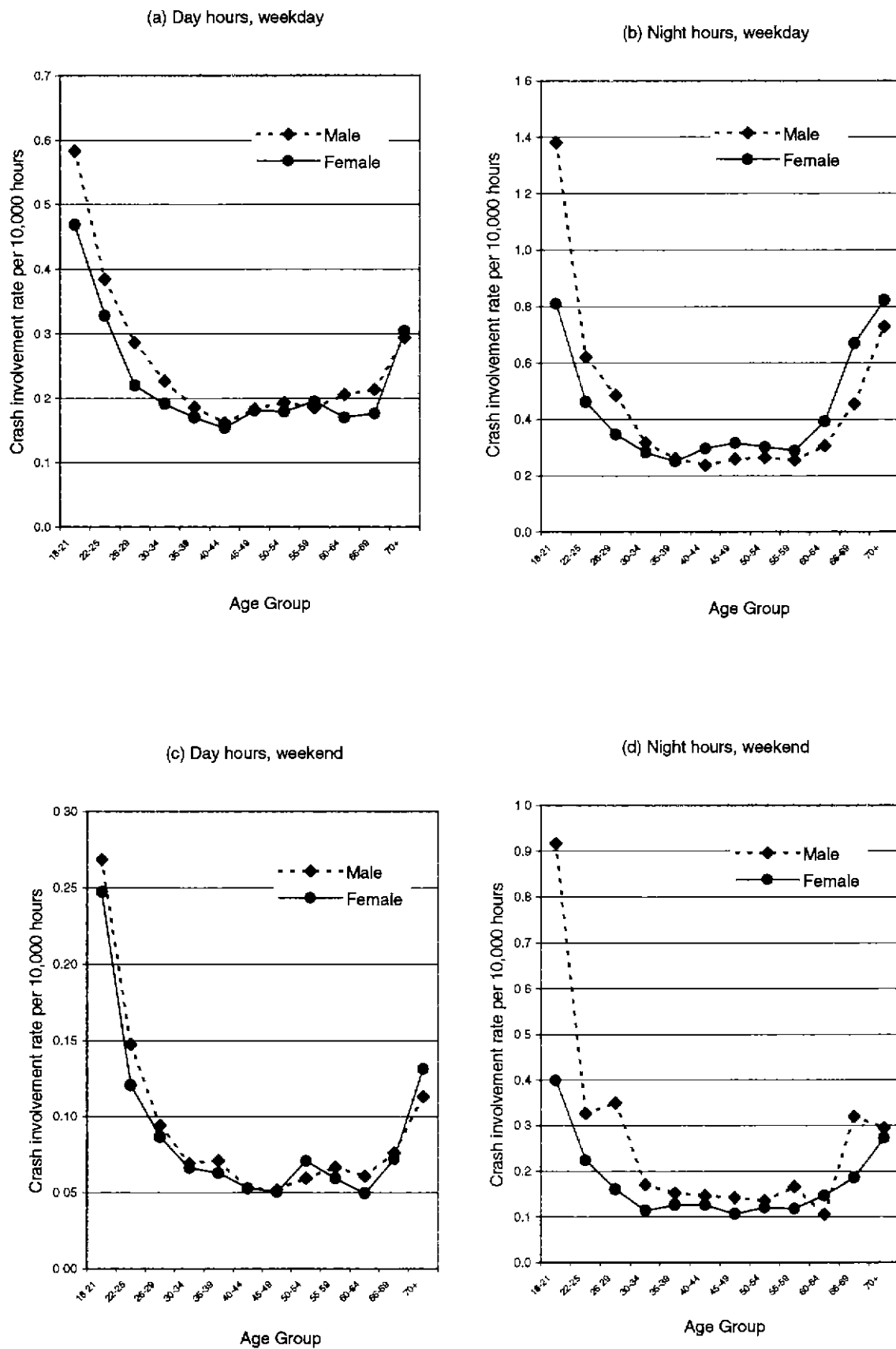


Figure 9

Crash Involvement Rate Per 10,000 Hours by Age-Sex Characteristics

5.2 CRASH RISK BASED ON TRAVEL CORRIDORS

Expressing crash rates in terms of accidents per million trip-km based on exposure per travel corridor, the familiar U-shape curve disappears when such rates are plotted against age. In its place is a polynomial function, with a general shape conforming to a cubic equation. Barring minor variations between time of day and day of week, the maxima generally lies between the 22-29 cohort and the minima is found within the 55-65 age category, as Figure 10 reveals.

Such a function suggests that the very young and very old are no longer the two most vulnerable groups. Among the male drivers, those in the 26-29 and 35-39 cohorts are two of the most crash-prone groups during the day hours of a weekday; and those in the 22-26 are the most dangerous during the day hours of weekends. The under 21s are only a problem during the evening and night hours, weekdays and weekends alike.

As for females, those in the 22-25 and 26-29 are the most risky groups of drivers regardless of day or night, weekday or weekend. These two groups of female drivers are among the most risky bunch of night-time drivers, recording a crash rate hovering between 4 and 4.5 accidents per million trip-km on weekdays and between 0.75 and 0.85 accidents per million trip-km during weekends.

Another feature distinguishing these sets of curves from those of Figures 8 and 9 is that male drivers seem to have much higher risks than female drivers for all age groups. The exceptions are those of the 22-25 and 26-29 cohorts. As pointed out earlier, females in these age groups have crash rates which far surpass those of men drivers in corresponding age categories.

Further, there seems to be little difference between the crash rates of day and night hours. These outcomes contrast very distinctly from results obtained using the conventional aggregated approach, which show that nighttime driving is far more dangerous than daytime driving. The only finding which is consistent between the two sets of approaches is that driving on a weekend is less dangerous than driving on a weekday.

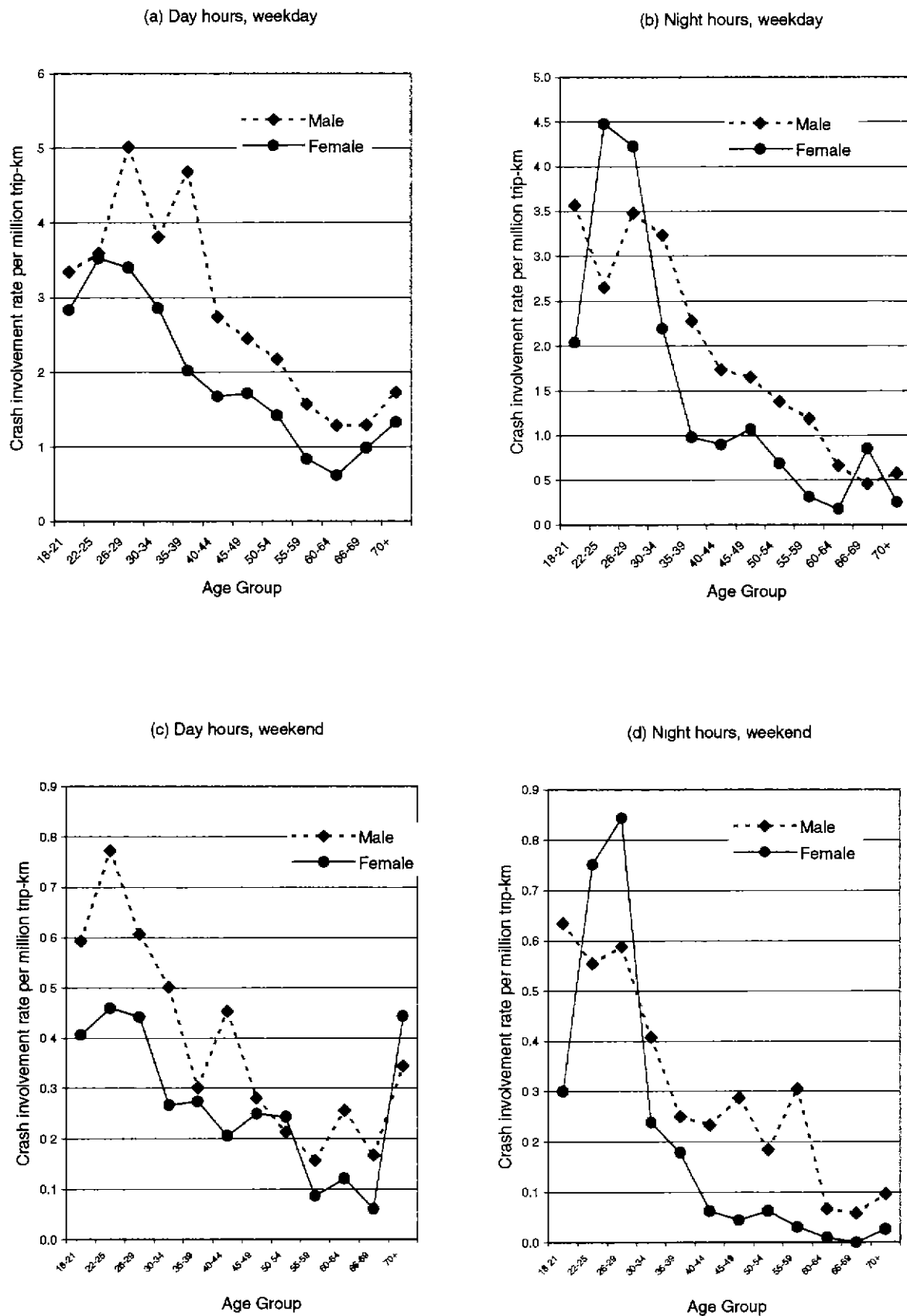


Figure 10

Crash Involvement Rate Per Million Trip-Km by Age-Sex Characteristics

When crash rates are expressed as number of accidents per 10,000 trip hours, the cubic function curve trend generally persists (Figure 11). There is close resemblance between the curves displayed on Figures 10 and 11. The only two curves which do not quite conform are those pertaining to male drivers during the evening and night hours of weekends (compare Figures 10(d) and 11(d)).

Behaviourally, these curves indicate that the young novice drivers and the aged elderly drivers are not necessarily the two most vulnerable groups, although the crash risk of those in the 18-21 cohort is still among the highest. They suggest that, perhaps owing to their lack of experience, the new licensees (as exemplified by those under 21) tend to exercise slightly greater prudence in driving than those who have already had a license for a while (as indicated by those between 22 and 29). As their skills improve with experience after the first few years, their confidence increases. At that prime age, with the confidence gained in the first few years, there is also a tendency to "show-off" some "hard-earned" skills, such as in the presence of passengers. The increase in level of crash risk among the 22-29 cohort may be interpreted as the tendency of wanting to be cautious being overpowered by the inclination to be over-confident, in contrast with the situation when they first obtained their license. But as these drivers past their thirties, the added years of driving experience may have given them a further "boost"; and with increasing confidence, their crash risk also decreases. Perhaps, after 30 is also a sign of driving maturity, such as less easily distracted, and self-discipline. With added personal and other responsibilities, drivers pass the age of 30 may have reinstated the importance of being prudent when on the road, which helps to decrease their crash risks. The decline in crash risk continues as driving experience increases. As age catches on, however, physical disabilities, such as poor vision and slower muscle reflexes, which affect driving, would start to prevail. The net result is a reversal of the declining crash rate trend. However, the present analysis suggests that this does not usually occur until post 65, in general.

Because crash rate is now determined on a trip-by-trip basis, the shorter trip distance made by the elderly no longer relegates them to a higher crash rate ratio.* Likewise, the faster driving speed, which means shorter driving time, generally associated with the young drivers no longer helps to reduce their crash risk.**

* The VATS94 to VATS97 data indicate that the average trip length of those above the age of 70 is 5.6 km, compared with the average length of 8.6 km for all drivers and between 9.5 and 10 km for those below 30 during the day-hours of weekday.

** The mean travel speed of daytime driving for those less than 30 is about 28 km per hour on a typical weekday, compared with only 20.7 km per hour for elderly over 70 years of age.

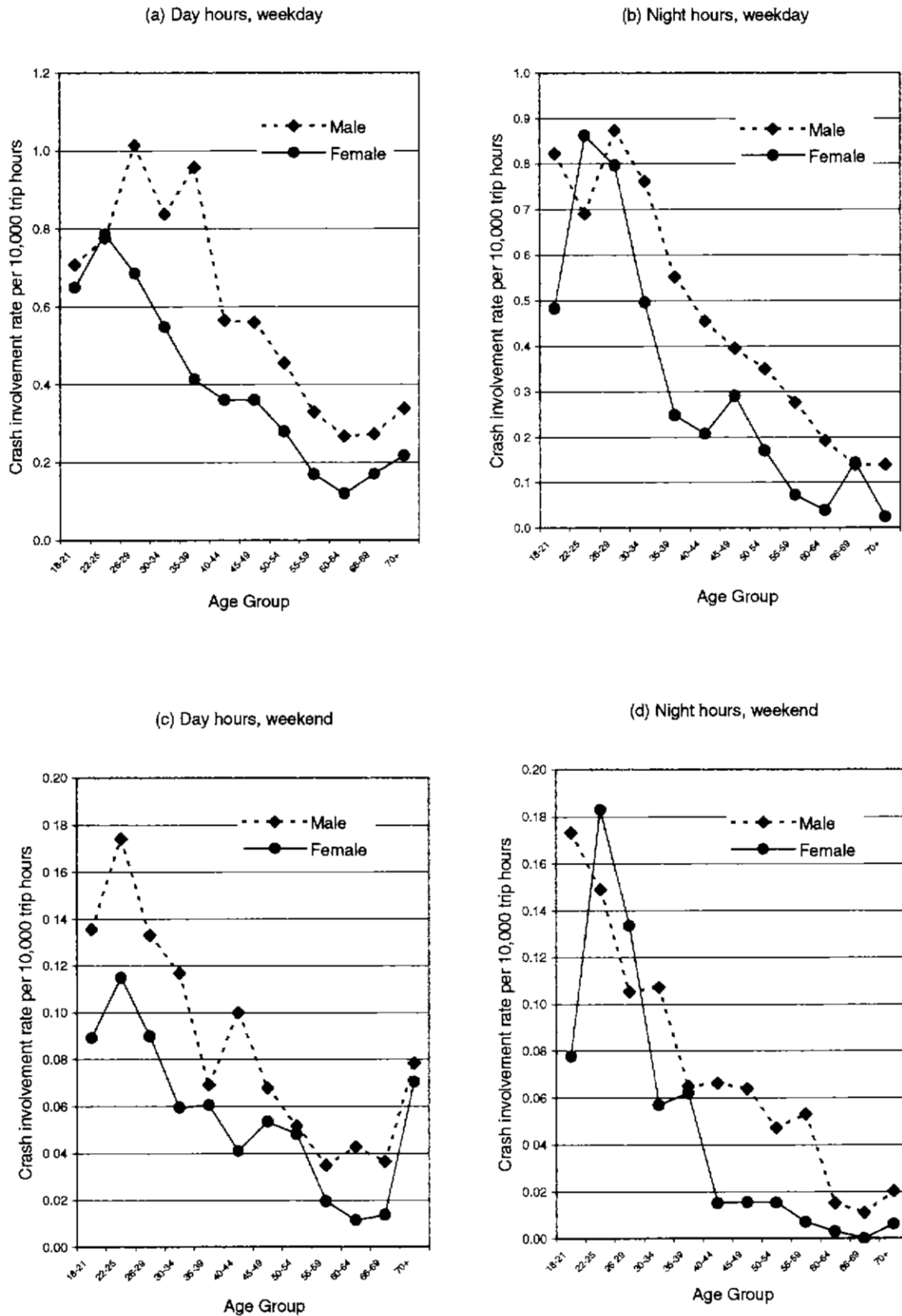


Figure 11

Crash Involvement Rate Per 10,000 Trip-Hours by Age-Sex Characteristics

5.3 CRASH RISK BASED ON TRAVEL CORRIDORS: A CONFIRMATORY ANALYSIS

To ascertain the shape of these curves, crash rates is next calculated on per trip basis at two different exposure levels: trip lengths less than 10 kilometers, and trip lengths greater than 10 kilometers. Figure 12 depicts the results of these enumerations. Again, barring minor variations, the polynomial shape described earlier continues to reign, reaffirming the results obtained in Figures 10 and 11. From the various curves shown in Figures 12 (a) to (d), trips greater than 10 kilometers in length obviously have a much higher accident risk overall. Apart from that, the curves also show that, in some cases, those in the 50-65 age groups have a much lower risk even for trips longer than 10 km than the crash risk of those in the younger cohorts for trips less than 10 km. These findings clearly suggest that accident risks need not necessarily increase with distance travelled, which is a premise implicit in the conventional aggregated approach. The crash risk differential between the "more at risk" and "less at risk" population groups is also less distinct for short trips (ie, less than 10 km) than for long trips (ie, more than 10 km), further implying that accident risk does not increase linearly with distance. Since the travel distances of the elderly are generally shorter, it thus substantiates their lower crash rates, as depicted in Figures 10 and 11. Lastly, the curves in Figure 12 also reveal that male drivers generally have a higher crash risk than female drivers, all else being equal.

To further illustrate the versatility of the travel corridor approach, the crash rates of residents in four different parts of metropolitan Melbourne are computed. The four zones used for this purpose are accordingly labeled as Central Zone, North Western Zone, North Eastern Zone and South Eastern Zone (Figure 13). The four zones have been defined to reflect the intensity of accident occurrences in the four areas (Figure 14). The underlying premise is that persons whose travel and activity spaces are predominantly confined to high accident areas would have a higher accident rate than those whose activity spaces have less incidence of accident occurrences. Figures 15 to 16 show the crash rates of male and female residents in the four zones by age groups during weekday and weekend respectively. On a typical weekday, residents from the Central Zone, which has the highest incidence of accident occurrences, have the highest crash rates. This is followed by those residing in the North-western Zone. Except for the North-eastern and South-eastern Zones, the cubic polynomial function observed earlier could also be discerned from the crash rate versus age curves for the Central and North-western Zone.

During weekends, the pattern is less distinct. This is because the crash rates during weekends is only about one-tenth of those incurred during weekdays. It may also be that the travel and activity spaces of Melbournians during weekends are more diverse and less confined to areas close to their home residence. Yet, the higher crash risk of residents in the central zone is evident. The lack of a distinctive pattern between the four zones also suggest that crash risk is a function of many factors; age or age-related factors are but one of many accident contributing factors.

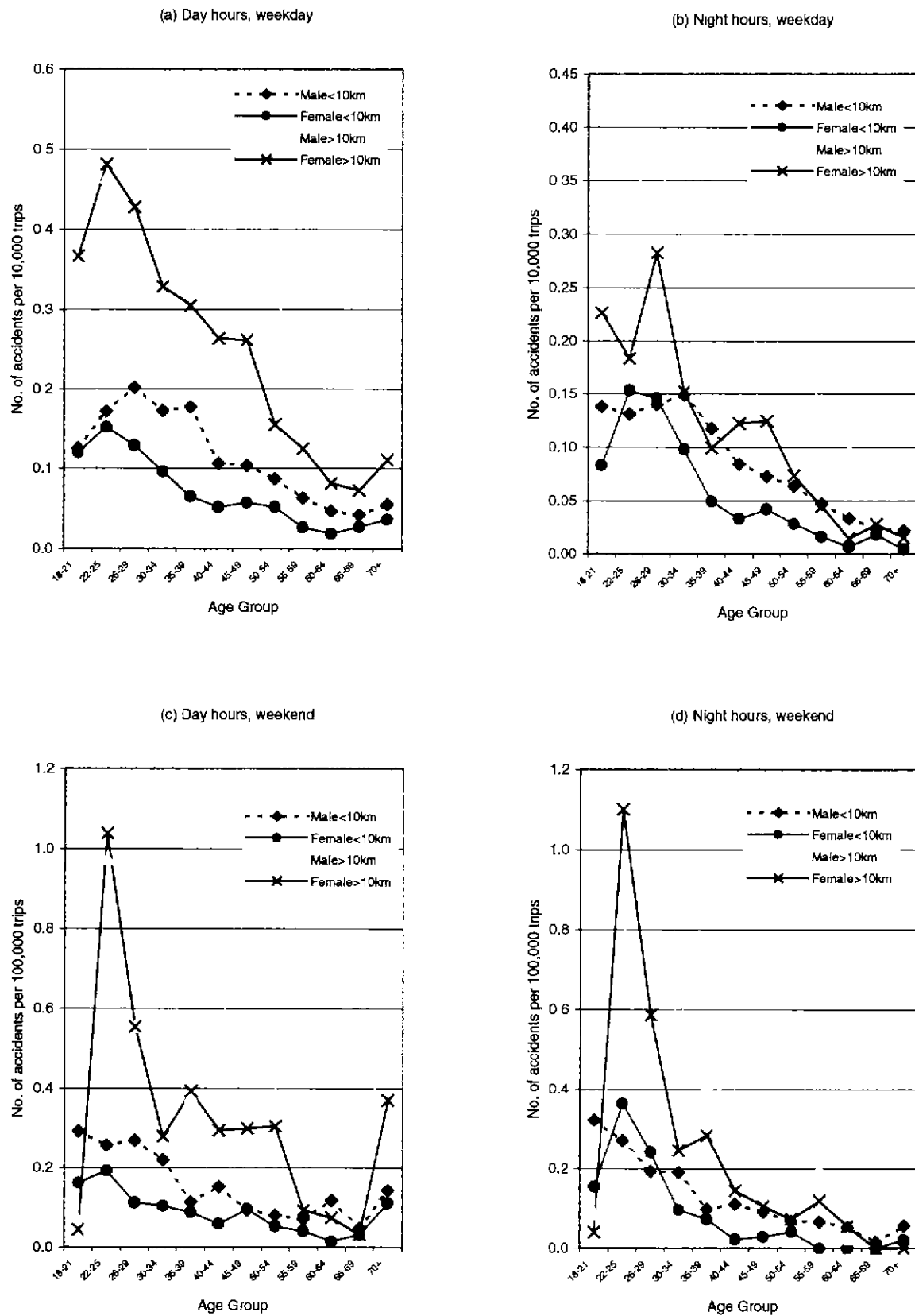


Figure 12

Crash Involvement Rate Per 10,000 Trips by Age-Sex Characteristics and Distance Travelled

It must be pointed out that the intention of showing Figures 13 and 14 is not so much in understanding why drivers residing in different parts of Melbourne may have different crash rates; but more so in demonstrating the versatility of the approach. Expectedly, people with different activity space and travel routes would be exposed to different levels of risk. With the conventional approach, such a distinction would be difficult to make as the crash rate is computed based on data already aggregated. With the current approach, this is feasible as the data can be aggregated in any fashion as the analysis warrants. This is a promise which the corridor concept could offer.

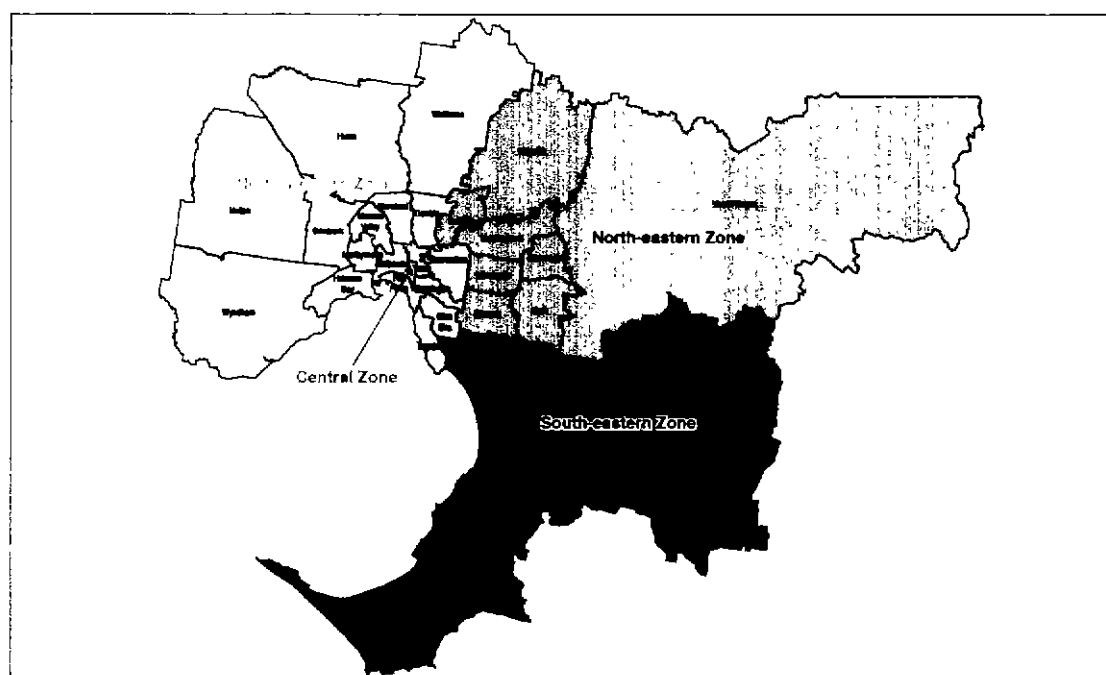


Figure 13

**Boundary of Central, North-Western, North-Eastern, and South-Eastern Zones
in Metropolitan Melbourne**

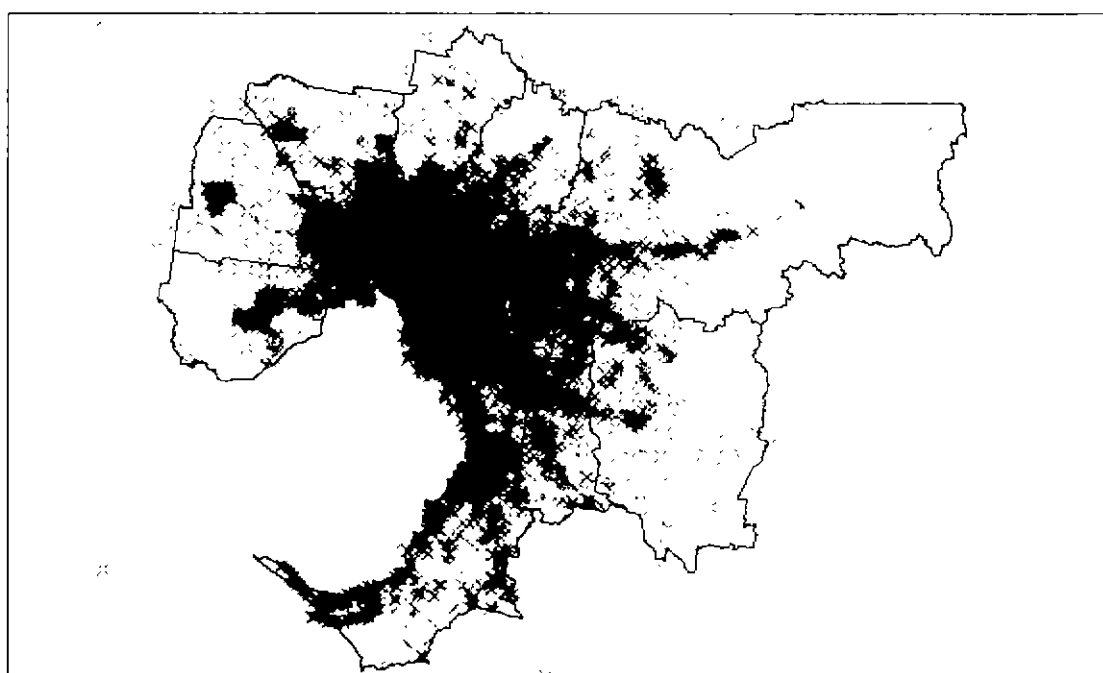


Figure 14

Incidence of Accident Occurrences in Metropolitan Melbourne

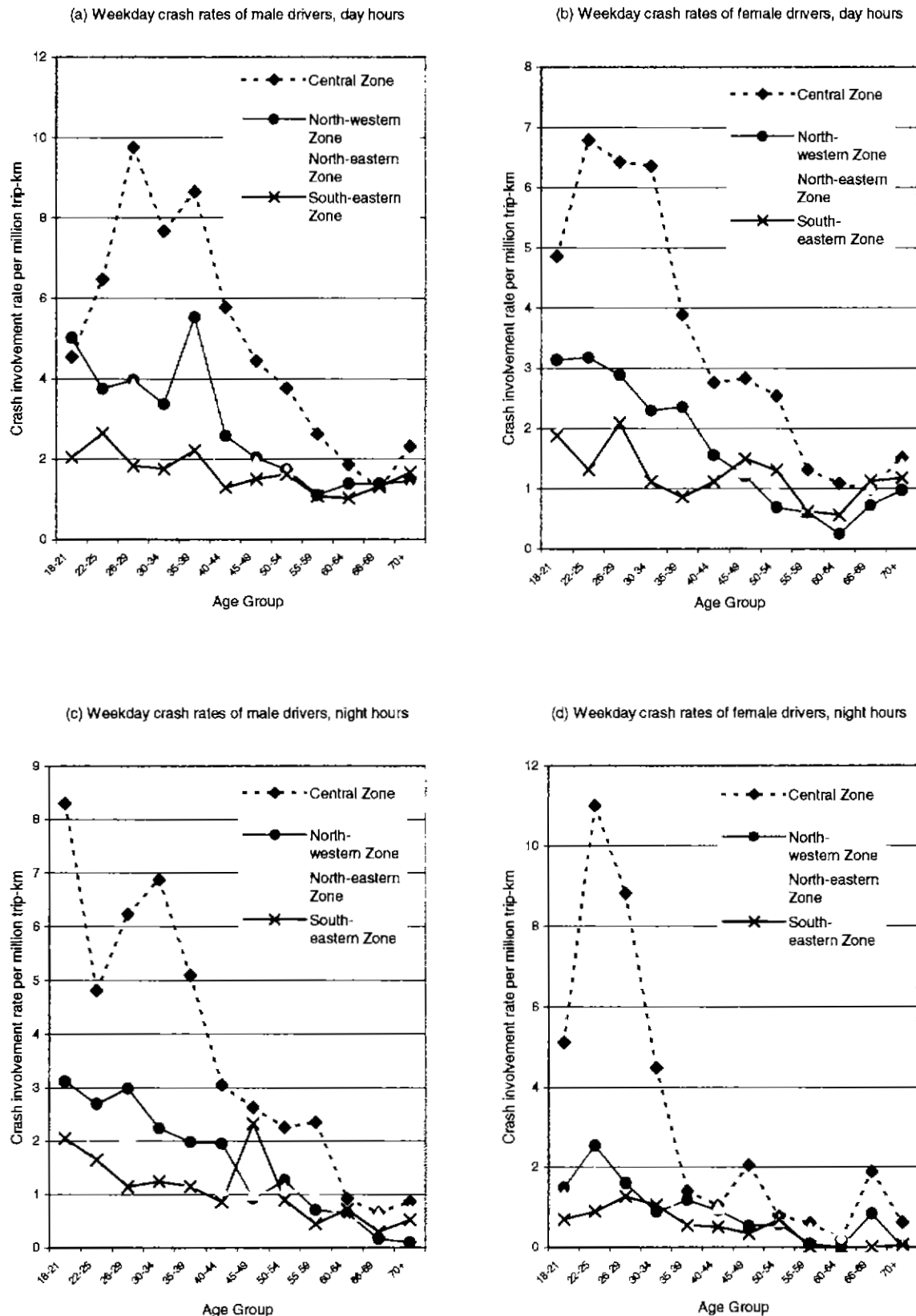


Figure 15

Crash Involvement Rate Per Million Trip-Km by Age-Sex Characteristics and Residential Zones - Weekday

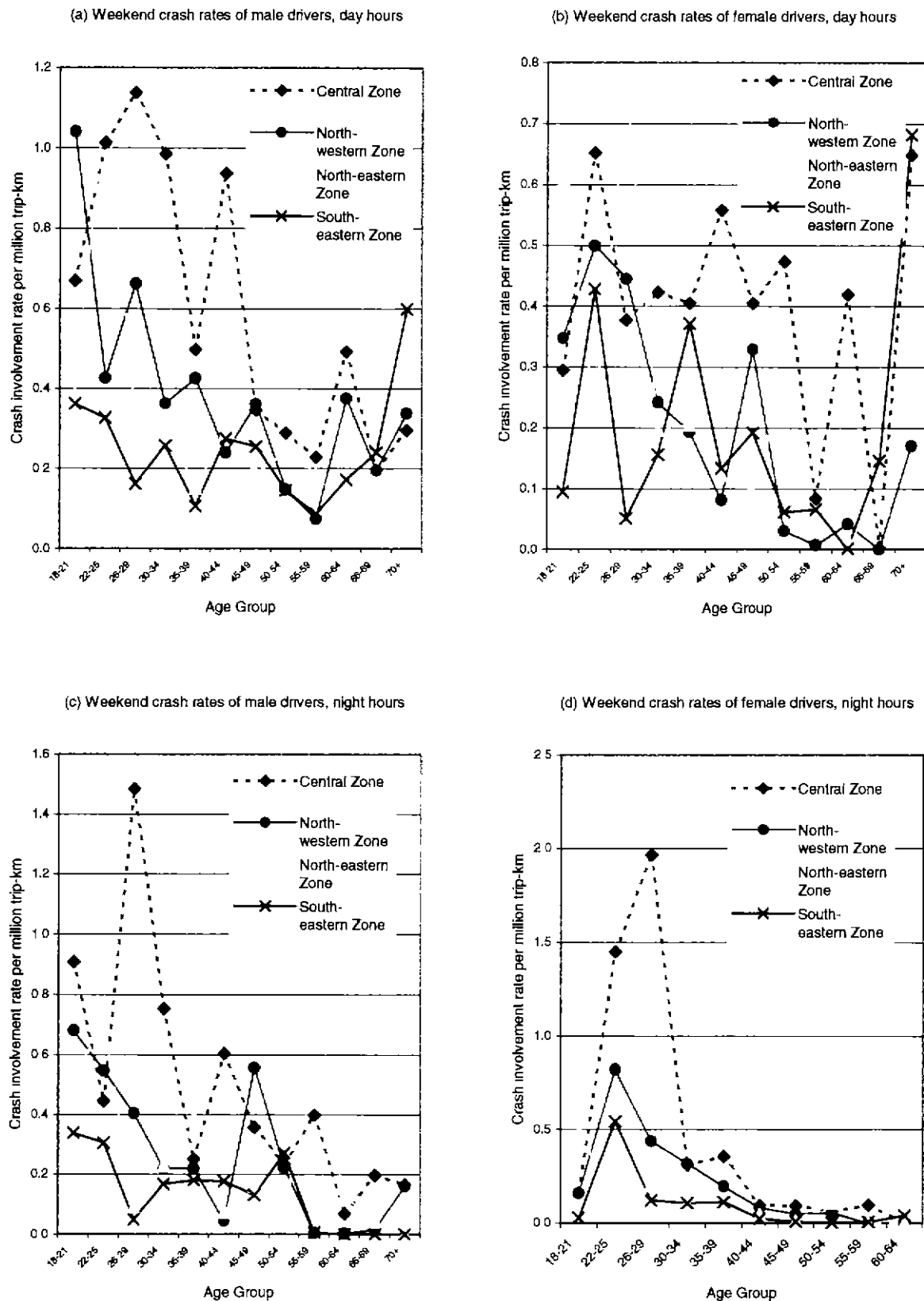


Figure 16

Crash Involvement Rate Per Million Trip-Km by Age-Sex Characteristics and Residential Zones - Weekend

CHAPTER 6

CONCLUSION AND DIRECTION FOR FUTURE RESEARCH

6.1 SUMMARY OF FINDINGS AND CONCLUSION

This study has presented a new approach to estimating crash risk. The concept on which the approach is based stems from the premise that an accident has to be understood as the interaction of three sets of environmental factors. The first set pertains to the internal car environment, which includes the driver characteristics, the behaviour of the passenger(s), if present, and the condition of the car itself. The second refers to the external physical environment. They encompass the weather, the geometric characteristics of the road as well as the condition of the roadway. The third is the dynamic traffic environment or the traffic condition on the road, which also includes the behaviour of other road users. As each trip is unique with respect to the three sets of factors, the adoption of this concept suggests that crash risk has to be examined from the perspective of the individual trips. A measure predicated on “number of accidents per trip-km”, instead of the conventional “number of accidents per km”, is proposed.

The implementation of the concept invokes the use of GIS. The development of the proposed exposure measure necessitates the capture of the three sets of factors into the computation equation. In its attempt to demonstrate the development and use of the proposed measure, this study has managed to account for the effects of some of these factors by separately examining crash rate of persons according to their age-sex characteristics, the day of the travel, and the time of travel. Linking four years of travel information pertaining to households in the Melbourne Statistical Division to corresponding road accident records, the crash risk of persons in different age-sex cohorts were computed separately for weekday and weekend, and for day and night hours. The results were also compared with those obtained using the conventional approach.

The results of the comparative analysis show that the proposed measure produces a polynomial function of a cubic order when crash rate is plotted against age group. This contrasts sharply with that derived using the conventional aggregated approach, which is a U-shape curve with population at either end of the age spectrum (ie, those below 21 and those above 70) having a higher crash rate than those in the middle. The variation of crash rate with respect to age as revealed by the polynomial function

suggests that persons in their 20s are among the most vulnerable group in terms of crash risk. The new licensees or those under 21 and senior citizens above the age of 70 are not the most accident-prone, though their crash rates are also among the highest. This observation is explained as the interactions of a number of behavioural traits which covary with age: driving experience, skills, confidence, self-discipline in terms of the relative ease of being distracted, and the atrophying of physical abilities that affect driving. A second attempt to recompute the crash rates of these population groups on a per trips basis at two different levels of exposure (trips longer than 10 km and those less than 10 km) confirms the omnipresence of the cubic function.

Being able to disaggregate crash rate down to the individual trip level implies that the proposed approach is versatile. Individual crash rate for each trip can be aggregated in any way to produce aggregated crash rate as desired. To demonstrate the versatility of the measure, separate exposure indicators were also estimated for persons residing in different parts of Metropolitan Melbourne. The results show that people residing in different parts of Melbourne have very dissimilar crash risk. Persons whose routine travel and activity spaces fall largely within high accident areas are more at-risk than those with less contact with such black spots. These findings highlight two things: the importance of having an exposure measure which can be aggregated at different levels to produce results of strategic value; and the limitation of an overall risk exposure indicator to summarily represent the crash risk for people residing at different parts of a metropolitan area.

It has long been recognised that different accident exposure measures will produce dissimilar risks of road crashes among different population groups (Chipman et al. 1992; Janke 1991, White 1976 and Foldvary 1976, 1977). The choice of exposure measures, as such, will influence our appreciation and interpretation of the accident risks affecting specific population groups. The disparate results obtained by using the conventional aggregated approach and the proposed disaggregated measure developed in this study have clearly demonstrated that. This study does not advocate that the results produced by the disaggregated approach developed are necessarily providing the "true" picture. It is, however, worthwhile to recognise the implication of formulating policy measures designed to impose driving restrictions on some apparently at-risk groups, while ignoring others who seem to be less culpable of a crash involvement. The consequence of targeting the "wrong" group in such a case needs no further elaboration.

Apart from pointing to the possible misconceptions associated with the use of the aggregated quotient of crash rate to interpret crash risk, the proposed disaggregated approach has brought forth several noteworthy features. These include:

- a conceptual recognition that each trip is unique in terms of its exposure to crash risk;
- a crash risk measure which is independent of the linearity assumption implicit in the conventional aggregated approach that crash risk increases proportionately with distance travelled; and
- a dataset in which the crash rate for each trip can be estimated and aggregated measures can be computed.

With recent advances in GIS technology and travel survey techniques, it has become possible to link two or more apparently incompatible databases through their spatial attributes. As travel and activity surveys move with the tune of time to take advantage of emerging GIS technology, incorporating spatial tracking devices, such as the Global Positioning System (GPS), into travel surveys to trace individual trips will not be a far-too-distant vision (Sarasua and Meyer 1996). Likewise, accident locations could also be readily geocoded without the burden of matching incomplete or approximate addresses. At that stage, more refined travel route and trip information will be readily available to facilitate a better linkage between travel data and accident records. The proposed exposure concept of using individual trips as a unit of road crash analysis could serve as a starting point from which other more refined GIS-based methods may evolve.

6.2 DIRECTION FOR FUTURE RESEARCH

A number of issues have arisen in the process of developing a new conceptual framework from which a GIS based methodology could be devised to link travel information from a travel and activity database to accident records. These issues pertain primarily to refinements both at the conceptual and methodological levels:

a) Conceptual Refinement:

This research has asserted that looking at exposure from the perspective of the individual trip is the way ahead to understanding exposure to accident risk. For a

given trip, the probability of an accident occurring is a function of three interacting sets of factors: the internal car environment, including the characteristics of the driver, the external physical environment and the dynamics of the traffic flow situation. In the process of operationalising the exposure concept, attempts have been made to demarcate the limits of exposure by assuming that:

- 1) the travel corridor is ± 0.5 km from the centre line of the shortest travel path;
- 2) an individual of age n would be exposed to accidents involving those between $(n-2)$ and $(n+2)$ years old, with adjustment made for the end groups (ie, under 21 and over 67); and
- 3) a trip made within a given time frame in a day is expected to be exposed to accidents occurring within one of six pre-defined time periods, the boundaries for which have been established based on the distribution of traffic on the urban network in Melbourne.

While the rationale for these assumptions have been deliberated, the statistical validity of these assumptions needs further investigation. One way to test such a validity will be to conduct a sensitivity analysis on the results by adopting different limits for these variables and compare them with the present study.

A second issue of concern is to incorporate other accident-inducing variables into the algorithm to further refine the exposure measure. Such variables may include road traffic condition at time of travel, light and weather condition at time of accident, road width and road surface condition, characteristics of other passengers in car when an accident occurs.

b) Methodological Refinement

Pertaining to each of the potential accident-causing variables used in refining the concept of exposure is the question of how to define the boundary of exposure. Methodologically, the manner in which the boundary of exposure for each accident-causing variable may be algorithmatically modified using fuzzy logic. In this study, the two-value logic is adopted: an accident is considered either within or outside the exposure boundary, with no intermediate shape of possibility. For instance, a person aged 40 is assumed to be exposed to all accidents involving persons between the age of 38 and 42, and accidents outside this boundary are excluded. By the same token,

an accident falling within the ± 0.5 km limits of the travel route is included and all accidents outside this demarcation are excluded. The adoption of some form of limits like these is, evidently, purely a mathematical convenience. The limit of exposure is imprecise. As such, a two-value logic for determining the exposure boundary is not very appropriate. As Leung (1988) puts it: "[w]hen the system is under uncertainty and is due to randomness, probability theory is a useful method of analysis. When the system is under uncertainty and is due to imprecision, fuzzy set theory appears to be an appropriate analytical framework" (p.9). Adopting the mathematics of fuzzy theory to establish the exposure boundaries represents an exciting venue for further research.

In addition to the above refinements, a range of other methodological issues awaits empirical verification. One such area is to explore the yet-to-be resolved relationship between accident risk and distance travelled at different exposure levels. One of the reasons why this issue has remain outstanding despite the repeated acknowledgement of its inherent weakness is due to the lack of suitable data to allow the derivation of a disaggregated measure. The concept of using individual trips as the premise for exploring accident risk exposure and the capability of the GIS method to link accident data to travel route have provided an avenue for deriving a disaggregated measure as illustrated in this study. It is now possible to empirically explore the nature of that relationship.

APPENDIX A

VATS QUESTIONNAIRE: HOUSEHOLD FORM

APPENDIX B

VATS QUESTIONNAIRE: TRAVEL FORM

- This questionnaire is all about your travel and activities on one particular Travel Day.

Your Travel Day is

Saturday

- Now write in your **person number**, your **first name** and the **date** of your Travel Day.

Person number

First Name

Date
of Travel
Day

- Include **all travel** over the whole day, from 4 a.m. on the Travel Day till 4 a.m. the next day.
- **Even short trips like walking to lunch and back are important.**
And, by the way, going from home to a shop and back would be 2 'stops'
– one from home to the shop, and one from the shop back home!
- Even if you did not leave the house on the Travel Day,
please tell us why in the space provided – because this is important information as well.
- Everyone should fill in these forms **for themselves.**
- However, if you are filling in the form for **children**,
please ask them if you have missed any of their travel.
- If you have any questions about how to fill in these forms,
please check the **Example Form** we have enclosed.

Now continue here:

1. Where were you at 4 a.m. on this Travel Day?

At the address to which the survey was sent?

☐

Somewhere else

☐

*(Please write in the address of
this location in the space below)*

Number

Street name

Nearest intersection/landmark

Suburb/Town

2. At what time (after 4 a.m.) did you begin the first trip of the day?

a.m.

p.m.

Now turn the page to Stop 1 ►

If you did not leave the house at all on this Travel Day, please give the reason and then **go to page 15**

▶ Stop 1

A WHAT was Stop 1? (please select one only)

A bus stop ☐

A tram stop ☐

A train station ☐
Name of station

My workplace ☐

Another workplace ☐

Pre-school/Childcare ☐

Primary/Secondary school ☐
Name of school

University/TAFE ☐
Name of university/TAFE

A petrol station ☐
Name/brand of petrol station

A shop ☐
Name of shop
Type of shop

My home ☐

Someone else's home ☐

Elsewhere (please write in)

B WHERE was Stop 1?

Number

Street name

Nearest Intersection/Landmark

Suburb/Town

C WHY did you go to Stop 1? (please select one only)

To get on or off a bus, train or tram ☐

To accompany someone ☐

To buy something ☐
What did you buy?

To pick-up or deliver something ☐

To pick-up or drop off someone ☐

To eat or drink ☐

For education ☐

For work purposes ☐

To go home ☐

Other reason (please write in)

D HOW did you get to Stop 1? (please select one only)

Walking ☐

Bicycle ☐

Taxi ☐

Go to question G

Car - as driver ☐

- as passenger ☐

Go to question E

Train ☐

Tram ☐

School bus ☐

Other bus ☐
(please write in route number or operator of bus)

Go to question F

Other (please write in)

Go to question G

E Car Trip Details

Was the car used on this trip listed on the Red Household form?

Yes ☐ No ☐

If so, what is the number of that car on the Red Household Form?

If the car was NOT listed on the Red Household form, was it a:

Company car ☐

Private car ☐

Rental car ☐

How many people, including the driver, were in the car?

What were the main streets or roads used on this trip?

Where was the car parked?

On-street ☐

Off-street ☐

Residential property ☐

Car not parked ☐

Was a parking fee paid?

No fee paid ☐

Fee paid by me ☐

Fee paid by employer ☐

Fee paid by someone else ☐

How long did it take to walk from the car to Stop 1?

minutes

Go to question G

F Public Transport Trip Details

What type of ticket was used for this trip?

2 hour ☐

Daily ☐

Weekly ☐

Monthly ☐

Yearly ☐

Other (please write in)

For what zones did this ticket apply?

Zone 1 ☐ Zone 1/2 ☐

Zone 2 ☐ Zone 2/3 ☐

Zone 3 ☐ Zone 1/2/3 ☐

Not a zonal ticket ☐

Was this ticket a:

Full adult fare ☐

Concession ☐
Type of concession

Other (please write in)

G WHEN?

Go to Stop 2

▶ Stop 2

A WHAT was Stop 2? (please select one only)

A bus stop ☐

A tram stop ☐

A train station ☐

Name of station

My workplace ☐

Another workplace ☐

Pre-school/Childcare ☐

Primary/Secondary school ☐

Name of school

University/TAFE ☐

Name of university/TAFE

A petrol station ☐

Name/brand of petrol station

A shop ☐

Name of shop

Type of shop

My home ☐

Someone else's home ☐

Elsewhere (please write in)

B WHERE was Stop 2?

Number

Street name

Nearest Intersection/Landmark

Suburb/Town

C WHY did you go to Stop 2? (please select one only)

To get on or off a bus, train or tram ☐

To accompany someone ☐

To buy something ☐

What did you buy?

To pick-up or deliver something ☐

To pick-up or drop off someone ☐

To eat or drink ☐

For education ☐

For work purposes ☐

To go home ☐

Other reason (please write in)

D HOW did you get to Stop 2? (please select one only)

Walking ☐

Bicycle ☐

Taxi ☐

Go to question G

Car – as driver ☐

– as passenger ☐

Go to question E

Train ☐

Tram ☐

School bus ☐

Other bus ☐

(please write in route number or operator of bus)

Go to question F

Other (please write in)

Go to question G

E Car Trip Details

Was the car used on this trip listed on the Red Household form?

Yes ☐ No ☐

If so, what is the number of that car on the Red Household Form?

If the car was NOT listed on the Red Household form, was it a:

Company car ☐

Private car ☐

Rental car ☐

How many people, including the driver, were in the car?

What were the main streets or roads used on this trip?

Where was the car parked?

On-street ☐

Off-street ☐

Residential property ☐

Car not parked ☐

Was a parking fee paid?

No fee paid ☐

Fee paid by me ☐

Fee paid by employer ☐

Fee paid by someone else ☐

How long did it take to walk from the car to Stop 2?

minutes

Go to question G

F Public Transport Trip Details

What type of ticket was used for this trip?

2 hour ☐

Daily ☐

Weekly ☐

Monthly ☐

Yearly ☐

Other (please write in)

For what zones did this ticket apply?

Zone 1 ☐ Zone 1/2 ☐

Zone 2 ☐ Zone 2/3 ☐

Zone 3 ☐ Zone 1/2/3 ☐

Not a zonal ticket ☐

Was this ticket a:

Full adult fare ☐

Concession ☐

Type of concession

Other (please write in)

G WHEN?

Go to Stop 3

▶ **Stop 3**

A WHAT was Stop 3? (please select one only)

A bus stop ☐

A tram stop ☐

A train station ☐
Name of station

My workplace ☐

Another workplace ☐

Pre-school/Childcare ☐

Primary/Secondary school ☐
Name of school

University/TAFE ☐
Name of university/TAFE

A petrol station ☐
Name/brand of petrol station

A shop ☐
Name of shop
Type of shop

My home ☐

Someone else's home ☐

Elsewhere (please write in)

B WHERE was Stop 3?

Number

Street name

Nearest intersection/Landmark

Suburb/Town

C WHY did you go to Stop 3? (please select one only)

To get on or off a bus, train or tram ☐

To accompany someone ☐

To buy something ☐
What did you buy?

To pick-up or deliver something ☐

To pick-up or drop off someone ☐

To eat or drink ☐

For education ☐

For work purposes ☐

To go home ☐

Other reason (please write in)

D HOW did you get to Stop 3? (please select one only)

Walking ☐

Bicycle ☐

Taxi ☐

Go to question G

Car - as driver ☐

- as passenger ☐

Go to question E

Train ☐

Tram ☐

School bus ☐

Other bus ☐
(please write in route number or operator of bus)

Go to question F

Other (please write in)

Go to question G

E Car Trip Details

Was the car used on this trip listed on the Red Household form? Yes ☐ No ☐

If so, what is the number of that car on the Red Household Form?

If the car was NOT listed on the Red Household form, was it a:

Company car ☐

Private car ☐

Rental car ☐

How many people, including the driver, were in the car?

What were the main streets or roads used on this trip?

Where was the car parked?

On-street ☐

Off-street ☐

Residential property ☐

Car not parked ☐

Was a parking fee paid?

No fee paid ☐

Fee paid by me ☐

Fee paid by employer ☐

Fee paid by someone else ☐

How long did it take to walk from the car to Stop 3?

minutes

Go to question G

F Public Transport Trip Details

What type of ticket was used for this trip?

2 hour ☐

Daily ☐

Weekly ☐

Monthly ☐

Yearly ☐

Other (please write in)

For what zones did this ticket apply?

Zone 1 ☐ Zone 1/2 ☐

Zone 2 ☐ Zone 2/3 ☐

Zone 3 ☐ Zone 1/2/3 ☐

Not a zonal ticket ☐

Was this ticket a:

Full adult fare ☐

Concession ☐
Type of concession

Other (please write in)

G WHEN?

Go to Stop 4

► Stop 4

A WHAT was Stop 4? (please select one only)

A bus stop ☐

A tram stop ☐

A train station ☐

Name of station

My workplace ☐

Another workplace ☐

Pre-school/Childcare ☐

Primary/Secondary school ☐

Name of school

University/TAFE ☐

Name of university/TAFE

A petrol station ☐

Name/brand of petrol station

A shop ☐

Name of shop

Type of shop

My home ☐

Someone else's home ☐

Elsewhere (please write in)

B WHERE was Stop 4?

Number

Street name

Nearest Intersection/Landmark

Suburb/Town

C WHY did you go to Stop 4? (please select one only)

To get on or off a bus, train or tram ☐

To accompany someone ☐

To buy something ☐

What did you buy?

To pick-up or deliver something ☐

To pick-up or drop off someone ☐

To eat or drink ☐

For education ☐

For work purposes ☐

To go home ☐

Other reason (please write in)

D HOW did you get to Stop 4? (please select one only)

Walking ☐

Bicycle ☐

Taxi ☐

Go to question G

Car – as driver ☐

– as passenger ☐

Go to question E

Train ☐

Tram ☐

School bus ☐

Other bus ☐

(please write in route number or operator of bus)

Go to question F

Other (please write in)

Go to question G

E Car Trip Details

Was the car used on this trip listed on the Red Household form?

Yes ☐ No ☐

If so, what is the number of that car on the Red Household Form?

If the car was NOT listed on the Red Household form, was it a:

Company car ☐

Private car ☐

Rental car ☐

How many people, including the driver, were in the car?

What were the main streets or roads used on this trip?

Where was the car parked?

On-street ☐

Off-street ☐

Residential property ☐

Car not parked ☐

Was a parking fee paid?

No fee paid ☐

Fee paid by me ☐

Fee paid by employer ☐

Fee paid by someone else ☐

How long did it take to walk from the car to Stop 4?

minutes

Go to question G

F Public Transport Trip Details

What type of ticket was used for this trip?

2 hour ☐

Daily ☐

Weekly ☐

Monthly ☐

Yearly ☐

Other (please write in)

For what zones did this ticket apply?

Zone 1 ☐ Zone 1/2 ☐

Zone 2 ☐ Zone 2/3 ☐

Zone 3 ☐ Zone 1/2/3 ☐

Not a zonal ticket ☐

Was this ticket a:

Full adult fare ☐

Concession ☐

Type of concession

Other (please write in)

G WHEN?

Go to Stop 5

► Stop 6

A WHAT was Stop 6? (please select one only)

A bus stop ☐

A tram stop ☐

A train station ☐

Name of station

My workplace ☐

Another workplace ☐

Pre-school/Childcare ☐

Primary/Secondary school ☐

Name of school

University/TAFE ☐

Name of university/TAFE

A petrol station ☐

Name/brand of petrol station

A shop ☐

Name of shop

Type of shop

My home ☐

Someone else's home ☐

Elsewhere (please write in)

B WHERE was Stop 6?

Number

Street name

Nearest Intersection/Landmark

Suburb/Town

C WHY did you go to Stop 6? (please select one only)

To get on or off a bus, train or tram ☐

To accompany someone ☐

To buy something ☐

What did you buy?

To pick-up or deliver something ☐

To pick-up or drop off someone ☐

To eat or drink ☐

For education ☐

For work purposes ☐

To go home ☐

Other reason (please write in)

D HOW did you get to Stop 6? (please select one only)

Walking ☐

Bicycle ☐

Taxi ☐

Go to question G

Car – as driver ☐

– as passenger ☐

Go to question E

Train ☐

Tram ☐

School bus ☐

Other bus ☐

(please write in route number or operator of bus)

Go to question F

Other (please write in)

Go to question G

E Car Trip Details

Was the car used on this trip listed on the Red Household form?

Yes ☐ No ☐

If so, what is the number of that car on the Red Household Form?

If the car was NOT listed on the Red Household form, was it a:

Company car ☐

Private car ☐

Rental car ☐

How many people, including the driver, were in the car?

What were the main streets or roads used on this trip?

Where was the car parked?

On-street ☐

Off-street ☐

Residential property ☐

Car not parked ☐

Was a parking fee paid?

No fee paid ☐

Fee paid by me ☐

Fee paid by employer ☐

Fee paid by someone else ☐

How long did it take to walk from the car to Stop 6?

minutes

Go to question G

F Public Transport Trip Details

What type of ticket was used for this trip?

2 hour ☐

Daily ☐

Weekly ☐

Monthly ☐

Yearly ☐

Other (please write in)

For what zones did this ticket apply?

Zone 1 ☐ Zone 1/2 ☐

Zone 2 ☐ Zone 2/3 ☐

Zone 3 ☐ Zone 1/2/3 ☐

Not a zonal ticket ☐

Was this ticket a:

Full adult fare ☐

Concession ☐

Type of concession

Other (please write in)

G WHEN?

Go to Stop 7

▶ Stop 7

A WHAT was Stop 7? (please select one only)

☐ A bus stop
☐ A tram stop
☐ A train station
☐ Name of station
☐ My workplace
☐ Another workplace
☐ Pre-school/Childcare
☐ Primary/Secondary school
☐ Name of school
☐ University/TAFE
☐ Name of university/TAFE
☐ A petrol station
☐ Name/brand of petrol station
☐ A shop
☐ Name of shop
☐ Type of shop
☐ My home
☐ Someone else's home
☐ Elsewhere (please write in)

B WHERE was Stop 7?

Number
 Street name
 Nearest Intersection/Landmark
 Suburb/Town

C WHY did you go to Stop 7? (please select one only)

☐ To get on or off a bus, train or tram
☐ To accompany someone
☐ To buy something
☐ What did you buy?
☐ To pick-up or deliver something
☐ To pick-up or drop off someone
☐ To eat or drink
☐ For education
☐ For work purposes
☐ To go home
☐ Other reason (please write in)

D HOW did you get to Stop 7? (please select one only)

☐ Walking
☐ Bicycle
☐ Taxi

Go to question G

☐ Car – as driver
☐ – as passenger

Go to question E

☐ Train
☐ Tram
☐ School bus
☐ Other bus
 (please write in route number or operator of bus)

Go to question F

Other (please write in)

Go to question G

E Car Trip Details

Was the car used on this trip listed on the Red Household form?
Yes ☐ No ☐
If so, what is the number of that car on the Red Household Form?
If the car was NOT listed on the Red Household form, was it a:
Company car ☐
Private car ☐
Rental car ☐
How many people, including the driver, were in the car?

What were the main streets or roads used on this trip?

Where was the car parked?

☐ On-street
☐ Off-street
☐ Residential property
☐ Car not parked

Was a parking fee paid?

☐ No fee paid
☐ Fee paid by me
☐ Fee paid by employer
☐ Fee paid by someone else

How long did it take to walk from the car to Stop 7?

minutes

Go to question G

F Public Transport Trip Details

What type of ticket was used for this trip?

☐ 2 hour
☐ Daily
☐ Weekly
☐ Monthly
☐ Yearly
☐ Other (please write in)

For what zones did this ticket apply?

Zone 1 ☐ Zone 1/2 ☐
Zone 2 ☐ Zone 2/3 ☐
Zone 3 ☐ Zone 1/2/3 ☐
☐ Not a zonal ticket

Was this ticket a:

☐ Full adult fare
☐ Concession
 Type of concession

Other (please write in)

G WHEN?

☐
☐
☐

Go to Stop 8

▶ Stop 8

A WHAT was Stop 8? (please select one only)

A bus stop ☐

A tram stop ☐

A train station ☐

Name of station

My workplace ☐

Another workplace ☐

Pre-school/Childcare ☐

Primary/Secondary school ☐

Name of school

University/TAFE ☐

Name of university/TAFE

A petrol station ☐

Name/brand of petrol station

A shop ☐

Name of shop

Type of shop

My home ☐

Someone else's home ☐

Elsewhere (please write in)

B WHERE was Stop 8?

Number

Street name

Nearest Intersection/Landmark

Suburb/Town

C WHY did you go to Stop 8? (please select one only)

To get on or off a bus, train or tram ☐

To accompany someone ☐

To buy something ☐

What did you buy?

To pick-up or deliver something ☐

To pick-up or drop off someone ☐

To eat or drink ☐

For education ☐

For work purposes ☐

To go home ☐

Other reason (please write in)

D HOW did you get to Stop 8? (please select one only)

Walking ☐

Bicycle ☐

Taxi ☐

Go to question G

Car – as driver ☐

– as passenger ☐

Go to question E

Train ☐

Tram ☐

School bus ☐

Other bus ☐

(please write in route number or operator of bus)

Go to question F

Other (please write in)

Go to question G

E Car Trip Details

Was the car used on this trip listed on the Red Household form?

Yes ☐ No ☐

If so, what is the number of that car on the Red Household Form?

If the car was NOT listed on the Red Household form, was it a:

Company car ☐

Private car ☐

Rental car ☐

How many people, including the driver, were in the car?

What were the main streets or roads used on this trip?

Where was the car parked?

On-street ☐

Off-street ☐

Residential property ☐

Car not parked ☐

Was a parking fee paid?

No fee paid ☐

Fee paid by me ☐

Fee paid by employer ☐

Fee paid by someone else ☐

How long did it take to walk from the car to Stop 8?

minutes

Go to question G

F Public Transport Trip Details

What type of ticket was used for this trip?

2 hour ☐

Daily ☐

Weekly ☐

Monthly ☐

Yearly ☐

Other (please write in)

For what zones did this ticket apply?

Zone 1 ☐ Zone 1/2 ☐

Zone 2 ☐ Zone 2/3 ☐

Zone 3 ☐ Zone 1/2/3 ☐

Not a zonal ticket ☐

Was this ticket a:

Full adult fare ☐

Concession ☐

Type of concession

Other (please write in)

G WHEN?



Go to Stop 9

▶ Stop 9

A WHAT was Stop 9? (please select one only)

A bus stop ☐

A tram stop ☐

A train station ☐

Name of station

My workplace ☐

Another workplace ☐

Pre-school/Childcare ☐

Primary/Secondary school ☐

Name of school

University/TAFE ☐

Name of university/TAFE

A petrol station ☐

Name/brand of petrol station

A shop ☐

Name of shop

Type of shop

My home ☐

Someone else's home ☐

Elsewhere (please write in)

B WHERE was Stop 9?

Number

Street name

Nearest Intersection/Landmark

Suburb/Town

C WHY did you go to Stop 9? (please select one only)

To get on or off a bus, train or tram ☐

To accompany someone ☐

To buy something ☐

What did you buy?

To pick-up or deliver something ☐

To pick-up or drop off someone ☐

To eat or drink ☐

For education ☐

For work purposes ☐

To go home ☐

Other reason (please write in)

D HOW did you get to Stop 9? (please select one only)

Walking ☐

Bicycle ☐

Taxi ☐

Go to question G

Car – as driver ☐

– as passenger ☐

Go to question E

Train ☐

Tram ☐

School bus ☐

Other bus ☐

(please write in route number or operator of bus)

Go to question F

Other (please write in)

Go to question G

E Car Trip Details

Was the car used on this trip listed on the Red Household form?

Yes ☐ No ☐

If so, what is the number of that car on the Red Household Form?

If the car was NOT listed on the Red Household form, was it a:

Company car ☐

Private car ☐

Rental car ☐

How many people, including the driver, were in the car?

What were the main streets or roads used on this trip?

Where was the car parked?

On-street ☐

Off-street ☐

Residential property ☐

Car not parked ☐

Was a parking fee paid?

No fee paid ☐

Fee paid by me ☐

Fee paid by employer ☐

Fee paid by someone else ☐

How long did it take to walk from the car to Stop 9?

minutes

Go to question G

F Public Transport Trip Details

What type of ticket was used for this trip?

2 hour ☐

Daily ☐

Weekly ☐

Monthly ☐

Yearly ☐

Other (please write in)

For what zones did this ticket apply?

Zone 1 ☐ Zone 1/2 ☐

Zone 2 ☐ Zone 2/3 ☐

Zone 3 ☐ Zone 1/2/3 ☐

Not a zonal ticket ☐

Was this ticket a:

Full adult fare ☐

Concession ☐

Type of concession

Other (please write in)

G WHEN?



Go to Stop 10

▶ Stop 10

A WHAT was Stop 10? (please select one only)

A bus stop ☐

A tram stop ☐

A train station ☐

Name of station

My workplace ☐

Another workplace ☐

Pre-school/Childcare ☐

Primary/Secondary school ☐

Name of school

University/TAFE ☐

Name of university/TAFE

A petrol station ☐

Name/brand of petrol station

A shop ☐

Name of shop

Type of shop

My home ☐

Someone else's home ☐

Elsewhere (please write in)

B WHERE was Stop 10?

Number

Street name

Nearest Intersection/Landmark

Suburb/Town

C WHY did you go to Stop 10? (please select one only)

To get on or off a bus, train or tram ☐

To accompany someone ☐

To buy something ☐

What did you buy?

To pick-up or deliver something ☐

To pick-up or drop off someone ☐

To eat or drink ☐

For education ☐

For work purposes ☐

To go home ☐

Other reason (please write in)

D HOW did you get to Stop 10? (please select one only)

Walking ☐

Bicycle ☐

Taxi ☐

Go to question G

Car - as driver ☐

- as passenger ☐

Go to question E

Train ☐

Tram ☐

School bus ☐

Other bus ☐

(please write in route number or operator of bus)

Go to question F

Other (please write in)

Go to question G

E Car Trip Details

Was the car used on this trip listed on the Red Household form? Yes ☐ No ☐

If so, what is the number of that car on the Red Household Form?

If the car was NOT listed on the Red Household form, was it a:

Company car ☐

Private car ☐

Rental car ☐

How many people, including the driver, were in the car?

What were the main streets or roads used on this trip?

Where was the car parked?

On-street ☐

Off-street ☐

Residential property ☐

Car not parked ☐

Was a parking fee paid?

No fee paid ☐

Fee paid by me ☐

Fee paid by employer ☐

Fee paid by someone else ☐

How long did it take to walk from the car to Stop 10?

minutes

Go to question G

F Public Transport Trip Details

What type of ticket was used for this trip?

2 hour ☐

Daily ☐

Weekly ☐

Monthly ☐

Yearly ☐

Other (please write in)

For what zones did this ticket apply?

Zone 1 ☐ Zone 1/2 ☐

Zone 2 ☐ Zone 2/3 ☐

Zone 3 ☐ Zone 1/2/3 ☐

Not a zonal ticket ☐

Was this ticket a:

Full adult fare ☐

Concession ☐

Type of concession

Other (please write in)

G WHEN?

Go to Stop 11

▶ Stop 11

A WHAT was Stop 11? (please select one only)

A bus stop ☐

A tram stop ☐

A train station ☐

Name of station

My workplace ☐

Another workplace ☐

Pre-school/Childcare ☐

Primary/Secondary school ☐

Name of school

University/TAFE ☐

Name of university/TAFE

A petrol station ☐

Name/brand of petrol station

A shop ☐

Name of shop

Type of shop

My home ☐

Someone else's home ☐

Elsewhere (please write in)

B WHERE was Stop 11?

Number

Street name

Nearest Intersection/Landmark

Suburb/Town

C WHY did you go to Stop 11? (please select one only)

To get on or off a bus, train or tram ☐

To accompany someone ☐

To buy something ☐

What did you buy?

To pick-up or deliver something ☐

To pick-up or drop off someone ☐

To eat or drink ☐

For education ☐

For work purposes ☐

To go home ☐

Other reason (please write in)

D HOW did you get to Stop 11? (please select one only)

Walking ☐

Bicycle ☐

Taxi ☐

Go to question G

Car – as driver ☐

– as passenger ☐

Go to question E

Train ☐

Tram ☐

School bus ☐

Other bus ☐

(please write in route number or operator of bus)

Go to question F

Other (please write in)

Go to question G

E Car Trip Details

Was the car used on this trip listed on the Red Household form?

Yes ☐ No ☐

If so, what is the number of that car on the Red Household Form?

If the car was NOT listed on the Red Household form, was it a:

Company car ☐

Private car ☐

Rental car ☐

How many people, including the driver, were in the car?

What were the main streets or roads used on this trip?

Where was the car parked?

On-street ☐

Off-street ☐

Residential property ☐

Car not parked ☐

Was a parking fee paid?

No fee paid ☐

Fee paid by me ☐

Fee paid by employer ☐

Fee paid by someone else ☐

How long did it take to walk from the car to Stop 11?

minutes

Go to question G

F Public Transport Trip Details

What type of ticket was used for this trip?

2 hour ☐

Daily ☐

Weekly ☐

Monthly ☐

Yearly ☐

Other (please write in)

For what zones did this ticket apply?

Zone 1 ☐ Zone 1/2 ☐

Zone 2 ☐ Zone 2/3 ☐

Zone 3 ☐ Zone 1/2/3 ☐

Not a zonal ticket ☐

Was this ticket a:

Full adult fare ☐

Concession ☐

Type of concession

Other (please write in)

G WHEN?

Go to Stop 12

► Stop 12

A WHAT was Stop 12? (please select one only)

☐ A bus stop
☐ A tram stop
☐ A train station
 Name of station
☐ My workplace
☐ Another workplace
☐ Pre-school/Childcare
☐ Primary/Secondary school
 Name of school
☐ University/TAFE
 Name of university/TAFE
☐ A petrol station
 Name/brand of petrol station
☐ A shop
 Name of shop
 Type of shop
☐ My home
☐ Someone else's home
 Elsewhere (please write in)

B WHERE was Stop 12?

Number
 Street name
 Nearest Intersection/Landmark
 Suburb/Town

C WHY did you go to Stop 12? (please select one only)

☐ To get on or off a bus, train or tram
☐ To accompany someone
☐ To buy something
 What did you buy?
☐ To pick-up or deliver something
☐ To pick-up or drop off someone
☐ To eat or drink
☐ For education
☐ For work purposes
☐ To go home
☐ Other reason (please write in)

D HOW did you get to Stop 12? (please select one only)

☐ Walking
☐ Bicycle
☐ Taxi
☐ Car - as driver
☐ - as passenger

Go to question G

Go to question E

☐ Train
☐ Tram
☐ School bus
☐ Other bus
 (please write in route number or operator of bus)

Go to question F

Other (please write in)

Go to question G

E Car Trip Details

Was the car used on this trip listed on the Red Household form?

Yes ☐ No ☐

If so, what is the number of that car on the Red Household Form?

If the car was NOT listed on the Red Household form, was it a:

☐ Company car
☐ Private car
☐ Rental car

How many people, including the driver, were in the car?

What were the main streets or roads used on this trip?

Where was the car parked?

☐ On-street
☐ Off-street
☐ Residential property
☐ Car not parked

Was a parking fee paid?

☐ No fee paid
☐ Fee paid by me
☐ Fee paid by employer
☐ Fee paid by someone else

How long did it take to walk from the car to Stop 12?

minutes

Go to question G

F Public Transport Trip Details

What type of ticket was used for this trip?

☐ 2 hour
☐ Daily
☐ Weekly
☐ Monthly
☐ Yearly
☐ Other (please write in)

For what zones did this ticket apply?

☐ Zone 1 ☐ Zone 1/2
☐ Zone 2 ☐ Zone 2/3
☐ Zone 3 ☐ Zone 1/2/3
☐ Not a zonal ticket

Was this ticket a:

☐ Full adult fare
☐ Concession
 Type of concession
☐ Other (please write in)

G WHEN?

Go to Stop 13 ►

▶ Stop 13

A WHAT was Stop 13? (please select one only)

A bus stop ☐

A tram stop ☐

A train station ☐

Name of station

My workplace ☐

Another workplace ☐

Pre-school/Childcare ☐

Primary/Secondary school ☐

Name of school

University/TAFE ☐

Name of university/TAFE

A petrol station ☐

Name/brand of petrol station

A shop ☐

Name of shop

Type of shop

My home ☐

Someone else's home ☐

Elsewhere (please write in)

B WHERE was Stop 13?

Number

Street name

Nearest Intersection/Landmark

Suburb/Town

C WHY did you go to Stop 13? (please select one only)

To get on or off a bus, train or tram ☐

To accompany someone ☐

To buy something ☐

What did you buy?

To pick-up or deliver something ☐

To pick-up or drop off someone ☐

To eat or drink ☐

For education ☐

For work purposes ☐

To go home ☐

Other reason (please write in)

D HOW did you get to Stop 13? (please select one only)

Walking ☐

Bicycle ☐

Taxi ☐

Go to question G

Car – as driver ☐

– as passenger ☐

Go to question E

Train ☐

Tram ☐

School bus ☐

Other bus ☐

(please write in route number or operator of bus)

Go to question F

Other (please write in)

Go to question G

E Car Trip Details

Was the car used on this trip listed on the Red Household form?

Yes ☐ No ☐

If so, what is the number of that car on the Red Household Form?

If the car was NOT listed on the Red Household form, was it a:

Company car ☐

Private car ☐

Rental car ☐

How many people, including the driver, were in the car?

What were the main streets or roads used on this trip?

Where was the car parked?

On-street ☐

Off-street ☐

Residential property ☐

Car not parked ☐

Was a parking fee paid?

No fee paid ☐

Fee paid by me ☐

Fee paid by employer ☐

Fee paid by someone else ☐

How long did it take to walk from the car to Stop 13?

minutes

Go to question G

F Public Transport Trip Details

What type of ticket was used for this trip?

2 hour ☐

Daily ☐

Weekly ☐

Monthly ☐

Yearly ☐

Other (please write in)

For what zones did this ticket apply?

Zone 1 ☐ Zone 1/2 ☐

Zone 2 ☐ Zone 2/3 ☐

Zone 3 ☐ Zone 1/2/3 ☐

Not a zonal ticket ☐

Was this ticket a:

Full adult fare ☐

Concession ☐

Type of concession

Other (please write in)

G WHEN?

Go to new booklet ▶

**What is the total income (including pensions and allowances)
that you usually receive each week from all sources?**

Count all income including:

family allowance
family allowance supplement
pensions
unemployment benefits
student allowance
maintenance (child support)
worker's compensation
superannuation
wages
salary
overtime
dividends
rents received
interest received
business or farm income
(less expenses of operation)

Nil income

☐

\$1 to \$39 per week
(\$1 to \$2,079 per year)

☐

\$40 to \$79 per week
(\$2,080 to \$4,159 per year)

☐

\$80 to \$119 per week
(\$4,160 to \$6,239 per year)

☒

\$120 to \$159 per week
(\$6,240 to \$8,319 per year)

☐

\$160 to \$199 per week
(\$8,320 to \$10,399 per year)

☒

\$200 to \$299 per week
(\$10,400 to \$15,599 per year)

☐

\$300 to \$399 per week
(\$15,600 to \$20,799 per year)

☐

\$400 to \$499 per week
(\$20,800 to \$25,999 per year)

☒

Do not deduct:

tax
superannuation
health insurance

\$500 to \$599 per week
(\$26,000 to \$31,199 per year)

☒

\$600 to \$699 per week
(\$31,200 to \$36,399 per year)

☒

\$700 to \$799 per week
(\$36,400 to \$41,599 per year)

☒

\$800 to \$999 per week
(\$41,600 to \$51,999 per year)

☐

\$1,000 to \$1,499 per week
(\$52,000 to \$77,999 per year)

☒

\$1,500 or more per week
(\$78,000 or more per year)

☐

Thank you very much for your help.

REFERENCES

- Armitage, P. and Berry, G. (1987) *Statistical Methods in Medical Research*, 2nd edn. Blackwell Scientific Publications, Oxford, U.K.
- Burg, A. (1973) *The Effects of Exposure to Risk on Driving Record*, Los Angeles, CA, University of California.
- California Business, Transportation, and Housing Agency (1985) *1984 Accident Data on California State Highways (Road miles, Travel, Accident, Accident Rates)*. Department of Transportation, Division of Traffic Engineering, Sacramento.
- Carroll, P.S. (1971) *The Meaning of Driving Exposure*, HIT-Lab Reports 1:1-3, Highway Safety Research Institute, University of Michigan.
- Carroll, P.S. (1973) "Classifications of Driver Exposure and Accident Rates for Highway Safety Analysis," *Accid. Anal. and Prev.*, 5:81-94, Pergamon, London.
- Caliper Corporation (1996) *TransCAD – Transportation GIS Software*, User's Guide, Massachusetts.
- Chipman, M.L. (1982) "The Role of Exposure, Experience and Demerit Point Levels in the Risk of Collision," *Accid. Anal. and Prev.*, 14:475-483, Pergamon, London.
- Chipman, M.L. and MacGregor, C.G. (1990) "Time vs Distance as Measures of Exposure in Driving Surveys." *Proceedings of the 34th Conference of the Association for the Advancement of Automotive Medicine*, 421-432, Scottsdale, Arizona
- Chipman, M.L., MacGregor, C.G., Smiley, A.M. and Lee-Gosselin, M. (1992) "Time vs Distance as Measures of Exposure in Driving Surveys." *Accid. Anal. and Prev.*, 24:679-684, Pergamon, London.
- Chipman, M.L., MacGregor, C.G., Smiley, A.M. and Lee-Gosselin, M. (1993) "The Role of Exposure in Comparisons of Crash Risk Among Different Drivers and Drinking Environments," *Accid. Anal. and Prev.*, 25:207-211, Pergamon, London.

- Doherty, S.T., Andrey, J.C. and MacGregor, C. (1998) "The Situational Risks of Young Drivers: The Influence of Passengers, Time of Day and Day of Week on Accident Rates," *Accid. Anal. and Prev.*, 30:45-52, Pergamon, London.
- Frantzeskakis, J. M. (1983) Accident Analysis on Two-Controlled Access National Highways in Greece. *ITE Journal*, 53,2,26-32.
- Freedman A. N., Michalek A.M., Marshall J. R., Mettlin C. J., Petrelli N. J., Zhang Z. F., Black J. D., Satchidanand S and Asirwatham J. E. (1996) "The Relationship between Smoking Exposure and Overexpression in colorectal cancer," *Br. J. Cancer*, 902-8.
- Foldvary, L.A. (1976) "Road Accident Involvement per Miles Travelled-II," *Accid. Anal. and Prev.*, 8:97-127, Pergamon, London.
- Foldvary, L.A. (1977) "Road Accident Involvement per Miles Travelled-III," *Accid. Anal. and Prev.*, 9:21-54, Pergamon, London.
- Hauer, E. (1982) "Traffic Conflicts and Exposure," *Accid. Anal. and Prev.*, 14:359-364, Pergamon, London.
- Howard G., Wagenknecht L. E., Burke G. L., Diez-Roux A., Evans G. W., McGovern P., Nieto F. J. and Tell G.S. (1998) "Cigarette Smoking and Progression of Atherosclerosis: The Atherosclerosis Risk in Communities (ARIC) Study," *JAMA*, 279(2):119-24
- Janke, M.K. (1991) "Accidents, Mileage, and the Exaggeration of Risk," *Accid. Anal. and Prev.*, 23:183-188, Pergamon, London.
- Joly, P., Joly, M-F., Desjardins, S.M., Maag, U., Ghadirian, P. and Laberge-Nadeau, C. (1993) "Exposure for Different License Categories through a Phone Survey: Validity and Feasibility Studies," *Accid. Anal. and Prev.*, 25:529-536, Pergamon, London.
- Lee B. W., Wain J. C., Kelsey K. T., Wiencke J. K. and Christiani D. C. (1998) "Association of Cigarette Smoking and Asbestos Exposure with Location and Histology of Lung Cancer," *Am J Respir Crit Care Med*, 157 (3 Pt 1):748-55.
- Lenne, M.G., Triggs, T.J. and Redman, J.R. (1997) "Time of Day Variations in Driving Performance," *Accid. Anal. and Prev.*, 29:431-437, Pergamon, London.

- Leung, Y. (1988) *Spatial Analysis and Planning Under Imprecision*, Studies in Regional Science and Urban Economics 17, Elsevier, Amsterdam.
- Lupien, A.E., Moreland, W.H. and Dangermond, J. (1987) "Network Analysis in Geographic Information Systems," *Photogrammetric Engineering and Remote Sensing*, 53 (10):1417-1421.
- Mahalel, D. (1986) "A Note on Accident Risk," *Trans. Res. Rec.*, 1068:85-89
- Massie, D.L., Campbell, K.L. and Williams, A.F. (1995) "Traffic Accident Involvement Rates by Driver Age and Gender," *Accid. Anal. and Prev.*, 27:73-87, Pergamon, London.
- Massie, D.L., Green, P.E. and Campbell, K.L. (1997) "Crash Involvement Rates by Driver Gender and the Role of Average Annual Mileage," *Accid. Anal. and Prev.*, 29:675-685, Pergamon, London.
- Nyberg F., Hou S.M., Hemminki K., Lambert B. and Pershagen G. (1998) "Glutathione S-Transferase Mu1 and N-Acetyltransferase 2 Genetic Polymorphisms and Exposure to Tobacco Smoke in Nonsmoking and Smoking Lung Cancer Patients and Population Controls". *Cancer Epidemiol Biomarkers Prev*, 7(10): 875-83
- Openshaw, S. (1984) *The Modifiable Areal Unit Problem*. Concepts and Techniques in Modern Geography: Number 38, Norwick: Geo Books.
- Quimby, A.R., Maycock, G., Carter, I.D., Dixon, R. and Wall, J.G. (1986) *Perceptual Abilities of Accident Involved Drivers*, Transport and Road Research Laboratory, Berkshire, U.K.
- Richardson, A.J., Ampt, E.S. and Meyburg, A.H. (1996) *Survey Methods for Transport Planning*, Eucalyptus Press, Melbourne.
- Risk, A. and Shaoul, J.E. (1982) "Exposure to Risk and the Risk of Exposure," *Accid. Anal. and Prev.*, 14:353-357, Pergamon, London.
- Sarasua, W. A. and Meyer, M. D. (1996) "New Technologies for Household Travel Surveys," Conference Proceedings 10, Conference on Household Travel Surveys: New Concepts and Research Needs, National Academic Press, Washington, D.C.

- Tracy R. P., Psaty B. M., Macy E., Bovill E. G., Cushman M., Cornell E.S. and Kuller L. H. (1997) "Lifetime Smoking Exposure Affects the Association of C-Reactive Protein with Cardiovascular Disease Risk Factors and Subclinical Disease in Healthy Elderly Subjects," *Arterioscler Thromb Vasc Biol*, 17(10): 2167-76
- VicRoads (1999) *Traffic System Performance Monitoring 1997/98*. VicRoads, Melbourne.
- White, S.B. (1976) "On the Use of Annual Vehicle Miles of Travel Estimates from Vehicle Owners," *Accid. Anal. and Prev.*, 8:257-261, Pergamon, London.