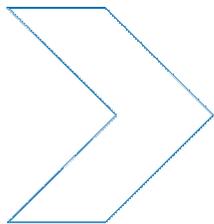


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Identifying and improving exposure measures

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Identifying and improving exposure measures

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ABSTRACT

Exposure information, accompanied by comparable crash data, allows the identification of specific high crash risk groups and road environments that can be targeted by appropriate road safety measures. This report aimed to firstly identify the current sources of exposure data available in South Australia and examine their limitations and secondly, make recommendations about the most useful measures of exposure for road safety and how they might best be obtained. Based on a review of the international literature, examination of relevant databases and discussions with organizations collecting exposure data, a list of sources of exposure data available in South Australia was produced, acknowledging any limitations associated with the data. A discussion of the usefulness of exposure measures in road safety, in general terms and specific to South Australia, concluded with comments on four possible strategies for collecting better exposure data in the future: data collection by conventional means, the use of new technology for data collection, better theoretical understanding of induced exposure methods and the collection of compatible exposure data for road crash research.

KEYWORDS

Exposure, Risk, Travel behaviour, Travel survey

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Summary

The concept of “exposure” to risk is used in the context of the equation *number of crashes = rate × exposure*. In a practical sense, exposure refers to quantities such as distance travelled, time spent travelling, or number of vehicles passing a point. Comparison of crash rates of different groups of people, different types of vehicle, different roads, different environmental conditions, and so on, may be desired.

This report has four main sections.

Section 2 examines the main classes of measurement methods and what they are used for.

Section 3 discusses some problems associated with the concept of exposure.

Section 4 describes the main sources of exposure data in South Australia.

Section 5 discusses how exposure data is used, and how its usefulness in road safety could be improved.

In addition, there is a short Introduction and a short Conclusion.

The two most important classes of method for measuring exposure are household-based surveys of travel, in which people keep a diary of what trips they make, and on-road counts of vehicles and pedestrians. However, when exposure as recorded with these methods is compared with crash numbers, serious conceptual and practical problems are encountered. For example, risk is usually thought of as referring to an individual, and yet a rate (ratio of number of crashes to exposure) refers to a group of individuals. Travel and traffic flow are often measured for their own interest, without consideration for their use as measures of exposure to risk, and consequently the methods used may not be compatible with the methods of road crash data collection. And it could not be expected that even the most elaborate methods would estimate the total traffic encountered (rather than distance driven) by drivers of different age groups, for example. Consequently, there has been persisting interest in “induced exposure” methods, in which exposure is estimated from the crash dataset (from the number of crashes in which the relevant unit was entirely passive). However, these methods have not been very successful, either.

The concept of exposure has been something of a disappointment in road safety research, and there are probably solid reasons why this has been so. However, new technology offers considerable potential. As an example, it seems likely that a random sample of teenagers could be tracked when using a motor vehicle, by giving each of them an iPhone (which has a Global Positioning System built in): knowledge of distances driven, and the conditions in which the driving took place, in the first two years after first licensure would be of great use in understanding the changing crash numbers and changing driving violation numbers.

Another reason for a degree of optimism is that understanding the important features of exposure data (e.g., distances driven) in a qualitative way may throw useful light on crash data, even if the data collection methods are not sufficiently compatible or robust to support the calculation of rates.

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1 Introduction

Observed differences in crash numbers between different groups of people may be due to underlying differences in crash risk or differences in exposure to risk. For example, truck drivers may have more crashes per year than car drivers because they drive more. While groups having a high number of crashes per year can be identified from crash data, identification of high crash risk groups requires a measure of exposure. The concept of exposure is also relevant in contexts such as locations (e.g., the traffic flow or number of pedestrians past a point) and vehicles (e.g., distance travelled by a certain model of car). Specific applications for exposure information include planning transport infrastructure, monitoring road user behaviours, and evaluating the effectiveness of road safety programs.

In the past, there has been inadequate treatment of exposure in road safety research making it difficult to effectively measure risk and determine the effectiveness of road safety countermeasures. This is primarily due to appropriate exposure data often not being available or difficult or expensive to obtain. Furthermore, there is no clear consensus in the literature as to which exposure measures are most useful and how they are most effectively obtained. Selecting an appropriate exposure measure is particularly important because the relationship between the number of crashes and driving exposure is not always linear.

To determine crash rates in South Australia for different road user groups, behaviours, vehicles, locations and environments, accurate exposure data is required. While a number of different sources of exposure data might be available in South Australia, it is not known whether the data are useful for answering questions of interest to road safety.

Consequently, the objectives of this study are to:

- identify and catalogue the current sources of exposure data available in South Australia and examine their limitations.
- make recommendations about the most useful measures of exposure for road safety and how they might best be obtained.

The objectives of this study are addressed through a review of the international literature, examination of relevant databases, and discussions with organisations that collect exposure measures. Information concerning exposure measures is collated in this report to provide a reference for road safety researchers interested in understanding and obtaining travel exposure measures. The investigation of ways to improve exposure data will assist future evaluations of road safety measures.

The main body of this report is in four sections, followed by some concluding remarks. In Section 2, the methods used to obtain exposure measures are examined, considering their advantages and disadvantages. The different measures of exposure obtained by each of these measures are also discussed. In Section 3, problems associated with the concept of exposure are explored. Section 4 contains a comprehensive list of sources of exposure data available in South Australia that are relevant to road safety. The sources are grouped under the different methods used to collect exposure data: population surveys, on-road monitoring, case-control studies, and observational special purpose studies. Any known limitations associated with these measures are discussed. The final section consists of a discussion of research topics for which exposure is important in road safety: people (specific individuals and groups), behaviours and states, environmental conditions, locations (specific locations and designs of roadways), and vehicles. Some comments are provided on methods for determination of exposure that are likely to be most appropriate and how exposure data could be more useful in road safety research. There is a short Conclusion.

2 Methods for collecting exposure data

Risk is often used as a way of quantifying the level of road safety (Hakkert & Braimaister, 2002). Exposure is an essential component of risk measurement. Erroneous conclusions about risk may be drawn if the total number of injuries or fatalities is examined without controlling for exposure. Risk has been defined as the probability of a crash occurring (Hauer, 1982). The risk of a crash occurring can be estimated by dividing the number of crashes by the road users exposure to the opportunity for a crash to occur. Essentially, exposure is a measure of the number of opportunities for crashes or injuries to occur. Thus, exposure measures are used as the denominator when calculating crash rates to estimate crash or injury risk. A distinction can be made between the risk of a crash occurring and the risk of an injury occurring, given a crash has occurred. Consequently, countermeasures to improve road safety may be designed to reduce the risk of exposure, the risk of a crash, or the risk of an injury or death once a crash has occurred (Hakkert & Braimaister, 2002). Cameron and Oxley (1995) suggest the use of two different frameworks for the measurement of exposure in road safety research. Firstly, measurements of site exposure consider the type of road, road conditions, road geometry and the environmental conditions. Secondly, driver exposure measures examine the number of opportunities a driver has to crash when driving on the road network. These concepts of exposure can be applied to various groups of road users such as pedestrians, bicyclists, motorcyclists, and truck drivers.

Different methods have been used to measure exposure but there is considerable disagreement in the literature as to which exposure measures are most desirable to use and how they should be collected (Wolfe, 1982). Furthermore, some of the most easily obtained exposure measures are not always the most appropriate ones for developing meaningful crash rates. Choosing the appropriate measure of exposure depends on the intended use of the data and the population studied (e.g. comparing safety infrastructure and countermeasures, risk between different groups or risk between different modes of travel), as different exposure measures can produce different results (Kam, 2003). The two main methods of collecting road safety exposure data are surveys of travellers (population based) that rely on self-reported travel behaviour from household surveys and surveys of traffic (vehicles) through on-road vehicle counts or observational surveys. In addition, studies of traffic conflicts and control observations at crash sites can provide exposure data.

The following sections discuss the advantages and disadvantages of each of the main methods for collecting exposure data and describe the exposure measures that can be obtained through each of these methods.

2.1 Surveys of travellers (Household travel and population surveys)

To obtain information about the characteristics and travel behaviour of different groups or individuals within the population, surveys of people are required. Surveys collecting information about travel behaviour typically gather information by face-to-face interviews, telephone interviews, mail surveys, or a combination of these methods. In addition, the Internet offers a relatively new method of obtaining exposure information.

The most common form of this type of survey involves asking a representative sample of households about their travel patterns. Respondents are typically requested to record details of all trips taken, including walking and cycling, over a specified number of days in a travel diary or logbook. Travel diaries are considered one of the best means of obtaining travel behaviour as they can cover an extended period of time and are not retrospective (Bobevski et al., 2007). Surveys that rely on retrospective recall tend to record typical travel behaviour rather than providing an accurate account (Richardson et al., 1995). In addition, travel diary-based surveys can provide a comprehensive picture of travel behaviour with information including mode of travel or vehicles used, distance and time taken for travel, characteristics of the traveller (i.e. sex, age), travel costs, and purpose of the journey. In particular, more information about the travel behaviours of cyclists and pedestrians can be obtained from these surveys than observational studies.

Nevertheless, there are some limitations associated with these types of surveys. Firstly, these surveys rely on self-reported data that is dependent on the honesty and thoroughness of the respondent rather than a direct behavioural observation. In particular, travel diaries requiring detailed information tend to be less complete on the last day than on the first (ETSC, 1999). Secondly, the representativeness of the survey is reliant on the population sampled and response rates. Groups with lower response rates are often under-represented in these surveys (i.e. young people) although statistical weighting can modify this problem to a small extent.

Household surveys based on interviews, compared to observational surveys, are also likely to be somewhat biased towards underestimating the travel of the general population because individuals who travel more are least likely to be home for an interview (Bobevski et al., 2007). Also, household studies are likely to underestimate commercial vehicle travel. Consequently, it is important to compare the results of self-report surveys with the results of observational surveys every few years (Bobevski et al., 2007).

To gain a more complete picture of travel behaviour and exposure data, households need to be sampled on different days of the week and at different times of the year. To satisfy this requirement and to provide regular survey data, some travel surveys are carried out on an on-going basis throughout the year (e.g. Sydney Household Travel Survey, New Zealand Travel Survey and National Travel Survey of Great Britain). The advantage of an on-going survey is that survey data can regularly be combined with crash data to provide up to date estimates of crash risk for different groups of road users. The continuous Sydney survey is designed so that the sample size obtained from three years of data collection is similar to that achieved by a single household travel survey conducted approximately every ten years. However, such continuous travel surveys can be expensive to run. Alternatively, a less costly approach is to conduct frequent (i.e. twice yearly) smaller scale surveys that seek to maximise response rates (Bobevski et al., 2007). High response rates can be more important than a large sample size if the characteristics studied are quite variable (e.g. Fogliani, 1999).

In respect of the households that participate in a travel survey, there are at least two types of concern, which might be exemplified as follows. Suppose one wanted to estimate the total distance driven by those aged at least 80.

- Response rates of different ages of people might be different, and the sample would then differ systematically from the population. However, the ages in the population would probably be available from some other source (e.g. the Census), and the ages in the sample could be compared with this, and the total distance driven by the population of those aged at least 80 could be adjusted according to the differential response rates of different ages.
- Response rates of people of different levels of health might be different, and the sample would again differ systematically from the population. But in this case, level of health would be known neither for the sample nor for the population: there would be no way of correcting distance driven for any difference between the sample and the population in respect of level of health.

In the Sydney Household Travel Survey in the period 2004-2007, some 65 per cent of the households approached did respond (Transport Data Centre, 2008, p. 47). We fear this is low enough to cause substantial problems if the data were used to calculate crash rates.

With respect to the various methods used to collect travel behaviour data, face-to-face interviews are more effective in improving response rates compared to mail surveys and telephone interviews (Richardson et al., 1995). Using this method, respondents are likely to give more honest and thorough responses, increasing data quality, as rapport is built with the interviewer. The main disadvantage of this method is its costliness.

Alternatively, mail surveys are the least expensive of these methods but response rates are often quite low. Mail surveys also tend to under-sample less educated or literate people

(Bobevski et al., 2007). Another significant disadvantage is that data quality can be lower due to incomplete or incorrectly completed questionnaires.

Telephone interviews are cheaper than face-to-face interviews but more expensive than mail surveys. While telephone interviews produce better data quality than mail surveys because responses are checked, this method is also subject to poor response rates. In comparison to face-to-face interviews, telephone interviews have several disadvantages. Firstly, it is usually only possible to conduct an interview with one person per household, which can bias the sample. Secondly, the length of time for the survey is limited by respondents concentration span. Research indicates that response rates decline rapidly after 10 to 15 minutes of interviewing (Stopher, 1985). Finally, telephone surveys typically rely on recall of detailed travel behaviour, rather than a travel diary, which can be unreliable.

To improve response rates and data quality, a combination of these methods might be more appropriate. For example, Richardson et al. (1995) suggested a combination of a mail survey followed by a brief interview might be the most cost effective method. Using this combination, any incomplete or incorrect responses can be reviewed by the interviewer. Bobevski et al. (2007) note that in Sweden, a travel diary is mailed to sampled households then followed up by a telephone interview to collect the data (the travel diary does not need to be mailed back).

Some exposure measures that can be obtained from travel surveys are described in the following subsections.

2.1.1 Aggregate measures

Aggregated measures provide rough overall indicators of exposure, for example, total population, number of registered vehicles, number of licensed drivers, and fuel sales (Bobevski et al., 2007). These measures are popular for estimating crash risk because they are readily available and can be obtained at a low cost. However, such measures often do not allow the estimation of risk for specific groups of road users or in specific situations (see Section 3.2). In addition, they do not account for differences in risk associated with the amount of time or distance travelled. Generally, the more aggregate the exposure measure, the more intervening variables are introduced (Hakkert & Braimaister, 2002).

Disaggregate measures of exposure examine individual travel choices, based on individual characteristics and preferences. Generally, disaggregate measures are more complicated and difficult to obtain but they provide a more accurate means for estimating crash risk.

2.1.2 Distance travelled

Distance travelled, measured as number of vehicle kilometres travelled, is a popular measure of exposure that enables disaggregation by travel and demographic groups for meaningful comparisons. However, other aspects of exposure, such as time of day, road type, speed, traffic flow and density of traffic conflicts often vary considerably among drivers. Consequently, the relationship between distance travelled and these other aspects of exposure is not simple (Chipman et al., 1993). In particular, researchers have observed that distance driven can exaggerate the risk of low mileage groups such as young and elderly drivers (Janke, 1991; Maycock, 1997). For these low mileage drivers, crashes do not appear to increase in a linear fashion with an increase in the number of kilometres travelled. For example, Forsyth et al. (1995) found that crash rates per mile for novice drivers decreased with increased annual mileage. According to Janke (1991), individuals travelling shorter distances tend to drive on more congested city streets where traffic conflicts are more likely to occur while high mileage drivers spend more time driving on highways where driving is a simpler task and, consequently, the crash risk is lower.

Chu (2003) notes that when comparing risk between different modes of transport, distance-based measures of exposure can misrepresent results because of differences in travel speed. For example, one person-mile of walking (relatively slow speed) represents greater exposure to traffic than one person-mile as riding in a vehicle (relatively fast speed).

Nevertheless, problems with distance travelled as a measure of exposure might be overcome by disaggregating risk, that is by separating out the different demographic and environmental factors that are known to vary among drivers (for a discussion, see Keall, 1995). Thus, despite the limitations of distance driven as an exposure measure, this measure is popular due to its convenience, particularly when it can be disaggregated by demographic and environmental factors (Bobeviski et al., 2007).

2.1.3 Number of trips

The number of distinct trips made by an individual, regardless of the distance or time taken for the journey, is another exposure measure. This measure is not particularly useful for assessing risk at specific locations. However, trip data can be used to make comparisons between large jurisdictions and determine changes over time. In addition, trip data can be linked to other survey information obtained at the same time such as trip purpose, mode, time of day etc. Note that pedestrian trips are often under-reported in surveys (Schwartz & Porter, 2000), most likely because they are often only a small part of a multi-modal trip (see Section 4.1.1).

2.1.4 Time spent travelling

When explaining crash risk among road users and regions with very different travelling patterns and environments, some researchers argue that time spent travelling is a better measure of exposure than distance travelled (Chipman et al., 1993). This is because time-based measures take into account different travelling speeds and the environment, factors that are particularly important when comparing risk among different travel modes (e.g. walking, cycling, motorised vehicles). For example, Hakkert and Braimaister (2002) suggest normalising exposure by multiplying vehicle kilometres travelled by speed to account for variation in the travel speeds of different modes of transport. While Greene-Roesel (2007) argue that time-based exposure measures are the best measures to compare the risks of different travel modes, the European Transport Safety Council (ETSC, 1999) suggests using passenger kilometres per year because "...it relates to the decision about how to travel a certain distance rather than how to spend a certain amount of time" (p. 9).

Like distance travelled, time spent travelling can easily be measured on the individual level through surveys or through direct measurements at specific locations. Nevertheless, even supporters of travel time as an exposure measure (e.g. Chipman et al. 1993) acknowledge that time-based exposure measures can lead to the conclusion that driving at higher speeds (lower exposure in terms of driving time) leads to fewer crashes, contrary to the known relationship between speed and crash risk (Kloeden et al., 1997).

2.2 Surveys of traffic (On-road monitoring and observational surveys)

Exposure is often measured in a form related to the amount of travel. Traffic surveys typically involve the direct observation, either by researchers or monitoring equipment, of the number of vehicles or pedestrians passing a specific observation point. Ideally, these counts should be carried out systematically at a series of sites that are representative of the jurisdiction and cover all road types. Counts should be able to classify different types of vehicles and time of day. In reality, most surveys only sample part of the road network (local and minor roads are rarely included) for a limited period of time.

Fuel sales can be used to estimate national or state traffic volumes when there is no system for reliably counting traffic. Surveys determine the average fuel efficiency of the vehicle fleet (i.e. average no of kms travelled per unit of fuel sold) and this is then used to convert the total fuel sold into total distance travelled. While the use of fuel sales data is less expensive than traffic counts, this measure is sensitive to the annual national fuel efficiency and this, in turn, varies with other factors such as the weather and purchase of new vehicles (ETSC, 1999). In addition, the total distance travelled cannot be disaggregated by type of road or vehicle.

Generally, observational methods are a reliable measure of behaviour because behaviour is directly observed rather than relying on self-report that is subject to forgetfulness and misrepresentation. The representativeness of estimates from observation-based traffic surveys increases with the number of observations at different times, therefore, observational surveys tend to be costly (Bobevski et al., 2007).

A significant limitation of traffic surveys and on-road monitoring, specifically automated devices, is that limited behavioural information about road users can be obtained. Although some observational surveys might involve researchers briefly interviewing drivers stopped at traffic lights (e.g. Melbourne On-Road Exposure Survey, cited in Bobevski et al, 2007), due to time and safety constraints, minimal detailed information can be obtained. In addition, it is often difficult for on-road surveys to obtain good quality information about pedestrians and cyclists at the same time as vehicles. Some automated traffic survey equipment (e.g. amphotometers) does not count pedestrians or cyclists at all. Separate surveys of cyclists and pedestrians might overcome these problems but they would also create additional costs.

To summarise, traffic surveys provide exposure measures for different road types but cannot be disaggregated into subgroups of road users that are not externally observable. In contrast, surveys of travellers or road users do not provide reliable information on exposure for different road types but can provide information about subgroups that cannot be observed (ETSC, 1999). Data from a combination of different sources can be combined to calculate disaggregate exposure estimates for different population subgroups (Hakkert & Braimaister, 2002).

2.2.1 Traffic volumes

A common exposure measure is the number or volume of vehicles and other road users that pass by a fixed point during a specific time period. Risk estimates for specific roads and intersections can be made from this data. Traffic volumes are relatively easy to measure, particularly with automated counting technology such as speed cameras, red light/speed cameras, amphotometers, infrared, electronic vehicle tags etc. However, while some automated vehicle counting devices can distinguish between different vehicle types, they do not differentiate by individual-level attributes that may influence individual risk such as sex, age, income level etc. Manual counts through direct observation are able to estimate some individual characteristics. Furthermore, this type of exposure measure is very site specific and not easily adapted to assess exposure over wider areas, and does not account for the time or distance spent travelling.

Of interest, studies taking alternative approaches to this exposure method have produced different results. For example, one US study concluded that the probability of crashing increases with traffic volume (Brodsky & Hakkert, 1983) while another study from Greece suggested that the capacity of the road, combined with the traffic volume results in different crash risk (Frantzeskakis & Iordanis, 1987). They suggested that the volume-to-road capacity ratio might be a superior measure of exposure than traffic volume.

2.3 Other measures of exposure

2.3.1 Traffic conflicts

Traffic conflicts or near misses, at specific sites such as intersections, are sometimes used as a proxy for crashes. This method is used primarily when the number of crashes at the location is small and subject to large chance variations. Consequently, the occurrence of near misses or conflicts gives more statistically reliable estimates than actual crashes (Hauer, 1982). An advantage of this method is that conflicts can be measured over a short period of several days rather than relying on years to obtain crash data. However, Hauer (1982) warns that the definition of a 'traffic conflict' is not always clear.

When studying traffic conflicts, traffic volume or flow at the site is usually used as an exposure measure (i.e. to calculate crash rates, rather than relying on crash frequency). At intersections,

the sum or the combined daily traffic volumes of intersecting roads are used as exposure measures, sometimes subdivided into separate turning movements (Bobevski et al., 2007). Examining traffic conflicts can be expensive although advances in automated observation technology make detection of incidents increasingly feasible. Such systems are already being used on motorways around the world (Hakkert & Braimaister, 2002).

At the level of an individual site on a road network, crashes are usually very rare, the number in any one year is very small, and consequently the year-to-year variability is very great. It seems possible that counting traffic conflicts (e.g., instances of emergency braking) would provide a useful measure of how dangerous a site is. There was hope in the 1970's that traffic conflicts would tell us a lot about the injury crashes that are much rarer and thus more difficult and time-consuming to study. Traffic conflicts can be studied with video recording, devices that detect honking horns and screeching tyres, and perhaps pattern recognition methods that operate on digital images. However, results to date have been rather disappointing. One of the reasons is conceptual. If conflicts serve as a proxy for crashes, we can calculate the ratio of conflicts to traffic flow as an indicator of how dangerous it is. But there is some reason why a conflict did not become a crash, and so perhaps conflicts should be regarded as opportunities for crashes to occur, and the ratio of crashes divided by conflicts calculated. So the number of conflicts is in the numerator of one index of danger, but in the denominator of the other, which is very confusing. There is a considerable practical problem, too, in judging whether a conflict has indeed occurred: this is more difficult than one might suppose.

2.3.2 Control observations at crash sites

Information collected about individuals not involved in crashes or 'controls' at crash sites, provides a specific measure of exposure data. The characteristics of crash involved road-users can then be compared to those of the controls to determine factors associated with a higher relative risk of crashing. Controls can be matched on certain variables that have a confounding effect on risk (e.g. sex, age, site, time of day). Studies of this nature have established the relationship between factors such as alcohol and speed, and crash risk.

2.3.3 Pedestrians and cyclists

When estimating the risk of crash involvement for pedestrians, road crossing exposure should be distinguished from roadside or footpath exposure because crossing the street is a riskier behaviour (Hunter et al., 1996; Ossenbrugen, 1999). For pedestrians walking on the footpath, a measure of pedestrian kilometres travelled might be adopted. However, distance travelled is not an ideal exposure measure for pedestrians because it does not differentiate in terms of walking speed or other factors that moderate the risk associated with distance (Greene-Roesel et al., 2007).

For pedestrians crossing the road, some measure of traffic volume on the road is needed in addition to the number of road crossings. Hakkert and Braimaister (2002) suggest a measure of exposure that is the product of traffic flow and the number of crossings. Knoblauch et al. (1996) argue that the estimated time a pedestrian spends crossing a street provides an even better measure of exposure than simple volume counts as pedestrian crossing speed can vary by pedestrian age, gender, pedestrian compliance with intersection controls, weather conditions and signal cycle length. However such data could be difficult to obtain.

Similar to pedestrians, exposure for cyclists should distinguish between travel on footpaths, travel on roads and road crossings, taking into account traffic flow. With respect to collecting pedestrian and cyclist exposure information, a review by Howarth (1982) recommended that a combination of questionnaire surveys and observations at random sites provided the best exposure data at a low cost. For measurements based on distance walked, pedometers could be attached to pedestrians (Greene-Roesel et al., 2007).

To summarise, measures of the exposure of pedestrians and cyclists should include traffic flow and the number of road crossings in addition to time spent walking on footpaths/cycling on roads.

3 Some problems with the concept of exposure

From a practical point of view, specific exposure measures for different groups are often not available or difficult and costly to obtain. But there are also some conceptual problems with the idea of exposure, and these are briefly discussed below.

3.1 Nonlinearity

One may wish to use the equation $number\ of\ crashes = rate \times exposure$, and yet it may be found that there is a non-linear relationship between number of crashes and the most obvious measures of exposure, such as a count of traffic. That is, suppose site B has four times the traffic as site A, but crashes are only twice as many. On the face of things, site B has only half the crash rate of site A; but alternatively it might be said that a count of traffic is an inappropriate measure of exposure, that perhaps exposure is more appropriately considered to be proportional to the square root of amount of traffic, and thus sites A and B have the same crash rate. (Theoretical justification for some non-linear transformation might be based on arguing that most danger comes from gaps of a certain size between vehicles, and the number of these gaps is some non-linear function of amount of traffic.) The question of the functional form of the most appropriate way of measuring exposure is encountered in the context of intersection crashes, when separate counts of traffic on two roads that intersect are available: the product of conflicting flows may be used as the measure of exposure, or the square root of the product, or the sum (Chapman, 1973).

Rather than a theoretical justification, it is more likely that a contention that exposure should be measured by some non-linear transformation of a traffic count would come from empirical study of traffic and crashes at different locations (e.g., Qin et al., 2004). Concerning the safety of pedestrians and cyclists, Jacobsen (2003) claims that the numbers of casualties are less than proportional to the amounts of walking and cycling (specifically, that the increase is approximately according to the amount of walking or cycling raised to the power 0.4).

Empirical research on this typically involves estimating a regression relationship between the logarithm of the number of crashes and the logarithm of some straightforward measure of exposure (such as a traffic count), with the data points referring to different road locations. (A linear relationship between their logarithms implies that number of crashes is a power function of the measure of exposure.) However, there is then a problem of interpretation. Suppose one finds that $number\ of\ crashes$ is proportional to $traffic^{0.5}$; it is then not clear whether this should be interpreted (a) as $exposure$ being proportional to $traffic^{0.5}$ and $crashes$ being proportional to $exposure$, or (b) as $exposure$ being proportional to $traffic$ and $crashes$ being proportional to $exposure^{0.5}$. The first interpretation is presumably based on a wish to be fair when comparing road locations: the regression equation tells us, so the argument would go, that there is a general tendency for crashes to only double when traffic is quadrupled, and a fair comparison of accident rates at different locations will involve calculating the ratio of $crashes$ to $traffic^{0.5}$.

This report is largely restricted to discussing what straightforward measures of exposure are available, without going into the question of whether some non-linear transformation should be applied.

3.2 Aggregation

Crash rates are typically calculated at a highly aggregated level --- for example, the ratio of crashes in a city to the total distance driven in that city in the relevant time period, or the ratio of crashes involving 18 year old drivers to the total distance driven by 18 year old drivers. A rate refers to a collective of a great number of individuals, but risk is typically thought of as applying to an individual. Yet facts about a group may not be true of any of the individuals in that group.

3.2.1 Aggregation of rates

To reinforce the idea that the group may differ from the individual, consider the following aggregation paradox. In the artificial example in Table 3.1, Condition A has a lower crash rate than Condition B in both District 1 and District 2, yet a higher crash rate when the two districts are combined. (Conditions A and B might be two ages of driver, two models of car, two designs of road infrastructure, etc. District 1 and District 2 might be geographical areas, but they might be time periods, driver age groups, or other categories.)

We do not suggest that such a misleading result as that in Table 3.1 is at all common, but that it is a warning that a concept intended to apply at the level of the individual may be misleading when calculated at the level of the group. It is vague to say “may be misleading”, but we do not know of any guidance available concerning for what purposes and in what circumstances is an aggregate crash rate an informative concept. If exposure were measured in such a way that it obviously could not be summed when two districts are combined — for example, if it were kilometres driven per square kilometre of area — then this result would be avoided.

Table 3.1
Demonstration that crash rate (ratio of crashes to exposure) may be higher for Condition A than for Condition B in a combined dataset even when the rate is lower for Condition A than for Condition B in both subsets of the data.

	Condition A			Condition B		
	Crashes	Exposure	Rate	Crashes	Exposure	Rate
District 1	40	20	2.0	6	2	3.0
District 2	2	2	1.0	30	20	1.5
Combined	42	22	1.9	36	22	1.6

3.2.2 Aggregation of two distances when exposure is their product

A similar point may be made about the measurement of exposure itself (rather than crash rate), when exposure is measured as a product, as it sometimes is. In Table 3.2, exposure to pedestrian accidents is measured by the product of pedestrian distance travelled and vehicle distance travelled. If analysis is at the level of districts, there is greater exposure in Condition B than Condition A, for both districts. But if data were only available with districts combined, there would appear to be greater exposure in Condition A.

Table 3.2
Demonstration that the product of pedestrian and vehicle distances may be higher for Condition A than for Condition B in a combined dataset even when the product is lower for Condition A than for Condition B in both subsets of the data.

	Condition A			Condition B		
	Pedestrian distance	Vehicle distance	Product	Pedestrian distance	Vehicle distance	Product
District 1	10	50	500	25	25	625
District 2	50	10	500	25	25	625
Combined	60	60	3600	50	50	2500

3.3 By-passing measurement and conceptual problems: Induced exposure

Exposure is difficult to define and difficult to measure. Haight (1970) identified three general strategies for dealing with the difficulty.

- To plough ahead with crude quantities such as distance driven, eliminating confounding factors to as great extent as is practicable with the data available.

- To ignore exposure, concentrate on absolute numbers of crashes, carry out cost-benefit analyses with these, and decide on the measures that give the greatest expected rate of return.
- To manipulate crash data in such a way as to obtain “exposure-corrected” crash figures, without using any other data such as distances driven.

It is the third of these, known as the induced exposure approach, that we now outline. As an example, consider the ratio of the number of teenage drivers responsible for crashes to the number of teenage drivers innocently involved in crashes. This expresses the danger of teenage drivers compared to the rest of the population. It might be called an over-involvement ratio. The amount of traffic to which this group of drivers is exposed will be reflected both in the number of times they are an innocent party in crashes and in the number of crashes they cause. The inherent danger of the group will only affect the latter, however, and therefore taking the ratio of one to the other results in a crash figure corrected for exposure.

The difficulty with using the ratio of responsible to innocent drivers is in the determination of responsibility for each crash. The subjectivity of the judgment is a major problem, and so is the sheer time involved in going through the police files for each crash. Such studies are sometimes carried out, but for work on large datasets of crashes, some alternative is needed. There are a variety of different induced exposure methods, but the following is sufficient to give their flavour.

The following assumptions permit some useful calculations to be made (Thorpe, 1964).

- Single-vehicle crashes are caused entirely by the driver-vehicle combination concerned. (A driver-vehicle combination means a category such as young drivers in old cars.)
- In each two-vehicle crash, there is a responsible and an innocent party.
- The proportionate involvement of each driver-vehicle combination as the responsible party in two-vehicle crashes is the same as its proportionate involvement among single-vehicle crashes.

Expressed informally, a dangerous category of drivers or vehicles will show greater over-representation in single-vehicle crashes than in two-vehicle crashes, as there is an innocent party in each two-vehicle crash as well as a responsible party.

The following quantities can be found from crash data: S_j = the proportion of single-vehicle crashes that the j th driver-vehicle combination constitutes, and T_j = the proportion of the j th group in two-vehicle crashes. What is wanted is the over-involvement ratio G_j/I_j , where: G_j = the proportion of responsible parties in two-vehicle crashes that the j th group constitutes, and I_j = the corresponding proportion among innocent parties. The assumptions stated earlier mean that $S_j = G_j$ and $T_j = (G_j + I_j)/2$. (The division by 2 in the second equation is because there are two vehicles in each two-vehicle crash.) Therefore, $2T_j - G_j = I_j$, and finally $G_j/I_j = S_j/(2T_j - S_j)$. That is, a simple calculation involving the known quantities S_j and T_j gives a result that is interpretable as an over-involvement ratio.

Induced exposure methods have achieved only modest popularity: Google Scholar finds 13 articles using the phrase in Accident Analysis and Prevention in the period 1998-2007. One reason for this may be that the third of the assumptions above is too restrictive: it seems to imply that there is only one kind of fault, that may lead to either a single-vehicle crash or to (responsibility for) a two-vehicle crash. This is surely unrealistic: as simple examples, consider driving fast on an empty road and accepting short gaps in a traffic stream. These are different, even though they might stem from a common source, such as poor judgment or a tolerance of risk. And they will have different effects, increasing single-vehicle crashes in the first case and increasing two-vehicle crashes in the second case.

The theoretical objection above is reinforced by the empirical finding that in some datasets (e.g., Hutchinson and Jones, 1975), the model can be seen to fail: the ratio of single to two-

vehicle crashes is greater than it should theoretically be. Despite those theoretical and empirical objections, the most likely reason that induced exposure methods have not been more popular is that they are not very well known. We think there is scope for their greater use. In particular, there is no need to immediately jump to calculation of some ratio of types of crash. Less formal exploratory accounts of how single and two-vehicle crashes (and different types of single and two-vehicle crashes) are similarly affected by some variables and differently affected by others might be more fruitful.

4 Measures of exposure in South Australia

Many different measures of exposure are available in South Australia but not all sources are useful with respect to road safety. The following section contains a list of sources of exposure data that are relevant to road safety, grouped under the different methods used to collect exposure data: population surveys, on-road monitoring, case-control studies, and observational special purpose studies. Any known limitations associated with these measures are discussed.

There are probably other sources of exposure data collected by local government authorities, consultants, transport planners etc. that have not been included in this report and it is likely that many new sources are currently being developed. Therefore, this list of exposure measures should not be seen as exhaustive and it is recommended that this inventory is updated regularly.

4.1 Population surveys

There are a number of sources of exposure data that come from surveys of the population. The main travel survey conducted in South Australia is the Metropolitan Adelaide Household Travel Survey (MAHTS). Much of the other population-based exposure information is derived from censuses, of which some are conducted on an annual basis while others are collected every couple of years. Descriptions of these surveys are provided in the following section.

4.1.1 Metropolitan Adelaide household travel survey (MAHTS 99)

In 1986 and in 1999, the Department of Transport, Energy and Infrastructure (DTEI) conducted surveys to determine travel patterns and the number of trips made in the Adelaide metropolitan area. The most recent survey is known as the Metropolitan Adelaide Household Travel Survey (MAHTS99). The main purpose of the survey was to collect details on the travel behaviour of all members in a sampled household, regardless of age, for a consecutive two-day period including weekdays and weekends.

This survey was based on face-to-face interviews with a random sample of approximately 9000 households in the Adelaide Statistical Division (ASD). Of these, 5615 households completed the survey. Using census data, factors were calculated to expand the sample interview data to be representative of all households in the ASD. Data collection extended over seven consecutive months. For further details concerning data correction and validation, data expansion, and trip linking, the reader is referred to the report "Processing of 1999 Metropolitan Adelaide Household Travel Survey" (Benham, 2001).

There are three measures of travel exposure collected in the MAHTS survey data: trips, trip distance, and trip time. The travel survey is recorded as a number of individual "stops" and each break in a journey is recorded as a separate stop. Travel from one stop to the next stop is a trip segment. A "trip" is one or more segments of travel that have been linked. Trip distance is not specifically recorded during the household interviews but it is calculated from the origin and destination zones (zone centroid to zone centroid by the shortest road path). Note that the trip distance measure tends to become less accurate in larger zones. Individual's estimates of time taken for a trip are recorded but are likely to be somewhat inaccurate (e.g. time is rounded to the nearest 5 or 10 minutes). It is possible to calculate trip time by looking at the origin and destination time although this calculation is only accurate to the nearest hour. Other information recorded includes age and sex of each respondent, mode of travel, purpose of trip, day of week, and start and end time of trip.

There are some limitations associated with the data. In some zones, only a small number of samples were obtained and these may not be representative of the whole zone. Moreover, the survey data is representative of those zones where sampling was undertaken. Consequently, the percentages in each distribution are important, not the actual values. Another concern is that multi-modal trips are categorised by a single dominant mode. As a result walking, which is usually a small part of a multi-modal trip (e.g. walking to transit), is likely to be under-reported.

For the same reason, but perhaps to a lesser extent, cycling trips are also likely to be under-reported.

DTEI is planning a third household travel survey in 2011.

More recent information on household travel behaviour in Adelaide can be obtained from a PhD thesis examining urban design quality, neighbourhood urban form and travel behaviour in Adelaide (Soltani, 2007). This mail based household travel survey was conducted in 2005. However, unlike MAHTS, this survey covered four suburbs (Golden Grove, Norwood, Para Hills, Unley) rather than the all of metropolitan Adelaide. Approximately three per cent of the population in each of these suburbs was sampled with only one adult aged over 16 years responding in each household. Information on the number of trips made on one weekday was recorded in a travel diary. Trips details recorded include: mode of travel, location of trip origin and destination, time when trip started and ended and purpose of travel. Although this household survey is not as comprehensive and representative of metropolitan Adelaide as MAHTS, it gives an indication of current broad trends in travel behaviour (trip purpose and mode) in specific suburbs. Due to the small sample size and sampling of only one household member, the data cannot be meaningfully disaggregated by sex and age to create trip or time based exposure measures.

4.1.2 ABS Motor vehicle census

Motor vehicle censuses have been conducted periodically from 1971 to 1999 and annually from 2001 to 2007 by the Australian Bureau of Statistics (ABS). The census includes information on all vehicles registered with a state, territory or other government motor vehicle registry for unrestricted use on public roads with the exception of recreational vehicles (e.g. sand dune buggies, trail bikes), consular vehicles, and vehicles registered by the defence forces. A vehicle registered at the date of the census, or had registration expire less than one month before the date is counted in the census. Consequently, the census provides a snapshot count of registered vehicles. Since 2001, the motor vehicle census has consistently been conducted on 31 March.

Motor vehicle registration statistics are available based on information provided by state and territory motor vehicle registration authorities and reflect information derived from registration documents and, where possible (vehicles manufactured during or after 1990), Vehicle Identification Numbers (VIN). Although records are matched to previous records and additional internal checks are conducted, the ABS acknowledge that there is still some variation in reporting from different jurisdiction registries and care should be taken when making comparisons across jurisdictions. The quality of some detailed data is not known.

The vehicle registration data can be sourced from the annual publication "Motor vehicle census Australia" (ABS catalogue No. 9309.0). Data cubes are also available for individual states with information including: make and model of vehicle, postcode of registered owner, vehicle type, and year of manufacture.

4.1.3 ABS Surveys of motor vehicle use

The ABS surveys of motor vehicle use are designed to collect information from a sample of vehicles with regard to the number of kilometres driven in different vehicle types. The survey sample includes all private and commercial vehicles registered for normal road use. The survey is collected quarterly and published annually. The information collected about drivers includes the age and gender of individuals driving a sample vehicle, and the proportion of total distance travelled in each vehicle by each driver. The data refer to the average number of kilometres driven by drivers of a sampled vehicle. However, some drivers may drive multiple vehicles, therefore, the recorded number of kilometres driven by some drivers will be an underestimate.

The latest published survey of motor vehicle use in Australia (2006), is comprised of a stratified sample of 16,000 vehicles selected from the 13.9 million registered vehicles identified at this time (ABS Motor Vehicle Census). Vehicle use is reported over a three-month period within the

reference year. Estimates from the latest survey, consisting of 26 tables, can be downloaded as an excel file (data cube). The data were collected in four quarterly sample surveys conducted by the ABS over the period 1 November 2005 to 31 October 2006. The tables contain statistics on passenger vehicles, motor cycles, trucks, and buses for characteristics such as distance travelled (total and average), fuel consumption, year of manufacture, and area of operation. Data cubes derived from the survey data cover vehicle type, state of registration, kilometres travelled, fuel consumption, type of fuel used, state/territory of operation, year of manufacture and details on freight carrying vehicles such as tonnes carried, tonne-kilometres, commodity carried and GVM/GCM. The ABS web site also provides data cubes in excel file format for surveys conducted in previous years (1998 – 2005).

It is important to remember that this survey examines the number of kilometres driven by drivers of a sampled vehicle, that is, it is vehicle-based rather than driver-based. Information from these surveys can be sourced from the annual "Survey of motor vehicle use" (ABS Catalogue No.9208.0). Historical data (1970-2002) for vehicle kilometres travelled derived from these surveys for individual states and territories is summarised in an ATSB publication (see Table 16; ATSB 2003).

Note that information on the numbers of new motor vehicle sales by dealers and direct sales for manufacturers throughout Australia is also collected by the ABS (see "Sales of new motor vehicles, Australia", May 2008, ABS Catalogue No. 9314.0). Sales of new motor vehicles can be compared with data from the motor vehicle census based on the year of manufacture. Individual information for each state and territory is available on a monthly basis. However, this survey does not collect as much detailed information as the Survey of Motor Vehicle Use.

4.1.4 ABS Population data

The ABS provides population data that can be used to calculate driving exposure per head of population. These data are based on the 2006 Census of Population and Housing. Estimates of population for each state and territory classified by sex and single years of age (0 – 84 years) are available; also grouped ages, sex ratios, median and mean ages of the population.

The latest population data for Australia, including separate statistics for South Australia, is sourced from the annual publication "Population by age and sex, Australian states and territories" (ABS Catalogue No. 3201.0).

4.1.5 ABS Census: Journey to work information

The Australian Census of Population and Housing collects information on the patterns of respondent's journeys from their home to place of work. State transport authorities use this data to identify travel patterns, predict public transport patronage, plan changes to existing transport systems and model fuel usage. On the date specified by the census, individuals record their departure point, destination and method of transport. Respondents also record their age and gender. From this information, travel distances to work are calculated. Note that travel distance is not a good indicator of time taken for the trip due to factors such as time of day, traffic congestion, speed limits etc.

This data source is not ideal for estimating regional travel rates because it only includes commuting trips for work purposes. Some transport modes may be used differentially for recreational or personal purposes. For example, if walking and cycling are more likely to be used for recreational purposes, they will be underestimated in this census data.

Data is available at the Statistical Local Area (SLA) level from the ABS. Any data below the level of SLA is not validated by the ABS and so, it should only be used in consultation with the relevant state transport authority. An atlas of workplace travel for the Adelaide statistical division, based on for the census data from 2001, has been published (Edwards & Flynn, 2004). Note that journey to work information has been collected from population censuses since 1971. However, data are not comparable across censuses because study areas and destination zones have been constantly redefined.

4.1.6 Health Omnibus survey

DTEI includes 10 questions about bicycle use in the annual health omnibus survey. This survey relies on self-report and data is collected through face-to-face interviews of householders including children. Information is obtained about the number of bicycles in the household, frequency of cycling trips, level of cycling, and where individuals choose to cycle. Results from this survey can be obtained from the Office for Cycling and Walking at DTEI.

4.1.7 DTEI: Registration and licensing data

Licensing data maintained on the TRUMPS database by Registration and Licensing at DTEI contains information that can be used to form driving exposure measures. The data set include the number of licensed drivers by sex, age, licence type; date received each licence type; and dates of licence disqualifications. The number of registered vehicles can also be obtained and cross tabulated with driver age, sex, and licence type. Note that using the number of registered vehicles as a measure of travel is insensitive to short term changes in travel that might result from rises in fuel costs, changes to public transport, changes to the cost of living etc.

Specific registration and licensing information can be obtained from DTEI.

4.2 On-road monitoring

Data collected through on-road monitoring in South Australia include traffic volumes or vehicle counts, traffic flows, vehicle speeds, and travel time (road-based not person-based). In addition, roadside surveys of drink driving and an observational survey of pedestrian movement have been conducted. Little of this data has been collected on an on-going basis. Rather data is collected on an annual basis or on a one-off basis to meet the specific needs of a project.

Generally, on-road monitoring data collection is not specifically designed to measure exposure and it is predominantly aggregate data that does not identify individual vehicles. Nevertheless, survey results have some limited application for site exposure with respect to certain sections of the road network at certain times of day, day of week and time of year.

4.2.1 Metropolitan traffic volumes

Traffic volume data is routinely collected for the metropolitan road network via the Adelaide Coordinated Traffic Signal (ACTS) system (Woolley, 2007). Loop detectors buried in the pavement at or near stop lines at signalised intersections measure traffic volumes. Information on traffic volumes is used for strategic modelling purposes and calculating annual average daily traffic (AADT) estimates. The AADT estimate represents the total volume of traffic (the sum of traffic travelling in both directions on a two-way road) passing a roadside observation site over a full year, divided by the number of days in the year. AADT estimates for all traffic and commercial vehicles in metropolitan and rural areas in South Australia are depicted in a series of maps on the DTEI website, see: http://www.transport.sa.gov.au/transport_network/facts_figures/traffic_volumes.asp. AADT estimates are expressed on the maps as both an absolute number and a percentage proportion of the total traffic flow.

4.2.2 DTEI traffic volume surveys

An estimate of Vehicle Kilometres Travelled (VKT) on the metropolitan road network is made using current macro traffic modelling software. Volumes are taken from various counter stations around South Australia. For more information, refer to Traffic Information Management Section, DTEI.

4.2.3 Fixed red light / speed cameras

Dual-purpose fixed red light/speed cameras record data concerning the running of red lights, vehicle speeds and the number of vehicles passing the camera (i.e. traffic volumes) at

intersections. DTEI records indicate that in 2006 there were 44 sites, predominantly intersections, at which dual-purpose red light/speed cameras could operate and 31 cameras were available for use at these sites. Data is recorded continuously at sites where the camera is operating but not all sites have cameras operating throughout the year. Note also, that traffic volumes are only recorded for the direction of travel in which the camera is pointed. Consequently, the cameras provide limited exposure data for specific sites. The sites are not representative of all metropolitan intersections, rather they are likely to reflect intersections selected on the basis of high crash frequency. Information can be requested from the Traffic Support Branch at SAPOL.

4.2.4 Auslink surveys

As part of Auslink, a federal project aiming to improve the movement on road freight, 42 permanent sites have been established on the National Highway system within South Australia to measure traffic volumes on an on-going basis. Many of the sites were selected in the 1960s and until the last decade, only volume and vehicle axle data was collected. In October 2004, most of the equipment was upgraded to new classifiers that could also measure individual vehicle speeds (Woolley, 2007). This system uses two tubes laid across the road surface. To date (May 2008), all but eight of the sites are situated in 110 km/h zones: four in 100km/h zones, three in an 80km/h zone and one in a 60km/h zone (Woolley & Kloeden, In press). The continual collection of data allows a better understanding of seasonal effects and random variation in traffic volumes on these arterial rural roads. For more general information about Auslink, visit <http://www.auslink.gov.au>.

4.2.5 Rural speed surveys (DTEI)

Routine vehicle counts are conducted by DTEI on lesser rural roads to fill in the gaps between counts on the National Highway system (i.e. Auslink surveys). There are several hundred of these sites throughout South Australia. Although these sites should be surveyed on a three-yearly cycle, Woolley (2007) notes that current resources have meant that the sites tend to be surveyed on a five-year basis. Data from these surveys usually represents at least seven days of observation of traffic in both directions of travel. In the past two years, some long-term surveys of six months duration were conducted at several of these sites to determine seasonal variation and confirm adjustment factors for permanent counter sites (Woolley, 2007).

Regular on-road speed surveys using traffic classifiers have been conducted by DTEI throughout rural South Australia on an annual basis from the year 2000 (see Wundersitz & Baldock, 2008 for the latest results). The surveys are undertaken at 21 locations: six in country towns on 60 km/h or 50 km/h speed zoned roads, six on 100 km/h zoned roads, six on 110 km/h zoned roads and three on remote outback roads. Since the surveys began, there have been some changes to the speed zoning at four of the sites. The regions for each measurement site were chosen on a convenience basis but the road to be surveyed in each region was selected randomly.

These surveys are not conducted on an on-going basis but are usually conducted around the beginning of August because this month was found to most closely represent the annual average daily traffic (AADT). A minimum of one week's worth of speed and volume data are collected for all traffic travelling in both directions. Information on the length of the vehicle, for classifying the vehicle type, is also collected.

4.2.6 Metropolitan speed surveys (DTEI)

Before 2007, there were no systematic on-road traffic volume or speed surveys conducted in the Adelaide metropolitan area. Speed and traffic volume data was collected on selected metropolitan roads in 2002, 2003 and 2005 for the specific purpose of evaluating the reduction of the default urban speed limit from 60 to 50 km/h on local roads and most collector roads in 2003. The speed limit on arterial roads remained unchanged at 60 km/h.

Surveys of on-road vehicle speeds and traffic volumes were conducted using traffic classifiers at 52 locations in urban areas (including the Adelaide metropolitan area and South Australian regional towns). The surveys were conducted at randomly selected sites, with 30 surveys undertaken on local access streets (18 urban, 12 rural), 12 surveys on collector roads and 10 surveys on arterial roads. The surveys were undertaken in late November and early December with a minimum of 24 hours of speed data recorded during weekdays at each site.

Due to the specific purpose of these surveys, the data is limited in its representativeness of metropolitan roads and does not constitute a reliable source of data for determining historical trends.

4.2.7 CASR speed monitoring surveys

In 2007, DTEI asked CASR to establish a regular speed monitoring program for South Australian roads (Woolley & Kloeden, In press). In addition to vehicle speeds, traffic volume data including vehicle type and time of day are recorded at 136 sites. Data is collected over seven days, rather than one, to account for daily variation. The rural surveys are conducted in August as traffic in this month is closest to annual average daily traffic on the roads under observation. Metropolitan surveys are conducted in November.

With 73 sites on rural roads and 63 sites on metropolitan roads, these surveys provide probably the most comprehensive traffic volume data for different roads in South Australia. However, it is important to note that sites were not randomly chosen. Instead, survey sites have made use of previous and existing surveys sites to maintain some historical trends. Furthermore, sites were chosen that represent different speed zones and some speed zones were more of interest to the survey designers than others. For rural areas, Woolley and Kloeden (In press) commented that 12 sites adequately represent local 50 km/h rural roads and although local 60 km/h rural roads have less representation with a sample of five roads, it was deemed that there was not sufficient interest in these roads to justify an increase in sample size. There are six 80 km/h sites but these are all located in the Adelaide Hills, chosen on the basis that they were monitored in a previous study and would therefore, have some historical data. The 100 km/h roads are represented by 10 sites but it is likely that some of the 110 km/h roads may have their limit reduced in the future. The 110 km/h roads are well represented by the Auslink survey with 35 sites.

In the metropolitan area, of the 63 sites selected, 18 are on 50 km/h local roads, 12 on 50 km/h collector roads, 27 on arterial roads (split into subgroups based on number of lanes and median) and six on 80 km/h arterial roads. Fourteen sites on 60km/h arterial roads and all six sites on 80km/h arterial roads have no historical data. Due to limitations with the measurement equipment, not all lanes on multilane roads can be monitored. Therefore, on multilane arterial roads with no median, only the kerbside traffic lanes are monitored; on multilane arterial roads with a median, only the median traffic lanes are monitored.

While the sites provide a reasonable snapshot of speeds and traffic volumes on the road network, these observations are 12 months apart and only represent a snapshot of one week in the whole year. Data collected on an on-going basis at these sites, or at least some of these sites, would be necessary to obtain a better understanding of seasonal effects and random variation of traffic volumes in these areas.

4.2.8 CULWAY sites

Heavy vehicle volumes and classification counts can be obtained from CULWAY sites that are designed to covertly measure the mass of heavy vehicles as they pass over the site. At each site, a weigh in motion system is attached to the roof of a culvert and additional piezo-electric cables are buried in the road pavement to measure speed and axles. The system also records information on the time, date, headway between vehicles, travel lane, and direction of travel.

At present, only heavy vehicle data is collected (Class 3 and above on the AUSTRROADS classification system) although the system is capable of measuring data for all vehicle types

(Woolley, 2007). A review of the system in terms of speed surveys by Woolley (2007) found that due to memory limitations, a survey of all vehicle types would require the data to be downloaded at least twice per week. There are currently eight CULWAY sites covering 11 traffic lanes located on primary freight routes throughout South Australia. The Transport Information Management Section at DTEI can be contacted for further information.

4.2.9 Safe-T-Cam sites

The Safe-T-Cam system consists of a series of cameras placed strategically throughout the road network using overhead gantry structures to manage heavy vehicle travel times and consequently driver fatigue and speeding. The cameras read the number plates on vehicles that pass within their lane under the gantry and take a photo. The image and registration details are stored along with a date and time stamp in a central database. When the same vehicle passes through other Safe-T-Cam sites, the registration number is matched with other "sightings" of that vehicle and travel times are calculated. Although this system was designed for heavy vehicles, it has the capability to record data for all vehicle types.

In South Australia, Safe-T-Cam first came online officially at 11 sites in September 2006 following the trial of a pilot site in 2002 (Woolley et al., Unpublished). However, approximately half of the sites were offline for many months in 2006 due to vandalism.

This source of exposure data is useful for determining travel times of heavy vehicles on major highways and freight routes. In addition, the data could also be used to determine volumes of through traffic as opposed to local traffic passing through these sites. Unlike most other sites recording traffic volume data in South Australia, this data is recorded on an individual level. Nevertheless, there are privacy issues associated with obtaining this data. For further information on Safe-T-Cam see: <http://www.transport.sa.gov.au/freight/safetcam/index.asp>.

4.2.10 DTEI travel time surveys

DTEI perform annual travel time surveys to meet AUSTROADS reporting criteria about the performance of their road network. The floating car method is used on nominated arterial routes (10 routes in 2008). The surveys are conducted on weekdays during the morning and evening peak travel periods and during business hours. Travel times and average speeds are reported for each link in the route and the overall route. Information can be obtained from the Transport Information Management Section, DTEI.

4.2.11 RAA travel time surveys

The Royal Automobile Association Inc (RAA) conducts independent travel time surveys. These surveys measure average travel time and speeds of vehicles in the morning and evening peak travel periods on selected major arterial roads in Adelaide (8 routes in 2007). These annual surveys have been conducted since 1986. Information can be requested from RAA.

4.2.12 Roadside drink driving surveys

Both roadside breath alcohol surveys and random breath testing operations provide a useful measure of the distribution of drivers' BAC levels. Roadside surveys are advantageous in that they are not accompanied by enforcement (i.e. potentially less avoidance behaviour). The Road Accident Research Unit previously conducted ten night-time roadside surveys measuring BAC levels in metropolitan Adelaide between 1979 and 1997 (see Kloeden & McLean, 1997). No roadside surveys have been undertaken in South Australia in recent years.

4.2.13 Bicycle count sites

DTEI conducts a number of surveys to count cyclists. Since 1977, annual cordon counts of cyclists entering the City of Adelaide have been undertaken in collaboration with the Adelaide City Council. For one day in October (fine weather, not during holiday period), observers count

the number of cyclists at key entry points into the city, on bike tracks, paths and roads. There are approximately 30 observation sites at present; the number of sites has grown with the road network. In the last two years, the number of pedestrians has also been counted at these sites. However, the counts are likely to be an underestimate because many pedestrians do not stick to paths or major routes through the parklands surrounding the city. Nevertheless, these surveys provide some indication of longitudinal trends in cyclist numbers at sites around the city centre.

In addition to these surveys 'smart counters' have been installed at three bicycle lane sites to the west of the city centre: Anzac Highway at Keswick, Port Road at Thebarton and Sir Donald Bradman Drive in the parklands. The automated counters (inductive loops) record the number of bicycles travelling in one direction in 15-minute blocks and operate throughout the year. There is an additional new site in Linear Park near the Brewery that counts bicycles travelling in both directions. Information collected from these surveys is useful for evaluating hourly, daily, monthly and seasonal (e.g. weather dependent) trends for cyclists at these sites but they are not representative of metropolitan Adelaide or South Australia.

For the latest information from the cordon counts and bicycle counters, see: http://www.transport.sa.gov.au/personal_transport/bike_direct/facts_and_figures.asp.

4.2.14 Public spaces and public life, City of Adelaide: 2002 - Pedestrian survey

The purpose of this one-off study was to examine how urban spaces in the Adelaide CBD are used, primarily for the benefit of architects and town planners. As part of this study, pedestrian traffic was counted at 15 sites in the Adelaide city centre for 15 minutes every hour between 10am and 12pm on two days (one weekday, one Saturday) during summer in 2002 (Planning SA, 2002). However, the study does not specify on what basis the sites were selected. The pedestrian count results were extrapolated to produce hourly estimates. The hourly estimates of pedestrian volumes could be used as an exposure measure for pedestrian crashes at these specific sites.

4.3 Case-control studies

Case-control studies enable the behaviours and travel patterns of road users who are not involved in a crash to be compared to similar group who have been involved in a crash. Important factors contributing to crash involvement can then be separated out. In South Australia, case-control studies have established the relationship between travelling speed and crash risk on metropolitan and rural roads. Consequently, some limited exposure data (i.e. travel speeds) at specific crash sites exists. Note that case-control studies are costly, and are not always feasible or practical to conduct.

4.3.1 Travelling speed and the risk of crash involvement (Kloeden et al, 1997)

To estimate the relationship between travelling speed and the relative risk of crash involvement, a case-control study examined a series of crashes from 1995 to 1996. The case vehicles were passenger cars involved in casualty crashes in 60km/h speed zones in the Adelaide metropolitan area (the urban speed limit at the time of the study). These case vehicles had a free travelling speed prior to the crash. The 604 control vehicles (four per case) were passenger vehicles matched to cases by location, direction of travel, time of day, and day of week. Speeds were measured using a laser speed gun, typically with the operator some distance beyond the location where the vehicle speed was measured. Results from the study showed that the risk of crash involvement approximately doubles for each increase in travelling speed of 5km/h above the 60km/h speed limit.

4.3.2 Travelling speed and the risk of crash involvement on rural roads (Kloeden et al., 2001)

The relationship between free travelling speed and the risk of involvement in a casualty crash on 80 km/h or greater speed limit zones in rural South Australia was examined using a case-control study design. The crashes involved 83 case passenger vehicles. The 830 control passenger vehicles were matched to the cases by location, direction of travel, time of day, and day of week and their speeds were measured with a laser speed gun. The risk of involvement in a casualty crash increased more than exponentially with increasing free travelling speed above the mean traffic speed and travelling speeds below the mean traffic speed were associated with a lower risk of being involved in a casualty crash.

4.4 Observational special purpose studies

The studies described in the following sections involve observations of specific incidents or behaviours in South Australia. Each specific behaviour or incident (i.e. restraint use, bicycle helmet use, presence of bull bar) was measured as a proportion of all behaviours/incidents observed. Thus, each of these studies has incorporated a relevant measure of exposure, specific to South Australia.

4.4.1 Observational survey of bull bar prevalence at pedestrian crash sites in Adelaide (Anderson, Ponte & Doecke, 2008)

This survey was designed to examine the proportion of vehicles fitted with bull bars in Adelaide, South Australia, at sites where pedestrian crashes have occurred in the past. The sample was stratified to examine the prevalence in three separate geographical regions of the metropolitan area of Adelaide. Survey results were combined using weights determined from the relative incidence of pedestrian crashes in the three survey strata.

Observations of the traffic at each location were made for 40 minutes; 20 minutes each side of the time of the associated pedestrian crash. The survey included all vehicles in all traffic lanes in the same direction as the vehicle involved in the crash. Traffic at survey locations during daylight hours (and some night hours) was also recorded on video. Two research officers collected all of the survey data: the total number of passenger vehicles and other light vehicles, the total number of heavy vehicles, the number of vehicles with any sort of commercially produced 'frontal protection device' (typical bull bar, nudge bar or grille protection bar), and the type of vehicle it was attached to.

Overall, 8.6% of traffic was equipped with bull bars. Bull bar prevalence was much greater among heavy vehicles (28%), but heavy vehicles formed only a minor component of the traffic volume. The average bull bar prevalence amongst light vehicle traffic was 7.5% and was lowest in the CBD (average 5.5%) and highest in the Outer Metropolitan Region (average 9.1%). Differences between bull bar prevalence in each region were statistically significant, and there was additional variation between sites within each region. 4WD vehicles are the most common vehicle type to have a bull bar fitted and 4WD vehicles with bull bars are twice as prevalent at the sites of crashes as the next most common type of bull bar equipped vehicle, work utilities.

4.4.2 Observational survey of child restraint choice and knowledge (Edwards, Anderson & Hutchinson, 2006)

The survey was designed to assess the frequency of child restraint use, with a focus on the use of booster seats. Children aged 0-10 were observed arriving by car at pre-schools and primary schools in the Adelaide metropolitan area. After they had been observed, the vehicle driver was asked a few questions about their knowledge and perceptions of child restraints.

A sample of 16 pre-schools and 15 primary schools was randomly selected. The observations and interviews were undertaken on school days, over a four-week period during August 2004.

Of the 357 driver interviews, a total of 586 children in the desired age range (birth to 10 years) made up the sample. Observation of restraint use proved to be difficult when vehicles had tinted windows, were high and thus difficult to see into, and when children had removed their restraints ready to alight. In such instances, there was the need to rely on the driver's report of restraint use. In some cases, self-report data were corroborated by observation. Considering the 586 children, restraint type and use were observed for 74%, were reported for 16%, and for the remaining 10%, restraint type was observed but use was reported (as the child had already removed it before the observer could see).

The main survey result was that the rate of appropriate restraint was between 64% and 72% on such trips, (according to weight criteria in the Australian and New Zealand Standard on child restraints for motor vehicles). Only 1% were completely unrestrained. Most of those who were not restrained appropriately had prematurely progressed to an adult seatbelt. Appropriate child restraint use was lowest for children in the age range 5 to <7 years. Inappropriate restraint choice was strongly related to the child's age, their seating location (children seated in the rear being more likely to be restrained appropriately), and possibly the child's entry into primary school.

4.4.3 South Australian primary schools bicycle helmet usage survey (Thomas, Somers & Anderson, 2004)

Every primary school in South Australia received a letter of invitation to participate in a survey to assess bicycle helmet compliance rates amongst South Australian primary school students riding to school. The survey was conducted both in metropolitan and country South Australia, and across all public, Catholic and independent primary schools from 3-7 November 2003. Of the 683 invitations sent to schools, 217 (31.8%) schools agreed to participate. The responding schools accounted for approximately 42.3% of all primary school students in years R-7 (48,347/114,287) in South Australia.

Participation in the survey involved each school nominating an observer who spent one hour, on one designated morning of the survey week, standing at the school's bicycle racks recording whether students that arrived at school by bicycle were wearing a helmet. Schools were requested not to forewarn students of the upcoming survey, so that the survey results would be representative of regular helmet wearing activity.

To determine whether helmet wearing among responding primary schools was the same as that for non-responding primary schools, two weeks after the survey had concluded an appointed observer visited a random sample of all primary schools in the metropolitan Adelaide area that chose not to participate in the survey. At the non-respondent schools, the observer stood at the school's entrance gate and recorded whether students arriving by bicycle were wearing a helmet.

It was estimated that 4% of primary school children ride their bicycle to school. Of the students riding a bicycle to school, 92% wore a helmet. The highest rate of helmet compliance was reported in Catholic and independent primary schools (100%). Geographically, the lowest rate was reported in the metropolitan Adelaide region (89%). Given that the response rate for the survey was low (31.8%) calculations were made to determine what effect the non-responding schools (68.2%), with a lower rate of helmet-compliance, would have on an estimate of helmet compliance among all primary school students in South Australia. Assuming that all non-responding schools were similar to those observed in the study follow-up (compliance rate 83.5%) the estimate for helmet compliance for all primary school students in South Australia would be 89%, which is consistent with other surveys conducted in Australia.

4.4.4 On-road observational restraint use surveys (Wundersitz, Kloeden & McLean, 1999)

Four on-road observational surveys have been conducted from 1998 to 2002 in the Adelaide metropolitan area and in the regional areas of Whyalla, the Riverland and Mount Gambier. The

last two surveys also included Murray Bridge and Clare. No surveys were conducted in the year 2001.

Observational surveys were undertaken at intersections controlled by traffic lights, stop signs or give way signs. The observation sites in each city or town were selected because they appeared to be busy and represented a variety of occupant types (e.g. local traffic, commuting to work). Details were recorded for each stationary or slowed vehicle at the intersection until they began to move off. Observers only included through traffic to avoid vehicles pulling out of shopping centres, nearby parking spaces etc. Cars, panel vans, utilities and four wheel drives were the only vehicle types included for observation.

The number of occupants was recorded along with seating position, gender, estimated age and restraint wearing for all occupants. The positions of unrestrained children in the vehicle were also noted.

Some methodological limitations associated with the observation of on-road restraint use were noted: difficulties in completing the desired observations for all vehicle occupants in the time available and obtaining accurate information about restraint use of rear seat passengers, particularly with respect to lap belts.

5 Discussion

5.1 Comment on some examples of use of exposure data

Some decades ago, one of the present writers participated in an early attempt to calculate credible estimates of pedestrian crash rates (Goodwin and Hutchinson, 1977), and this can serve as an example of how exposure data is useful. The background was that normally no-one believes data on walking in travel surveys, because it is so easy for respondents to forget short trips, or not to bother reporting them; obviously walking trips are shorter than most trips by motorised modes. However, an unusual feature of the (U.K.) National Travel Survey of 1972-1973 was that in the week of data recorded by households, there was one day when all walking trips were included (those of under, say, one mile not being excluded). Goodwin and Hutchinson compared this dataset with crash data, and were able to show how pedestrian crash risk varied with age and sex of the pedestrian, time of day, day of week, and month of year, and they also made a comparison of pedestrian crash rate with that of other modes of transport.

Another convenient point of departure is *Exposure data for travel risk assessment: Current practice and future needs in the EU*, published in 1999, by the European Transport Safety Council. Section 3.1 of ETSC (1999) has several examples of how exposure data is used.

- Figure 1 shows the number of fatalities per hundred million vehicle kilometres in different countries of the EU (the U.K. having the lowest rate and Greece having the highest).
- Figure 2 shows the number of car driver fatalities per distance driven for different age groups in one country (the 40-49 age having the lowest rate and the 17-19 and 70+ age groups the highest).
- There is comment about the variation of car passenger fatalities with age, and that comparison of car drivers with car passengers permits the inference that the two peaks in driver fatality rate have different reasons: driving behaviour in the case of teenagers, and physical vulnerability in the case of the elderly.
- Table 1 shows the number of fatalities per distance travelled for different road types (traffic calming areas and motorways having the lowest rate and rural roads the highest).
- Figure 4 shows the number of fatalities per distance travelled in different years (decreasing by about 5 per cent per annum).

Several comments on this are worth making, both at the general level and prompted by the specific examples.

- Distance is the usual measure of exposure (not time, or number of vehicles encountered). It is the simplest measure.
- The comparisons are at a very gross scale, e.g., countries or ten-year age groups or types of road.
- It is not clear what real use the information has. It is interesting to know that 17-19 year old drivers have so much higher a fatality rate than 20-29 year olds, but one is left without much direction concerning what to do.
- The statistics of crashes are not good enough for injury rates (rather than fatality rates) to be given: injuries are incompletely reported, and definitions vary between countries and between modes of transport.

- There is no hint of why the fatality rate of Greece is approximately seven times that of the U.K. Is the standard of the roads comparable in the two countries? Are the vehicles different? Is the behaviour of road users different?
- The fatality rate of 17-19 year olds is about four times that of 20-29 year olds. It is reasonable to think, then, that the rates for 17 and 19 year olds might differ considerably. Are the exposure data capable, in respect of sample size and accuracy, of addressing such issues?
- Choices about traffic engineering measures are typically at a more detailed scale than “type of road”. If a comparison were being made of different levels of lighting, say, or different designs of junction, would vehicle kilometres be an adequate exposure measure?
- Knowing how the rate of fatalities changes over time may be more useful than knowing how the number changes, but is the degree of aggregation too great? For example, a reduction in speed limit may have reduced the crash rate of both car and motorcycles, and yet the overall rate may have increased if a switch from cars to motorcycles has taken place.

Travel survey data and traffic count data are both potentially useful in understanding crash occurrence. It might be expected that we would urge more such data be collected, and existing datasets be made easier to use for researchers. Yes, we support both those things. However, we believe that the previous paragraph suggests that there will be severe limitations with the usefulness of such datasets for the foreseeable future. This rather pessimistic outlook will be supported by the further arguments below.

5.2 Topics for which knowledge of exposure might be useful

At this point, it may be useful to identify some research topics for which exposure is important. The main topics in road safety may be classified as relating to people, behaviours and states, environmental conditions, locations, and vehicles. Of these, questions about people may be divided into questions about specific individuals and questions about types of people, and questions about locations may similarly be divided into those about specific locations and those about designs of the roadway. These questions are discussed along with comments on methods for determination of exposure that are likely to be most appropriate.

5.2.1 People

a) Specific individual people. Are some people accident prone? In the course of our in-depth at-scene investigations, we are able to look up the previous crash record of individual drivers. Sometimes, they seem to have had a lot of crashes. Are they genuinely at high risk per kilometre driven, or do they drive a lot of kilometres? People who come to notice by being involved in a crash could be asked how far they drive, but more generally the data collection problem is difficult: the individual data on distance driven needs to be accurate, and the sample size needs to be sufficiently big that there is good representation of drivers who have had many crashes.

b) People in different age/sex groups. Examples are as follows.

- Young novice car drivers (age/sex and time since licensure).
- Young novice motorcyclists (perhaps more difficult to study as there are fewer of them).
- Novice truck drivers (perhaps more difficult to study as there are fewer of them).
- Elderly car drivers.
- Special problems of estimating how much cycling is done.

- Special problems of estimating how much walking is done.

For topics in this group, travel survey data is likely to be used.

- It is quite common for results at a macro scale to be presented.
- In the case of young novice drivers, there are likely to be interesting questions concerning the evolution of crash rates on a scale of weeks (e.g., after gaining a full licence), and sample sizes have not usually been sufficient to permit such questions to be answered.
- In the case of elderly car drivers, there may be special problems in gaining honest and correct responses.
- There are particular difficulties with capturing data on non-motorised modes of transport (e.g., walking and cycling) and on being on the road for purposes other than travel (e.g., recreation, working, playing).

5.2.2 Behaviours and states

Some examples are:

- Alcohol
- Drugs
- Fatigue
- Speeding
- Following distance (i.e. vehicle headway)
- Presence of passengers
- Use of mobile phone
- Psychological states such as bad temper or feeling stressed

It is possible to ask people about the frequency of behaviours. In some cases, it might be possible to look inside a car and see. Intrusive observations, such as stop the vehicle and test the driver, may sometimes be feasible.

5.2.3 Environmental conditions

Examples include:

- Times of day
- Daylight vs. dark
- Wet vs. dry

For topics in this group, traffic count data is likely to be used.

5.2.4 Locations

a) Specific individual locations

- Crash rates of different specific lengths of road.
- Crash rates of different specific intersections.

For topics in this group, traffic count data is likely to be used. Intersections are a particular problem. A specific intersection will have specific flows on its several arms, but it is not clear how these various flows should be combined into a summary measure of exposure. Let us be optimistic and suppose that there exists a body of high quality research that has established that, say, the product of flows is a better measure than the sum of flows. Even in such a case, the research will probably have involved the comparison (perhaps via some form of regression analysis) of numerous different intersections — and it is not clear that good evidence about a broad-brush generalisation is any sort of evidence at all about what is appropriate for comparing a specific intersection with other intersections.

b) Locations of different designs

Examples are as follows:

- Crash rates in different traffic conditions — e.g., at different speeds, or at different levels of flow. (But flow is itself a natural measure of exposure: this opens up the question of nonlinearity – see Section 3.1.)
- Going beyond a finding that there are different crash rates on different lengths of road, one may wish to study whether the different crash rates are associated with different elements of road design — e.g., street lighting, pedestrian crossings, a centre median, sealed vs. unsealed surface, shoulder sealing, the maintenance of the road surface, tidying the footpath to remove visual obstructions (and camouflage), and so on.
- Going beyond a finding that there are different crash rates at different intersections, one may wish to study whether the different crash rates are associated with different elements of intersection design — e.g., gross design (roundabout vs. traffic signal; crossroads vs. offset junctions), skid-resistant surface treatment, phasing of traffic signals (such as the dangers of nonexclusive right turn), cycle time, road markings, and so on.
- Relevance of particular road and intersection features to particular types of vehicle (e.g., pedal cycles, motorcycles, trucks).

For topics in this group, traffic count data is likely to be used. In the case of both elements of road design and elements of intersection design, we suspect it would be impossible to find exposure data that was sufficiently detailed and sufficiently compatible with crash data.

5.2.5 Vehicles

Examples are as follows:

- Modes of transport: walk, pedal cycle, motorcycle, car, bus, rail, airliner. (Possible serious problems of having different methods of data collection for different modes.)
- Compare types or models of car.
- Attribute different crash rates to the effect of elements of car design — e.g., size, front wheel drive vs. rear wheel drive, sedans vs. four wheel drives, ratio of height of centre of gravity to width of track, electronic stability control, age of car.
- Attempt to detect differences between vehicles that differ in some small detail but are otherwise the same (e.g., the same model with or without electronic stability control).
- Compare different sizes of truck, and compare trucks with rail.

For topics in this group, a variety of types of data may be used: traffic count, methods based on the vehicle (e.g., odometer reading), travel survey, and freight survey in the case of truck issues. However, none of these types of data are very appealing.

5.2.6 Summary

A selection of the sources of exposure data available in South Australia, reviewed in Section 4, are cross tabulated with the topics for which exposure measures might be useful in Table 5.1. What is most striking about Table 5.1 is the lack of data sources that provide exposure data on several of these topics.

Table 5.1
Summary of selected driving exposure sources available in South Australia

Sources of exposure data	Topics						Comments	
	Individual		Behaviour	Environment	Location			Vehicle
	Specific	Groups			Specific	Road design		
3.1 Population surveys								
MAHTS99	Y	Y, age, sex	Y, purpose of trip				Y, travel mode	Measures: trips, distance, time
ABS Motor vehicle census							Y	Data for registered vehicles only
ABS Surveys of motor vehicle use							Y	Measure: distance driven
ABS Population data		Y, age, sex						Measure: population
ABS Census: Journey to work information		Y, age, sex					Y, travel mode	Measure: travel distances Data for trips to work only
Health Omnibus survey		Y, age, sex	Y, where ride					Bicycle data only
DTEI: Registration and licensing data	Y	Y, age, sex, licence type					Y	Measure: licensed drivers and registered vehicles
3.2 On-road monitoring								
Metropolitan traffic volumes					Y	?		Data for metropolitan Adelaide only
DTEI traffic volume surveys					Y		Y	Data for metropolitan Adelaide only
Fixed red light / speed cameras			Y, speed		Y		Y	Data not recorded for all directions at each intersection
Auslink surveys			Y, speed	Y, time of day, seasonal	Y		Y, heavy vehicle	Continual data collection, data for heavy vehicles only
Rural speed surveys (DTEI)			Y, speed		Y		Y	Data collected over limited time period. Not representative
Metropolitan speed surveys (DTEI)			Y, speed		Y		Y	Data collected over limited time period. Not representative
CASR speed monitoring surveys			Y, speed	Y, time of day	Y		Y	Data for rural and metro areas. Not representative
CULWAY sites			Y, speed		Y		Y, heavy vehicle	Data for heavy vehicles only
Safe-T-cam sites	Y	Y	Y, speed & fatigue		Y		Y, heavy vehicle	Measure: travel time. Data for heavy vehicles only
DTEI travel time surveys			Y, speed	Y, time of day	Y			Measure: travel time on specific arterial routes
RAA travel time surveys			Y, speed	Y, time of day	Y			Measure: travel time on specific arterial routes
Roadside drink driving surveys		Y	Y, alcohol		Y			No surveys have been conducted since 1997
Bicycle count sites				Y, time of day, seasonal	Y		Y, bicycle (+peds)	Measure: bicyclists and ped volumes. Not representative
City of Adelaide Pedestrian survey				Y, time of day	Y		Y, ped only	Measure: pedestrian volumes at specific sites

5.3 Could exposure data be more useful in road safety research?

In looking forward to how exposure data might be made more useful in road safety, several important features of the present situation need to be kept in mind.

- Traffic and travel surveys are usually not carried out with road safety purposes prominent. Consequently, they are sometimes not easily used.
- Judging by what is published, road safety practitioners and researchers make only limited use of exposure data. (Perhaps more use would be made if it were more detailed, and more readily compared with crash data.)
- It is common these days for researchers to want to study the simultaneous effects of several variables, rather than their effects one at a time, using (for example) multiple logistic regression. They are likely to want to do the same with crash rate data — and thus the exposure data needs to be compatible with crash data across a wide range of variables, not only (for example) variables relating to the drivers, or the road.
- It is natural to divide crashes by exposure in order to get a rate, and then see how this is affected by various independent variables. However, we are not compelled to calculate rates: separate presentation of the effect of independent variables on crashes and on exposure is sometimes worthwhile.
- Not all types of crash are affected by independent variables in the same way. Indeed, the numbers of some types of crash may be affected in approximately the same way that exposure is, and thus variation in crash rate is only small; such types of crash are then potentially useful as surrogate measures of exposure.
- Road safety researchers have not been very successful at developing and elaborating the concept of exposure. Moreover, the ideas of induced exposure and traffic conflicts have been less fruitful than at one time hoped.
- Traffic flow data is collected at a limited number of points on the road network. But traffic engineers seem not to have really embraced the idea of a random sample, and consequently it is difficult to generalise what is found for a limited number of points to a wider geographical area.

A key part of the idea of exposure is the relationship

$$\text{number of crashes} = \text{rate} \times \text{exposure}.$$

It is considered useful to distinguish between rate and exposure. The reason is presumably that we typically want at least some primitive theory of why a road safety measure is successful: has rate changed, or has exposure changed? However, there is ambiguity in attempting to attribute a road safety effect to either an effect on rate or an effect on exposure. Consider, for example, an improvement to a vehicle, such as better tyres. We might say that there are fewer crashes because the vehicle's crash rate is reduced. But, alternatively, we might say that its exposure in the condition of poor tyres is reduced, with an increase in exposure in the condition of good tyres. Neither viewpoint can be said to be wrong. The same thing could be said about various improvements to people and various improvements to roads. Making reference to a rate tends to suggest something that is fixed and difficult to change. In contrast, making reference to exposure suggests something that is more a matter of choice.

Let us consider further a few specific examples.

- Crash numbers and crash types change dramatically in the weeks after a driver gets a provisional licence, and this continues for a few years. Suppose one wished to compare these changes with changes in distance driven. It is unlikely that a general purpose survey would have enough young inexperienced drivers; instead, a special sample of recently-licensed drivers would probably be taken.

- Suppose it were thought that removing structures that created visual obstruction or had a camouflaging effect would improve pedestrian safety. Such an initiative would take place where footpaths were busy with pedestrians and streets were busy with traffic. How could the numbers of pedestrians and vehicles be both allowed for in any comparison? This seems largely unanswerable.
- One might want to study how different are the crash rates of different models of car. Distance travelled by different models would not be easy to find out, but odometer readings and on-road counts would give some information. However, it is likely that factors such as nature of ownership (fleet vs. private), age of driver, and traffic conditions would have strong effects on crash rates, and they might not be independent of model — with the consequence that differences between models could arise for spurious reasons. Disaggregating distance travelled by different models according to such risk factors is a step or two more difficult than the already difficult task of getting aggregate data for car models.

These examples suggest the conclusion that many studies for which one might think exposure data would be useful would actually be very difficult if they were attempted. There is good reason for what was said earlier, that road safety practitioners and researchers make only limited use of exposure data.

5.4 What potential does new technology hold?

New technology provides some opportunities for better collection of exposure data.

- Some electronic device might be “attached to” a person, and record their travel (and identify whether the travel was as a vehicle driver).
- Some electronic device might be “attached to” a vehicle, and record its movements.
- There is much surveillance already being conducted by traffic cameras and security cameras.

Following on from this third possibility above, it may not necessarily be new technology but the review of video or surveillance records could in principle provide exposure information that is difficult to collect in any other way. Video recording was successfully used to record the prevalence and type of bull bars at selected pedestrian crash sites in Adelaide (Anderson et al, 2008) Other potential uses include observing vehicle movements at complex intersections, identifying and classifying vehicle types and recording the movements and behaviour of pedestrians or cyclists.

The first point (above) also holds particular potential. A recent study by a colleague gives South Australian data on the crashes and motoring offences of young drivers in their first few years after licensure (Kloeden, 2008). The conclusions that could be drawn were limited by the absence of information on distances driven. There was a wealth of detail, and the following gives some flavour of the findings.

Casualty crashes approximately halve during the first year after licensure, and they approximately halve again during the next four years.

The reduction in crashes is probably not due to driving less. This seems unlikely from the little that is known of driving habits. Further, casualty crashes for which the young novice driver was not responsible hardly change during the first year after licensure.

The reduction in crashes is probably not due to behaving better: speed offences, seat belt offences, and alcohol offences (behaviours that are the result of a choice by the driver) rise over the years following licensure.

By a process of elimination, then, it may be suggested that the reduction in crashes is due to increased competence in driving skills. That offences involving a moving violation rise, not fall, over the years following licensure is consistent with that.

Crashes involving turning right through oncoming traffic and crashes involving hitting a fixed object show a particularly sharp decline. These are suggestive of the skills that are developing most.

These findings would be much more interpretable if it were known how distance driven evolves over the months and years following licensure!

In principle, it is not difficult to imagine how that information could be collected.

- Randomly select 200 teenagers making their first application for a Learner's Permit.
- Give them each a modified iPhone for two years. (Teenagers generally keep their phones with them all the time.)
- The iPhone has a GPS (Global Positioning System) built in.
- The iPhone communicates with a satellite. Whenever the teenager is moving fast enough to be in a motor vehicle, that is recorded.
- There seems to be no way of automatically determining whether the teenager was driving or was a passenger, so it would be necessary for the iPhone to ask them that question (when stopped).

At the end of the project, there would be good data on how much driving teenagers do in their early years of driving. Some disaggregation by age, sex, and place of residence would be possible. Some classification according to conditions of driving (place, time of day, speed) would be possible.

6 Conclusion: Possible strategies for the future

The road safety community makes rather little use of exposure data at present. Some worthwhile results would be expected from expanding this use. Comments are offered below on four options for strategies to collect better exposure data, with our expectations for the results. Of course, exposure to risk may refer to people, vehicles, places, and so on; what is the best option for one of these units is not necessarily also the best option for the others.

Option 1: Better data collected by conventional means.

- MAHTS is probably the most comprehensive exposure data source in South Australia, and is based on a representative sample. However, the most recent survey of this type was in 1999. A new survey is planned for 2011, so we understand. To provide regular survey data and up to date estimates of crash risk for different groups of road users, such a travel survey could be carried out on an on-going basis throughout the year or a smaller scale survey conducted annually.
- Safe-T-cam sites have the potential to provide a wide variety of data, including individual data, but there are significant privacy issues.
- None of the traffic count surveys are representative, and little data is collected on an on-going basis. Nevertheless, understanding the data would be expected to contribute to understanding some aspects of crash data.
- Pedestrian and cycling data is especially limited, in South Australia as it is in many other places.

Our expectation: more exposure data of conventional types — whether a household survey or an on-road count — would be useful. Improvements in usability of the datasets would be welcome, too. But we would not expect a major boost to understanding of road safety problems from this.

Option 2: New technology for collecting data.

- This holds considerable potential. In particular, it seems likely that a random sample of teenagers could be tracked when using a motor vehicle, as described in Section 5.4 above.

Our expectation: knowledge of distances driven, and the conditions in which the driving took place, in the first two years after first licensure would be of great use in understanding the changing crash numbers and changing driving violation numbers.

Option 3: Better theoretical understanding of induced exposure methods.

- The basic idea of induced exposure methods seems to capture an important truth. Further, even if conventional exposure data were much better than it really is, it is almost inconceivable that it would measure the traffic conditions (number of other vehicles encountered, speed, environmental conditions such as rain), whereas it is quite possible that an induced exposure method would compensate for this. But induced exposure is also known to be unsatisfactory in important ways. Effort should be put into improving this class of analysis methods, perhaps as outlined in Section 3.3.

Our expectation: it is difficult to predict whether theoretical advance would take place, or if any formal theory developed would be successful. However, even if nothing can be achieved in that way, it is very likely that the investigation would proceed by cross-tabulating crash data (e.g., showing how different types of single and two-vehicle crashes are similarly affected by some variables and differently affected by others), and that the tables would give important new insights in an informal way.

Option 4: Collect compatible exposure data in the course of road crash research.

- Lack of data, as such, is not the main reason why exposure has been a concept of only limited usefulness in road safety. Rather, it is lack of data that is tailored both to the crash data available and to the research question under study.
- If society, collectively, wants to pay only for descriptive studies of the numbers of crashes, without the data being illuminated by complementary studies of exposure to traffic, that is what it gets. In the short term, everyone can focus on the value of such studies, which is appreciable. After two or three decades, however, there may be disappointment that no-one knows whether one feature of the road environment is safer than another, or one vehicle feature is safer than another, or one type of driver is safer than another, because the studies of exposure to traffic were always considered too expensive and not conducted. Road crash research could pay much more attention than it usually does to collecting or accessing exposure data that is compatible with the crash data.
- One form that this could take would be a greater number of case-control studies. These do not give total absolute figures for exposure, but figures that are relative to those found in crashes, and thus allow relative risk to be calculated.

Our expectation: roughly the same amount of effort and expertise would need to be devoted to exposure as to crashes, and roughly the same amount of effort and expertise would need to be devoted to putting the two types of data together and calculating risks. Thus the cost of road crash research would perhaps be tripled.

For those interested in crashes, it is natural to calculate a rate (i.e., a ratio of crashes to exposure). However, we would like to conclude by suggesting that there is much to be gained by taking a step backwards from that, and attempting to understand the important features of exposure data (e.g., distances driven) in a qualitative way, even if the data collection methods are not sufficiently compatible or robust to support the calculation of rates.

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