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THE CONCEPT OF EXPOSURE TO THE RISK OF A ROAD TRAFFIC ACCIDENT AND AN OVERVIEW OF EXPOSURE DATA COLLECTION METHODS

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Abstract—Carroll's 1971 definition of exposure is expanded to simply "being in a situation which has some risk of involvement in a road traffic accident". After a brief discussion of the potential utility of exposure data for developing safety countermeasures, an overview of various exposure measures and data collection methods is presented. Finally some important questions regarding appropriate exposure data collection methods are listed along with the hope that more comparative research on exposure data collection methodology will be carried out in the near future.

Exposure to the risk of a road traffic accident is a concept which has been frequently talked about in road safety research, and fortunately there have not been great divergences in opinion as to its basic meaning. Phillip Carroll [1971] reviewed the literature on the use of this concept, and he proposed that "driving exposure" be defined as "the frequency of traffic events which create a risk of accident". In his brief discussion of the concept in *Traffic Accident Exposure and Liability* [1977] Carsten Wass seems satisfied with the Carroll definition. In his 1973 article in this journal on "The Concept of Risk Exposure" Roger Chapman discusses exposure as a measure of the opportunities for an accident to occur, but he focuses more on different ways exposure has been measured in accident research than on the concept itself.

Despite general agreement with the flavor of Carroll's definition, two limitations are apparent when one analyzes it closely. First the expression "*driving* exposure" ignores the exposure to the risk of accident of pedestrians as well as of fixed objects such as bridge abutments, utility poles, and parked cars. In road safety research it seems desirable to define a road traffic accident broadly to include any interaction between a non-fixed-track land vehicle and another vehicle, or a pedestrian, or a fixed object, or the ground, which causes any property damage or personal injury, whether it takes place on or along a public roadway or in a parking lot or driveway. Road safety research tends to neglect accidents involving two bicyclists, or a bicyclist and a pedestrian, or a bicyclist and a fixed object because usually only accidents involving motor vehicles are entered into police accident files. But these types of accidents are important in understanding the totality of road traffic accident risks, and the definition of the concept of exposure should be broad enough to encompass road traffic accidents not involving the driver of a motor vehicle.

Second, the Carroll definition implies too much that exposure is an active process, while in reality one can be *exposed* to the possibility of being hit by a moving vehicle just sitting in a parked car or even sleeping in a ground floor bedroom. Obviously the latter risk is quite low, but one does read about the occasional odd case of a car crashing into a house.

Thus a broader but less active definition of the concept of exposure might simply be *being in a situation which has some risk of involvement in a road traffic accident*, a risk which theoretically can be measured for both active and passive elements of the traffic system.

THE UTILITY OF EXPOSURE DATA

Inherent in the concept of exposure is the idea of using exposure data to determine accident rates which indicate the relative degree of risk or danger of various road traffic situations (defining situation broadly to include all relevant vehicle, person, and environmental characteristics). Comparisons of accident *rates* can assist road safety researchers in developing safety countermeasures in ways that comparisons of absolute *frequencies* of accidents can not. For example, one would like to be able to compare accident rates of 20-foot wide roads and 24-foot wide roads, or wet roads and dry roads, etc. Thus an operational definition of exposure for road safety researchers might be:

> A measure of the frequency of being in a given traffic situation, which number can be used as the denominator in a fraction with the number of accidents which take place in that situation as the numerator, thus producing an accident rate or risk of being in an accident when in that situation.

It is obvious that for a meaningful comparison of accident rates there must be a common measure of exposure (time, mileage, or whatever) as the denominator for each rate.

An example of the successful use of accident and exposure data in determining appropriate improvements in road design given by Dunlap *et al.* [1974]. They were able to obtain data on reported accidents, on traffic volumes, and on vertical and horizontal alignment characteristics for each 0.1 mile section of the Ohio Turnpike (a toll road) for a $4\frac{1}{2}$ yr period. Thus they were able to calculate accident rates per 100,000,000 miles traveled for various combinations of roadway curvature and grade. Their analysis showed that one particular combination stood out sharply with an accident rate of 665 compared to an overall Turnpike accident rate of 96. This particularly risky roadway category involved a 1° curve combined with a 3% downgrade. Further analysis of the accident data showed that a wet surface was disproportionately involved in accidents on these road sections, and the researchers determined that the superelevation was inadequate for proper drainage—a problem which became particularly acute for vehicles with worn tires. This led to a recommendation concerning changes in superelevation and skid resistance design standards for this type of roadway. Clearly this useful analysis was possible only because the accident data and the exposure data could both be related to particular road sections with known alignment characteristics, an unfortunately rare situation for either type of data.

TYPES OF EXPOSURE MEASURES

There is probably not much controversy about the concept of exposure or about its potential utility for countermeasure development, but there is considerable disagreement on what exposure measures are most appropriate to use and how they should be collected for particular road safety research problems. Unfortunately, the most easily obtained exposure measures are seldom the most desirable ones for developing meaningful accident rates. For example, various accident rates based on total population, or numbers of registered vehicles, or numbers of licensed drivers are often published, but these are generally recognized as poor surrogates for the actual amount of accident risk incurred by various classes of traffic units. When such accident rates are produced for different age groups, they almost always show a considerable overinvolvement of younger drivers in accidents relative to their numbers in the licensed population, but one can not tell whether this overinvolvement is a result primarily of below average driving behavior or primarily of above average distances traveled or time spent on the road or in general of above average driving in particularly risky situations, for example under dark conditions. On a per mile basis young people may not have a higher rate of after-dark accidents than older people, but their total rate may be higher because they do proportionately more of their driving after dark.

As Chapman [1973] points out, there are two ways of viewing exposure to the risk of accident in the road traffic network. One can seek to determine exposure and accident rates for the vehicle or road user as it/he/she moves along in the system, or one can seek to determine exposure and accident rates for particular sites or fixed objects as the road users go past. For the first type distance traveled seems generally the most appropriate exposure measure [see Carroll 1973], while for the second type a direct count of road user movements seems the most appropriate exposure measure. However, other exposure measures sometimes suggested for the first type include duration of travel, number of discrete trips, and number of road crossings. For the second type, in addition to simple traffic counts, various interaction measures have been suggested, such as counts of the number of conflicts which lead to some kind of evasive action (braking, lane changing), the sum of entering flows at intersections, the cross-product of conflicting flows at intersections, and the square root of the cross-product of conflicting flows at intersections [Chapman, 1973]. For some purposes these types of measures can be complementary, as in the Ohio Turnpike example cited above in which tollbooth counts of vehicles were translated into vehicle miles traveled on the road sections between tollbooths.

METHODS OF EXPOSURE DATA COLLECTION

While there are clearly some important issues in determining the most appropriate exposure measures for particular road safety problems, the most serious exposure concern for most road safety researchers is *how* to obtain adequate exposure data in the most cost-effective manner given the limited funds available. For many road safety problems this will involve some kind of sampling procedure. Accidents are relatively rare events, and whenever more exposure data is needed than can be provided by mechanical counters it will seldom be feasible to collect these data over the whole time period of the accident data collection. Thus a controlled probability sampling scheme would be needed—of time, of road locations, of drivers, or whatever—so that the exposure data collected could be generalized to the same frame as the accident data.

There are two basic approaches used in collecting travel exposure data. One involves obtaining data while trips are in process, and the second involves obtaining data on completed trips. Sometimes these two methods are combined by beginning the data collection while the trip is in process and then obtaining more data after the trip is completed.

Obviously the simplest trip-in-process method is the mechanical counter which generally records the numbers of axles which go past it (or pedestrian footsteps, etc.). Increasingly sophisticated (and expensive) equipment is becoming available which can also record vehicle length and weight, turning movements, exact time of day, moisture conditions, etc. More detailed information can also be recorded by human observation or by automatic cameras, but the latter method also requires human viewing in order to code the data. Even more information can be obtained by actually stopping a vehicle along the roadside and interviewing the occupants (or similarly stopping a pedestrian). However, such roadside surveys face many operational difficulties, especially on busy roads. It would be easier to interview drivers while stopped at gasoline stations or in rest areas, but it's difficult to determine the representativeness of such a sample. Such trip-in-process interviews are easier to carry out with mass transportation passengers who can be interviewed without stopping their vehicles.

Another approach to obtaining trip-in-process data involves installing special instruments in a sample of vehicles to obtain such information as acceleration and deceleration rates, distance traveled, fuel consumed, etc. A variation on this approach involves instrumenting a research car which is assigned to follow a sample car and to imitate its behavior as exactly as possible. This has the advantage that the following driver can record other types of data also, such as number of conflicts, the type of roadway traveled on, the density of traffic, etc.

Turning to the collection of exposure data concerning completed trips, the three obvious methods are in-person interview, telephone interview, and mailback questionnaire. Such surveys usually seek data on all relevant travel behavior during one or more days. They can involve samples of vehicle owners, drivers, household members, employees, license renewal applicants, etc. Studies suggest that such travel reports will be more accurate and complete if the respondents have been alerted in advance and have been furnished travel diaries or trip log forms for recording each trip on the designated days, especially if actual vehicle odometer readings are desired. Thus there are many possible combinations of these three methods which may be used: initial in-person interview leaving a mailback form, initial in-person interview plus a follow-up in-person interview, initial in-person interview plus a follow-up telephone interview, two telephone interviews plus a mailing of a trip log form for respondent use on the travel day(s), etc. It seems clear that more complete data will be obtained if an interviewer comes in person to go over the trip records with the respondent than if he/she just mails them back. Such an in-person interview also provides the opportunity to obtain detailed information on types of roads and intersections used by having the respondent actually map his/her trips with the interviewer. But of course in-person interviews can be very expensive.

A combination of the trip-in-process and completed trip approaches involves a short roadside interview plus passing out a mailback form for the road user to complete later, or obtaining a telephone number for a subsequent telephone interview about the completed trip.

Similarly, surveys of mass transportation passengers may also involve handing out a form to be returned by mail. Another combined method uses automatic cameras or human observation to record license plate numbers of traveling vehicles (on paper, magnetic tape, or film) and then contacts those vehicle owners with a mailback form or a telephone interview.

Examples of all of these exposure data collection methods have been found in the literature [Wolfe 1978a, 1978b], but very little research has been carried out concerning the relative reliability, validity, and costs of the exposure data collected by these various methods. Many questions remain. How accurately can respondents recall all of their trips with and without the use of a trip log form? How accurately can they estimate the distances traveled on particular trips without recording the actual odometer readings? How much improvement in the quality of completed trip data can one expect from a two-contact procedure, and which two-contact procedure is most cost-effective? What is the most appropriate time period for obtaining records of completed trips? In a household survey how much difference in sampling variance is there if one interviews all household members in a small sample compared to one member per household in a larger sample? How much can modest compensation of respondents increase respondent participation and completeness of trip recording? Can a random digit dialing telephone sample of households provide a sufficiently representative sample of travel behavior? Can modern time-lapse photography be used to obtain valid information on vehicle occupants (number, sex, age group) as well as vehicle type? How accurately can license plate numbers be recorded and matched with official license records for a license plate trip-in-process sample? Can techniques be found for overcoming the operational difficulties of roadside surveys on busy roads?

These are the kinds of practical questions which face a road safety researcher who wants to design a system for collecting complex exposure data. Unfortunately, there seems to be very little comparative research going on to try to resolve these methodological questions. These questions are of interest not only to road safety researchers but also to transportation and energy consumption planners who also have needs for detailed information about travel behavior. One can hope that these interests can be combined to find support for more comparative research on appropriate exposure data collection methodologies in the near future.

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