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Some implications of an event-based definition of exposure to the risk of road accident

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ABSTRACT

This paper proposes a new definition of exposure to the risk of road accident as any event, limited in space and time, representing a potential for an accident to occur by bringing road users close to each other in time or space of by requiring a road user to take action to avoid leaving the roadway. A typology of events representing a potential for an accident is proposed. Each event can be interpreted as a trial as defined in probability theory. Risk is the proportion of events that result in an accident. Defining exposure as events demanding the attention of road users implies that road users will learn from repeated exposure to these events, which in turn implies that there will normally be a negative relationship between exposure and risk. Four hypotheses regarding the relationship between exposure and risk are proposed. Preliminary tests support these hypotheses. Advantages and disadvantages of defining exposure as specific events are discussed. It is argued that developments in vehicle technology are likely to make events both observable and countable, thus ensuring that exposure is an operational concept.

1. Introduction

Exposure is a key concept in road safety studies and many definitions of the concept have been proposed. This paper reviews some of these definitions and identifies three main classes of definitions of exposure. Following the review, the paper proposes a definition of exposure as events that have the potential of becoming accidents. Some implications of this definition of exposure are discussed. The discussion is illustrative only and intended to suggest ideas that can be pursued in further research. The main research questions discussed in this paper are:

1. What are the most common definitions of exposure?
2. Have scientific views about how best to define exposure changed over time?
3. What are the advantages and drawbacks of defining exposure as events?
4. What are the principal implications, in particular for the relationship between exposure and the number of accidents, of defining exposure as events?

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2. Review of definitions and indicators of exposure

In an early review, Chapman (1973) defined exposure as the number of opportunities for accidents of a certain type in a given time in a given area. He added that these opportunities include cars crossing each other's path, cars following each other and cars travelling on a winding road. He illustrated studies of the relationship between exposure and accidents for head-on collisions, rear-end collisions and intersection collisions. He suggested that a count of traffic conflicts could serve as a measure of exposure. Chapman's definition of exposure, and his illustrations of it, has much in common with the event-based definition of exposure proposed later in this paper.

Brown (1981) defined the accident potential of an intersection in terms of the conflict points between the traffic movements passing the junction. Conflict points are all points where two traffic movements cross or merge. When the potential for rear-end conflicts in the approaches are included, Brown identified 36 potential conflict points in a four leg junction with two-way traffic on all approaches and no restrictions on turning movements. Based on a small sample of junctions in Johannesburg and Pretoria, Brown estimated accident rates per million conflicts for the various types of conflicts. He found that some conflict types are associated with higher accident rates than others. Similar findings were reported by Johannessen and Heir (1974) in an early Norwegian study.

Hauer (1982) discusses the relationship between traffic conflicts and exposure, and argues that the two concepts are distinct (although, some definitions of exposure come close to making the concepts identical). He states that the concepts of exposure and risk can be defined by reference to the basic concepts of probability theory. Exposure can then be defined as a trial which has two possible outcomes: an accident or no accident. A trial will typically have a short duration. Exposure in a traffic system is the number of trials in that system in a given period of time. A trial, as defined and exemplified by Hauer, represents an event as defined later in this paper.

Risk and Shaoul (1982) discuss the common use of vehicle kilometres as an indicator of exposure. They note: "It is not possible to calculate a true accident probability using conventional mileage-exposure data, since, no means exist by which the accident "trials" may be identified or counted. Accident rates for this reason alone cannot be taken as true probability values". While not proposing a formal definition of exposure, the examples given are all encompassed by the following definition of exposure: Exposure is any hazard, fixed or moving, that has the potential of generating an accident. The examples given by Risk and Shaoul include access points along a road, potential conflict points in junctions and any location requiring a manoeuvre to be made.

Wolfe (1982) defined exposure as 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. This is intended as an operational definition of exposure. From the examples given, it is clear that Wolfe regards vehicle kilometres of travel as a useful operational definition of exposure.

Hauer et al., (1988) discuss how best to estimate safety in signalised intersections. They argue that the potential for accidents (exposure) is generated by the various traffic movements in an intersection and identify 15 different traffic movements that may generate accidents. Accident prediction models based on negative binomial regression were developed for all 15 movements, but only four of them were associated with a sufficient number of accidents to be regarded as statistically reliable. The definition of exposure underlying the classification is potential conflicts between traffic movements sharing space in an intersection.

Hauer (1995) notes that estimates of exposure tend to be used for two purposes: (1) to control for differences in traffic volume, so that the number of accidents can be compared between locations with different traffic volume; (2) to identify locations that have a higher than normal number of accidents for a given traffic volume. In both these uses of exposure, it serves as the denominator when estimating an accident rate (number of accidents per million units of exposure; usually per million vehicle kilometres). These uses of exposure are correct only if the number of accidents is proportional to the amount of exposure: twice the exposure, twice the number of accidents. However, many studies have found that the relationship between exposure and the number of accidents is non-linear. This invalidates the traditional use and interpretation of accident rates.

Persaud and Mucsi (1995) provide very clear examples of the non-linear relationship between traffic volume (average hourly volume) and the number of accidents. The shape of the relationship between hourly traffic volume and the number of accidents varies depending on the time of the day (day or night) and the type of accident used as dependent variable (single vehicle accidents or multi vehicle accidents). It is therefore clear that, estimates of the relationship between traffic volume and the number of accidents based on averages or totals can be misleading.

This point is further elaborated by Mensah and Hauer (1998). They discuss two problems of averaging arising in the estimation of the relationship between accidents and traffic flow. The first type of averaging is called argument averaging. An example of argument averaging is the use of AADT to measure traffic volume, rather than an estimate of the traffic volume at the time of the accident, which could be quite different from AADT, since traffic volume varies throughout the day, week and months of the year. Mensah and Hauer develop closed-form estimators for the size of the bias associated with argument, averaging for four of the most common functional forms used to relate accidents to traffic volume. The second type of averaging is called function averaging. It occurs when a single function is estimated for a relationship, which in reality is best represented by two or more functions that differ in shape. Using a single function will then generate bias. Mensah and Hauer illustrate the potential size of this bias, but do not develop closed-form expressions to estimate the typical size of the bias. The analysis of Mensah and Hauer constitutes a strong argument for using disaggregate measures of exposure, as well as using specific types of accidents as dependent variable.

Qin et al. (2004) developed exposure measures for various types of accident that are intended to be linear, i.e. the rate of accidents per unit of exposure will be independent of the amount of exposure. They identify four types of accident: single vehicle, multi vehicle same direction (rear-end), multi vehicle opposite direction (head-on), and multi vehicle intersecting direction (angle). For each type of accident, an exposure function was developed. The function had the same form for all types of accident:

$$\text{Exposure} = V_i^{\alpha V_k} \times L_i^{\alpha L_k}$$

where V denotes traffic volume (AADT) on section i, L is the length of section i, αV and αL are estimated coefficients, and k is accident type k. The models developed clearly show that the assumption that the number of accidents is proportional to section length, normally made when using vehicle kilometres of travel to measure exposure, is not valid. The coefficients for section length where less than one for all types of accident. Thus, all else equal, short road sections may not have the same number of accidents per unit of length as long road sections. The study controlled for lane width, shoulder width and speed limit, but there could be other differences between short and long road sections, such as the number of intersections or access points, parking regulations and pedestrian and cyclist volume.

Oh et al. (2006) developed a measure of the risk of rear-end collision based on stopping distances. Based on data collected by inductive loop detectors that continuously monitor traffic, it is possible to estimate the distance between vehicles following each other in the same travel lane. When both distance and speed are known, stopping distance can be estimated, given a certain driver reaction time. It is then possible to estimate the proportion of vehicles keeping an unsafe following distance, i.e. a distance shorter than the estimated stopping distance. Drivers keeping such a short distance may, however, never discover the high risk involved in doing so: if the need to brake never arises, the driver may experience what Fuller (1991) referred to as a learning trap: risky behaviour is reinforced by the absence of feedback revealing the risk involved to the driver.

Lassarre et al. (2007) developed a microscopic measure of pedestrian exposure to risk. The starting point is that, pedestrians are principally exposed to risk when crossing the road. The possibility of crossing the road at an unregulated location depends on whether there are sufficient gaps in traffic or not. A closed-form solution is developed to assess the risk involved in crossing at a given location. The risk is a function of time taken to cross