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A comprehensive review on the quasi-induced exposure technique

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ABSTRACT

Objective: The goal is to comprehensively examine the state-of-the-art applications and methodological development of quasi-induced exposure and consequently pinpoint the future research directions in terms of implementation guidelines, limitations, and validity tests.
Methods: The paper conducts a comprehensive review on approximately 45 published papers relevant to quasi-induced exposure regarding four key topics of interest: applications, responsibility assignment, validation of assumptions, and methodological development.
Results: Specific findings include that: (1) there is no systematic data screening procedure in place and how the eliminated crash data will impact the responsibility assignment is generally unknown; (2) there is a lack of necessary efforts to assess the validity of assumptions prior to its application and the validation efforts are mostly restricted to the aggregated levels due to the limited availability of exposure truth; and (3) there is a deficiency of quantitative analyses to evaluate the magnitude and directions of bias as a result of injury risks and crash avoidance ability.
Conclusions: The paper points out the future research directions and insights in terms of the validity tests and implementation guidelines.

1. Background

Traditionally, crash-rate based safety studies are favored by traffic safety researchers as opposed to those on the basis of crash frequency. The main difference between studies based on crash frequency and those based on crash rates is that crash-rate studies have a denominator (exposure). The introduction of crash exposure in safety analysis provides more flexibility and capacity to assess the relative degree of risk or danger of road-traffic situations in a quantitative manner. Historically, a variety of crash exposure measurements have been employed in the traffic safety research, illustrated in Fig. 1. The measurements can be generally classified into direct and indirect exposures. The former is stand-alone and has an absolute value such as vehicle miles traveled (VMT), while the latter is a relative value and meaningful only through comparisons with other drivers or vehicle types. Comparatively, direct exposure is the mainstream in the field of traffic-safety research, among which VMT is the most commonly used technique. Nonetheless, the application of VMT has aroused challenges and criticisms in the safety community due to the "linear conjecture" between crash-frequency and VMT (Steward, 1960; Janke, 1991; Hauer, 1995), and the difficulties to obtain VMT data particularly at the finely disaggregated levels (Lyles et al., 1991).

The limitations of conventional exposure techniques provide a niche for the indirect exposures in the crash-exposure family, namely "induced exposure." Basically, induced exposure estimates the relative exposure of a particular driving cohort by means of the readily available crash data on the basis of a number of interlaced hypotheses (Thorpe, 1967, refer to the Appendix A). Haight (1970) modified Thorpe's work by supplementing a well-defined responsibility-assigning system to measure the relative exposure of certain driver/vehicle combination to the driving hazards and renamed the technique as "quasi-induced exposure." Quasi-induced exposure theory has two underlying assumptions: (1) there is an at-fault (D1) and a not-at-fault driver (D2) in two-vehicle crashes; and (2) not-at-fault drivers (D2s) in two-vehicle crashes are randomly selected from motorists and vehicles on the road at the time of crash occurrence. The first hypothesis requires the utilization of two-vehicle crash data only with one at-fault driver and one not-at-fault driver. And the second states that the D2s are representative of the corresponding driving population on the road, thus inductively, a measure of exposure. Subsequently, the ratio of D1s with specific characteristics to D2s with the same cohort is defined as the relative crash involvement ratio (IR). The parameter is an indicator of whether a driving population causes disproportionately more (>1) or fewer (<1) crashes as to its presence on the road. Obviously, the way of measuring relative exposure and crash

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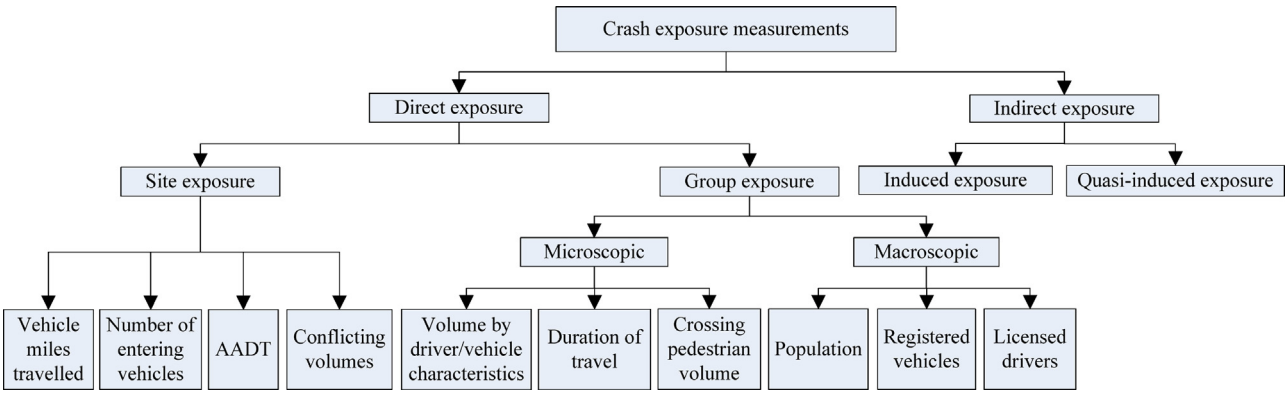

Fig. 1. Crash exposure measurements in traffic safety research.

propensity inherently avoids the assumption of linear relationship between crash counts and the distance traveled as confronted by VMT.

Fundamentally, the theory of quasi-induced exposure has three essential and integral components: (1) the preliminary screening of crash data, which aims to improve the quality of raw crash data and potentially circumvent biases due to the data uncertainties; (2) the assignment of crash responsibility to each individual driver involved in a two-vehicle crash, which classifies all the driving cohort into either responsible or non-responsible drivers; and (3) the test on the validity of the not-at-fault assumption of the quasi-induced exposure technique, which serves to identify the applicability, the strengths, and the weaknesses of the exposure measurement. Thus, the objectives of the paper are to comprehensively examine the state-of-the-art methodological development and applications of quasi-induced exposure and consequently pinpoint the future research directions in terms of implementation guidelines, limitations, and validity tests.

The review content is organized as follows. The first reviews the existing applications of quasi-induced exposure and then discusses the historical research on responsibility assignment for crash causation; the next summarizes the current research efforts on validating the not-at-fault hypothesis and methodological development of quasi-induced exposure; and the final section discusses the future research directions.

2. Method

Extensive efforts were engaged to collect approximately 45 published papers with the keyword "quasi-induced exposure" through the most prevalent search engine "Google Scholar" and the TRID database offered by Transportation Research Board. In order that a study could be included, basically the selected papers would have to improve the understandings of quasi-induced exposure and be supported by validated statistical analyses. Conclusions were drawn from the review to illustrate the findings, the issues, the deficiency, and the future research of quasi-induced exposure.

3. Results

3.1. Applications

There were limited amount of applications related to quasi-induced exposure in the early two decades after its first introduction; comparatively, in recent years when more and more work has been conducted to explore the pros and cons of quasi-induced exposure, it has seen a substantial implementation. In comparison with the conventional approach such as VMT, quasi-induced exposure has great potentials to offer in the safety analysis considering its simplistic data requirements and the capability of estimating exposure, particularly under the finely disaggregated circumstances (Lyles et al., 1991).

Table 1 summarizes the most prevalent applications of quasi-induced exposure. Researchers have implemented the technique to measure the risk of young drivers (Aldridge et al., 1999; Kirk and Stamatiadis, 2001), elder drivers (Davis and Yang, 2001; Hing et al., 2003), or both (Padlo et al., 2005; Mueller et al., 2007), examine the crash propensity of different driver–vehicle characteristics (Stamatiadis and Deacon, 1997; Lardelli-Claret et al., 2002, 2003, 2005; Dorn and Wahlberg, 2008; Keall and Newstead, 2009b; Mohaymanya et al., 2010; Newstead and D'Elia, 2010; Lardelli-Claret et al., 2011; Haque et al., 2012; Huggins, 2013), study the crash risk of specific crash types (Yan et al., 2005; Lardelli-Claret et al., 2006; Yan and Radwan, 2006; Harb et al., 2008; Haque et al., 2008; Huang and Chin, 2009; Chin and Haque, 2012), assess the risk of vehicle crashes under the influence of alcohol (Voas et al., 2007; Hours et al., 2008), evaluate the effectiveness of graduated driver licensing program (Rice et al., 2003; Fohr et al., 2005; Jiang and Lyles, 2011), and quantify the crash risk of certain driving behaviors (Backer-Grøndahl and Sagberg, 2011). The widespread acceptance of quasi-induced exposure in the assessment of crash risk can be mainly attributed to the facts that (1) there is a great lack of disaggregated exposure data, particularly under certain spatial or temporal circumstance for a specific driving cohort; and (2) quasi-induced exposure has the capacity to derive the exposure from the crash data directly (if the assumptions hold to be true).

It is evidenced that the majority of the studies in Table 1 utilize quasi-induced exposure in the case–control study. The "cases" are defined as those who contribute to the crash occurrence, while the "controls" are those identified as the non-responsible drivers, presumably representative of their corresponding driving group as a whole. Also observed from Table 1 is that the standard case–control design is supplemented with various statistical modeling (e.g., logistic regression or binary tree models) to quantitatively estimate the magnitude and significance of risk factors in the role of being the "cases." The generalized-linear modeling produces the odd ratios for each individual risk factor and the associated level of significance, which is basically equivalent to the relative crash involvement ratio provided by the quasi-induced exposure technique (but with more statistical powers to provide confidence interval at a given significance level).

Fundamental to the applications in Table 1 is the prerequisite that the underlying hypothesis of quasi-induced exposure is sufficiently satisfied with a given crash set, namely, the not-at-fault drivers in the two-vehicle crashes are a random sample of the corresponding driving population at the crash scene. This is an important requirement, which dictates whether the estimated exposure can act as a surrogate to the general population (typically unavailable).