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Evaluation of a simulation-based surrogate safety metric

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ABSTRACT

The development of surrogate safety measures is essential due to the problems of availability and quality of historical crash data. The Aggregate Conflict Propensity Metric (ACPM) is a surrogate metric recently proposed and it is based on conflict studies and traffic simulations. ACPM is expected to be capable of assessing the relative safety levels of traffic facilities and/or treatments in order to help traffic engineers to select appropriate treatments based on traffic safety estimates. This paper presents three experimental tests conducted to evaluate the reliability of ACPM. In each test, ACPM is compared to a traditional conflict indicator in terms of identifying and ranking safety of traffic conditions under various traffic volumes based on traffic simulations. ACPM shows its strength and reliability in all three tests, as it provides results highly consistent with the Highway Safety Manual. The experimental tests indicate that ACPM is a promising surrogate safety measure that can appropriately identify relative safety among traffic treatments and/or facilities and provide traffic engineers with useful information on potential safety impact.

1. Introduction

The development of surrogate safety measures is essential for traffic safety studies, mainly due to the problems of availability and quality of historical crash data (Tarko et al., 2009). Amundsen and Hyden (1977) defined traffic conflict as "an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged." Traffic conflicts are considered as one of the most promising surrogate measures as they are much easier to observe than crashes (Hyden, 1987).

Traditionally, traffic conflicts are collected by field observations, which are time-consuming, labor-intensive and sometimes inaccurate. To overcome these deficiencies, automated techniques and traffic simulations have been utilized recently to assist in conflict studies. Though a substantial progress has been achieved in automated video-based techniques, this paper will only focus on conflict studies based on microscopic simulations. The development of computer sciences allows simulation software to collect and store simulated data instantly and precisely during a simulation period. The Surrogate Safety Assessment Model (SSAM) has been recently developed to utilize simulation trajectory outputs to gather conflict information that could be used as safety surrogate measures (FHWA, 2008). However, according to the final report of SSAM (FHWA, 2008), there is no surrogate measure widely accepted as a benchmark for conflict studies based on traffic simulations.

The original design purpose of most simulation platforms is for traffic operations and therefore, traffic simulations mostly generate normal and safe vehicle interactions instead of emergent or near-crash events. This defect hinders the development of surrogate measures as a direct predictor of crash frequency based on traffic simulations. Despite of that, it is still necessary to develop a qualified surrogate measure that is able to identify the relative safety among traffic facilities/treatments. As such, one can predict and estimate the relative safety of traffic treatments so as to provide useful and important information on their potential safety impact for traffic engineers and policy makers. Wang and Stamatiadis (2013) proposed a conflict metric that can be used as such a surrogate measure. This metric succeeds in identifying relative safety of multiple traffic facilities, based on calibrated simulation models. In this paper, three experimental tests are conducted and presented in order to further evaluate and demonstrate the strength and reliability of this new surrogate safety metric.

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2. Literature review

Substantial efforts have been completed on developing surrogate safety measures. For field-based studies, the most utilized surrogate measure is Time-to-Collision (TTC). TTC refers to "the time that remains until a collision between two vehicles would have occurred if the collision course and speed difference are maintained" and is the most frequently used metric (Archer, 2005). The derivation of TTC relies on motion prediction models and the assumptions of unchanged collision course and speeds (Archer, 2005).

Since field observations are labor-intensive and time-consuming, new technologies have been recently developed to address this problem. Recently, researchers utilized naturalistic driving data to develop exploratory models and crash surrogates (Tarko, 2012; Wu and Jovanis, 2012). Although these studies showed promising results, additional work needs to be undertaken to refine methodologies and validate crash surrogates. Moreover, the collection of naturalistic driving data could also be time-consuming (Wu and Jovanis, 2012). Two other promising techniques include video techniques and microscopic simulations and these have been extensively studied in the recent years.

An ample body of research has been conducted based on video techniques (Tarko et al., 2009). Songchitruska and Tarko (2006) utilized the Extreme Value Method (EVM) to estimate right-angle crashes at signalized intersections through the use of Post Encroachment Time (PET) as a surrogate measure. Davis et al. (2008) introduced a probability framework in 2008 to calculate crash probability of near-crash events (i.e. an event where a strong evasive maneuver is required to avoid a crash) by incorporating the distribution of evasive actions. Laureshyn et al. also developed a framework for estimating TTC utilizing a video-based approach identifying the promising nature of the technology (Laureshyn, 2010). In addition, a number of studies have been performed to develop surrogate safety measures on the basis of automated video techniques (Suanier and Sayed, 2008; Saunier et al., 2010; Autey et al., 2012). Suanier and Sayed (2008) presented a comprehensive probabilistic framework for automated video analysis in 2008. Then in 2010, Saunier et al. (2010) presented a refined probabilistic framework for automated safety analysis.

In recent years, the rapid development in computing technology has allowed for the use of traffic simulations in conflict studies. Compared to traditional field observations, traffic simulations significantly reduce the workload of data collections and improve the data accuracy in terms of eliminating human errors (FHWA, 2008). Though a number of surrogate measures have been developed based on traffic simulations, most of them are only designed for certain conflict types, preventing them from being widely accepted (Minderhoud and Bovy, 2001; Ozbay et al., 2008; Saccomanno and Cunto, 2006; Saccomanno et al., 2008). Validation efforts on those surrogate measures are also lacking. SSAM has been developed to extract conflict information from simulated trajectory files to gather surrogate measures (FHWA, 2008). Although SSAM is able to provide various traditional surrogate measures (e.g. speed, TTC, PET), none is recommended as a reliable surrogate safety metric according to the final repot of SSAM (FHWA, 2008). TTC is still utilized as the benchmark indicator and the authors of the SSAM report demonstrated the necessity and importance of developing a more reliable conflict indicator due to the problems they identified in validation efforts (FHWA, 2008). To fill this gap, Wang and Stamatiadis (2013) proposed the Aggregate Conflict Propensity Model (ACPM) as a surrogate metric and this metric had shown the potential to identify relative safety and be further utilized as a predictor of crash frequency. This metric is also designed for multiple conflict types.

The Highway Safety Manual (HSM) provides a means for estimating average crash frequency for a specific traffic facilities using regression models developed from historical crash data (El Esawey and Sayed, 2013). HSM proposes Safety Prediction Functions (SPFs) for base conditions of a number of different traffic facilities, including urban/rural highways and intersections. The Crash Modification Factors (CMFs) are used to account for the safety difference between base conditions and specific traffic conditions different from the base condition. Thus, the safety of desired traffic treatments can be estimated utilizing the CMFs and compared to the base condition. This paper examines and evaluates the strength of ACPM, the proposed surrogate measure, by comparing traffic treatments with known safety implications from HSM. This approach was utilized in the final report of SSAM by examining a traditional surrogate TTC indicator. The TTC indicator performed mixed results in identifying safety differences and thus the authors of that report pointed out the necessities of developing other surrogate measures based on traffic simulations. If ACPM appropriately identifies the safety difference among different traffic treatments/design alternatives as HSM does, it could be considered to be a promising safety surrogate measure based on traffic simulations that could be used in additional evaluations that HSM does not currently cover. This new measure could provide traffic agencies with useful and crucial information on potential safety impacts of different traffic plans and thus help them improve their decision-makings.

3. Methodology

Simulation tools have been extensively utilized in traffic operation studies to estimate travel time and delays. However, they are designed for normal and safe traffic operations and therefore when used in traffic safety studies can pose problems. In a microscopic simulation environment, drivers and vehicles are defined by and follow certain rules (acceptance gap, look ahead distance and fixed/zero reaction time etc.), they always obey these rules, and react immediately to dangerous situations. However, that is not always the case in real life where some drivers react quickly while others react slowly. Moreover, vehicles have different braking limitations allowing drivers to escape a crash. Crashes often occur because of driver's fault (inattention) and vehicle's poor performance. Those variations are not precisely reflected in simulation packages due to their design purpose of simulating traffic operations. However, those variations could greatly influence the outcome of a conflict. Shelby addressed that crossing conflicts with the same minimum TTC can have various crash probabilities due to the variations of drivers' reaction time (Shelby, 2011). Davis et al. also demonstrated examples of utilizing empirical probability density to determining the crash probability of rear-end events in the real world (Davis et al., 2008). Hence, it appears that those variations need to be carefully considered in conflict studies based on microscopic simulations but they do not diminish the ability to develop surrogate safety measures based on traffic simulations (Archer, 2005).

3.1. Crash propensity model and aggregated crash propensity metric

To fill this gap, a probabilistic model is developed to estimate the relative safety of an intersection by calculating the probability of each simulated conflict to result in a crash, without ignoring those significant variances such as reaction time and braking limitations. The model takes into account human and vehicle variability in conjunction with the characteristics of simulated conflicts to determine the crash probability.

The model only focuses on conflicts between two vehicles. For each potential conflict, the vehicle which is supposed to reach first the conflict point will retain its speed during the process while the