Transportation Research Part C 36 (2013) 284–295

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

An automated surrogate safety analysis at protected highway ramps using cross-sectional and before–after video data

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ARTICLE INFO

Article history:
Received 11 February 2012
Received in revised form 23 August 2013
Accepted 27 August 2013

Keywords:
Driver behaviour
Automated surrogate safety
Highway ramps
Time-to-collision
Road user interactions
Video-data
Trajectories

ABSTRACT

This study presents a method for surrogate safety analysis to investigate the safety of limited-access highway facilities. The proposed methodology is based on automated trajectory collection and behavioural analysis from surrogate safety measures (in particular, time-to-collision). The methodology is applied to a sample of urban highway sections at on-ramps and off-ramps to study the effectiveness of a lane-change ban treatment in Montreal, Canada. To the authors' knowledge, this is the largest automated video-based surrogate safety analysis of real sites. The applicability of the methodology is explored using (i) a cross-sectional comparison and (ii) a before–after comparison. Video data is collected using the highway traffic surveillance system and a mobile video camera unit. Various methods of aggregating the data, spatially and temporally, are explored. Although the treatment does not have a statistically significant impact on the time-to-collision distributions, it is found empirically that lane changing interactions are less predominant than rear-end interactions at these highway ramps, lane changes across the protected side of the treatment (infractions) occur in great numbers regardless of the implementation of the treatment, and that the start of the treatment produces an artificial critical point in the highway stream causing increased lane-change interactions at this point.

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1. Introduction

An important area of research in road safety is the identification of the safety effectiveness of various transportation facility designs and countermeasures. Typically, this type of research relies on collision data collected at many sites over long time periods to overcome the problem of long return periods between collision observations. However, this methodology proves insufficient when evaluating new designs or countermeasures for which little historical data exists, when environmental factors change significantly over time, or when collision data collection programs become prohibitively expensive or unreliable. In addition, the unknown conditions of newly proposed designs or countermeasures further the challenge of collecting sizeable amounts of historical data as practitioners are reluctant to experiment on the public beyond focused pilot projects. In a broader sense, we still face the challenge of evaluating road safety without waiting for collision events occur. To this end, more proactive analysis techniques need to be introduced to maximise interpretation of rich datasets of observations collected over shorter periods of time.

The surrogate safety approach substitutes the long return period of collision observations with observations of road user interactions under driving conditions. An interaction is the relationship between pairs of road users within the area of study.

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0968-090X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.trc.2013.08.015

The surrogate safety approach relies on the existence of some quantifiable relation between collisions and interactions or indicators derived from their observation.

This approach can be traced back at least to the late 1960s (Perkins and Harris, 1968) where interactions without a collision, called conflicts, were studied and characterised using "severity" measures (Häkkinen and Luoma, 1991). However, the use of this conflict analysis in road safety studies is so far less popular than historical collision-based diagnosis. The primary arguments against the approach typically include the cost of manual data collection, the subjectivity of conflict interpretation or observation, the difficulty in defining universally comparable measures of interaction safety, and the unknown relationship between conflicts and collision frequency or collision severity (Chin and Quek, 1997). Many papers in road safety have argued for and against the use of conflict analysis as a reliable safety measure, both on the standpoint of collision severity and frequency. The reader is invited to consult (Svensson and Hydén, 2006) for an extensive overview of early attempts at conflict studies and (Laureshyn, 2010) for a comprehensive overview of the Swedish conflict analysis technique.

Part of the data collection and subjectivity issues are being solved thanks to advances in computer vision. This paper presents a complete practical methodology for surrogate safety analysis, including video data collection from traffic cameras as well as from a purpose-built mobile camera system, and for the interpretation of road user trajectories and interactions. This methodology is applied to a case study of safety inside highway merging zones that involved the collection of a large video dataset. More specifically, the objective of this research is to develop a methodology for evaluating vehicular interactions for a particular road element (highway ramps). The use of the proposed methodology is demonstrated using a before–after and cross-sectional comparison of interactions for a sample of sites with a design countermeasure: a particular lane-change ban along highway ramps in Montréal, Québec.

The paper is organised as follows: the next section will cover previous research, followed by an overview of the methodology, a description of the case study, and, finally, some experimental results.

2. Background

The problem of acquiring low-cost, objective, and consistent trajectory data has been solved in part by advances in computer vision and cheap video equipment. Computer vision allows for the procedural acquisition of rich road user trajectory data: position in time and space of every road user inside of camera space, such as applied in the NGSIM (Kim et al., 2005) and SHRP2 (Gordon et al., 2012) projects. Computer vision applied to surrogate safety has been developed and used extensively by several research groups. Sayed, Saunier, and Ismail developed video analysis tools primarily for road safety analysis at intersections in North America, including vehicle–vehicle interactions (Saunier et al., 2010) and pedestrian–vehicle interactions (Ismail et al., 2009), (Ismail et al., 2010). Meanwhile, Hydén, Svensson, Laureshyn, and Ardo, among others, have developed a computer vision framework in Europe, as early as 1996 (Hydén, 1996), and more recently using background subtraction and hidden Markov models (Laureshyn et al., 2009). More recently, surrogate safety analysis has been applied for recent before–after studies (Phillips et al., 2011), (Autey et al., 2012). The reader is invited to consult (Buch et al., 2011) for a survey of computer vision for urban transportation applications. Video analysis provides the trajectories of all road users in the camera field of view (or a subset depending on resolution and angle). This detailed microscopic data at high temporal resolution (typically between 15 and 30 measurements per second, depending on the chosen frame rate) is used to characterise road user interactions, computing, for example, relative distance, velocity, etc.

Although there has been a lot of research since the end of the 1960s first in traffic conflict techniques and more recently in more general surrogate safety analysis, there is still a lack of agreement over the methods and their interpretation, and a lack of guidelines. Considerable work has been done to define conflicts, and in particular the most serious ones (the conflicts most similar to collisions) using several indicators and to validate their relationship to safety. The essential idea is to observe all road user interactions (benign and risky behaviours alike) that can be analysed to produce some kind of safety diagnosis. In this quest, a large number of indicators or surrogate safety measures have been proposed to quantify the road user interactions according to position and time. Speed (particularly absolute speed) has already been widely used as a catch-all surrogate safety measure in the field of road safety. Other measures have emerged, notably Time-to-Collision (TTC) and Post Encroachment Time (PET). Gettman and Head have published extensive summaries of additional surrogate safety measures (Gettman and Head, 2003) commonly used in the literature such as Gap Time (GT) and Proportion of Stopping Distance (PSD) among others. Laureshyn has compiled and even more thorough list of measures (Laureshyn, 2010), though many are scenario specific or their significance is loosely defined in a more general context (e.g. speed or "steering"). Among these, TTC is probably the most commonly used and encompasses the core concept of a conflict situation where "a collision is imminent if [the road users'] movements remain unchanged" (Amundsen and Hydén, 1977). It relies on the prediction of the motion of road users at a given time to identify potential future collision points assuming events such as driver reaction or emergency breaking fail to take place. In practice, most methods rely on motion prediction at constant velocity. This unrealistic assumption is being questioned in recent work since many paths may lead interacting road users to a collision (Mohamed and Saunier, 2013).

A large number of surrogate safety studies have been conducted in simulated environments using, for example, the Surrogate Safety Assessment Model (SSAM) which uses trajectories extracted from microsimulation, and thus relies on simulated driver behaviour. So far, studies applying surrogate safety to real trajectories have remained small and experimental in scope (typically a case study at one or two sites) such as Svensson et al. (2011) and Guido et al. (2010). Of particular note

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