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Traffic accident risk assessment with dynamic microsimulation model using range-range rate graphs

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ABSTRACT

Analysis of accidents that involve vehicles and pedestrians requires accurate reproduction of the dynamics of the vehicles and pedestrians immediately prior to and during the accident. In many cases, only centimeters and milliseconds separate survival from disaster, particularly when high-speed aggressive drivers and careless pedestrians are involved. In this paper we present a methodology for analyzing the dynamic interaction between drivers in conflict scenarios with pedestrians. We assess the safety of a traffic location's environment with a high-resolution, spatially explicit, dynamic agent-based simulation model – SAFEPED. Based on the resulting data, Range-Range Rate (R-RR) graphs are generated. These graphs provide compact, simple, and objective presentation of the dynamic interaction between vehicles and pedestrians. Significant traffic risk indicators such as Time-To-Collision, acceleration/deceleration rates, and minimal distances between vehicles and pedestrians are easily extracted from the R-RR graphs. These indicators can provide insights on particular traffic scenarios and can assist road planners and developers of traffic safety measures in understanding the dynamic behavior of drivers and pedestrians before and during a conflict scenario.

1. High-resolution overview of road safety

Progress in road safety has been achieved over the last decades by implementing measures related to infrastructure, vehicle operator, and road user behaviors. These include road safety engineering measures, improved crashworthiness of vehicles, compulsory seat-belt wearing, drink-driving interventions, speed enforcement, etc. Nonetheless, road accidents have become one of the leading causes of death in the world, predicted to reach fifth place in the year 2030 (Hakkert and Gitelman, 2014). Further improvement in road safety will be achieved by developing methodological tools for exploring road users' interactions with greater focus on behavior indicators, and by providing a deeper understanding of the impact of the physical environment, aspiring to adjust transportation systems and road design to the capabilities and limitations of human road users.

1.1. Aggregate statistics

In pedestrian safety research, accident statistics have proven to be useful for the identification of problems associated with particular types of road facility or different groups of road users (Campbell et al., 2003; Chang, 2008). Recent studies use Geographic Information Systems (GIS) methodologies for understanding the spatial patterns of accidents (Pulugurtha et al., 2007). Most of the statistical findings, which guide authorities in coordinating countermeasures, were motivated by the need to examine the effectiveness of road safety or vehicle engineering improvements; and compared the safety state before and after making modifications (Hakkert et al., 2002; Markowitz et al., 2006). However, statistical data is inefficient for determining accident causation, since the complex chain of events that preceded an accident is rarely recorded in detail that is sufficient to draw conclusions (Archer, 2005). This can be the reason for the counterintuitive results obtained in comprehensive multi-year studies, such as that of Zegeer et al. (2005), who analyzed pedestrian accidents at 1000 marked and 1000 matched unmarked crosswalks over 5 years. They demonstrated that the presence of marked crosswalks without additional regulation measures makes no difference or even worsens accident rates compared with unmarked crossing locations.

1.2. Disaggregate modeling of vehicular-pedestrian interaction

From the early 1970s, traffic micro-simulation models became popular for the evaluation and development of road traffic management and control systems. Increased computing capabilities allows

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simulating ever-larger networks, including vehicle-pedestrian interactions, on a transportation network. However, inherent differences between the behavioral models of pedestrians and drivers cause developers of popular simulation systems, such as VISSIM, PARAMICS, SUMO and Aimsun, to withhold extending their systems to perform safety assessment (Gettman and Head, 2003; Ishaque and Noland, 2008). In parallel, multi-agent models of crowd dynamics in evacuation scenarios are rarely include vehicle traffic hindering pedestrian flow, Papadimitriou et al. (2009).

Modeling of vehicle-pedestrian interaction requires explicit representation of pedestrian decision-making. Typically, this is done by Discreet Choice Models (DCMs). Wang et al. (2010) acknowledge the risk of jaywalking outside crosswalks in pedestrian crossing situations in their Gap Acceptance model. The model is based on observations of a bi-directional two-lane road, captured by a pair of synchronized video cameras on each side of the road, one for pedestrians and the other for vehicles. The result is a binary logit model (an individual choice with two alternatives - to cross or to stay) depending on the estimated approaching traffic gap time, the age of the pedestrian, the number of pedestrians in a group crossing together, and the waiting time before crossing. The model was positively validated in ~90% of cases. Typically, DCMs do not account for the sequence of events *after* a pedestrian, driver or both have made a decision. The exception is the DCM representing motion decision-making done by Robin et al. (2009). Their cross-nested logit model of pedestrian decision-making includes submodels that describe decisions on directions and accelerations, turning and collision avoidance. Another exception is the research of Sun et al. (2002), who propose a framework for modeling vehicle-pedestrian interaction that combines pedestrians' gap acceptance with motorists' yielding behavior (Yannis et al., 2013).

The sequence of events during pedestrian-vehicle interaction is explicitly considered in dynamic models (Xie et al., 2009, 2012; Echab et al., 2016). Zhang and Duan (2007) propose the Cellular Automata model that describes the interactions between vehicles and pedestrians at a crosswalk. It combines the vehicle flow sub-model of Nagel and Schreckenberg (1992) with the pedestrian sub-model. The model adequately estimates the effect of pedestrians' disobedience to traffic laws, but its temporal and spatial resolutions are insufficient to reflect the urgent maneuvering of vehicles and pedestrians at dangerous locations, when they are within centimeters and milliseconds of an accident.

1.3. Modeling "last second" maneuvers

In 2005, the U.S. Department of Transportation (US DoT) started the Intelligent Transportation System Program, which aimed, among other goals, at developing safety applications that issue real-time warnings to drivers. For this purpose, large scale studies of the "last second" maneuvers before crashes were performed. Drivers' actions and vehicles' performances were continuously recorded and analyzed during predefined vehicle-to-vehicle conflict scenarios (Kiefer et al., 2003; Smith et al., 2003; Najm and Smith, 2004). In another study, "100 Cars Naturalistic Driving" project, data on drivers' behaviors and vehicles' movements were recorded (Dingus et al., 2006; Klauer et al., 2006). This data provided a solid background for describing drivers' real-time behaviors in standard situations. However, the number of recorded close-to-accident situations and pedestrian-related episodes was very low.

Computer simulation has the potential to overcome some of the limitations of field experiments (Rossi et al., 2011; Kim et al., 2016). However, the success of an accident simulation critically depends on the accurate reproduction of the vehicle's dynamics and the driver's behavior in the case of urgent maneuvering (Grácio et al., 2011). A number of studies exploited traffic simulation systems for deriving better driver behavior models (Vladisavljevic et al., 2009) and understanding drivers' behavior (Farah et al., 2007). However, few driver simulators explicitly include pedestrian agents. Engel and Curio, 2012; Pomarjanschi et al., 2012; and Salamati et al., 2012 use pedestrian agents with simple behavior models in order to investigate the eye movements of drivers who are avoiding a crash in critical road situations.

In this paper we assess the safety of a traffic spot environment with a high-resolution, spatially explicit, dynamic agent-based simulation model - SAFEPED (Waizman et al., 2014). In particular, we are interested in the behavior of aggressive drivers and careless pedestrians during the final seconds before a crash. SAFEPED reproduces traffic spot infrastructure and moving objects in fine 3D detail, and operates at a spatial resolution of 10 cm and a temporal resolution of up to 1/100 of a second. Based on the SAFEPED simulations, we propose methods for accident risk assessment, which includes identification of near-crash conditions, estimation of the level of risk to the pedestrian, and the severity of a potential crash. By near-crash we refer to circumstances that require rapid, evasive maneuvers by vehicles, pedestrians, cyclists, or animals to avoid a crash (Dingus et al., 2006). Behavioral rules of SAFEPED agents (vehicles and pedestrians) are based, when possible, on experimental data, and are verified using real data recorded on video cameras (Waizman et al., 2014). Based on data from SAFEPED, various risk indicators are extracted using Range-Range Rate (R-RR) graphs. These graphs express the dynamic interaction between pedestrians and vehicles before and during a potential crash.

Section 2 briefly describes the SAFEPED simulator. Section 3 discusses a risk analysis technique for vehicle-pedestrian interaction at crossroads using R-RR graphs. Section 0 presents experimental results based on the model of a real road location, and Section 4 provides a disccusion.

2. SAFEPED, an agent-based model of vehicle-pedestrian interaction

In this section we describe our microsimulation model–SAFEPED–that is used in this paper. SAFEPED exploits a precise 3D representation of road spots, including road surface elements (e.g. road borders, separating lines and pedestrian crossings) parked vehicles, buildings, trees, traffic lights and traffic signs. It can incorporate an almost unlimited number of agents (pedestrians and vehicles) in a wide range of environments and scenarios. The description of SAFEPED in this section provides only limited details that are relevant to the proposed methodology. For a comprehensive, detailed description of SAFEPED, we refer readers to (Waizman et al., 2014).

2.1. SAFEPED agents and their behavior

SAFEPED drivers and pedestrians behave autonomously, according to a set of probabilistic behavioral rules. Each agent–driver or pedestrian–is assigned with a profile that includes its physical dimensions (height and width), maximal and standard velocity, acceleration and deceleration rates.

Each SAFEPED agent is also assigned with a desired trajectory, a driving/walking path, and the preferred speed along that path (Fig. 1). An agent drives/walks along its trajectory while trying to maintain its desired direction and velocity.

If agents cannot follow their predefined trajectory because of unexpected objects or other agents they react, not necessarily adequately, by deviating from their predefined trajectory, accelerating or decelerating or even stopping. After deviating from its trajectory, the agent tries to return to its original trajectory. To do so, the agent identifies a return point along the initial trajectory at a certain distance ahead (Fig. 2) and constructs a safe path from its current location to the original trajectory, accounting for its kinematic properties and immobile or mobile obstacles appearing on the way (Millington and Funge, 2009).

In reality, there are formal and informal rules that define the traffic behavior of vehicles and pedestrians. We reflect these rules by