Abstract

Road crash is the leading cause of death for young people (5 – 29 years old) across the world. This problem is even more serious in developing countries where despite having only 72% of the world's powered vehicles, 92% of all road fatalities occur [1]. Quantifying these crashes/fatalities and investigating the causes behind them is essential for developing appropriate countermeasures. In general, crash data is required for such safety assessment. However, in the absence of crash data, surrogate safety measures (SSMs) have been widely accepted for proactive safety assessment. Despite such a merit, SSMs have not been explored enough for safety assessment in developing countries.

Traffic stream in developed countries is characterized as lane-based traffic where vehicle composition is homogeneous, and strict lane discipline is followed. In contrast, traffic in many developing countries (e.g., China and India) is characterized by vehicular heterogeneity and multi-vehicle interactions resulting from non-lane-based vehicular movement. This traffic condition is also described as "disordered traffic," "lane-free traffic," and "mixed traffic." The two key components that make it different from homogeneous traffic are vehicular heterogeneity and non-lane-based vehicular movement. Vehicular heterogeneity refers to the difference in microscopic traffic parameters (space and time headway, lateral gap) resulting from differences in static and dynamic characteristics of a vehicle [2]. Further, in a heterogeneous traffic stream, vehicles do not necessarily travel at the center of the lane. Each vehicle is influenced by multiple vehicles not just the one in the front as assumed in the car following models. Drivers in such conditions maintain lateral gaps without following lane discipline [3]. In such traffic streams, vehicle interaction is generally multi-vehicle and 2-dimensional with both longitudinal and lateral interactions [4].

The aim of this study is to develop a non-crash-based safety assessment framework for heterogeneous and non-lane-based traffic. Review of existing surrogate safety studies in heterogeneous traffic conditions highlight the salient features and challenges associated with SSMs-based safety assessment in developing countries. These challenges include conflict data collection in non-lane-based traffic, suitability of various conflict indicators for defining conflict in non-lane-based 2-dimensional interaction, the effect of vehicular size on conflict and crash risk, and lack of methodology for incorporating site-based and vehicular heterogeneity while safety assessment.

Based on these research gaps, three research objectives were defined. In the first objective, this study proposes a framework for defining traffic conflict using video-based vehicle trajectory in non-lane-based traffic scenario. A two-dimensional conflict indicator is proposed to incorporate two-dimensional vehicular interactions. In the second objective, the effect of vehicle size on crash risk is investigated using a bivariate extreme value approach. In the third objective, a Bayesian hierarchical framework for safety assessment in heterogeneous traffic conditions is proposed. To fulfill the above research objectives, traffic video data was recorded at four unsignalized T-intersections, identified as black spots on divided highways in India. Vehicle trajectories were extracted from the recorded video data using a semi-automated tool. A total of 8326 vehicles were tracked for an approximate trap length of 60 m. Conflict indicators were estimated using the extracted vehicle trajectories.

Most of the previously defined conflict indicators are only suitable for one-dimensional vehicle interactions, such as in lane-based traffic. For example, rear-end conflicts can be quantified using TTC in lane-based traffic, where vehicles are moving in strict lane discipline, generating inline interactions. However, it is not appropriate to use such conflict indicators alone to define conflict when vehicles move in non-lane-based traffic, leading to a 2-dimensional vehicular interaction. For defining conflicts in such traffic streams, this study considers lateral along with longitudinal interactions. A Bivariate EVT model was proposed for crash risk assessment using Lateral gap and TTC. The results show that incorporating lateral and longitudinal conflict indicators together into the bivariate models can significantly improve the conflict-based risk assessment in non-lane-based traffic.

A proper threshold value of a conflict indicator must be used to segregate conflicts from normal interactions. While research shows that this threshold depends on vehicle size, it has not been studied before. This study utilizes bivariate conflict indicators to define conflict in two-dimensional interaction. In addition, the effect of vehicle size on crash risk was examined for different leader-follower pairs. Bivariate extreme value modeling was used to relate crash risk with vehicle size. Results show that interactions involving cars and light commercial vehicles were riskier than interactions involving motorized two-wheelers and motorized three-wheelers. This is significantly different from what was found using a global threshold of conflict indicators. The proposed framework can be used for a more accurate risk assessment in heterogeneous traffic conditions.

Extreme value theory (EVT) has been extensively used to assess road safety with traffic conflicts. However, most studies used pooled models that do not account for site-based and vehicular heterogeneity. Literature suggests that minimum spacing and microscopic conflict indicators depend upon the leader-follower (LF) pairs. As traffic streams in heterogeneous traffic consist of multiple subgroups, vehicular heterogeneity should be incorporated in estimating crash risk. A completely pooled model will lead to a biased estimate of crash risk, while the separate model for individual LF reduces the sample size. To address this research gap, this study proposes a risk assessment technique for rear-end crashes incorporating site-based and vehicular heterogeneity using a hierarchical model framework. Conflicts were estimated using modified time-to-collision (MTTC) derived from extracted trajectories as the conflict measure for rear-end crashes. Both pooled and hierarchical models were fitted to compare the crash risk among subgroups. If there is heterogeneity (LF-based model) in the population, the pooled model leads to a biased estimate. In contrast, for the homogeneous case (site-based model), the hierarchical and pooled model leads to comparable crash risk. Further, the pooled model leads to the same crash risk across all vehicle types. In contrast, the hierarchical model revealed that crash risk varied across leader-follower pairs. Interactions involving cars and light commercial vehicles with other slow-moving vehicles are more likely to lead to a rear-end crash.

The novelty of this study is in defining conflict and crash risk considering two-dimensional vehicular interactions in mixed traffic environments. The methodology presented in this study may be used to define conflict in traffic that does not follow lane discipline. Further, this study demonstrates the importance of incorporating vehicle type as well as 2-dimensional interactions in safety assessment. This approach can be used for a more accurate risk assessment in a traffic stream with vehicle size heterogeneity and lane-free movements. In addition, a Bayesian hierarchical framework is proposed to incorporate site-based and vehicular heterogeneity in safety assessment. The proposed safety assessment framework can be used to define critical safety events required in vehicle warning systems for heterogeneous and non-lane-based traffic conditions.