Issues in Developing and Applying Crash-Conflict Models

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EXTENDED SUMMARY

Introduction

Vision Zero programmes are now commonplace around the world in agencies charged with improving road safety through strategies to mitigate serious traffic related injuries and deaths. The evaluation process for implementing innovative strategies may be challenging, as prior information may be non-existent. This challenge could be addressed with the use of surrogate measures, such as traffic conflicts. Statistical models of the relationship between crashes and conflicts are fundamental to this application. The objective of this paper is to build on previous research in exploring some key issues related in establishing relationships between different measures of traffic conflicts from microsimulation and crash frequency. This investigation is based on microsimulation of four-legged signalized intersections in the City of Toronto to generate traffic conflicts identified from both time to collision (TTC) and post encroachment time (PET) -- the most prevalent indicators of traffic conflicts. TTC is originally defined by Hayward [1] as ”…the time that remains until a collision between two vehicles would have occurred if the collision course and speed difference are maintained”. As defined by Allen et al. [2], PET is the time between the moment that the first road user passes a certain point, and the moment that the second road user reaches that point.

The main points of departure of the current study are the investigation of speed as a predictor in the conflict-based crash prediction models, and the use of microsimulation to derive those speeds. While speed measures have been proposed for defining the severity of conflicts derived from observations [3, 4, 5], there is precious little research evaluating the applicability of microsimulation-derived speeds, in addition to conflicts, in crash prediction models. The transferability of the proposed models to different jurisdictions is also explored, as is the applicability to estimating crash modification factors (CMFs) for contemplated treatments.

Issues are addressed with a case study in which traffic conflicts identified from both time to collision (TTC) and post encroachment time (PET) are generated from microsimulation of four-legged signalized intersections in the City of Toronto. These vehicle-vehicle traffic conflicts, in addition to speed of conflicting vehicles, a variable that has received little emphasis in previous research, are used to develop and explore improved statistical relationships between frequency of crashes and surrogate measures. Transferability of the models to another Canadian jurisdiction is also investigated by estimating calibration factors and assessing goodness-of-fit.

Methodology

A sample of 91 four-legged signalized intersections in the City of Toronto was modelled in the SYNCHRO software [6] by incorporating important aspects related to the road geometry, signal timings, and traffic volumes. The modelled intersections from SYNCHRO were saved as a comma-delimited file and then imported into the PTV VISSIM software [7] to conduct the microsimulation. Another 13 signalized intersections in York Region, about an hour’s drive from Toronto, were similarly modelled to assess the transferability.

Ten random runs were simulated in VISSIM for 3600 seconds representing the morning peak hour. After conducting the microsimulation, the outputs were saved in the form of vehicle trajectory files to be imported into

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the Surrogate Safety Assessment Model (SSAM) software package [8]. SSAM yields the total number of conflicts and the number of conflicts per simulation run based on time-to-collision (TTC) and post-encroachment time (PET) thresholds. Based on previous research, PET thresholds of 5 sec. and 2.5 sec. and TTC thresholds ranging from 1.5 sec. to 0.5 sec. were deemed of interest for the investigation in this study [9, 10]. A TTC threshold of 1.5 sec. in fact represents the same number of conflicts as a PET of 5 sec. since these values were set as the maximum thresholds in SSAM. Conflicts involving pedestrians, and conflicts that occur beyond a 50 m. radius of the intersection were filtered out. Thus, the investigation pertains to vehicle-vehicle conflicts only.

Crash prediction models were developed from 5 years of crash data at each of the 91 intersections using a generalized linear modeling (GLM) approach with the specification of a Negative Binomial (NB) error structure. Independent variables investigated include the number of conflicts grouped by type, PET and TTC, average and maximum speeds of conflicting vehicles, and a risk score identified by a link function pertaining to the severity of conflicts. These models were developed with the SAS software package. The estimated NB overdispersion parameter was used predominantly as a goodness-of-fit measure for comparative evaluation of various model options, with smaller values indicating a better fit for the same data.

Following our recent research [5] to develop crash prediction models from video-derived conflicts classified by a risk score, a link function was developed to distinguish between severe and non-severe conflicts. The intended effect of the risk score was to analyze the conflicting speeds of the two vehicles and observe the relationship that these speeds would have with the estimated PET for each conflict individually. Following [5], the risk score was determined using:

$$Risk\ Score = \frac{Speed\ of\ First\ Vehicle + Speed\ of\ Second\ Vehicle}{PET} \tag{1}$$

where the numerator reflects the summation of the speeds of each conflicting vehicle and the PET is the post encroachment time. The severity of a conflict is correlated with the risk score as the higher the risk score, the greater the severity and vice-versa. Furthermore, as the PET approaches zero, the risk score increases, which is logical, as a PET value approaching zero indicates a near-collision. The model formulation of the risk score approach is based on the following equation:

$$Crashes/year = e^{\alpha} * (Conflicts\ with\ risk\ score < x)^{\beta_1} * (Conflicts\ with\ risk\ score \geq x)^{\beta_2} \tag{2}$$

where *crashes* pertains to the type of crash being modelled, α is the estimate of the intercept, *conflicts* is the number of peak hour conflicts, x is the specified risk score threshold, β_1, β_2 are estimated coefficients for explanatory variables. The value of x was determined from a trial-and-error process that yielded a threshold value producing the most favourable goodness of fit measures for the model.

The transferability of the models was assessed to determine whether the most promising conflict-based crash prediction models were suitable for calibration to York region. The CALIBRATOR software tool [11] was used to assess the transferability. This software tool generates goodness-of-fit tools and measures such as Cumulative Residual (CURE) Plots, modified R^2, Mean Absolute Deviation (MAD), coefficient of variation (CV) of the calibration factor, and overdispersion factor based on the calibration data.

Finally, as a follow-up to our previous research [12], the ability of the models to estimate crash modification factors (CMFs) was investigated by first estimating, from microsimulation, conflicts with and without a contemplated change at selected intersections. The models were then used to estimate crashes with and without the change, before calculating the CMF as the ratio of the two estimates.

Results and Discussion

Crash-Conflict Models

As noted earlier, the simulated conflicts extracted from the SSAM software and the crash data obtained from the City of Toronto were used in the development of the crash prediction models. These relationships were estimated for the two sets of PET and TTC thresholds – 2.5 and 5 sec for PET and 0.5 and 1 sec for TTC. The following model formulations were investigated:

$$Crashes/year = e^{\alpha} * (Conflicts)^{\beta_1} \tag{3}$$

$$Crashes/year = e^{\alpha} * (Conflicts)^{\beta_1} * (Average\ Speed)^{\beta_2} \tag{4}$$

$$Crashes/year = e^{\alpha} * (Conflicts)^{\beta_1} * (Maximum\ Speed)^{\beta_2} \tag{5}$$

where *crashes* pertains to the type of crash which is being modelled against, α is the estimate of the intercept, β_1 is the estimate of the coefficient for conflicts, β_2 is the estimate of the coefficient for average or maximum speed. Models were estimated for total and injury crashes. The following provides some insights based on the results for modeling based on Equations 3-5:

- The coefficient estimates for all independent variables were significant at the 10% level or better.
- The directions of the speed variable effect all indicate that crashes increase with an increase in speed.
- Models that incorporate the PET threshold consist of a smaller dispersion parameter in all cases. And models with the 2.5 sec. threshold tend to be better by this measure than models with the 5 sec. threshold.
- The addition of the speed variable (average speed and maximum speed) results in the overdispersion parameter being slightly smaller for almost all cases. In the majority of these cases, the average speed variable tends to perform better than the maximum speed variable.
- The addition of the speed variable (average speed and maximum speed) generally results in a stronger effect for conflict frequency. This disparity is much more pronounced for the PET models.
- Six of the eight speed-based models indicate a stronger effect of speed for injury crashes than for total crashes.

Regarding the models estimated by the risk score approach based on Equations 1 and 2, the following insights were provided:

- The magnitude of the coefficient for conflicts classified as more severe by risk score is larger than for those classified as less severe, confirming the logic of the approach.
- The conflict severity threshold is greater for injury crashes in comparison with the threshold for total crashes; this indicates that injury crashes result from more severe conflicts in comparison to non-injury crashes.
- The overdispersion parameters for the risk score models are slightly larger than those for the other models, suggesting that alternative model formulations for the risk score approach should be pursued. (For this investigation, the formulation in [5] was adopted.)

In sum, the main indication from all of these insights is that the average speed models with the 2.5 sec PET threshold are the most promising for this particular dataset and for the model formulations investigated.

Transferability Assessment

The transferability of these models to another jurisdiction (York Region) was assessed using the CALIBRATOR software tool [11] to calibrate the models to data for 13 intersections for which 6 years of crash data were obtained. This software tool calculated a calibration factor and various goodness-of-fit (GOF) measures to assess whether the crash prediction model would be suitable or not. These measures include the mean absolute deviation (MAD), modified R^2, the variance [V(C)] and coefficient of variation [CV(C)] of the calibration factor, CURE plots and associated measures – the maximum CURE deviation and the % of residuals with deviation outside the 2 standard deviation limits, Akaike's information criterion (AIC) and Schwarz Bayesian Information Criterion (BIC). Table 5 shows the calibration results for York Region. It should be noted that the models with a PET threshold were used to assess the transferability, since, as noted above, these models captured the information better in comparison to the models with a TTC threshold.

The following provides some insights pertaining to the results:

- The calibration procedure produced similar results for a PET threshold of 5 sec and 2.5 sec.
- The GOF measures indicate that the crash-conflict models without a speed variable performed best in terms of transferability. The transferability of these and almost all of the other models can be deemed acceptable in satisfying the condition in the CALIBRATOR user guide that "five percent or less of CURE plot ordinates for *fitted* values (after applying the calibration factor) exceed the 2σ limits" [11].
- Satisfactory results were obtained with a relatively small calibration dataset of 13 intersections.

Applicability to Estimation of Crash Modification Factors

Our previous research [12] found that crash-conflict model can potentially be used to estimate crash modification factors (CMFs) for contemplated changes at a signalized intersection. As a follow-up, it was desired to investigate whether the improved models that incorporate speed can also be used for this purpose. For this exercise, CMFs for changing left turn phasing from permissive to protected-permissive on multiple approaches at each of 10 Toronto intersections were estimated. The criteria used for selecting intersections were that the intersections should have at least one approach with an exclusive left turn lane and that the level of service (LOS) and traffic volumes would justify consideration of protected-permissive signal phasing.

The phasing of the intersections was modified in Synchro and the simulation was performed in VISSIM. Based on the conflicts generated before and after the modification, the Crash - Conflict and Average Speed models with a PET of 5 sec. were used to estimate CMFs for total and injury crashes.

These results confirm the viability of estimating CMFs with the improved crash conflict models incorporating conflicting vehicle speeds in that the estimates are reasonably consistent with those from an empirical Bayes before-after study [13] for intersections in Toronto for which the left turn phasing was changed from permissive to protected-permissive. Notably, it was possible to estimate a CMF that was unique to each intersection, in effect mimicking the application of a Crash Modification *Function*.

Summary and Conclusions

The research investigated some key issues related to the development and application of crash-conflict models for safety assessments. Among issues addressed were model specification, the very definition of conflicts, model transferability, and application of the models for estimating of crash modification factors. Issues are addressed by a case study in which traffic conflicts based on both time to collision (TTC) and post encroachment time (PET) were generated from microsimulation for four-legged signalized intersections in the City of Toronto.

The case study results indicate that the inclusion of the speed variable along with simulated traffic conflicts provides strong relationships in comparison to traffic conflicts as a standalone variable. In particular, the results confirm the viability of estimating CMFs with the improved crash conflict models. The transferability investigation results indicate that the crash experience in the other Canadian jurisdiction is quite different in relation to the correlation with traffic conflicts, but that it is reasonable to apply the Toronto models to the other jurisdiction with caution.

The paper was limited in scope to an investigation of some key issues related to the development and application of crash-conflict models for safety assessments. To actually develop such models for specific applications, more research will be needed to, for example, explore additional speed measures such as the difference in speed of conflicting vehicles for rear-end conflicts and alternative model formulations for the risk score approach. Such research should also consider modifications to the VISSIM car-following parameters to optimize the crash-conflict models.

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