ESTIMATING CRASH MODIFICATION FACTORS USING SURROGATE MEASURES OF SAFETY

Taha Saleem
Ryerson University, Department of Civil Engineering
350 Victoria Street, Toronto, M5B2K3

Adrian Lorion
BA Consulting Group Ltd.
300 – 45 St. Clair Ave W, Toronto, ON, M4V1K9

BA Group

RYERSON UNIVERSITY

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Table of Contents

Introduction

- Crash Modification Factors (CMFs) represent the effects of safety treatments on crashes from observational studies based on reported crashes.
- Observational studies are largely dependent on the availability of crash data and collection of such data requires a lengthy evaluation/observation period.
- Traffic conflicts can be used as a traffic safety surrogate for a less time-consuming measure to assess the safety effectiveness of a countermeasure.
- The main objective of this paper is to use traffic simulation to assess changes in traffic conflicts due to a change in road designs or features which would subsequently lead to the computation of Conflict Modification Factors (CfMFs). CMFs can then be estimated by using the crash-conflict relationship (i.e. the conflict based crash prediction models).

Summary of Data

- The data for this study were provided by the City of Toronto's Traffic Control Centre.
- Signalized intersections data used consisted of a 113 4SG intersections, whereas, the stop controlled intersection data consisted of 133 2ST intersections.

Table 1: Volume Statistics

Volume	113 - 4SG Intersections		133 - 2ST Intersections	
	Major AADT	*Minor AADT*	*8 Hour*	*Peak Hour*
Mean	12669	6453	10815	1635
Minimum	5048	78	2064	375
Maximum	23807	15772	23775	3802

Table 2: Crash Statistics

Collisions	4SG Intersections (2006-2010)			2ST Intersection (1999-2010)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Total	10.894	0	36	6.72	0	53
Injury	2.265	0	9	2.25	0	18
PDO	8.628	0	27	4.46	0	36
HEO	0.23	0	2	0.2	0	3
Angle	1.858	0	8	2.47	0	32
Rear End	4.195	0	19	0.82	0	6
Side Swipe	1.566	0	12	0.41	0	3
Turning	1.77	0	7	2.44	0	23

Conflict Estimation

- Simulation was done in VISSIM using the default values from the Wiedemann 99 car-following model.
- For each intersection, the whole peak hour (3600 sec) was simulated. 10 Simulation runs with 10 random seeds were used.
- SSAM trajectories for each simulation run were analyzed in SSAM to classify conflicts.
- SSAM classifies conflicts into five main categories: Rear End; Lane Change; Crossing; Unclassified; and Total
- After the analysis, conflicts were filtered out to remove any values of TTC and PET equal to zero. Pedestrian conflicts were also filtered out by excluding conflicts with speeds of less than 5mph or 7.3ft./sec.
- Intersection coordinates were also filtered to get conflicts within 50m radius of the intersection.

Conflict Estimation (Results)

Table 3: Conflicts Stats for 4SG Sites with and without Turning Lanes

Conflicts Estimation Statistics (80 Sites With Turning Lanes)				
Collisions	**Mean**	**Minimum**	**Maximum**	**Percentage**
Total	148.310	14	448	100.00%
Crossing	9.648	1	48	6.51%
Rear End	128.419	6	416	86.59%
Lane Change	10.223	1	37	6.89%

Conflicts Estimation Statistics (33 Sites Without Turning Lanes)				
Collisions	**Mean**	**Minimum**	**Maximum**	**Percentage**
Total	117.000	10	262	100.00%
Crossing	7.739	0	28	6.61%
Rear End	102.509	7	242	87.61%
Lane Change	6.761	1	24	5.78%

Table 4: Conflicts Stats for 2ST Sites

Conflicts Estimation Statistics				
Collisions	**Mean**	**Minimum**	**Maximum**	**Percentage**
Total	20.6	0	458.5	100.00%
Crossing	0.5	0	5.3	2.64%
Rear End	18.1	0	429.7	87.86%
Lane Change	2.0	0	27.7	9.51%

Crash Prediction Models

- Consistent with state-of-the-art methods, generalized linear modeling, with the specification of a negative binomial (NB) error structure, was used to develop the Crash Prediction Models (Persaud *et al*, 2012).
- The general form of crash prediction models used is as follows:

$$Crashes = e^{\alpha} \times Variable\ 1^{\beta_1} \times Variable\ 2^{\beta_2} \times --- \times Years$$

Where;

  - Crashes = Type of crash modeled (e.g. Total, Injury, Rear End, etc.,
  - α = Intercept estimate,
  - β_1, β_2, etc. = Coefficient estimates for the explanatory variables, &
  - Years = No. of years of crash data used
- Goodness of Prediction measures used to assess the predictive capabilities of the models included Mean Absolute Deviation, Mean Squared Prediction Error and Mean Prediction Error.

Crash-Conflict Models (4SG)

$$Crashes = e^{\alpha} \times Conflicts^{\beta_1} \times Peak\ Hour\ Ratio^{\beta_2} \times Years$$

Table 5: Coefficient Estimates and Dispersion Parameter for 4SG Models

Crash Type	Conflict Type	α		β1		β2		k
		Est	*P>ChiSq*	*Est*	*P>ChiSq*	*Est*	*P>ChiSq*	
Total	***Total***	-0.9722	0.2771	0.3461	<0.0001	-1.0775	0.0023	0.235
Injury		-1.7527	0.0543	0.3030	<0.0001	-0.8498	0.0164	0.201
PDO		-1.3336	<0.0001	0.3593	<0.0001	-1.1303	0.0025	0.262
Angle	***Crossing***	-0.8015	0.2791	0.2549	0.0020	-0.7117	0.0485	0.274
Rear-end	***Rear-end***	-1.2676	0.2341	0.3423	<0.0001	-0.6609	0.1264	0.336
Side Swipe	***Lane Change***	-1.6218	0.1494	0.2608	0.0159	-1.0133	0.0639	0.550
Turning	***Crossing***	-0.7851	0.3321	0.3158	0.0009	-0.5477	0.1643	0.349

Crash-Conflict Models (2ST)

$$Crashes/year = e^{\alpha} \times Conflicts^{\beta_1}$$

Table 6: Coefficient Estimates and Dispersion Parameter for 2ST Models

Crash Type	Conflict Type	Group	α		β1		k
			Est	*P>ChiSq*	*Est*	*P>ChiSq*	
Total	***Total***	***All***	-0.8910	<0.0001	0.1805	0.0012	0.8946
		3 Leg	-0.8508	<0.0001	0.1568	0.0500	0.9828
		4 Leg	-0.9433	<0.0001	0.2065	0.0064	0.7635
Injury		***All***	-1.9234	<0.0001	0.1509	0.0162	0.8769
		3 Leg	-1.9445	<0.0001	0.1153	0.1956	0.8861
		4 Leg	-1.8668	<0.0001	0.1753	0.0475	0.8370
PDO		***All***	-1.3336	<0.0001	0.1948	0.0009	0.9549
		3 Leg	-1.2569	<0.0001	0.1731	0.0448	1.1298
		4 Leg	-1.4544	<0.0001	0.2251	0.0039	0.7251
Rear-end	***Rear-end***	***All***	-2.8805	<0.0001	0.1654	0.0057	0.5038
		3 Leg	-2.7649	<0.0001	0.1626	0.0598	0.7816
		4 Leg	-3.1528	<0.0001	0.2092	0.0105	0.0000
Sideswipe	***Lane-change***	***All***	-3.3697	<0.0001	0.2944	0.0095	0.4051
		3 Leg	-3.4246	<0.0001	0.3212	0.0537	0.3935
		4 Leg	-3.2875	<0.0001	0.2617	0.0934	0.4034
Turning Movement	***Crossing***	***All***	-1.2785	<0.0001	0.3501	0.0034	1.0012
		3 Leg	-1.2051	<0.0001	0.3989	0.0137	1.0091
		4 Leg	-1.3792	<0.0001	0.2881	0.1008	0.9760

Estimating Crash Modification Factors

- The purpose of this section is to use the crash conflict relationships as an alternative approach to crash based evaluations of contemplated or implemented intersection improvements.
- Treatment Scenarios evaluated included:
  - Installation of left turn lane on major road approaches at 4SG intersections,
  - Installation of left turn lane on major road approaches at three-leg 2ST intersections,
  - Installation of right turn lane on major road approaches at 4SG Intersections, and
  - Changing left turn signal control from permissive to protected-permissive at 4SG Intersections

Scenario 1: Introduction of Left Turn Lane on Major Road Approaches at 4SG

- The improvement explored is the hypothetical introduction of a left turning lane on a major approach of 4SG intersection.
- 16 4SG intersections were so identified as candidates for the addition of a major approach left turning lane. The major consideration for selecting these 16 intersections was that the traffic volumes and the current movement level of service (LOS) warrants an installation of the left turn lane.

Table 7: CMF Estimations for Scenario 1

Crash Type	Total Predicted Crashes		CMF Range		Average CMF
	Before	*After*	*Minimum*	*Maximum*	
Total	1313.87	1286.13	0.816	1.336	0.994
Injury	312.96	307.095	0.837	1.288	0.994
PDO	998.47	976.568	0.811	1.350	0.994
Angle	246.11	293.599	0.975	1.479	1.202
Rear-end	408.68	371.481	0.748	1.336	0.929
Sideswipe	181.17	227.496	1.000	1.538	1.268
Turning	207.62	258.973	0.969	1.623	1.259

- The validity of the CMF estimation approach was assessed by comparing the estimated CMFs with those in the Highway Safety Manual for this treatment, which are based on a state of the art crash based empirical Bayes before and after evaluation.
  - That study identified a CMF of 0.90 for total crashes and 0.91 for injury crashes at urban 4SG intersections. The results presented in this study for the same improvement identify a CMF of 0.99 for both total and injury crashes with individual values ranging from 0.8 – 1.3.

Scenario 2: Introduction of Left Turn Lane on Major Road Approaches at 3 Leg 2ST

- The improvement explored is the hypothetical introduction of a left turning lane on a major approach of an urban 3-leg 2ST intersection.
- 30 2ST intersections were so identified as candidates for the addition of a major approach left turning lane.

Table 8: CMF Estimations for Scenario 2

Crash Type	Total Predicted Crashes		CMF Range		Average CMF
	Before	***After***	***Minimum***	***Maximum***	
Total	30.95	26.40	0.63	1.09	0.86
Injury	9.80	8.75	0.71	1.06	0.89
PDO	21.10	17.70	0.60	1.10	0.85
Rear-end	4.15	2.70	0.12	1.12	0.64
Sideswipe	1.80	1.00	0.22	1.04	0.51
Turning	9.35	14.70	0.07	2.95	1.38

- The validity of the CMF estimation approach was assessed by comparing the estimated CMFs with those in the Highway Safety Manual for this treatment, which are based on a state of the art crash based empirical Bayes before and after evaluation.
  - That study identified a CMF of 0.67 for total crashes at three-leg urban 2ST intersections. The results presented in this study for the same improvement identify a CMF of 0.86, with individual values that range from 0.63 to 1.09.

Scenario 3: Introduction of Right Turn Lane on Major Road Approaches at 4SG

- The improvement explored is the hypothetical introduction of a right turning lane on a major approach of 4SG intersection.
- 28 4SG intersections were so identified as candidates for the addition of a major approach right turning lane. The major consideration for selecting these 28 intersections was that the traffic volumes and the current movement level of service (LOS) warrants an installation of the right turn lane.

Table 9: CMF Estimations for Scenario 3

Crash Type	Total Predicted Crashes		CMF Range		Average CMF
	Before	*After*	*Minimum*	*Maximum*	
Total	2346.38	2060.95	0.715	1.102	0.883
Injury	560.65	500.25	0.746	1.089	0.896
PDO	1783.92	1559.35	0.706	1.106	0.879
Angle	419.53	515.97	0.876	1.573	1.243
Rear-end	760.32	602.78	0.622	1.023	0.799
Sideswipe	308.13	370.48	0.811	1.840	1.216
Turning	365.20	473.86	0.848	1.752	1.314

- The validity of the CMF estimation approach was assessed by comparing the estimated CMFs with those in the Highway Safety Manual for this treatment, which are based on a state of the art crash based empirical Bayes before and after evaluation.
  - That study identified a CMF of 0.92 for total crashes at urban 4SG intersections. The results presented in this study for the same improvement identify a CMF of 0.88 for total crashes with individual values ranging from 0.72 - 1.10.

Scenario 4: Changing Left Turn Phasing from Permissive to Protested – Permissive at 4SG

- The improvement explored is hypothetically changing the left turn phase from permissive to protected – permissive at 4SG intersections
- 20 4SG intersections were selected for this hypothetical treatment.
  - The criteria used for selecting intersections was 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 permit the installation of a protected-permissive signal

Table 10: CMF Estimations for Scenario 4

Crash Type	Total Predicted Crashes		Average CMF
	Before	*After*	
Total	1646.6	1368.3	0.831
Angle	304.8	250.7	0.822
Rear End	519.4	433.2	0.834
Side Swipe	240.2	203.4	0.847
Turning	259.9	204.2	0.786

- The results indicate that the treatment would be beneficial in reducing the number of angle and turning crashes (the target crash types). These results are reasonably similar to those from an empirical Bayes before-after study conducted by Srinivasan et al. (2012) for 55 intersections in the City of Toronto for which the left turn phasing was changed from permissive to protected-permissive.
  - The sum of target crashes (Angle + Turning) reduced by about 19% (i.e. average of Angle and Turning CMFs) which is comparable to the reduction achieved by Srinivasan et al. of about 14% with an error of about 5%.
- The study by Srinivasan et al. also found statistically insignificant increases in total and rear end crashes, whereas the results of the conflict-based analysis show a decrease in both of them of about 16%. This may be because the samples for the two analyses are different.

Summary and Conlcusions

- All of the models developed showed that the coefficients estimates for the variables were statistically significant in almost all cases to the 5% level.
- The MAD/year, MPE/year, and the MPB/year values are also very small when compared with the average crashes/year/site.
- Although the aggregate CMFs in all four scenarios differ slightly from their respective compared study, the fact that the use of surrogate safety measures can provide results within the range of a crash before and after study is encouraging.
- It should be further noted that the larger benefit estimated by the comparison studies should be expected since the treatment was actually implemented at sites identified as requiring that treatment.
  - The Toronto intersections, by contrast, were neither treated nor identified for treatment.
  - The models compare well for CMFs overall but not so well for turning, angle, and sideswipe collisions for some interventions.
- This is an encouraging result that suggests that research on using surrogate measure based crash prediction for safety assessment should continue with a view to filling voids that could not be otherwise accomplished with conventional crash based evaluations.
- To conclude, it can be said that the conflict based crash prediction models provide a good alternative and can be effectively used to evaluate the safety of a road entity.