Evaluating the Safety Impacts of Countermeasures for Winter Weather Collisions

Matthew Colwill, B.A.Sc., P. Eng., Associate, IBI Group
Tianjiao Zhang, Co-op Student, University of Waterloo

Paper prepared for presentation at the
Winter Road Maintenance - Getting You There Safely Session

Of the 2015 Conference of the
Transportation Association of Canada
Charlottetown, PEI

Abstract

In Canada, winter weather is a fact of life, and one unfortunate consequence of our sometimes-snowy climes is weather related collisions. Based on geography and associate microclimate, certain highway corridors are particularly susceptible to weather conditions that complicate winter driving, and the result is a higher-than-expected concentration of winter-weather-related collisions.

One such location is the section of Highway 401 that passes through Northumberland County, in southeastern Ontario. In recent years, the Ministry of Transportation has implemented a number of countermeasures aimed at reducing the frequency of winter-weather-related collisions along this corridor. Included in those measures are warning messages on static and dynamic signs, snow fencing, and measures to prohibit highway access and communicate detours during weather-related highway closures.

As a Traffic Engineering Services Retainer assignment for the Ministry of Transportation of Ontario (MTO), IBI Group was asked to assess the safety effectiveness of the applied countermeasures. The assessment was conducted by means of an Empirical Bayes before-after study. In addition to providing an account of the safety effectiveness of the countermeasures in their current application, the assessment also attempted to develop collision modification factors (CMF) for the various treatments for future use.

Based on the available data and the types of countermeasures that were applied along the corridor, CMFs were initially developed to account for the aggregate impacts of all treatments at the project level. The analysis produced CMFs that suggest a 37% reduction in total collisions (40% reduction in fatal + injury collisions and 36% reduction in property damage only collisions) across the study corridor. Subsequent analysis produced CMFs that isolated the impacts of installing snow fencing. The results of that analysis suggest a 33% reduction in total collisions that is attributable to snow fencing alone. However, the specific micro-climate within the study area is such that it may amplify the benefits of the applied treatments, and were they applied elsewhere the countermeasures might not achieve the same effect. As a result, caution should be exercised in adopting the CMFs described herein for application in any other context.

Disclaimer

The contents of this report reflect only the views of the authors. The authors are responsible for the opinions, facts, and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of IBI Group and/or the Province of Ontario. This report was prepared for academic purposes only, and it does not constitute a standard, specification, or regulation.

Acknowledgements

Some of the information presented herein was originally produced as part of an assignment by IBI Group for the Ministry of Transportation of Ontario (MTO), and the successful completion of that work was only possible through the contributions of the MTO Project Manager, Lori Brake, and our colleagues Anthony Lui, Attila Hertel, and Ron Stewart.

Table of Contents

Introduction

In Canada, winter weather is a fact of life, and one unfortunate consequence of our sometimes-snowy climes is winter-weather-related collisions. Based on geography and associate microclimate, certain highway corridors are particularly susceptible to weather conditions that complicate winter driving, and the result is a higher-than-expected concentration of winter-weather-related collisions.

One such location is the section of Highway 401 that passes through Northumberland County, in southeastern Ontario. In recent years, the Ministry of Transportation has implemented a number of countermeasures aimed at reducing the frequency of winter-weather-related collisions along this corridor. Included in those measures are warning messages on static and dynamic signs, snow fencing, and measures to prohibit highway access and communicate detours during weather-related highway closures.

As a Traffic Engineering Services Retainer assignment for the Ministry of Transportation of Ontario (MTO), IBI Group was asked to assess the safety effectiveness of the applied countermeasures. The assessment was conducted by means of an Empirical Bayes before-after study. In addition to providing an account of the safety effectiveness of the countermeasures in their current application, the assessment also attempted to develop collision modification factors (CMF) for the various treatments for future use.

Background

On February 1, 2007, there was a 32-vehicle collision on the eastbound lanes of Highway 401, east of Eagleson Road, which resulted in several fatalities and personal injuries. The collision, which garnered significant political and media attention, occurred under white-out conditions, with 25-50mm of snow on the roadway.

Following the event, the MTO undertook a comprehensive winter operations review that examined snow drifting, microclimate/unique weather, and highway engineering elements that could have contributed to collisions during winter conditions (*Highway 401 Winter Operational Review Northumberland County Finding and Mitigation Report, AECOM,* 2007). Some key findings from the review are listed below:

- The combination of the rolling topography and unique winter climates, and their related events, increase the risk of winter-weather-related collisions within the study area;
- Snow related events are the primary environmental condition under which winter collisions occur;
- The influence of Lake Ontario and prevailing winds results in Lake Effect Snow (LES) events within the eastern portion of the study area.
- The percentage of fatal/injury collisions steadily decreased from 1988 to 2005;
- At sections with tall-wall median barriers, certain collision types were significantly over-represented during the winter months.

Based on the analysis, the following highway operations and maintenance improvements were recommended in the AECOM report:

- Improvements to road weather information systems (RWIS), such as upgrading sensor abilities and providing additional RWIS stations in microclimate regions;
- Improvements to providing and disseminating weather information (e.g., providing advance warning of deteriorating conditions, web mapping/services, etc.) to alert drivers and contractors of deteriorating conditions;
- Implementation of snow fencing at strategic locations; and
- Improvements to winter maintenance operations (e.g., removing snow from shoulders along tall-wall median barriers).

Following the 2007 report, the MTO initiated an action plan to target identified issues. Specific items that were identified in the action plan include:

- Geometric and collision reviews along Highway 401 within Northumberland County;
- Review of detour routes and signage for highway closures;
- Erection of new signage, including: variable message signs (VMS), static warning signs, winter weather information warnings and safety messaging, and mile markers (to improve emergency vehicle response times);
- Improved winter maintenance and general highway service, including: review of ministry standards, revisions to plow routes, changes to direct liquid application (DLA) compounds, and implementation of snow hedging/fencing;
- Communications for on-site representatives and emergency volunteer groups;
- Weather monitoring;
- Traffic monitoring via cameras; and
- Speed studies during winter weather conditions.

IBI Group was asked to assess the safety performance impacts of the countermeasures applied through the action plan.

Study Area

The analysis corridor of Highway 401 from Quinte West Road 33 to the MTO Eastern Region (ER)/Central Region (CR) Boundary, illustrated in Figure 1, spans 74 km. Accesses along the corridor include 10 interchanges and 3 OnRoute service centres. Highway 401 operates is a rural four-lane freeway (two lanes in each direction) east of the Burnham Street interchange. West of the Burham Street interchange, Highway 401 is a six-lane freeway (three lanes in each direction). The freeway median treatment varies between grass median and concrete tall-wall median barriers.

Figure 1: Study Area

Analysis Methodology

The analysis of the winter weather collision countermeasures was conducted in two stages. The first stage involved the development of collision modification factors (CMF) for the various treatments, while the second stage consisted of a review of recent collision trends and attributes.

The CMFs were developed to assess the safety performance impacts of the treatments implemented through the MTO action plan. The review of collision trends and attributes was conducted in an attempt to identify environmental and operational factors that could be contributing to the change in collision frequency described by the CMF.

CMF Development

The CMFs were developed by applying the observational, empirical Bayes (EB) before-after study methodology outlined in *A Guide to Developing Quality Crash Modification Factors* (FHWA, 2010). The methodology involves comparing observed collisions at treatment sites to the number of collisions that would have been expected to occur at those same sites had the treatment not been applied. For the current assessment, the treatment was the implementation of winter weather collision countermeasures.

Applying the EB methodology, makes it possible to account for issues related to regression-to-the-mean, and changes in safety due to traffic volume and time trends, resulting in more precise collision estimates for the “without treatment” scenario. In the EB methodology, the untreated comparison group is replaced by a weighted average of observed collisions at the treatment sites and predicted collision frequencies for the treatment sites, calculated using safety performance functions (SPF).

The specific steps for applying the EB methodology are as follows:

1. Collect observed collision frequencies for the before period (N_{OB}) and for the after period (N_{OA}) for the treated sites;
2. Collect average annual daily traffic (AADT) volumes for the treatment sites for each year of the analysis period;
3. Using applicable SPFs, calculate the predicted number of collisions (without treatment) at the treated sites for the before period (N_{PB});

   SPF for freeway segments (Persaud, Begum, & Lyon, 2009):

   $$Collisions/year\ (N_{PB}) = \alpha(length)(AADT)^{\beta} \quad (1)$$

   SPF for freeway interchange mainlines (Parajuli, Lyon, & Persaud, 2006):

   $$Collisions/year\ (N_{PB}) = \alpha(AADT)^{\beta 1}e^{\beta 2(length)} \quad (2)$$

   Where the α, β, β1, *and* β2 *are coefficients estimated during the SPF development, that vary based on collision severity and freeway geometry, and “length” is the freeway segment length or interchange area of influence in kilometers.*

4. Using the same SPFs, calculate the predicted number of collisions (without treatment) at the treated sites for the after period (N_{PA});
5. Calculate the “project level” *SPFweight* by assuming both fully independent ($SPFweight_0$) and perfectly correlated ($SPFweight_1$) relationships between the corridor freeway segments, and taking the arithmetic average of the two values. The process for calculating the *SPFweight* is detailed in Appendix B of the *Highway Safety Manual* (AASHTO, 2014);
6. Use the project level *SPFweight* to estimate the expected number of collisions for the before period (N_{EB});

   $$N_{EB} = SPFweight(N_{PB}) + (1-SPFweight)N_{OB} \quad (3)$$

7. Calculate the ratio of N_{PA}/N_{PB} for the treatment sites;
8. Calculate the expected number of collisions for the after period (N_{EA});

   $$N_{EA} = N_{EB}(N_{PA}/N_{PB}) \quad (4)$$

9. Calculate the variance of N_{EA} ($Var(N_{EA})$);

   $$Var(N_{EA}) = N_{EA}(N_{PA}/N_{PB})(1-SPFweight) \quad (5)$$

10. Calculate the CMF;

$$CMF = (N_{OA}/N_{EA})/(1+(Var(N_{EA})/(N_{EA})^2) \quad (6)$$

11. Calculate the standard error for the CMF;

$$Standard\ Error = ((CMF^2((1/N_{OA})+(Var(N_{EA})/(N_{EA})^2))/(1+Var(N_{EA})/(N_{EA})^2)^2))^{1/2} \quad (7)$$

12. Calculate the 95% confidence interval for the CMF; and

$$95\%\ confidence\ interval = CMF \pm 1.96(Standard\ Error) \quad (8)$$

13. Verify the statistical significance of the CMF (i.e., check to see if the 95% confidence interval include the value 1.0).

Steps 1 through 13 of the process described above were followed for each of the two collision severity classifications: fatal + injury (FI) and property damage only (PDO). The combined results were then used to develop a CMF for total Collisions.

By further segmenting the study corridor, based on locations with and without snow fencing, and repeating the process described in Steps 1-13 above for the sections without snow fencing, it was possible to develop a CMF to account for the combined effects of all other countermeasures (i.e., all applied countermeasures except snow fencing). The resulting CMF was then applied to the sections with snow fencing, and the process was again repeated to isolate the impacts of snow fencing, resulting in a third set of CMFs (i.e., CMFs for FI, PDO, and total Collisions related to snow fencing).

Collision Trend Review

The review of collision trends and attributes involved an over-representation analysis of collision attribute distributions (e.g., severity, initial impact type, driver actions, road and weather conditions, time of day, day of week, etc.) along the study corridor, as well as an investigation of weather trends in the before and after periods.

Collision Modification Factors

Following the methodology presented above, unique CMFs were developed for FI collisions, PDO collisions, and total collisions for the set of winter weather collision countermeasures that were implemented along the study corridor. For the analysis, the “before” and “after” periods were Jan 1, 2002 to December 31, 2006 and Jan 1, 2009 to December 31, 2011, respectively. The period from January 1, 2007 to December 31, 2008 was considered to be the “construction” period for the countermeasures. In all, four sets of CMFs were developed:

1. **Corridor-wide Winter Countermeasures** – CMFs that represent the corridor-wide safety performance impacts of all applied countermeasures (warning messages on static and dynamic signs, snow fencing, improved winter road maintenance, and measures to prohibit highway access and communicate detours during weather-related highway closures);
2. **Snow Fence + Other Countermeasures** – CMFs that represent the localized safety performance impacts of all applied countermeasures at locations where snow fencing was installed;
3. **Other Countermeasures** – CMFs that represent the localized safety performance impacts of applied countermeasures at locations where snow fencing was not installed; and
4. **Snow Fence Only** – CMFs that isolate the localized safety performance impacts of snow fencing.

All of the CMFs, along with their variances and 95th percentile confidence intervals, are presented in Table 1.

Table 1: Winter Weather Collision Countermeasure CMFs

CMF		Value	Variance	95% Confidence Interval		
Corridor-wide Winter Countermeasures	FI	0.60	0.0098	0.40	to	0.79
	PDO	0.64	0.0032	0.53	to	0.75
	Total	0.63	0.0024	0.54	to	0.73
Snow Fence + Other Countermeasures	FI	0.37	0.0260	0.06	to	0.69
	PDO	0.46	0.0109	0.26	to	0.67
	Total	0.45	0.0082	0.27	to	0.63
Other Countermeasures	FI	0.64	0.0130	0.42	to	0.86
	PDO	0.68	0.0042	0.55	to	0.80
	Total	0.67	0.0032	0.56	to	0.78
Snow Fence Only	FI	0.58	0.0621	0.09	to	1.07*
	PDO	0.68	0.0237	0.38	to	0.99
	Total	0.67	0.0183	0.41	to	0.94

*CMF is not statistically significant since 95% confidence interval includes 1.0

The analysis suggests that the combined winter weather collision countermeasures (snow fencing and all other measures) have resulted in a 37% reduction in total collisions across the study corridor. The analysis also suggest a corresponding 40% reduction in FI collisions, and a 36% reduction in PDO collisions, and all three CMFs are significant at the 95% confidence level (i.e., the confidence interval does not include the value 1.0).

The analysis shows event greater collision reductions for the freeway sections where snow fencing was installed. The localized total collisions CMF for sections that had snow fencing, also considering all other mitigation, was 0.45, representing a 55% reduction in total collisions.

The analysis also produced a CMF that suggests a 33% reduction in total collisions attributable to measures other than snow fencing (e.g., signage, winter maintenance, and highway closure improvements). Similar reductions were observed for FI collisions (36%) and PDO collisions (32%), as a result of the other non-snow-fencing countermeasures.

To isolate the safety benefit of snow fencing, the CMFs for all other countermeasures were applied to the sections where snow fencing was installed, and the EB analysis was repeated. Coincidentally, the analysis also showed a 33% reduction in total collisions as a result of snow fencing; the same percent reduction that was realized as a result of the other countermeasures combined. However, based on the limited area over which snow fencing was applied, and the resulting lower frequency of collisions observed and predicted in those areas, the FI CMF for snow fencing alone is not statistically significant at the 95% confidence level. For similar reasons, the variances of the PDO and total collisions CMFs for snow fencing only are also relatively high.

Additional Collision Trends

Following the development of the CMFs, a collision trend analysis was conducted with the goal of trying to better understand the contributing factors that have resulted in the observed changes in freeway safety performance following the implementation of the action plan treatments. The collision trend analysis was conducted using data spanning the period from January 1, 2007 to December 31, 2011, the five most recent years for which data were available.

Table 2 summarizes the frequency and severity of observed collisions for each year of the collision trend analysis period.

Table 2: Collision Frequency and Severity (2007-2011)

YEAR	COLLISION SEVERITY			TOTAL
	Fatal	Injury	PDO	
2007	4	45	297	346
2008	1	61	322	384
2009	1	61	252	314
2010	0	61	218	279
2011	1	48	171	220
Total	**7**	**276**	**1260**	**1543**

Although traffic volumes along the corridor have remained steady or increased, with the exception of a slight uptick in 2008, the collision data show a consistent decreasing trend over the analysis period. The data reflect an approximate 25% reduction in average annual collision frequency in the years following the implementation of the winter weather collision countermeasures. The general downward trend in collision frequency parallels the overall trend for the province. Based on the data presented in the Ontario Road Safety Annual Report 2012 (MTO, 2015), collision totals province-wide were down by 15%, on average, for the “after” period, relative to the “before” period. Although significant, the general reduction in collisions on the provincial road network does not account for all of the improvement observed at the treatment sites, and related sensitivity analysis showed little impact on the calculated CMFs.

Most of the collision reductions observed on the study corridor in recent years have been realized in the PDO category, which corresponds to the dominant collision type throughout the study area: single motor vehicle (SMV) collisions. More than 80% of SMV collisions are PDO collisions. Along the study corridor, SMV collisions are over-represented, when compared to overall provincial freeways distributions. Winter weather conditions have been a major contributing factor to SMV collisions over the analysis period; more than 42% of SMV collisions occurred when road surface conditions were compromised by winter weather conditions (e.g., ice, snow, slush, etc.), and more than 35% of SMV collisions occurred during active snow events. In the years following the implementation, the proportion of SMV collisions that occurred under compromised road surface conditions decreased, but the proportion that occurred during active snow events remained relatively constant.

Given the very positive results of the EB Before-After study, a comparative review of the collision data for the “before” and “after” periods was conducted in an attempt to identify any other factors, beyond the applied countermeasures, that may have contributed to the observed reduction in collisions. The review revealed that 66% of the total collisions occurred during the winter months in the “before” period, while only 58% of total collisions occurred in winter months in the “after” period. This finding supports the results of the previous analysis, given that the treatments being assessed target winter collisions. However, it is not confirmation that the applied mitigation measures were solely responsible for the observed reduction in collisions. Weather conditions during the “before” and “after” period were subsequently analyzed to determine if they could have played a role in the observed reduction in collisions.

Weather Data

To determine if weather conditions might have resulted in over-estimation of the safety benefits of snow fences, daily climate data recorded at Environment Canada’s Cobourg meteorological station for the “before” and “after” period are reviewed. The average temperatures and average total precipitation for each month in the “before” and “after” period are calculated and presented in Table 3.

Table 3: Cobourg Climate Data Summary

Month	Mean Temp (°C)		Total Rain (mm)		Total Snow (cm)	
	Before	After	Before	After	Before	After
January	-5.4	-6.9	31.5	6.6	35.8	24.4
February	-4.4	-4.5	31.8	27.3	17.2	8.6
March	-0.2	1.4	43.9	42.1	11.2	2.3
April	5.6	7.0	86.6	113.3	1.2	0
May	11.2	12.7	89.8	107.0	0	0
June	17.4	17.3	70.8	88.3	0	0
July	20.6	20.6	103.1	61.9	0	0
August	20.2	20.3	47.7	107.8	0	0
September	16.8	16.5	102.6	100.5	0	0
October	8.9	9.4	87.4	109.7	0	0
November	4.2	5.2	93.1	125.4	4.6	0
December	-1.5	-2.5	57.4	60.6	24.4	10.2

The data show that the winter months in the “after” period were, on average, colder than in the “before” period, but there was less snowfall recorded in the “after” period than in the “before” period. Therefore, the adverse road and environmental impacts of snow in the “after” period could reasonably be assumed to be less significant than in the “before” period. Based on the available weather data, it is possible that the CMFs developed may over-estimate the safety benefits of the applied countermeasures, due to the fact that there was generally less snowfall in the “after” period. Furthermore, the specific micro-climate within the study area is such that it may amplify the benefits of the applied treatments, and were they applied elsewhere the countermeasures might not achieve the same effect. As a result, caution should be exercised in adopting the CMFs described herein for application in any other context.

Conclusions

Following from the findings and analysis results presented throughout this paper, several conclusions can be drawn:

- All of the analysis shows a considerable reduction in collisions along the study corridor, particularly in the winter months, in the years following the implementation of the winter weather collision countermeasures;
- The analysis suggests that the combined winter weather collision countermeasures have produced a 37% reduction in total collisions across the study corridor (40% reduction in FI collisions and a 36% reduction in PDO collisions);
- The localized total collisions CMF for sections that had snow fencing, also considering all other mitigation, was 0.45, representing a 55% reduction in total collisions;
- The analysis suggests a 33% reduction in total collisions attributable to countermeasures other than snow fencing (e.g., signage, winter maintenance, and highway closure improvements); and
- The analysis suggests a 33% reduction in total collisions as a result of snow fencing alone; however, the related FI CMF for snow fencing alone was not statistically significant at the 95% confidence level; and
- Based on the available weather data, which indicates that there was generally less snowfall during the “after” period, and the general downward trend in collision frequencies across the Province, it is probable that not all of the observed reduction in winter weather collisions can be attributed to the applied countermeasures; therefore, caution should be exercised in adopting the CMFs described herein for application in any other context.

References

1. AASHTO. (2014). *Highway Safety Manual.* Washington, DC: American Associsation of State Highway and Transporation Officials.
2. AECOM. (2007). *Highway 401 Winter Operational Review Northumberland County Finding and Mitigation Report.* Toronnto: AECOM.
3. FHWA. (2010). *A Guide to Developing Quality Crash Modification Factors.* Washington, DC: U.S. Department of Transportation, Federal Highway Administration.
4. MTO. (2015). *Ontario Road Safety Annual Report 2012.* Toronto: Ministry of Transporation, Road Safety Research Office, Safety Policy & Education Branch.
5. Parajuli, B., Lyon, C., & Persaud, B. (2006). *Operational performance Assessment of Freeway Interchanges, Ramps and Ramp Terminals.* St. Catharines: MTO - Highway Infrastructure Innovaiton Funding Program.
6. Persaud, B., Begum, M., & Lyon, C. (2009). *Operational Performance Assessment of Highway and Freeway Sections.* St. Catharines: MTO - Highway Infrastructure Innovation Funding Program - 2007.