BEFORE-AND-AFTER SAFETY EVALUATION OF EDMONTON'S SNOW AND ICE PROGRAM: A FOLLOW-UP STUDY

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EXECUTIVE SUMMARY

This study is a continuation of a previous project which was completed by the University of Alberta. The initial project investigated the safety effects of following a winter maintenance strategy that aims to achieve bare-pavement conditions on major roads in the City of Edmonton (CoE) using a diverse toolbox. The City uses various tools based on the existing road conditions to maintain or achieve bare pavement and safe driving environments. These tools included using mechanical means, anti-icing, and de-icing to improve traction to improve safety and mobility. Each tool in the City's toolkit is used for a different purpose, and the City's goal is to use the right tool for the right conditions to reach bare pavement during the winter season. Recently, the use of anti-icing has been discontinued, and the impact of removing this tool on safety needed to be evaluated.

The goal of this study is to investigate the safety performance of the CoE snow and ice (SNIC) program after the discontinuation of anti-icing using a state-of-the-art statistical technique (i.e., before-and-after Empirical Bayes approach). The safety effectiveness and statistical significance of the SNIC program on 1,293 road-km of urban roads, for different collision types and severities, were determined.

Despite removing anti-icing from the City's toolbox, the results indicate that the SNIC program continued to significantly reduce all collision types and severities on midblock and intersection locations. All reductions were statistically significant, and a summary of the evaluation results are shown in Table E1. These findings indicate that the City's overall SNIC program has continued to achieve its intended goals of improving safety and achieving Vision Zero.

While these results are promising, it is pertinent to note that one of the limitations of the previous and current study is that the results speak to the overall program effectiveness. It was not possible to isolate the impact of achieving bare pavement as a result of each tool that the City has within its toolkit. To be more specific, the previous and current study utilized a location and winter season-based approach to the evaluation. This has led to several questions on the true safety of using each of the strategies and how they each contribute to the overall improvement in safety. To overcome this challenge, a new evaluation framework that focused primarily on winter events is being developed.

This type of microscopic approach to the evaluation of the safety impacts of each deployment is going to offer valuable insights, not only on the impacts of each strategy within the City's toolbox but also on the efficacy of the City's winter maintenance program and its ability to respond effectively to changing weather events while achieving the City's goals on increasing mobility and safety.

TABLE E1 Overall Before-and-After Evaluation Results

Collision Location/Type		**Severity**	**SE1 (%)**	**SE2 (%)**
Midblock Collisions	*All*	*TOT*	29.1*	38.5*
		PDO	26.9*	36.4*
		INJ	45.0*	56.6*
	ILC	*TOT*	22.6*	36.3*
	RE	*TOT*	31.9*	39.1*
	SPEED	*TOT*	32.3*	41.5*
Intersection Collisions	*All*	*TOT*	13.6*	12.4*
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		INJ	21.4*	32.4*
	LTXP	*TOT*	22.0*	30.0*
	FOTC	*TOT*	8.9*	17.0*

*Statistically significant at the 99% confidence level; *SE1* = safety effectiveness comparing 2019/20 season to the 2017/18 and 2018/2019 seasons, *SE2* = safety effectiveness comparing 2019/20 season to the 2012/13 to 2016/2017 seasons, positive implies reduction; *TOT* = Total; *ILC* = Lane change improperly; *RE* = Rear-end; *LTXP* = Left turn cross path; *FOTC* = Failed to observe traffic control; *PDO* = Property-damage only; *INJ* = Non-fatal Injury.

TABLE OF CONTENTS

1 INTRODUCTION

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The goal of this study is to investigate the safety performance of the CoE snow and ice (SNIC) program after the discontinuation of anti-icing using a state-of-the-art statistical technique (i.e., before-and-after Empirical Bayes approach). The safety effectiveness and statistical significance of the SNIC program on urban roads, for different collision types and severities, were determined.

2 PROGRAM & DATA DESCRIPTION

A total of 100 maintenance routes on arterial and collector roads, with different priority levels based on corridor importance and traffic volume, were included in the project. The same routes were used for both the 2018/2019 and 2019/2020 studies. The routes were split as follows: 55 routes (total distance of 1,293 road-km [treatment routes]_had anti-icing applied during the 2017/2018 and 2018/2019 seasons, and 45 routes (total distance of 1,068 road-km [reference routes]) received the regular reactive approach. Figure 1 shows Edmonton's road network, anti-icing routes, and reference (regular WRM) routes for the anti-icing pilot project, conducted for the 2017/2018 and 2018/2019 winter seasons. Figure 2 shows the study maintenance routes road and their classification (i.e., arterial and collector roads).

The CoE provided both the AADT and traffic collision data. Recorded traffic collision data between October and February over seven fall/winter seasons between 2012 and 2020 were used in the analysis. The CoE maintains a Motor Vehicle Collision Information System (MVCIS). It is a database with all reported collisions in Edmonton that involve at least one motor vehicle and results in an injury, fatality, or property damage of at least CAD 2000. The collisions database includes several details about each collision, such as severity, date, location (intersection or midblock), coordinates, cause, etc.

Several collision types, identified based on the cause and severity, were used in the analysis. Table 1 summarizes all collision severities and types included in the study. It is worth mentioning that a population ratio was used to estimate missing AADT values for specific years and locations.

TABLE 1 Collision Classifications Description

Collision Classification	**Description**
Total (*TOT*)	Includes all collisions
Injury (*INJ*)	Includes all nonfatal injury collisions
Property damage only (*PDO*)	Includes collisions that resulted in property damage only
Rear-end (*RE*)	Includes collisions caused by vehicles following too closely to each other
Improperly lane changing (*ILC*)	Includes collisions caused by improper lane changing
Speed-related (*SPEED*)	Includes collisions where speed was identified as a contributing factor
Left turn cross path (*LTXP*)	Includes collisions caused between left-turning vehicles and through movement at intersections
Failed to observe traffic control (*FOTC*)	Includes collisions caused by failure to observe or yield to traffic control devices

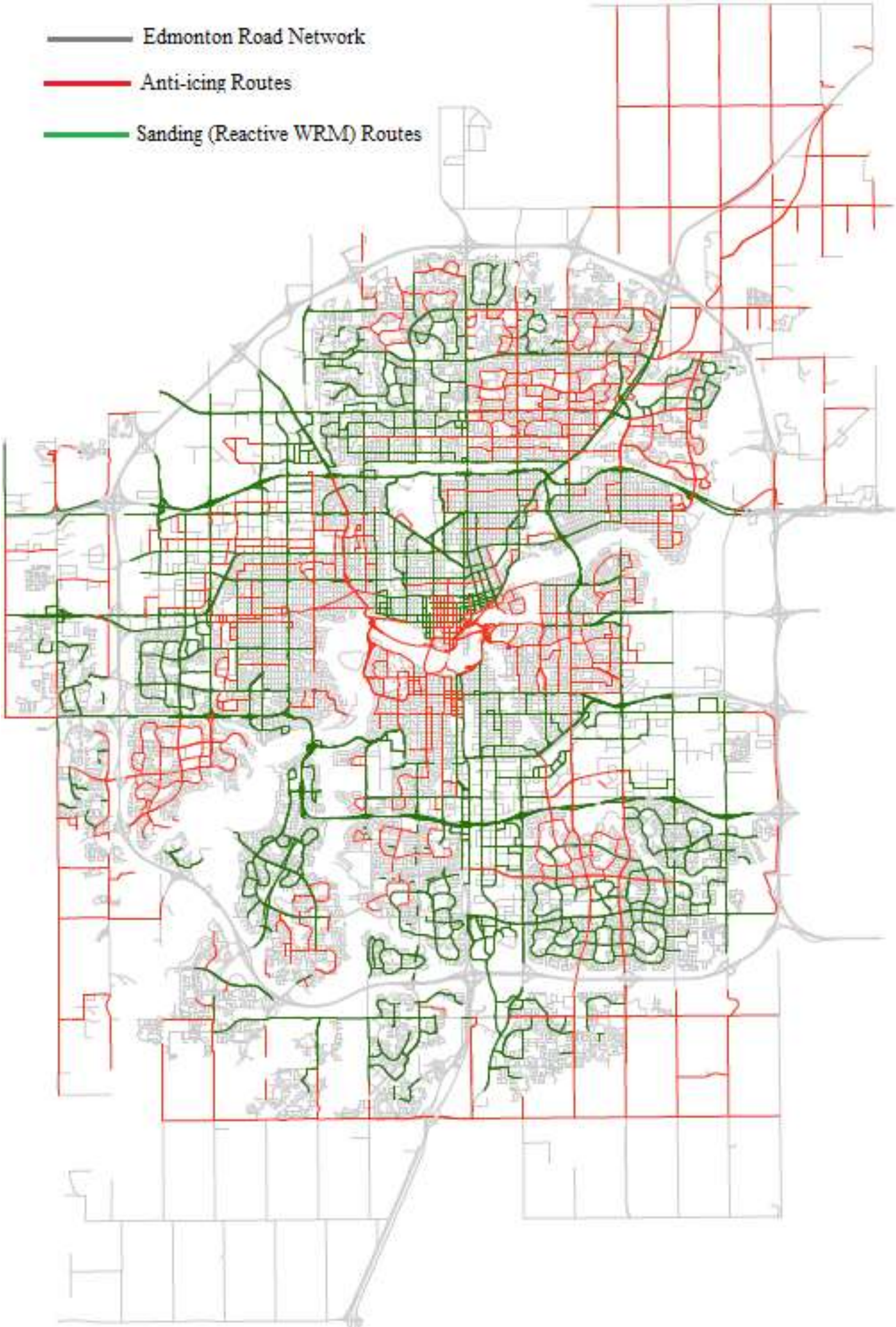

Figure 1 Pilot project WRM anti-icing and sanding (regular reactive) routes

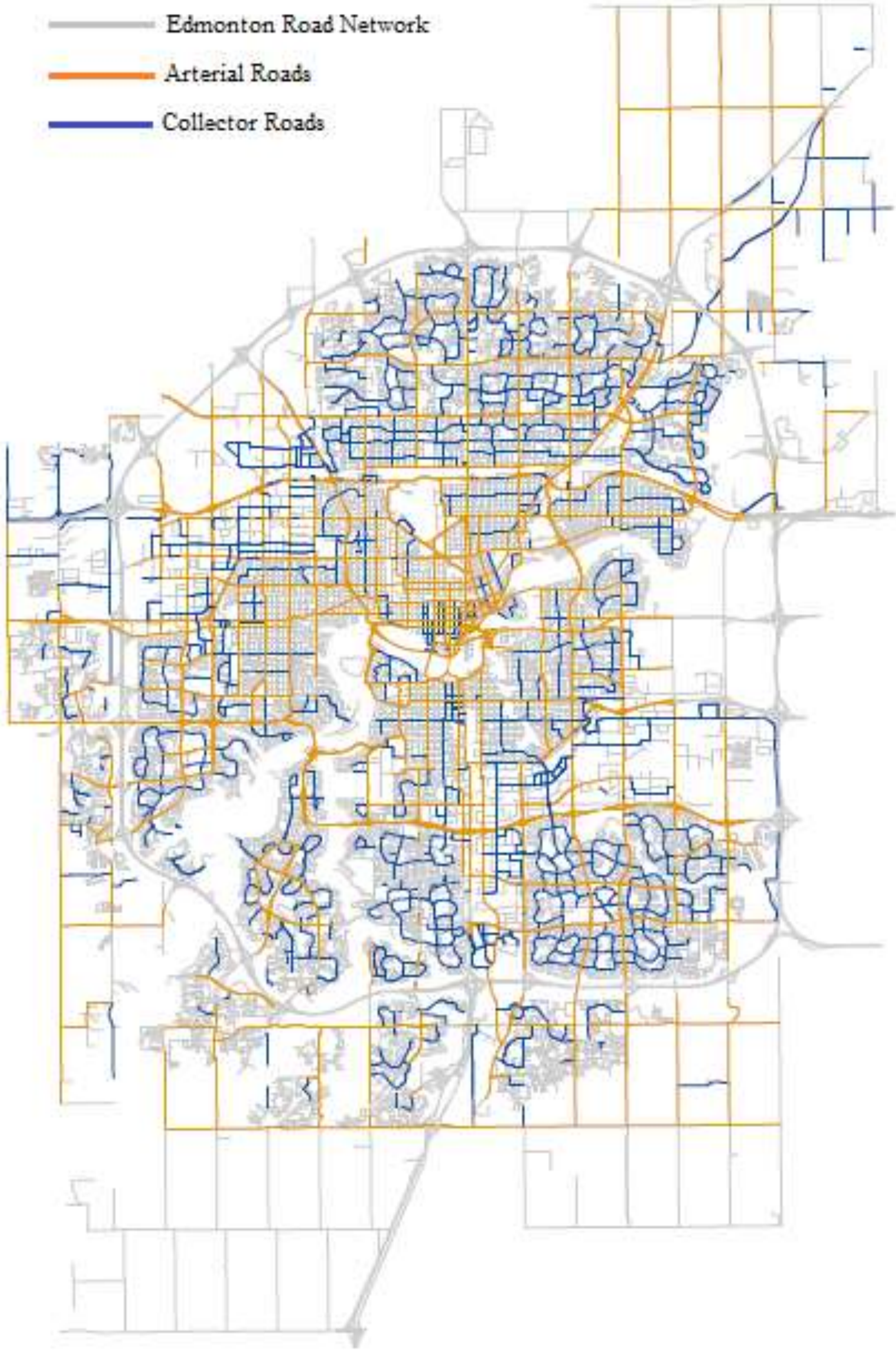

Figure 2 Pilot project arterial and collector routes

3 METHODOLOGY

3.1 Safety Performance Functions

Developing Safety performance functions (SPFs) is an essential step in the before-and-after evaluation. SPFs are used to capture the relationship between collision frequency at specific locations, such as intersections or midblock road segments, and a set of explanatory variables (e.g., AADT, road segment length, etc.). A reference group is used to develop the SPFs for predicting collisions on the treated group, assuming no treatment has happened at these locations. Collision distribution is expressed using a negative binomial (NB) error structure, which can capture the overdispersion in collision data (*1*). The models' parameters are estimated using SAS GENMOD, which uses the maximum likelihood estimation (*2*). The models goodness-of-fit were assessed using Pearson x^2 and the scaled deviance (SD). SPFs were developed for several combinations of collision severities and types on midblock and intersection locations. **Equations 1** and **2** show the final model forms and significant variables used for midblock and intersection locations, respectively. A backward stepwise elimination process was performed to select model variables to retain.

$$\text{Collisions per year} = \mathrm{AADT}_{average} * \beta_1 * \text{Length} * e^{\beta_0} \tag{1}$$

$$\text{Collisions per year} = (Length * \mathrm{AADT}_{major}) * \beta_1 * \mathrm{AADT}_{minor} * \beta_2 * e^{(\beta_0+\beta_3 * ID)} \tag{2}$$

where $\mathrm{AADT}_{average}$ is the average *AADT* on a route; *Length* is total route length; AADT_{major} is the average *AADT* on major intersection approaches on a route; $AADT_{minor}$ is the average *AADT* on minor intersection approaches on a route; β_0, β_1, β_2 and β_3 = model parameters; and *ID* is the intersection density on a route that is equal to the number of intersections/route length.

The reference group and treatment group have similar routes in terms of maintenance priorities, road classes, and geometric features. This is essential to ensure the accurate estimation of the effects of the performed treatments.

3.2 Yearly Calibration Factors (YCF)

YCF is the ratio between the sum of the observed number of collisions and the sum of the predicted number of collisions calculated by SPFs in the same season using the reference group data (**Equation 3**). Predicted SPFs number of collisions in the treatment group are adjusted by multiplying them with the corresponding YCFs. YCFs are used to account for confounding factors that are not captured in the variables of the SPFs (e.g., weather conditions, roadway improvements, etc.) (*3*). It is assumed that the effect of these confounding factors is similar on both the treatment and reference groups.

$$C_{ij} = \frac{\sum_{ref} N_i}{\sum_{ref} \mu_i} \tag{3}$$

where *C* is the yearly calibration factor; *N* is the observed number of collisions; μ is the predicted number of collisions; *i* is the collision type and severity; and *j* is the season.

3.3 Before-and-After Evaluation with EB Method

The before-and-after Empirical Bayes (EB) analysis technique is used to account for regression-to-the-mean (RTM) bias in collision frequencies (*4*). RTM reflects the random fluctuation in collision frequency without any effect from external factors. That is to say, RTM is the tendency of high collision frequencies to drop over time, and vice-versa, without any external effect or intervention. By incorporating information from a reference group into the collisions prediction, the RTM effect is accounted for, as proposed by Hauer et al. (*4*). Safety effectiveness using the EB approach is defined as the ratio between the observed number of collisions and the expected number of collisions.

The first step in the EB method is to calculate the expected number of collisions in the before period for each route in the treatment group. The expected number of collisions is a weighted average of the observed number of collisions and the predicted number of collisions using the SPFs adjusted by the YCFs. **Equations 4** and **5** show the calculation of the expected number of collisions on each route.

$$N_{Expected,B} = (w)N_{Predicted,B} + (1-w) * N_{Observed,B} \tag{4}$$

$$w = \frac{1}{1+\frac{N_{Predicted,B}}{k}} \tag{5}$$

where w is a weighted adjustment factor (between 0 and 1); $N_{Expected,B}$ is the expected number of collisions in the before period; $N_{predicted,B}$ is the predicted number of collisions in the before period; $N_{observed,B}$ is the observed number of collisions in the before period; and *k* is the overdispersion parameter estimated in SPF.

The second step is to calculate the expected number of collisions in the after period. In order to account for traffic volume and the differences in the before and after periods length, a multiplier that equals the ratio between the predicted collisions in the after period and the predicted collisions in the before period, is developed. Then, this multiplier is applied to the expected number of collisions in the before period to calculate the expected number of collisions in the after period. The third step is the calculation of the overall odds ratio of collision reduction (θ) and its standard error (SE) (**Equations 6** to **8**).

$$\theta = \frac{\frac{\sum_{Allsites} N_{Observed,A}}{\sum_{Allsites} N_{Expected,A}}}{\left(1+Var\frac{(\sum_{Allsites} N_{Expected,A})}{(\sum_{Allsites} N_{Expected,A})^2}\right)} \tag{6}$$

$$Var\left(\sum_{Allsites} N_{Expected,A}\right) = \left(\sum_{Allsites}\left(\left(\frac{\sum_{Allsites} N_{Predicted,A}}{\sum_{Allsites} N_{Predicted,B}}\right)^2 * N_{Expected,B} * (1-w)\right)\right) \tag{7}$$

$$\mathrm{SE}(\theta) = \sqrt{\frac{\left(\frac{\sum_{Allsites} N_{Observed,A}}{\sum_{Allsites} N_{Expected,A}}\right)^2\left(\frac{1}{\sum_{Allsites} N_{Observed,A}}+Var\frac{(\sum_{Allsites} N_{Expected,A})}{(\sum_{Allsites} N_{Expected,A})^2}\right)}{\left(1+Var\frac{(\sum_{Allsites} N_{Expected,A})}{(\sum_{Allsites} N_{Expected,A})^2}\right)^2}} \tag{8}$$

where $N_{Expected,A}$ is the expected number of collisions in the after period; $N_{Predicted,A}$ is the predicted number of collisions in the after period; and $N_{Observed,A}$ is the observed number of collisions in the after period.

The safety effectiveness (SE) or percent reduction is then calculated using the odds ratio as in **Equation 9,** and its SE is calculated using **Equation 10**.

$$\text{Collision reduction (aka safety effectiveness)} = 100 \times (1 - \theta) \tag{9}$$

$$\text{SE} = 100 * \text{SE}\ (\theta) \tag{10}$$

The last step is to assess the statistical significance of the estimated collision reduction percentage. The ratio between the collision reduction estimate and its standard error is compared with the significance critical values. If the value of the ratio is less than 1.645, then the treatment effect is not significant at the 90% confidence level. If the ratio is more than or equal to 1.645, conclude that the treatment effect is statistically significant at the 90% confidence level. Finally, if the ratio is more than or equal to 1.96, the treatment effect is significant at the 95% confidence level. The before-and-after EB evaluation was repeated for several collision types, severities, and priority levels. It is worth noting that all routes included in the project were in either priority levels 1, 2, and 3.

4 RESULTS & DISCUSSION

Despite removing anti-icing from the City's toolbox, the results indicate that the SNIC program continued to significantly reduce all collision types and severities on midblock and intersection locations. All reductions were statistically significant, and a summary of the evaluation results are shown in Table 2. These findings indicate that the City's overall SNIC program has continued to achieve its intended goals of improving safety and achieving Vision Zero.

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5 CONCLUSIONS AND FUTURE WORK

While these results are promising, it is pertinent to note that one of the limitations of the previous and current study is that the results speak to the overall program effectiveness. It was not possible to isolate the impact of achieving bare pavement as a result of each tool that the City has within its toolkit. To be more specific, the previous and current study utilized a location and winter season-based approach to the evaluation. This has led to several questions on the true safety of using each of the strategies and how they each contribute to the overall improvement in safety. To overcome this challenge, a new evaluation framework that focuses primarily on winter events is being developed.

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