Road Safety Performance Associated with Improved Traffic Signal Design and Increased Signal Conspicuity

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SYNOPSIS

Inconspicuous traffic signals is often cited as a contributing factor by drivers who are involved in collisions at intersections and as such, increasing the conspicuity of traffic signals should lead to improved safety performance. This paper describes a project that was undertaken to evaluate the safety impacts that are associated with improved signal conspicuity, and specifically improvements to the traffic signal backboards (backplates), which included the addition of yellow diamond grade reflective tape along the outer edge in an attempt to frame the signal heads and make them more visible to motorists. The evaluation included a time-series analysis to investigate the effectiveness of the traffic signal improvements on road safety performance. The use of comparison groups, prediction models and an Empirical Bayes analysis technique was used to account for the problematic confounding factors associated with road safety evaluation and ensure that the results are reliable. Anecdotal information concerning the effectiveness of the improved traffic signals were also collected and evaluated. The British Columbia Ministry of Transportation (MOT) partnered with the Insurance Corporation of British Columbia (ICBC) on a multi-year program to upgrade all primary signal displays to the improved design. This paper quantifies and describes how the improved signal design and the use of diamond grade yellow tape at signalized intersections can provide cost-effective road safety benefits.

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INTRODUCTION

In British Columbia Canada, 46 percent of all accidents occur at intersections that are controlled by traffic signals (ICBC, 1998). In an effort to reduce the number of accidents at intersections, the British Columbia Ministry of Transportation (MoT) and the Insurance Corporation of British Columbia (ICBC) have collaborated on numerous road safety initiatives. One of these initiatives has been to improve the visibility of traffic signal displays through improved traffic signal design and increased signal conspicuity. The first phase of this project was to test improvements to traffic signal design, including the use of larger signal lens. Sayed conducted this evaluation (Sayed, et. al, 1998(1)) and found that the improved signal design was effective in reducing the frequency of collisions at treated intersections. This second paper describes a subsequent phase of the project, which dealt specifically with the visibility improvements to the traffic signal backboards.

RESEARCH HYPOTHESIS

The conspicuity of traffic signal backboards is improved through the application of highly retro-reflective tape around the outside border. The hypothesis is to test whether the increase in conspicuity will have measurable improvement in road safety performance.

BACKGROUND

The Manual of Uniform Traffic Control Devices (MUTCD) for Canada states that traffic signal backboards (backplates) are used to improve the visibility (conspicuity) of traffic control signals both by making the signal head stand out from its surroundings, and by helping to prevent confusion due to distracting features in the background (TAC, 1998). It further recommends that backboards should be used on all primary signal heads. The U.S. Manual of Uniform Traffic Control Devices is more general in that it states that a signal backboard for target value enhancement should be used on signal faces viewed against a bright sky or bright or confusing backgrounds (FHWA, 2000). It further states that the use of backboards enhances the contrast between the traffic signals and their surroundings for both day and night conditions, which is also very helpful to elderly drivers. However, neither document outlines any requirements for the sheeting of the backboard. Furthermore, both manuals state that the colour conspicuity of signs must be maintained under all lighting conditions or otherwise illuminated. Hence many jurisdictions provide sheeting with retro-reflective properties on their signs to meet this requirement and thereby avoiding the need for illumination. Therefore, it is reasonable to assume that in order to improve the conspicuity of traffic signal backboards, that the boards should be fitted with retro-reflective sheeting. Also, since signal backboards are located overhead, they are disadvantaged with respect to vehicle headlights, which are aimed to illuminate the roadway directly in front of the driver and not directed to the overhead signs. As such, the use of highly reflective sheeting, such as prismatic sheeting (e.g., 3M-diamond grade VIP) is necessary.

Early Installations

In September 1998, standard size traffic signal backboards were fitted with an additional 75mm border of 3M yellow diamond grade retro-reflective tape. This reflective tape was placed on the outer edge of the yellow backboards and was installed on signals heads at a number of intersections on located Vancouver Island, in the southwest part of British Columbia Canada.

Figure 1 shows a backboard with tape during the daytime, providing evidence that the tape highlights the border of the backboard and the effect of the reflective tape during nighttime is very pronounced as shown in Figure 2. The tape provides a very distinctive frame around the traffic signal display, allowing drivers to more readily locate the signal head among background lighting. It is noted that tThere may be a secondary benefit when there is a power failure since the driver will see the backboard without a signal display.

Figure 1: Signal During the Day

Figure 2: Signal During the Night

The relative effect of the retro-reflective tape on the backboard is considered to be very significant. Figure 3 on the following page, shows an intersection that has two primary signal heads for the through traffic movement. Both signal heads have backboards however only the left-side signal head has retro-reflective tape around the outside of its backboard. The visibility of the right-side signal head (located to the right of the street sign) is difficult to identify from the background lighting. The figure clearly illustrates the difference in visibility between the two signal displays.

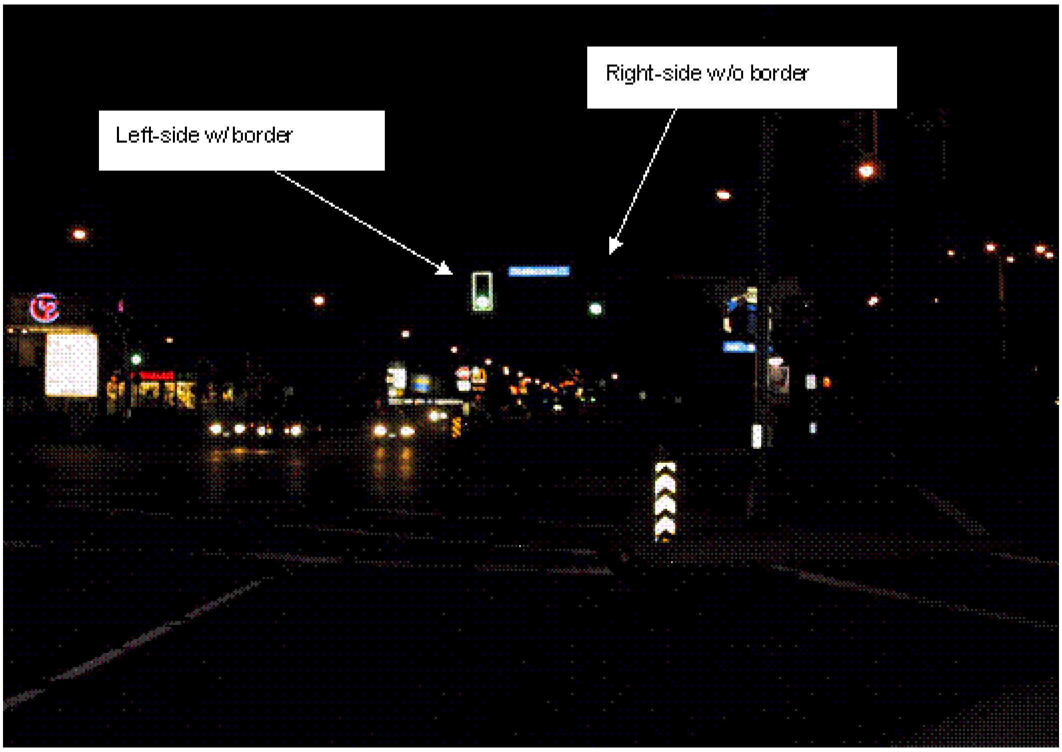

Figure 3: Traffic Signal Framed with Highly Reflective

Installation Costs

The cost of applying this improvement is minimal, especially when combined with regular signal construction or maintenance activities. The installation requires four strips of tape per backboard and only a few minutes of staff time to install. The cost to retrofit a backboard with reflective tape is approximately $35 (CDN). Therefore, for very large intersections that may have backboards for the two through movements and one protected left turn per approach, there are a total of 12 backboards and thus, the cost of retrofitting the intersection is less than $500. As backboard use in various agencies is dependent on local policy it is not possible to estimate the cross Canada cost however the B.C. costs should be representative since most of the cost is the tape itself.

USING PREDICTION MODELS FOR ROAD SAFETY ANALYSIS

The methodology used to evaluate the safety performance of improved traffic signal conspicuity is based on the application of an auto-insurance claim prediction model. A claim prediction model is mathematical model that relates the claim frequency experienced by a road entity (intersection, road segment, etc.) to the various traffic and geometric characteristics of that entity. Prediction models that are developed on collision records are more common in the road safety engineering literature, however, in British Columbia because of the public nature of the auto insurance company, auto insurance claims data can be used as a source of road safety data. Collision or claim models have several road safety engineering applications such as the evaluation of the safety for various road facilities, identifying problematic locations, and evaluating the effectiveness of road safety improvement measures. In general, there are two main approaches that can be used to model road safety. The first option is to use conventional linear regression, whereas the second option is to use a generalized linear modeling approach (GLIM). Conventional linear regression assumes a Normal distribution error structure whereas a generalized linear modeling approach (GLIM) assumes a non-Normal distribution error structure (usually Poisson or negative binomial). In the past, many researchers developed collision prediction models using conventional linear regression. However, several researchers (Jovanis and Chang, 1986, Hauer et-al., 1988) have shown that conventional linear regression models lack the distributional property to adequately describe collisions. This inadequacy is due to the random, discrete, non-negative, and typically sporadic nature that characterize the occurrence of a vehicle collision (these characteristics also describe an auto insurance claim). GLIM has the advantage of overcoming these shortcomings of conventional linear regression and recognizing these advantages, the GLIM approach was utilized in this study. The theoretical background concerning the development of these prediction models is beyond the scope of this paper and the reader is directed to road safety engineering literature for more information.

The prediction model structure relates the frequency of auto insurance claims to the product of traffic flows entering the intersection. In some cases, the sum of the traffic flows entering the intersection is used instead of the product of the traffic flows. However, it is has been shown (Hauer, 1988) that a model that utilizes the product of the traffic flows, provides a better representation of the relationships between collisions (or claims) and the traffic flows at intersections. In this model structure, claim frequency is a function of the product of traffic flows raised to a specific power (usually less than one). The model form is shown below in equation (1).

$$E(\Lambda) = a_{\circ} V_1^{a_1} V_2^{a_2} \tag{1}$$

where: $E(\Lambda)$ = expected auto insurance claim frequency,
V_1, V_2 = major / minor road traffic volume (AADT),
$a_{\circ}, a_1, a_2$ = model parameters.

The claim prediction model that used for the analysis of the signal head effectiveness is based on the work of Sayed and de Leur (de Leur and Sayed, 2001). The developed claim prediction model is assumed to follow a negative binomial distribution that is included within the GLIM software package through a macro designed by NAG (NAG, 1996). The model predicts the total number of claims over a three-year time period at a signalized intersection based on major and minor road traffic volumes. The prediction model and the model parameters are shown in Table 1.

Table 1: Developed Claim Prediction Models

Model Formulation	**t-ratio**		**κ**	**S.D. (DoF)**	**Pearson χ^2 (χ^2 test)**
MODEL 1: Total Claims Model: $Claims\ /\ 3yrs = 2.7429 \times \left(\frac{AADT_{maj\ \mathrm{rd}}}{1000}\right)^{0.8256} \times \left(\frac{AADT_{\mathrm{mnr\ rd}}}{1000}\right)^{0.4028}$	A_o A_1 A_2	2.3 6.8 4.3	5.36	113 (105)	101 (129)

Several measures are used to assess the significance of GLIM models. These measures include the t-ratio test for the model parameters, the κ value (the model's dispersion parameter), the scaled deviance (SD), and the *Pearson* χ^2 statistic. The SD is defined as the likelihood test ratios, measuring the difference between the log likelihood of the model and the saturated model (Kulmala, 1995). The formulation of SD (for a negative binomial distribution) is shown in equation (2). The *Pearson* χ^2 statistic is another measure to assess the significance of a GLIM model and is shown in equation (3). For a well-fitted model, both the scaled deviance and the *Pearson* χ^2 should be significant compared with the value obtained from the χ^2 table for the given degrees of freedom.

$$SD = 2\sum_{i=1}^{n}\left[y_i \ln\left(\frac{y_i}{E(\Lambda_i)}\right) - (y_i + \kappa)\ln\left(\frac{y_i + \kappa}{E(\Lambda_i) + \kappa}\right)\right] \tag{2}$$

where: y_i = observed number of claims at an intersection
κ = shape parameter of the distribution and the mean

$$Pearson\ \chi^2 = \sum_{i=1}^{n} \frac{[y_i - E(\Lambda_i)]^2}{Var(y_i)} \tag{3}$$

where: y_i = observed number of claims at an intersection,
$E(\Lambda_i)$ = predicted number of claims obtained from model,
$Var(y_i)$ = the variance of the observed claims.

These measures indicate that the claim prediction model that is to be used for this analysis has a relatively good fit and the value that is calculated for the t-ratios for all independent variables are significant.

Data for Road Safety Evaluation

Traffic and safety data was collected at 25 locations where improvements to the traffic signals were made. Considerable effort was undertaken to collect reliable traffic volume data for the before and after time periods. Initially, collision data was investigated for use in the road safety analysis. However, the quality and quantity of the police-reported collision data in British Columbia has deteriorated in recent years, making the collision data somewhat unreliable. In addition, the time lag between the time of the collision event and when the data is available from the collision database is lengthy and as such, the data was not useful for this safety analysis. Fortunately and as mentioned, the public nature of the Insurance Corporation of BC (ICBC) provides another complete source of safety data. ICBC warehouses the provincial auto insurance claims data that has been proven to be very useful in road safety analysis (de Leur and Sayed 2001). This auto insurance claims data is very current, comprehensive and considered quite reliable for intersection locations. As such, the before and after claims data was obtained and used in the time series safety analysis. Finally, the date of the signal improvements was obtained and verified such that accurate before and after time periods could be established. A summary of the treatment sites is provided in Table 2. It is noted that similar data (traffic volume data and claims data) was collected for a group of comparison sites. This group of comparison sites is used to improve the reliability of the time-series safety analysis as described in the subsequent section.

Table 2: Description of Improvement Sites

ID No.	Site Type	Major Road	Minor Road	City Location	Implementation Date
1	Treatment	Rte 17	Halibuton	Saanich	November 2000
2	Treatment	Rte 17	Island View	Saanich	November 2000
3	Treatment	Rte 17	Beacon	Saanich	November 2000
4	Treatment	Rte 1	Morden	Nanaimo	April 2001
5	Treatment	Rte 1	Cedar Rd N.	Nanaimo	April 2001
6	Treatment	Rte 19	College Rd	Nanaimo	April 2001
7	Treatment	Rte 19	Jingle Pt	Nanaimo	April 2001
8	Treatment	Rte 19	Northfield	Nanaimo	April 2001
9	Treatment	Rte 19	Molstar/Jingle	Nanaimo	April 2001
10	Treatment	Rte 19	Aulds	Nanaimo	April 2001
11	Treatment	Rte 19	Ware	Nanaimo	April 2001
12	Treatment	Rte 19	Cook Creek	Qualicum	April 2001
13	Treatment	Rte 19	Cliff	Courtney	June 2001
14	Treatment	Rte 19	Comox	Courtney	June 2001
15	Treatment	Rte 19	Ryan	Courtney	June 2001
16	Treatment	Rte 19	26th St	Courtney	June 2001
17	Treatment	Rte 97	Rte 33	Kelowna	October 2000
18	Treatment	Rte 97	Prairie Valley	Summerland	October 2000
19	Treatment	Rte 97	Rosedale	Summerland	October 2000
20	Treatment	Rte 97	Banks	Kelowna	October 2000
21	Treatment	Rte 97A	Smith	Armstrong	October 2000
22	Treatment	Rte 97A	Cliffe	Enderby	October 2000
23	Treatment	Rte 16	1st Ave	Prince George	June 2001
24	Treatment	Rte 17	17th Ave	Prince George	June 2001
25	Treatment	Rte 18	20th Ave	Prince George	June 2001

METHODOLOGY TO ESTIMATE THE SAFETY IMPROVEMENT EFFECTS

The method used in this study is based on the application of the claims prediction model in an Empirical Bayes (EB) approach, as described by Hauer (Hauer, 1997) and Sayed (Sayed, et al., 1998(2) and Sayed 1999). This approach corrects for the regression to the mean effects, an important consideration in road safety analysis. The methodology also uses claim and traffic volume data for a comparison group to represent the time trend from the before to after time periods. Therefore, it is important that the comparison group represents a random sample and not selected because of high claim experience. The reduction in the number of claims at the treatment sites (sites where the visibility of the signal backboard has been improved) can be calculated using the Odds Ratio (O.R.) according to equation (4). With the odd-ratio calculated, the effect of the treatment is determined by subtracting 1 from the odds ratio, as shown below.

$$O.R. = \frac{A/C}{B/D}$$

$$TreatmentEffect = O.R. - 1 \quad (4)$$

where: *A* = number of claims in the comparison group during the pre-improvement period.
B = the EB estimate of claims in the treatment site(s) had no treatment taken place.
C = number of claims in the comparison group during the post-improvement period.
D = number of claims in the treatment group during the post-improvement period.

It should be noted that all quantities in the Odds Ratio are observed quantities (with assumed Poisson distribution), with the exception of quantity *B,* which is calculated. Therefore, the major work involved in evaluating the benefits of a certain treatment consists of determining the quantity *B. T*his quantity is calculated by utilizing claim prediction models and the Empirical Bayes refinement procedure. Note that the theoretical background associated with the Empirical Bayes technique is beyond the scope of this paper and again, the reader is directed to road safety engineering research for greater detail of the Empirical Bayes approach.The Empirical Bayes safety estimate and its variance are calculated using equations 5 and 6 as follows:

$$EB_i = \left(\frac{E(\Lambda_i)}{\kappa + E(\Lambda_i)}\right) \times (\kappa + count_i) \quad (5)$$

$$Var(EB_i) = \left(\frac{E(\Lambda_i)}{\kappa + E(\Lambda_i)}\right)^2 \times (\kappa + count_i) \quad (6)$$

where:

κ = the negative binomial parameter of the claim prediction model.

$count_i$ = the observed claim frequency in the before period.

The value B in the Odds Ratio (equation 3) is calculated by using equation (6) (Sayed and de Leur, 2001*).*

$$B = \sum_{i=1}^{n} (EB_i)_a = \sum_{i=1}^{n} (EB_i)_b \times \frac{E(\Lambda_i)_a}{E(\Lambda_i)_b} \quad (6)$$

where:

$(EB_i)_a$ = the Empirical Bayes safety estimate of treated site i in the “after” period had no treatment taken place.

$(EB_i)_b$ = the Empirical Bayes safety estimate of treated site i that occurred in the “before” period.

$E(\Lambda_i)_a$ = the claim frequency given by the claim prediction model for treated site i using its traffic flows in the “after” period.

$E(\Lambda_i)_b$ = the claim frequency given by the claim prediction model for treated site i using its traffic flows in the “before” period.

RESULTS AND DISCUSSION

By utilizing the methodology described in the preceding section, the treatment effects can be calculated for each improvement site. Table 3 shows the results that were obtained for the reductions in the total number of claims for the 25 sites that were investigated.

Table 3: Reductions Factors for each Improvement Site

ID No.	Site Type	Major Road	Minor Road	City Location	Claims Reduction [1.]
1	Treatment	Rte 17	Halibuton	Saanich	-25.5%
2	Treatment	Rte 17	Island View	Saanich	-5.5%
3	Treatment	Rte 17	Beacon	Saanich	-8.2%
4	Treatment	Rte 1	Morden	Nanaimo	-21.0%
5	Treatment	Rte 1	Cedar Rd N.	Nanaimo	-23.4%
6	Treatment	Rte 19	College Rd	Nanaimo	-24.9%
7	Treatment	Rte 19	Jingle Pt	Nanaimo	*6.1%*
8	Treatment	Rte 19	Northfield	Nanaimo	-11.7%
9	Treatment	Rte 19	Molstar/Jingle	Nanaimo	*4.3%*
10	Treatment	Rte 19	Aulds	Nanaimo	*16.8%*
11	Treatment	Rte 19	Ware	Nanaimo	-51.0%
12	Treatment	Rte 19	Cook Creek	Qualicum	-38.3%
13	Treatment	Rte 19	Cliff	Courtney	-2.8%
14	Treatment	Rte 19	Comox	Courtney	-60.7%
15	Treatment	Rte 19	Ryan	Courtney	-15.4%
16	Treatment	Rte 19	26th St	Courtney	-60.7%
17	Treatment	Rte 97	Rte 33	Kelowna	-5.5%
18	Treatment	Rte 97	Prairie Valley	Summerland	*20.6%*
19	Treatment	Rte 97	Rosedale	Summerland	*2.9%*
20	Treatment	Rte 97	Banks	Kelowna	-16.9%
21	Treatment	Rte 97A	Smith	Armstrong	-21.0%
22	Treatment	Rte 97A	Cliffe	Enderby	-47.2%
23	Treatment	Rte 16	1st Ave	Prince George	*3.0%*
24	Treatment	Rte 17	17th Ave	Prince George	-54.0%
25	Treatment	Rte 18	20th Ave	Prince George	-22.3%
				Total Overall	**-14.8%**

[1.] A negative value indicates a reduction

Of the 25 sites that were and investigated in this study, a total of 19 sites have shown a reduction in the number of claims after the implementation of the improvements to the conspicuity of the signal head backboard. The magnitude of the reduction in claim frequency ranged from a low of 2.8 percent to a high of 60.7 percent. Overall, it is estimated that the improvements to the signal head backboard will result in a 14.8 percent reduction in the total number of claims at an improved intersection. A total of 6 of the 25 improvement sites experienced an increase in the number of claims after the improvements to the signal head, with the magnitude of the increase ranging from a low of 2.9 percent to a high of 20.6 percent. These results are shown graphically in Figure 4. As mentioned earlier, this current phase of the study represents the follow-up from an original study (phase 1) undertaken by Sayed in 1998 (Sayed et. al, 1998(1)). A similar methodology was used in the original study, with the exception that a reference group was used to account for the regression to the mean bias instead of the prediction model that was used in this study. In addition, the original study utilized collision data and not claims data. Based on 10 treatment sites in phase 1 of the study, Sayed reported a reduction of 24 percent in the total number of accidents. This result is considered to be consistent with the results of this study (i.e., 15 percent reduction), given the noted differences between the two studies.

There are several opportunities to expand the safety analysis, which will be completed and published at a later date. These opportunities include increasing the number of treatment sites, disaggregating the safety performance analysis into high severity claims (fatal and injury) and low severity claims (property damage only), determining the economic justification (i.e., benefit–cost ratios) for the signal head backboard upgrade, and evaluating the reliability of the results (Sayed and de Leur, 2001).

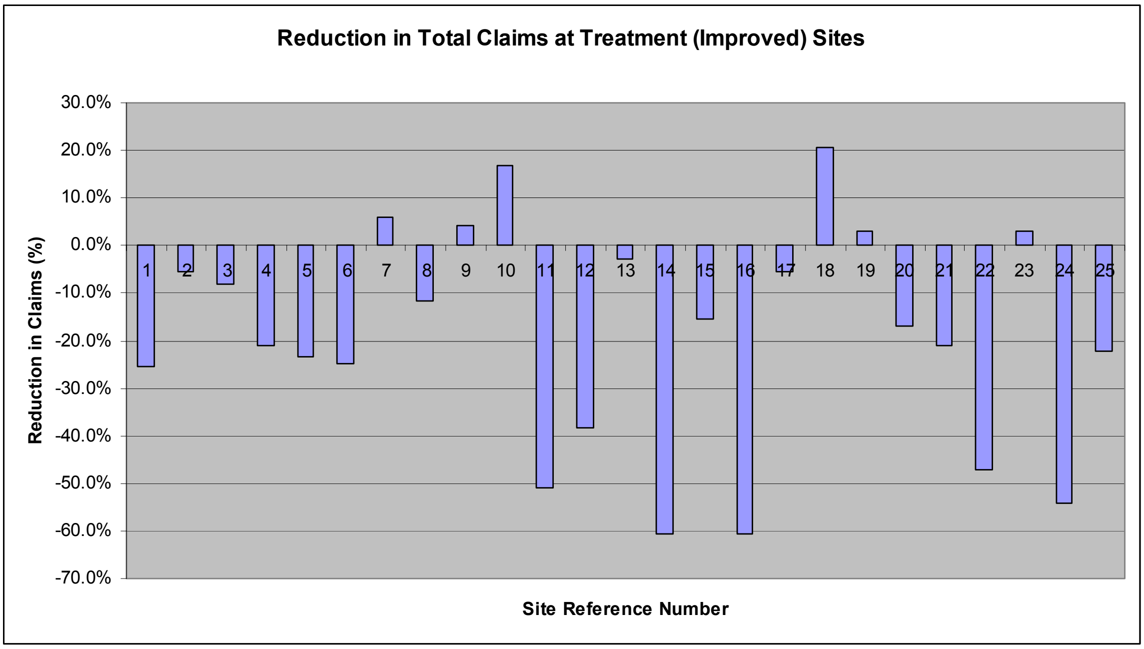

Figure 4: Reduction in the Total Claims at Treatment (Improved) Sites

ACKNOWLEDGEMENT

he authors gratefully acknowledge the contributions of the Insurance Corporation of British Columbia (ICBC) and the BC Ministry of Transportation (BC MOT) for their financial and/or resource commitment to this project.

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