EVALUATION OF SAFETY AND OPERATIONAL PERFORMANCE OF HIGH TENSION MEDIAN CABLE BARRIER ON DEERFOOT TRAIL, CALGARY, ALBERTA

Tony Churchill, M.Sc., E.I.T., C.E.T. (*Presenter)
Transportation Engineer, EBA, A Tetra Tech Company

Upal Barua, M.Sc., E.I.T.
Transportation Engineer, EBA, A Tetra Tech Company

Masood Hassan, Ph.D., P.Eng.
Senior Transportation Engineer, EBA, A Tetra Tech Company

Muhammad Imran, M.A.Sc., P.Eng.
Traffic Safety Engineer, Technical Standards Branch, Alberta Transportation

Bill Kenny, P.Eng.
Director, Design, Project Management and Training
Technical Standards Branch, Alberta Transportation

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ABSTRACT

This study is an examination of the safety and operational performance of the high tension median cable barrier (HTCB) installed between January and May 2007 on a 10.75 km section of Deerfoot Trail, a six-lane divided freeway with a depressed median in Calgary, Alberta, carrying 150,000 vehicles per day. It was the first major HTCB in Canada and a discussion of its design elements and preliminary safety impacts have been reported before. This paper presents the results of a rigorous analysis of nearly three years of detailed collision and operational data. The study of the barrier's performance reported here makes this HTCB installation one of the most robustly studied in North America, and should therefore be of interest to highway safety professionals.

The main objectives of this study were to examine the safety performance of the HTCB in terms of collision severity reduction, effects on the numbers of median collisions, severity distribution of the HTCB collisions compared to median collisions without the HTCB, and the operational and maintenance characteristics of the barrier. The results of a comprehensive benefit-cost analysis are also presented.

The main steps of the study were: 1) Collect and review collision data; 2) Analyse median collisions before and after the installation of HTCB; 3) Compare the rate and severity of median collisions before and after HTCB installation; 4) Obtain feedback from maintenance contractor, RCMP and emergency responders; 5) Evaluate safety effects of HTCB on Deerfoot Trail using AASHTO Highway Safety Manual (2010); and 6) Conduct a benefit-cost analysis.

The before and after analyses of the safety performance of the HTCB revealed that the rate and severity of median-related severe collisions dropped significantly after the installation of the barrier (severe collisions are defined as collisions resulting in fatalities and major injuries). After the installation of the HTCB, the percentage of median related fatal collisions dropped from 4.4% to 0%, and the percentage of injury collisions dropped from 21.1% to 11.8%. The analyses also showed that although there was an increase in property damage only collisions the frequency of severe collisions dropped by 25% and the rate of severe collisions dropped by 40% after the installation of the HTCB. Application of Empirical Bayes method according AASHTO Highway Safety Manual (2010) shows that the safety performance on the study section of Deerfoot Trail improved by 27.92% with respect to reduction in severity (fatal and injury collisions) and by 32.46% with respect to reduction in fatality (fatal collisions). The benefit-cost analysis (with a 20-year analysis period, and taking into account the construction and maintenance costs and the monetary benefits of the reduction in severe collisions) indicated a benefit-cost ratio of 11.1 and a payback period of less than one year which are strong indications of the safety benefits of the HTCB. This study concludes that the HTCB on Deerfoot Trail has been performing well with respect to safety and operation, and can serve as a model for applicability in other jurisdictions.

INTRODUCTION

This study is an examination of the safety and operational performance of the high tension cable barrier (HTCB) installed between January and May 2007 in the median of a 10.75 km section of Deerfoot Trail in Calgary, Alberta. Deerfoot Trail is the name given to approximately 42 km of Control Section 2:15 of Alberta Provincial Highway 2 which is a six-lane divided freeway with a depressed median within the incorporated boundaries of the City of Calgary. It is an urban freeway and acts as a major north south corridor in Calgary and is the busiest roadway in Alberta, carrying between 43,230 vehicles per day (vpd) and 158,450 vpd (2009 Average Annual Daily Traffic (AADT)). The HTCB installed on Deerfoot Trail was the first major HTCB installation in Canada and has been topic of several conference papers regarding the design, construction, and preliminary safety performance of the system [1; 2; 3]. This study included the rigorous analysis of detailed collision and operational data and this paper presents the results that reflect the safety and operational performance of the HTCB installation. This study also evaluates the safety effects of the HTCB system on Deerfoot Trail based on the Empirical Bayes method as described in the AASHTO Highway Safety Manual (HSM) (2010)[4]. The results for the safety and operational performance of the HTCB system provide highway safety professionals a robust Canadian study which verifies the validity of the HSM Crash Modification Factor for HTCB in Canada.

SITE LOCATION

The site location for this study was the 10.75 km section of Deerfoot Trail from 16 Avenue NE (km 35.35 of Control Section 2:15) to Country Hills Blvd (2:15 km 46.10) where the HTCB system was installed. Over the years, approximately 20 km of concrete barriers and approximately 4 km of W-beam median barriers have been installed on portions of Deerfoot Trail south of 16 Avenue NE (2:15 km 35.35). In 2005, concerned with a number of fatal cross median collisions on Deerfoot Trail north of 16 Avenue NE, Alberta Transportation (AT) initiated an in-service road safety review to determine the safety issues and identify and recommend road safety measures to address those issues [5]. The recommendation of the review was to install a high tension median cable barrier on the 6.8 km section from 16 Avenue NE north to Beddington Trail. AT elected to extend the length of the installation to a total of 10.75 km, from 16 Avenue NE past Beddington Trail to Country Hills Blvd. Construction of the 10.75 km HTCB was completed in early May 2007, with design and construction supervision undertaken by EBA, A Tetra Tech Company (EBA). Figure 1 shows the location of HTCB system installed on Deerfoot Trail in Calgary as of July 2010. The HTCB is located at an offset of 4 m from the painted yellow shoulder line of the northbound lanes of Deerfoot Trail.

PURPOSE AND OBJECTIVES OF THE STUDY

The purpose of this study was to evaluate the operation, safety, and economic performance of the high tension HTCB. The following summarizes the main objectives of the study:

- Evaluate the operational impacts of the HTCB considering maintenance records, mowing and snow clearing on HTCB section of Deerfoot Trail;
- Compare the collision rate, frequency, and severity before and after HTCB installation;
- Evaluate the safety effects of HTCB on Deerfoot Trail based on the Empirical Bayes method contained in Highway Safety Manual (HSM, 2010); and
- Estimate annual societal cost, document construction and annual maintenance costs, and estimate the annual savings and payback period for the HTCB using AT's Benefit Cost Analysis Guidelines (2005)[6].

Note that the "before" period for this study is defined as the five calendar years January 2002 to December 2006; the "after" period is defined as two years and eight months (32 months) from May 2007 to December 2009.

DATA COLLECTION

The main source of the data used in this study was AT's Collision Information System. This was supplemented, as appropriate for comparison and other purposes, by data and comments from AT's operations engineer for Deerfoot Trail and from the maintenance contractor. The operations engineer and the maintenance contractor provided information about the maintenance and repair cost of the HTCB system on Deerfoot Trail, increased effort for mowing/trimming, snow clearing and any known adverse effect of the HTCB.

The collision data on Deerfoot Trail were supplied by Office of Traffic Safety, AT from Alberta Collision Information System (ACIS). The focus of this study was on the HTCB section of Deerfoot Trail from 16 Avenue North (km 35.35) to Country Hills Boulevard (km 46.10). AT's collision data contained collisions on Deerfoot Trail as well as collisions on crossroads, interchanges and ramps along Deerfoot Trail. The collision data was sorted using a number of criteria to screen for collisions on crossroads, interchanges and ramps. Following these procedures, only the collisions on Deerfoot Trail mainline were utilized for analysis purposes after screening out the collisions on crossroads, interchanges and ramps.

OPERATIONAL EFFECTS OF THE HIGH TENSION MEDIAN CABLE BARRIER

The repair cost for the HTCB from May 2007 to December 2009 is presented in Table 1. Compared to the annual repair cost in 2007 and 2008, the annual repair cost in 2009 was significantly lower. According to the AT operations engineer, AT had ordered extra HTCB hardware including hairpins, lock plates etc. in 2007 and 2008. Many of the materials ordered in 2007 and 2008 were left over and were used for the repair of HTCB system in

2009. As a result of the stockpiled materials, fewer materials were purchased in 2009 by AT which reflected in significantly lower expense for repair in 2009.

After every hit to the HTCB, the repairs are carried out and the maintenance contractor is paid for items such as traffic accommodation, and replacement of HTCB components such as posts, hairpins, locks plates, and foam/caulking/grouting. The cost for repair of the HTCB mentioned above are separated from the traffic accommodation cost and inspection cost for the HTCB. The traffic accommodation cost and inspection cost for HTCB system on Deerfoot Trail are part of a monthly lump sum bid item paid by AT to the maintenance contractor. According to the information from the maintenance contractor, the additional traffic accommodation cost for HTCB system on Deerfoot Trail is estimated to be $13,000 per year (2007 dollar value) for the 10.75 km section (or $1,210 per km per year).

The maintenance contractor confirmed that there is an increased cost for manually mowing/trimming of grass around the cable posts and that this additional cost is $3,700 per year for the total 10.75 km section of the HTCB on Deerfoot Trail (or $344 per km per year). According to the AT operations engineer and the maintenance contractor, there has been no additional cost or operational effects related to snow clearing after the installation of the HTCB system on Deerfoot Trail.

The operations engineer confirmed that the emergency responders such as EMS or fire trucks are not negatively impacted. There is sufficient space between the HTCB and the painted yellow shoulder line in the northbound direction for emergency vehicles and maintenance vehicles to park on the shoulder. Adequate traffic accommodation measures are taken during maintenance or emergency so that hazards posed by parking on the shoulder are minimized.

MEDIAN COLLISIONS ON DEERFOOT TRAIL

For the eight year period from 2002 to 2009, a total of 2,399 collisions were reported on the study section of Deerfoot Trail. Of these collisions, 200 collisions (8.34% of total collisions) were median collisions. These median collisions can be divided into three different periods of time based on the installation of the HTCB system. The median collisions on this section of Deerfoot Trail were divided according to the following periods of time for analysis purposes:

- collisions before the installation of the HTCB from January 2002 to December 2006;
- collisions during the installation of the HTCB from January 2007 to April 2007; and
- collisions after the installation of the HTCB from May 2007 to December 2009.

Although there would be potential for the introduction of a seasonal bias in the median related collision data with the exclusion of January to April 2007 the distribution of collisions was reviewed and no seasonal patterns were observed. The time period from May 2007 to December 2007 was, therefore, included in the after period for a total time period of 32 months.

MEDIAN COLLISIONS BEFORE THE INSTALLATION OF THE HTCB SYSTEM

Before the installation of the HTCB, 114 median collisions occurred on this section of Deerfoot Trail for the five years from 2002 to 2006. The frequency of median collision before the installation of median cable is 2.12 collisions per km per year and the rate of median collision is calculated to be 0.06 collisions per million-vehicle km. The median collisions on this section of Deerfoot Trail before the installation of the HTCB are broken down according to severity of collisions in Table 2.

It should be noted that at least one fatal collision related to median occurred every year from 2002 to 2006 except in 2003, on the study section of Deerfoot Trail. The frequency of severe collisions (fatal and major injury) before the installation of the HTCB was 0.186 collisions per km per year. The rate of severe collisions on this section was 0.005 collisions per million-vehicle km.

MEDIAN COLLISIONS DURING THE CONSTRUCTION PERIOD OF THE HTCB SYSTEM

During the construction period for the installation of the HTCB from January 2007 to April 2007, ten collisions occurred on this section of Deerfoot Trail. Of the ten collisions, two were major injury collisions and the rest (eight) were PDO collisions. No fatal collisions occurred during construction period on this section.

MEDIAN COLLISIONS AFTER THE INSTALLATION OF THE HTCB SYSTEM

After installation of the HTCB along the median of the study section of Deerfoot, from May 2007 to December 2009, 76 median collisions occurred on this section of freeway. The frequency of median collision after the installation of the HTCB was 2.65 per km per year and the rate of median collision was calculated to be 0.06 collisions per million-vehicle km. The median collisions on this section of Deerfoot Trail after the installation of the HTCB are broken down according to severity of collisions in Table 3.

It should be noted that no fatal collisions related to median collisions occurred after the installation of the HTCB on the study section of Deerfoot Trail. However, 4 major and 5 minor injury collisions related to median occurred after the installation of the HTCB on the study section of Deerfoot Trail. The frequency of severe collisions (fatal and major injury) after the installation of the HTCB was calculated to be 0.140 per km per year. The rate of severe collisions on this section was calculated to be 0.003 collisions per million-vehicle km. The frequency and rate of severe collisions after the installation of the HTCB on this section of freeway are notably lower than those before the installation of the HTCB.

BEFORE AND AFTER COMPARISON OF MEDIAN COLLISIONS SEVERITY

As discussed in the previous section, 114 collisions occurred on the study section of Deerfoot Trail with at least one fatal collision every year except in 2003 before the installation of the HTCB. After the installation of the HTCB in the first quarter of 2007, 76 median related collisions occurred on this section of freeway from May 2007 to December

2009 with no fatal collisions and 9 injury collisions (4 major and 5 minor). Figure 2 shows the proportion of collisions of different severity level before and after installation of the HTCB. This figure shows the drop in proportion of fatal and injury collisions (major and minor) after the installation of the HTCB. After the installation of the HTCB, the percentage of median related fatal collisions dropped from 4.4% to 0%. There was a slight increase in the percentage of major injury collisions 4.4% to 5.2%, whereas the percentage of minor injury collision dropped drastically from 16.7% to 6.6%.

The safety aspect of high tension median cable barrier can also be revealed by comparing the frequency and rate of collisions before and after the installation of HTCB. Figure 3 presents the comparison of frequencies of collisions before and after the installation of the HTCB on Deerfoot Trail and shows that there is an increase in overall frequency of collisions. This is to be expected with any type of newly installed median barrier, because some of the errant vehicles which previously might have recovered in the median and returned to the travelled way are now hitting the barrier simply because it is there.

Another safety aspect of high tension cable as a median barrier can also be established by the comparison of rates of collisions before and after the installation of the cable barrier as presented in Figure 4. The figure shows that the collision rate after the installation of the HTCB remained approximately the same as before; however, the rate of severe collisions dropped by 40% after the installation of the HTCB. This reduction in the frequency and rate of severe median-related collisions is because of the inherent flexibility of the HTCB which flexes and thus cradles the errant vehicle rather than redirect it back into the traffic stream as is the case for more rigid barriers.

A key finding regarding HTCB is that there is a decrease in the frequency and rate of severe collisions (fatal and major injury collision) after installation of the HTCB compared to more rigid median barriers as shown in the comparative collision frequencies with various median barrier types, illustrated in Figure 5. The comparison to more rigid median barrier types included other segments of Deerfoot Trail during the study period and therefore represents similar traffic volumes and background factors. More rigid median barriers are typically used at locations where there is less room for barrier deflection and the offset from the travel lane to the barrier is typically less than that of the HTCB. The data collected and comparisons among barrier types are being prepared for future publication.

SAFETY PERFORMANCE OF HTCB USING HSM (EMPERICAL BAYES) METHODOLOGY

The effect of the HTCB system on the overall safety performance of the study section of Deerfoot Trail from 16 Avenue North to Country Hills Boulevard was evaluated following the Empirical Bayes (EB) method contained in AASHTO Highway Safety Manual (2010).

In this study, the EB method uses existing Safety Performance Functions (SPFs) to predict average crash frequency before and after the installation of HTCB. The EB method combines the observed crash frequency (before period) and the SPF predicted average crash frequency (before and after periods) to estimate the expected average crash frequency in the after period had the treatment not been implemented. The comparison of the observed crash frequency in the after period and the expected average after crash frequency provides the effect of the HTCB system on overall safety performance of the study section on Deerfoot Trail.

Safety performance functions for a six-lane divided urban freeway have not yet been developed for Alberta highways or included formally in the HSM. After review of available literature, the safety performance functions developed for the road segments in the state of Illinois [7] were used for the purpose of this study. The comprehensive study in Illinois developed SPFs for several types of highway facilities and intersections in response to an identified need in the HSM, including the six-lane divided urban freeway which is representative of Deerfoot Trail. For verification purposes, the SPF was applied to the study segments of Deerfoot Trail using the traffic volumes for each year and the model predictions were found to predict the observed collisions in the before period with relative accuracy of +/- 2 collisions per year on average as shown in Table 5.

The main safety benefit of HTCB is expected from the reduction of fatal and injury collisions. For the purpose of this study, the evaluation of the safety benefit was focused on the comparison of casualty collisions (fatal and injury collisions combined) and fatal collisions before and after the installation of HTCB system.

The collisions that occurred on the study section of Deerfoot Trail in the before period (2002 to 2006, five years) and in the after period (May 2007 to December 2009, 2 years 8 months) were used for the evaluation of safety performance according to Highway Safety Manual (2010) and are presented in Table 4 which includes non-median related collisions.

EFFECT OF HTCB ON THE SAFETY PERFORMANCE OF DEERFOOT TRAIL WITH RESPECT TO REDUCTION IN CASUALTY COLLISIONS

The safety performance function (SPF) for the casualty collisions (fatal and injury collisions combined) applicable for a six-lane divided urban freeway, as developed in Illinois [7] can be expressed as:

$$N_{predicted} = (1/5) * L * (e^{-13.022}) * (AADT)^{1.425} \quad \text{(eq. 1)}$$

where $N_{predicted}$ is the expected number of fatal and injury collisions per year, L is the segment length in mile, and AADT is the average annual daily traffic for the length of the segment.

Using equation 1, the predicted crash (fatal and injury) frequency for the before period($N_{Predicted,B}$) was calculated to be 196.52 collisions.

The over-dispersion parameter (k) is given by:

$$k = \frac{d}{L} \quad \text{(eq. 2)}$$

where *d* is the over-dispersion parameter per mile and *L* is the length of the segment in mile. For the Illinois casualty collision model *d* was found to be 3.032.

The weighted adjustment for the before period is given by:

$$w = \frac{1}{1 + k \ \sum_{Before\ Period}(N_{Predicted})} \qquad \text{(eq. 3)}$$

The expected average crash (fatal and injury) frequency for the before period is given by,

$$N_{expected,B} = w * N_{predicted,B} + (1 - w) * N_{observed,B} \qquad \text{(eq. 4)}$$

Using, equations 2, 3, and 4, the expected average crash (fatal and injury) frequency for the before period ($N_{expected,B}$) was calculated as 185.13 collisions.

The predicted average crash (fatal and injury) frequency for the after period($N_{Predicted,A}$) was calculated using equation 1 and was found to be 128.08 collisions.

The adjustment factor, r, to account for the differences between the before and after periods in duration is given by:

$$r = \frac{\sum_{After\ Period}(N_{Predicted,A})}{\sum_{Before\ Period}(N_{Predicted,B})} \qquad \text{(eq. 5)}$$

The expected average crash (fatal and injury) frequency for the after period is given by:

$$N_{expected,A} = N_{expected,B} * r \qquad \text{(eq. 6)}$$

Using equations 5 and 6, the expected average crash frequency in the after period (had the HTCB not been installed) was calculated. It was found that 121.52 fatal and injury collisions would have been expected in the after period had the HTCB system not been installed in the median of the study section of Deerfoot Trail.

The effectiveness of the HTCB system with respect to reduction in fatal and injury collisions is given by in the form of an odds ratio:

$$OR' = \frac{\sum N_{Observed,A}}{\sum N_{Expected,A}} \qquad \text{(eq. 7)}$$

The adjusted unbiased odds ratio is given by,

$$OR = \frac{OR'}{1 + \frac{Var\left(\sum N_{Expected,A}\right)}{\left(\sum N_{Expected,A}\right)^2}} \qquad \text{(eq. 8)}$$

where:

$$Var\left(\sum N_{Expected,A}\right) = \sum\left[r^2 \times N_{Expected,B} \times (1-w)\right] \quad \text{(eq. 9)}$$

Using equations, 7, 8 and 9, the adjusted unbiased odds ratio was calculated and was found to be 0.7208. The overall reduction of fatal and injury collisions on Deerfoot Trail from 16 Avenue North (km 35.35) to Country Hills Boulevard (km 46.10) after the installation of HTCB was calculated by:

$$Safety\ Effectivenss = (1 - OR) \times 100\% \quad \text{(eq. 10)}$$

Using equation 10, the overall reduction in fatal and injury collisions on the study section of Deerfoot Trail after the installation of HTCB was found to be 27.92%. It should be noted that this reduction in severity of collisions reflects the overall improvement of safety performance of Deerfoot Trail from 16 Avenue North to Country Hills Boulevard considering all collisions along this sections (not only median collisions). Interestingly, the result of the analysis is very consistent with the reported Crash Modification Factor for HTCB of 0.71 in all injuries reported in section 13.5.2.4 of the HSM, equivalent to a 29% reduction in injury collisions.

EFFECT OF HTCB ON THE SAFETY PERFORMANCE OF DEERFOOT TRAIL WITH RESPECT TO REDUCTION IN FATAL COLLISIONS

The safety performance function (SPF) for the fatal collisions applicable for a six-lane divided urban freeway, as developed in Illinois [7] can be expressed as:

$N_{predicted} = (1/5) * L * (e^{-6.927}) * (AADT)^{0.499}$
(eq. 8)

where $N_{predicted}$ is the expected number of fatal collisions per year, L is the segment length in miles, and AADT is the average annual daily traffic for the length of the segment.

Using equation 8, the predicted fatal crash frequency for the before period $(N_{Predicted,B})$ was calculated to be 2.05 collisions.

Using, equations 2, 3, and 4, the expected average fatal crash frequency for the before period $(N_{expected,B})$ was calculated as 2.52 collisions. For the Illinois fatal collision model *d* was found to be 2.36.

The predicted average fatal crash frequency for the after period $(N_{Predicted,A})$ was calculated using equation 8 and was found to be 1.17 collisions.

Using equations 5 and 6, the expected average crash frequency $(N_{expected,A})$ in the after period (had the HTCB not been installed) was calculated. It was found that 1.44 fatal collisions would have been expected in the after period had the HTCB system not been installed in the median of the study section of Deerfoot Trail.

Using equations, 7, 8 and 9, the adjusted unbiased odds ratio was calculated and was found to be 0.6754. Using equation 10 the overall reduction in fatal collisions after the installation of HTCB on Deerfoot Trail from 16 Avenue North (km 35.35) to Country Hills Boulevard (km 46.10) was found to be 32.46%. It should be noted that this reduction in fatal collisions reflects the overall improvement of safety performance of Deerfoot Trail from 16 Avenue North to Country Hills Boulevard considering all collisions along this sections (not only median collisions).

BENEFIT-COST PERFORMANCE OF THE HTCB ON DEERFOOT TRAIL

For the benefit-cost analysis of the HTCB installed from 16 Avenue North to Country Hills Boulevard on Deerfoot Trail, AT's standard benefit-cost analysis procedure was used. This procedure requires two alternatives to be considered and compared. Alternative 1 assumed no HTCB is installed, and Alternative 2 assumed the HTCB is installed at the current location on Deerfoot Trail. Both benefit-cost alternatives consider only the median related collisions on the study section.

Alternative 1: No HTCB Installed

Alternative 1 considered the case when HTCB was not installed on Deerfoot Trail. Road users' cost for Alternative 1 only includes collision costs because the gradient, curvature and time costs are the same irrespective of the installation of HTCB. The collision cost was calculated from the median collisions that would have occurred from May 2007 to December 2009 (after period) if the HTCB had not been installed. During the analysis period there were 1,359 collisions reported along the study section of Deerfoot Trail. Of the 1,359 collisions, 114 (8.4%) were related to the median. These collisions include vehicles involving off road left, head-on, sideswipe-opposite direction and off road left hit-object collisions.

Using the AT standard costs for different collision severities, the cost for median collisions on the study section of Deerfoot Trail was calculated to be $2.029 million per year. As no installation of HTCB is considered in Alternative 1, no construction and maintenance cost are involved. Additional costs for the installation and maintenance and operation of the HTCB system are considered in Alternative 2.

Alternative 2: HTCB Installed

Alternative 2 considered the case when HTCB was installed on Deerfoot Trail. As was the case for Alternative 1, road users' cost only includes collision costs since the gradient, curvature and time costs are the same irrespective of the installation of HTCB. Two cases of collision cost and safety benefits of the HTCB were considered for the benefit-cost analysis. The first case considers the observed reduction in severity and frequency of median collisions after the installation of HTCB and the second case considers the sensitivity of benefit-cost analysis of the HTCB with a more conservative assumption of 80% reduction in median related fatal collisions and 25% reduction in median related injury collision after the installation of the HTCB.

The collision history from May 2007 to December 2009 inclusive was used to calculate the annual collision cost after the installation of the HTCB on Deerfoot Trail. The focus of the analysis was collisions involving the median (i.e., those identified as off road left and striking the HTCB), as was the case for Alternative 1. During the analysis period there were 938 collisions reported along Deerfoot Trail from km 35.35 (16 Avenue N) to km 46.10 (Country Hill Boulevard). Of the 938 collisions, 76 (8.1%) were related to vehicles running off the road on the left side (median side) and striking the HTCB. No collisions were reported with vehicles involving median crossover head-on or median crossover sideswipe (opposite direction) incident. Using AT's standard costs for different collision severities, the cost for median collisions after the installation of the HTCB on Deerfoot Trail was calculated to be $0.639 million per year. This annual collision cost was used as the observed case for the benefit-cost analysis of the installed HTCB.

After the installation of the HTCB on Deerfoot Trail, no fatal collision related to median was reported and the percentage of injury collisions related to median dropped from 21.1% (5 major and 19 minor injury collisions) to 11.8% (4 major and 5 minor injury collisions) while the number of PDO collisions increased. To make the benefit-cost analysis conservative, it was assumed that the fatal collisions would be reduced by only 80% (instead of 100% which is the case on Deerfoot Trail); the injury collision would be reduced by only 25% (instead of 44% observed on Deerfoot Trail); while the number of PDO collisions increased. These assumptions are based on studies in different jurisdictions of United States where the reduction of cross-median fatal collisions were below 80% after the installation of HTCB in six out of fourteen cases investigated [8]. Based on these assumptions, the annual cost of collisions after the installation of the HTCB was estimated at $1.073 million per year. This annual collision cost was used as the conservative case for the benefit-cost analysis of the HTCB.

The capital construction cost of the HTCB installation on the Deerfoot Trail was $946,000 which equates to a unit construction cost of $92,000 per km (2007 dollars). It should be noted that this estimate excludes the cost of short sections of other barrier type, e.g., Modified Thrie Beam, involved in the Deerfoot Trail project. In this context, it is worth mentioning that the unit construction costs of concrete barrier and W-beam barrier are $301,000 per km (2007 dollars) and $137,000 per km (2007 dollars) respectively (AT Southern Region's unit price average report, 2007). The total maintenance cost for repair of the HTCB from May 2007 to December 2009 amounted to $130,864 which equates to a yearly maintenance cost (repair only) of $43,621. This cost does not include the additional traffic accommodation and inspection cost for the HTCB (i.e. beyond the cost of no barrier case) of $13,000 per year (2007 dollar value) for the entire 10.75 km section of HTCB on Deerfoot Trail. There is also an increased cost for manually mowing/trimming of grass around the cable posts. According to the maintenance contractor, the additional cost for this item is $3,700 per year (2007) for the total 10.75 km section. Considering all these maintenance and operational cost, a total annual maintenance cost of $60,320 ($43,621 +

$13,000 + $3,700), rounded to $60,500 per year in 2007 dollars was considered. No adverse impact of the cable barrier on the operation or cost of snow clearing or litter pick-up were reported.

Results of the Benefit-Cost Analysis

The design life for a barrier system was assumed to be 20 years. A conservative assumption was considered regarding the salvage value of the median cable barrier system since no examples of value at the end of service life were available. In this benefit-cost analysis, it was assumed that there will be no salvage value of the system at the end of the design life which may result in an underestimate of the real cost-effectiveness.

Based on the savings due to actual reduction in severity of median collisions on Deerfoot Trail, the net present value (NPV) after the installation of the HTCB is estimated to be $18,452,000 and the benefit-cost ratio is estimated to be 11.1 at the end of the design life of 20 years. The NPV-capital cost ratio is estimated to be 19.5 at the end of the design life. The benefit starts exceeding the cost in the first year after installation. For the conservative benefit-cost analysis of the HTCB the estimated NPV after the installation of the HTCB is estimated to be $12,116,000 and the benefit-cost ratio is estimated to be 7.6 at the end of the design life of 20 years. The NPV-capital cost ratio is estimated to be 12.8 at the end of the design life. The benefit starts exceeding the cost in the second year after installation. The above results of the benefit-cost analysis are summarised in Table 6.

The experience in other jurisdictions also shows high benefit-cost ratios for HTCB. The results from Washington State indicate that the benefit-cost ratio is 3.2 for cable barriers, 2.3 for guardrails and 1.4 for the concrete barriers when applied on 15.5 m to 18.3 m wide medians [5]. The projected benefit-cost ratios for HTCB, w-beam guardrail median barrier and concrete median barrier on Deerfoot Trail from 16th Avenue NE to Beddington Trail NE were 20.1, 16.5 and 9.6 respectively [5]. Overall, the HTCB performs best of the three median barrier systems in economic terms.

CONCLUSIONS

The 10.75 km HTCB installation on the study section of Deerfoot Trail in Calgary completed in early May 2007 was the first major installation of its kind in Canada. This study assessed the safety aspects of the HTCB on Deerfoot Trail, applied the methodology outlined in the AASHTO HSM (2010), as well as performed a benefit-cost analysis to estimate the predicted benefit over cost at the end of the design life. This study confirmed that the HTCB on Deerfoot Trail has been safety-effective and cost-effective. In terms of safety improvements, reductions in the frequency and rate of injury collisions were observed and the reduction in injury collisions of 28% calculated using the EB method presented in the HSM was found to be consistent with the reported Crash Modification Factor for HTCB listed in the HSM. In terms of cost-effectiveness, using a 20-year design life, the Deerfoot Trail HTCB has an estimated NPV of $18,452,000 with a benefit-cost ratio of 11.1 and a NPV-capital cost ratio of 19.5. This HTCB has saved lives, is highly cost-effective and can serve as a model for applicability in other Canadian jurisdictions.

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TABLES

Table 1: Maintenance Cost for Repair of HTCB on Deerfoot Trail

Year	2007	2008	2009
Annual Repair Cost	$48,161	$53,796	$29,201
Repair Cost per km per year	$4,676	$5,223	$2,835
Average Repair Cost per km per year	$4,245		

Table 2: Median Collisions Before Installation of HTCB (2002 to 2006)

Severity/Year	2002	2003	2004	2005	2006	Total (5 years)	%
Fatal	1	0	1	1	2	5	4.4
Major Injury	0	0	2	1	2	5	4.4
Minor Injury	4	2	2	6	5	19	16.7
PDO	22	14	21	16	12	85	74.5
Total	27	16	26	24	21	114	100.0

Table 3: Median Collisions after Installation of HTCB (May 2007 to Dec 2009)

Severity/Year	2007 (May-Dec)	2008	2009	Total (2 years 8 months)	%
Fatal	0	0	0	0	0.0
Major Injury	0	0	4	4	5.2
Minor Injury	1	2	2	5	6.6
PDO	14	27	26	67	88.2
Total	15	29	32	76	100.0

Table 4: All collisions along the HTCB Section of Deerfoot Trail (2002 to 2009)

Severity / Year	2002	2003	2004	2005	2006	2007 (May to Dec)	2008	2009	Total
Fatal	2	1	1	2	3	1	0	0	10
Injury	39	32	32	39	34	17	37	33	263
PDO	258	202	204	239	271	222	354	274	2024
Total	299	235	237	280	308	240	391	307	2297

Table 5: Traffic Volumes, Observed and Predicted Collisions (2002 to 2009)

Year	2002	2003	2004	2005	2006	2007 (May to Dec)	2008	2009
Traffic Volume (AADT)	92,050	95,460	98,330	102,780	110,170	113,450	114,650	116,170
Fatal + Injury Observed	41	33	33	41	37	18	37	33
Fatal + Injury Predicted	35.01	36.87	38.46	40.96	45.22	31.44	47.87	48.77
Fatal Observed	2	1	1	2	3	1	0	0
Fatal Predicted	0.39	0.4	0.41	0.42	0.43	0.29	0.44	0.44

Table 6: Benefit-Cost Analysis Results for HTCB Section of Deerfoot Trail

HTCB Collision reduction case	NPV after Design Life	Payback Period	Benefit-Cost Ratio	NPV-Capital Cost Ratio
Observed Case	$18.5 million	< 1 year	11.1	19.5
Conservative Case	$12.1 million	< 2 years	7.6	12.8

FIGURES

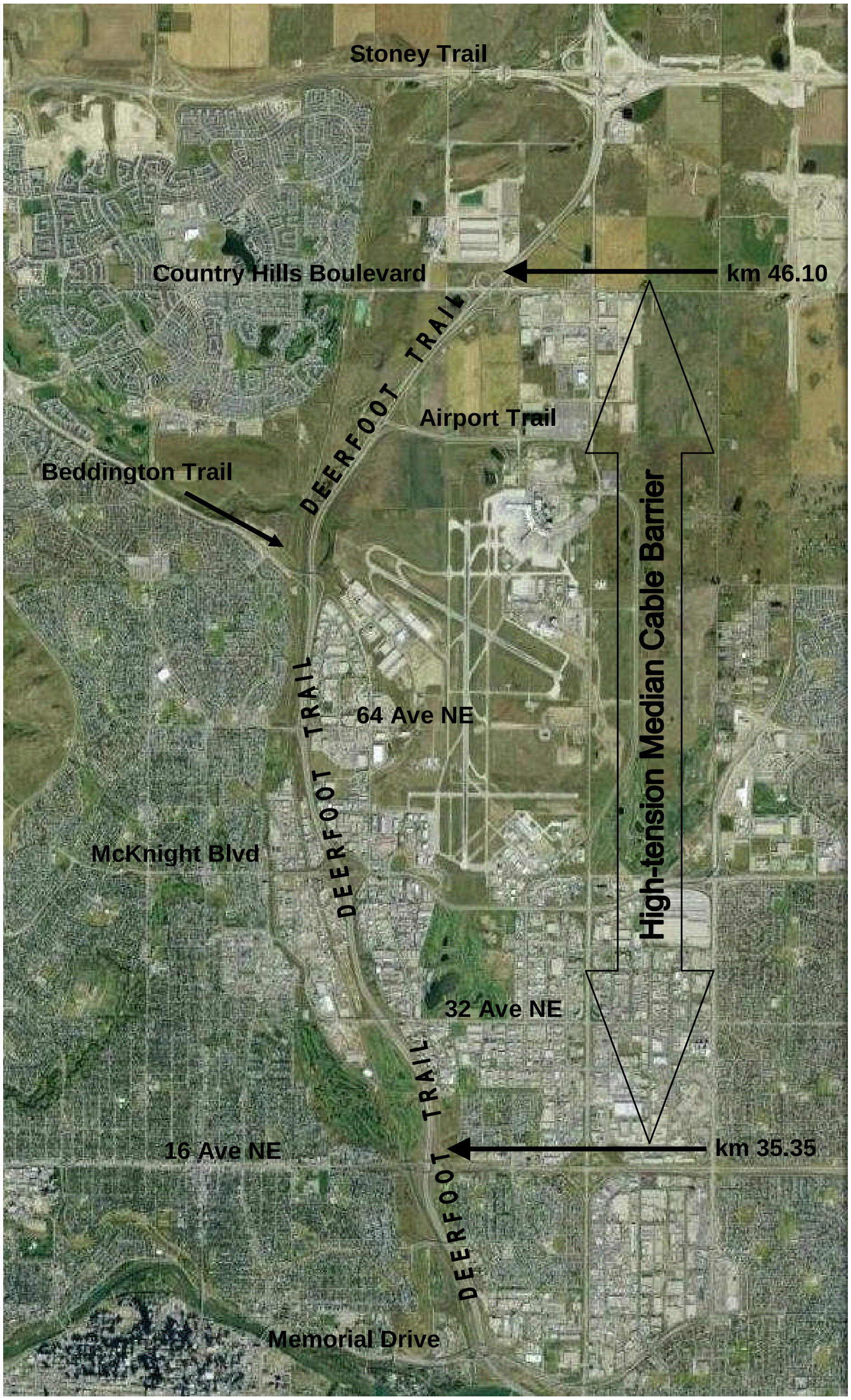

Figure 1: Deerfoot Trail in Calgary with HTCB Installation

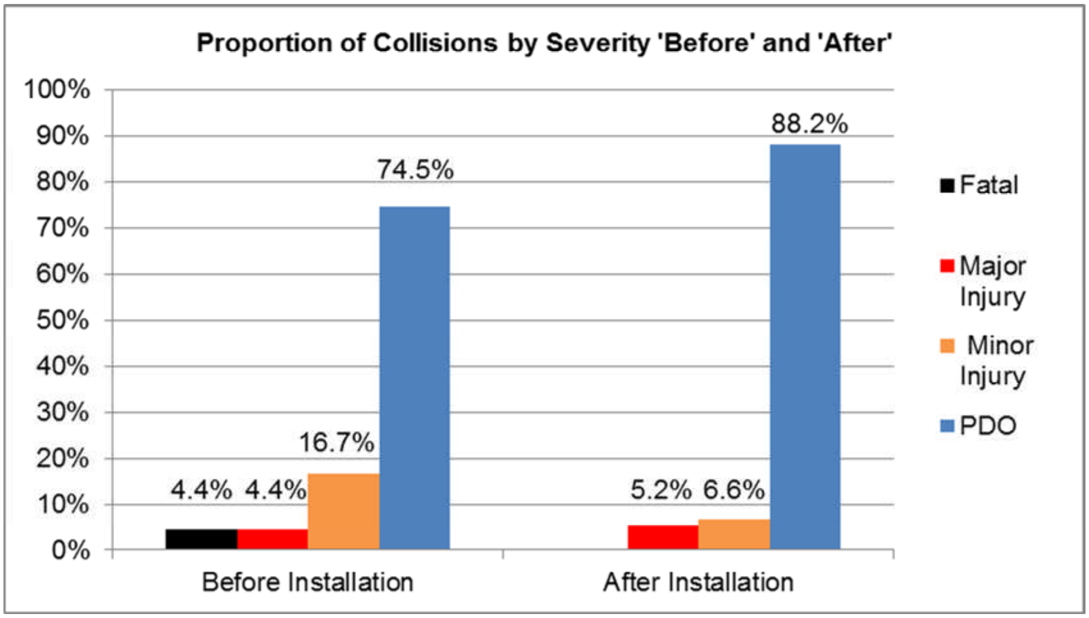

Figure 2: Severity of Collisions 'Before' and 'After' Installation of HTCB

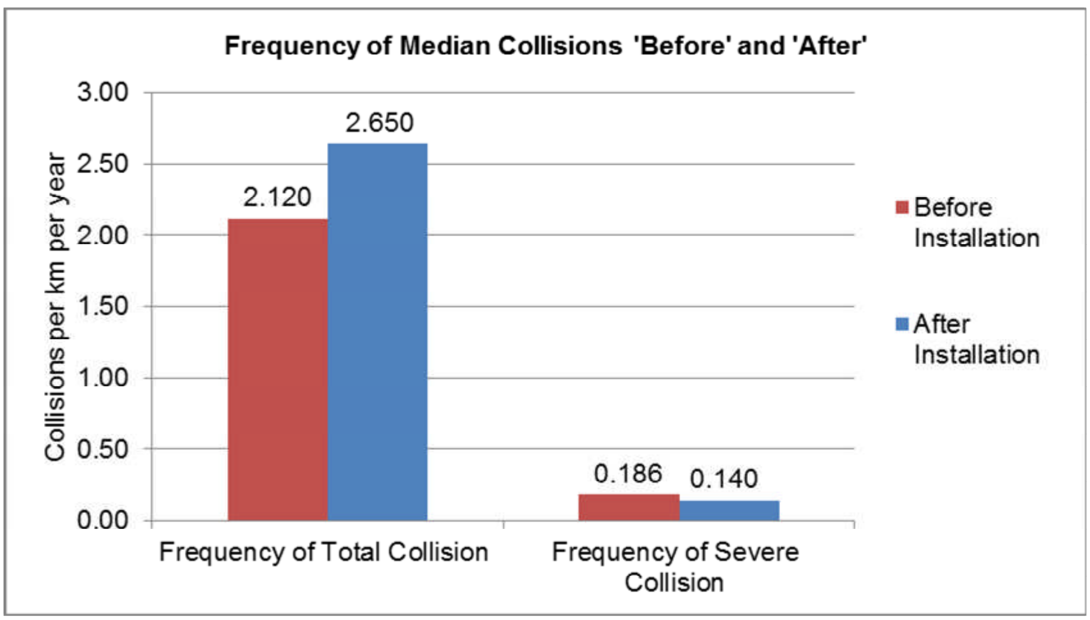

Figure 3: Frequency of Collisions 'Before' and 'After' Installation of HTCB

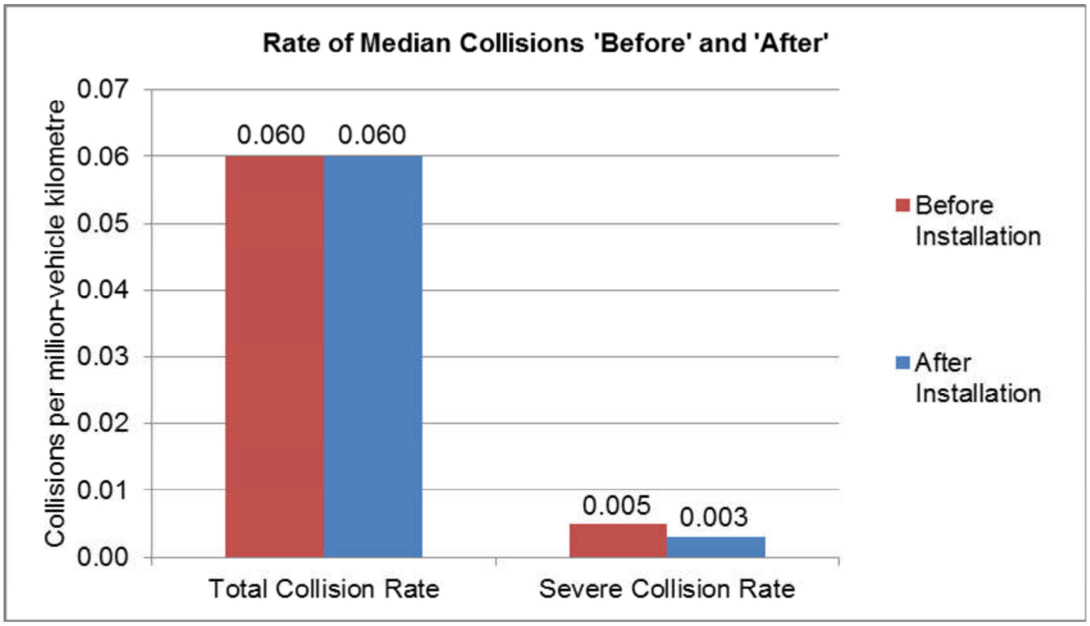

Figure 4: Rate of Total Collisions 'Before' and 'After' Installation of HTCB

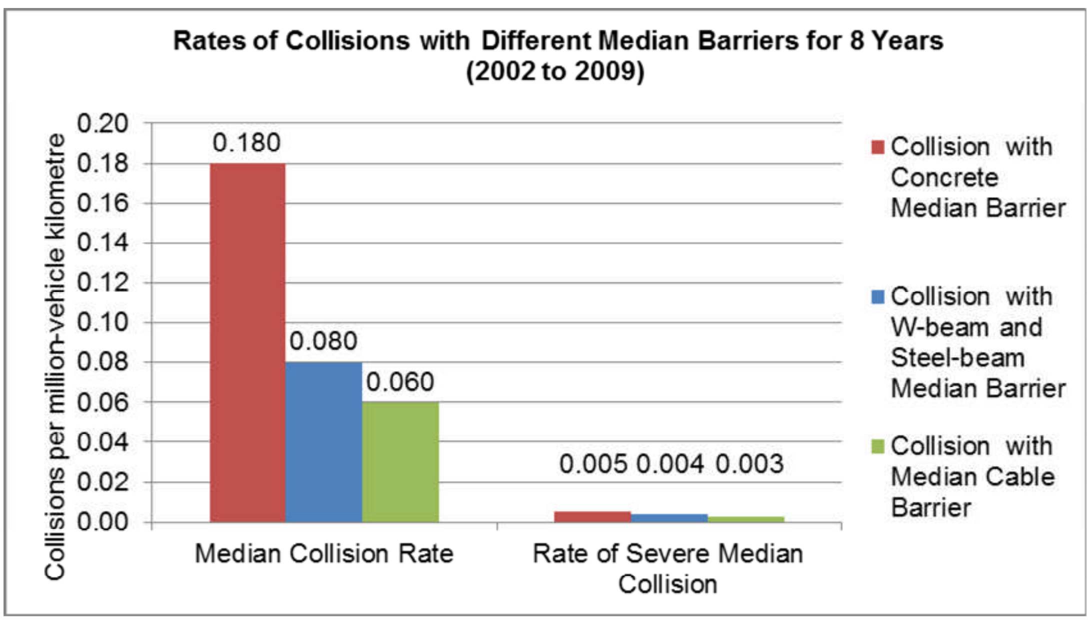

Figure 5: Rate of Collisions with Different Median Barriers on Deerfoot Trail