Safety Assessment of a Rural Highway in a Design Process

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ABSTRACT

Transportation agencies are constantly faced with the challenge of upgrading their road network systems; as infrastructure ages and traffic volumes increase. However, improvements to each roadway are not feasible due to limited available budgets and resources. A variety of design alternatives should be considered in order to achieve a safe, efficient and economical highway design. Therefore, there is a need for an approach or method to estimate the operational and safety benefits of different alternatives designs. For this reason, the authors have undertaken an analysis of the current and potential future safety performance of Autoroute 50, for which an undivided highway section was recently opened in the Outaouais area, in Québec. First, a scientific safety analysis was conducted to quantitatively measure the safety performance of the existing condition and compare it to adjacent roadways. Based on the outcome of the first analysis, a series of alternative designs were recommended to improve the safety performance of the existing condition. Then, a comparison of the existing and the future safety performance was completed for alternative designs. Finally, a benefit cost analysis was completed for the future 20 years in order to assess the cost-effectiveness of the design alternatives.

Les différentes juridictions doivent constamment relever le défi d'entretenir et d'améliorer le réseau routier alors que les infrastructures sont vieillissantes et que les débits de circulation augmentent. Pour optimiser les améliorations à réaliser, les juridictions doivent souvent considérer plusieurs alternatives, leur effet sur la sécurité routière, leur efficacité et leur coût. Elles ont donc besoin d'une méthode permettant d'estimer les bénéfices de chaque alternative considérée en termes de sécurité routière et de circulation. Pour tenter de répondre à ce besoin, les auteurs ont effectué une analyse de la performance actuelle et anticipée au niveau de la sécurité routière de l'autoroute 50 située dans la région de l'Outaouais, au Québec, où un nouveau tronçon a récemment été ouvert à la circulation. Tout d'abord, une analyse scientifique a été réalisée pour mesurer de façon quantitative la performance actuelle en sécurité routière de ce tronçon. Cette performance a été comparée à la performance d'une autre route de la région. Des alternatives de réaménagement ont par la suite été suggérées afin d'améliorer la performance actuelle de ce tronçon de l'autoroute 50. Ensuite, une comparaison des performances actuelle et anticipée au niveau de la sécurité a été réalisée pour chaque alternative. Finalement, une analyse avantages-coûts de chaque alternative a été effectuée pour les 20 prochaines années afin de déterminer à quel moment il serait avantageux de mettre en place chaque alternative de réaménagement.

INTRODUCTION

Transportation agencies are constantly faced with the challenge of upgrading their road network systems; as infrastructure ages and traffic volumes increase. Moreover, the road authority is obligated to improve substandard road services. However, improvements to each roadway are not feasible, due to limited available budgets and resources. Also, in order to achieve a safe, efficient and economical highway design, a variety of design alternatives should be considered. In order to improve safety on existing or future roads, the transportation agencies usually have to choose between different design alternatives. To select the best alternative in each case, they must consider different factors that impact safety and operation of the facility. To do that a quantitative measure of the safety performance as well as the cost-effectiveness of each design alternative should be evaluated. Therefore, there is a need for an approach or a method for estimating the operational and safety benefits of different alternatives designs.

Autoroute 50 is a provincial expressway in the province of Québec in Canada. The expressway was extended by adding a new link in the Outaouais area, in two stages from 2004 to 2008. Adding the new link is part of a plan to connect the regions of Outaouais and Laurentides, providing an expressway between the Cities of Montréal and Gatineau. However, as this expressway is not yet complete, drivers travelling between the two regions, Outaouais and Laurentides, currently have to use a combination of Autoroute 50 and Route 148, which is a provincial highway.

Since their opening of a new link in November 2004 of the first part and the opening of the second part of the undivided east section in 2008, the new link for Autoroute 50 has experienced a few fatal and major injury collisions. That created a major concern about the safety level of this link for the population.

The objectives of this document can be divided in three folds: 1) evaluate the existing safety level for Autoroute 50 and Route 148 using the collision rate method and the Empirical Bayes (EB) approach; 2) evaluate the safety performance of the proposed alternative designs for improvement to Autoroute 50; and, 3) undertake a benefit cost analysis of alternative designs for the existing sections of Autoroute 50.

This paper first describes the study area, followed by an outline of the research database. Then it presents the methodology used to undertake the analysis, including the segmentation procedure and the approach for conducting the safety analysis of the study area. Next, it details the results of the safety assessment of Autoroute 50, the comparison of safety levels with other highways, the analysis of potential safety improvements for alternative designs, and the benefit-cost analysis. The results are followed by a comparative analysis. Finally, there is a summary and conclusion.

STUDY AREA

Figure 1 - Study Area

Figure 1 presents a map of the study area, located east of the City of Gatineau, along the Ottawa River. For the purpose of the analysis, Autoroute 50 and Route 148 have been divided into sections.

Autoroute 50 includes two major sections in the study area:

- The **50-West** section is located between the de la Vérendye interchange and the municipality of Masson-Anger. This section is a fully operational four-lane divided expressway with limited access control. It must be noted here that this section of the study area was not a safety concern, and given the built-out stage of both the expressway and adjacent land use, no alternative design was considered.
- The **50-East** section, which is the newly opened link, is located between the municipalities of Masson-Anger and Thurso. It has a two-lane undivided cross-section with passing and climbing lanes creating portions with up to four lane cross-section, and access is provided through interchanges. This section raises safety concerns for the population, and was therefore the main focus of the analysis. Current safety performance levels were calculated, design alternatives and their potential on safety were analysed, and a benefit cost analysis was undertaken for this section.

Figure 1 also depicts the section of Autoroute 50 which will be opened in the near future, the **50-Planned** section.

Route 148 is a provincial undivided highway with a two lane cross-section and passing lanes, creating portions with up to four lane cross-section. It has at-grade intersections and private accesses. This highway has been divided into two sections, both of which were analysed only for their current safety levels.

- The **148-West** section is located between the municipalities of Masson-Anger and Thurso. This section is an alternative route to the 50-East section.

- The **148-East** section is located between the municipalities of Thurso and Montebello. This section is currently the only direct link between the municipalities of Thurso and Montebello, and will be an alternative route to the 50-Planned section once it is opened to traffic.

AVAILABLE DATA

To undertake this analysis, three main types of data were used. They namely are: geometric characteristics, collision history, and historical volumes.
The geometric characteristics were provided through different existing documents:

- Reference safety indicators per road type, including collision rates and severity indexes;
- Driving video of Route 148;
- Inventory of lane and shoulder widths for the existing sections of both Autoroute 50 and Route 148;
- Orthophotos of Route 148,
- Surveys; and,
- Plans for the 50-East section, and preliminary plans for the 50-Planned section.

Depending on the year of the opening, the collision history was provided from 1999 to 2009 through a database of collision information taken from the collision reports, including collision location, severity, and impact type.

Historical average annual daily traffic (AADT) was also available for different portions of Autoroute 50 and Route 148. Available AADTs varied for each portion of the study area, but ranged from years 1976 to 2009.

METHODOLOGY

This section presents the methodology used to complete the three-fold analysis. It includes sub-sections explaining the procedure followed to divide Autoroute 50 and Route 148 into homogeneous segments; the volume projection; the alternative designs considered; the safety evaluation methodology, including the collision rate method and the Empirical Bayes approach; and the process used to undertake the benefit cost analysis.

Segmentation Procedure

The study area was further divided into shorter and more homogeneous segments in order to calculate safety levels based on the segments' characteristics. The following criteria have been applied for the segmentation, depending on the location:

- Divided/undivided lanes;
- Interchange and major intersection areas;
- Number of lanes;
- Area type; and,
- Speed limit.

Autoroute 50 has been divided into 40 segments with a total length of 71 km, including the divided portion of the highway, and Route 148 has been divided into 21 segments with a total length of 40 km.

After the segments were created, the collisions were assigned to the segment corresponding to their location based on chainage information. Collisions impossible to locate due to missing information and collisions located on ramps have been removed. For each segment, the number of collisions was calculated for different severity levels: personal damage only (PDO), minor injuries, severe injuries, and fatal.

Collision history was available for a period of 9.9 years for most segments. However, due to the recent opening of the 50-East section, collision history was only available for periods of 4.6 years and 0.75 year for the new link of Autoroute 50.

Volume Projection

Since the traffic volumes were not available for each year of the study period, different methodologies were used to project the missing volume. First, a short term rate was used to project the volumes from the latest year with available AADT information to the base year of 2010. This short term rate was calculated based on available historic AADTs. Second, a long term growth rate, previously calculated for the area, has been used to project AADTs from 2010 onwards.

Starting in 2012, Autoroute 50 will provide a direct, complete connection between the regions of Outaouais and Laurentides, and will be part of an expressway network between the cities of Gatineau and Montréal. This is achieved in steps, with the opening of new links in 2004, 2008, 2011, and 2012. With the opening of each new link, it is expected that drivers previously using Route 148 and the 417 expressway in Ontario will start using Autoroute 50. Therefore the Autoroute 50 projected AADTs include four point-in-time increases, reflecting those volume transfers.

Design Alternatives

Different design alternatives were analysed to understand their impact on safety for the 50-East section. These alternatives include the do nothing option; the implementation of median rumble strips and additional passing lanes (alternative A); the implementation of median rumble strips without the addition of passing lanes (alternative B); the installation of a concrete median barrier (alternative C); the installation of a cable median barrier (alternative D); and the construction of the additional lanes required to modify the 50-East section into a divided expressway (alternative E).

The following characteristics were assumed for alternative designs. Median rumble strips are considered to be 0.5 m wide strips implemented by reducing the lane width from 3.7 m to 3.5 m. Passing lanes would be added to the current configuration with the objective of offering 2 km long passing lanes with 5 km in between, but have been modified to take into account the current geometric characteristics and the existing physical constraints (e.g. overpasses, ramps). The concrete barriers would have a width of 0.65 m and be installed in the centre of the roadway. Inside shoulders would be widened to a minimum of 1.3 m, or more in horizontal curve areas, while the width of outside shoulders would be reduced compared to existing. Finally, cable barriers would include a cable barrier width of 150 mm inside of a central 2 m wide zone. The outside shoulder width would be reduced by approximately 1 m. It should be noted that this configuration does not allow for an inside shoulder width accommodating the full displacement of the cable barrier, therefore still allowing for a vehicle to cross the median to the opposite direction lane, but the vehicle would be redirected onto its travel lane by the cable barrier.

Safety Evaluation Methodology

Collision Rate

The first method used to evaluate the safety levels for each segment was the collision rate method. This method uses two different safety indicators to identify segments where the number or severity of collisions could be a concern.

The first indicator is the collision rate (R). The collision rate is first calculated for each segment based on the collision frequency, the number of years studied, and the segment length and AADT; and it is then compared to a critical collision rate (R_c). A collision rate lower than or equal to the critical collision rate indicates a normal safety performance for the studied segment. However, a collision rate higher than the critical collision rate indicates a safety concern for the studied segment.

The second indicator is the severity index (I_s). It is calculated based on the number of collisions of each severity type (fatal, severe injuries, minor injuries, and PDO), with a larger weight given to more severe collisions. It is then compared to the severity index for comparable locations ($I_{s\ comp}$). A severity index lower than or equal to the comparable severity index indicates that the average collision severity on the segment is similar to or better than the average severity in comparable locations. Conversely, a severity index higher than the one for comparable sites suggests collisions on the studied segment tend to be more severe on the road segment than on similar roads.

Empirical Bayes (EB) Approach

The second method used to evaluate the safety levels for each segment was the Empirical Bayes (EB) approach. This approach combines the number of observed collisions (f) and the number of predicted collisions (f_p) from safety performance functions (SPFs) to obtain the long term expected number of collisions (f_{EB}) for each road segment, as shown in Figure 2.

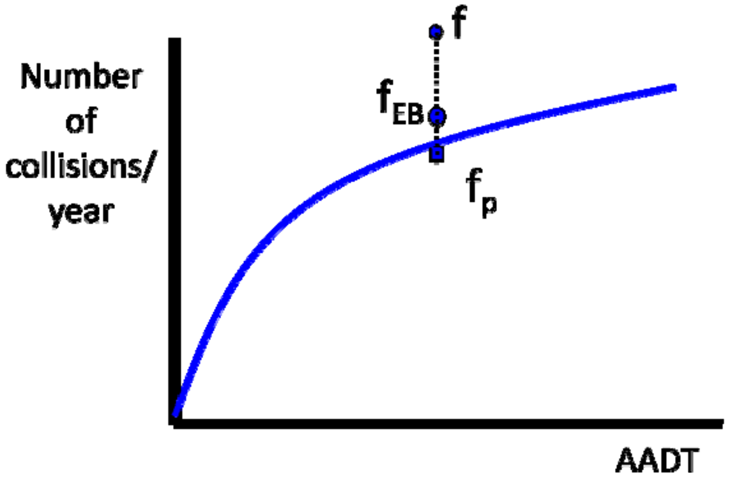

Figure 2 - EB Approach

First, the number of predicted collisions is calculated based on SPFs developed for the studied area or for similar locations, and collision modification factors (CMFs), used to account for the differences in geometric characteristics between the studied segments and the SPFs. This is shown by the equation below.

$$f_p = Number\ of\ collisions\ from\ SPF \times CMF_{TOT}$$

Where:

$$CMF_{TOT} = \prod_k CMF_k$$

For k = each CMF applicable for the alternative considered.

For this study, no SPFs were specifically developed for the segments studied due to limited available data. The SPFs chosen from literature were developed for Ontario and the United States, for intersections, undivided highways with two and four lane cross-sections, and divided highway with four lane cross-section. The SPFs used are the following:

Table 1 - Safety Performance Functions

Intersections				
	Log Intercept (a)	Coefficient of AADT$_{major}$ (b)	Coefficient of AADT$_{minor}$ (c)	Dispersion Factor (k)
Equation	$N = e^{(a)} + AADT_{major}^{(b)} + AADT_{minor}^{(c)}$			
All collisions	-5.73	0.60	0.20	0.11
Fatal and injury collisions	Stop-controlled intersections (minor roads): 41.7% of total collisions Signalized intersections: 37.7% of total collisions			

Undivided 2-lane cross section			
	Log Intercept (a)	Coefficient of AADT (b)	Dispersion Factor (k)
Equation	$N = e^{a} \times AADT^{b} \times SL$		
All collisions	-4.7287	0.5673	0.1497
Fatal and injury collisions	-7.0925	0.6696	0.1537

Undivided 4-lane cross section			
	Log Intercept (a)	Coefficient of AADT (b)	Dispersion Factor (k)
Equation	$N = e^{a} \times AADT^{b} \times SL$		
All collisions	-11.1188	1.2205	0.2390
Fatal and injury collisions	-11.4111	1.1045	0.1024

Divided 4-lane cross section			
	Log Intercept (a)	Coefficient of AADT (b)	Dispersion Factor (k)
Equation	$N = e^{a} \times AADT^{b} \times SL$		
All collisions	-16.6250	1.5881	0.7384
Fatal and injury collisions	-16.0511	1.4300	0.5115

Sources: [1, 2, 3, 4]

These SPFs were also complemented by CMFs. The CMFs used are the following:

Table 2 - Collision Modification Factors

Characteristics	Alternative Design	CMF Value for All Collisions	CMF Value for Fatal and Injury Collisions
Passing lane	Do nothing Median rumble strips with additional passing lanes	0.75	0.75
Median rumble strip	Median rumble strips with additional passing lanes Median rumble strips without additional passing lanes	0.85	0.86
Concrete Median Barrier	Concrete median barrier	1.24	0.70
Cable Median Barrier	Cable median barrier	1.34	0.85*

Source: [5]

*Note: The original factor found was 0.70, but as the design of the cable median barrier used for this project is different from the design used to develop the CMF, the efficiency of this measure has been reduced by half from its original value.

Once the observed and the predicted number of collisions are known, the expected number of collisions for the reference year (2009) can be found using the following equation:

$$f_{EB}^{2009} = w_1 \times f + w_2 \times f_p$$

Where:

f_{EB}^{2009} = expected number of collisions for the year 2009
w_1 = multiplicative factor 1
f = number of observed collisions
w_2 = multiplicative factor 2
f_p = predicted number of collisions, function of AADT, SPFs, CMFs

The multiplicative factors w_1 and w_2 are calculated as follows:

$$w_1 = \frac{f_p}{{}^{1}/_{k} + n \times f_p}$$

$$w_2 = \frac{{}^{1}/_{k}}{{}^{1}/_{k} + n \times f_p}$$

Where:

f_p = predicted number of collisions
k = dispersion parameter
n = number of years

Then, as no collision history was available past the year 2009, the following equation was used to find the expected number of collisions for the base year (2010):

Where:

f_{EB}^{2010} = expected number of collisions for 2010
f_{EB}^{2009} = expected number of collisions for 2009
f_{p}^{2010} = predicted number of collisions for 2010, function of projected AADTs for 2010, SPFs and CMFs
f_{p}^{2009} = predicted number of collisions for 2009

Once the number of expected collisions was found for each segment, it was compared to the number of predicted collisions for the same segment, as this number represents the average number of collisions for a similar roadway. A higher number of expected collisions than predicted collisions ( ) was found to indicate a safety concern for the studied segment.

Following the safety analysis for the current (2010) situation, alternative designs were analysed to understand their impact on safety levels. To complete this analysis, the expected numbers of collisions for alternative designs, for years 2011 to 2030, were found using the following equation:

Where:

i = year
j = alternative design
f_{EB} = estimated number of collisions
f_{p} = predicted number of collisions, function of AADT, SPFs, CMFs

This process is shown in Figure 3 below.

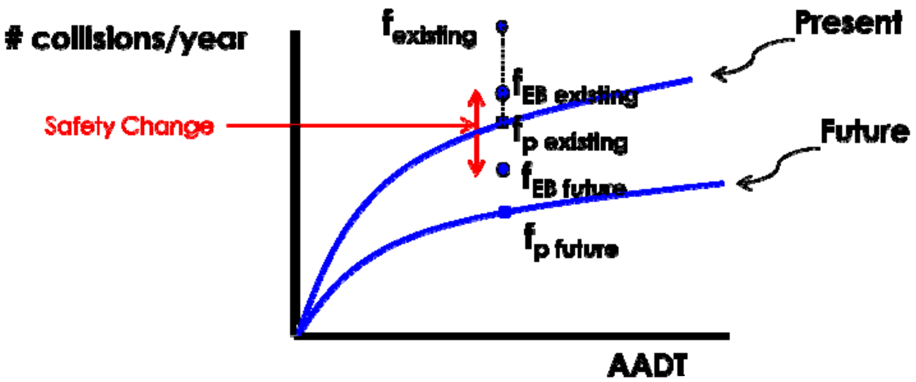

Figure 3 - Present and Future Expected Number of Collisions

The safety change can be evaluated through the calculation of the long term potential for safety improvements by calculating the index of effectiveness for each year and each alternative design. The equation used to calculate the index of effectiveness is the following:

$$I_e = \frac{\left(\frac{f_{EB}^{i,j}}{f_{EB}^{2010}}\right)}{1 + \left(\frac{Var(f_{EB}^{2010})}{(f_{EB}^{2010})^2}\right)}$$

Where:

i = year

j = alternative design

I_e = index of effectiveness

$f_{EB}^{i,j}$ = estimated number of collisions for year i and alternative j

f_{EB}^{2010} = estimated number of collisions for 2010 and the existing design

Source: [6]

An index of effectiveness greater than one ($I_e > 1$) indicates the alternative design creates a decrease in safety, whereas an index of effectiveness lower than one ($I_e < 1$) indicates the alternative design creates an increase in safety.

Benefit Cost Analysis

After evaluating the safety levels of both roadways and the suggested design alternatives for Autoroute 50, a benefit cost analysis was performed to evaluate the cost effectiveness of the different alternative designs.

Benefits

The number of collisions saved per year on the 50-East section for each alternative design was calculated by using the following equation:

$$\begin{aligned} &Collisions\ saved\ for\ alternative\ j\ and\ year\ i \\ &\quad = Expected\ number\ of\ collisions\ for\ alternative\ j\ and\ year\ i \\ &\quad - \sum Expected\ number\ of\ collisions\ for\ do\ nothing\ option\ and\ year\ i \end{aligned}$$

The total number of collisions saved for each alternative design, for years 2011 to 2030 was calculated using the following equation:

$$\begin{aligned} &Total\ collisions\ saved\ for\ alternative\ j\ from\ 2011\ to\ 2030 \\ &\quad = \sum_{i=2011}^{2030} Collisions\ saved\ for\ alternative\ j\ and\ year\ i \end{aligned}$$

The total collisions saved for alternative j from 2011 to 2030 (TCS_j) was then used to find the benefit value, for each alternative, using the following equation:

$$\begin{aligned} &Benefit\ for\ alternative\ j \\ &\quad = TCS_j \times \%PDO \times CostPDO \\ &\quad + TCS_j \times \%MinI \times CostMinI \\ &\quad + TCS_j \times \%MajI \times CostMajI \\ &\quad + TCS_j \times \%F \times CostF \end{aligned}$$

Where:

j = alternative design
%PDO = Percentage of total collisions that are PDO collisions
CostPDO = Societal cost of a PDO collision
%MinI = Percentage of total collisions that are minor injury collisions
CostMinI = Societal cost of a minor injury collision
%MajI = Percentage of total collisions that are major injury collisions
CostMajI = Societal cost of a major injury collision
%F = Percentage of total collisions that are fatal collisions
CostF = Societal cost of a fatal collision

These calculations were done for total collisions and fatal and injury collisions. It should also be noted that for some alternatives, the number of total collisions was greater than for the do nothing option, but the severity of those collisions was reduced.

Societal costs of collisions vary depending on the jurisdiction, but the societal costs accepted by MTQ for the human capital method were used for this analysis. These costs, in 2006 dollars, include $591,258 for fatal collisions, $160,823 for major injury collisions, $19,816 for minor injury collisions, and $12,351 for PDO collisions [7].

Costs

The costs were calculated based on construction costs for the design alternatives. It should be noted that the costs calculations did not include the maintenance costs, which are negligible compared to constructions costs. They also did not consider some specific geotechnical treatment costs as well as the construction of new bridges or the widening of existing ones, except in the case of the construction of the additional lanes required for a divided freeway.

Costs have first been calculated for a linear meter of highway, and then projected to the full length of the 50-East section in order to obtain total costs for each alternative design.

Benefit Cost Ratio

After both the benefits and the costs have been calculated and capitalized, the benefit-cost ratio was found for each alternative design, using the following equation.

$$Benefit\ Cost\ Ratio = \frac{Capitalized\ Benefits\ Value}{Capitalized\ Costs\ Value}$$

The benefit cost ratio was calculated for each year between 2011 and 2030, for each alternative design. When the ratio became greater than one, the alternative's benefits were considered to outweigh its costs.

RESULTS

This section presents the results obtained from the safety analysis of Autoroute 50 and Route 148 in terms of safety of existing conditions, safety of proposed alternative designs, and the results of the benefit cost analysis.

Measuring Safety of Existing Condition

The safety of existing conditions was measured for Autoroute 50 and Route 148 for the year 2010.

First, the number of collisions per section are shown below. It should be noted that since some links of Autoroute 50 have only recently been opened to traffic, the number of years with collision history varies.

Table 3 - Collisions per Section

Section	Number of years with data	Total number of collisions	Minimum number of collisions for 1 segment	Maximum number of collisions for 1 segment	Average number of collisions per segment	Standard deviation
50-West	9.9 4.6	828	1	131	27.6	29.8
50-East	4.6 0.75	36	0	13	3.6	4.6
148-West	10	595	9	156	59.5	53.9
148-East	10	805	9	231	73.2	67.2

Analysis of the safety level for each section was done with the collision rate method and the EB approach. Results for both methods are summarized below using the number and percentage of segments raising safety concerns. The results for the collision rate method are presented first, showing the number and proportion of segments where the collision rate was higher than the critical collision rate, and where the severity index was higher than that of comparable sites.

Table 4 - Results - Collision Rate Method

Collision Rate Method		
	Autoroute 50	Route 148
Total number of segments	40	21
Number of segments where $(R > R_c)$	2 *(5%)*	3 *(14%)*
Number of segments where $(I_s > I_{s\,comp})$	10 *(25%)*	9 *(43%)*

The collision rate method showed very few segments causing safety concern on the base of the comparison between the collision rate and the critical collision rate. Although no direct comparison is possible between the collision rates of both highways, Autoroute 50 showed fewer segments with a collision rate above the critical rate than Route 148. In terms of the severity of collisions, it is again impossible to make a direct comparison between severity indexes on both highways, but Autoroute 50 showed proportionally less segments than Route148 where the severity of collisions was above that of comparable sites.

The results found using the EB approach are presented below, showing the number and percentage of segments having a potential for safety improvement. Results are shown for all collisions as well as fatal and injury collisions.

Table 5 - Results - Empirical Bayes Approach

Empirical Bayes Approach		
	Autoroute 50	Route 148
Total number of segments	40	21
Number of segments where $f_{EB} - f_p > 0$ for total collisions	28 *(70%)*	17 *(81%)*
Number of segments where $f_{EB} - f_p > 0$ for fatal and injury collisions	18 *(45%)*	16 *(76%)*

These results show that using the EB approach, Autoroute 50 shows proportionally less segments where safety is a concern than Route 148. This is true for calculations made with all collisions and with fatal and injury collisions. These results illustrate that a large proportion of segments of both Autoroute 50 and Route 148 have potential for safety improvements, indicating that more collisions are recorded on Autoroute 50 and Route 148 than on similar highways.

Measuring Safety of Proposed Alternative Designs

In an attempt to improve safety levels, different alternative designs were recommended, for their potential effectiveness at increasing safety levels. They were evaluated using the index of effectiveness for different years (2011, 2020, 2030), for each alternative. The indexes of effectiveness are presented below for each proposed alternative design.

Table 6 - Indexes of Effectiveness

Index of effectiveness	Years		
	2011	**2020**	**2030**
Alternative A			
Total Number of Collisions	0.79	0.80	0.81
Fatal and Injury Collisions	0.45	0.59	0.65
Alternative B			
Total Number of Collisions	0.82	0.84	0.84
Fatal and Injury Collisions	0.47	0.62	0.68
Alternative C			
Total Number of Collisions	1.18	1.21	1.22
Fatal and Injury Collisions	0.39	0.51	0.56
Alternative D			
Total Number of Collisions	1.27	1.30	1.22
Fatal and Injury Collisions	0.47	0.62	0.68
Alternative E			
Total Number of Collisions	0.06	0.10	0.13
Fatal and Injury Collisions	0.06	0.12	0.16

Results of the index of effectiveness analysis indicate that all measures would reduce the number of fatal and injury collisions. Additionally, the median rumble strip, with or without the additional passing lanes (alternatives A and B), and the construction of the lanes required for a divided expressway (alternative E) would all reduce the total number of collisions. The implementation of a concrete or cable median barrier (alternatives C and D) would increase the total number of collisions. This result was expected, as concrete and cable median barriers usually tend to increase the PDO collisions, but reduce the fatal and injury collisions.

The most effective alternative for reducing all collisions would be the construction of the divided expressway. The results also show that the construction of additional passing lanes have a minimal effect on safety after the implementation of median rumble strips.

Benefit and Cost Analysis

After evaluating the safety benefits of implementing different alternative designs, their costs should also be taken into consideration. The costs estimated for the different alternative designs are presented below. A contingency of 25% was applied to all costs.

Table 7 - Construction Costs

	Construction Costs	
Alternative Design	Cost per linear metre $/lin m	Total Costs for 50-East Section $
Median rumble strips with additional passing lanes	150	2,767,500
Median rumble strips alone	14	258,300
Concrete median barrier	2,200	40,590,000
Cable median barrier	650	11,992,500
Construction of additional lanes required for a divided freeway	8,000 – 12,000	147,600,000 – 221,400,000

The benefits were calculated for each alternative design, for each year from 2011 to 2030. After capitalization, the benefit cost ratios were calculated for every alternative design and every year, for the predicted total number of collisions and fatal and injury collisions. These ratios are presented below.

Table 8 - Benefit Cost Ratios

	Benefit Cost Ratios									
	Total Collisions					Fatal and Injury Collisions				
Year	Alternative A	Alternative B	Alternative C	Alternative D	Alternative E	Alternative A	Alternative B	Alternative C	Alternative D	Alternative E
2011	0.03	0.33	0.00	-0.01	0.00	0.08	0.81	0.01	0.01	0.00
2012	0.07	0.67	-0.01	-0.01	0.00	0.15	**1.55**	0.01	0.01	0.00
2013	0.11	**1.02**	-0.01	-0.02	0.00	0.20	**2.11**	0.02	0.02	0.00
2014	0.15	**1.36**	-0.01	-0.03	0.00	0.26	**2.74**	0.02	0.02	0.00
2015	0.18	**1.70**	-0.02	-0.04	0.00	0.33	**3.41**	0.02	0.03	0.00
2016	0.22	**2.04**	-0.02	-0.05	0.00	0.39	**4.08**	0.03	0.04	0.00
2017	0.25	**2.37**	-0.02	-0.06	0.00	0.45	**4.73**	0.03	0.04	0.00
2018	0.29	**2.70**	-0.03	-0.06	0.00	0.52	**5.38**	0.04	0.05	0.00
2019	0.32	**3.02**	-0.03	-0.07	0.00	0.58	**6.02**	0.04	0.05	0.01
2020	0.36	**3.34**	-0.04	-0.08	0.00	0.64	**6.65**	0.05	0.06	0.01
2021	0.39	**3.66**	-0.04	-0.09	0.00	0.70	**7.27**	0.05	0.06	0.01
2022	0.43	**3.97**	-0.04	-0.10	0.00	0.76	**7.88**	0.05	0.07	0.01
2023	0.46	**4.28**	-0.05	-0.10	0.00	0.81	**8.49**	0.06	0.07	0.01
2024	0.49	**4.59**	-0.05	-0.11	0.00	0.87	**9.09**	0.06	0.08	0.01
2025	0.53	**4.90**	-0.05	-0.12	0.00	0.93	**9.68**	0.07	0.08	0.01
2026	0.56	**5.20**	-0.06	-0.13	0.00	0.98	**10.26**	0.07	0.09	0.01
2027	0.59	**5.50**	-0.06	-0.14	0.00	**1.04**	**10.84**	0.07	0.09	0.01
2028	0.63	**5.79**	-0.07	-0.14	0.00	**1.10**	**11.42**	0.08	0.10	0.01
2029	0.66	**6.09**	-0.07	-0.15	0.00	**1.15**	**11.98**	0.08	0.10	0.01
2030	0.69	**6.38**	-0.07	-0.16	0.00	**1.21**	**12.55**	0.09	0.11	0.01

As shown from the benefit cost ratios for both total collisions and fatal and injury collisions, only the option of median rumble strips without the additional passing lanes reached a ratio above one before the 2030 future horizon for all collisions. Looking only at the fatal and injury collisions, the option of median rumble strips with additional passing lanes also reaches a ratio above 1 before 2030, but years later than the option of median rumble strips without additional passing lanes. This implies that the high costs of other designs more than offset their benefits in terms of improved safety.

COMPARATIVE ANALYSIS

Following the safety analysis of Autoroute 50 and Route 148, a comparative analysis was also completed to understand the impact on safety of the Autoroute 50 new 50-East section. This comparative analysis was done to address the population's concerns about the safety level of the 50-East section, and that opening the 50-East section to traffic would have decreased the safety level of the highway network in the area.

To understand this impact of the 50-East section, safety levels were compared for two scenarios: scenario 'A' is the existing situation, with the 50-East section open; while scenario 'B' considers the hypothetical situation where the 50-East section would not be opened to traffic. Calculations were completed for both scenarios using the collision rate method and EB approach, with 2010 conditions. In the case of scenario 'A', volumes projected from 2009 have been used to predict the number of collisions on both roadways. For scenario 'B', volumes used were estimated by averaging the 2010 predicted volumes on the 50-East section and transferring them to the 148-West section. The results are presented below, using both the collision rate method and the EB approach.

Table 9 - Comparative Analysis

		Number of collisions/year	
		Total	Fatal and Injury
Collision Rates Method			
Scenario A	Autoroute 50	12.32	3.08
	Route 148	50.30	12.80
	Total	**62.62**	**15.88**
Scenario B	Route 148	93.14	24.13
	Total	**93.14**	**24.13**
EB Approach			
Scenario A	Autoroute 50	14.22	3.34
	Route 148	38.26	6.59
	Total	**52.48**	**9.93**
Scenario B	Route 148	56.37	10.27
	Total	**56.37**	**10.27**

For both approaches, the conclusion drawn from this analysis is that safety levels were improved with the opening of the 50-East section of Autoroute 50. In fact, the number of collisions on the 50-East and 148-West sections combined (scenario 'A') is lower than the number of collisions on the 148-West section where the 50-East section is not opened to traffic (scenario 'B'). This indicates that had the 50-East section not been opened to traffic, the safety level would have been inferior to what it currently is.

SUMMARY AND CONCLUSION

Results from this study indicate that Autoroute 50 has proportionally less segments raising safety concerns than Route 148. It was also found that results from both the collision rate method and the Empirical Bayes approach differ in relation to the number and location of segments where safety concerns were raised. The EB approach was found to be more sensitive, identifying a greater number of locations where the potential for safety improvement exists. In comparison, the collision rate method identified a smaller number of segments where the collision rate was larger than the critical collision rate, or where the severity index was larger than the severity index for comparative sites. The collision rate method therefore seems to underestimate the number of locations where potential for safety improvement exists. This could be due to the fact that the collision rate method does not take into account the regression to the mean phenomenon, and is based on the assumption of linearity between the volumes and the number of collisions. Additionally, the collision rate method does not allow for direct comparison of safety levels on different highway types.

Results also showed that Autoroute 50 appears to provide a safer driving environment than Route 148. This is reflected by the proportionally smaller number of segments where a safety concern was raised, and also through the comparative analysis, where it was shown that the scenario with both Autoroute 50 and Route 148 opened provided better safety levels than a hypothetical scenario where the 50-East section is not opened to traffic.

Alternatives designs were considered for the 50-East section, and their impact on safety was analyzed. All alternative designs showed improvements in safety levels, but the alternative C, concrete median barrier, and alternative D, cable median barrier showed an increase in the number of collisions of the PDO type. However, after a benefit cost analysis, the alternative B, median rumble strips without additional passing lanes, proved to be a better option by far for the study period.

Some difficulties were encountered during this study that could influence the findings, including the limited collision data due to the fact that this section has only recently been opened to traffic, and the very short period of collision data. Additionally, there are no safety performance functions developed for similar Québec highways, particularly for Autoroute 50. The 50-East section of this highway is unusual as it is undivided, has a cross-section varying between 2 and 4 lanes, and has limited access control. The development of safety performance functions and collision modification factors for similar Québec highways would help improve the findings.

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