Highway 3 Twinning Feasibility: A Cost-Benefit Analysis

A Report Prepared for the Highway 3 Twinning Development Association

by

Kien C. Tran, Ph.D.
Professor
Department of Economics
University of Lethbridge

Revised: April 22, 2017
I would like to take this opportunity to express my gratitude to Alberta Transportation, AMA, Alberta Tourism and Culture, Transportation Association of Canada and Lethbridge Economic Development for providing historical data, sources and information relating to this project. Without their generous support, it would not be possible to complete this project. Also, I would like to thank, without any implications, Jerry Lau, Dr. Kamar Ali, Dr. Stavroula Malla and Jeff Davidson for stimulating discussions relating to this project. Finally, I would also like to thank Gloria Roth and all the Highway 3 Twinning Development Association Members for the opportunity to work on this project.
This report presents the results of an economic feasibility analysis to determine the costs and benefits associated with twinning construction of the remaining (approximately) 220 kilometers of Alberta Highway 3 known as Crowsnest Pass Highway. The main benefits that accrue from twinning Highway 3 include not only for safety improvement/time saving but also for increase in social/economic activities, tourism and agricultural needs. The main objective of this report is to perform a high-level assessment that will help determine whether the twinning investment is worthy to pursue, given the financial availability and infrastructure budgetary commitment.

The idea of twinning Highway 3 has been previously discussed, and the costs and benefits study have been conducted by the Van Horne Institute, at the University of Calgary under the direction of Dr. Frank J. Atkins in 2002 and 2004 (revised report). The results from the final report show that the benefit-cost ratios vary from 3.03 (using 10% real discount rate) to 3.65 (using 4% real discount rate) indicating the highway 3 twinning is a worthy investment. Those benefit calculations were based on differences between real gross domestic product (GDP) forecasts with and without highway capitals for Southern Alberta region (economic activities). In this report, we provide an alternative (and can be taken as complement to the previous report) benefit calculations and update the cost estimation of the twinning project. The methodology for this analysis can be summarized as follows.

1. Research and analyze traffic volumes, tourism, pattern and flows, economic and demographic data for the study area (from Fort Macleod to Crowsnest Pass, Waterton Lakes National Park, and from Taber to Medicine Hat).

2. Develop a cost-benefit analysis (CBA) model in a risk analysis framework, allowing for the estimation of costs and benefits associated with Highway 3 twinning construction. We include the following categories of costs and benefits in the CBA:
(a) Direct cost of Highway 3 twinning construction and operations, maintenance and rehabilitations costs thereafter;

(b) Travel time cost savings;

(c) Accident cost savings;

(d) Vehicle operating cost and emission cost savings; and

(e) Tourism, commercial catchment basin and local trade area.

3. Conduct Risk analysis to account for the uncertainty surrounding the key assumptions used in the model. The risk analysis reveals the spectrum of potential outcomes given its probability of occurrences. That is, it reveals the magnitude of both the downside and the upside of the project given the possible fluctuations in the assumptions.

4. Run Monte Carlo simulation, applying appropriate discount rate, and calculate the benefit/cost ratio of the Highway 3 twinning.

5. Provide a matrix summary of the findings and offer recommendations.

Results of the cost-benefit analysis in this report demonstrate that the net present value of Highway 3 twinning project over twenty years, using Alberta Transportation recommended real discount rate of 4%, exceed $2.3 billions dollars. Or equivalently in terms of benefit-cost ratio, the analysis shows that for each dollar spent on this project, there is $2.97 in benefits which translates into the internal rate of return of 12.3%. Consequently, for a public infrastructure investment, these results are highly significant and demonstrate the worthiness of the twinning investment project.

From an economic perspective, the assessment of uncertainty in the forecast proves further worthiness of the investment. Given the assignment of probabilities of all technical assumptions that were used in generating the forecasts and with two standard discount rates that are recommended by the Alberta Transportation (AT) and the Canadian Federal Treasury Board (CFTB), the tables below show that the Highway 3 twinning project offers the public over 90% assurance of generating more benefits than costs.
Summary of the Results Based on Risk Analysis  
(In Millions of 2016 Dollars)  
Discount rate = 4% (AT)

<table>
<thead>
<tr>
<th>Discounted Categories</th>
<th>Most Likely Outcome</th>
<th>90% Probability of Exceeding</th>
<th>10% Probability of Exceeding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Benefits</td>
<td>$3,550.39</td>
<td>$3,482.14</td>
<td>$3,707.15</td>
</tr>
<tr>
<td>Total Project Costs</td>
<td>$1,197.13</td>
<td>$1,158.51</td>
<td>$1,217.85</td>
</tr>
<tr>
<td>Net Present Value</td>
<td>$2,353.36</td>
<td>$1,998.23</td>
<td>$2,501.432</td>
</tr>
<tr>
<td>Benefit-Cost Ratio</td>
<td>2.97</td>
<td>2.12</td>
<td>3.46</td>
</tr>
<tr>
<td>Internal Rate of Return</td>
<td>12.3%</td>
<td>8.6%</td>
<td>21.5%</td>
</tr>
</tbody>
</table>

Source: based on author’s calculations. The data were obtained from Alberta Transportation, Alberta Culture and Tourism, AMA, Alberta Treasury Board and Finance (Southern Alberta Region) and Environics Research/Economic Development Lethbridge. A computer program @RISK was used to compute the above probabilities via Monte Carlo simulations.
# TABLE OF CONTENTS

Executive Summary ...........................................................................................................3
List of Figures ....................................................................................................................7
List of Tables ....................................................................................................................7

1. Introduction ....................................................................................................................8
   1.1 Report Objective and Methodology Overview .........................................................8
   1.2 Brief Description of Highway 3 ...........................................................................10
   1.3 Past Reports on Highway 3 Twinning Study .........................................................12
   1.4 Plan of the Report ...............................................................................................12

2. Cost and Benefit Methodology ....................................................................................13

3. Study Findings .............................................................................................................15
   3.1 Costs Estimates ...................................................................................................15
   3.2 Benefits Estimates ..............................................................................................16
   3.3 Net Present Value and Benefit-Cost Ratio ............................................................18
   3.4 Risk Analysis ......................................................................................................19

4. Concluding Remarks ..................................................................................................20

Appendix A – Benefits Estimation and Risk Analysis ......................................................23
   A.1 Benefits of Highway 3 Twinning ...........................................................................23
   A.1.1 Travel Time Cost Savings ................................................................................23
   A.1.2 Accident Cost Savings ....................................................................................24
   A.1.3 Vehicle Operating and Emission Cost Savings ................................................25
   A.1.4 Tourism and Others ......................................................................................27
   A.2 Main Assumptions and Risk Analysis ..................................................................28
   A.2.1 Main Assumptions ..........................................................................................28
   A.2.2 Assumption Ranges .......................................................................................30
   A.2.3 Risk Analysis .................................................................................................31
LIST OF FIGURES

Figure 1: Benefits Break Down Over Twenty Years .................................................17
Figure 2: Discounted Benefits Over Twenty Years ................................................17
Figure 3: Risk Analysis Results of Net Present Value .............................................20
Figure 4: Risk Analysis Results of Benefit-Cost Ratio ..........................................20
Figure 5: PV of Benefits of Tourism and Trade .....................................................28
Figure 6: Example of a Structure Model ...............................................................32

LIST OF TABLES

Table 1: Traffic Volume (AADT, 2015) .................................................................11
Table 2: Summary of Analysis .............................................................................18
Table 3: Sensitivity Analysis of Real Discount Rate .............................................19
Table 4: Summary of Results Based on Risk Analysis .........................................21
Table 5: Collision Severity on Highway 3: 2005 – 2014 .......................................24
Table 6: Example of Data Sheet for Value of Time ..............................................33
1. INTRODUCTION

1.1 Report Objective and Methodology Overview

In June 2016, Alberta Transportation announced that it would fund the Highway 3 Twinning Development Association to update a 2002 (and revised 2004) Van Horne Institute study related to the twinning of Highway 3 from B.C. border to the Medicine Hat. From the infrastructure investment perspective, this approach is used in the case where the proposed twinning highway investment is at the conceptual stage and a high-level assessment will help determine whether the investment is worthy of advancement to the next stage. The next step would likely be - if the proposed twinning is to be seriously considered - a financial feasibility study and environmental assessment of the project. This report outlines the findings of this cost-benefit analysis. Note that this report is not simply an update of the 2002 Van Horne Institute study (i.e., updating the previous study using current data), but it provides an alternative cost-benefit analysis to the 2002 study. In some sense, the results of the analysis can be viewed as complimentary to those results in the 2002 study.

Therefore, the main objective of this report is to perform an independent social/economic feasibility in a risk analysis framework to assess the costs and benefits associated with the twinning construction of Highway 3, mainly from the B.C. border to the town of Fort MacLeod, and from the town of Taber to Medicine Hat. The assessment of the costs and benefits of this investment consists of the following:

(a) Research traffic, demographic, and socioeconomic data from the available sources;
(b) Estimate the comprehensive social benefits and costs;
(c) Conduct risk analysis to account for assumptions and uncertainty in the model parameters.

As mentioned above, in this analysis, twinning construction from B.C. border to Fort Macleod, and from Taber to Medicine Hat are examined. The Cost-Benefit Analysis (CBA) is performed in order to quantify the worthiness of the Highway 3 Twinning construction project. The CBA
estimates and totals up to the equivalent money value of the benefits and costs to the community of twinning project to determine whether they are worthwhile. In other words, it is an analysis of expected balance of benefits and costs, including an account of foregone alternatives and the status quo.

Both costs and benefits can be diverse. Financial costs (or direct costs) can be easily determined due to relatively abundant market data. Benefits may include cost saving and public willingness to accept compensation (implying that public has the right to benefit from the project) for the welfare change resulting from the project. The impact of a project is the difference between what the situation in the study area would be with and without the project. That is, when a project is being evaluated, the analysis must estimate not only what the situation would be with the project but also what it would be without the project.

The main criteria for the project’s decision is to examine the difference between the discounted present value of benefits and the discounted present value of costs (i.e., net present value). If the net present value is positive, or equivalently, the ratio of discounted present value of benefits to the discounted present value of costs exceeds one, then the project is worthwhile.

The costs of Highway 3 twinning construction include the following:

(a) Direct cost of Highway 3 twinning construction;
(b) Maintenance costs;

It should be noted that the surrounding areas for construction are not all equalled as there are approximately 25 kilometers from the B.C. border to the Crowsnest Pass area that are considered to be ‘difficult’ due to the mountainous terrain. Consequently, the costs of twinning (direct and OMR) this part of the highway will be higher.

The estimated benefits of Highway 3 twinning construction in this analysis include the following:

(a) Travel time cost savings;
(b) Accident cost savings;
(c) Vehicle operating cost savings and emission cost savings;
(d) Other economic benefits (tourism and agricultural needs).
1.2 Brief Description of Highway 3

Alberta Provincial Highway No. 3, commonly known as Highway 3, with its entire length of 324 kilometers (201 miles), is a highway that transverses southern Alberta, Canada, connecting the Crowsnest Pass to the Trans-Canada Highway in Medicine Hat, and it serves as an alternative route to the Trans-Canada from Lower Mainland to the Canadian Prairies. Highway 3 in Alberta begins in the Canadian Rockies at Crowsnest Pass, parallel to the Canadian Pacific Railway. It winds through the foothills of southern Alberta past Pincher Creek to a major junction at Highway 2 west of Fort Macleod where it becomes a divided highway and part of Alberta’s “Export Highway” - a name given to the southern portion of Alberta’s north-south trade corridor which is a segment of the CANMEX Corridor that stretches from Alaska to Mexico. The divided Highway then curves northeast to Monarch where it crosses the Oldman River and meets Highway 23 before bending back southeast. It bisects the city of Lethbridge as an expressway named Crowsnest Trail that carries nearly 35,000 vehicles per day, the busiest section of the highway. Crowsnest Trail marks the northern termini of Highways 4 and 5; the former is a major route that assumes the designation of the Export Highway, connecting to Interstate 15 in Montana, whilst the latter branches south west to Magrath and Cardston. Continue east alongside the railway and Highway 3 passes through Coaldale en route to Taber, after which the divided highway reverts to a two-lane that carries past farmland into Cypress County. The highway ends at the Trans-Canada Highway (Highway 1) in Medicine Hat. Table 1 below shows an example of the traffic volumes at several locations along Highway 3 based on an average of daily vehicle count over the span of a year for 2015 (AADT).

---

1 Part of this section is taken from Wikipedia on Alberta Highway 3.
Table 1: Traffic Volumes (AADT, 2015)

<table>
<thead>
<tr>
<th>Location</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.C. Border</td>
<td>4,520</td>
</tr>
<tr>
<td>Brocket</td>
<td>4,850</td>
</tr>
<tr>
<td>Hwy 2 W. of Fort Macleod</td>
<td>9,900</td>
</tr>
<tr>
<td>Kipp</td>
<td>15,050</td>
</tr>
<tr>
<td>Hwy 25 Lethbridge</td>
<td>25,360</td>
</tr>
<tr>
<td>Oldman River Lethbridge</td>
<td>34,110</td>
</tr>
<tr>
<td>Hwy 4/43rd St. Lethbridge</td>
<td>18,460</td>
</tr>
<tr>
<td>Coaldale</td>
<td>14,710</td>
</tr>
<tr>
<td>Taber</td>
<td>9,190</td>
</tr>
<tr>
<td>Hwy 1 Medicine Hat</td>
<td>9,990</td>
</tr>
</tbody>
</table>

Alberta Highway 3 was designated as a core of the National Highway System in 1988, an interprovincial route connecting large population center. From Fort Macleod to Taber, it is a divided highway (approximately 104 kilometers) with a speed limit of 100-110 km/h through the rural area with the remaining route as an undivided two-lane highway (approximately 220 kilometers) with a speed limit of 100 km/h.
Alberta Transportation (AT) has a long-term plan to upgrade the entire Highway 3 corridor to a freeway from B.C. border to Medicine Hat. In April 2008, AT published a study analyzing twinning and potential changes to the alignments of Highway 3 and 6 near Pincher Creek, including construction of a diamond interchange at Highway 6\(^3\). In 2013, a study identified the preferred alignment for a freeway bypass of Burdett and Bow Island, likely to be operated as a divided expressway until the freeway is completed in the long-term\(^4\).

### 1.3 Past Report of Highway 3 Twinning

As far as Alberta Highway 3 is concerned, there exists only one cost-benefit study which dated back in 2002 and subsequently a revised report in 2004, by the Van Horne Institute at the University of Calgary under the direction of Dr. Frank J. Atkins. The results from that final report show that the benefit-cost ratios vary from 3.03 (using 10% real discount rate) to 3.76 (using 3% real discount rate) indicating the highway 3 twining is a worthy investment. Those benefit calculations were based on differences between real gross domestic product (GDP) forecasts with and without highway capitals for Southern Alberta region (economic activities). Since the revised report published in 2004, the next stage of the twinning project did not formalize until recent renewed interest by the Alberta Transportation. Consequently, this study provides a new update on the estimated costs and a renewed alternative approach in estimating expected benefits.

### 1.4 Plan of the Report

The plan of the report is as follows. This introduction is followed by Section 2, which provides an overview of the methodology used in estimating costs and expected benefits associated with Highway 3 twinning. Section 3 summarizes the study findings. Concluding remarks and recommendations for the next steps are given in Section 4. Detailed calculations and supporting documents are gathered in the Appendices.

---

\(^3\)“Highway 3/6 Interchange Functional Planning Study” (PDF). Alberta Transportation, April 2008.

2. **COST AND BENEFIT METHODOLOGY**

The methodology used in this report is based on the approaches formalized by the Alberta Transportation, the Transportation Association of Canada (TAC) and HLB (HDR|HLB Decision Economics Inc.) models\(^5\) which rely on the information on traffic, demographic, and economic data from available sources. The methodology employs comprehensive benefits and cost estimating model, in a risk analysis framework. It consists of the following steps:

1. Research and analyze traffic volumes, tourism, pattern and flows, economic and demographic data for the study area (from Fort Macleod to Crowsnest Pass, Waterton Lakes National Park, and from Taber to Medicine Hat).

2. Develop a cost-benefit analysis (CBA) model in a risk analysis framework, allowing for the estimation of costs and benefits associated with Highway 3 twinning construction. We include the following categories of costs and benefits in the CBA:
   
   (a) Direct cost of Highway 3 twinning construction and operations, maintenance and rehabilitations costs thereafter;  
   (b) Travel time cost savings;  
   (c) Accident cost savings;  
   (d) Vehicle operating cost and emission cost savings;  
   (e) Tourism, commercial catchment basin and local trade area.

3. Conduct Risk analysis to account for the uncertainty surrounding the key assumptions used in the model. The risk analysis reveals the spectrum of potential outcomes given its probability of occurrences. That is, it reveals the magnitude of both the downside and the upside of the project given the possible fluctuations in the assumptions.

---

4. Run Monte Carlo simulation, applying appropriate discount rate, and calculate the benefit/cost ratio of the Highway 3 twinning.

5. Provide a matrix summary of the findings and offer recommendations.

For the estimation of costs and expected benefits, we make the following fixed assumptions throughout the analysis. Based on recent report on the completed Highway 63 twinning and personal communications with Alberta Transportation, it is estimated that it will take 10 years to complete the project. Thus, the direct cost of the project is expected to spread over the 10 years’ period. In addition, the expected benefits and maintenance costs are estimated for the life cycle of the investment, starting the year after the construction is completed. In this analysis, 20 years was used as the life cycle for the investment.

To determine the worthiness of the project, the following criterions are used:

1. Net Present Value (NPV) which is defined as the difference between the present value of benefits (PVB) and the present value of costs (PVC). The project is worthy if the value of NPV is positive and not worthy if it is negative. Or equivalently, the project is worthy if the ratio of PVB to PVC exceeds one (i.e., $(PVB/PVC > 1)$), otherwise it is not worthy.

2. Internal rate of return (IRR) which is defined as a rate of interest that sets the NPV equal to zero. If IRR is larger than the discount rate used in the calculations of PVB and PVC, then the project is worthy, otherwise, it is not worthy.

Two different values of discount rate were used in the estimation: 4% (based on recommendation by Alberta Transportation) and 10% (based on the recommendation of Canadian Federal Treasury Board). However, other values of discount rate were also used in conducting sensitivity analysis to ensure a wide range of scenarios was adequately covered\(^6\).

\(^6\) In the literature, the discount rate of 10% is often used for private investment on a particular project. The main reason for the high value of the discount rate is that, the same money could be used to invest elsewhere to earn a higher rate of return. For public investment on a particular project, the discount rate used is typically the real interest rate.
3. **STUDY FINDINGS**

### 3.1 Cost Estimates

As described in the Methodology section and according to Alberta Transportation and the recent completed Highway 63 twinning, it took approximately 10 years to complete the twinning project. Furthermore, it will cost approximately $6,000,000 per kilometer (including structure costs) to twin under “normal” conditions and $12,000,000 to $18,000,000 per kilometer to twin under “difficult” conditions\(^7\). As mentioned previously, there are approximately 25 kilometers from Crowsnest Pass area to the B.C. border that can be classified as “difficult” conditions due to mountainous terrain. As such, the approximated total direct costs of twining 220 kilometers on Highway 3 is $1.49 billion dollars.

In addition to the direct costs, there is an annual maintenance cost of $7,000 per kilometer the year after the project is completed. This annual maintenance cost for the next 20-year life cycle will be included as part of the total cost of the project. Finally, the incremental rehabilitation (overlay) cost is approximately $200,000 per kilometer every 20 years. However, this incremental rehabilitation cost is not included in the estimation of cost since the analysis is conducted within the allowable time frame before rehabilitation begins.

For clarity in terms of estimation of costs and benefits, it is assumed that the construction will begin in 2018 and will be completed in 2027. The expected benefits will then be calculated for next 20-year life cycle, starting in 2028.

---

\(^7\) Personal communication with Jerry Lau (P. Eng.), Infrastructure Manager, Delivery Services – Southern Region, Alberta Transportation, March 2017. The structure costs consist of land acquisition/compensation/relocation if there are homes/structures on the way.
3.2 Benefit Estimates

As previously mentioned in the Methodology section, this analysis estimates key benefits categories in regards to travel time savings, vehicle operating cost savings, safety savings, emission savings, tourism, commercial catchment basin and local trade area. The detailed calculations of these benefits categories are given in Appendix A.

It is important to recognize, albeit the total benefits are calculated after the twinning is completed, there are other short-term immediate incremental benefits during the construction phase, such as temporarily increase in employment and economic gains within the region, which are not included in the calculation as these benefits are typically difficult to measure. For example, suppose that the 220 kilometers to be twinned can be divided equally in 10-year period, and then in the second year of the construction phase, there would be 22 kilometers that would be twinned and would be available for public use; this is known as partial or incremental adoption benefit. Consequently, one must keep in mind that with the additional short-term immediate incremental benefits, it would only enhance the total benefits and the benefit-cost ratio.

Finally, it is worth to mention that with the recent development of $350 million potato processing plant in the industrial area of the City of Lethbridge (suggested completion in 2019) will provide valuable benefits to the agricultural needs in the region (in terms of employment and values of output added). Based on this development, existing developments and future developments the projection of traffic volume would likely be an added increase, and subsequently, the additional increase was included in the calculation of total benefits.

The expected benefits breakdown is illustrated in Figure 1, and the net benefit estimates per year over twenty-year life cycle is demonstrated in Figure 2. For illustration purposes, the discount rate of 4% was used in each figure.
It is clear from Figure 1 that the largest benefit category is vehicle operating cost and emission cost savings, and as such, the economic benefit of the investment increases as fuel price increases.
3.3 Project Worthiness

Based on AT recommended real discount rate of 4%, Table 2 below shows that the net present value of the Highway 3 twinning project over twenty years exceeds $2.3 billion dollars. Similarly, in terms of benefit-cost ratio, the results show that for each dollar spent on this project there are over $2.97 in benefits. These results translate to an internal rate of return of 12.3%. Thus, for a public infrastructure investment, these results are highly significant and illustrate the worthiness of the project’s investment.
Table 2: Summary of Analysis (In Millions of 2016 Dollars)
Discount Rate: 4% over 20 years

<table>
<thead>
<tr>
<th>Project Benefits</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Time Cost Savings</td>
<td>$1,292.72</td>
</tr>
<tr>
<td>Accidental Cost Savings</td>
<td>$804.64</td>
</tr>
<tr>
<td>Vehicle Operating and Emission Cost Savings</td>
<td>$1,358.62</td>
</tr>
<tr>
<td>Tourism and Others</td>
<td>$94.41</td>
</tr>
<tr>
<td><strong>Total Benefits</strong></td>
<td><strong>$3550.39</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Projected Costs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Construction Costs</td>
<td>-$1,183.38</td>
</tr>
<tr>
<td>Maintenance and Repair costs</td>
<td>-$13.75</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>-$1,197.13</strong></td>
</tr>
<tr>
<td><strong>Net Present Value</strong></td>
<td><strong>$2,353.26</strong></td>
</tr>
<tr>
<td><strong>Benefit-Cost Ratio</strong></td>
<td><strong>2.97</strong></td>
</tr>
<tr>
<td><strong>Internal Rate of Return</strong></td>
<td><strong>12.3%</strong></td>
</tr>
</tbody>
</table>

Source: based on author’s calculations. The data were obtained from Alberta Transportation, Alberta Culture and Tourism, AMA, Alberta Treasury Board and Finance (Southern Alberta Region) and Environics Research/Economic Development Lethbridge.

To account for the sensitivity of the results due to the choice of the real discount rate, Table 3 presents the total present values of benefits, the total present values of costs and the benefit-cost ratios for various real discount rates: 1% to 10%. As can be seen from Table 2, regardless of the real discount rate choices, the benefit-cost ratio is always greater than 1. Therefore, the sensitivity analysis of the real discount rate reinforces the worthiness of the project’s investment.
Table 3: Sensitivity Analysis of Real Discount Rate  
(In Millions of 2016 Dollars)

<table>
<thead>
<tr>
<th>Discount Rate</th>
<th>PVB</th>
<th>PVC</th>
<th>NPV</th>
<th>B-C Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1%</td>
<td>$6,318.98</td>
<td>-$1,406.34</td>
<td>$4,912.64</td>
<td>4.49</td>
</tr>
<tr>
<td>2%</td>
<td>$5,188.08</td>
<td>-$1,360.65</td>
<td>$3,857.43</td>
<td>3.81</td>
</tr>
<tr>
<td>3%</td>
<td>$4,281.27</td>
<td>-$1,261.14</td>
<td>$3,020.13</td>
<td>3.39</td>
</tr>
<tr>
<td>4%</td>
<td>$3,550.39</td>
<td>-$1,197.13</td>
<td>$2,353.26</td>
<td>2.97</td>
</tr>
<tr>
<td>5%</td>
<td>$2,958.33</td>
<td>-$1,138.06</td>
<td>$1,820.27</td>
<td>2.60</td>
</tr>
<tr>
<td>6%</td>
<td>$2,476.35</td>
<td>-$1,083.43</td>
<td>$1,392.92</td>
<td>2.29</td>
</tr>
<tr>
<td>7%</td>
<td>$2,082.09</td>
<td>-$1,032.81</td>
<td>$1,049.28</td>
<td>2.02</td>
</tr>
<tr>
<td>8%</td>
<td>$1,758.07</td>
<td>-$985.81</td>
<td>$772.26</td>
<td>1.78</td>
</tr>
<tr>
<td>9%</td>
<td>$1,490.56</td>
<td>-$942.11</td>
<td>$548.45</td>
<td>1.58</td>
</tr>
<tr>
<td>10%</td>
<td>$1,268.73</td>
<td>-$901.41</td>
<td>$367.32</td>
<td>1.41</td>
</tr>
</tbody>
</table>

Source: based on author’s calculations. The data were obtained from Alberta Transportation, Alberta Culture and Tourism, AMA, Alberta Treasury Board and Finance (Southern Alberta Region) and Environics Research/Economic Development Lethbridge.

### 3.4 Risk Analysis

To account for uncertainty of various key assumptions made in the model, a risk analysis was conducted. By doing so, risk analysis provides the spectrum of potential outcomes given its probability of occurrence. In other words, given the sensitivity of the assumptions, it reveals the magnitude of both the upside and the downside of the project.

Figure 3 and Figure 4 below depict the risk analysis results for the Net Present Value (NPV) and Benefit-Cost ratio (BCR) using 4% real discount rate, respectively. Figure 3 shows that whilst the most likely NPV for this project is over $2.3 billion dollars (approximately 50%), there is a 10% chance that the NPV exceeds $3.6 billion dollars. The risk analysis also shows that there is virtually no downside to this investment as the chance of having negative NPV is less than 0.1%. Similarly, Figure 4 reveals that whilst the most likely BCR for this project is 2.79 (approximately 50%), there is a 10% chance that the BCR exceeds 3.93, and there is virtually no downside to the investment as the chance of having BCR falls below 1 is less than 0.1%.
**Figure 3: Risk Analysis Results of Net Present Value**  
*(Discount Rate: 4%)*

Source: based on author’s calculations. A computer program @RISK was used to conduct risk analysis via Monte Carlo simulations to obtain the results.

**Figure 4: Risk Analysis Results of Benefit-Cost Ratio**  
*(Discount Rate: 4%)*

Source: based on author’s calculations. A computer program @RISK was used to conduct risk analysis via Monte Carlo simulations to obtain the results.
4. **CONCLUDING REMARKS**

The main objective of this report is to assess the worthiness of the Highway 3 twinning project (given all the relevant information and existing data on the project) by examining the economic benefits, costs and net benefits (benefits minus costs) over the next 30 years. These estimates of economic benefits, costs and net benefits are calculated as the difference between the base line model (i.e. using the existing Highway 3 without twinning) and the model that assumes the Highway is twinned. The main results using risk analysis and simulations in this report are summarized in Table 4 below.

**Table 4: Summary of Results Based on Risk Analysis (In Millions of 2016 Dollars)**

<table>
<thead>
<tr>
<th>Discounted Categories</th>
<th>Most Likely Outcome</th>
<th>90% Probability of Exceeding</th>
<th>10% Probability of Exceeding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Benefits</td>
<td>$3,550.39</td>
<td>$3,482.14</td>
<td>$3,707.15</td>
</tr>
<tr>
<td>Total Project Costs</td>
<td>$1,197.13</td>
<td>$1,158.51</td>
<td>$1,217.85</td>
</tr>
<tr>
<td>Net Present Value of Benefits</td>
<td>$2,353.26</td>
<td>$1,998.23</td>
<td>$2,501.43</td>
</tr>
<tr>
<td>Benefit-Cost Ratio</td>
<td>2.97</td>
<td>2.12</td>
<td>3.46</td>
</tr>
<tr>
<td>Internal Rate of Return</td>
<td>12.3%</td>
<td>8.6%</td>
<td>21.5%</td>
</tr>
</tbody>
</table>

Source: based on author’s calculations. The data were obtained from Alberta Transportation, Alberta Culture and Tourism, AMA, Alberta Treasury Board and Finance (Southern Alberta Region) and Environics Research/Economic Development Lethbridge. A computer program @RISK was used to compute the above probabilities via Monte Carlo simulations.

As can be seen from the second column of Table 4, the results from the benefits and costs analysis suggest that the twinning of Highway 3 emerges as a worthy investment project in terms of the net contribution to the economic welfare of the Southern Alberta region. With the economic benefits that exceed the costs of constructing and maintenance over twenty-year life cycle by more than
$2.3 billion, Highway 3 twinning project provides an estimated $2.97 of economic return for each dollar invested (or incurred cost).

The last two columns of Table 4 show the assessment of uncertainty in the forecasts presented above. Based on the assigned probabilities to various technical assumptions entailed in the forecasting process, the results provide further support for the Highway 3 twinning as a worthy investment project in the sense that it offers the public over a 90 percent assurance of generating more future benefits than costs.

Finally, the results in this analysis are based on the available information and existing data. However, other benefits such as short-run incremental benefits, economic growth and development in the Southern Alberta region would lend even stronger support for the Highway 3 twinning as a worthy investment project. A natural next step following this report would be to conduct a study on the financial feasibility to assess the affordability condition, including the involvement of the private sector, if any.
This Appendix presents the detailed calculations of the present value of benefits for various categories described in the main body of the report, and the risk analysis methodology. The approaches taken in this report are similar to the HLB (HDR|HLB Decision Economics Inc.) and the Transportation Association of Canada (TAC) approaches. All the values used in this analysis were taken from Alberta Transportation User Guide.

### A.1 Benefits of Highway 3 Twinning Construction

This section describes the methodology used in the estimation of benefits associated with Highway 3 twinning construction. All the values are taken from Alberta Transportation User Guide.  

#### A.1.1 Travel Time Cost Savings

Based on the TAC and HLB modeling approaches, the travel time cost is assumed to be a function of delays and the value of time of highway users. The values of travel of time for passenger Cars and pickups (including SUV), straight trucks and buses, and Combination of Trucks are given in Section A.2.2. The estimated daily travel time costs can be defined as the combination of value of time, daily traffic on the highway segment, length of the segment and average travel speed. It is given by:

\[
Travel Time Costs = VOT \times \left( \frac{Traffic \times Length}{Speed} \right)
\]

where

*Travel Time Costs*: total daily travel time costs by period of day and vehicle class;

---

$VOT$: value of time, cost per hour of vehicle travel time by vehicle class;

$Traffic$: traffic volume by period of day and vehicle class;

$Length$: length of the highway segment in kilometers;

$Speed$: calculated average travel speed on highway segment by period of day.

The daily travel time costs are then annualized. The difference between the total travel time costs in the Base (not twinned) and Alternative (twinned) case constitutes the travel time cost savings associated with Highway 3 twinning construction.

### A.1.2 Accident Cost Savings

Typical accident rates and severity distribution for highway fatalities are based on the values from Alberta Transportation accident report on Highway 3. Table 5 below shows the total number of accidents by accident type and the number of fatalities and injuries on Highway 3 for 10-year periods: 2005 - 2014.

<table>
<thead>
<tr>
<th>Collision Severity</th>
<th>Collision</th>
<th>Fatality</th>
<th>Injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatal</td>
<td>57</td>
<td>70</td>
<td>61</td>
</tr>
<tr>
<td>Injury</td>
<td>746</td>
<td>-</td>
<td>1,212</td>
</tr>
<tr>
<td>Property Damage</td>
<td>3,975</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>4,778</td>
<td>70</td>
<td>1,273</td>
</tr>
</tbody>
</table>

Source: Alberta Transportation.

Divided highways are believed to confer safety benefits both upstream and downstream of its location. Current research suggests that divided highways changes the distribution of accident severity by reducing the number of collisions within its effective length.

Accident costs are based on accident rates and cost-per-accident estimates. Accident rates depend on the facility type and traffic volume. The average cost by accident type is outlined in Section
A.2.2. Note that in the case of an accident that involves death, the value of life is determined from Alberta Transportation User Guide (based on 2014 dollar) which is approximately $9.12 (Rural) to $9.46 million (urban). Moreover, on average, the costs of injury accident and property damage accident are approximately from $67,000 (Rural) to $60,000 (Urban) and from $5,900 (Rural) to $8600 (Urban), respectively.9

The accident costs are calculated as a combination of accident rates with annual vehicle kilometers of travel and costs per accident in the Base and Alternative case, and it is given by:

\[
\text{Accident Costs} = AR \times (Traff \times Length) \times AC,
\]

where

\[
\text{Accident Costs}: \quad \text{total accident costs savings by accident type};
\]

\[
AR: \quad \text{accident rate by accident type};
\]

\[
Traff: \quad \text{annual traffic volume};
\]

\[
Length: \quad \text{length of the highway segment in kilometers};
\]

\[
AC: \quad \text{cost per fatal (include death), property damage and injury accident.}
\]

The accident cost savings is estimated by taking the difference between the accident costs in the Base and Alternative cases due to Highway 3 twinning construction.

**A.1.3 Vehicle Operating Cost and Emission Cost Savings**

A.1.3.1 Vehicle Operating Costs (VOC) Savings:

The VOC are the costs associated with owning, operating and maintaining a vehicle. Thus, the VOC depend on a wide range of factors including a region’s economy, vehicle technology, driver behaviour and fleet operation decisions. Based on TAC and HLB modelling approaches, there are

---

9 These values have been adjusted to 2016 dollar using 2016 CPI (Consumer Price Index).
two types of VOC: (1) Constant Speed vehicle operating costs; and (2) Excess vehicle operating costs.

The constant speed vehicle operating costs include fuel consumption, oil consumption, maintenance and repair, tire wear, and road way related vehicle depreciation. Each component is assumed to be a function of vehicle class, travel speed, and road way geometry. Cost/unit estimates for each component are listed in Section A.2.2.

The excess vehicle operating costs estimation combines the results of pavement profile, traffic and speed/flow components to derive excess consumption rates.

The total (annualized) VOC are calculated as follows:

\[
VOC = \left( [\text{ConsRates} \times (\text{Traf} \times \text{Length}) + \text{XSV}] \times \text{Cost} \right) \times \text{PAF},
\]

where \( \text{Traf} \) and \( \text{Length} \) are defined as before and

\[VOC:\text{ total (annualized) vehicle operating cost by vehicle class};\]

\[\text{ConsRates}: \text{ VOC consumption rate by vehicle class and component type};\]

\[\text{XSV}: \text{ Excess VOC component consumption by vehicle class and component type};\]

\[\text{Cost}: \text{ component cost per litre of fuel, per litre of oil, per tire, average maintenance and repair costs, and vehicle depreciation};\]

\[\text{PAF}: \text{ pavement adjustment factor based on pavement condition}.\]

The estimated VOC savings is the difference between total VOC in the Base and Alternative case due to Highway 3 twinning construction.

A.1.3.2 Vehicle Emission Cost Savings:

Vehicle emission costs are based on emission rates for vehicle type and unit emission cost. Clearly emission rates vary with average travel speed and vehicle type on the highway segment. Cost estimates of one ton of Carbon Monoxide (CO), Volatile Organic Compound (VOC), Nitrous
Oxide (NOx), Carbon Dioxide (CO\(_2\)), Particular Matter (PM\(_{10}\)) and Sulphur Oxide (SO\(_x\)) are given in Section A.2.2. The annualized vehicle emission costs can be computed as follows:

\[ EC = ER \times (Traff \times Length) \times Cost, \]

where \( Traff \) and \( Length \) are defined previously, and

- \( EC \): total emission costs by vehicle class and emission type;
- \( ER \): emission rate by vehicle type and emission type;
- \( Cost \): emission cost/ton of CO, VOC, NOx, and CO\(_2\).

The estimated emission cost savings is the difference between total vehicle emission costs in the Base and Alternative case due to Highway 3 twinning construction.

**A.1.4 Tourism and Others**

The following economic data were considered in the analysis for the Based and Alternative case: population growth forecast for Southern Alberta region (Alberta Treasury Board and Finance), auto registration (Alberta Motor Association, (AMA)), tourism arrival and spending value data (Alberta Culture and Tourism) and southern trade area\(^{10}\) (Environics Research and Economic Development Lethbridge).

These data were used for the purpose of extrapolation analysis to project growth for both the Based and Alternative case. For the Based case, it is assumed that linear growth and the respective Compound Annual Growth Rates (CAGR) based on the forecast and extrapolation of historical data. Note that, the historic tourism and spending values for the southern region of Alberta have been quite flat, and hence similar values were assumed for the forecast. For the Alternative case, the tourism and spending value projections were based on a fixed CAGR of 0.75%, whilst the southern trade area values are projected to growth a rate of linear trend plus 1%. Figure 5 below

---

show the PV of benefit of tourism and trade values resulting from Highway 3 twinning construction.

**Figure 5: Present Value (PV) Benefits of Tourism and Trade (Million 2016 Dollar)**

Real Discount Rate: 4%

Source: based on author’s calculations. The data were obtained from Alberta Culture and Tourism and Environics Research/Economic Development Lethbridge.

### A.2 Main Assumptions and Risk Analysis

This section provides the main assumptions that were used in various components of the model whilst accounting for uncertainty surrounding these assumptions (i.e., probability distributions are used to account for the uncertainty for these main assumptions).

#### A.2.1 Main Assumptions

The main assumptions used in deriving the results consist of the following:

1. General traffic characteristics:
   a. AADT average annual growth rate;
   b. Traffic distribution by vehicle type;
   c. Traffic distribution by period of day;
d. Length of peak period.

2. Costs associated with Highway 3 twinning construction:
   a. Direct construction cost;
   b. Average highway maintenance cost.

3. Benefits associated with Highway 3 twinning construction:
   a. Value of time by vehicle type;
   b. Cost/accident by accident type;
   c. Vehicle operating cost by vehicle type, VOC component, and emission cost by emission type.
   d. Tourism and Trade.

4. Others:
   a. Discount rate;
   b. Average annual population growth in southern Alberta.

A.2.2 Assumptions Ranges

<table>
<thead>
<tr>
<th>ASSUMPTIONS</th>
<th>MEDIAN</th>
<th>LOWER 10% LIMIT</th>
<th>UPPER 10% LIMIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confidence Interval</td>
<td></td>
<td>10%</td>
<td>90%</td>
</tr>
<tr>
<td>Discount rate</td>
<td>4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak period traffic</td>
<td>40%</td>
<td>40%</td>
<td>40%</td>
</tr>
<tr>
<td>Value of time, 2016$/hour (work &amp; non-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>work/leisure)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger Cars</td>
<td>$40.0</td>
<td>$35.0</td>
<td>$45.0</td>
</tr>
<tr>
<td>Trucks</td>
<td>$40.0</td>
<td>$35.0</td>
<td>$45.0</td>
</tr>
<tr>
<td>Buses</td>
<td>$33.0</td>
<td>$28.0</td>
<td>$38.0</td>
</tr>
<tr>
<td>Accident costs, 2016 $/accident</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatal accident</td>
<td>$9,250,000</td>
<td>$5,000,000</td>
<td>$13,400,000</td>
</tr>
<tr>
<td>Injury accident</td>
<td>$64,500</td>
<td>$27,000</td>
<td>$186,000</td>
</tr>
<tr>
<td>Property damage only accident</td>
<td>$7,300</td>
<td>$3800</td>
<td>$8,900</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>--------</td>
<td>-------</td>
<td>--------</td>
</tr>
<tr>
<td><strong>Emission costs, 2016 $/ton</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>$99.40</td>
<td>$50</td>
<td>$450</td>
</tr>
<tr>
<td>VOC</td>
<td>$2,060</td>
<td>$1,000</td>
<td>$5,000</td>
</tr>
<tr>
<td>NOx</td>
<td>$30,900</td>
<td>$16,000</td>
<td>$50,500</td>
</tr>
<tr>
<td>CO₂</td>
<td>$41</td>
<td>$22</td>
<td>$198</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>$251,320</td>
<td>$126,100</td>
<td>$426,300</td>
</tr>
<tr>
<td>SOₓ</td>
<td>$105,060</td>
<td>$53,250</td>
<td>$210,000</td>
</tr>
<tr>
<td><strong>Vehicle operating costs 2016 $/unit of consumption</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Auto</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel, $/litre</td>
<td>$1.15</td>
<td>$0.87</td>
<td>$1.25</td>
</tr>
<tr>
<td>Oil, $/litre</td>
<td>$3.12</td>
<td>$2.65</td>
<td>$3.74</td>
</tr>
<tr>
<td>Tire, $/tire</td>
<td>$113.43</td>
<td>$96.42</td>
<td>$136.12</td>
</tr>
<tr>
<td>Maintenance and Repair (average)</td>
<td>$69.55</td>
<td>$59.10</td>
<td>$83.47</td>
</tr>
<tr>
<td>Depreciation value</td>
<td>$18,500</td>
<td>$15,700</td>
<td>$22,160</td>
</tr>
<tr>
<td><strong>Truck</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel, $/litre</td>
<td>$1.25</td>
<td>$1.01</td>
<td>$1.30</td>
</tr>
<tr>
<td>Oil, $/litre</td>
<td>$3.12</td>
<td>$2.65</td>
<td>$3.74</td>
</tr>
<tr>
<td>Tire, $/tire</td>
<td>$723.89</td>
<td>$610.22</td>
<td>$873.66</td>
</tr>
<tr>
<td>Maintenance and Repair (average)</td>
<td>$201.88</td>
<td>$172.27</td>
<td>$241.55</td>
</tr>
<tr>
<td>Depreciation value</td>
<td>$128,600</td>
<td>$115,380</td>
<td>$155,320</td>
</tr>
<tr>
<td><strong>Buses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel, $/litre</td>
<td>$1.25</td>
<td>$1.01</td>
<td>$1.30</td>
</tr>
<tr>
<td>Oil, $/litre</td>
<td>$3.12</td>
<td>$2.65</td>
<td>$3.74</td>
</tr>
<tr>
<td>Tire, $/tire</td>
<td>$723.89</td>
<td>$610.22</td>
<td>$873.66</td>
</tr>
<tr>
<td>Maintenance and Repair (average)</td>
<td>$194.86</td>
<td>$166.28</td>
<td>$233.16</td>
</tr>
<tr>
<td>Depreciation value</td>
<td>$295,570</td>
<td>$265,200</td>
<td>$356,980</td>
</tr>
</tbody>
</table>

Source: based on author’s calculations. The data were obtained from Alberta Transportation (Benefit Cost Model User Guide, Version 2, Applications Management Consultant LTD, February 3, 2017). A computer program @RISK was used to conduct the simulations to obtain the results.
A.2.3 Risk Analysis

Risk analysis using Monte Carlo simulation provides a way to account for uncertainty of various assumptions by assigning ranges (probability distributions) to the forecasts of each input variable. This approach allows all input variables to vary simultaneously within their probability distributions. Probability ranges are established based on both statistical analysis and subjective probability. In addition, probability ranges need not to be normal or symmetric; that is there is no need to assume the bell shaped normal probability curve. The bell-shaped curve assumes an equal likelihood of being too low and being too high in forecasting a particular value. For example, if a projected growth deviates from expectations, circumstances are such that it is more likely to be higher than the median expected outcome than lower.

Risk analysis process involves the following steps:

1. Define the structure of the forecasting problem.
2. Assign central estimates and ranges (probability distribution) to each variable and forecasting coefficient in the forecasting structure.
3. Conduct risk analysis.

Step 1: Define Structure Model

The structure model depicts the variables and cause and effect relationships that underpin the forecasting problem at hand. Albeit the structure model is written down mathematically to facilitate analysis, it can also be depicted diagrammatically, see Figure 6 below for an illustration.
**Figure 6: Example of a Structure Model**

```
Legend:  Input  Output (Result)
```

**Step 2: Assign Central Estimates and Conduct Probability Analysis**

Each variable is assigned a central estimate and a range (probability distribution). Data sheets are used to record these estimates. An example is given in Table 6. As can be seen from Table 6, the second column gives the median value whilst the last two columns show the lower and upper limits of an 80 percent confidence interval. In other words, there is an 80 percent chance of finding the actual value of the variable within this range. The greater the uncertainty associated with a forecast variable, the wider the range of possible values the variable can take on.
Table 6: Example of Data Sheet for Value of Time

<table>
<thead>
<tr>
<th>Value of Time</th>
<th>Median</th>
<th>Lower 10% Limit</th>
<th>Upper 10% Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car, 2016 $/hour</td>
<td>38.8</td>
<td>36.3</td>
<td>41.2</td>
</tr>
<tr>
<td>Truck, 2016 $/hour</td>
<td>38.8</td>
<td>36.3</td>
<td>41.2</td>
</tr>
<tr>
<td>Bus, 2016 $/hour</td>
<td>31.9</td>
<td>22.6</td>
<td>43.4</td>
</tr>
</tbody>
</table>

Source: based on author’s calculations. The data were obtained from Alberta Transportation (Benefit Cost Model User Guide, Version 2, Applications Management Consultant LTD. February 3, 2017). A computer program @RISK was used to conduct the simulations to obtain the results.

Step 3: Conduct Risk Analysis

The final probability distributions are formulated as a combination of subjective probability and statistical probability, and these are combined by using a simulation technique (commonly known as “Monte Carlo simulation”) which allows each variable and forecasting coefficient to vary simultaneously according to its associated probability distribution.

The computer program @RISK is designed to execute the above process and transforms the ranges given in A.2.2 into formal probability distributions and determines the final desired outcomes (e.g., Figure 4 and Figure 5).