Development of Objective Payment Adjustment Criteria for Nova Scotia

Sameh Zaghloul, Ph.D., P.E., P.Eng.
Formerly of Stantec Consulting, now of H.W. Lochner, Inc.
310 Fullerton Ave, Suite 200
Newburgh, NY 12500
Phone: (845) 863-0960
Fax: (845) 863-0961
Email: szaghloul@hwlochner.com

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ABSTRACT

Most highway agencies in North America adopt specifications to control the level of initial roughness of new or rehabilitated pavements. Previous studies have indicated that high initial roughness results in higher Life Cycle Costs (LCCs). Therefore, controlling initial roughness leads to longer pavement service life, lower maintenance and rehabilitation costs, and consequently to more cost-effective pavements. Smoothness acceptance specifications typically include a value for acceptable initial roughness (in terms of a roughness index), together with payment adjustment factors that result in full payment, a bonus, or a penalty to the contractor.

This paper summarizes an initiative to review the current smoothness acceptance specification of the Nova Scotia Department of Transportation and Public Works (TPW), which had been in place for about 15 years, and to evaluate the benefits of other equipment, roughness indices and payment adjustment factors. This initiative was geared towards developing and proposing an alternative smoothness acceptance specification that the province could choose to implement. Within this paper, a particular emphasis is placed on the effort made to objectively identify the impact of initial roughness on expected pavement service life, and hence objectively determine the levels of bonus and penalty that should be awarded to contractors. Two alternative approaches were considered to objectively quantify the impact of initial roughness on the pavement economics. Comparisons between TPW's current specification, the specifications of three other Departments of Transportation (DOTs) in US and Canada, and the two alternative approaches developed, are presented in this paper.

INTRODUCTION

Most highway agencies in North America adopt specifications to control the level of initial roughness of new or rehabilitated pavements. Previous studies have indicated that high initial roughness results in higher Life Cycle Costs (LCCs). Therefore, controlling initial roughness leads to longer pavement service life, lower maintenance and rehabilitation costs, and consequently to more cost-effective pavements. Smoothness acceptance specifications typically include a value for acceptable initial roughness (in terms of a roughness index), together with payment adjustment factors that result in full payment, a bonus, or a penalty to the contractor.

Several highway agencies began adopting smoothness acceptance specifications as early as the late 1950s and into the 1960s. Straightedges and response-type devices, such as the Roughometer, were among the equipment used to implement the specifications at that time. In the late 1960s, the profilograph started to become popular among highway agencies as a tool for measuring initial roughness. Profilographs provide profile traces that are used to identify severe bumps, as well as a Profile Index (PRI) that is used as an overall measure of smoothness. In the late 1970s, more complex profiling systems were developed (i.e. high-speed profilers), capable of providing more accurate measurements. In 1982, the World Bank introduced a universal measure of roughness – the International Roughness Index (IRI). As a result, many highway agencies have been moving towards using high-speed profilers and IRI to control the initial roughness of pavements.

Until recently, however, most highway agencies' smoothness specifications were based on the PRI smoothness statistic, measured using a profilograph. Although these specifications differ primarily in terms of acceptable PRI limits and payment adjustment provisions, there are also differences in testing procedures, equipment, and blanking band sizes (e.g. 0, 2.5, or 5 mm). In the 1990s, several US national surveys were conducted to document the smoothness specifications used by different states. In general, about 50% of the responding agencies used a California- or Rainhart-type profilograph for testing new asphalt concrete (AC) pavements. Since the survey, many of these agencies have moved away from profilographs and/or the 5 mm blanking band width.

The current smoothness specification of the Nova Scotia Department of Transportation and Public Works (TPW) (1) has been in place for approximately 15 years. The current TPW specification uses the California-type profilograph and 5 mm blanking band width. TPW initiated a project, as have many other highway agencies, to review the Department's smoothness specification and to evaluate the benefits of other equipment, roughness indices and payment adjustment factors. The final product of this project was a proposed new smoothness acceptance specification that TPW could choose to adopt to control the smoothness of new or rehabilitated AC surfaces. This report describes the steps taken in the development of this new draft specification, with particular focus on the development of objective payment adjustment criteria.

LITERATURE REVIEW

A literature review was conducted for the current smoothness specifications of TPW and three other North American highway agencies – the Ministry of Transportation, Ontario (MTO) (*2*), the Virginia Department of Transportation (VDOT) (*3*), and the New Jersey Department of Transportation (NJDOT) (*4*). The specifications were examined for general requirements (such as equipment, roughness index, applicability, etc.), testing protocols, accepted levels of roughness, provisions for remedial work, and the methods used for calculating contractor payment adjustments.

TPW's current smoothness specification, as well as those of MTO, VDOT, and NJDOT were implemented and applied to sample Nova Scotia roughness data for Highways 101, 104, 105, 106, 111 and Trunk 4 eastbound and westbound to calculate the payment adjustments that would be made in each case and to allow comparison between the four agencies. Table 1 shows the payment adjustments that would be applied by each agency for each of the seven sets of data. These are graphically represented overall in Figure 1.

As can be seen from these results, for the data under consideration, the payment adjustments resulting from TPW's current specification are appreciably different from those of the other agencies. For Highways 101, 104 and 111, the bonuses awarded using the TPW specifications are substantially less those that would be awarded using VDOT and

NJDOT specifications. Also, in the cases of Highways 105 and 106, TPW would award a bonus where either two, or all three, of the other agencies would not.

DEVELOPMENT OF OBJECTIVE PAYMENT ADJUSTMENT CRITERIA

Economic analyses were performed to develop potential objective payment adjustment criteria that TPW could choose to implement in the future. Ideally, a pavement section was to reach its trigger level IRI value in about 15 years. As such, an assumption was made that although projects are designed typically for a 20-year design life, the expectation is still that the section will be triggered in 15 years. It was also assumed that highways within the same posted speed category are built to the same smoothness standards.

Performance of different pavement designs is a key component of any economic analysis. Different design alternatives will have different costs and different expected performance. For example, an asphalt pavement structure has lower initial cost, but a shorter expected service life than a PCC pavement structure. This will mean that in some cases the PCC structure is the more cost-effective option due to its longer service life. In a similar way, sections with similar construction costs, but different initial roughness, are expected to perform differently and have different service lives. Therefore, the fundamental issue that is addressed in this section is the value of the change in service life as a result of initial roughness.

The first stage in this process was to objectively identify the impact of initial roughness on expected pavement service life through the development of master IRI-age deterioration models. Economic analysis was then employed to quantify this extension or reduction of service life as monetary gain or loss to TPW. Two alternative approaches were applied in this analysis: Equal Yearly Service Life Value and Reduced / Increased Pavement Design Life. The bonuses / penalties that would result from these two approaches, when applied to IRI data from Highways 101, 104, 105, 106, 111 and Trunk 4 eastbound and westbound, were compared against each other and then against those awarded using the current smoothness specifications of TPW, MTO, VDOT and NJDOT.

Impact of Initial Roughness on Pavement Service Life

Development of Master IRI-Age Deterioration Models

As mentioned above, the first step towards developing payment adjustment criteria was to objectively identify the impact that initial roughness has on expected pavement service life. A master IRI-age deterioration model was developed for roads with posted speed greater than or equal to 100 kph (Category A), based on a limited data set obtained for the 100-series highway segments. IRI data from the first year after pavement construction (i.e. IRI at Year 0, or ‘as-built IRI’), along with that measured in subsequent years, was used to develop this master IRI-age deterioration curve. A sigmoidal model was developed to fit all the data for the 100 series, resulting in the Category A model. The model, together with the expected service life, is shown graphically in Figure 2. The “o” value of the model (as-built IRI) was determined as the 70th percentile of the detailed IRI data of the 100-series projects, i.e. the IRI value which 70% of the data is less than. A similar approach was followed to develop a master IRI-age deterioration curve for roads with posted speeds of 80 to <100 kph (Category B) and with posted speeds of 60 to <80 kph (Category C).

Trigger IRI values of 1.8, 2.3, and 2.4 mm/m were selected for Categories A, B, and C, respectively. These trigger values are used to identify the need for rehabilitation, i.e. approaching the end of service life. Using the master IRI-age deterioration model for Category A roads, Figure 3 shows the impact that initial roughness has on the length of a pavement’s expected service life. As can be seen, in this figure, the expected service life ranges from about 10 to 18 years, depending on the initial IRI value.

Quantifying the Impact of Initial Roughness

Having objectively identified the impact of initial roughness on pavement service life, the next stage in the development of payment adjustment criteria was to perform economic analysis to quantify this extension or reduction of service life as monetary gain or loss to TPW. Two alternative approaches were considered in this analysis: Equal Yearly Service Life Value and Reduced / Increased Pavement Design Life.

Approach 1 - Equal Yearly Service Life Value In the first approach, the value of each year of service life is assumed to be equal to the total cost of the project divided by the desired service life. In other words, if a project has a total cost of $450,000 and a desired service life of 15 years, then the value of each year of service life is $450,000/15 = $30,000. If the project is built with initial roughness close to the desired roughness, then it is expected that the pavement will last the designed 15 years, assuming that all other design and construction related issues meet the desired specifications. If the as-built IRI is better or worse than the desired roughness, then it is expected that the pavement will last more than or less than the designed 15 years. Therefore, the expected gain or loss to TPW can be calculated as follows:

$$\text{Gain/Loss} = (SL_{expected} / SL_{trigger} - 1) * \text{Total Project Cost} \quad [2]$$

Where,
$SL_{expected}$ = expected service life, as a result of the initial roughness
$SL_{trigger}$ = 15- year service life at which pavement reaches trigger level for rehabilitation

Figure 4 (a, b and c) illustrates an example of implementing this approach. In this example, the average cost per lane km of the 100-series sample Nova Scotia data sets was used ($180,000). If a 15-year service life is assumed, then the yearly value is $12,000 per year per lane km.

Figure 4a shows the pavement service life that would be expected for this project, depending on its initial roughness. As illustrated, if the initial IRI value is 1.0 mm/m, then the expected service life would be 15 years. Figure 4b shows the positive or negative change in service life that would be expected should the initial IRI value be less than or greater than 1.0 mm/m. Based on the number of years that the expected service life has been increased or decreased by, Figure 4c illustrates the bonus or penalty that would be applied at a rate of $12,000.00 per year per lane km.

Approach 2 - Reduced / Increased Pavement Design Life In this approach, the expected change in the pavement service life as a result of the initial roughness is addressed in the pavement design. The 1993 American Association of State of Highway Transportation Officials (AASHTO) Pavement Design Procedure was used in this task (*5*). The 1993 AASHTO Procedure utilizes the measure of Structural Number (SN) to define the pavement structure required to support different traffic levels under different conditions. SN is calculated using the following formula (*5*):

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 \quad [3]$$

Where,
a_1, a_2, a_3 = layer coefficients representative of surface, base, and subbase courses, respectively
D_1, D_2, D_3 = actual thicknesses (in inches) of surface, base, and subbase courses, respectively
m_2, m_3 = drainage coefficients for base and subbase layers, respectively

A typical pavement design was prepared for a 15-year design life using the 1993 AASHTO Procedure, and the required SN for this design life was determined. The same analysis was then repeated to determine the required SN for other service lives under the same conditions (e.g. 14-year, 16-year, etc.). The differences between the required SN of the standard design life (15 years) and those of other design lives were calculated and converted to equivalent asphalt thickness using a layer coefficient for asphalt, a_1, equal to 0.42, as shown in Table 2. A unit cost of $7.5 per m^2 for each 1” of asphalt was then used to calculate the corresponding difference in cost for a reduction or increase in pavement design life, as shown in Table 2 and Figure 5.

Comparison Between the Two Approaches Figure 6 shows a comparison between the two abovementioned approaches. As can be seen, Approach 1 provides larger cost implications as the result of any change in the pavement service life. However, these larger implications are justifiable and also provide a practical solution for the following reasons:

- The higher bonus and penalty levels would give contractors a definite incentive to construct smoother pavements.
- The approach is fair to all parties, being neither biased towards bonuses or penalties.
- It would ensure that TPW received the level of service that it paid for.

Comparison between Current Payment Adjustments and Alternative Approaches

Table 3 shows a comparison of the payment adjustments that would be applied for the 100-series highway segments when implementing TPW current specifications, the two alternative approaches, and the specifications of MTO, VDOT, and NJDOT. Graphical presentation of the same data is presented in Figure 7. As can be seen, Approaches 1 and 2 both award reasonable bonuses / penalties when compared with those that would be applied by other agencies. It should be noted that penalties for localized roughness have not been implemented in these calculations.

SUMMARY

TPW's current smoothness specification has been in place for approximately 15 years. This specification uses the California-type profilograph with 5 mm blanking band width and reports roughness in terms of PRI_5. TPW initiated a project to review the Department's smoothness specification and to evaluate the benefits of other equipment, roughness indices and payment adjustment factors. This paper summarized the effort made to develop a procedure that objectively accounts for the impact of the initial roughness on pavement LCCs.

A literature review was conducted for the current smoothness specifications of TPW, MTO, VDOT, and NJDOT. The specifications of all four agencies were applied to the roughness data for seven sample Nova Scotia road segments, and the calculated payment adjustments were compared. For the available data, the payment adjustments resulting from TPW's current specification were noted to be appreciably different from those of the other agencies. Alternative payment adjustment criteria were investigated. The first stage in this process was to objectively identify the impact of initial roughness on expected pavement service life through the development of master IRI-age deterioration models. Economic analysis was then employed to quantify this extension or reduction of service life as monetary gain or loss to TPW. Two alternative approaches were applied in this analysis: Equal Yearly Service Life Value (Approach 1) and Reduced / Increased Pavement Design Life (Approach 2).

The bonuses / penalties that would be awarded using these two objectively-based approaches were calculated for the seven sample road segments. While both approaches were shown to award reasonable bonuses / penalties when compared with those that would be applied by other agencies, Approach 1 provided larger cost implications as a result of any change in the initial roughness level. However, these larger implications were considered justified and practical. The approach would provide a definite incentive to contractors to construct smoother pavements, is fair to all parties in not being biased towards bonuses or penalties, and would ensure that TPW receives the level of service that it pays for. Consequently, the Equal Yearly Service Life Value approach was recommended as the basis for the proposed smoothness acceptance payment adjustments.

REFERENCES

1. Smoothness Testing & Remedial Measures (Asphalt Concrete; Portland Cement Concrete), Appendix F, Nova Scotia TPW, February 2003.

2. Asphaltic Concrete Surface Tolerance and Payment Adjustment for Surface Smoothness, MTO Special Provision No. 103F31, February 2006.

3. Special Provision for Rideability (Plant Mix Schedule), VDOT, October 2005.

4. Pavement Smoothness Performance Related Specification, Advanced Infrastructure Design, Inc. Final Report, November 2004.

5. Guide for Design of Pavement Structures, American Association of State Highway and Transportation Officials (AASHTO), 1993.

TABLE 1 Comparison Between TPW and Other Agencies' Payment Adjustments

	TPW	MTO	VDOT	NJDOT
Highway 101	$4,873.12	$0.00	$25,223.81	$17,138.75
Highway 104	$6,563.43	($338.18)	$42,967.51	$18,121.25
Highway 105	$1,279.05	($10,471.86)	($31,643.68)	($32,562.60)
Highway 106	$7,968.29	($1,752.21)	$3,819.80	($9,846.50)
Highway 111	$3,037.20	($979.47)	$37,724.22	$19,042.25
Trunk 4 EB	($36,930.25)	($60,052.18)	($16,876.03)	($6,930.75)
Trunk 4 WB	($29,539.71)	($91,030.99)	($29,459.55)	($11,746.10)

TABLE 2 Difference in Cost of Pavements with Different Design Lives

Design Life	SN Required	Diff in AC	TI Delta $ per lane
12	3.6	-0.31	($8,473.21)
13	3.65	-0.19	($5,214.29)
14	3.69	-0.10	($2,607.14)
15	3.73	0.00	$0.00
16	3.77	0.10	$2,607.14
17	3.81	0.19	$5,214.29
18	3.84	0.26	$7,169.64
19	3.88	0.36	$9,776.79
20	3.91	0.43	$11,732.14
21	3.94	0.50	$13,687.50

TABLE 3 Payment Adjustment Comparison for Alternative Approaches

	TPW	MTO	VDOT	NJDOT	Approach 1: Equal Yearly Service Life Value	Approach 2: Reduced / Increased Pavement Design Life
Highway 101	$4,873.12	$0.00	$25,223.81	$17,138.75	$30,173.33	$4,994.38
Highway 104	$6,563.43	($338.18)	$42,967.51	$18,121.25	$21,900.00	$3,433.44
Highway 105	$1,279.05	($10,471.86)	($31,643.68)	($32,562.60)	($32,120.00)	($4,262.89)
Highway 106	$7,968.29	($1,752.21)	$3,819.80	($9,846.50)	$973.33	$655.85
Highway 111	$3,037.20	($979.47)	$37,724.22	$19,042.25	$34,066.67	$3,851.11

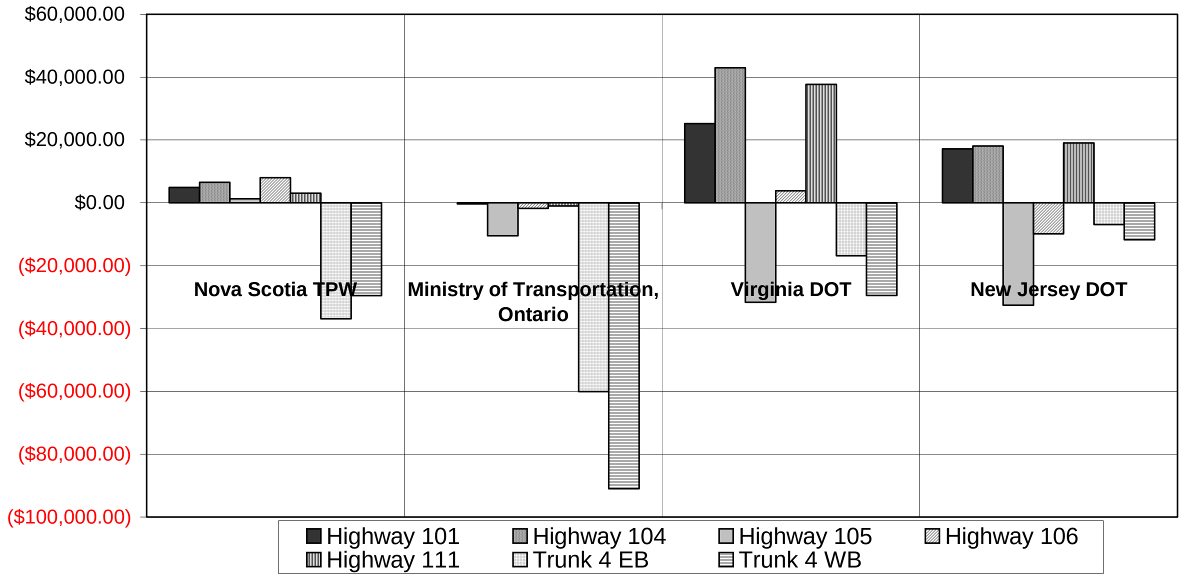


FIGURE 1 Comparison Between TPW and Other Agencies' Payment Adjustments

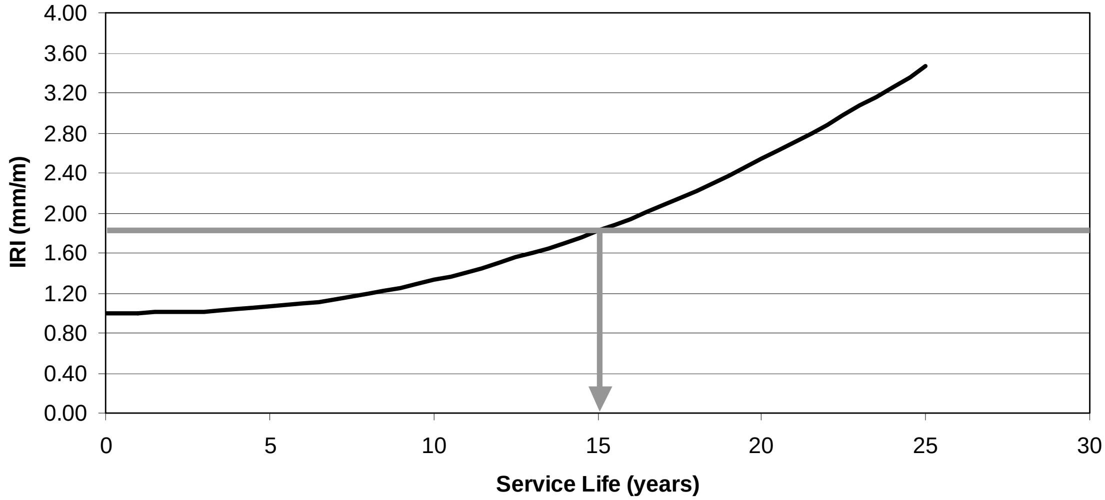


FIGURE 2 Expected Service Life using Category A Master IRI Model

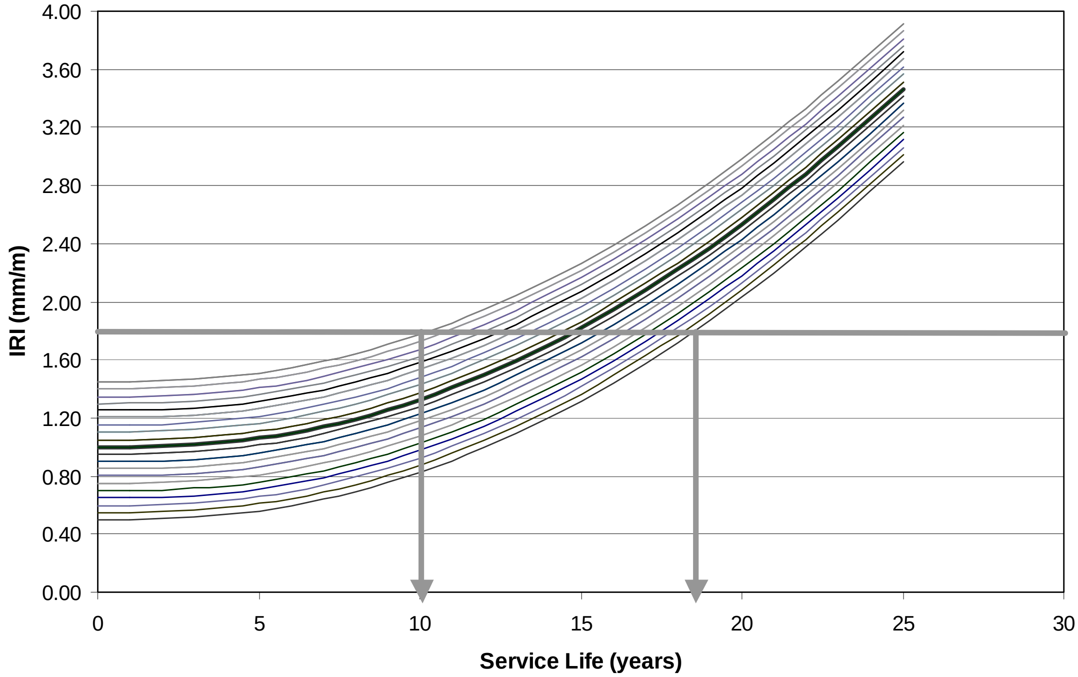
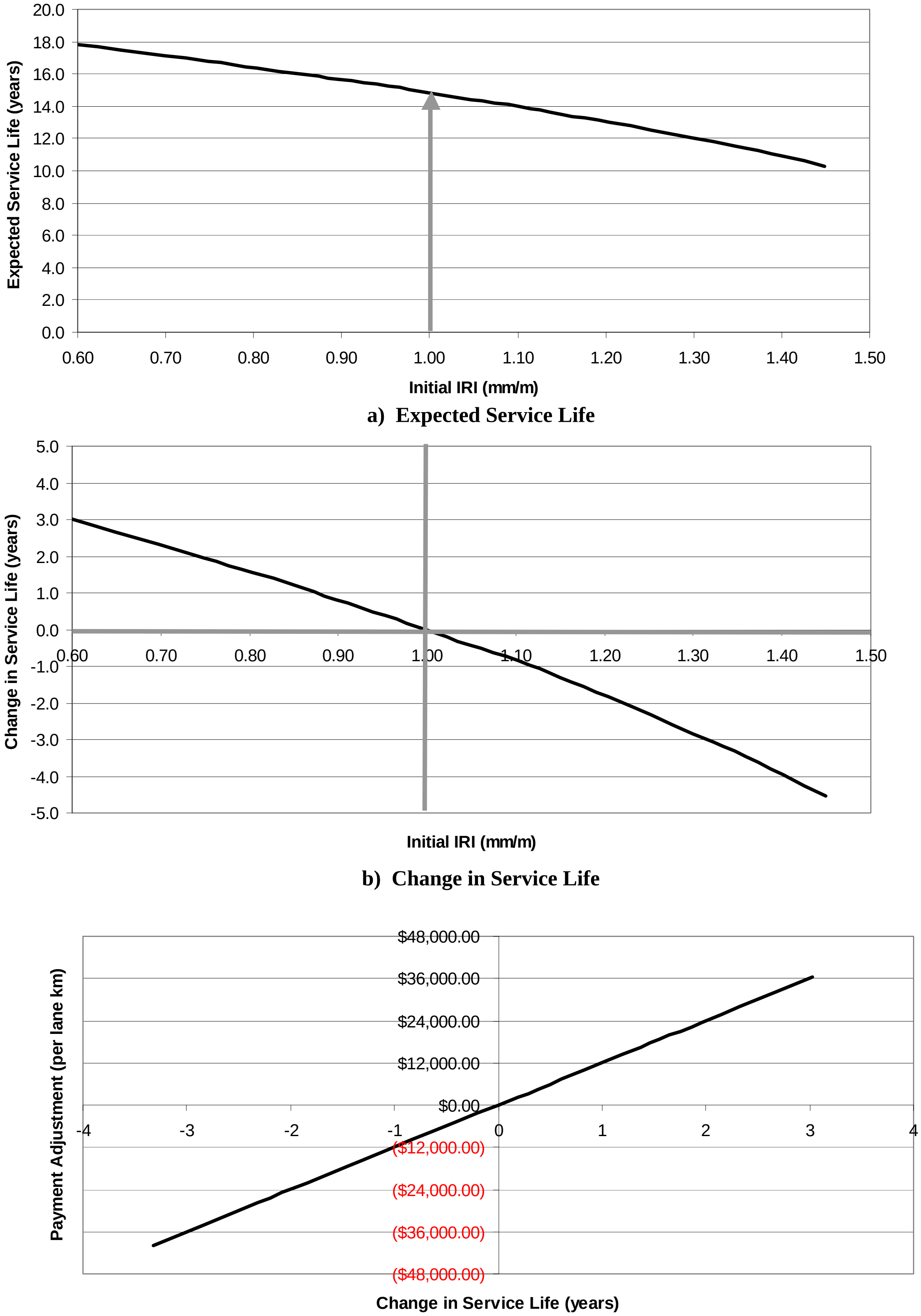


FIGURE 3 Impact of Initial IRI on Expected Service Life (Category A)



a) Expected Service Life

b) Change in Service Life

c) Payment Adjustment

FIGURE 4 Example of Approach 1 Implementation - Equal Yearly Service Life Value

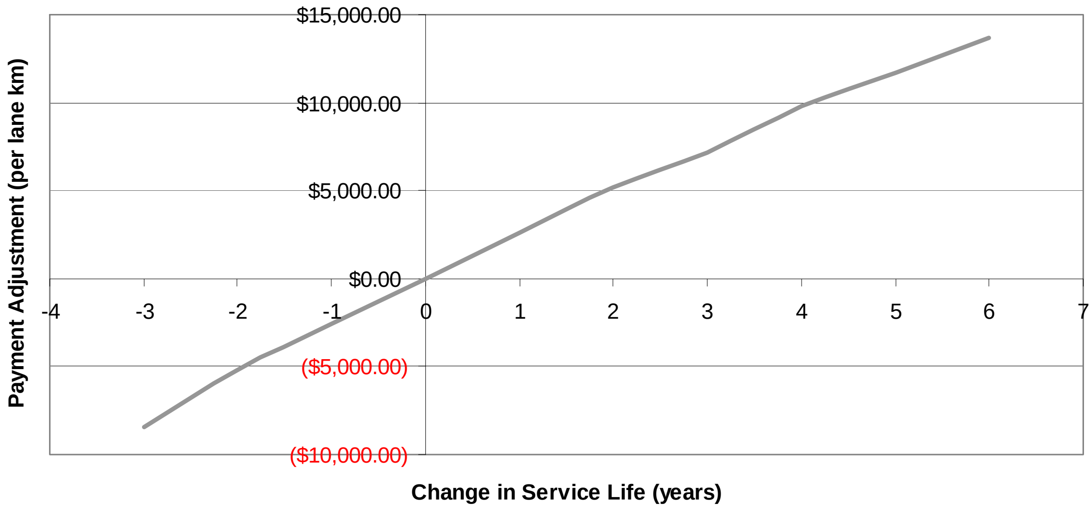


FIGURE 5 Payment Adjustment Based on Reduced / Increased Pavement Design Life

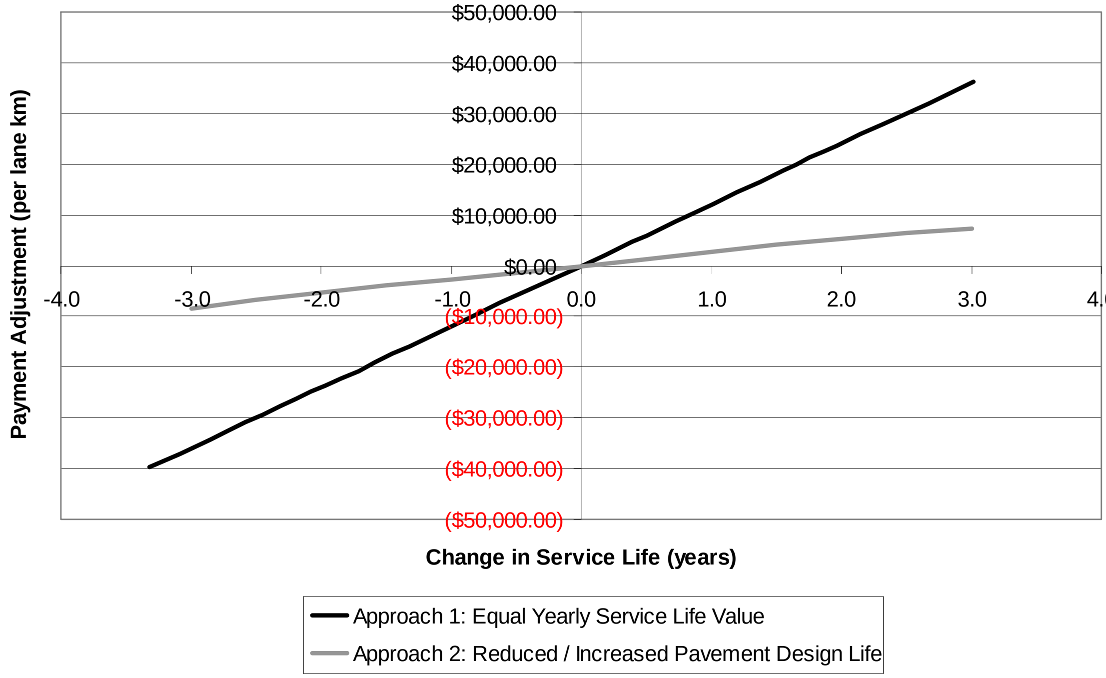


FIGURE 6 Payment Adjustment Comparison for Approaches 1 and 2

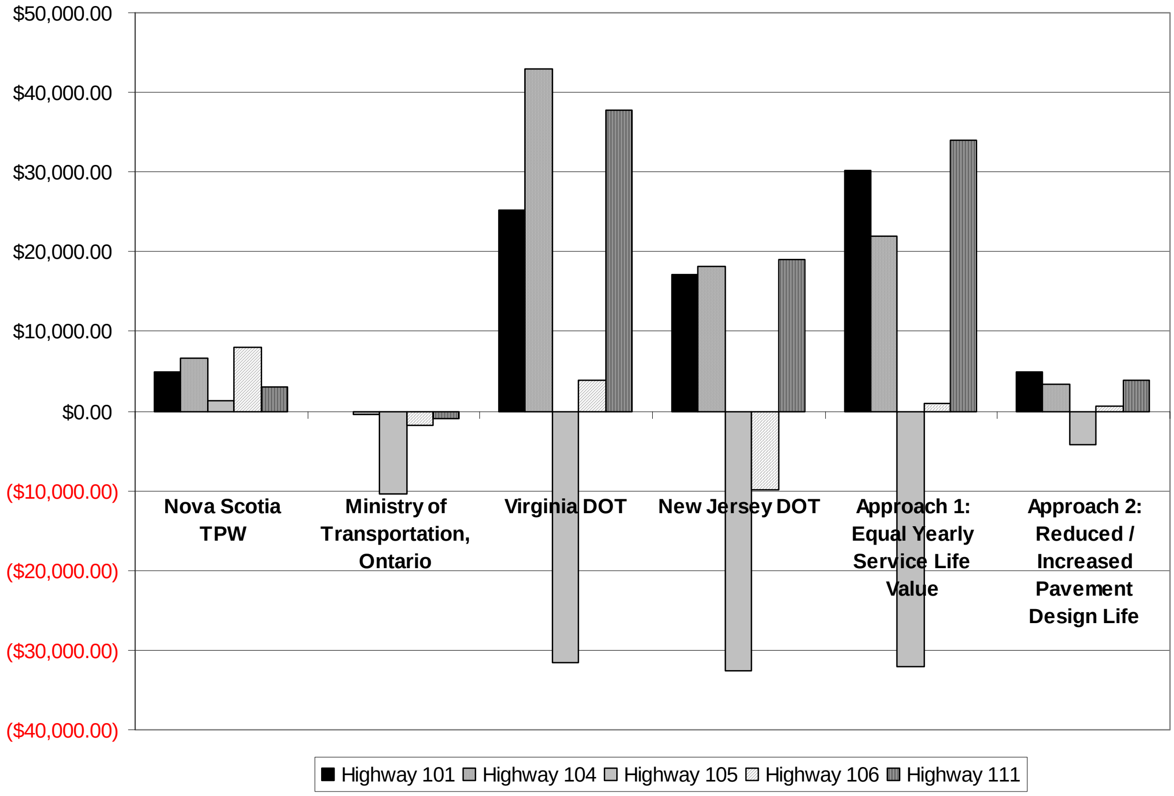


FIGURE 7 Payment Adjustment Comparison for Alternative Approaches