Cost-Effective Pavement Performance Management of Indiana's Enhanced National Highway System through Strategic Modification of the Pavement Rehabilitation Treatment Trigger Values

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ABSTRACT

In October 2012, the MAP-21 (Moving Ahead for Progress in the 21st Century) legislation automatically expanded the National Highway System to include all principal arterials, intermodal connectors, and the strategic highway network (STRAHNET). The network's final mileage may change in the near future, based on states' requests, but the existence of a high priority network with such a large extent presents a big challenge to state highway agencies in preserving the network's sections in the best condition in an era of limited funding. Strategic modification of the treatment trigger values at which pavement projects are implemented can aid the agencies in performance management in the face of budget restrictions, but only after careful evaluation of the long-term influence of varying the project-level treatment trigger values on the pavement conditions at the network level.

This research examines the impact of modifying (a) the pavement rehabilitation trigger policy and (b) the funding on the pavement service lives and on the vehicle operating costs incurred on the Enhanced National Highway System's Indiana sections.

The analysis provides estimates of what improvements in infrastructure performance and reductions in user operating cost are achievable for different funding levels and trigger policies.

INTRODUCTION

In October 2012, the MAP-21 legislation expanded the extent of the National Highway System (NHS) to include all principal arterials, intermodal connectors, and the strategic highway network (STRAHNET). Nationally, the expansion of the NHS was from 164,000 miles to 224,000 miles (1). For the State of Indiana, the expansion was more dramatic, from 2900 miles to 4800 miles (1). To support the newly expanded NHS, the National Highway Performance Program (NHPP) was created to serve as the core funding program for achievement of performance goals for improving infrastructure condition, safety, mobility, or freight movement on the NHS. In preparation for the release of the proposed rule-making for infrastructure condition performance targets anticipated in August 2014 (2), this paper presents an analysis conducted to approximate the service life achievable for the Indiana NHS pavement network under different funding levels that may be provided by the NHPP. For this analysis, the impact of modifying the pavement rehabilitation trigger, which influences the conditions at which a road section is labeled "deficient" and placed on a candidate list for possible rehabilitation treatment implementation, was explored as a possible strategy to preserve the network sections' lives in an era of limited funding. The impacts are presented in the form of projections of the resulting network's total service life (in mile-years), 25th percentile, 50th percentile, and 75th percentile service life (weighed by miles), the percent of miles with a service life of five years or less, and the unit vehicle operating cost due to pavement condition twenty years after the adoption of one of three specified pavement rehabilitation trigger policies and assignment of a certain budget amount for pavement rehabilitation projects. The service life definition in the analysis is based upon the present serviceability rating measure (PSR), which has the advantage of both good correlation with the International Roughness Index (3), while also capturing the severity and extent of non-roughness distresses on a pavement section. The vehicle operating costs presented in the analysis are based upon the fuel, oil, maintenance, and depreciation costs incurred due to poor pavement condition only. In other words, the operating costs do not include the components of road curvature, grades, and speed variability.

METHODOLOGY

Data

FHWA requires state departments of transportation to collect and report certain data items annually regarding the extent, condition, performance, use, and operating characteristics of their state highway network under the Highway Performance Monitoring System (HPMS) program. The 2009 HPMS file for Indiana was used to generate the projections presented in this paper. The following data items were used for calculating the deterioration of pavement condition over time (*4*):

- Pavement Surface Type,
- Initial Pavement Condition: Pavement Serviceability Rating (PSR) and/or International Roughness Index (IRI)
- Structural Number (SN) for flexible pavements/Depth of slab (D) for concrete pavements,
- FHWA Climate Classification,
- Average Annual Daily Traffic (AADT) at current year and the expected AADT twenty years later
- Percentages of Single-Unit and Combination Trucks (vehicle classes 4-7; vehicle classes 8-13)

Software Used

For this project, the FHWA's Highway Economic Requirements System (HERS-ST) version 4.5 was used to conduct the analysis. HERS-ST is an LCCA tool that gives the user flexibility to define and change the treatment trigger policy, which is the process by which deficient sections are identified. Once identified, each deficient section is placed on a candidate list to potentially receive a restorative treatment. A cost-effective, budget-constrained work program is subsequently developed through prioritization of the potential projects. Project prioritization occurs based on the benefit-cost ratio, with "benefit" consisting of reduction in discounted future costs incurred by users due to traveling on the pavement section and "cost" being the cost incurred by the agency for implementation of a project or improvement.

The HERS-ST software process is shown in Figure 1 (*5*).

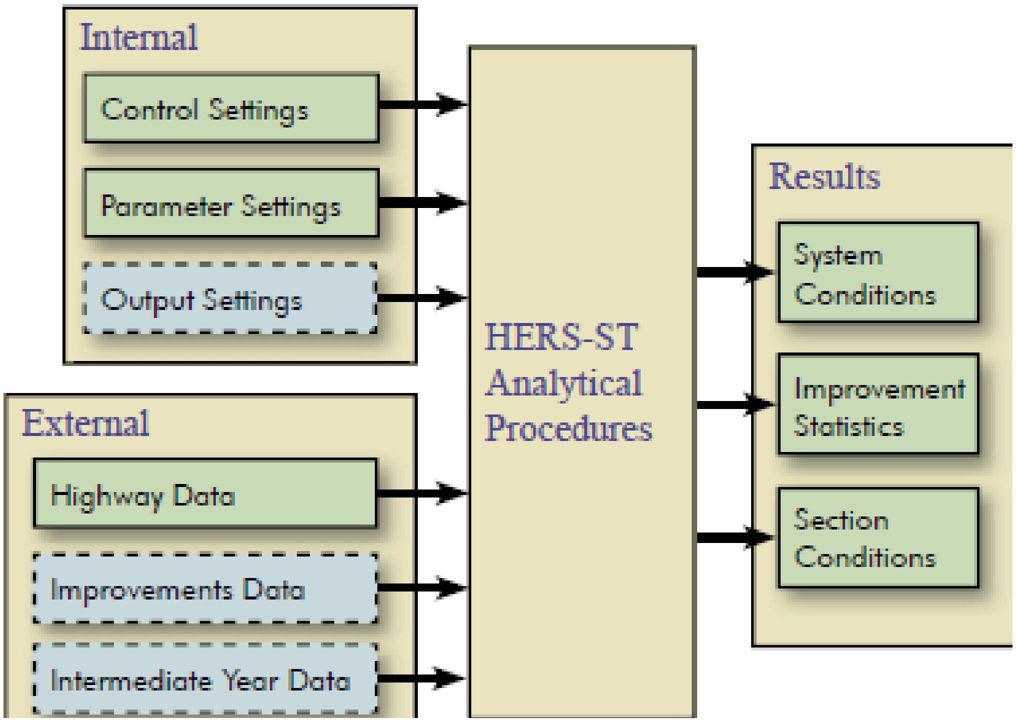

FIGURE 1 Overview of HERS-ST process (5)

The alternative policies featured in Table 1 are labeled as the "Low Condition Level", "Medium Condition Level", and "High Condition Level" trigger policies. The Medium Level trigger policy is an approximation of INDOT's current policy in identifying sections eligible for receiving pavement rehabilitation; it was developed with input from INDOT's Office of Roadway and Pavement (Davidson, unpublished data). The other trigger policies were constructed as alternatives to INDOT's current trigger policy. They were developed to demonstrate what would occur with the pavement network condition if the rehabilitation treatments were triggered at a worse condition level or better condition level than the current trigger policy, respectively. The terms "Heavy" and "Moderate" Rehabilitation are meant to represent rehabilitation treatments of different strengths. For example, HMA Structural Overlay treatment (up to 8 inch overlay) is considered "heavy" rehabilitation and HMA Functional Overlay (2-4 inch overlay) is considered "moderate" rehabilitation.

TABLE 1 Pavement Rehabilitation Condition Level Trigger Policies

Trigger Policy Label	Heavy Rehabilitation Trigger (PSR)	Heavy Rehabilitation Trigger (equivalent IRI in inches/mile) *(3)*	Moderate Rehabilitation Trigger (PSR)	Moderate Rehabilitation Trigger (equivalent IRI in inches/mile) *(3)*
Low	2.3	156	2.9	129
Medium	2.4	151	3.0	126
High	2.5	146	3.1	122

The “heavy” and “moderate” pavement rehabilitation costs, in units of thousands of 2008 constant dollars per lane mile, were set as shown in Table 2. These costs were developed based on input from INDOT's Office of Roadway and Pavement (Davidson, unpublished data). For the same treatment, there is a variety of costs based upon the location of the improvement. Cost of treatments implemented on urban roads varies by the type of urbanized area as defined by the population.

- Small Urban – population 5,000-49,999
- Small Urbanized– population 50,000-199,999
- Large Urbanized– population 200,000 or more

The cost differential contained for the same treatments implemented in different areas is based upon the cost differential that existed for the default pavement treatment cost values contained in HERS.

TABLE 2 Cost of Pavement "Heavy" and "Moderate" Strength Rehabilitation Treatments on Roadways

	Functional Classification	Category of Rural/Urban Area	Cost of Heavy Rehabilitation (thousands of 2008 constant dollars per lane mile)	Cost of Moderate Rehabilitation (thousands of 2008 constant dollars per lane mile)
Rural	Interstates	Flat	200	100
		Rolling	215	105
		Mountainous	315	160
	Principal Arterials	Flat	160	80
		Rolling	180	90
		Mountainous	255	125
	Minor Arterials	Flat	145	70
		Rolling	155	75
		Mountainous	210	105
Urban	Interstates/Expressways	Small Urban	235	120
		Small Urbanized	280	140
		Large Urbanized	470	235
	Principal Arterials	Small Urban	200	100
		Small Urbanized	235	120
		Large Urbanized	295	150
	Arterials/Collectors	Small Urban	145	75
		Small Urbanized	165	85
		Large Urbanized	205	100

Table 3 shows the post-treatment pavement conditions for sections that have undergone rehabilitation treatments (*6*).

TABLE 3 Post-treatment Pavement Condition

Post-treatment Pavement Condition	Pavement condition (PSR)
Heavy Rehabilitation post-treatment condition	4
Moderate Rehabilitation performance jump	0.9
Moderate Rehabilitation maximum post-treatment condition	3.8

To model the subsequent deterioration of pavement sections, HERS-ST uses the equations of the 1993 AASHTO Guide for Design of Pavement Structures. The use of the AASHTO 1993 equations as condition deterioration models is valuable because they can predict the condition of pavements that have been improved with a treatment of a certain improvement intensity, such as moderate rehabilitation or heavy rehabilitation. The main advantage is obviating the need to use different equations to predict condition deterioration over time or to predict the post-treatment performance of a section based on which individual treatment it received. This approach simplifies the analysis at least until more disaggregate performance indices can be developed, tested, included as performance measures in condition prediction models, and used to trigger restorative treatments for Indiana pavements. In practice, the analysis presented in this paper can be repeated periodically, such as once every five years, with disaggregate performance indices as long as the trigger policies tested represent feasible conditions at which a class of treatments of a certain intensity could get implemented.

Initial Characteristics of the Indiana Enhanced National Highway System

At a length of 4800 center-line miles, the Indiana Enhanced National Highway System accommodated a total of 32.5 billion VMT (including 7.5 billion for trucks) in 2009 with an anticipated 42 billion VMT (including 10 billion for trucks) in 2029.

Table 4 shows the total network service life (in mile-years), the 25th percentile, 50th percentile and 75th percentile service lives (weighed by miles), and the percent of miles with a service life of five years or less.

TABLE 4 Pavement Service Life Condition of the Indiana Enhanced National Highway System in 2009

Network-level Total Service Life (mile-years)	25th percentile Service Life (years)	50th percentile Service Life (years)	75th percentile Service Life (years)	Percent of Miles in the Network with service life ≤ 5 years
66384	8.3	14.6	20.0	16.2

RESULTS & DISCUSSION

This section provides estimates of what improvements in pavement service life and reductions in user operating cost are achievable for different funding levels and trigger policies. As stated earlier, the service life definition in the analysis is based upon the present serviceability rating (PSR) measure.

Tables 5-7 show that, at the lowest annual funding level of $10 million and beyond, the policy being used to trigger pavement rehabilitation has a moderate impact on the network-level total pavement service life of the Indiana Enhanced National Highway System. As the funding level increases, the total pavement service life of the network increases with approximately the same slope for all trigger policies, as can be seen in Table 8. From the lowest funding level to the highest funding level, the total pavement service life doubles for all trigger policies. All the trigger policies result in increases in the 25th, 50th and 75th percentile pavement service lives as the rehabilitation funding levels increase. The increase rate in the 50th and 75th percentile service lives with funding is smaller than for the 25th percentile for all trigger policies. However, Tables 5-7 show that the 25th, 50th and 75th percentile service lives at all funding levels increase as the trigger policy shifts from Low to Medium to High. Table 8 shows that all trigger policies result in the same rate of decrease in the percent of miles with pavement service life of five years or less with increased funding. Table 8 suggests that the influence of the trigger policy is also apparent for the increase in the 25th percentile service life of the pavement network. Each additional $10 million in rehabilitation funding increases the 25th percentile service life by 0.85 years, 0.89 years, and 0.95 years under the Low, Medium and High policies for triggering pavement rehabilitation, respectively.

TABLE 5 Pavement Service Life Condition of the Indiana Enhanced National Highway System in 2029 under the Low Deficiency Standard for Triggering Pavement Rehabilitation

Annual Investment in Pavement Rehabilitation for the Indiana Enhanced National Highway System (millions of 2008 constant dollars)	Network-level Total Service Life (mile-years)	25th percentile Service Life (years)	50th percentile Service Life (years)	75th percentile Service Life (years)	Percent Miles in the Network with service life ≤ 5 years
10	36149	0.4	7.5	12.1	38.9
20	38991	1.2	8.1	12.5	36.1
30	42163	2.8	8.9	12.8	31.4
40	44923	4.2	9.7	13.1	27.7
50	46967	5	9.9	13.4	24.2
60	50556	6.5	10.5	14	19.6
70	54305	6.8	10.9	14.6	16.3
80	56745	6.9	11.5	15	14.4
90	61003	7.9	12.4	16.2	11.9
100	65308	9	13.1	17.8	9
110	67746	9.7	13.5	18	6.1
120	70319	10.3	13.8	18.5	3.6
130	73523	10.7	14.2	19.2	1.5

TABLE 6 Pavement Service Life Condition of the Indiana Enhanced National Highway System in 2029 under the Medium Deficiency Standard for Triggering Pavement Rehabilitation

Annual Investment in Pavement Rehabilitation for the Indiana Enhanced National Highway System (millions of 2008 constant dollars)	Network-level Total Service Life (mile-years)	25th percentile Service Life (years)	50th percentile Service Life (years)	75th percentile Service Life (years)	Percent Miles in the Network with service life ≤ 5 years
10	39037	0.6	8.7	12.9	38.5
20	42413	1.4	9.2	13.5	35.1
30	45924	3.7	9.9	13.7	29.5
40	47391	4.5	10.4	13.9	28.4
50	49591	5.4	10.6	14.2	25.2
60	53716	6.7	11.5	14.8	20.9
70	57436	7.7	11.7	15.3	16.8
80	59724	7.9	12.1	15.9	14.7
90	62858	8.4	12.9	16.6	13
100	68145	9.7	13.7	18.2	9.7
110	71937	10.8	14.2	19	6.7
120	74018	11.4	14.7	19.4	4.6
130	76462	11.7	14.9	19.9	3.1
140	77697	12.1	15.2	19.9	2.3

TABLE 7 Pavement Service Life Condition of the Indiana Enhanced National Highway System in 2029 under the High Deficiency Standard for Triggering Pavement Rehabilitation

Annual Investment in Pavement Rehabilitation for the Indiana Enhanced National Highway System (millions of 2008 constant dollars)	Network-level Total Service Life (mile-years)	25th percentile Service Life (years)	50th percentile Service Life (years)	75th percentile Service Life (years)	Percent Miles in the Network with service life ≤ 5 years
10	41576	0.6	9.8	13.8	37.6
20	44556	1.4	10.3	14.2	34
30	48907	4.2	10.6	14.6	28.1
40	50276	4.7	10.9	14.8	25.8
50	52352	5.5	11.4	15.1	24.7
60	55592	6.7	12	15.6	20.9
70	59356	7.8	12.6	16.2	16
80	61909	8.3	12.9	16.4	13.8
90	65328	9.2	13.5	17.2	11.8
100	70689	10.3	14.2	18.3	8.8
110	74087	11.2	15	19.5	7.3
120	76988	12.1	15.5	20.3	4.9
130	79477	12.6	16.1	20.6	3.8
140	81590	12.9	16.1	20.9	2.9

TABLE 8 Summary of the Effects of the Pavement Rehabilitation Trigger Policies on the Pavement Service Life Condition of the Indiana Enhanced National Highway System in 2029

Pavement Rehabilitation Trigger Policy Label	Increase in Network-level Total Service Life (mile-years) for each additional \$10 million annual investment	Increase in the 25th percentile Service Life (years) for each additional \$10 million annual investment	Increase in the 50th percentile Service Life (years) for each additional \$10 million annual investment	Increase in the 75th percentile Service Life (years) for each additional \$10 million annual investment	Decrease in the percent of miles with pavement service life ≤ 5 years for each additional \$10 million annual investment
Low	3179	0.85	0.57	0.63	3.1
Medium	3130	0.89	0.52	0.6	2.9
High	3181	0.95	0.52	0.59	2.7

Figures 2-4 show the unit vehicle operating costs incurred by the users due to pavement condition for all three trigger policies. As stated earlier, the vehicle operating costs presented in the analysis are based upon the fuel, oil, maintenance, and depreciation costs incurred due to poor pavement condition only. In other words, the operating costs do not include the components of road curvature, grades, and speed variability.

The fitted functions demonstrate the relationship of the unit vehicle operating cost with the annual pavement rehabilitation funding for the Indiana Enhanced National Highway System. These functions were used to estimate the total vehicle operating cost incurred by highway users due to pavement condition in 2029 as shown in Table 9 and the influence of the trigger policies in providing savings to the users in Table 10. The rightmost column of Table 10 shows that as the funding level increases, the share of the benefit of switching from the Medium to the High Trigger policy increases and the share of the benefit of switching from the Low to the Medium Trigger policy decreases. Results contained in Tables 9 and 10 show that the most significant effect of changing the pavement rehabilitation trigger policy is in providing great vehicle operating cost savings to road users.

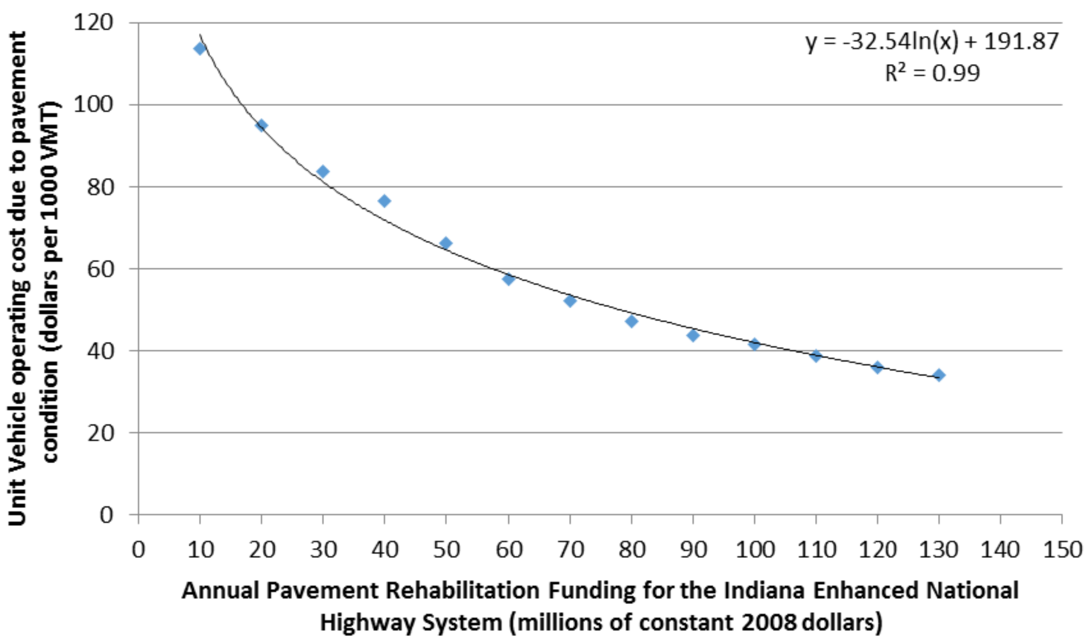

FIGURE 2 The unit vehicle operating cost incurred in 2029 on the Indiana Enhanced National Highway System due to pavement condition with respect to the annual pavement rehabilitation funding under the Low Trigger Policy

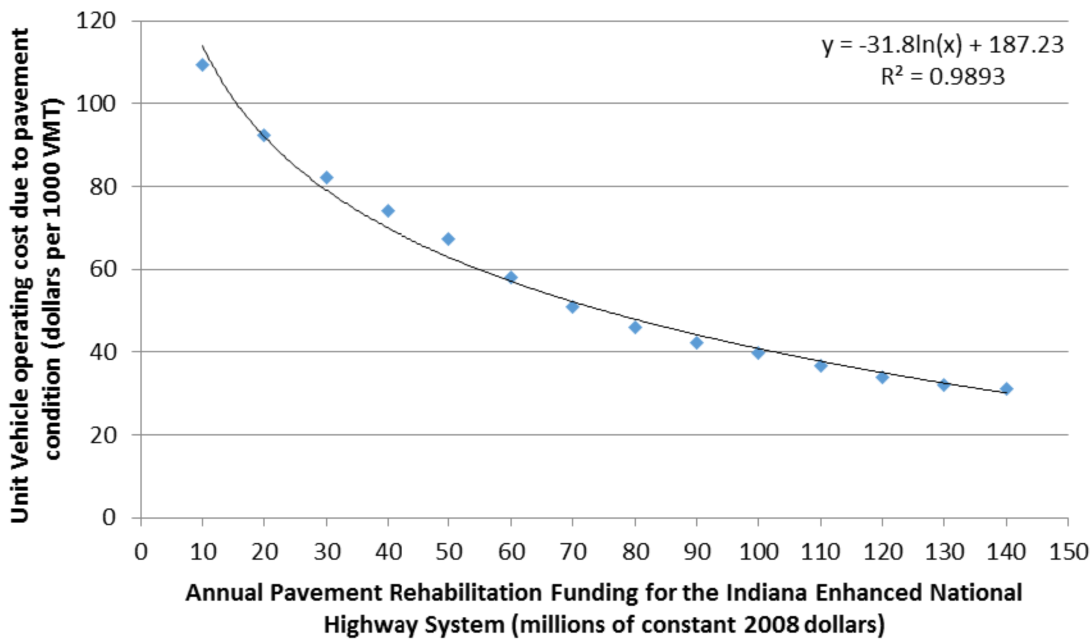

FIGURE 3 The unit vehicle operating cost incurred in 2029 on the Indiana Enhanced National Highway System due to pavement condition with respect to the annual pavement rehabilitation funding under the Medium Trigger Policy

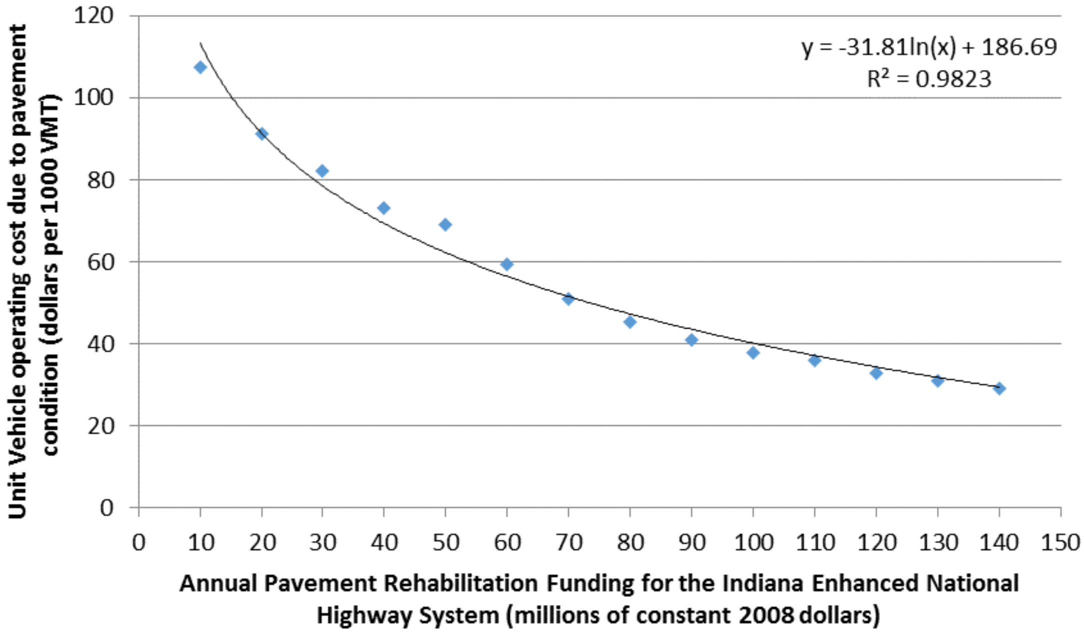

FIGURE 4 The unit vehicle operating cost incurred in 2029 on the Indiana Enhanced National Highway System due to pavement condition with respect to the annual pavement rehabilitation funding under the High Trigger Policy

TABLE 9 The vehicle operating cost incurred in 2029 on the Indiana Enhanced National Highway System due to pavement condition under the Low, Medium, and High Trigger Policies

Annual Investment in Pavement Rehabilitation for the Indiana Enhanced National Highway System (millions of 2008 constant dollars	Unit vehicle operating cost incurred in 2029 due to pavement condition under the Low Trigger Policy (dollars per 1000 VMT)	Unit vehicle operating cost incurred in 2029 due to pavement condition under the Medium Trigger Policy (dollars per 1000 VMT)	Unit vehicle operating cost incurred in 2029 due to pavement condition under the High Trigger Policy (dollars per 1000 VMT)	Total vehicle operating cost incurred in 2029 due to pavement condition under the Low Trigger Policy (millions of dollars)	Total vehicle operating cost incurred in 2029 due to pavement condition under the Medium Trigger Policy (millions of dollars)	Total vehicle operating cost incurred in 2029 due to pavement condition under the High Trigger Policy (millions of dollars)
10	116.9	113.7	113.4	4911.6	4777.5	4762.5
20	94.4	91.9	91.4	3964.3	3857.8	3838.2
30	81.2	79	78.5	3410.2	3319.8	3297.5
40	71.8	70	69.4	3017	2938.2	2913.9
50	64.6	62.9	62.3	2712.1	2642.1	2616.3
60	58.6	57.1	56.5	2462.9	2400.2	2373.2
70	53.6	52.3	51.6	2252.2	2195.7	2167.6
80	49.3	48.1	47.4	2069.7	2018.5	1989.6
90	45.4	44.3	43.6	1908.7	1862.2	1832.5
100	42	41	40.3	1764.7	1722.4	1692
110	38.9	38	37.3	1634.5	1596	1564.9
120	36.1	35.3	34.5	1515.6	1480.5	1448.9
130	33.5	32.7	32	1406.2	1374.3	1342.2
140		30.4	29.6		1276	1243.3

TABLE 10 The relative savings in the vehicle operating cost incurred due to pavement condition in 2029 on the Indiana Enhanced National Highway System when switching among Pavement Rehabilitation Trigger Policies

Annual Investment in Pavement Rehabilitation for the Indiana Enhanced National Highway System (millions of 2008 constant dollars)	Savings in Vehicle Operating Cost incurred due to pavement condition in 2029 caused by a switch from the Low to the Medium Trigger policy (millions of dollars)	Savings in Vehicle Operating Cost incurred due to pavement condition in 2029 caused by a switch from the Low to the High Trigger policy (millions of dollars)	Savings in Vehicle Operating Cost incurred caused by a switch from the Low to Medium Trigger Policy divided by Savings in Vehicle Operating Cost incurred caused by a switch from the Low to the High Trigger Policy (%)
10	134.1	149.1	89.9
20	106.5	126.1	84.5
30	90.4	112.7	80.2
40	78.8	103.1	76.4
50	70	95.8	73.1
60	62.7	89.7	69.9
70	56.5	84.6	66.8
80	51.2	80.1	63.9
90	46.5	76.2	61
100	42.3	72.7	58.2
110	38.5	69.6	55.3
120	35.1	66.7	52.6
130	31.9	64	49.8

CONCLUSION

The objective of this paper was to provide estimates of what improvements in pavement network performance and reductions in the user operating cost are achievable for the Indiana Enhanced National Highway System under different funding levels and trigger policies. The impacts found are presented in the form of projections of the resulting conditions twenty years after the adoption of each of three specified pavement rehabilitation trigger policies and assignment of different budget amounts available for pavement rehabilitation projects. Based on the analysis, certain observations can be made, including that changing the pavement treatment policy to trigger rehabilitation results in modest changes to the total network-level pavement service life, the 25th, 50th, 75th percentiles in pavement service lives, and the percent of pavement miles with service life of five years or less. The most significant effect of changing the trigger policy is in providing great vehicle operating cost savings to road users. The total pavement service life and the unit vehicle operating cost measures both reflect the pavement condition of the entire network. However, it is suspected that because the vehicle operating cost is very sensitive to a small change in the pavement condition, the change in trigger policy demonstrates a much greater effect in changing the vehicle operating cost than in changing the total pavement service life measure.

The analysis conducted in this paper can be repeated periodically by a pavement management office in a highway agency to estimate the likely consequences of the external change of varying budget availability and the internal change of modifying the treatment trigger policy.

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