A RISK-BASED OPTIMIZATION METHODOLOGY FOR MANAGING COUNTY PAVED ROADS

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ABSTRACT

A Pavement Management System (PMS) is a strategic and systematic process to maintain, and upgrade the road network. When funding is limited, it is very important to identify the best mix of road preservation projects that provide the most benefits to society in terms of overall life cycle cost of the road network. The most common factors that play an important role for identifying projects are: budget, traffic volume, Present Serviceability Index (PSI) and risk associated with selecting treatment types. This research develops an optimization methodology for county paved roads that identify the best mix of preservation projects within budget maximizing traffic (passengers and trucks traffic) on treated roads, maximizing the weighted average PSI, and minimizing the risk. This methodology will facilitate a statewide implementation of PMS for counties in the state of Wyoming.

Keywords: Pavement Management System (PMS), county roads, risk-based PMS, optimization model.

INTRODUCTION

A well-functioning transportation infrastructure is key for economic growth. According to the Federal Highway Administration (FHWA), the U.S. roadway network has 3.9 million miles of roadway *(1)*. On the basis of current highway classifications, 79 percent of these roads are under the control of county and local government, but make up only 13.1 percent of total travel. The remainder of the roads are maintained by federal and state government *(1)*. According to the Federal 2015 Budget, $74 billion has been allocated for maintaining surface transportation *(2)*. In the state of Wyoming, there are a total of 27,831 miles of roadway owned and maintained by federal, state, and local entities. Sixty-three percent of these roads are maintained by local government. According to Moving Ahead for Progress in the 21st Century Act (MAP-21), each state is required to develop a Pavement Management System (PMS) to improve or preserve the present pavement condition and the performance of the system *(3)*. All states already have their own pavement management plan. The Wyoming Department of Transportation (WYDOT) utilizes their PMS to maintain 6,844 miles of interstate and state highways. Currently, there is no PMS or road maintenance database for the 63 percent of roads maintained by local governments. Many county roads were built over 40 years ago and have had inconsistent maintenance, resulting in overall poor road conditions. Moreover, the growth of oil and gas industries has increased truck traffic on many county roads. Increased truck traffic, no maintenance database, and limited funding necessitate the development of an innovative PMS to utilize resources more efficiently for local roads.

In order to develop a PMS for county paved roads, the Wyoming Technology Transfer Center (WYT^2/LTAP) and WYDOT signed an agreement with counties to collect the required data in the summers of 2014 and 2015. The collected data will be utilized to determine current road conditions, determine each road’s vulnerability to damage from increased truck traffic, and recommend appropriate maintenance and construction practices for individual roads under various traffic loads. This data will be also used to better allocate budgets by recommending maintenance and rehabilitation to various roads. Previous research identified that more than 75 percent of Wyoming county paved roads are in poor condition (PSI < 1.0) *(4)*. The high percentage of roads in poor condition and limited budgets increases the need to develop a PMS. Such PMS should consider the increase in truck traffic by oil and gas industry, the poor pavement conditions of county paved roads, and life-cycle costs of individual roads. The methodology developed in this research can be used to identify the best mix of pavement preservation projects within a certain budget. It will ensure that higher traffic roadways have higher priority. It will also maximize the weighted average PSI and minimize the risk. This methodology was implemented in Laramie County, located in the southeastern corner of Wyoming, as a case study. This county is responsible for the maintenance of 122 paved roads totaling 229.2 miles. This study utilized only 17 paved roads totaling 103.5 miles to demonstrate the implementation of the proposed optimization model.

LITERATURE REVIEW

This section summarizes previous research relevant to the modeling strategy of infrastructure asset management plan focusing on PMS.

Infrastructure Asset Management Plan

General infrastructure assets include transportation network, energy supply systems, parks and recreational facilities, water utilities, flood protection and land drainage systems, solid waste facilities, telecommunication networks, etc. Internationally, and in the U.S., significant research has been performed to provide a guideline for infrastructure asset management plan *(5, 6, 7* and *8)*. The Association of Local Government Engineers of New Zealand and the Institute of Public Works Engineering Australia published a manual named *International Infrastructure Management Manual* in 2011*(5)*. This manual is considered as the standard for infrastructure asset management system. Using this manual, infrastructure and asset providers can apply different approaches to services and activities that have a lower asset–base. Section 3 of this manual discusses different decision making techniques applicable for managing PMS, such as benefit-cost analysis, multi-criteria analysis, and risk-based decisions. In the U.S., almost every state Department of Transportations (DOT) has their own infrastructure management system to maintain the roads and highways under their control *(6, 7 and 8).*

Pavement Management Model

According to MAP-21, each state is required to develop a risk-based asset management plan for the National Highway System (NHS) in order to best utilize funding to improve or preserve the transportation network. According to WYDOT’s transportation asset management plan, the program uses a preservation based strategy *(6)*. This strategy determines the best point in each asset’s life cycle to apply a given rehabilitation treatment. The goal of this strategy is to maintain existing pavements, keeping a minimum number of roads in poor condition. When the condition of a road falls from poor to a “fail: condition, rehabilitation costs increase four to eight times. The Colorado Department of Transportation (CDOT) has a similar transportation management plan for maintaining more than 9,100 miles of highway *(7)*. In the CDOT transportation asset management plan, three types of risks have been considered: agency, programmatic and asset risks. Agency risks include politics, public perception, reputation, level of available revenue. Programmatic risk comes from delivery risks, revenue uncertainties, and construction cost variations. Project risks include cost, schedule, and quality of projects. According to the Georgia Department of Transportation (GDOT) transportation management plan, a risk matrix was developed considering AADT, percent of truck traffic and the population of the county *(8)*. The risk matrix assigns a risk factor to each roadway segment that affects the pavement condition. Saha et al. studied rural pricing model incorporating pavement deterioration and maintenance in Wyoming *(9)*. In this study, optimum tolling has been identified to generate sufficient revenue for maintaining rural roadways.

Although all states have their own pavement management model, but that does not include county roads. The research on PMS for county roads are still in progress. In this regard, The University of Alabama in Huntsville designed a PMS computer program to collect data that was analyzed with linear regression to build a pavement deterioration equation *(14)*. The Washington Department of Transportation (WSDOT) started a research to define the usage and practices among local agencies so that the implementation gaps could be found and effective practices and tools could be recommended *(15)*. The Illinois Department of Transportation (IDOT) designed a PMS for county roads based on seven main steps: (1) Define the roadway network and collect inventory data, (2) collecting condition data, (3) predict Condition, (4) select treatments, (5) report results, (6) select pavement management tool, and (7) keep the process current. It is important to note that PMS for county roads are very different than state highways. A state specific PMS for county roads needs to be developed considering local factors *(16)*.

MODELING METHODOLOGY

This section presents the formulation of the risk-based pavement management model used in this research, The primary variable of this model, Present Serviceability Index (PSI), is discussed briefly. Depending on the PSI, a decision tree was used to identify the appropriate treatment type. Then, the algorithm for identifying the best mix of preservation projects is discussed. It is important to mention that this model does not consider political factors, but purely life cycle cost of pavements.

Present Serviceability Index

PSI provides a single number on a scale from 0 to 5 that evaluates the overall condition of the pavement from the traveling public's perspective. Equation 1 is used by WYDOT to calculate the PSI of the state highway system.

$$PSI = 5.35e^{-0.0058*IRI} - 4*RUT^2 - 3\left\{1-\left(\frac{PCI}{100}\right)\right\} \quad (1)$$

Where, IRI is the International Roughness Index measured in inches per mile. RUT indicates the Rut Depth measured in inches and PCI is the Pavement Condition Index based on ASTM D6433. This equation was utilized in this study to calculate PSI on local county roads.

Treatment Types

The six possible treatment options for local paved roads are summarized in Table 1 along with descriptions, applications, and estimated costs/mile. In this table, it can be noticed that the estimated costs per mile for different treatment types are rounded to the nearest $10,000. From previous research, it was found that general maintenance (GM) cost ranges from $1,000 to $2,500 *(13)*. Because of having very low cost associated with GM compared to other treatment types, GM is considered as zero (0) in this research.

TABLE 1. Pavement Preservation Strategy for Paved County Roads.

Treatment Type	Details and Applications	Est. Cost/Mile
GM General Maintenance	➢ General Maintenance Procedures ➢ Asphalt Patching ➢ Pothole Repair ➢ Crack Sealing ➢ Road Striping	$0
1-R Preventative Rehabilitation	➢ Chip Seal ➢ Micro-surface ➢ Thin overlay (<2”)	$60,000
2-R Minor Rehabilitation	➢ Surface preparation (mill, level, full-depth reclamation, or combination thereof) ➢ Thick Overlay (>2”) ➢ Seal Coat	$250,000
3-R Preventative Rehabilitation with Shoulder Needs	➢ 1-R plus shoulder or widening requirements ➢ Applicable on roads in good condition with shoulder needs	$350,000
4-R Major Rehabilitation	➢ 2-R plus shoulder or widening requirements ➢ Applicable on narrow roads with shoulder or widening needs	$650,000
5-R Full Reconstruction	➢ Complete Reconstruction	$1,200,000

Huntington et al. *(4)* proposed the decision tree shown in Figure 1 for identifying appropriate treatment types for Wyoming county paved roads. According to the decision tree, three variables are considered: PSI, road width, and rut depth. The PSI break points were established based on the *1993 AASHTO Guide* and WYDOT’s ranking system. According to the *1993 AASHTO Guide*, local roads with a PSI < 2.0 have reached terminal serviceability and road segments with PSI < 1.0 are characterized as severely deteriorated pavement. Therefore, these roads are in need of more intense treatment. As the PSI increases, rehabilitation strategies are also determined based on rut depths and road widths. If the PSI is considered to be in good or better condition, PSI > 3.0, rehabilitation is warranted only when the surface should be widened to improve the road’s safety characteristics.

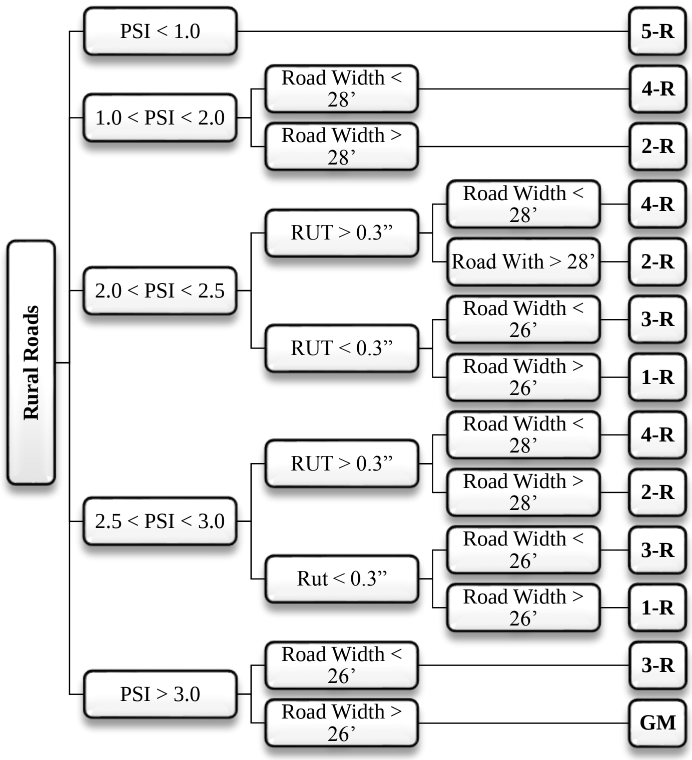

FIGURE 1. Paved Rural Road Treatment Decision Process.

Rut depth becomes a deciding factor when choosing between a thin overlay or a chip seal and a more intense surface treatment or a thicker overlay. Rut depth of 0.3 inches is utilized as the break point in this analysis since WYDOT deems rut depths in excess of 0.3 inches to be hazardous. Excessive rut depths, RUT > 0.3 inches, must be treated before any overlay can be placed on a road segment; therefore, high rut depth values will warrant more extensive treatment methods. Roads with lower rut depths, RUT < 0.3 inches, may be treated with a chip seal or a thin overlay.

Many of the paved county roads analyzed in this study are constructed with very narrow lanes and shoulders. Width affects many aspects of road performance including capacity, travel speed, and safety. The width of a road determines the feasibility of placing overlay pavements on existing surfaces. According to AASHTO's *A Policy on Geometric Design of Highways and Streets*, commonly referred to as the 'Green Book,' lane widths of 12 feet are generally provided in the design of two lane highways with expected high percentages of commercial vehicles, such as oil and gas trucks *(10)*. In addition, shoulders on paved roadways increase lateral clearance and improve capacity, while at the same time accommodating stopped vehicles and emergency uses. They also provide lateral support for the sub base, base, and surface courses. Therefore, the presence of a shoulder is essential on paved roadways. The 'Green Book' recommends a minimum two foot shoulder width on minor rural roads. It states that "roads with a narrow traveled way, narrow shoulders, and an appreciable traffic volume tend to provide poor service, have a relatively higher crash rate, and need frequent and costly maintenance." Based on design parameters regarding road width and shoulder presence, local paved roads should have enough width for 12-foot lanes with at least some shoulder in order to properly service the oil and gas industry. Therefore, thin overlays were recommended only for roads 26 feet wide or wider.

Thick overlays were only recommended for roads 28 feet wide or wider. Setting these roadway width parameters ensures that road widths following treatment are adequate to safely and efficiently serve oil and gas traffic.

Risk-based Pavement Management System

The proposed PMS for county roads considers not only the risk but also local conditions such as average daily truck traffic (ADTT), average daily traffic (ADT) and overall PSI. The objective of the developed model is to maximize overall expected PSI, maximize treated sections with high traffic, and minimize risk, given by:

$$Maximize \sum_{i=1}^{n} ADT_i * ADTT_i * Risk_i(Treatment\ type) * Expected\ PSI_i(Treatment\ type) * x_i \quad (2)$$

Where ADT_i and $ADTT_i$ express the Average Daily Traffic and Average Daily Truck Traffic for road i; $risk_i$ and $expected\ PSI$ are the function of treatment type; x_i is an integer equal to one if the project is selected and 0 if it is not selected. This is a combinatorial optimization problem where one must select a collection of projects of maximum value while satisfying some weight constraint. More formally, the problem can be written:

$$Maximize \sum_{i=1}^{n} ADT_i * ADTT_i * Risk_i(Treatment\ type) * Expected\ PSI_i(Treatment\ type) * x_i \quad (3)$$

$$Subject\ to \sum_{i=1}^{n} Treatment\ Cost_i * x_i \leq budget \quad (4)$$

$$x_i \in \{0,1\} \quad (5)$$

The risk and expected PSI can be determined using Equations 6 and 7. The discussion of how the values of Risk were determined, is placed in Data Analysis section.

$$Risk_i = \begin{cases} 0.05, & if\ Treatment\ Type = GM \\ 0.092, & if\ Treatment\ Type = 1-R \\ 0.385, & if\ Treatment\ Type = 2-R \\ 0.538, & if\ Treatment\ Type = 3-R \\ 1.0, & if\ Treatment\ Type = 4-R \\ 0.05, & if\ Treatment\ Type = 5-R \end{cases} \quad (6)$$

$$Expected\ PSI_i = \begin{cases} 3.9, & if\ Treatment\ Type = 1-R \\ 4.0, & if\ Treatment\ Type = 2-R \\ 4.0, & if\ Treatment\ Type = 3-R \\ 4.1, & if\ Treatment\ Type = 4-R \\ 4.3, & if\ Treatment\ Type = 5-R \end{cases} \quad (7)$$

The General Maintenance (GM) is applied on all the roads that are not selected for implementing treatments (1-R through 5-R). The selected model can be used to satisfy any budget limit. This algorithm can also be used to prepare a Five Year Capital Improvement Plan (CIP) for pavements. In this regard, it is very important to predict next year's pavement condition based on the existing condition. Pavement condition is represented by PSI and Rut Depth (RD). WYDOT provided the necessary data to develop the pavement performance models for county roads. The models can be seen in Equations 8 and 9.

$$Pavement\ Age = 0.00005 * PSI^3 - 0.0029 * PSI^2 - 0.0306 * PSI + 4.2744 \quad (8)$$

$$Pavement\ Age = 0.0000003 * RD^3 - 0.00008 * RD^2 + 0.0107 * RD + 0.00005 \quad (9)$$

Where, PSI represents Present Serviceability Index and RD is for Rut Depth in a specific year. Pavement age can be determined using existing PSI and RD values of a road. The optimization formulation used in this research has been solved using the Generalized Reduced Gradient Nonlinear Algorithm.

CASE STUDY (LARAMIE COUNTY)

DATA COLLECTION

Table 2 summarizes data sources with the type and number of units of data collected for the case study. WYDOT contracts annually with the company named Pathway Services, Inc. to survey road and pavement condition data such as IRI, RUT, and PCI.

TABLE 2. Features and Data Collected for Laramie County.

Feature	Data Source	Quantity	Units	Data types
County Roads	WYDOT	17	Roads	GIS layer of county paved roads
Segmentation	Field	23	Segments	Location of new construction joints
Traffic Counts	Field	23	Counts	ADT, ADTT
Pavement Performance	Pathway Services, Inc.	23	Segments	IRI, PSI, RUT, PCI, PSR[1], Location

[1]**PSR: Present Serviceability Rating**

Segmentation

The paved roads were segmented by driving the roads and determining any differences in the pavement types. A total of 17 segments were established. The segments begin and end where there are overlays, new construction, or other changes in the pavement. Each segment was mapped with ArcGIS.

Traffic Counts

A total of 23 traffic counts were conducted. All the traffic counts were entered into ArcGIS and mapped.

Pavement Performance Data

WYDOT contracted with Pathway to collect data for the local paved roads in Laramie County. The data was provided to the WYT^2/LTAP Center for analysis. Pathway collected and delivered the following data:

- International Roughness Index, IRI, to measure slope variance/road roughness
- Rutting measurements, RUT, measure of permanent deformation
- Surface imaging, for use in analyzing pavement distresses, PCI

The pavement serviceability was developed based on a panel rating system. The roughness, or quality of ride, is the dominating factor in estimating the PSI of pavement. Pathway collected data for IRI calculations using a South Dakota type laser profiler based on active class 1 ASTM E950 standards (Pathway Services Inc.) (11). After data collection was completed, the IRI was calculated in accordance with ASTM E1926 (12).

Rutting information was gathered using PathRunner Data Collection systems, designed to capture more than 1500 points up to three times per inch at highway speeds. The precise profile enables accurate RUT measurement to be extracted at any given point.

The WYT^2/LTAP followed the same process utilized by WYDOT to obtain PCIs on county roads. This was done to allow comparisons between county and state-maintained systems.

Data base for the Risk-based PMS

All variables used in this study except risk were collected from field investigation for each roadway segment and then combined in a single data base for implementing the optimization model. Risk was calculated using the treatment cost for each roadway segment. The combined dataset contains length of the segment, existing PSI, ADT and ADTT for each roadway segment. Segment length was used to determine the treatment cost for the whole segment. Existing PSI is the primary variable in the model used to maximize the network average PSI. ADT and ADTT were incorporated to give a higher priority to roadways with higher traffic volumes. A sample dataset for the model is shown in Table 3.

TABLE 3. Combined Dataset for Implementing Risk-Based PMS Model.

Segment ID	Road Name	Length	Existing PSI	ADT	ADTT
222-1	Chalk Bluff Road/"78" Rd	6.1	0.3	168	72
3	Albin/LaGrange Rd	10.7	0.9	108	22
6	Black hills Rd	10.1	0.1	114	36
19-1	Old Highway Birns West	6.5	0.3	198	26
222	Chalk Bluff Road/"78" Rd	5.5	1	168	72

DATA ANALYSIS

As mentioned in a previous sections, the following treatments are normally applied to county paved roads: GM, 1-R, 2-R, 3-R, 4-R, and 5-R. As treatment cost increases, risk also increases. For example, the cost of 3-R treatment is 54 percent lower than 4-R treatment. So the risk of 3-R treatment is also 54 percent lower than 4-R treatment. The variation of treatment cost and risk can be seen in Figure 2. In this research, the risk ranges between 0 and 1 where 1 represents high risk roads that require immediate treatment and 0 represents no-risk roads. For 4-R treatment type, risk was considered as the highest because treatment cost will be substantially higher if the 4-R treatment is not applied. When 5-R treatment is appropriate for a specific road, risk is the lowest (0.05). This is due to the fact that the road already requires full replacement. Therefore, applying immediate treatment does not reduce the life cycle cost in any way.

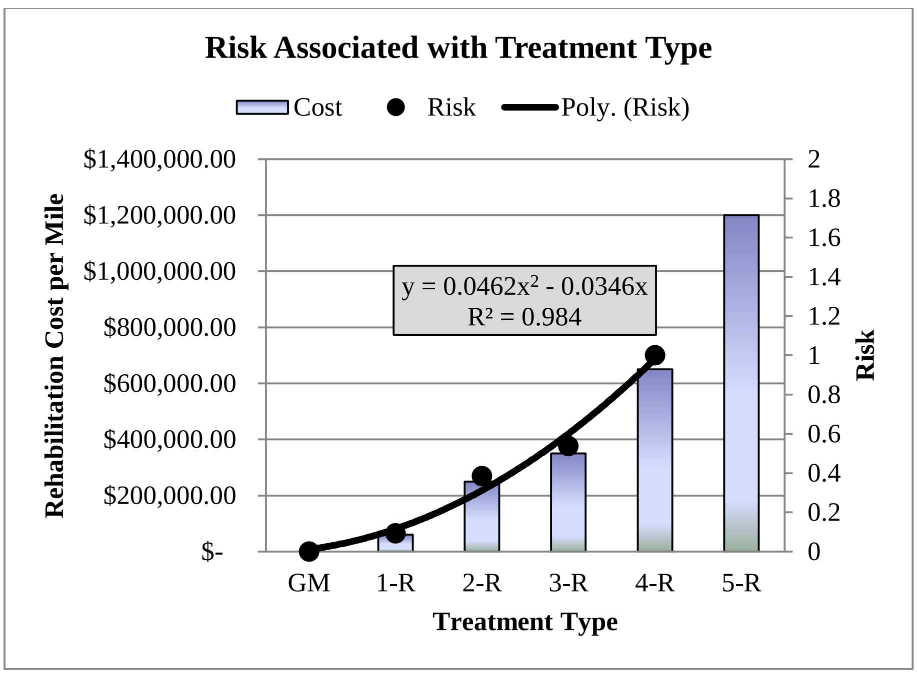

FIGURE 2. Variation of Risk Associated with Treatment Cost.

In this research, the following five possible options were analyzed to demonstrate to counties the potential of the proposed optimization:

The optimization model developed in this research was based on the following principles:

- Preventive and minor rehabilitation treatments are more cost effective than reconstruction
- High traffic volume roadways should have higher priority when selecting treatments.
- The only constraint in this model is budget.

In the objective function, annual budget was determined by the cost of a single project applying the most expensive treatment. From the data used in this research, it was found that Black Hills Road costs $12.12 million for implementing a 5-R construction treatment. Therefore, $13 million was considered as the budget limit.

In order to optimize the budget, different counties might be interested in optimizing different parameters. For example, engineers might want to maximize the average expected PSI. In this research, the following five possible options were analyzed to demonstrate to counties the potential of the proposed optimization:

Option 1: Maximizing weighted expected PSI

Option 2: Minimizing weighted expected Risk

Option 3: Maximizing ADT

Option 4: Maximizing ADTT

Option 5: Combining above 4 options

In Table 4, the results of the five different optimization models are presented. Among the options, Option 5 provides the most benefit to society by optimizing PSI, risk, ADT, and ADTT.

TABLE 4. Summary Results Optimizing Different Objective Functions with a Budget of $13 Million.

Optimization	**Objective Function**	**Weighted Expected Average PSI**	**Weighted ADT**	**Weighted ADTT**	**Expected Weighted Risk with Treatment**	**Budget**
Option 1	Maximizing weighted expected PSI	**2.11**	260	36	0.11	$ 12,905,000
Option 2	Minimizing weighted expected Risk	2.02	230	32	**0.09**	$ 12,998,000
Option 3	Maximizing ADT	2.11	**260**	36	0.11	$ 12,905,000
Option 4	Maximizing ADTT	2.03	213	**43**	0.20	$ 12,990,000
Option 5	Maximizing weighted expected PSI, ADT and ADTT with minimum risk	2.01	240	34	0.10	$ 12,473,000

Since Option 5 provides the most benefit to society, this model is used to analyze the following three possible scenarios to demonstrate the potential of this model.

1. Selecting projects with a certain budget limit.
2. Improving the weighted average PSI from existing conditions to good conditions. In this research, good conditions were defined as a weighted average PSI above 3.0

3. Keeping the same weighted average PSI next year as it is now.

Table 5 provides a summary of the first scenario with a budget of $13 million. In this table, the summarized of selected projects appear in bold type. Similarly, the second and third scenarios select the segments that cost approximately $40.9 and $5.1 million, respectively.

TABLE 5. Selected Projects for Next Year Using Option 5 with a $13 Million Budget

Segment ID	Road Name	Length	Existing PSI	Existing Rut Depth	Treatment Type	ADT	ADTT	Estimated Cost	Expected PSI with Treatment within Budget
222-1	Chalk Bluff Road/"78" Rd	6.1	0.3	0.3	GM	168	72	$ -	0.00
3	Albin/LaGrange Rd	10.7	0.9	0.295	GM	108	22	$ -	0.19
6	Black hills Rd	10.1	0.1	0.322	GM	114	36	$ -	0.00
19-1	Old Highway Birns West	6.5	0.3	0.359	GM	198	26	$ -	0.00
222	Chalk Bluff Road/"78" Rd	5.5	1	0.296	GM	168	72	$ -	0.41
21-2	Old Yellowstone Rd	2.7	0.2	0.319	GM	36	6	$ -	0.00
21-1	Old Yellowstone Rd	1.9	0.9	0.241	GM	36	6	$ -	0.19
21	Old Yellowstone Rd	1.2	0	0.328	GM	36	6	$ -	0.00
10	**Chalk Bluff Road/"78" Rd**	**7.7**	**1.4**	**0.377**	**4-R**	**350**	**40**	**$ 5,005,000**	**4.10**
18-1	Moffet Rd	4.5	1.3	0.308	GM	26	1	$ -	0.96
15	**Hillslade Rd West**	**3.8**	**2.2**	**0.157**	**3-R**	**372**	**62**	**$ 1,330,000**	**4.00**
14-1	**Hillslade N Rd/Midway**	**5.1**	**2.8**	**0.275**	**3-R**	**372**	**62**	**$ 1,785,000**	**4.00**
13	**Gillaspie Rd**	**4.8**	**2.8**	**0.272**	**3-R**	**37**	**7**	**$ 1,680,000**	**4.00**
18	Moffet Rd	3.5	3.1	0.228	GM	26	1	$ -	2.98
2	**A-118-1**	**2**	**3.2**	**0.277**	**3-R**	**34**	**7**	**$ 700,000**	**4.00**
11	**Chalk Hill/Bliss Rd**	**2**	**3.2**	**0.264**	**3-R**	**34**	**7**	**$ 700,000**	**4.00**
7	**Bristol Ridge/Hirsig Rd**	**1.6**	**2.9**	**0.208**	**3-R**	**31**	**1**	**$ 560,000**	**4.00**
8	**Bruegman Rd**	**1.3**	**2.9**	**0.26**	**3-R**	**24**	**4**	**$ 455,000**	**4.00**
1	**CR 140-1**	**4.3**	**2.4**	**0.219**	**1-R**	**328**	**40**	**$ 258,000**	**3.90**
5	Bear Creek/marsh Rd	2.7	2.1	0.26	GM	15	1	$ -	1.99
9	Carpenter Rd/Berger Rd	2.5	3.1	0.193	GM	518	243	$ -	2.98
14	Hillslade N Rd/Midway	8.1	3.5	0.216	GM	372	62	$ -	3.40
21-3	Old Yellowstone Rd	4.9	3.6	0.154	GM	36	6	$ -	3.51
Average			**1.71**						**2.01**
Total		**103.5**						**$ 12,473,000.00**	

Sensitivity Analysis

Engineers must know the appropriate budget providing the maximum benefit to society. The appropriate budget has been determined based on the four performance parameters: Weighted PSI, Weighted Rut Depth, Weighted ADT and ADTT. The Option 5 model has also been implemented here. Figure 3 shows the trends of the performance parameters as the budget increases.

For identifying the appropriate budget, the slope of the performance curves is critical. Figure 3 shows that the slope of the rut depth curve from $3 to $12 million is higher than from $12 to $24 million. Therefore, $12 million is the appropriate budget. Similarly, the trends of weighted PSI and weighted ADT and ADTT have been analyzed and show that $12 million is the most appropriate budget.

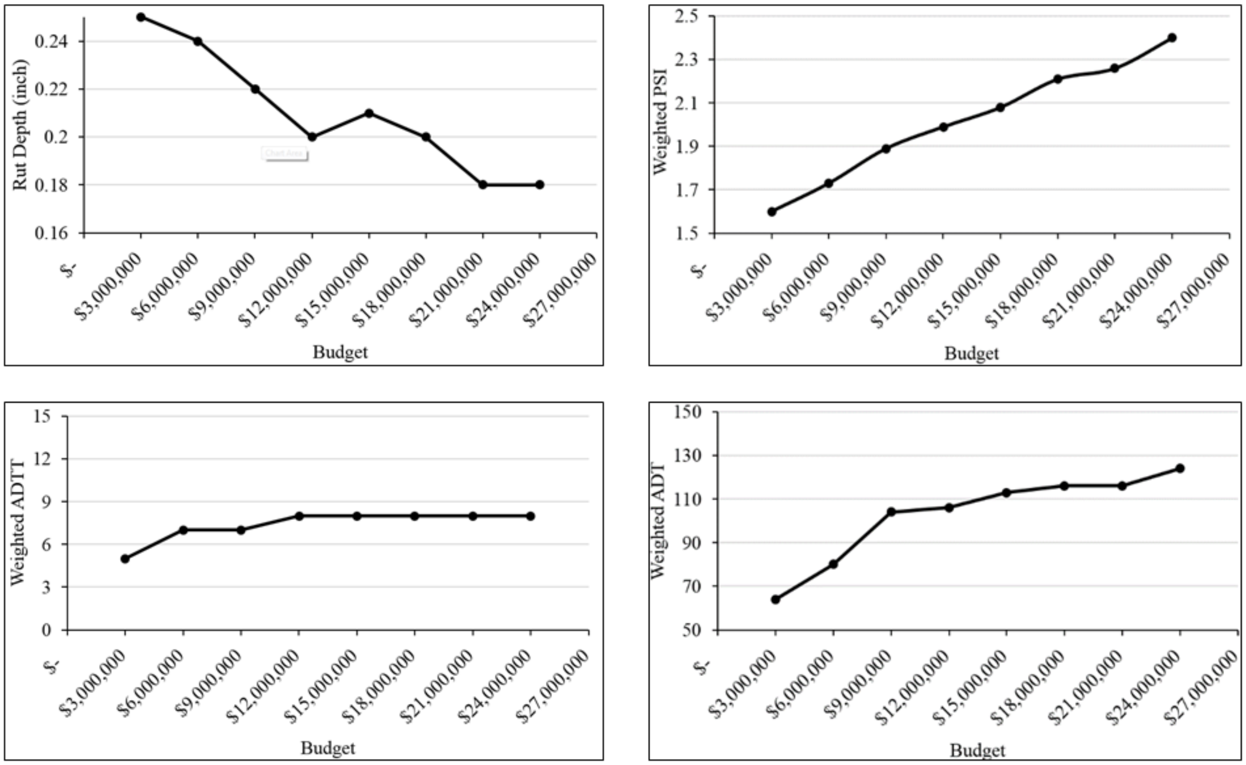

FIGURE 3. PMS Performance Parameters Comparison for Different Budgets.

Five Year Capital Improvement Plan (CIP)

A capital improvement plan (CIP) is a roadmap for counties that provides direction and guidelines to carefully plan and manage their capital and roads. This model can also be implemented to develop a CIP. As a case study, the Option 5 model has been implemented to develop a five-year CIP.

It was assumed that in five years the weighted average PSI is expected to increase from existing conditions to 3.25. To achieve this goal, engineers may want to know how much funding can be requested. In order to do this analysis, every year the PSI and rut depth of each segment were predicted based on the performance curves provided by WYDOT. It was also assumed that narrow roads (road width < 26 feet) need to be widened to at least 30 feet in the first treatment in five years. Considering all of these conditions, the Option 5 model has been implemented to develop a five-year CIP. Table 6 shows the summary results indicating how much money needs to be requested every year to achieve the goal in five years. It can be seen that for every year except year 5 approximately $12.5 million is required. Year 5 requires only $7.8 million to achieve the goal. Table 7 presents the list of treatments every year. The table shows that when a treatment is applied on a specific road, for next few years' just GM is required, which is as expected.

TABLE 6. Five Year Spending Plan with a $13 Million per Year Budget.

	Budget	Weighted PSI	Weighted Rut Depth (inch)	ADT	ADTT
Existing		1.71	0.28	45	11
Year1	$12,473,000	2.01	0.20	106	8
Year2	$12,730,000	2.35	0.16	131	18
Year3	$11,280,000	2.68	0.14	141	23
Year4	$12,120,000	3.05	0.12	152	26
Year5	$7,800,000	3.26	0.10	135	26

TABLE 7. Selected Projects for Next Five Years with a $13 Million per Year Budget.

Segment ID	Road Name	Year1	Year2	Year3	Year4	Year5
222-1	Chalk Bluff Road/"78" Rd	GM	**5-R**	GM	GM	GM
3	Albin/LaGrange Rd	GM	GM	GM	GM	GM
6	Black hills Rd	GM	GM	GM	**5-R**	GM
19-1	Old Highway Birns West	GM	GM	GM	GM	**5-R**
222	Chalk Bluff Road/"78" Rd	GM	GM	**5-R**	GM	GM
21-2	Old Yellowstone Rd	GM	GM	**5-R**	GM	GM
21-1	Old Yellowstone Rd	GM	**5-R**	GM	GM	GM
21	Old Yellowstone Rd	GM	GM	**5-R**	GM	GM
10	Chalk Bluff Road/"78" Rd	**4-R**	GM	GM	GM	GM
18-1	Moffet Rd	GM	GM	GM	GM	GM
15	Hillslade Rd West	**3-R**	GM	GM	GM	GM
14-1	Hillslade N Rd/Midway	**3-R**	GM	GM	GM	GM
13	Gillaspie Rd	**3-R**	GM	GM	GM	GM
18	Moffet Rd	GM	**3-R**	GM	GM	GM
2	A-118-1	**3-R**	GM	GM	GM	GM
11	Chalk Hill/Bliss Rd	**3-R**	GM	GM	GM	GM
7	Bristol Ridge/Hirsig Rd	**3-R**	GM	GM	GM	GM
8	Bruegman Rd	**3-R**	GM	GM	GM	GM
1	CR 140-1	**1-R**	GM	GM	GM	GM
5	Bear Creek/marsh Rd	GM	**4-R**	GM	GM	GM
9	Carpenter Rd/Berger Rd	GM	**1-R**	GM	GM	GM
14	Hillslade N Rd/Midway	GM	GM	GM	GM	GM
21-3	Old Yellowstone Rd	GM	GM	GM	GM	GM

CONCLUSIONS

In the state of Wyoming, WYDOT utilizes their PMS to keep track of 6,844 miles of interstate and state highways. The remaining 63 percent of the roads in the state are maintained by the local government and are not included in the WYDOT PMS. Currently, WYDOT and WYT^2/LTAP Center are working together to develop a state-wide PMS for county paved roads. The necessary data for developing the PMS will be collected in the summers of 2014 and 2015 for all paved local roads in Wyoming. In this study, a risk-based methodology was developed to identify the best mix of road preservation projects that utilizes limited available resources. The developed methodology was implemented in a small county road network consisting of 17 roads divided into 23 segments totaling 103.5 miles. This methodology optimized overall expected PSI, traffic and truck traffic, and risk by selecting the best mix of road preservation projects. Various analysis scenarios were examined using the proposed model including selecting projects for the next five years considering a limited budget, allocating variable annual budgets for five years to maintain a certain PSI, determining minimum budget to maintain existing PSI, and determining budget to provide maximum benefit to society.

The developed methodology can be highlighted as follows:

- It is tailored specifically to county paved roads.
- As FHWA requires incorporation of risk into PMS, this methodology includes risks related to minimizing life-cycle cost, increasing traffic and truck loading and budget constraints.
- This methodology is flexible to analyze different scenarios such as developing a five-year CIP within a limited budget, determining minimum budget to keep existing condition and to provide maximum benefit to society.
- This methodology can be implemented in all 23 counties in the state of Wyoming and can be used by other states for developing a PMS for county roads. It is important to note that the objective function used in this model considered the parameters that may not be important to other states. For example, in the case study truck traffic was incorporated in order to consider the impact of oil and gas industry. For other states, this parameter may not be as important. In this regard, some minor changes in the methodology may be needed to reflect local conditions in other states.

RECOMMENDATIONS

It is recommended that the proposed risk-based pavement management model should be implemented on county roads statewide. This model is based on the current conditions of the road maximizing the expected average PSI and ADT with minimum risk associated with the future maintenance cost. Indicators used in this research are IRI, PCI, Rut depth, PSI, Road Width, ADT, ADTT, risk associated with future maintenance, and available funding. It is also recommended that additional sources of data, such as previous maintenance records and pavement conditions, be incorporated in the optimization in the future to increase the accuracy of the results.

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