CONSEQUENCES OF DELAYED MAINTENANCE OF PAVEMENT NETWORKS

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ABSTRACT

Pavement networks must preserve an acceptable level of service to sustain the economic, social, and environmental development of society. The preservation of pavements is only possible when timely maintenance actions are conducted on a regular basis. Delayed maintenance can cause significant impacts on the pavement network but a systematic procedure to quantify this impact is required. This paper describes the application of a framework to quantify the consequences of delayed maintenance of pavement networks. In this framework, a pavement preservation policy is defined, and performance objectives are established. Maintenance treatments and budget needs are identified based on the pavement condition. A case study is used to demonstrate the impact of delayed maintenance of three pavement networks at different conditions (Good, Fair, Poor) at the beginning of the analysis. A number of maintenance scenarios are analyzed for these pavement networks: all needs, do nothing, delayed maintenance treatments by 2 years, and budget-driven with limited funds for maintenance. The trends observed in the pavement network condition, total agency costs, backlog costs, and remaining life as a result of the analysis were similar for the three pavement networks, although the impact is higher for pavement networks in fair and poor condition. In a broader perspective, delayed maintenance may affect not only pavement condition, but also mobility, safety, transportation agency and user's costs over time.

INTRODUCTION

Transportation asset management is a complex decision-making process which includes strategic, systematic, and coordinated planning and programming of investments or expenditures to operate, maintain, upgrade, and expand physical transportation assets effectively throughout their entire life cycle. Pavement networks are one of the main transportation assets which contribute to a nation's economic development. This is evident by comparing U.S. vehicle-miles of travel with the Gross Domestic Product, that have grown largely in parallel since 1936, excepting World War II years (FHWA, 2012).

In order to continue this economic progress, pavement networks must provide a level of service acceptable to society, enhancing quality of life, and generating positive effects not only in economic terms, but also taking into account social and environmental impacts. Some of the challenges faced by pavement networks are the aging or deterioration, over time, increased demand of road users, and limited availability of resources. Adequate, cost-effective, and timely pavement management strategies are required to address those problems.

The American Association of State Highway and Transportation Officials (AASHTO) states that "highway maintenance encompasses a program to preserve and repair a system of roadways with its elements to its designed or accepted configuration and to an accepted quality of performance" (AASHTO, 2007). Preservation is defined as "work that is planned and performed to improve or sustain the condition of the transportation facility in a state of good repair. Preservation activities generally do not add capacity or structural value, but do restore the overall condition of the transportation facility" (FHWA, 2016). Delayed maintenance is defined as "work that is needed to preserve the highway system but postponed in the agency-defined maintenance program." (Chang et al, 2017).

This paper describes a framework to quantify the consequences of delayed maintenance of pavement networks. A case study is used to demonstrate the applicability of the framework to analyze delayed maintenance scenarios on three pavement networks at different conditions at the beginning of the analysis.

FRAMEWORK TO QUANTIFY THE CONSEQUENCES OF DELAYED MAINTENANCE

The framework to quantify the consequences of delayed maintenance of pavement networks is shown in Figure 1. The three main steps to quantify the impact of not applying maintenance at a proper time during the life of the asset includes: defining the pavement network preservation policy, determining maintenance treatments and budget needs for the preservation policy, and conducting delayed maintenance scenarios analyses.

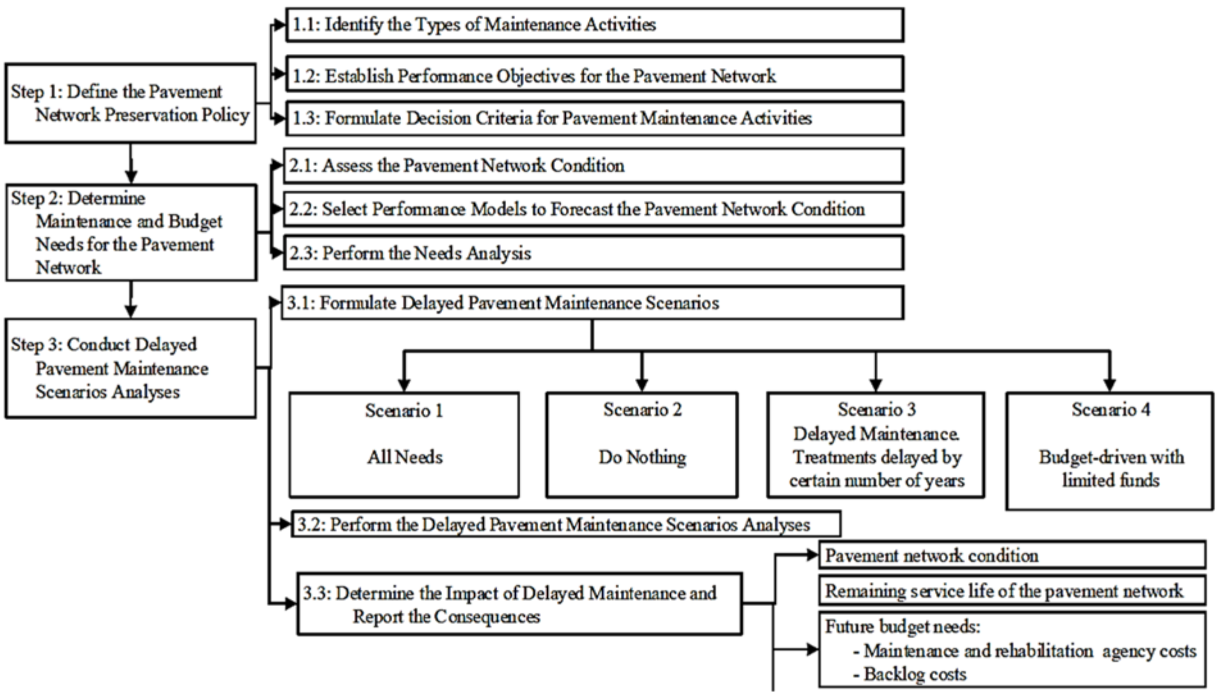


Figure 1. Framework to quantify the consequences of delayed maintenance (Chang et al, 2017).

The first step is to define the pavement network preservation policy by identifying the types of maintenance treatments, establishing performance objectives, and decision criteria for maintenance. The second step is to determine the pavement treatments and budget needs required to implement the agency-desired preservation policy. Needs are identified based on the pavement condition of the sections that composed the network, and performance models are used to forecast the pavement condition over time. The third step is to conduct delayed maintenance scenarios analyses to determine the impact and report the consequences using selected performance measures.

CASE STUDY

A case study is conducted to demonstrate the consequences of delayed maintenance on three pavement networks with different existing conditions: Good, Fair, and Poor. The consequences of delayed maintenance are quantified following the steps shown in the framework. Each step of the process is described as follows.

1. Define the Pavement Network Preservation Policy

Identify the types of maintenance and rehabilitation activities

Maintenance is defined as “work that is performed to maintain the condition of the transportation system or to respond to specific conditions or events that restore the highway system to a functional state of operation. Maintenance is a critical component of an agencies asset management plan that is comprised of both routine and preventive maintenance” (FHWA, 2016). Preventive maintenance is defined as “a cost-effective means of extending the useful life of the Federal-aid highway (23 U.S.C. § 116 (e))” (FHWA, 2016). Routine maintenance is defined as "work that is performed in reaction to an event, season, or over all deterioration of the transportation asset. This work requires regular reoccurring attention" (FHWA, 2016). Examples of maintenance treatments are: crack seals, slurry seals, and microsurfacing. Pavement rehabilitation is defined as “structural enhancement that extend the service life of an existing pavement or improve its load carrying capability, or both” (AASHTO 2012). Examples of rehabilitation treatments include: hot-mix-asphalt overlays with milling or recycling prior to the overlay.

Establish performance objectives for the pavement network

Performance objectives are established based on performance measures. Pavement Condition Index (PCI) is a performance measure calculated from individual pavement distresses observed in the field. The PCI ranges from 0 to 100, where 100 is a pavement in very good condition and 0 in very poor condition. Another performance measure is the remaining service life (RSL). RSL is defined as the time between the current condition and the time when the pavement reaches a PCI of 25. Examples of performance objectives for the pavement network are:

- Minimum network average PCI 80
- Minimum network average RSL: 25 years
- Minimum percent of the network in good condition: 75 percent
- Maximum percent of the network in poor condition: 10 percent.

Formulate decision criteria for maintenance and rehabilitation activities

The decision criteria are based on predefined time-intervals for maintenance and condition triggered for rehabilitation. Condition categories are formulated in terms of the PCI by setting breakpoints as shown in Table 1. A decision tree based on pavement condition, functional class, and surface types is used to identify treatment needs for each pavement section as shown in Figure 2.

Table 1. PCI breakpoints for pavement condition categories.

Category	PCI	Condition
I	100-91	Very Good
II	90-71	Good
III	70-51	Fair
IV	50-25	Poor
V	Under 25	Very Poor

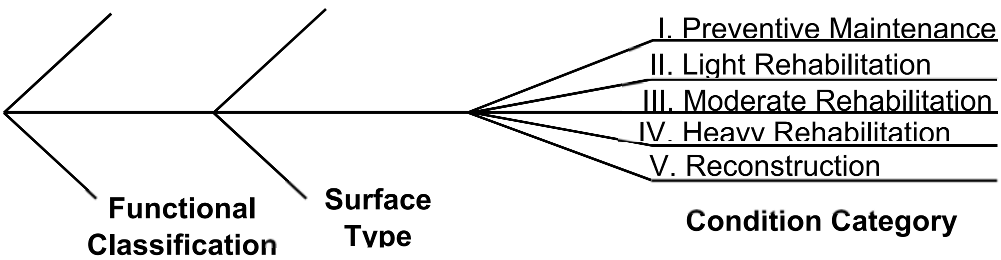


Figure 2. Decision tree to identify treatment needs based on pavement condition (MTC, 1988).

2. Maintenance and Budget Needs for the Pavement Network

Assess the pavement network condition

Field survey inspections are conducted periodically to update the pavement network condition. Most agencies survey their high volume roads (e.g. interstates, primary arterials) every one to two years, and low volume roads on a three to four-year schedule. A commonly used distress protocol is ASTM D6433-11, Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys. State Highway Agency can use their own distress protocols and pavement management systems. For the case study, the distresses considered are defined in the Pavement Condition Index Distress Identification Manual for Flexible Pavements, published by the Metropolitan Transportation Commission in 2016 (MTC, 2016). Eight distresses are described in the MTC pavement distress manual: alligator cracking, block cracking, distortion, longitudinal cracking, patching, rutting, weathering, and raveling.

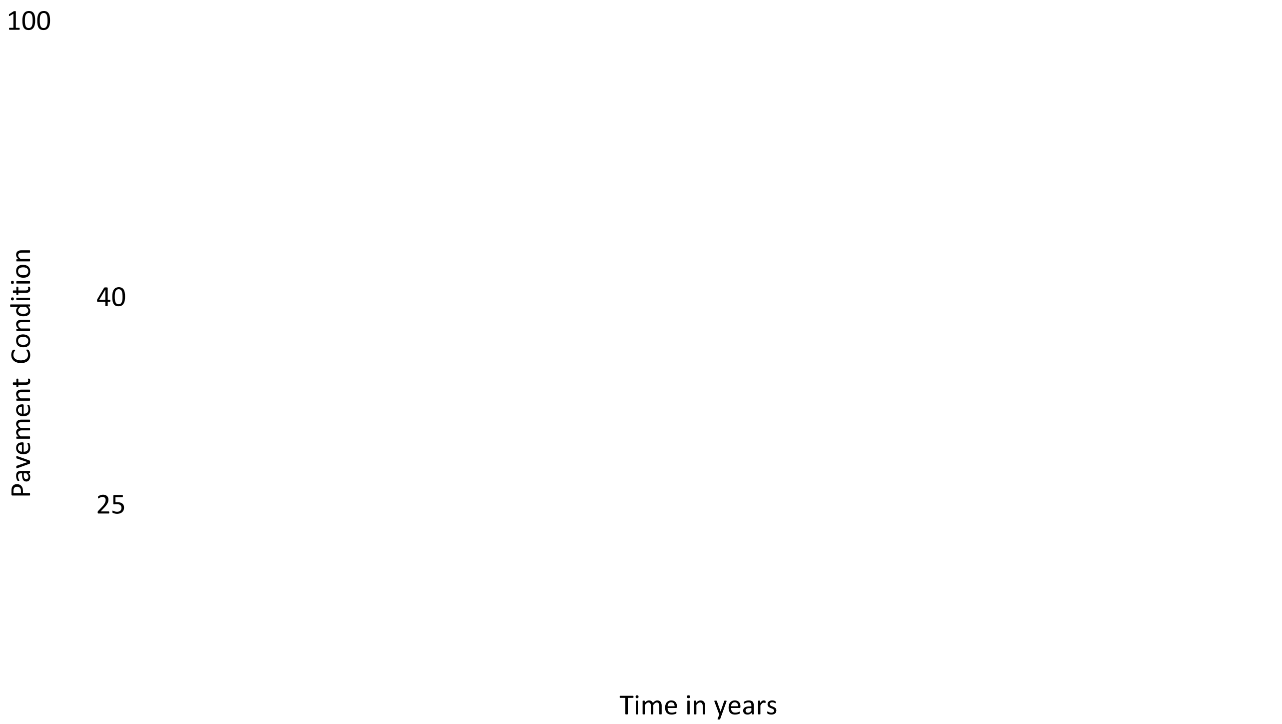
The pavement condition for three networks included in the case study are summarized in Table 2.

Table 2. Summary of the Pavement Network Conditions.

Pavement Network Condition	Average Condition Index (PCI)	Very Good	Good	Fair	Poor	Very Poor
Good	80	29.8%	52.2%	14.7%	2.6%	0.7%
Fair	65	1.7%	47.8%	35.6%	12.8%	2.2%
Poor	41	7.0%	14.4%	12.8%	29.3%	36.5%

Pavement performance models

Family performance curves are used to forecast the future condition of individual sections. Performance curves are developed for different combinations of functional class and pavement type and the condition is projected as function of age. These family performance curves are adjusted for individual pavement sections when a treatment is performed or a pavement inspection is conducted. Figure 3 shows a general pavement condition over time as related to pavement treatments and level of service (Chang et al, 2017). The x-axis represents the service life that is related to the design period (e.g. 20 - 30 years); and the y-axis shows a pavement condition index or other metric that decreases over time. The rate of deterioration depends on the traffic, climate, and other factors.



Source: Adapted from AASHTO 2012

Figure 3. Generic representation of pavement condition deterioration, maintenance, and rehabilitation treatments over time. (Chang et al, 2017).

Needs analysis

Based on the decision criteria for the maintenance and rehabilitation and using family performance curves to project the PCI over time, the treatment and funding needs are identified for the individual pavement sections that composed the network. The needs analysis considers that sufficient funds are available to the preservation policy established by the agency. For the case study, the following assumptions are made:

- Length of the analysis period: 20 years (from 2017 to 2036)
- Treatment costs (Table 3)
- Interest rate: 3 percent
- Inflation rate: 3 percent

Table 3. Treatment costs for functional classes of highways.

Functional class	Treatment	Cost
Major/Minor Arterial, Collector	Seal cracks	$1.00/LF
	Microsurfacing	$4.00/Sq Yd
Major/Minor Arterial	Thin overlay for condition cat. II	$30.00/Sq Yd
	Thin overlay for condition cat. II and III	$31.00/Sq Yd
	Thick overlay for condition cat. IV	$45.00/Sq Yd
	Mill and thin overlay for condition cat. II and III	$33.00/Sq Yd
	Mill and thick overlay for condition cat. IV	$47.00/Sq Yd
	Reconstruction	$81.00/Sq Yd

Table 3 (Continued). Treatment costs for functional classes of highways.

Functional class	Treatment	Cost
Collector	Thin overlay for condition cat. II and III	$28.00/Sq Yd
	Thick overlay for condition cat. IV	$40.00/Sq Yd
	Thin overlay for condition cat. II	$28.00/Sq Yd
	Mill and thin overlay for condition cat. II and III	$30.00/Sq Yd
	Mill and thick overlay for condition cat. IV	$42.00/Sq Yd
	Reconstruction	$60.00/Sq Yd

3. Conduct Delayed Maintenance Scenarios Analyses

Formulate delayed maintenance scenarios

The pavement maintenance scenarios for the case study are:

Scenario 1. Maintenance and rehabilitation treatments are performed with sufficient funds to implement the agency's preservation plan: a) Preserve the pavement network in very good condition, b) Preserve the pavement network at the same existing condition.
Scenario 2: Do nothing. No maintenance, rehabilitation, or reconstruction treatments are performed.
Scenario 3: Maintenance treatments are delayed by 2 years.
Scenario 4: Budget-driven. Limited funds are available for maintenance: a) 40 percent of baseline budget for maintenance, b) 0 percent of baseline budget for maintenance, only major rehabilitation treatments received funds.

Perform delayed maintenance scenarios analyses

Maintenance scenarios were run in StreetSaver to analyze the consequences of delayed maintenance. StreetSaver is Pavement Management System supported by the Metropolitan Transportation Commission (MTC) in California. StreetSaver includes an inventory, condition assessment based on the Pavement Condition Index (PCI), needs analysis, and scenarios budget and target-driven scenarios analysis using the Dynamic Bubble Up Technique (DBU) to prioritize maintenance and rehabilitation investments (Chang 2007). Table 4 includes a summary of the results for the three pavement networks including: total agency costs, backlog costs, and percent pavements in very poor condition at the end of the analysis period (20 years).

Table 4. Summary of the pavement maintenance scenarios analyses.

Scenario			Total Agency Cost[1,2] (Millions of dollars)			Backlog Cost[1,2] (Millions of dollars)			Percent Pavements in Very Poor Condition[1]		
			Pavement Network Condition[3]			Pavement Network Condition[3]			Pavement Network Condition[3]		
			Good	Fair	Poor	Good	Fair	Poor	Good	Fair	Poor
1	a.	All Needs	231	325	457	0	0	0	0	0	0
	b.	Preserve current condition	138	181	245	140.8	234.2	280.6	0	22.2	24.5
2		Do Nothing	0	0	0	479	593.5	646.6	18.9	45.1	78.2
3		Delayed Maintenance by 2 years	159	192	248	133	209.7	263	11.6	18.6	21.4
4	a.	Budget-driven with limited funds 40 percent of baseline budget for maintenance	135	170	242	229	274.7	315.4	9.8	34.1	58.5
	b.	0 percent of baseline budget for maintenance	128	181	245	267	310.9	337.2	8.6	22.2	35.8

[1] At the end of the analysis period.
[2] Total cost using a 3 percent interest and inflation rate.
[3] Pavement network condition at the beginning of the analysis

The total agency costs increase in all the scenarios as the pavement network condition at the beginning of the analysis moves from good to poor. For Scenario 1.a, All Needs, the total agency cost is $231M for the pavement network in good condition, and $ 453M for the pavement network in poor condition. There are not backlog costs in Scenario 1.a since there are sufficient funds to preserve the pavement network addressing all the needs. In all the other scenarios, the backlog costs increase as the pavement network condition at the beginning of the analysis is worst. It is also observed that the percent of pavement in very poor condition at the end of the analysis period is higher for the pavement network in poor condition in all the scenarios. In Scenario S3, delaying maintenance by 2 years, the percent of pavement in very poor condition increases from 11.6% to 21.4% for the pavement network in good condition when compared to the pavement network in poor condition. The difference is more significant for Scenarios 4.a and 4.b.

Report the consequences of delayed maintenance

- Consequences on Pavement Network by Condition Category: PCI and other performance measures including the International Roughness Index (IRI), International Friction Index (IFI), Present Serviceability Rating (PSR), and Structural Number (SN) are meaningful to engineers and used in technical reports. Therefore, a more efficient manner to report the impact on the pavement network condition to funding authorities is the percentage of the pavement network at different condition categories over time. Figure 4 shows the percent of area in each pavement condition category over the entire analysis period for Scenarios 3 and 4.a. In both scenarios, the percent of pavement area in very poor condition is higher as the pavement network is in worst condition. This is observed over the entire period of analysis.

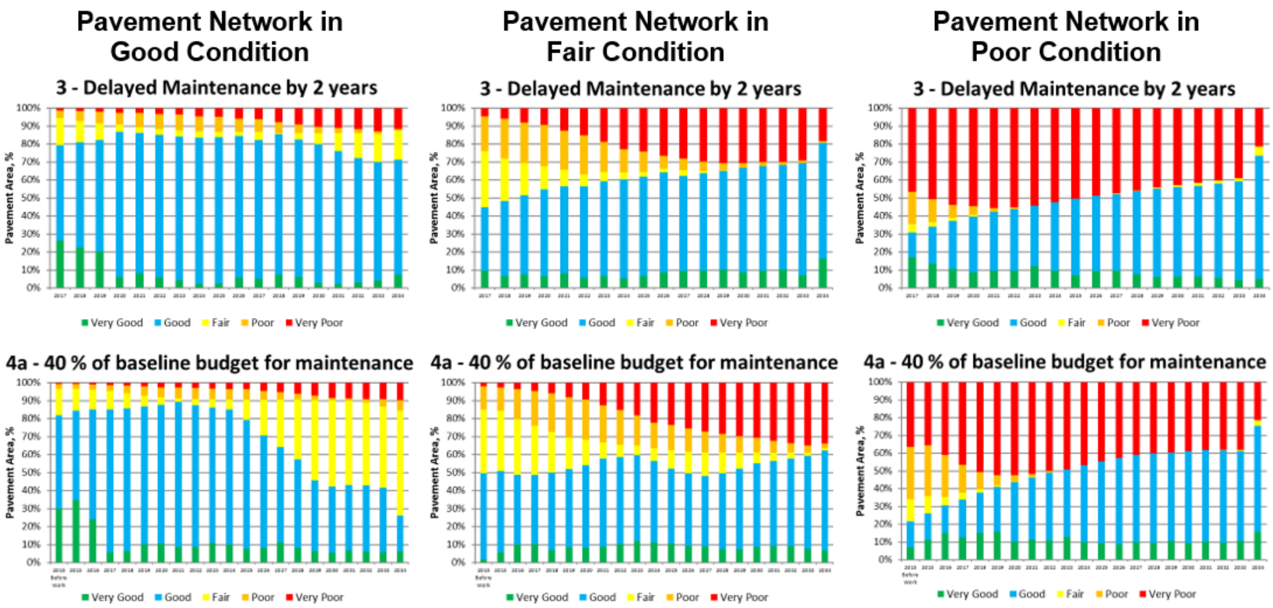


Figure 4. Pavement network condition over time, Scenarios 3 and 4a.

For this case study, the consequences of delaying maintenance by 2 years (Scenario 3.a) are similar to a 40% budget driven scenario (Scenario 4.a) in terms of pavement sections in each condition category; although in Scenario 4a there are fewer sections in very good and good condition in the last five years of the analysis period.

- Consequences on Backlog Costs. There are not backlog costs in Scenario 1 since there are sufficient funds to implement the agency preservation program. Scenario 2 has the highest backlog costs in the three pavement networks. In Scenarios 1.b, 3, 4.a and 4.b, the backlog costs increase when the condition of the pavement network decreases (from good to poor).

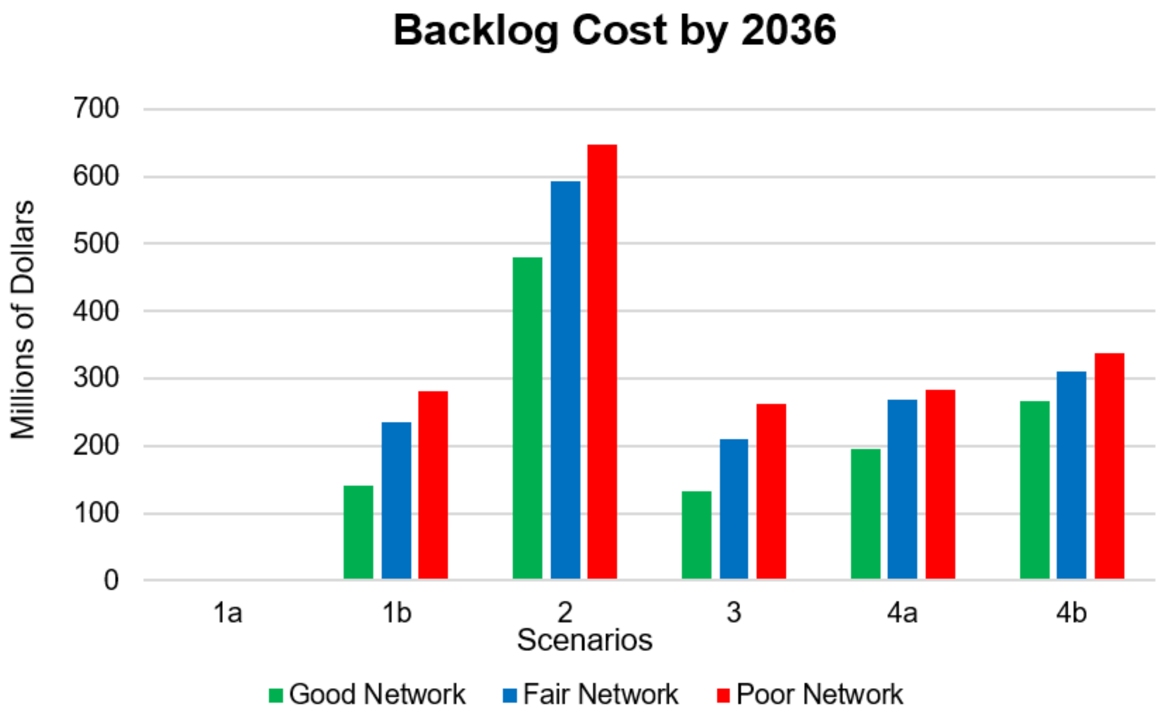


Figure 5. Backlog costs for different maintenance scenarios.

- Consequences on the Remaining Service Life. Figure 6 shows the Remaining Category in percentage for all the scenarios during the entire analysis period. Since the trends are similar for the three pavement network conditions, the results are shown only for the pavement network in fair condition.

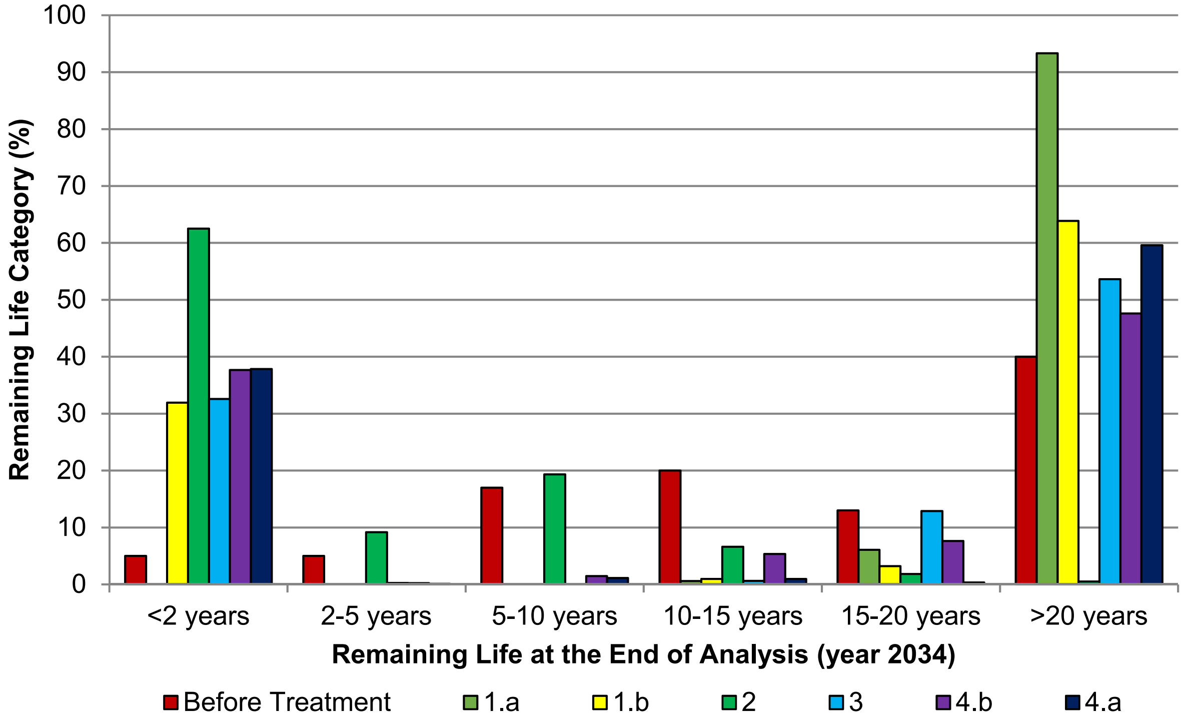


Figure 6. Remaining Service Life (RSL) at the end of the analysis period. (Chang et al 2017).

Scenario 1.a, all needs, maintains 93 percent of the pavement network with RSL above 20 years, and 7 percent of the network with a RSL above 10 years. Scenario 1.b, preserving the current condition, results in 63 percent with RSL above 20 years and 37 percent of the network with a RSL below 2 years. Scenario 2, do nothing, results in 62 percent of the pavement network with a RSL below 2 years, 10 percent with a RSL between 2 and 5 years, and 20 percent with a RSL between 5 and 10 years. Scenarios 3, 4.a, and 4.b show similar remaining lives with about half of the network with RSLs above 20 years but also one third of the network with RSLs less than 2 years.

CONCLUSIONS

a. The consequences of delaying maintenance are quantified by comparing the agency-preferred maintenance scenario to delayed maintenance scenarios following a step-by-step framework approach that is easy to adapt to the preservation policies, performance measures, and analytical tools used by the agency. Pavement network condition, total agency costs, backlog costs, and remaining life are performance measures recommended to show the consequences of delayed maintenance.

b. The percentage of the pavement network at different condition categories over time and remaining service life are recommended as a more efficient manner to report the impact on the pavement network condition to funding authorities. The Pavement Condition Index (PCI) and other performance measures including the International Roughness Index (IRI), International Friction Index (IFI), Present Serviceability Rating (PSR), Structural Number (SN) may be more meaningful at the technical level.

c. A case study demonstrated the applicability of the framework to quantify the consequences of delayed maintenance. Three pavement networks at different conditions at the beginning of the analysis (Good, Fair, Poor) were analyzed. The trends observed in the performance measures as a result of the analysis were similar for the three pavement networks. Total agency costs and backlog costs increase in all the scenarios as the pavement network condition at the beginning of the analysis moves from good to poor. The impacts were more significant for the pavement network in poor condition.

d. Delaying maintenance by 2 years increases the percent of pavements in very poor condition in the long term, and the impact is higher for the pavement networks in fair and poor condition. Backlog costs due to delayed maintenance are also higher for the pavement networks in fair and poor condition. Similar consequences are observed for the budget-driven scenarios that allocate limited funds for maintenance.

e. At the end of the analysis period, remaining lives in the delayed and budget-driven scenarios are above 20 years for about half of the network, but there is also about one third of the network with remaining lives less than 2 years.

f. It is important to be aware that delayed maintenance may impact not only the pavement condition, but in a broader perspective also affects mobility, safety, and transportation agency and user costs (e.g. travel time costs, operating costs, and accident costs). These are areas of future research that will reinforce the importance of timely maintenance of the pavement networks.

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