Evaluating the Performance of Pavement Surface Treatments on Arizona Highways

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16. Abstract
This report presents a framework for long-term monitoring and evaluation of Arizona pavement surface treatments. The framework shows how to use constructed projects and existing monitoring methods to improve pavement preservation project and treatment selection as well as to model the performance of pavement preservation. The report also presents approaches for enhancing the pavement management processes at ADOT, specifically focusing on how the information gathered on treatment performance—data generated by monitoring the performance of pavements after the application of surface treatments—may be used.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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ACRONYMS AND ABBREVIATIONS

AADT	average annual daily traffic
AC	asphalt concrete
ACFC	asphalt concrete friction course
ACFC-TR+	asphalt concrete friction course with terminal blend asphalt rubber
ACHTR	asphalt spot repair + diamond milling + chip seal (TR+)
ADOT	Arizona Department of Transportation
ADT	average daily traffic
AMS	asphalt spot repairs and micro surface
APL	annual performance loss
AR-ACFC	asphalt rubber-asphalt concrete friction course
BCR	benefit-cost ratio
CA	cape seal
CH	chip seal
CHTR	TR+ chip seal
CS	crack seal
DCH	double chip seal
EAC	equivalent annual cost
FHWA	Federal Highway Administration
FS	fog seal
FY	fiscal year
HPMS	Highway Performance Monitoring System
IDOT	Illinois Department of Transportation
IRI	international roughness index
LCP	life-cycle planning
MS	micro surface/asphalt spot repairs and micro surface
NC	1” thin bonded overlay (Nova Chip)
OCI	overall condition index
ODOT	Ohio Department of Transportation
P2P	planning to programming
PCI	pavement condition index
PMS	pavement management section
SLI	state line item
TAMP	transportation asset management plan
TR+	terminal blend asphalt rubber
VPD	vehicles per day

REPORT ORGANIZATION

This report is organized into four sections:

1. **Introduction:** This introductory section summarizes project objectives and overall approach.
2. **Recommendations:** This section includes a list of recommended next steps for ADOT to implement the recommended framework for evaluating the effectiveness of pavement preservation treatments.
3. **Findings:** This section presents the key findings that support the recommendations.
4. **Methods:** This section describes the methods used to arrive at the key findings.

INTRODUCTION

The Arizona Department of Transportation (ADOT) has a long history of using surface treatments to improve pavement performance, especially on asphalt-surfaced pavements. The first well-documented procedures started in the late 1980s when ADOT began participating in the Long-Term Pavement Performance Program (LTPP) Specific Pavement Study-3 (SPS-3), a nationwide study initiated to evaluate the effectiveness of crack sealing, chip seals, slurry seals, and thin overlays as preventive maintenance treatments. ADOT provided 22 test sections for the SPS-3 experiment at four sites and added an additional 14 sections at those same four sites to test their own designs. In addition, ADOT committed a significant investment to the 1995 Maintenance Cost Effectiveness Study, SPR 371. This ambitious project resulted in the construction of over 200 asphalt test sections, covering three different phases, to study the contributions of wearing courses (Phase I), surface treatments (Phase II), and sealer-rejuvenators (Phase III). Building these sections was a collaborative effort of materials suppliers, contractors, and ADOT, resulting in the construction of test sections at 10 sites around the state between 1999 and 2002 (Peshkin 2006).

Beginning in fiscal year (FY) 2013 ADOT demonstrated a renewed commitment to pavement preservation. In FY 2019, ADOT received a state appropriation of $25.6 million to apply to pavement preservation projects, supplementing the approximately $16 million in federal funds that have been available annually for pavement preservation These funds are distributed through two separate programs at ADOT: the State Line Item (SLI) program and the 112 program. The SLI program is state-funded and the 112 program is federally funded. Figure 1 shows approximate ADOT preservation expenditures since FY 2013. This funding, which is primarily being used to preserve roads in good condition, is helping to build a culture of preservation around the state. With the ongoing implementation of a new pavement management system, a focus on cost-effective life-cycle strategies in the agency's Transportation Asset Management Plan (TAMP), and the use of automated pavement condition data collection since 2017, ADOT is experiencing a cultural change in how its roadway network is managed.

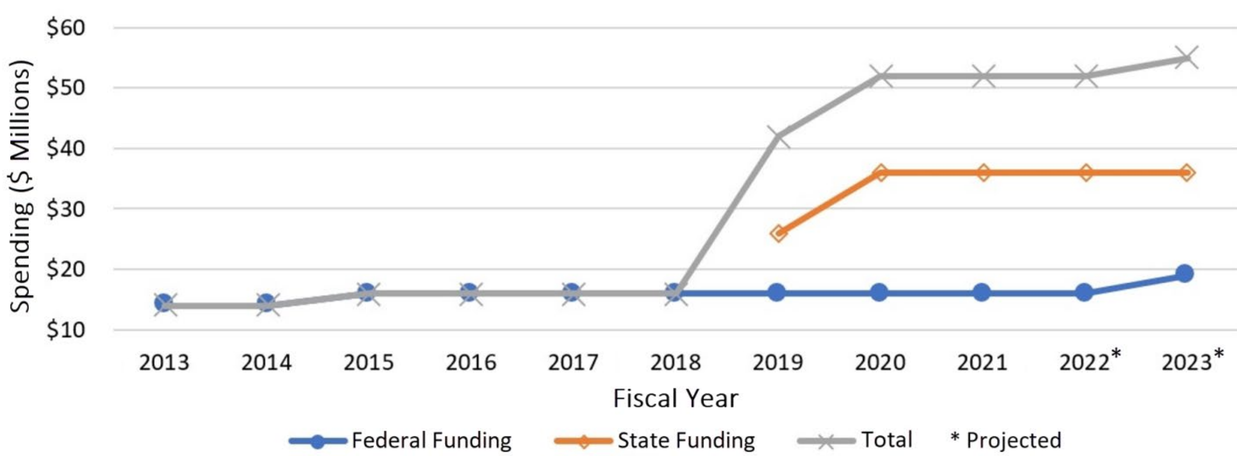

Figure 1. ADOT Spending on Pavement Preservation, Fiscal Years 2013–2023.

The state's additional preservation funding has already been used in the construction of pavement preservation projects throughout the state, and there is the promise of additional state funding in the future. This additional investment in pavement preservation has provided a unique opportunity to make even greater improvements to ADOTs pavement preservation practices relating to project and treatment selection. Such improvements may help ADOT's efforts to move toward data-driven decision-making, especially in the evaluation of potential project sections for pavement preservation and the selection of treatments for those pavements. With ADOT's background in preservation and the significant investments made in new preservation treatments, there is also an opportunity to apply many of the lessons learned from ADOT's previous preventive maintenance studies to improve practices moving forward.

PROJECT OBJECTIVES

This report presents the results from an ADOT project whose overall objective was to research "recent methods, guidance, and practices in evaluating the efficiency of pavement surface treatments, and to develop a framework (implementation plan) for long-term monitoring and evaluation of Arizona pavement surface treatments." This project was not intended to initiate a new preservation study, but to show how to use constructed projects and existing monitoring methods to improve project and treatment selection as well as model pavement preservation treatments in the pavement "management system. Improvements to ADOT's pavement preservation practices may emerge as the pavement preservation and pavement management staff use information currently available to better understand the effects of different pavement preservation treatments on pavement performance under the different conditions in which such treatments are used around the state.

RECOMMENDATIONS

A framework to evaluate pavement preservation treatment effectiveness is presented in this report in Findings and Methods sections. The next steps are outlined in Figure 2 and further explained in this section.

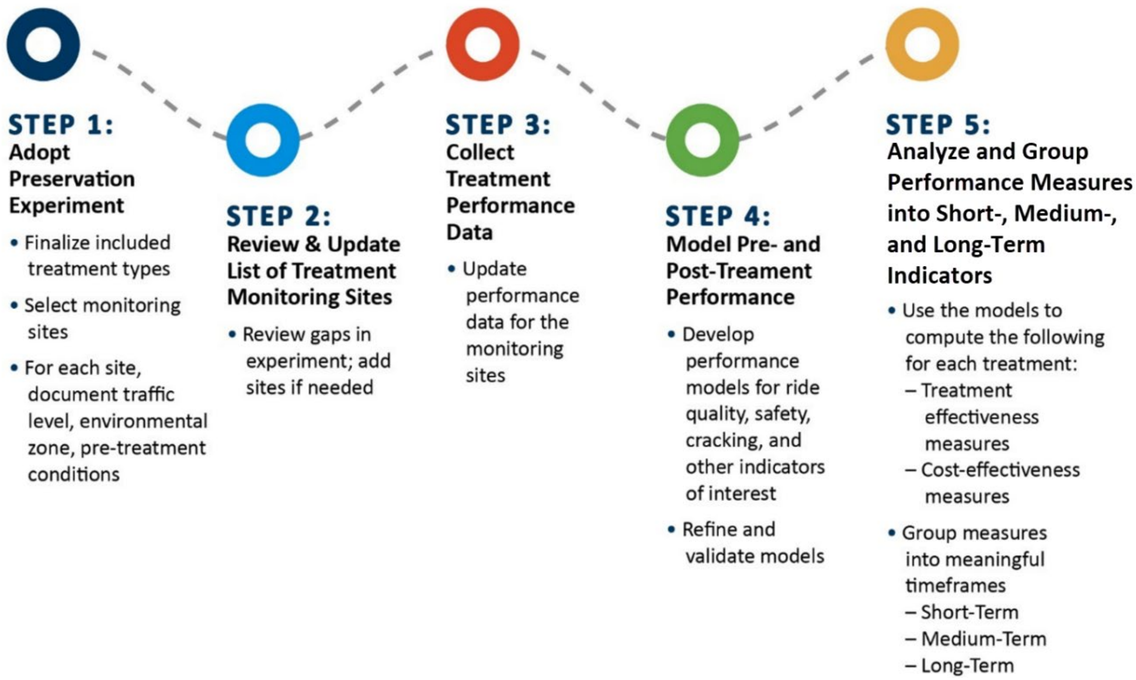

Figure 2. Steps for Implementation of Framework.

STEP 1: ADOPT A PRESERVATION EXPERIMENT

ADOT may gain insights into successful pavement preservation practices by implementing a pavement preservation experiment. The first step, as presented in the Findings section, is to formally adopt the preservation experiment, finalize the monitoring sites, and continue monitoring preservation treatment performance. The following list identifies the experimental variables for monitoring the performance of preservation treatments placed on asphalt-surfaced pavements. The variables include treatment types, traffic levels, and environmental zones. Also, pre-treatment pavement conditions ideally fall within the range identified in the following:

- **Treatment Type:** Thirteen different preservation treatment types that include a combination of simple surface treatments and life-extension treatments (presented in the Findings section):
  - 1-inch Thin Bonded Overlay (Nova Chip) [NC]
  - Asphalt Concrete Friction Course [ACFC]
  - Asphalt Concrete Friction Course with Terminal Blend Asphalt Rubber [ACFC-(TR+)]
  - Asphalt Concrete Friction Course with Asphalt Rubber [AR-ACFC]
  - Asphalt Spot Repair + Diamond Milling + Chip Seal (TR+) [ACHTR]
  - TR+ Chip Seal [CHTR]
  - Chip Seal [CH]

- Double Chip Seal [DCH]
- Asphalt Spot Repairs and Micro Surface [AMS]
- Micro Surface [MS]
- Cape Seal [CA]
- Fog Seal/Seal Coat [FS]
- Crack Seal [CS]

- **Traffic: Two levels:**
  - Low: ≤ 5,000 Annual average daily traffic (AADT)
  - High: > 5,000 AADT

- **Environmental Zones: Three zones based on the highest elevation within a project:**
  - Zone 1: 0 to 2,999 ft
  - Zone 2: 3,000 to 4,999 ft
  - Zone 3: 5,000 ft and above

- **Pre-treatment Pavement Conditions: Based on pavement performance data collected by ADOT:**
  - IRI: satisfactory (0 to 107 inches per mile) and tolerable (108 to 163 inches per mile) levels
  - Cracking: Low to Medium (≤ 30 percent)
  - Rutting: Low (< 0.25 inch)

STEP 2: REVIEW AND UPDATE LIST OF TREATMENT MONITORING SITES

Table 1 summarizes the number of available monitoring segments identified for each treatment under each category established for traffic level, environmental zone, and pre-treatment conditions. Gaps identified in the Table 1 experimental matrix are indicated using "ND" (no data). It is recommended that ADOT review the gaps in the treatment monitoring sites to determine if additional sites may be added to the experimental matrix.

Table 1. Number of Treatment Monitoring Sites and Gaps per Category.

Treatment	Categories								
	Traffic Level Low	Traffic Level High	Environ-mental Zone 1	Environ-mental Zone 2	Environ-mental Zone 3	Pre-treatment IRI Satisfactory/ Tolerable	Pre-treatment Cracking Low	Pre-treatment Cracking Med	Pre-treatment Rutting Low
1" Thin Bonded Overlay	ND	170	ND	170	ND	52/103	15	82	162
2.5" Mill and Replace	ND	ND	ND	ND	ND	ND/ND	ND	ND	ND
ACFC	ND	58	58	ND	ND	11/26	4	29	38
ACFC-(TR+)	165	188	116	78	159	234/100	249	99	332
AR-ACFC	ND	635	621	14	ND	471/95	635	ND	412
Asphalt Spot Repair, Diamond Milling, Chip Seal (TR+)	272	ND	ND	ND	272	141/121	138	68	272
Asphalt Spot Repairs and Micro Surface	ND	105	ND	38	67	64/23	58	41	79
Cape Seal	ND	146	ND	ND	146	78/29	20	46	133
Chip Seal	101	ND	39	62	ND	93/7	97	4	101
Crack Seal	214	215	100	191	138	268/115	305	113	384
Double Chip Seal	480	ND	ND	480	ND	410/68	438	42	471
Fog Seal/Seal Coat	136	1534	935	365	370	1582/77	1497	164	1606
Micro Surface	ND	233	127	40	66	110/90	172	55	162
TR+ Chip Seal	1332	ND	960	136	236	646/539	368	787	1010

Notes:

- Number of monitoring sites based on 0.1-mile segments
- Traffic Level—Low: ≤ 5000 AADT; High: > 5000 AADT
- Environmental Zones—Zone 1: Elevation 0 to 2999 ft.; Zone 2: Elevation 3000 to 4999 ft.; Zone 3: > 5000 ft
- IRI—Satisfactory: ≤ 107 inches per mi; Tolerable: 108 to 163 inches per mi
- Cracking—Low: < 10 percent; Medium: 10 to 30 percent
- Rutting—Low: < 0.25 inch
- ND—Gaps identified in the experimental matrix

STEP 3: COLLECT TREATMENT PERFORMANCE DATA

A master spreadsheet—used for storing information on pre- and post-treatment pavement condition—was developed using the dataset compiled for monitoring sites discussed in Step 2 (and provided as a separate deliverable to ADOT). This spreadsheet has already been populated with the following data:

- Sections without treatment applications that can be used to model pre-treatment performance:
  - Pavement condition data for years 2017, 2018, and 2019
  - Traffic data: AADT and year of data collection
  - Last construction and improvement date: year of the most recent surface improvement and latest year of construction for each pavement section
- Treatment monitoring sites:
  - Traffic data
  - Elevation category
  - Last construction year
  - Last improvement date
  - Pre-treatment condition
  - Funding source
  - Pre-treatment conditions
  - Post-treatment condition

The next step is to continue adding performance data for the monitoring sites from future data collection cycles.

STEP 4: MODEL PRE- AND POST-TREATMENT PERFORMANCE

Once sufficient data are available (at least 5 years' worth of post-treatment data), performance models may be developed to better understand treatment performance as it ages. Performance models may be generated for pavement performance indicators that describe ride quality (International Roughness Index [IRI]), safety (rutting), and cracking. Similarly, models may be generated for all other performance indicators routinely monitored by ADOT as a part of annual data collection efforts.

Based on available data, it may not be possible to develop pre- and post-treatment models for all the performance families listed in the Findings section (refer to Table 4 and Table 5). In the cases where models do not exhibit good statistical correlations or adequate data are not available, ADOT may choose to combine data from multiple families.

Once initial performance models are developed, the next step is to refine the performance models by eliminating data points that clearly do not follow common engineering logic. Referred to as outliers, an example is an unreasonably high performance-indicator value at a very early pavement age when indicators are expected to exhibit increasing trends over time, such as in rutting, cracking, and IRI.

Once performance models are developed, statistical comparisons may be conducted among treatments and between pre- and post-treatment performance to validate performance.

STEP 5: ANALYZE AND GROUP PERFORMANCE MEASURES INTO SHORT-, MEDIUM-, AND LONG-TERM INDICATORS

The following methods are recommended for analyzing performance and treatment effectiveness (details on each measure are provided in the Findings section):

- Performance jump
- Service life extension
- Benefit area
- Annual performance loss

The following methods are recommended for conducting cost-effectiveness analyses (details on each measure are provided in the Findings section):

- Benefit-cost ratio (BCR)
- Equivalent annual cost (EAC)

The final step in implementing the framework is the evaluation of treatment effectiveness using the treatment performance measures under short-, medium-, and long-term time periods. Some measures may be included in more than one time period:

- **Short term:** In most cases, the short term is a period of 1 to 2 years after construction and determines if the treatment was properly placed. Poor performance in the short term is often related to poor quality construction or a materials defect, since early performance reflects how well the contractor addressed the factors under their control. Preservation treatments that fail in the short-term may lead to conclusions indicating the treatment was improperly constructed, there was a material problem, the pavement was not a suitable candidate for that treatment, or the treatment was not appropriate for the given application. Performance measures that are considered short-term indicators are:
    - Performance jump
    - Annual performance loss
    - Friction (optional)

- **Medium term:** The duration of the medium term depends on the total life of the treatment. For longer-life treatments, this may be 2 to 5 years, while for others it could be closer to 2 to 3 years. Performance measures examined over the medium term may help determine if the treatment is on track to provide its expected benefits or if it is deteriorating faster or slower than expected. Faster deterioration could indicate poor construction quality or unexpected conditions (e.g., environment, traffic loads, external forces [snowplows]). Performance measures that can be grouped into medium-term indicators are:
    - Annual performance loss
    - Benefit area
    - Distresses: IRI, rutting, Highway Performance Monitoring System (HPMS) cracking, pavement management section (PMS) cracking

- **Long term:** Long-term performance aligns with the typical life of the treatment. For many preservation treatments, this should be longer than 5 years. Long-term measures provide an indication of whether the treatment is providing the benefits or serving the purpose for which it was constructed. It is recommended that long-term measures correlate to the expected life of the treatment. It is reasonable to assume that, in the long term, the focus is less on individual performance measures and more on the life of the treatment as well as the benefits of the treatment when compared to other treatments or to doing nothing. Performance indicators that can be used as long-term indicators are:
  - Annual performance loss
  - Service life extension
  - Benefit area
  - Benefit cost ratio
  - Equivalent annual cost

ADDITIONAL RECOMMENDATIONS FOR LONG-TERM TREATMENT PERFORMANCE MONITORING

One additional performance measure that could be useful in comparing the performance of treatments is a measure of pavement surface friction (or some other pavement surface characteristic such as microtexture, macrotexture, or megatexture). However, since friction data has not been previously collected and is not currently being collected by ADOT at the network level, additional effort would be needed to obtain this information. This is not currently recommended.

If ADOT is interested in monitoring the long-term performance of specific pavement sections that have received treatments, then control sections are needed for each treatment segment. Control sections are ideally located on the same stretch of roadway, close to the treated segment. If established, the control sections would need to be flagged in the pavement management system and visible signs may need to be posted on the highways to ensure ADOT maintenance crews do not apply any treatments (other than maintenance performed for safety purposes) to the control sections.

ADOT has a global performance indicator for asphalt pavements in their PMS, the Overall Condition Index (OCI), that is based on IRI, PMS cracking, rutting, and risk (Zavitski et al. 2020). ADOT does not use the OCI as a performance indicator for reporting purposes, but it is used as a parameter in the benefit model within the PMS. Each of the components that make up the OCI are normalized to a 25-point rating scale.

In order to use the OCI measure as another indicator of pavement performance in future analyses, the risk rating would need to be excluded from the OCI calculation. This is recommended because the risk ratings are primarily defined for the underlying pavement section based on susceptibility to geotechnical risks and because preservation treatments are not expected to have any measurable impact on risk ratings. Additionally, two different pavement sections with significantly different risk ratings may exhibit similar performance as measured using the IRI, PMS cracking, and rutting measures, and including the risk rating could skew the overall performance as measured by the OCI.

The development of another condition indicator that is based on a broader range (e.g., 0 to 100) and uses the raw distress data collected by ADOT (similar to the pavement condition index [PCI] rating system defined by ASTM D6433 *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys* [ASTM 2020]) may better facilitate the evaluation of treatment performance.

Recommendations for Enhancing Pavement Management Processes at ADOT

There are six approaches deemed most appropriate for enhancing the pavement management processes at ADOT. They specifically focus on how the information generated by a pavement treatment performance evaluation might be used to improve pavement management processes.

Pavement Condition Forecasting Models in ADOT's Pavement Management System

ADOT has been developing and modifying its pavement management practices since 1990 with increased investments in pavement preservation. In order to accurately capture the true impact of pavement preservation, performance models that are specific to each treatment type that ADOT uses are required. Performance models are fundamental to reasonably predicting future pavement conditions with or without treatments. Performance models also help determine which treatments to use and when to use them. ADOT's PMS currently uses treatment resets (i.e., the application of a treatment triggers a defined reset in pavement condition) and does not include performance models for preservation treatments. Using the analytical approaches previously documented in Tasks 4 and 5, ADOT will be able to use the collected data to generate performance models and treatment impacts for each treatment included in ADOT's preservation toolbox.

The development of the performance models will use inventory and historical condition information in equations that represent changes in performance over time. Traditional models explore the change in condition due to treatment age; but important factors such as traffic levels, functional classification, and condition prior to treatment may be incorporated into performance models to improve accuracy.

An important step in predicting future conditions involves the identification of impact rules that describe the change in conditions expected after treatment application. In a PMS, future conditions are predicted using the performance models and treatment rules to identify feasible treatments in each year of the analysis. To determine the cost-effectiveness of feasible treatments, a BCR is calculated based on the expected performance (benefit) and the cost of treatment application. The BCR is used to prioritize projects so that those with the highest ratio of benefit to cost are funded first under an analysis with constrained funding. This helps ensure recommended pavement preservation projects provide the most benefit to the agency.

Both the identification of treatment impact rules and the calculation of benefit may be enhanced with data from this study. Determining impacts of preservation includes identifying the immediate change in conditions resulting from the treatment's application. One challenge of determining the preservation impacts is that there are not always immediate improvements in condition metrics for all types of surface treatments. For example, the application of a fog seal may not result in a performance jump immediately after placement since the application of the treatment is expected to slow down the aging process of the asphalt binder in the existing pavement (by retarding the rate of oxidation). Rather than having a measurable effect in the short-term, the impact of some treatments may be an expected increase in overall pavement service life. This is demonstrated by using performance models to compare changes in condition with and without the surface treatment application. Data collected from this study clarify the types of performance changes expected with each surface treatment to enhance future estimates of pavement conditions.

Treatment-specific performance models also aid in determining pavement service life extensions associated with each treatment type. These will enable ADOT to identify the treatment types that provide the most cost-efficient improvements based on the treatment application conditions (such as pre-treatment condition, traffic levels, climate zone, and existing pavement type).

It is expected that a period of 5 years of monitoring the performance of pavement sections with preservation treatments is sufficient to begin the development of performance models. While there is no rule associated with this period, 3 years is too soon to confirm trends; and by 10 years, many treatments are nearing or have reached the end of their service lives. After 5 years, trends in the data may be seen. ADOT may opt to review and/or update the models as necessary in subsequent years as even more data become available.

PMS Decision Trees

ADOT's existing PMS decision trees drive treatment recommendations based on parameters such as facility type (interstate or not), pavement type (asphalt, jointed plain concrete, or continuously reinforced concrete), traffic level, number of prior rehabilitations, pavement distress (cracking and rutting), and so on. Based on the information expected to be gathered from the long-term monitoring efforts, ADOT may have the information needed to update the decision trees to include the surface treatments identified on ADOT's roads. The treatment trigger values tied to the pavement conditions that are currently included in the decision tree (based on IRI, cracking, and rutting) may also be updated if performance data show that this is warranted to better reflect the appropriate parameters for using each surface treatment.

Improvement of the Pavement Life-Cycle Planning Process

The availability of updated performance models and decision trees may help ADOT improve pavement life-cycle planning (LCP) processes and potentially reduce the life-cycle cost of managing its pavement network. With surface treatment performance data, ADOT could investigate the feasibility of investing in lower cost preservation treatments that have exhibited higher BCRs. ADOT may also determine the portion of its pavement network that can potentially benefit from each type of preservation treatment (e.g., lower traffic volume routes, low priority routes, and specific environments). A change in the pavement investment strategy may result in the availability of additional funds that may be invested elsewhere (such as safety or drainage improvements) or even be diverted to other asset classes that need additional funding.

Communicate Impacts to Decision Makers

Data from long-term monitoring can be used to develop infographics to help communicate pavement preservation impacts in a simple and effective manner. As an example, the Ohio Department of Transportation (ODOT) investigated the impact of an aggressive chip sealing program on low-traffic-volume routes and presented the results in terms of the expected cost savings compared to a traditional asphalt overlay-based approach (refer to Figure 3). ADOT could leverage the data that will be available from long-term monitoring efforts toward the development of similar graphics, which may then be used to bolster support for any change in ADOT's approach to managing its roadway network.

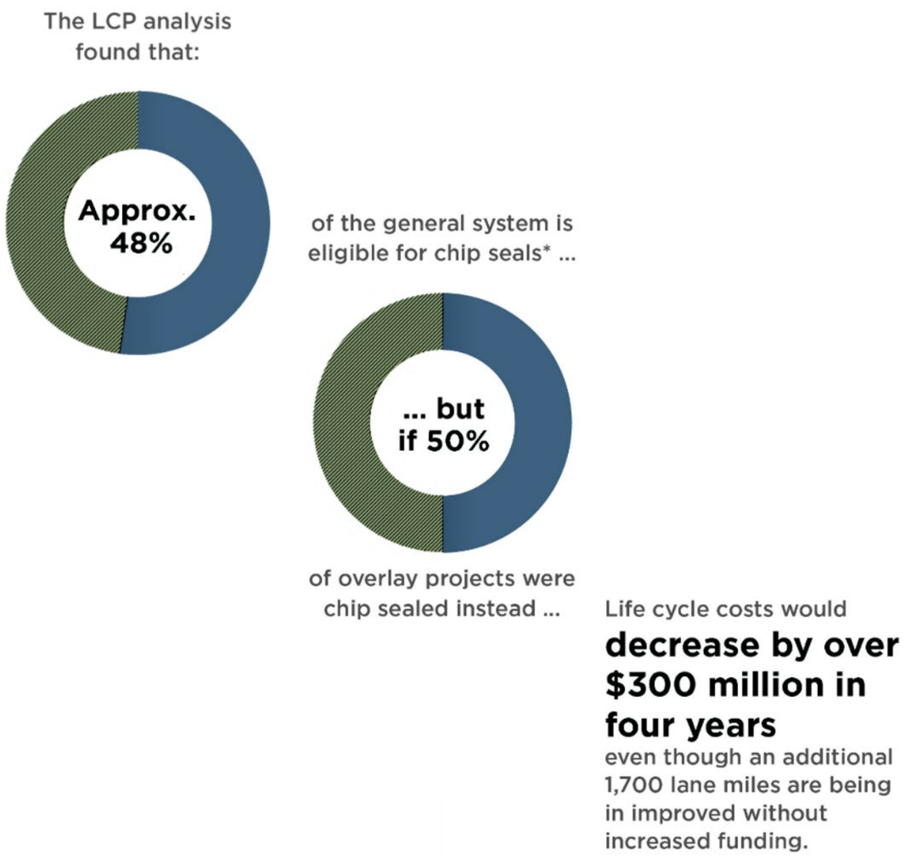

Figure 3. Example Infographic to Communicate Benefits of Pavement Preservation (ODOT 2019).

Update Training Materials for Districts

The asset management regulations require that ADOT update its TAMP at least every four years. This update specifies ADOT's planned investments over the next 10 years. The planned investments are summarized by work type each year. These planned investments are compared to actual investments in a consistency review document submitted annually to the Federal Highway Administration (FHWA) to demonstrate the TAMP's implementation. To ensure that the planned investments in the TAMP are aligned with actual expenditures, it is important for district personnel to be familiar with the expectations and to have a good working knowledge of the applicability of different treatments to achieve the expected performance.

To support this initiative, information related to pavement preservation treatment selection, treatment performance, and cost-effectiveness obtained from the long-term monitoring efforts may be part of an updated training program. This training program could help district personnel become more familiar with the characteristics of good pavement preservation candidates, thus allowing personnel to contribute to the project and treatment selection process. The training could also help institutionalize pavement preservation practices through knowledge transfer.

An updated manual documenting the following information may be particularly helpful for district personnel to support the training efforts:

- Treatment description
- Pavement conditions addressed through the treatment application
- Application limitations
- Construction considerations
- Traffic considerations
- Climate considerations
- Treatment-specific considerations (if any)
- Expected performance period
- Relative treatment cost and benefits

A treatment selection matrix that documents the feasibility of treatment application may also be a useful tool. An example matrix developed by the Illinois Department of Transportation (IDOT) is shown in Table 2. The letter- and color-coding in the matrix provides an easy guide to the appropriateness of different types of treatments under specific field conditions. Note that where multiple distresses are present, the user would need to further analyze which treatments are appropriate.

Table 2. Example Illustration of Treatment Selection Guidelines (IDOT 2012).

Pavement Conditions	Severity Levels	Crack Filling	Crack Sealing	Fog Seal	Sand Seal	Scrub Seal	Rejuvenator	Slurry Seal	Micro-surfacing	Chip Seal
Alligator/Fatigue Cracking	Light	F	F	NR	NR	NR	NR	F	F	F
Alligator/Fatigue Cracking	Moderate	NR	NR	NR	NR	NR	NR	NR	NR	F
Alligator/Fatigue Cracking	Severe	NR	NR	NR	NR	NR	NR	NR	NR	NR
Block Cracking	Light	R	R	F	R	R	NR	R	R	R
Block Cracking	Moderate	R	R	NR	NR	F	NR	F	NR	F
Block Cracking	Severe	F	F	NR	NR	NR	NR	NR	NR	NR
Bleeding	Light	NR	NR	NR	F	F	NR	F	R	R
Bleeding	Moderate	NR	NR	NR	NR	NR	NR	NR	R	F
Bleeding	Severe	NR	NR	NR	NR	NR	NR	NR	NR	NR
Longitudinal and Transverse Cracking	Light	R	R	F	R	R	NR	R	R	R
Longitudinal and Transverse Cracking	Moderate	R	R	NR	NR	NR	NR	F	F	F
Longitudinal and Transverse Cracking	Severe	F	F	NR	NR	NR	NR	NR	NR	NR
“Stable” Rutting	Light	NR	NR	NR	NR	NR	NR	F	R	F
“Stable” Rutting	Moderate	NR	NR	NR	NR	NR	NR	NR	R	NR
“Stable” Rutting	Severe	NR	NR	NR	NR	NR	NR	NR	F	NR
Weathering/Raveling	Light	NR	NR	R	R	R	R	R	R	R
Weathering/Raveling	Moderate	NR	NR	F	F	F	F	R	R	R
Weathering/Raveling	Severe	NR	NR	NR	NR	NR	NR	F	F	F
Ride	Poor	NR	F	NR	F	F	NR	NR	F	NR
Friction	Poor	NR	NR	NR	R	R	NR	R	R	R
ADT	< 2,500	R	R	R	R	R	R	R	R	R
ADT	2,500 – 10,000	R	R	F	F	F	F	F	R	R
ADT	> 10,000	R	R	NR	NR	NR	NR	NR	R	F
Will Trigger ADA Upgrades	Not Applicable	-	-	-	-	-	-	-	X	-

R: Recommended treatment
F: Feasible treatment, but depends on other constraints
NR: Not Recommended; note that the color coding is solely to facilitate visualizing guidance

Refine the Planning to Programming Process

To select infrastructure improvement projects, ADOT uses a data-driven approach to consider the needs within each performance area to maintain the overall performance of the transportation system. This is achieved through ADOT's Planning to Programming (P2P) process, which involves the consideration of safety, mobility, freight, economic vitality, and environmental sustainability objectives.

At the time of writing, ADOT is refining the P2P process used to prioritize pavement projects on the state highway system to ensure alignment with the planned TAMP investments and securing approval from the Transportation Board. The availability of information on preservation treatment effectiveness (based on the short-, medium-, and long-term measures documented in the Task 5 technical memo) may help establish a more robust pavement preservation prioritization process. The measures may help inform the decision-making process under Steps 2 and 3 of the P2P process (refer to Figure 4).

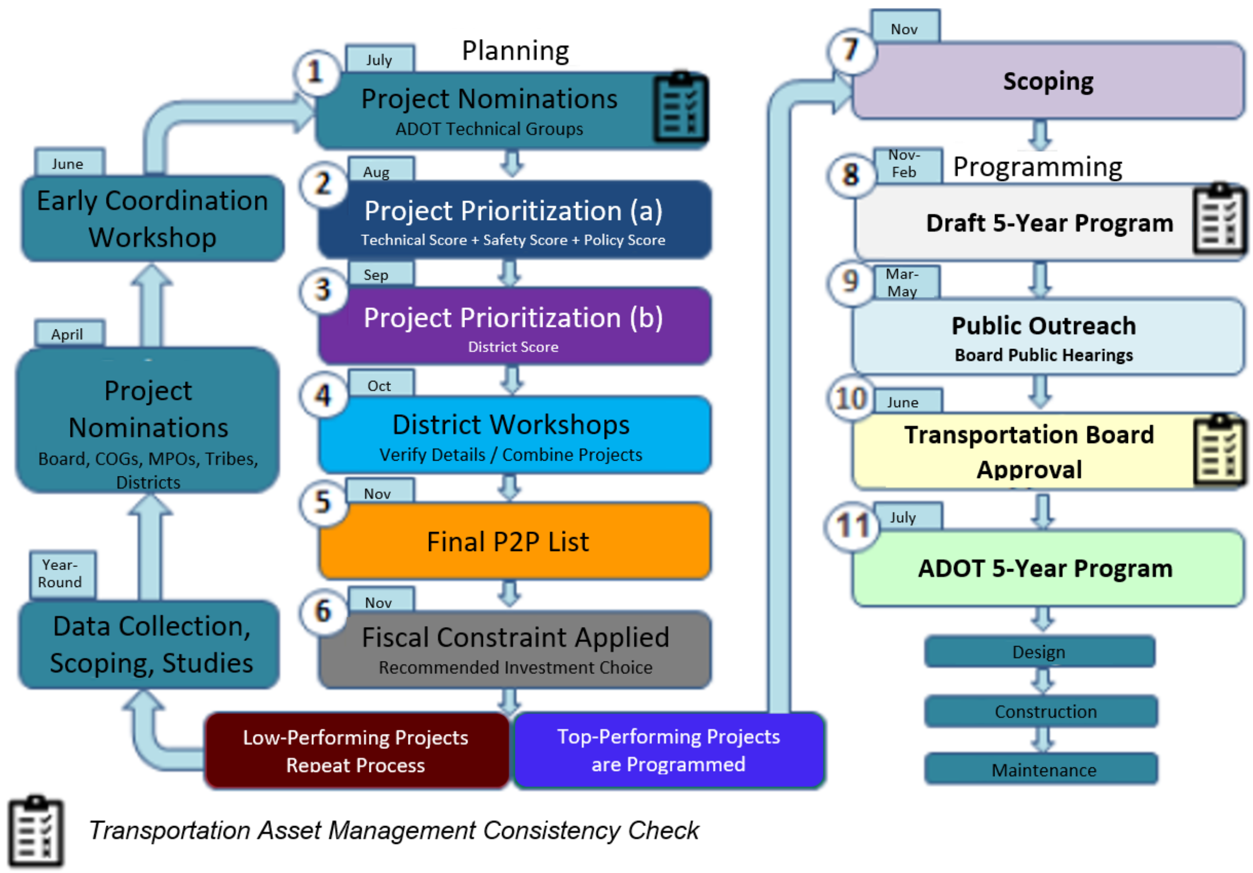

Figure 4. ADOT's P2P Process Flowchart (ADOT 2021).

FINDINGS

IDENTIFY TREATMENT MONITORING SITES

ADOT's PMS includes three types of pavements with asphalt surfaces:

- Full-depth asphalt pavements (AC)
- Jointed plain concrete pavements with a friction course (JPCP + FC)
- Continuously reinforced concrete pavements with a friction course (CRCP + FC)

Since the underlying concrete pavement can significantly impact the performance of preservation treatments, the project team determined that the selected preservation treatments should be applied only on full-depth asphalt concrete pavements if the pavement treatment evaluation is to be conducted.

Pre-Treatment Pavement Condition

The condition of pavement prior to the application of the preservation treatment impacts the long-term performance of the treatment applied. ADOT's existing efforts for automated annual data collection provide the following pavement condition information:

- Roughness/smoothness (as reported by the IRI)
- Permanent deformation (rutting)
- Fatigue (alligator) cracking
- Block cracking (currently categorized as longitudinal, transverse, or fatigue cracking)
- Longitudinal cracking (wheel path and non-wheel path)
- Transverse cracking
- PMS percent cracking in pavements with asphalt surfaces
- Potholes
- Reflection cracking

Table 3 summarizes pavement performance indicators and associated treatment actions documented in ADOT's pavement design guide (ADOT 2017).

Table 3. Performance Indicators and Treatments for Flexible Pavements (Adapted from ADOT 2017).

Performance Indicator	Category	Range of Values	Treatment Actions	Applicable Preservation Treatment(s)
IRI	Satisfactory	0 to 107 inches per mile	No action or seal coat	All
IRI	Tolerable	108 to 163 inches per mile	Min. 2-inch AC with or without milling	Only 2 to 2.5 inches AC mill and replace
IRI	Objectionable	> 164 inches per mile	Min. 2.5-inch AC with or without milling	Only 2.5 inches AC mill and replace
% Cracking	Low	< 10	No action or seal cracks	All
% Cracking	Medium	10 to 30	Min. 2-inch AC with or without milling	Only 2 to 2.5 inches AC mill and replace
% Cracking	High	> 30	Min. 2.5-inch AC with or without milling	Only 2.5 inches AC mill and replace
Friction Number	High	> 43 (60 mph) or > 50 (40 mph)	No action	All
Friction Number	Medium	34 to 43 (60 mph) or 44 to 50 (40 mph)	ACFC or seal coat	All
Friction Number	Low	< 34 (60 mph) or < 44 (40 mph)	ACFC or seal coat	All
Rut Depth	Low	0 to 0.25 inch	No action	All
Rut Depth	Medium	0.26 to 0.50 inch	Min 2-inch mill and replace	Only 2 to 2.5 inches AC mill and replace
Rut Depth	High	> 0.51 inch	Min. 2.5-inch mill and replace	Only 2.5 inches AC mill and replace

Note:

Friction Number measured using Dynatest Highway Slip Friction Tester (wetter surface friction). Test speeds are indicated in parentheses.

Based on the performance indicator values and the associated applicability of various treatments, the following pre-treatment pavement performance criteria were determined to be useful in the selection of pavement preservation sites for long-term monitoring:

- IRI levels: satisfactory and tolerable (0 to 163 inches per mile)
- Percent cracking: low to medium (0 to 30 percent)
- Rut depth: low (0 to 0.25 inches)

These criteria may help ensure any sites included in the pavement treatment experiment are good candidates for pavement preservation.

Traffic

ADOT collects the following traffic data on its roadways: AADT, single truck traffic (FHWA Class 4 to 7), and combo truck traffic (FHWA Class 8 to 13). ADOT's roadway functional classification is based on average daily traffic (ADT) (ADOT 2017):

- Freeways, interstates, and other high-volume non-interstates: > 10,000 ADT
- Arterials: 2,000 to 10,000 ADT
- Collectors: 500 to 2,000 ADT
- Local Roads: < 500 ADT

Traffic is a variable that must be considered in preservation projects and treatment selections. For example, ADOT has indicated that chip seals are not placed on roadways with AADT levels > 5,000. A summary of traffic levels for pavement preservation treatments used by other state highway agencies is provided here:

- Ohio DOT allows chip seals on roadways with < 4,000 ADT and average daily truck traffic < 250 (ODOT 2019).
- Washington State DOT places a vast majority of asphalt surface treatments on roads with AADT < 5,000 (WSDOT 2014).
- Minnesota DOT has used chip seals successfully on roadways with ADT of 20,000 (MnDOT 2006).
- The Strategic Highway Research Program 2 (SHRP 2) study that investigated preservation treatments for high-traffic volume roadways reported that a reasonable definition of high traffic volume is 5,000 vehicles per day (VPD) for rural roadways and 10,000 VPD for urban roadways. The study also noted that many highway agencies did not report on how truck traffic impacts the selection of preservation treatments (Peshkin et al. 2011).

Based on both ADOT's data and the examples provided by other states, a threshold for average annual daily traffic was determined for two traffic levels to be used when monitoring the performance of preservation treatments:

- Low: ≤ 5,000 AADT
- High: > 5,000 AADT

These criteria could help determine the best applicable pavement treatment to use and monitor in any potential pavement treatment experiment. Additional traffic levels may be established later if they are needed to better characterize the performance of treatments placed in high-traffic-volume urban areas.

Climate/Environmental Factors

Discussion with ADOT about the relationship between climate/environment and surface treatment selection and performance indicated that decisions were primarily based on a pavement's elevation. Elevation determines, in part, the temperatures to which a pavement is subjected and whether the presence of snow and/or ice requires the use of snowplows, both of which can affect the integrity of surface treatments. Furthermore, zones based primarily on USDA hardiness and topography, and organized by district, do not provide fine enough distinctions for districts with wide ranges in elevations. Three zones were defined to help classify climate/environment based on the highest elevation within a project segment:

- Zone 1: 0 to 2,999 ft
- Zone 2: 3,000 to 4,999 ft
- Zone 3: 5,000 ft. and above

In the pavement treatment experiment, the highest elevation within a project segment should be used to determine which zone to use.

DEFINE PERFORMANCE FAMILIES

Performance families were used to divide pavement sections into groups with similar characteristics and similar performance for modeling purposes. Separate homogeneous families were generated for pre-treatment and post-treatment conditions.

Listed here are thirteen different preservation treatment types used by ADOT; they include a combination of simple surface treatments and life-extension treatments. Each treatment is assigned a code, as shown in brackets, to track performance model families:

- 1-inch Thin Bonded Overlay (Nova Chip) [NC]
- Asphalt Concrete Friction Course [ACFC]
- Asphalt Concrete Friction Course with Terminal Blend Asphalt Rubber [ACFC-TR+]
- Asphalt Concrete Friction Course with Asphalt Rubber [AR-ACFC]
- Asphalt Spot Repair + Diamond Milling + Chip Seal (TR+) [ACHTR]
- TR+ Chip Seal [CHTR]
- Chip Seal [CH]
- Double Chip Seal [DCH]
- Asphalt Spot Repairs and Micro Surface [AMS]
- Micro Surface [MS]
- Cape Seal [CA]
- Fog Seal/Seal Coat [FS]
- Crack Seal [CS]

Table 4 summarizes the pavement families determined to be appropriate for modeling pre-treatment performance. Up to six pre-treatment performance models may be developed, as shown by the six family codes. Table 5 summarizes the pavement families for modeling post-treatment performance. Up to seventy-eight post-treatment performance models may be developed. During pavement treatment analysis, if multiple pavement families exhibit similar performance over time, then the models may be combined. It is advised that this be assessed on a case-by-case basis.

Table 4. Summary of Pavement Families for Modeling Pre-Treatment Performance.

Pavement Type (Code)	Traffic (Code)	Environmental Zones (Code)	Family Code
Asphalt (A)	Low (L)	Zone 1 (1)	AL1
Asphalt (A)	Low (L)	Zone 2 (2)	AL2
Asphalt (A)	Low (L)	Zone 3 (3)	AL3
Asphalt (A)	High (H)	Zone 1 (1)	AH1
Asphalt (A)	High (H)	Zone 2 (2)	AH2
Asphalt (A)	High (H)	Zone 3 (3)	AH3

Table 5. Summary of Homogeneous Pavement Families for Modeling Post-Treatment Conditions.

Pavement Type (Code)	Traffic (Code)	Environmental Zones (Code)	Treatment Codes	Family Code
Asphalt (A)	Low (L)	Zone 1 (1)	NC, ACFC, AR-ACFC, ACFC-TR+, ACHTR, CHTR, CH, DCH, MS, AMS, CA, FS, and CS	AL1 + Treatment Code
Asphalt (A)	Low (L)	Zone 2 (2)	NC, ACFC, AR-ACFC, ACFC-TR+, ACHTR, CHTR, CH, DCH, MS, AMS, CA, FS, and CS	AL2 + Treatment Code
Asphalt (A)	Low (L)	Zone 3 (3)	NC, ACFC, AR-ACFC, ACFC-TR+, ACHTR, CHTR, CH, DCH, MS, AMS, CA, FS, and CS	AL3 + Treatment Code
Asphalt (A)	High (H)	Zone 1 (1)	NC, ACFC, AR-ACFC, ACFC-TR+, ACHTR, CHTR, CH, DCH, MS, AMS, CA, FS, and CS	AH1 + Treatment Code
Asphalt (A)	High (H)	Zone 2 (2)	NC, ACFC, AR-ACFC, ACFC-TR+, ACHTR, CHTR, CH, DCH, MS, AMS, CA, FS, and CS	AH2 + Treatment Code
Asphalt (A)	High (H)	Zone 3 (3)	NC, ACFC, AR-ACFC, ACFC-TR+, ACHTR, CHTR, CH, DCH, MS, AMS, CA, FS, and CS	AH3 + Treatment Code

DEVELOP PAVEMENT PERFORMANCE MODELS

Pre-Treatment Pavement Performance

Pre-treatment pavement performance curves represent the performance of pavements that have not received a treatment; the comparison of real-world data during the pavement treatment experiment's observation period to these performance curves may provide valuable feedback about expected versus real treatment performance. These curves are presented as graphs of the pavement condition over time and may be generated for untreated (also referred to as non-treated) sections identified using ADOT PMS data. A pre-treatment pavement performance curve may be generated for each of the different pavement families defined in Table 4. An example of a pre-treatment performance curve is shown in Figure 5, with IRI as the condition indicator.

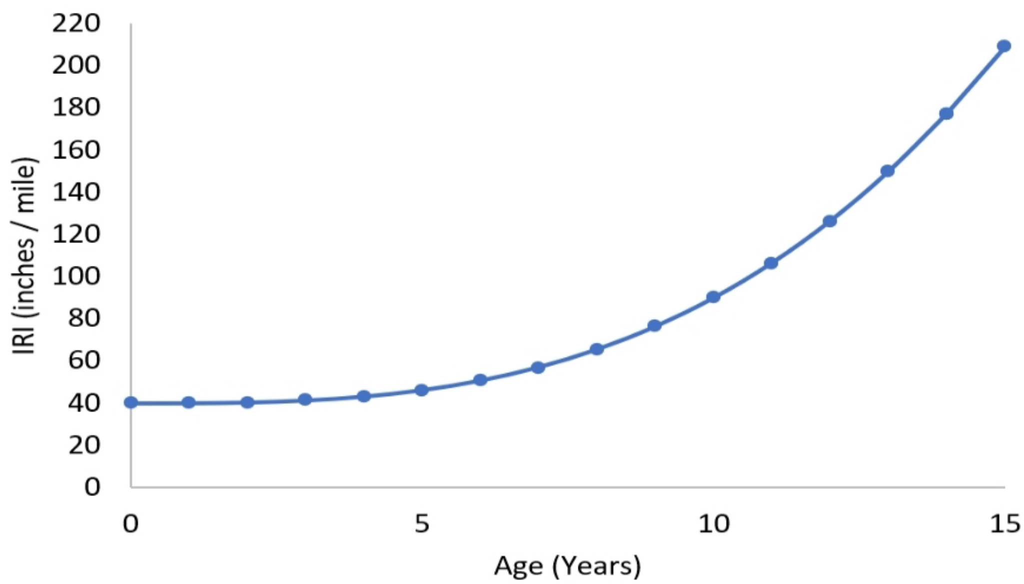

Figure 5. Example Pre-Treatment Pavement Performance Curve.

Post-Treatment Pavement Performance

Post-treatment pavement performance curves represent pavement performance after the application of surface treatments. These may be presented as graphs of the pavement condition over time after the initial treatment application. The applications of treatments are expected to impact a number of pavement performance indicators. Curves may be generated for different post-treatment families discussed in the previous section (refer to Table 5). An example of a post-treatment performance curve is shown in Figure 6, using cracking as the condition indicator for the AL2MS family.

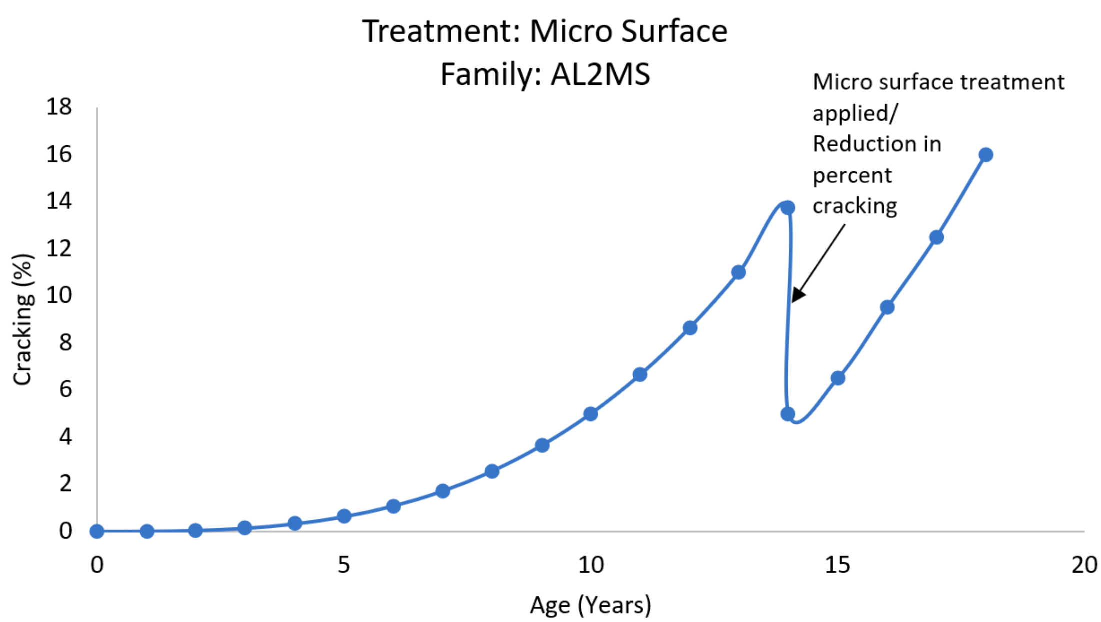

Figure 6. Example Post-Treatment Pavement Performance Curve.

EVALUATE TREATMENT IMPACTS AND EFFECTIVENESS

Various methods for analyzing the performance of surface treatments are discussed here and represent different ways to measure performance, acknowledging that different evaluation methods provide different insights into treatment performance. Each method may be considered for its usefulness and applicability in any pavement treatment evaluation.

Performance Jump

Performance jump is the instantaneous change in pavement condition after the application of a treatment. This performance metric may help to determine the impact of a treatment application on a wide range of pavement performance indicators such as IRI, cracking, or rutting.

To illustrate a performance jump, each performance measure is plotted against the age of the pavement for different families. When a surface treatment is applied, there is an instant change in pavement performance (e.g., IRI drop) which is measured as the "performance jump." The process is illustrated in Figure 7 for the AH3ARFC family. In this example, an AR-ACFC treatment is applied when the pavement is at the age of 14 years and results in an immediate drop in the pavement's IRI.

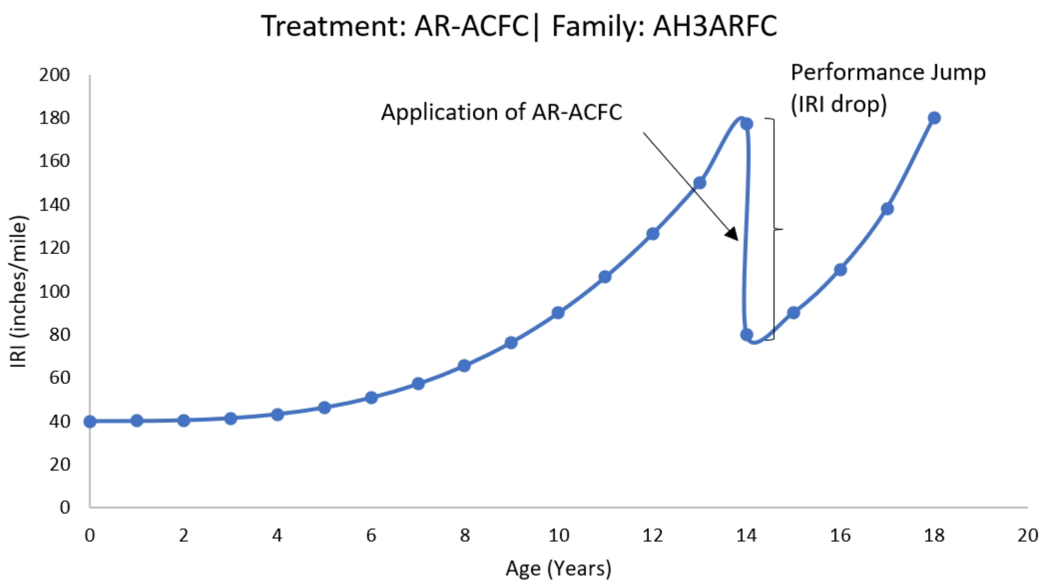

Figure 7. Example Illustration of the Performance Jump Method.

Service Life Extension

The difference between the time to reach a pre-determined threshold condition (for one or more pavement performance measures such as cracking, rutting, or roughness) for a pavement section that has received a treatment and the time required for an untreated section to reach the same threshold is typically reported as the service life extension associated with the treatment.

A pre-determined threshold condition for each performance indicator is used to calculate the service life extension. This is usually the trigger value for subsequent pavement action. Both the treated and untreated sections' performance are plotted together, and the service life extension is measured as the time between the treated and non-treated curve at the pre-determined threshold condition. This is illustrated in Figure 8 for the AH3MS family and rutting performance measure. The predetermined threshold condition is 0.25 inches for rutting. The extended service life from micro surface treatment application is 6 years.

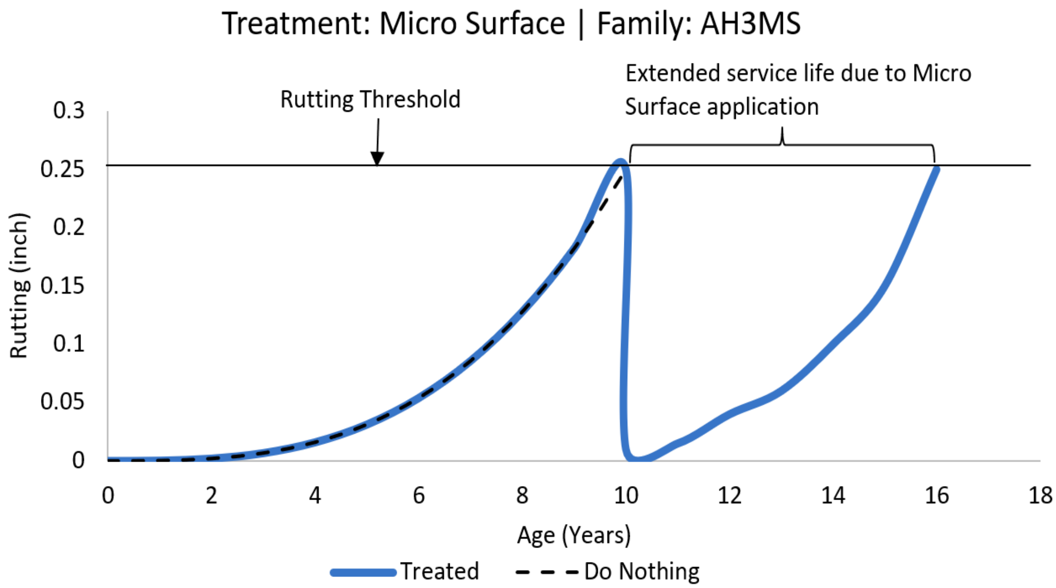

Figure 8. Example Illustration of the Service Life Extension Method.

Benefit Area

The benefit associated with the application of a treatment is calculated as the difference in the area bound by the performance curves of the treated pavement section and the area bound by the performance curve of the same pavement section if no treatment were applied.

Like the process involved in the calculation of service life extension, a pre-determined threshold condition is defined, and the pavement performance for both treated and untreated sections are plotted together. The benefit of the treatment is measured as the difference in the area bound by the treated and untreated curve and the threshold level. The process is illustrated in Figure 9 for the AH1NC family using rutting as the performance measure. The benefit area (shaded portion) is the area bound by the untreated pavement performance (do-nothing) curve, the 1-inch bonded overlay treated performance curve, and the rutting threshold (0.25 inch). The area bound by the pre- and post-treatment performance curves can be computed using simple numerical integration techniques such as the trapezoidal rule (a calculation that can be performed in a spreadsheet).

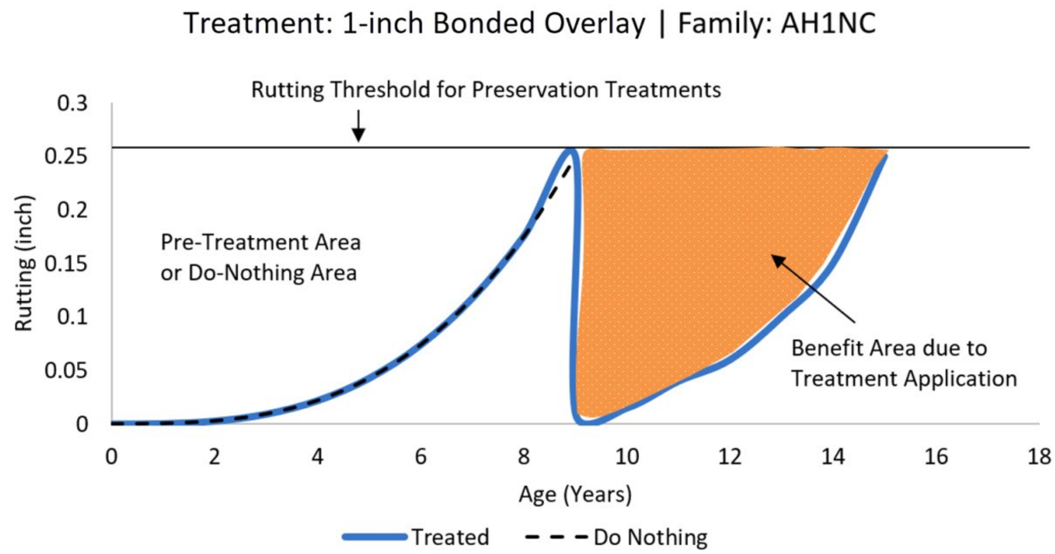

Figure 9. Example Illustration of Benefit-Area Method.

The pre- and post-treatment areas can be used to calculate a percent benefit area that is expressed as the ratio between the pre-treatment area and the benefit area due to treatment application, as shown in Equation 1. This is one approach to normalize the benefits using a common denominator so that the benefits of various treatments relative to pre-treatment performance can be compared on a uniform, dimensionless scale.

$$Percent\ Benefit\ Area = \frac{\text{Benefit Area due to Treatment Application}}{\text{Pre-Treatment Area}} \qquad \text{(Eq. 1)}$$

Benefit-Cost Ratio

The BCR is computed as the ratio of the net overall benefits (typically represented by the area under the performance curve) provided by a particular treatment (or a sequence of treatments) divided by the net overall costs associated with the selected treatment (or a sequence of treatments), as shown in Equation 2.

$$BCR = \frac{\text{Benefit Area (or Percent Benefit Area) Provided by Treatment}}{\text{Treatment Unit Cost}} \qquad \text{(Eq. 2)}$$

As elaborated in the "Benefit Area" method, the net benefits are computed as the area under the performance curve between treated and untreated sections. The next step in calculating a BCR is to identify unit costs for the different treatments under consideration. It is not as important how those costs are calculated as it is that the cost for each treatment includes the same elements and is expressed in the same units. With this information, a BCR can be calculated for every treatment and compared within a family to examine cost effectiveness.

Caution

In certain cases, the BCR should be used with caution. When only BCR is used as a performance measure for treatments with low unit costs, such as a crack seal, a high BCR often results. However, crack seals cannot mitigate all distresses nor provide service life extensions and improved functionality compared to other treatments (e.g., chip seals, thin overlays, or micro surfacing) that cover the whole pavement surface. Therefore, in addition to the BCR, other factors are also recommended for consideration to obtain a more complete picture of treatment effectiveness.

BCR values should only be used to compare treatments that are applied to address similar pavement deficiencies and are generally expected to exhibit similar functional performance.

Annual Performance Loss

The annual performance loss (APL) is another measure that can be used to evaluate the deterioration rate of preservation treatments. The performance measure is plotted against the pavement age for different treatments. The APL, as illustrated in Figure 10, is the difference in the performance measure from year to year. For example, after the application of an ACFC-TR+ and ACFC at year 14 there is an improvement in performance. The annual performance loss values for ACFC-TR+ and ACFC at year 15 are 20 inches per mile and 10 inches per mile, respectively. Similarly, the annual performance loss values for subsequent years are illustrated in Table 6.

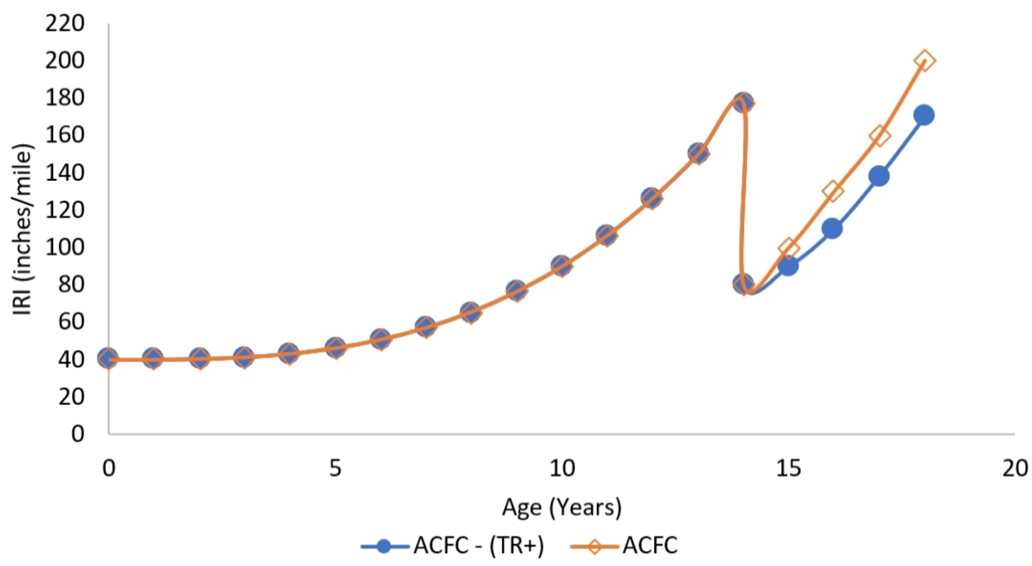

Figure 10. Example Illustration of the Annual Performance Loss Method.

Table 6. Example of Annual Performance Loss Values as Treatments Age.

Pavement Age	Treatment Age	ACFC-TR+ Annual Performance Loss (Based on IRI)	ACFC Annual Performance Loss (Based on IRI)
15	1	10	20
16	2	20	30
17	3	28	30
18	4	32	40

The APL may be used to evaluate both short- and long-term performance. The APL values in the first few years after treatment application (e.g., up to 3 years) can be compared to the APL values after the initial performance period. If there is a significant difference in the APL values, the rate of change of the APL measure can determine the time after treatment application when the deterioration is expected to accelerate at a faster rate. Additionally, the short- and long-term APL values can be compared across treatments to help better understand short- and long-term treatment effectiveness with the other performance indicators proposed in this study.

Equivalent Annual Cost

Equivalent Annual Cost is the average cost of the pavement treatment over its expected (or actual) service life. It is computed using Equation 3.

$$EAC = \frac{\text{Unit Cost of Treatment}}{\text{Expected (or Actual) Life of Treatments (in Years)}} \quad \text{(Eq. 3)}$$

The expected (or actual) life of an applied treatment is measured using the process described in the "Service Life Extension" method. The EAC is then obtained by dividing the treatment unit cost by the life of the applied treatment.

EXPECTED OUTCOMES FROM LONG-TERM PERFORMANCE MONITORING

Monitoring and analyzing the performance of preservation treatments over the long term may provide information on factors that have a significant impact on treatment effectiveness. The assessment of various items listed under each analysis category shown in Table 7 may help answer the following questions:

- Which treatments are more sensitive to variation in pre-treatment pavement condition?
- Does the underlying pavement/surface type have a measurable impact on treatment performance?
- What is the ideal pre-treatment condition for optimal treatment performance?
- Which treatments exhibit the best (and worst) performance in each environmental zone?
- Which treatments are more suited for high traffic volume applications?
- What is the optimal timing for treatment application?

Table 7. Potential Applications and Outcomes from Long-Term Performance Monitoring.

Analysis Category	Potential Applications/Outcomes
Similar Pre-Treatment Condition	• Compare impact of pre-treatment condition on treatment performance (treatment A vs B vs. C, etc.) • Determine pre-treatment condition for optimal performance
Underlying Pavement/Surface Type	• Determine impact of pre-treatment pavement/surface type on treatment performance
Similar Treatment Type and Environmental Zones	• Determine if variations in environmental zones impact treatment performance • Determine environmental conditions that result in good (or bad) treatment performance
Similar Traffic Levels and Treatment Types	• Determine if variations in traffic levels impact treatment performance • Determine traffic conditions that result in good (or bad) treatment performance
Similar Pre-Treatment Pavement Age	• Determine if pavement age at time of treatment application impacts treatment performance • Determine optimal treatment timing

The experimental framework described in this report and the proposed long-term monitoring program also describe a way to introduce and evaluate new preservation treatments and approaches as they become available.

METHODS

The methodology used for establishing pavement preservation treatment test sites, monitoring the sites over time, and analyzing the expected data obtained through long-term monitoring efforts was created with the goal of evaluating treatment performance and to conduct cost-effectiveness analyses. A general framework, illustrated in Figure 11, was developed for use in any future pavement treatment assessment that may involve the long-term monitoring and evaluation of the effectiveness of pavement preservation treatments.

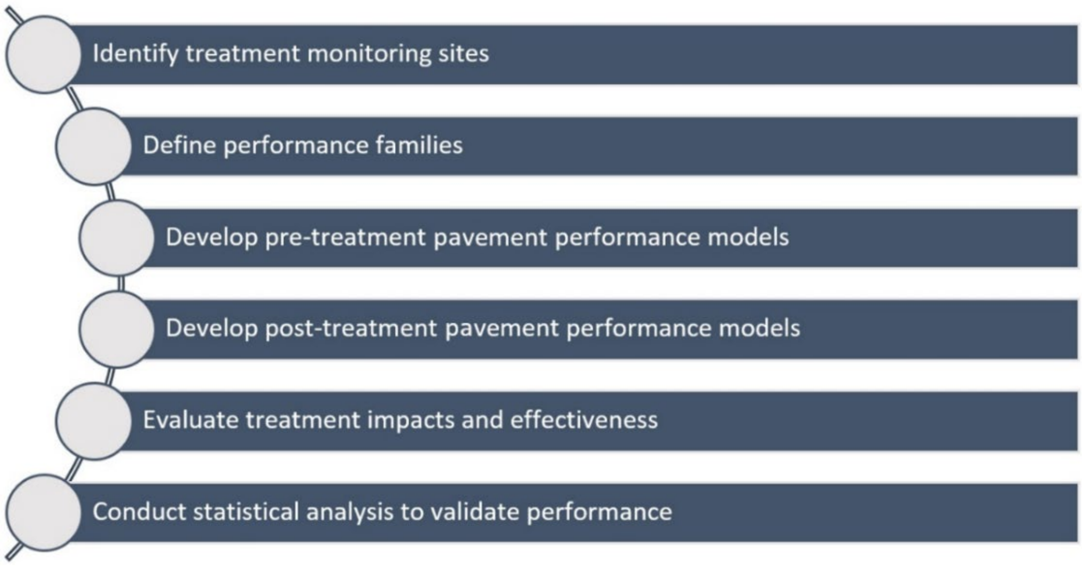

Figure 11. General Framework to Evaluate Preservation Treatment Effectiveness.

PROJECT APPROACH

Six tasks were carried out to achieve the project objectives. Brief technical memoranda summarizing the key takeaways from each task were submitted to ADOT. The tasks are identified and briefly described in Figure 12.

TASK 1 | **Document ADOT's pavement management practices relevant to the evaluation of the effectiveness and efficiency of surface treatments**

- Interview key ADOT staff, including the agency's Asset and Performance Manager, Surface Treatment Engineer Maintenance Management Services Supervisor, Transportation Engineer, and Senior Research Project Manager
- Review pavement preservation practices in the U.S., specifically focused on the analytical methodologies used to assess the effectiveness of preservation treatments

TASK 2 | **Develop Criteria and Sampling Plan**

- Develop criteria and sampling plan for selecting pavement preservation sites using information about existing pavement preservation projects

TASK 3 | **Identify Monitoring Sites and Establish Baseline Information**

- Apply site criteria and sampling plan to identify pavement preservation monitoring sites and develop an experimental matrix

TASK 4 | **Develop Analytical Method**

- Propose analytical methods that ADOT can use for its long-term monitoring and evaluation of pavement surface treatments
- Review methods for conducting cost-effective analysis

TASK 5 | **Apply Analytical Methods**

- Highlight the types of information that can be generated from the analytical methods identified under Task 4
- Present techniques to conduct statistical comparisons among treatments and between pre- and post-treated pavement sections
- Present performance measures to communicate treatment effectiveness

TASK 6 | **Use Information from Long-Term Monitoring and Evaluation to Enhance Pavement Management Processes**

- Identify approaches for leveraging the information generated from the long-term monitoring and evaluation efforts to improve ADOT's pavement management processes

Figure 12. Project Tasks and Work Approach.

As ADOT collects more data in the future and begins to implement the methodologies discussed in this report, it is possible that only a small subset of the recommended performance indicators and analytical methods proposed emerge as useful indicators for ADOT's evaluation of pavement treatment performances and effectiveness. Implementation will ultimately help ADOT to identify the most useful measures to compare treatments and specific metrics for statistical analysis.

REFERENCES

Arizona Department of Transportation (ADOT). 2017. *Pavement Design Manual*. Phoenix, AZ: Arizona Department of Transportation.

Arizona Department of Transportation (ADOT). 2021. *Transportation Asset Management Plan*. Phoenix, AZ: Arizona Department of Transportation.

ASTM International. 2020. *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys.* ASTM D6433. West Conshohocken, PA: ASTM International.

Illinois Department of Transportation (IDOT). 2012. "Chapter 52 Pavement Preservation." *Bureau of Design and Environment Manual.* Springfield, IL: Illinois Department of Transportation.

Minnesota Department of Transportation (MnDOT). 2006. *Minnesota Seal Coat Handbook 2006*. St. Paul, MN: Minnesota Department of Transportation.

Ohio Department of Transportation (ODOT). 2019. *Transportation Asset Management Plan.* Columbus, OH: Ohio Department of Transportation.

Peshkin, David G. 2006. "Assessment of Research Project SPR-371, Maintenance Cost Effectiveness Study." *Maintenance Cost Effectiveness Study.* FHWA-AZ-06-371. Washington, DC: Federal Highway Administration.

Peshkin, David G., Kelly L. Smith, Angie Wolters, James Krstulovich, Jim Moulthrop, and Cesar Alvarado. 2011. *Guidelines for the Preservation of High-Traffic-Volume Roadways*. SHRP 2 Report S2-R26-RR-2. Washington, DC: Transportation Research Board.

Washington State Department of Transportation (WSDOT). 2014. *WSDOT Chip Seals—Optimal Timing, Design and Construction Considerations*. Olympia, WA: Washington State Department of Transportation.

Zavitski, Jeff, Robert Piane, Gary Ruck, and Alfred Weninger. 2020. *A Guide to Understanding the Arizona Department of Transportation Pavement Management System*. Phoenix, AZ: Arizona Department of Transportation.

APPENDIX A – ACCESSIBLE CONTENT

This appendix is provided to ensure accessibility for all by listing longer, more detailed alternative text descriptions for figures where the short descriptions are insufficient.

FIGURE 1. ADOT Spending on Pavement Preservation. GRAPH.

ADOT preservation spending for fiscal years 2013 to 2023. The 112 Sub Program maintains funding from 15 to 20 million dollars through 2022. SLI Program begins funding in 2019 at 25 million dollars, then increases to 35 million dollars from 2020 to 2023. Combined funding reaches 50 to 55 million dollars by fiscal year.

FIGURE 2. STEPS FOR IMPLEMENTATION OF FRAMEWORK. INFOGRAPHIC.

- Step 1: Adopt Preservation Experiment
  - Finalize included treatment types
  - Select monitoring sites
  - For each site, document traffic level, environmental zone, pre-treatment conditions

- Step 2: Review and Update List of Treatment Monitoring Sites
  - Review gaps in experiment; add sites if needed

- Step 3: Collect Treatment Performance Data
  - Update performance data for the monitoring sites

- Step 4: Model Pre- and Post-Treatment Performance
  - Develop performance models for ride quality, safety, cracking, and other indicators of interest
  - Refine and validate models

- Step 5: Group Performance Measures into Short-, Medium-, and Long-Term Indicators
  - Use the models to compute the following for each treatment:
    - Treatment effectiveness measures
    - Cost-effectiveness measures

  - Group measures into meaningful timeframes
    - Short-Term
    - Medium-Term
    - Long-Term

FIGURE 3. EXAMPLE INFOGRAPHIC TO COMMUNICATE BENEFITS OF PAVEMENT PRESERVATION (ODOT 2019). GRAPHIC.

The LCP analysis found that approximately 48 percent of the general system is eligible for chip seals, but if 50 percent of overlay projects were chip sealed instead, life-cycle costs may decrease by over 300 million dollars in 4 years even though an additional 1,700 lane miles are being improved without increased funding.

FIGURE 4. ADOT'S P2P PROCESS FLOWCHART (ADOT 2021). FLOWCHART.

Transportation Asset Management Consistency Check. Process graphic begins in July with Planning. First is Number 1. Project Nominations with ADOT Technical groups. In August, Number 2. Project Prioritization (a) begins with technical, safety, and policy scores. September is Number 3. Project Prioritization (b) with district score. October is Number 4. District Workshops verify details and combine projects. November is Number 5. Final P2P list and Number 6 is Fiscal Constraint Applied-Recommended investment choice. Low-performing projects repeat the process with year-round data collection, scoping, and studies. Followed by April Project Nominations from the Board, COGs, MPOs, Tribes, and Districts. Then, in June, Early Coordination workshop, then back to Number 1 Planning in July.

Top-performing projects are programmed then move on to Number 7: Scoping in November. Then Programming from November to February in Number 8: Draft 5-Year Program. Then, from March to May is Number 9: Public Outreach with board public hearings. In June is Number 10: Transportation Board approval. Finally, in July Number 11: ADOT 5-Year Program, which includes design, then construction, and finally maintenance.

FIGURE 11. GENERAL FRAMEWORK TO EVALUATE PRESERVATION TREATMENT EFFECTIVENESS. GRAPHIC.

Framework from top to bottom:

- Identify treatment monitoring sites.
- Define performance families.
- Develop pretreatment performance models.
- Develop posttreatment performance models.
- Evaluate treatment impacts and effectiveness.
- Conduct statistical analysis to validate performance.

FIGURE 12. PROJECT TASKS AND WORK APPROACH. INFOGRAPHIC.

- **Task 1: Document ADOT's Pavement Management Practices Relevant to the Evaluation of the Effectiveness and Efficiency of Surface Treatments.**
  - Interview key ADOT staff, including the agency's Asset and Performance Manager, Surface Treatment Engineer, Maintenance Management Services Supervisor, Transportation Engineer, and Senior Research Project Manager.
  - Review pavement preservation practices in the U.S., specifically focused on the analytical methodologies used to assess the effectiveness of preservation treatments.

- **Task 2: Develop Criteria and Sampling Plan.**
  - Develop criteria and sampling plan for selecting pavement preservation sites using information about existing pavement preservation projects.

- **Task 3: Identify Monitoring Sites and Establish Baseline Information.**
  - Apply site criteria and sampling plan to identify pavement preservation monitoring sites and develop an experimental matrix.

- **Task 4: Develop Analytical Method.**
  - Propose analytical methods that ADOT may use for its long-term monitoring and evaluation of pavement surface treatments.
  - Review methods for conducting cost-effectiveness analysis.

- **Task 5: Apply Analytical Methods.**
  - Highlight the types of information that may be generated from the analytical methods identified under Task 4.
  - Present techniques to conduct statistical comparisons among treatments and between pre- and post-treated pavement sections.
  - Present performance measures to communicate treatment effectiveness.

- **Task 6: Use Information from Long-Term Monitoring and Evaluation to Enhance Pavement Management Processes.**
  - Identify approaches for leveraging the information generated from the long-term monitoring and evaluation efforts to improve ADOT’s pavement management processes.