Guidelines for Informing Decisionmaking to Affect Pavement Performance Measures: Final Report

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LTPP™

FOREWORD

The 2012 *Moving Ahead for Progress in the 21st Century Act* (MAP-21) required performance measures to be established for the Interstate Highway System (IHS). The succeeding bill, the *Fixing America's Surface Transportation Act,* maintained support of the performance management elements established under MAP-21. Subsequently, the Federal Highway Administration (FHWA) issued a Notice of Proposed Rulemaking (NPRM) to establish performance measures to assess the condition of the pavements on the IHS and the National Highway System (NHS) as follows: percentage of pavements on the IHS in good and poor condition and percentage of pavements on the NHS (excluding the IHS) in good and poor condition.

The research study that led to the guidelines contained in this report was intended to validate the proposed pavement performance measures established by the NPRM and to demonstrate their use within asset management. The findings of the validation suggest that the performance measures established by the NPRM and ultimately required by the issuance of the Final Rule by FHWA are appropriate, as all the metrics have an effect on overall condition and performance measures. As a result, guidelines for informing decisionmaking to affect pavement performance measures were developed, and they are presented in this report. The objective of these guidelines is to provide information and guidance to highway agencies on the following key pavement decisionmaking issues: method to identify which condition metric is driving the performance measure, temporal effects on performance measures, and effects of maintenance and rehabilitation treatments on performance measures.

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16. Abstract
The Federal Highway Administration (FHWA) issued a Notice of Proposed Rulemaking to establish performance measures for the Interstate Highway System (IHS) and the National Highway System (NHS) to assess the condition of the pavement on the IHS and NHS. The performance measures, as proposed by FHWA, to assess the condition of the pavement are based on the percentage of pavements on both the IHS and NHS (excluding the IHS) in good and poor condition. The condition of the pavements is to be determined based on the following metrics: International Roughness Index, cracking percent, rutting, and faulting. The overall objective of the research study that led to the guidelines contained in this report was to validate the proposed pavement performance measures and to demonstrate their use within asset management; this validation study is documented in a companion report. Guidelines for informing decisionmaking to affect pavement performance measures were developed based on the findings from the validation study. The goal of the guidelines is to illustrate to agencies potential strategies to move the overall condition from poor to fair to good. In meeting this goal, the guidelines will enable highway agencies to address critical questions such as the following: What are the drivers of the performance measures? What are the effects of maintenance and rehabilitation treatments on condition metrics and overall condition?

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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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LIST OF ABBREVIATIONS

AC	asphalt concrete
CRCP	continuously reinforced concrete pavement
DOT	department of transportation
FHWA	Federal Highway Administration
HPMS	Highway Performance Monitoring System
IHS	Interstate Highway System
IRI	International Roughness Index
JPCC	jointed portland cement concrete
LTPP	Long-Term Pavement Performance
M&R	maintenance and rehabilitation
MAP-21	*Moving Ahead for Progress in the 21st Century Act*
NCHRP	National Cooperative Highway Research Program
NHS	National Highway System
NPRM	Notice of Proposed Rulemaking
PMS	pavement management system
PSR	Present Serviceability Rating

CHAPTER 1. INTRODUCTION

BACKGROUND

The *Moving Ahead for Progress in the 21st Century Act* (MAP-21) legislation required that performance measures be established for the Interstate Highway System (IHS).(1) It also required that State departments of transportation (DOTs) develop and implement a risk- and performance-based Transportation Asset Management Plan covering the pavements and bridges within the National Highway System (NHS), as a minimum.

In January 2017, the Federal Highway Administration (FHWA) issued the Final Rule (effective February 17, 2017) to implement the performance management requirements of MAP-21 and the *Fixing America's Surface Transportation Act*.(2) The Final Rule established four pavement performance measures to assess pavement condition as follows:(3)

- Percentage of pavements on the IHS in good condition.
- Percentage of pavements on the IHS in poor condition.
- Percentage of pavements on the NHS (excluding the IHS) in good condition.
- Percentage of pavements on the NHS (excluding the IHS) in poor condition.

Condition of the pavements is to be determined based on the following metrics:(3)

- International Roughness Index (IRI).
- Cracking percent.
- Rutting.
- Faulting.

The pavement condition rating thresholds are provided in table 1.(3) The overall condition of the pavement is determined based on the individual metric conditions as follows:

- For asphalt concrete (AC) and jointed portland cement concrete (JPCC) Highway Performance Monitoring System (HPMS) pavement segments, the pavement is classified as good condition if all three metrics are in good condition—IRI, percent cracking, and either rutting (AC) or faulting (JPCC), respectively. The pavement is classified as poor condition if two or more of the metrics are in poor condition. All other combinations of metric conditions classify a pavement as fair.(3)

- For continuously reinforced concrete pavements (CRCPs), if both metrics—IRI and percent cracking—are in good condition, the pavement is classified as good. The pavement is classified as poor if both metrics are in poor condition. All other combinations of metric conditions classify the pavement as fair.(3)

Table 1. Pavement condition rating thresholds.

Condition Metric	Performance Level	Threshold
IRI	Good	<95
IRI	Fair	95–170
IRI	Poor	>170
Percent cracking, AC	Good	<5%
Percent cracking, AC	Fair	5–20%
Percent cracking, AC	Poor	>20%
Percent cracking, CRCP	Good	<5%
Percent cracking, CRCP	Fair	5–10%
Percent cracking, CRCP	Poor	>10%
Percent cracking, JPCC	Good	<5%
Percent cracking, JPCC	Fair	5–15%
Percent cracking, JPCC	Poor	>15%
Rutting	Good	<0.20
Rutting	Fair	0.20–0.40
Rutting	Poor	>0.40
Faulting	Good	<0.10
Faulting	Fair	0.10–0.15
Faulting	Poor	>0.15

The Final Rule allows State DOTs to report Present Serviceability Rating (PSR) instead of metrics where the speed limit is under 40 mph.(3) The pavement condition rating thresholds when using the PSR metric for all pavement types are provided in table 2.(3)

Table 2. Pavement condition rating thresholds using PSR metric.

Rating	Metric Range
Good	≥4.0
Fair	>2.0 and <4.0
Poor	≤2.0

The Final Rule notes that each of the above pavement condition data metrics is to be collected on the full extent of the IHS in the rightmost travel lane in the inventory direction of mainline travel on an annual basis.(3) For the non-interstate NHS pavements, data are to be collected on the full extent of the rightmost lane in one direction of travel on a biennial frequency.(3) Percent cracking, rutting, and faulting are not required to be collected on the non-interstate NHS until the 2020/2021 data collection cycles.(3)

The efforts of the study that led to these guidelines were undertaken to validate the proposed pavement performance measures issued as part of the Notice of Proposed Rulemaking and ultimately to support the measures established in the Final Rule.(4) Due to the completeness and volume of data contained in the Long-Term Pavement Performance (LTPP) Pavement Performance Database, the LTPP program was poised to assist in implementation of the MAP-21 legislation—both the validation of the performance measures as well as the development of these guidelines. The validation of the performance measures is documented in a companion report to these guidelines.[4] Users of the guidelines presented in this report are encouraged to read the companion validation study report, as it provides the background and analysis that resulted in the recommendations presented herein.

OBJECTIVE

The objective of these guidelines is to provide information and guidance to highway agencies on the following key pavement decisionmaking issues:

- Method to identify which condition metric is driving the performance measure.
- Temporal effects on performance measures.
- Effects of maintenance and rehabilitation (M&R) treatments on performance measures.

The goal of the guidelines is to illustrate to agencies what needs to happen to move the overall condition from poor to fair to good. In meeting this goal, the guidelines will enable highway agencies to address critical questions such as the following:

- What are the drivers of the performance measures?

- What are the effects of M&R treatments on condition metrics and overall condition?

- How can performance measures be improved from poor to fair, poor to good, and fair to good?

Figure 1 presents a flowchart summarizing the approach detailed in the guidelines. The flowchart begins with the development of performance measure drivers for both the metric condition and the overall condition. The performance measure drivers are then combined with the effects of M&R treatments on the metric and overall condition. These findings are then used to develop a list of M&R treatments that affect the condition. The final step in the process is the integration of the results with the pavement management system (PMS).

GUIDELINES ORGANIZATION

The guidelines present recommended procedures for assessing the effectiveness of M&R treatments to improve overall condition and performance measures. The chapters included in these guidelines are summarized below along with a brief description of their contents:

1. Introduction—provides the background, objectives, and organization of the guidelines.

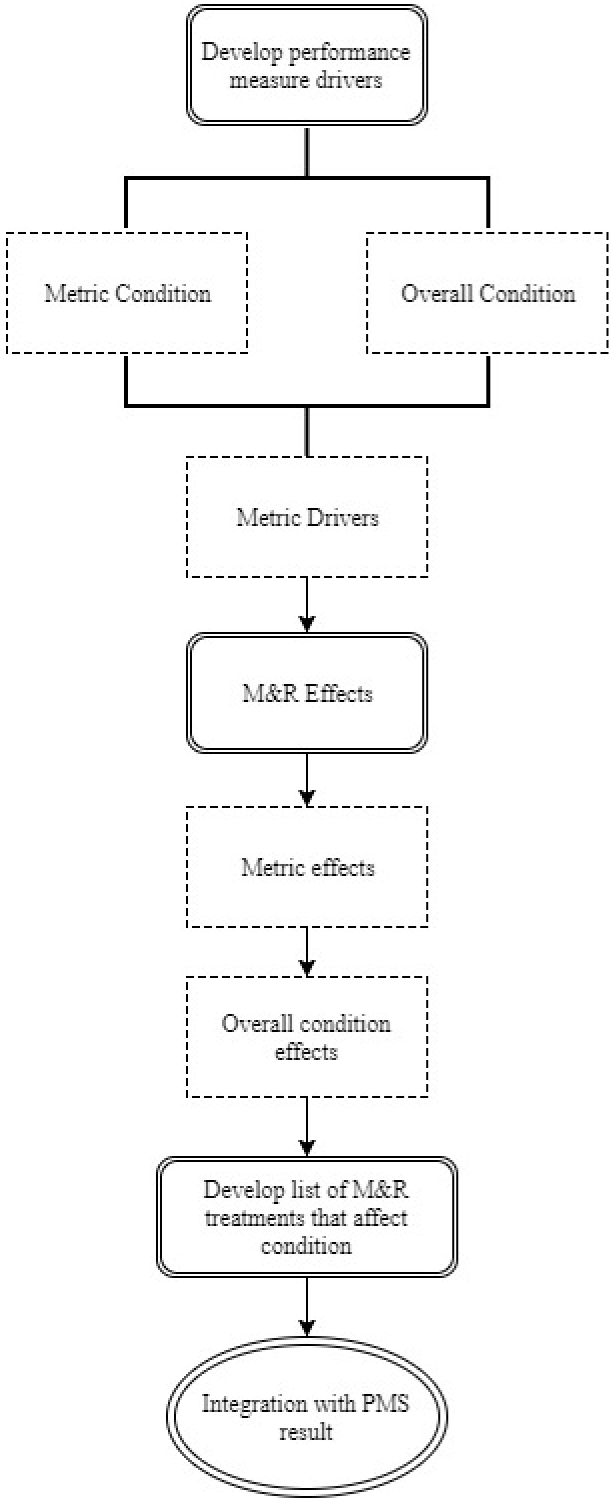
2. Development of Performance Measure Drivers—details how to develop the performance measure drivers.

3. Assessing the Effects of M&R Treatments—presents the effects of M&R treatments on metric and overall conditions.

4. Treatments Affecting Performance Measures—combines the effects of M&R treatments with the performance measure drivers to develop a list of M&R treatments that affect condition.

5. Summary, Challenges, and Recommendations—summarizes the findings from the previous chapters. In addition, challenges for integrating the findings of the guidelines with PMS results are presented and recommendations made.

The examples, conclusions, and recommendations developed in these guidelines are based on LTPP data. Highway agencies should review and analyze their own data to confirm that the LTPP-derived information is applicable to their agency and, if not, make the needed adjustments based on the examples provided in the guidelines.



Source: FHWA.

Figure 1. Flowchart. Guidelines general approach.

CHAPTER 2. DEVELOPMENT OF PERFORMANCE MEASURE DRIVERS

BACKGROUND

The purpose of developing the performance measure drivers is to understand the metric or metrics that are affecting the overall pavement condition. Understanding the performance measure drivers is necessary in the treatment selection process so that the treatments selected address the cause of the pavement condition, improving the individual metrics and, ultimately, the overall pavement condition.

To develop the performance measure drivers, there needs to be an understanding of the metrics for the various pavement types. The metrics according to pavement type are as follows:

- AC pavements.
  - Roughness, percent cracking, and rutting.
- JPCC pavements.
  - Roughness, percent cracking, and faulting.
- CRCPs.
  - Roughness and percent cracking.

The thresholds presented in table 1 are used to assign the metric condition, as illustrated in the following examples:

- **AC pavements example**. A given AC pavement has a roughness of 101 inches/mi, 4-percent cracking, and 0.15 inch of rutting. The metric conditions according to the thresholds in table 1 are fair, good, and good for roughness, percent cracking, and rutting, respectively. The overall condition is determined based on the Final Rule as detailed in chapter 1 of these guidelines. For the AC pavement, since two metrics are good and one metric is fair, the overall condition is fair.

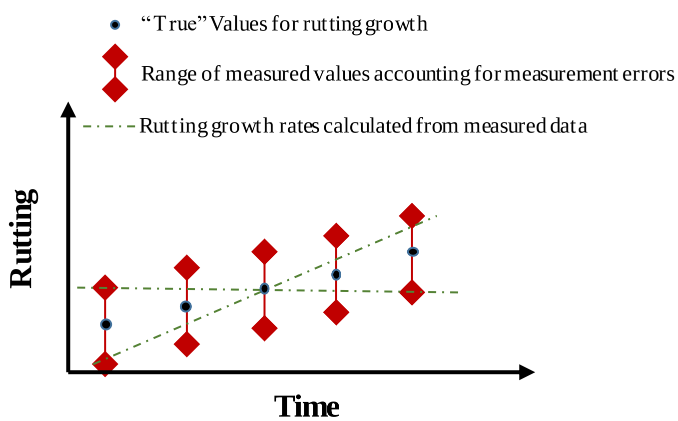
- **JPCC pavements example.** A given JPCC pavement has a roughness of 182 inches/mi, 3-percent cracking, and faulting of 0.20 inch. The metric conditions according to the thresholds in table 1 are poor, good, and poor for roughness, percent cracking, and faulting, respectively. The JPCC pavement overall condition is poor, since two metrics are poor and one metric is good.

- **CRCPs example.** A given CRCP has a roughness of 120 inches/mi and 11 percent cracking. The metric conditions according to the thresholds in table 1 are fair and poor for roughness and percent cracking, respectively. The CRCP overall condition is fair, since both metrics are neither good nor poor.

The goal of the guidelines is to inform decisionmaking that affects the pavement performance measures, which are the percent of pavements on the IHS and NHS in good and poor condition. While the discussion in this chapter and throughout the guidelines focuses on the impact of drivers on overall condition, it is that overall condition that is ultimately going to drive the performance measures of the network. For instance, by improving the overall condition to good, the performance measure (percent good) is improved. The overall condition feeds directly into the performance measures.

Another factor that can affect pavement condition and therefore needs to be recognized and considered is measurement error. For example, it is expected that rut depth will increase over time, but the rate of change (i.e., increase) in rutting is likely to be less than the measurement error. The *Guide for the Local Calibration of the Mechanistic–Empirical Pavement Design Guide* reports a reasonable standard error of the estimate for rutting to be 0.10 inch, while the average rate of change for rutting can be less than 0.01 inch per year.[(5)] Therefore, it is possible for the data to show a decreasing trend in the rutting as a result of measurement error, as discussed next.

Figure 2 illustrates two possible relationships for growth rates depending on the measurement errors—one with a positive trend and one with a negative trend—as well as the "true" rutting values, which show a positive growth rate. As shown, for every measurement, there is a "true" value that represents the actual value. Each measurement also has a range of likely measurable values, which can be attributed to errors such as measurement errors, errors in linear referencing from year to year, and errors introduced by averaging many measurements into one representative value for a segment. Due to this plausible interval of measurements, it is conceivable to report a variety of growth rates from the measured data depending on where in the interval the measured value falls in comparison to the true value. This example helps illustrate the possible impact of measurement error on pavement condition trends (e.g., improving pavement condition with time in the absence of M&R). State DOTs need to recognize the potential impact of measurement error on the data and the performance measures and should continuously strive to improve the accuracy of the data collection through improved technology with increased data collection accuracy and precision, training of personnel, and implementation of data quality management plans.



Source: FHWA.

Figure 2. Graph. Rutting growth.

DEVELOPMENT OF DRIVERS

The first step in developing performance measure drivers is to understand the metric condition combinations that compose the overall condition. It is important to differentiate between metric condition combinations because different metric condition combinations require different treatments to have an effect on the overall condition. The combination of metric conditions to consider for AC and JPCC pavements include the following:

- Good–good–fair (G-G-F).
- Good–good–poor (G-G-P).
- Good–fair–fair (G-F-F).
- Good–fair–poor (G-F-P).
- Fair–fair–poor (F-F-P).
- Good–poor–poor (G-P-P).
- Fair–poor–poor (F-P-P).

Three other possible metric condition combinations include those when all metrics are either good, fair, or poor. However, these are not included in this analysis, as there are no drivers of these conditions, since all three metrics contribute to the all good, all fair, and all poor conditions.

For CRCPs, the metric condition combinations considered are as follows:

- Good–fair (G-F).
- Good–poor (G-P).
- Fair–poor (F-P).

Emphasis should be given to the drivers of the borderline conditions, which are those conditions where one change (e.g., good to fair, fair to good, fair to poor, poor to fair) in metric condition would result in a change in overall condition. The borderline conditions for AC and JPCC pavements include the following:

- Good–good–fair (G-G-F).
- Good–fair–poor (G-F-P).
- Fair–fair–poor (F-F-P).
- Good–poor–poor (G-P-P).
- Fair–poor–poor (F-P-P).

For CRCP, the borderline conditions include the following:

- Good–fair (G-F).
- Good–poor (G-P).
- Fair–poor (F-P).

Note: There were insufficient LTPP data for use in the validation study and development of the guidelines to make distinctive observations and conclusions regarding the last two CRCP borderline conditions.[(4)]

To develop the performance measure drivers for each metric condition combination, the following steps are required:

1. Separate data based on pavement type (e.g., AC, JPCC, and CRCP).

2. Assign condition (good, fair, poor) for metrics for each pavement segment according to table 1.

3. Assign overall condition according to the pavement segment metric condition combinations as explained in chapter 1 of these guidelines.

4. Assign each pavement segment a metric condition combination (G-F-P, G-G-F, etc.).

5. Identify the metric or metrics that are driving the overall condition for each pavement segment. The driver is defined as the metric or metrics that are most responsible for the overall condition. The driver(s) are identified as follows:

    a. G-G-F—metric in fair condition.
    b. G-G-P—metric in poor condition.
    c. G-F-P—metrics in fair and poor condition.
    d. G-F-F—metrics in fair condition.
    e. F-F-P—metrics in fair condition.
    f. G-P-P/F-P-P—metrics in poor condition.

6. Calculate percentage that each metric is identified in step 5 for the metric grouping to determine the performance measure driver.

Although the emphasis of this chapter is on identifying the metric or metrics that are driving the overall condition, it should be noted that there are other possibilities that affect the condition besides the metrics and drivers identified in this chapter. The drivers identified are those metrics that are most responsible for the overall condition. However, there are other metrics that can also affect the condition and various scenarios that could change the overall condition. For instance, for the F-F-P grouping, the two metrics that are in fair condition are identified as the drivers. That is not to say that the metric that is in poor condition should be ignored. By improving the condition of the metric in poor condition, the overall condition would remain fair assuming the other metrics remained fair as well, but by improving the poor metric to fair, the overall condition may be less likely to become poor, as now two metrics would need to deteriorate to poor condition. Also, if a metric is identified as the driver, this does not mean that other metrics do not affect the condition but that it is not as likely. For example, if the driver of the G-G-F grouping is rutting, rutting is the metric that is most often the metric in fair condition. That is not to say that roughness and cracking are never in fair condition but that it is less likely than rutting being the metric in fair condition.

EXAMPLES

The following examples—one for each pavement type—were developed using LTPP data to illustrate the steps to develop the performance measure drivers. The metric conditions and overall conditions were assigned according to steps 2 and 3. The metric condition combinations were then assigned according to the metric conditions assigned in step 2.

- **AC pavements example.** This example illustrates the G-G-P and F-F-P metric condition combinations. The G-G-P and F-F-P groupings represent 12 percent and 8 percent of the AC pavement sections in fair condition, respectively. For the G-G-P grouping, the driver is the metric in poor condition. Table 3 presents the number of pavement sections in the G-G-P grouping where the metrics are in poor condition. The percentages in table 4 represent the proportion of all the pavement sections in the G-G-P grouping where the metric is in poor condition. The table shows that cracking, with 67 percent, is the metric that is most likely to be in poor condition and therefore is the driver of the overall condition for the G-G-P grouping. For the F-F-P grouping, the drivers are the metrics in fair condition. Table 5 presents the number of pavement sections in the F-F-P grouping where both metrics are in fair condition. The percentages in table 6 represent the proportion of all the pavement sections in the F-F-P grouping where the metrics are in fair condition. The table shows that rutting and roughness, with 90 percent, are the metrics that are most likely to be in fair condition and therefore the drivers of the overall condition for the F-F-P grouping.

Table 3. AC G-G-P grouping metric counts.

Metric	Rutting	Roughness	Cracking	Total
Number of sections	190	27	435	652

Table 4. AC G-G-P grouping metric percentage.

Metric	Rutting (%)	Roughness (%)	Cracking (%)	Total (%)
Number of sections	29	4	67	100

Table 5. AC F-F-P grouping metric counts.

Metric	Rutting/ Roughness	Roughness/ Cracking	Cracking/ Rutting	Total
Number of sections	376	20	20	416

Table 6. AC F-F-P grouping metric percentage.

Metric	Rutting/ Roughness (%)	Roughness/ Cracking (%)	Cracking/ Rutting (%)	Total (%)
Number of sections	90	5	5	100

- **JPCC pavements example.** The G-G-F and G-P-P/F-P-P groupings are illustrated in this example. The driver of the G-G-F metric grouping will be the metric that is in fair condition. For an LTPP dataset of JPCC pavements, table 7 presents the number of sections where the metric is in fair condition and the metric grouping is G-G-F. The percentages in table 8 represent the proportion of all pavement sections in the G-G-F grouping where the metrics are in fair condition. The results presented in table 8 show that the driver of the G-G-F metric grouping is roughness, since roughness is the metric in fair condition 66 percent of the time.

Table 7. JPCC G-G-F grouping metric counts.

Metric	Faulting	Roughness	Cracking	Total
Number of sections	294	734	88	1,116

Table 8. JPCC G-G-F grouping metric percentages.

Metric	Faulting (%)	Roughness (%)	Cracking (%)	Total (%)
Number of sections	26	66	8	100

The drivers of the G-P-P/F-P-P grouping are the metrics that are in poor condition. Table 9 presents the number of segments where the two metrics listed are both in poor condition and the metric grouping is G-P-P/F-P-P. The percentages in table 10 represent the proportion of all pavement sections in the G-P-P/F-P-P grouping where the metrics are in poor condition. The drivers of the G-P-P/F-P-P grouping shown in table 10 are roughness and cracking, since roughness and cracking are both in poor condition 62 percent of the time.

Table 9. JPCC G-P-P/F-P-P groupings metrics count.

Metric	Faulting/ Roughness	Roughness/ Cracking	Cracking/ Faulting	Total
Number of sections	26	99	35	160

Table 10. JPCC G-P-P/F-P-P groupings metrics percentages.

Metric	Faulting/ Roughness (%)	Roughness/ Cracking (%)	Cracking/ Faulting (%)	Total (%)
Number of sections	16	62	22	100

- **CRCPs example.** The LTPP dataset only had sufficient data to analyze the drivers of the G-F metric condition combination. The performance measure driver of this grouping is the metric in fair condition. Of the 178 pavement sections in the G-F grouping, 168 of them, or 90 percent, had roughness as the metric in fair condition, making roughness the driver of the G-F metric condition combination.

The process described in this chapter for determining the performance measure drivers was completed for all the metric condition combinations, and they are presented in the companion report.[4] The performance measure drivers identified in this companion report are summarized in table 11.

Table 11. Performance measure drivers.

Pavement Type	Metric Grouping	Driver(s)
AC	G-GF	Rutting
AC	G-G-P	Cracking
AC	G-F-F	Rutting/roughness
AC	G-F-P	Cracking/rutting
AC	F-F-P	Rutting/roughness
AC	G-P-P/F-P-P	Cracking/rutting
JPCC	G-G-F	Roughness
JPCC	G-G-P	Cracking
JPCC	G-F-F	Faulting/roughness
JPCC	G-F-P	Roughness/cracking
JPCC	F-F-P	Faulting/roughness
JPCC	G-P-P/F-P-P	Roughness/cracking
CRCP	G-F	Roughness

CHAPTER 3. ASSESSING THE EFFECTS OF M&R TREATMENTS

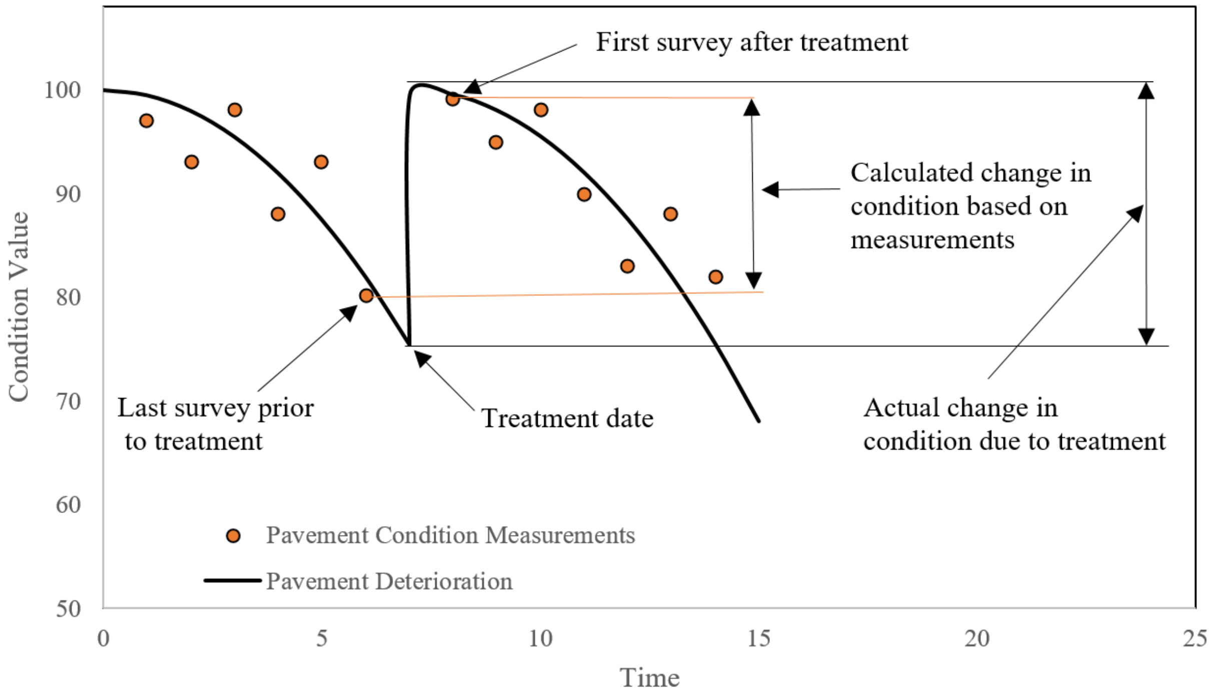
BACKGROUND

This chapter details the comparison of the time-series trends of performance measures against documented M&R treatments to assess the effects of the treatments. The trends in individual metrics and the overall pavement condition ratings over time were reviewed against recorded M&R treatments to determine whether they demonstrated any type of change in response to those treatments. For this analysis, the last survey prior to the M&R treatment was compared to the first survey after the M&R treatment. The surveys were not necessarily taken immediately before and after the M&R treatments. In some cases, a year or more transpired between the placing of the M&R treatment and the survey date.

The potential effect on the calculated change in condition versus the actual change in condition, depending on how closely the last survey prior to treatment and the first survey after treatment are measured, is illustrated in figure 3 and figure 4. As an example, in figure 3, the last survey prior to treatment was taken a year prior to the treatment date, and the first survey after treatment was taken a year after the treatment date. The actual change in condition as a result of the treatment was an improvement of 24 points. However, the condition improvement calculated based on the condition at the time of the last survey prior to treatment and the condition at the time of the first survey after treatment was only 19 points due to the time between survey measurements and treatment application. This results in a difference between the calculated change in condition based on the measurements at the time of survey and the actual change in condition due to treatment of more than 20 percent.

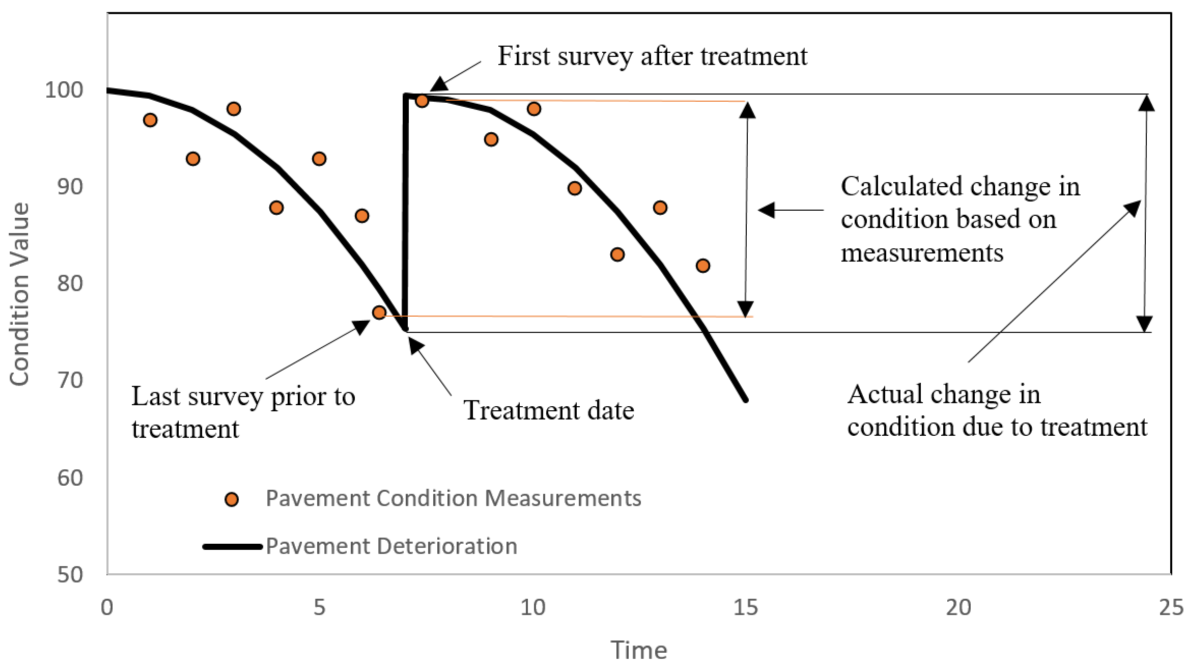
Similarly, in figure 4, the last survey prior to treatment was taken 7 months prior to the treatment date, and the first survey after treatment was taken 5 months after the treatment date. The actual change in condition as a result of the treatment was again 24 points. With the time between survey measurements and the treatment application being reduced from the first example, the improvement in condition value calculated based on the last survey prior to treatment and the first survey after treatment was 22 points. The difference between the calculated change in condition based on measurements and actual change in condition due to treatment was reduced to about 8 percent.

These two examples illustrate the importance of considering the time of survey dates as they relate to the treatment date. The closer the timing of the before and after treatment surveys to the time of treatment application, the more reliable the data in terms of M&R effects.



Source: FHWA.

Figure 3. Graph. Effect of survey dates on difference in change in condition—2 years between surveys.

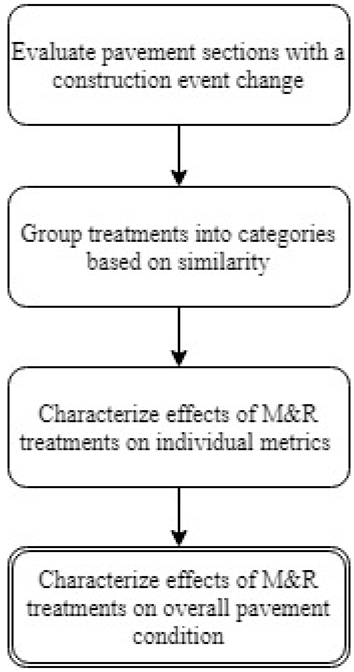


Source: FHWA.

Figure 4. Graph. Effect of survey dates on difference in change in condition—1 year between surveys.

PROCESS OVERVIEW

Figure 5 presents a flowchart detailing the steps required to assess the effects of M&R treatments on overall pavement condition.



Source: FHWA.

Figure 5. Flowchart. Assessing effects of M&R treatments.

The steps shown in figure 5 are as follows:

1. Identify pavement segments with a construction event change.

2. Group treatments for pavement segments identified in step 1 into M&R treatment categories based on similarity.

   For multiple and different improvements for a single construction event, the improvement should be grouped based on the treatment expected to have the greatest influence on pavement surface. For example, crack sealing and shoulder restoration should be classified as crack sealing, since shoulder restoration has no impact on the pavement metrics or overall condition rating.

   For illustration purposes, the various treatment types present within the LTPP data were grouped into categories based on similarity as shown in table 12 through table 14 by pavement type—AC, JPCC, and CRCP, respectively. For AC pavements, for example, the treatment categories include crack seal, grinding, mill and overlay, overlay, patch, and surface treatment. The treatment types in these tables represent the various types of treatments grouped together under each category. In table 12, for example, mill and overlay, mill existing pavement and overlay with hot-mix recycled AC, and mill off AC and overlay with AC are different treatment types that have been grouped together as mill and overlay. The paired treatments in the three tables are those that were applied at the same time as the treatment type but that are not expected to have as much influence on the surface. For example, in table 12, AC shoulder restoration applied at the same time as AC overlay is grouped as overlay, since the AC overlay treatment is expected to have more of an effect on the pavement surface condition.

Table 12. AC M&R treatment groupings.

M&R Treatment Groupings	Treatment Types	Paired Treatments
Crack sealing	• Crack sealing	No paired treatments
Grinding	• Grinding	No paired treatments
Mill and overlay	• Mill and overlay • Mill existing pavement and overlay with hot-mix recycled AC • Mill off AC and overlay with AC	• AC shoulder replacement • AC shoulder restoration • Aggregate seal coat • AC overlay • Longitudinal subdrains • Machine premix patch • Tack coat
Overlay	• AC overlay	• AC shoulder restoration • Aggregate seal coat • Full-depth patch of AC pavement • Grinding surface • Heater scarification, surface recycled AC • Machine premix patch • Manual premix spot patch • Strip patching • Tack coat
Patch	• Full-depth patch of AC pavement • Full-depth transverse joint repair patch • Machine premix patch • Manual premix spot patch • Mechanical premix patch • Patch potholes • Skin patching • Strip patching	• AC shoulder replacement • Crack sealing • Transverse joint sealing
Surface	• Aggregate seal coat • Fog seal coat • Sand seal coat • Slurry seal coat • Surface, single layer	• Saw and seal

Table 13. JPCC M&R treatment groupings.

M&R Treatment Groupings	Treatment Types	Paired Treatments
Crack sealing	• Crack sealing	No paired treatments
Grinding	• Grinding surface	• AC shoulder replacement • Crack sealing • Full-depth patching of PCC pavement other than at joint • Full-depth transverse joint repair patch • Longitudinal subdrains • Partial-depth patching of PCC pavement other than at joint • Partial-depth patching of PCC pavements at joints • Transverse joint sealing
Joint sealing	• Lane-shoulder longitudinal joint sealing • Transverse joint sealing	• AC shoulder restoration • Crack sealing
Patch	• Full-depth patching of PCC pavement other than at joint • Full-depth transverse joint repair patch • Lane-shoulder longitudinal joint sealing • Manual premix spot patch • Partial-depth patching of PCC pavement other than at joint • Partial-depth patching of PCC pavements at joints • Skin patching	• AC shoulder replacement • AC shoulder restoration • Crack sealing • Lane-shoulder longitudinal joint sealing • Transverse joint sealing
Shoulder	• AC shoulder restoration	No paired treatments
Slab replacement	• PCC slab replacement	• AC shoulder restoration • Grinding surface • Lane-shoulder longitudinal joint sealing • Partial-depth patching of PCC pavement other than at joint • Transverse joint sealing

Table 14. CRCP M&R treatment groupings.

M&R Treatment Groupings	Treatment Types	Paired Treatments
Crack sealing	• Crack sealing	No paired treatments
Grooving	• Grooving	No paired treatments
Joint sealing	• Joint sealing	• Crack sealing
Patching	• Full-depth patching of PCC pavement other than at joint • Full-depth transverse joint repair patch • Mechanical premix patch • Partial-depth patching of PCC pavement other than at joint • Partial-depth patching of PCC pavements at joints	• AC shoulder replacement • Lane-shoulder longitudinal joint sealing
PCC overlay	• PCC overlay	• AC shoulder restoration • Full-depth patching of PCC pavement other than at joint • Grinding surface • Lane-shoulder longitudinal joint sealing • PCC shoulder restoration
Shoulder	• AC shoulder restoration	No paired treatments

3. Characterize the effect of M&R treatments on individual pavement metrics. The three possible characterization options are as follows:

    a. No change in condition: Condition rating before and after treatment remains the same.

    b. Worse condition: Condition rating after the treatment has deteriorated; for example, before-treatment condition was fair, and after-treatment condition is poor.

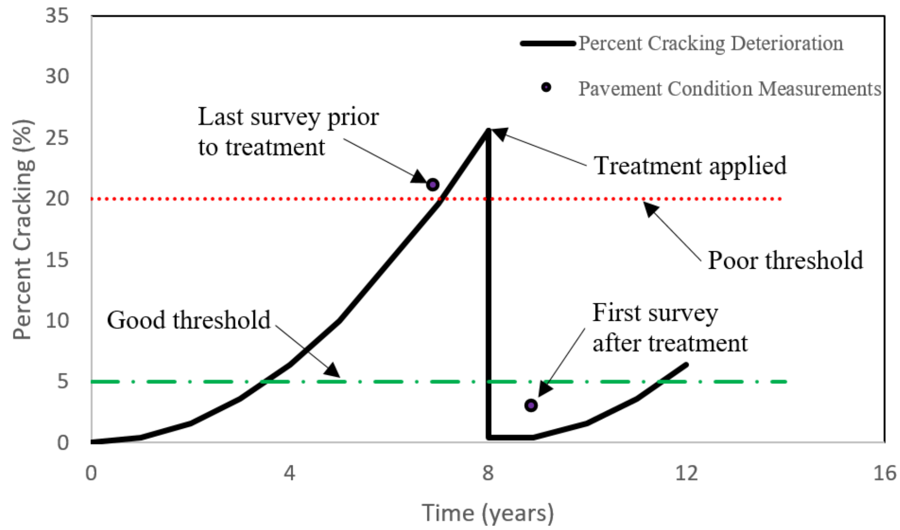
    c. Improved condition: Condition rating after the treatment improves; for example, before-treatment condition was fair, and after-treatment condition is good.

    Examples of this step are provided in the next section to provide greater detail, as this is at the heart of assessing the effects of M&R treatments.

4. Characterize the effect of M&R treatments on overall pavement condition as no change in condition, worse condition, or improved condition.

EFFECTS OF M&R TREATMENTS ON PAVEMENT CONDITION

This section addresses the characterization of the effect of M&R treatments on the individual pavement metrics. Figure 6 illustrates an AC pavement segment that received an overlay in January 2013. The last survey prior to the treatment was taken in February 2011, when the percent cracking was 21 percent (i.e., in poor condition according to table 1). The first survey after treatment was in December 2014, when the percent cracking was 3.1 percent (i.e., in good condition according to table 1). Therefore, the effect of the overlay on the percent cracking condition of the AC pavement in question was to improve it from poor to good.

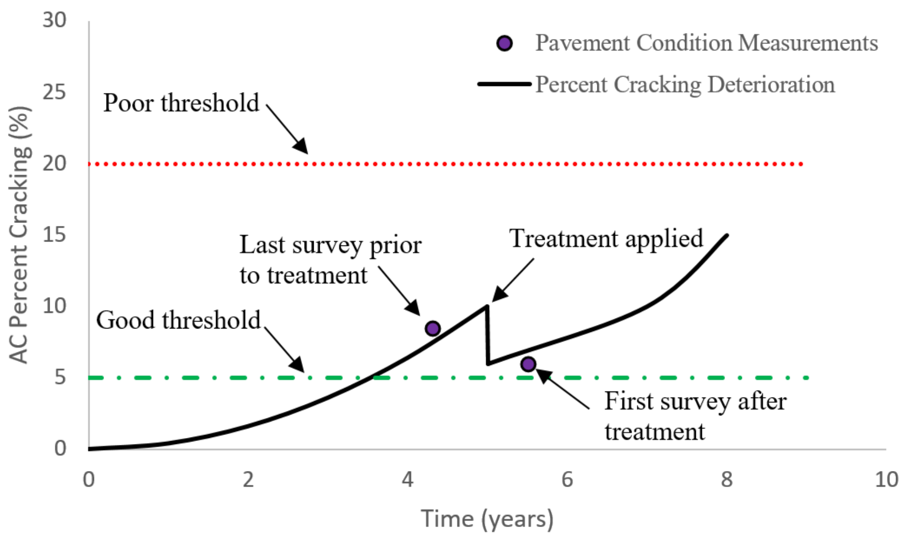


Source: FHWA.

Figure 6. Graph. Example of M&R treatment improving condition.

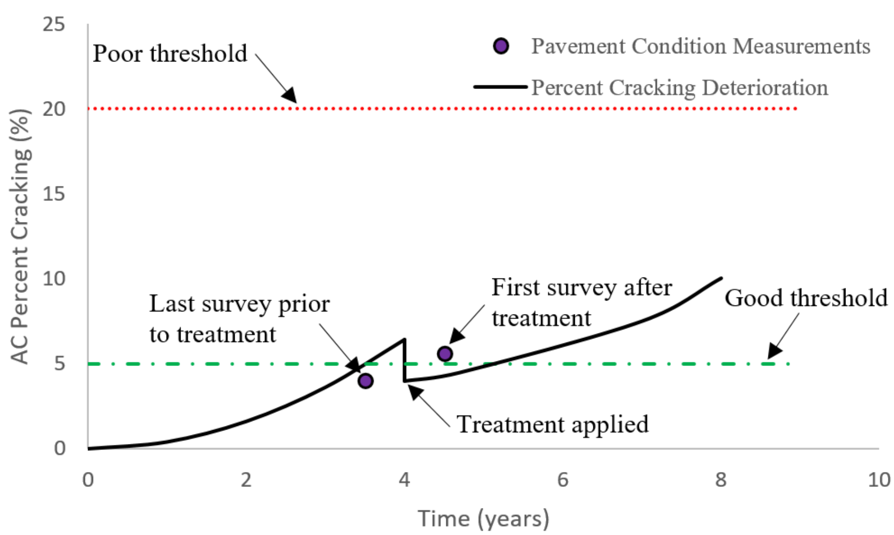
Figure 7 illustrates a pavement segment that received a patch in year 5. Most often, patching does not positively affect the percent cracking for AC pavements, as documented in the companion research study report that led to these guidelines.[4] The percent cracking may be reduced a small amount as a result of patching, as depicted in figure 7. In this example, the last survey prior to treatment had a percent cracking of 8.5 percent (in fair condition according to table 1). The first survey after treatment had a percent cracking of 6 percent (in fair condition according to table 1). Although the percent cracking improved slightly, the percent cracking condition remained fair according to table 1 (i.e., no change in metric condition).

Figure 8 illustrates a pavement segment that received a patch in year 4. Unlike the previous example, this figure depicts pavement condition (in terms of the percent cracking metric) worsening or deteriorating as a result of the patch. Again, the application of a patch has little effect on the percent cracking. The last survey prior to treatment had a percent cracking of 4 percent (in good condition according to table 1). The first survey after treatment had a percent cracking of 5.6 percent (in fair condition according to table 1). Therefore, the percent cracking condition deteriorated from good to fair after the application of the patch (i.e., worse condition).



Source: FHWA.

Figure 7. Graph. Example of M&R treatment not affecting condition.



Source: FHWA.

Figure 8. Graph. Example of M&R treatment reducing condition.

These examples have provided more detail on sample scenarios for when the effect of M&R treatment results in no change in condition, worse condition, or improved condition. These examples are not exhaustive of scenarios that could be encountered but illustrate only one possible situation that results in the effect on condition. Once the effect of M&R treatments on the metric condition is characterized in step 3, the same process is used to characterize the effect of M&R treatments on overall condition in step 4 above.

Measurement error can also contribute to the condition deteriorating over time or after the application of a treatment. As shown in figure 2, due to the range of likely measurable values, it is possible for the measured value to decrease or have a negative growth rate due to the intervals of likely measurable values.

EXAMPLES

- **AC pavements example.** A subset of LTPP pavement sections that had a change in construction event (i.e., M&R treatment was applied) were evaluated in terms of the percent cracking metric. Treatment groupings were assigned as shown in table 12. The condition was assigned good, fair, or poor based on the thresholds in table 1. A point-to-point comparison was conducted by comparing the condition after the treatment to the condition prior to treatment, and the effect of the treatment on pavement condition was characterized as no change, worse, or improved based on the definitions presented earlier.

  The effect of the M&R treatment on AC cracking by treatment type is presented in table 15. The table shows that mill and overlay and overlay most often improve the cracking condition and, to a lesser degree, surface treatment. The other treatments largely do not affect the percent cracking condition or result in a reduction in condition.

Table 15. Effect of M&R treatment on AC percent cracking.

Treatment	No Change (%)	Improve (%)	Reduce (%)
Crack seal	66	0	34
Grinding	100	0	0
Mill and overlay	42	56	2
Overlay	48	50	2
Patch	77	4	19
Surface	64	24	12

Once the effects of M&R treatments are assessed for each metric, the next step is to develop a treatment matrix that summarizes the M&R treatments that improved the metric conditions. Table 16 presents the percent improvement of the metric conditions by M&R treatment for AC pavements based on a subset of LTPP data. As shown, the mill and overlay and overlay treatments are the most effective ones at improving all three metric conditions. The percent improvement shown in table 16 is based on the pre-treatment and post-treatment conditions. For example, the mill and overlay treatment improves the roughness condition 41 percent of the time, which may appear to be low. However, a closer look at the data reveals that the roughness condition for the remaining 59 percent did not change; that is, the pre-mill and overlay condition and post-mill and overlay condition were both good, and therefore there was no change in condition. On the other hand, for those pavement sections where the pre-treatment roughness was not in good condition (remaining 41 percent of the time) and a mill and overlay treatment was applied, the roughness condition always improved.

Table 16. Percent improvement of metric condition after M&R treatment on AC.

Treatment	Roughness (%)	Cracking (%)	Rutting (%)
Crack seal	0	0	3
Grinding	0	0	50
Mill and overlay	41	56	81
Overlay	64	50	58
Patch	10	4	3
Surface	15	24	13

Once the effect of M&R treatments at the individual metric level is understood, the effect of M&R treatments on the overall condition should be assessed. The overall condition is assigned as good, fair, or poor based on the pavement segment metric condition combinations, as explained in chapter 1 of these guidelines. Similar to the metric-level analysis, the condition after the treatment is then compared to the condition prior to treatment, and the effect of the treatment on pavement condition is characterized as no change, worse, or improved. LTPP data were used to illustrate the effect on overall condition by M&R treatments presented in table 17. As shown in this table, the treatments that are most likely to improve the overall condition for AC pavements are mill and overlay and overlay, while grinding, patching, and surface treatments are much less likely to improve overall condition.

Table 17. Effect on AC overall condition by M&R treatment.

Treatment	No Change (%)	Improve (%)	Reduce (%)
Crack seal	83	2	15
Grinding	91	9	0
Mill and overlay	21	79	0
Overlay	31	68	1
Patch	75	5	20
Surface	75	13	12

- **JPCC pavements example.** In this example, the effects of M&R treatments on JPCC pavements are assessed for each metric as well as overall condition. Table 18 presents the percent improvement of the metric conditions by M&R treatments for JPCC pavements based on a subset of JPCC LTPP data. The table shows that grinding improves roughness the most, and grinding and grooving improve faulting the most. Slab replacement improves cracking and faulting between 22 and 25 percent. Similar to the AC pavement example, a percentage of the no change was a result of treatments being applied to pavements in good condition. When a treatment is applied to a pavement in good condition, improvement is not possible, since the condition was already good.

Table 18. Percent improvement of metric condition after M&R treatment on JPCC.

Treatment	Roughness (%)	Cracking (%)	Faulting (%)
Crack seal	0	0	0
Grinding	57	0	39
Grooving	No data	0	67
Joint seal	17	0	4
Patch	7	5	9
Shoulder	0	0	11
Slab replacement	No data	22	25

The overall pavement condition of the pavement sections used to develop table 18 was then determined by combining the metric conditions. Table 19 presents the effect of M&R treatments on overall condition for these LTPP JPCC pavement sections. The table shows that most treatments do not have an effect on the overall condition for JPCC pavements. Treatments that do improve the overall condition include grinding, joint seal, and slab replacement. However, these treatments improve the overall condition for less than 5 percent of all the JPCC LTPP pavement sections analyzed. It should be noted that the crack seal, shoulder, and slab replacement treatments are based on limited data. It will be important for State DOTs to perform similar analysis on the JPCC pavements in their network to understand the effects of M&R treatments on the pavement metrics and overall condition.

Table 19. Effect on JPCC overall condition by M&R treatment.

Treatment	No Change (%)	Improve (%)	Reduce (%)
Crack seal	100	0	0
Grinding	70	18	12
Joint seal	87	5	8
Patch	90	0	10
Shoulder	60	0	40
Slab replacement	50	17	33

- **CRCPs example.** The LTPP dataset available for CRCPs was limited. Only the patching and PCC overlay treatments had enough pavement sections in the sample to assess the effects of the M&R treatments on metric and overall conditions. Table 20 presents the percent improvement of the metric condition as a result of the two stated treatments. As shown, the PCC overlay is effective at improving the metric condition, while patching has little to no effect on the two metrics in question. Similar to the AC pavement example, a percentage of the no change was a result of treatments being applied to pavements in good condition. When a treatment is applied to a pavement in good condition, improvement is not possible, since the condition was already good.

Table 20. Percent improvement of metric condition after M&R treatment on CRCP.

Treatment	Roughness (%)	Cracking (%)
Patch	5	0
PCC overlay	50	23

Note: Since patching results in an increase in percent cracking based on how CRCP percent cracking is defined, it is reasonable that patching would not improve the percent cracking and could potentially contribute to condition deterioration.

Table 21 presents the effect on overall condition by M&R treatments for CRCPs. The table shows that only PCC overlay is effective at improving the overall condition of CRCPs in the LTPP dataset.

Table 21. Effect on CRCP overall condition by M&R treatment.

Treatment	No Change (%)	Improve (%)	Reduce (%)
Patch	90	0	10
PCC overlay	15	85	0

CHAPTER 4. TREATMENTS AFFECTING PERFORMANCE MEASURES

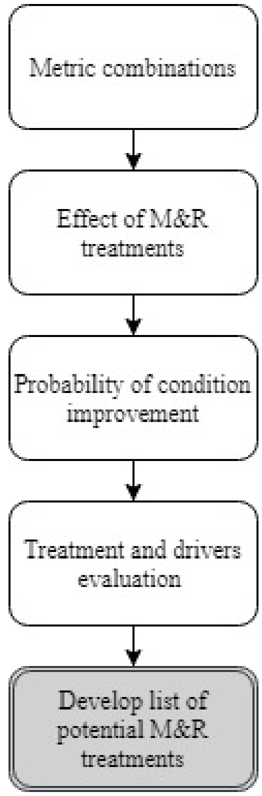
The previous chapter explained how to determine the effects of M&R treatments at the metric level and on the overall condition. This chapter presents how to combine the findings from chapters 2 and 3 of these guidelines—the performance measure drivers and the effects of M&R treatments—to develop a list of potential M&R treatments to improve overall pavement condition (and hence performance measures) from poor to fair, fair to good, or poor to good.

Chapter 3 of these guidelines presented the effects of M&R treatments on overall condition and showed that many treatments do not affect the overall condition. However, it is important to consider the metric condition combinations that make up the overall condition. The development of the performance measure drivers considered the makeup of the overall condition and emphasized the borderline condition. Figure 9 presents a flowchart for the major components of the process presented in this chapter. The steps in figure 9 include the following:

1. Assign data into metric condition combinations (G-F-F, G-G-P, etc.).
2. Determine effect of M&R treatment by comparing overall condition of last survey prior to treatment to overall condition for first survey after treatment as no change, worse, or improved.
3. Calculate percentage that M&R treatment improves condition for each metric condition combination.
4. Evaluate M&R treatments that show improvement while considering drivers of metric grouping.
5. Develop list of potential M&R treatments.

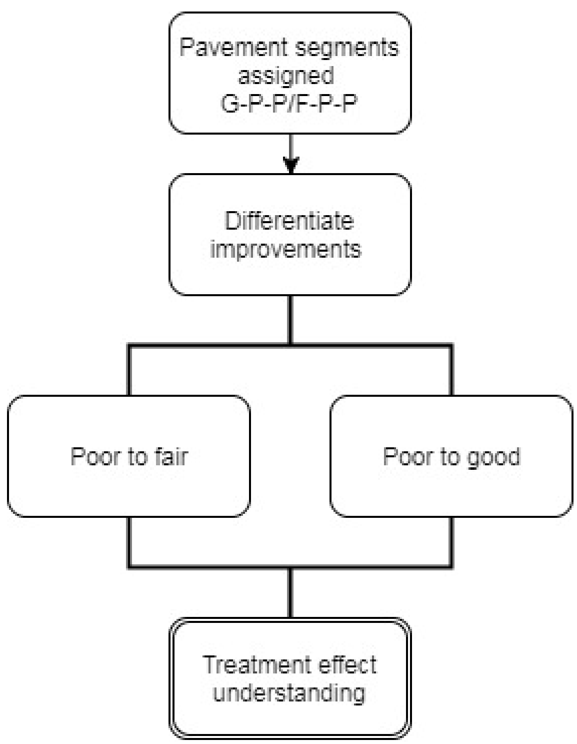
Further understanding regarding how M&R treatments affect the overall condition is necessary, especially for those cases where the condition prior to treatment is poor (e.g., G-P-P/F-P-P). Since the overall condition is poor, an improvement can result in either fair or good condition. This is a critical component in forecasting (i.e., condition prediction) when considering the performance measures. Figure 10 presents the flowchart for evaluating poor condition improvement.

The process illustrated in the five steps for developing treatments that affect the performance measures combines the effect of M&R treatments and the driver analysis by assessing how the M&R treatment affects the overall condition based on the original metric condition combination and driver. For the process presented in this section, LTPP pavement sections that were evaluated in chapter 3 of these guidelines for the effect of M&R treatments were grouped based on the metric groupings. The trend of the overall condition was characterized as no change, worse, or improved.



Source: FHWA.

Figure 9. Flowchart. Development of treatments that affect performance measures.



Source: FHWA.

Figure 10. Flowchart. Evaluating poor condition improvement type.

EXAMPLES

- **AC pavements example.** For each LTPP pavement section in the AC subset of data, the metric condition combination was assigned according to step 1. The effect of the M&R treatment was determined for the pavement sections according to step 2 and as described in chapter 3 of these guidelines. The percentage that M&R treatments improved the overall condition for the AC pavement dataset was calculated for each metric condition combination for step 3. This percentage was calculated as the number of sections that improved the overall condition for each treatment type and metric condition grouping divided by the total number of sections for the treatment type and metric condition grouping (i.e., the percentage of no change in condition, worse, and improved equaled 100). Table 22 presents the percentage that M&R treatments improve the overall condition for the various fair groupings for the LTPP AC pavement sections. Since the overall condition prior to treatment is in fair condition, an improvement in condition results in the overall condition of good.

Table 22. Percentage M&R treatments improve overall condition for AC pavements.

M&R Treatment	G-G-F (%)	G-G-P (%)	G-F-F (%)	G-F-P (%)	F-F-P (%)
Crack seal	7	0	0	0	0
Grinding	20	0	0	33	No data
Joint seal	33	No data	No data	No data	No data
Mill and overlay	86	84	81	79	93
Overlay	69	74	74	85	71
Patch	10	0	0	0	6
Surface	24	19	0	6	0

The drivers of each grouping as shown in table 11 are as follows:

- G-G-F—rutting.
- G-G-P—cracking.
- G-F-P—cracking and rutting.
- G-F-F and F-F-P—roughness and rutting.

The final steps are to develop a list of potential M&R treatments based on the metric grouping, the driver of the grouping, and the M&R treatments that improve the condition of that grouping. Based on the values presented in table 22, crack seal, joint seal, and patching should be removed from consideration for improving the overall condition for AC pavements.

Note: This should not be interpreted as stating that these treatments should not be used, but rather that they do not immediately improve overall pavement condition. There is a benefit to using treatments to improve a metric condition or prevent or slow deterioration, such as pavement preservation treatments.

Grinding is also removed due to the small sample size and the inability to draw accurate conclusions. The remaining treatments are mill and overlay, overlay, and surface treatment. Surface treatments show the most improvement for the G-G-F and G-G-P groupings. They are most effective at improving cracking condition (see table 16). For the G-G-P grouping, cracking is the driver. Although rutting is the driver of the G-G-F grouping, surface treatments did improve rutting condition 13 percent of the time based on table 16. However, for the pavement segments where surface treatments improved the overall condition of the G-G-F grouping, cracking was more likely the metric in fair condition. As stated previously, although rutting is the performance measure driver, there are occurrences when cracking is the metric in fair condition. It is these occurrences mostly where the surface treatments improved the overall condition. As shown in table 22, mill and overlay improves the condition between 79 and 93 percent of the time, while overlays improve the condition between 69 and 85 percent of the time with the greatest effectiveness on the G-F-P grouping, where cracking and rutting are the drivers.

In the case that the overall condition is poor due to two metrics being poor, the drivers according to table 11 are cracking and rutting. Table 23 presents the effect of M&R treatments on the G-P-P and F-P-P groupings for the treatments that improve condition. It is important to consider how these treatments affect the overall condition. The analysis investigated the improvement in condition and classified the improvement as poor to fair or poor to good. The results of the analysis show that mill and overlay and overlay are more likely to improve the overall condition from poor to good, whereas surface treatments and patching are more likely to improve the condition from poor to fair.

Table 23. Change in condition based on treatment from poor condition.

M&R Treatment	No Change (%)	P-F (%)	P-G (%)
Mill and overlay	5	37	58
Overlay	0	43	57
Patch	0	100	0
Surface	0	100	0

- **JPCC pavements example.** For each LTPP pavement section in the JPCC subset of data, the metric condition combination was assigned according to step 1. The effect of the M&R treatment was determined for the pavement sections according to step 2 and as described in chapter 3 of these guidelines. The percentage that M&R treatments improved the overall condition for the JPCC dataset was calculated for each metric condition combination for step 3. This percentage was calculated as the number of sections that improved the overall condition for each treatment type and metric condition grouping divided by the total number of sections for the treatment type and metric condition grouping (i.e., the percentage of no change in condition, worse, and improved equaled 100). Table 24 presents the percentage that M&R treatments improve the overall condition for the various fair groupings. Since the overall condition prior to treatment is in fair condition, an improvement in condition results in the overall condition of good.

Table 24. Percentage M&R treatments improve overall condition for JPCC pavements.

M&R Treatment	G-G-F (%)	G-G-P (%)	G-F-F (%)	G-F-P (%)	F-F-P (%)
Crack seal	No data	No data	No data	0	No data
Grinding	33	No data	0	50	No data
Joint seal	13	No data	0	0	0
Patch	0	No data	0	0	0
Shoulder	0	0	No data	No data	No data
Slab replacement	No data	No data	No data	No data	0

The drivers of each grouping according to table 11 are as follows:

- G-G-F: roughness.
- G-G-P: cracking.
- G-F-F and F-F-P: faulting and cracking.
- G-F-P: roughness and cracking.

The final steps are to develop a list of potential M&R treatments based on the metric grouping, the driver of the grouping, and the M&R treatments that improve the condition of that grouping. Based on the values in table 22, grinding emerges as the most effective treatment. Grinding improves both the G-G-F grouping where roughness is the driver and the G-F-P grouping where roughness and cracking are the drivers.

- **CRCPs example.** For CRCPs, only the G-F metric grouping was assessed due to insufficient data to make distinctive observations and conclusions regarding the other two CRCP borderline conditions. Steps 1 through 3 were conducted on the CRCP LTPP dataset similar to the AC and JPCC subsets. The driver of the G-F grouping is roughness according to table 11. Table 25 presents the percentage that the M&R treatment improved the overall condition for the CRCP dataset. This percentage was calculated as the number of sections that improved the overall condition for each treatment type and metric condition grouping divided by the total number of sections for the treatment type and metric condition grouping (i.e., the percentage of no change in condition, worse, and improved equaled 100). PCC overlay improved the condition 100 percent, while patching was not effective for improving the overall condition.

Table 25. Percentage M&R treatments improve overall condition for CRCPs.

M&R Treatment	G-F (%)
Patch	0
PCC overlay	100

Note: There were not sufficient data to perform the "poor" analysis for the LTPP JPCC or CRCP datasets.

TEMPORAL ANALYSIS CONSIDERATIONS

Many agencies consider the expected lives for M&R treatments within their PMS. However, the expected lives are likely not tied to the performance measures required by the Final Rule. The temporal analysis documented in the research report that led to these guidelines showed that the performance measures are stable over time.[(4)] Although these guidelines have shown that M&R treatments can affect the overall condition of a pavement, it is important that repairs are strategic in nature to have the desired effect on the performance measures. Agencies should consider the expected life of treatments with respect to the metric groupings and overall condition ratings. The analysis should consider the pre-treatment condition of the pavement, the treatment type, and the type of change in condition. The data should be analyzed from the first survey after treatment until the time where the overall condition changes or noted if the overall condition remains constant. The following steps should be followed to conduct the temporal analysis:

1. Select pavement segments with at least three surveys between construction events.

2. Assign metric conditions and overall condition.

3. Classify temporal category according to the trend of condition as follows:

    - Good to fair.
    - Fair to poor.
    - Good to poor.
    - Fair to good.
    - Poor to good.
    - Good—no change.
    - Fair—no change.
    - Poor—no change.

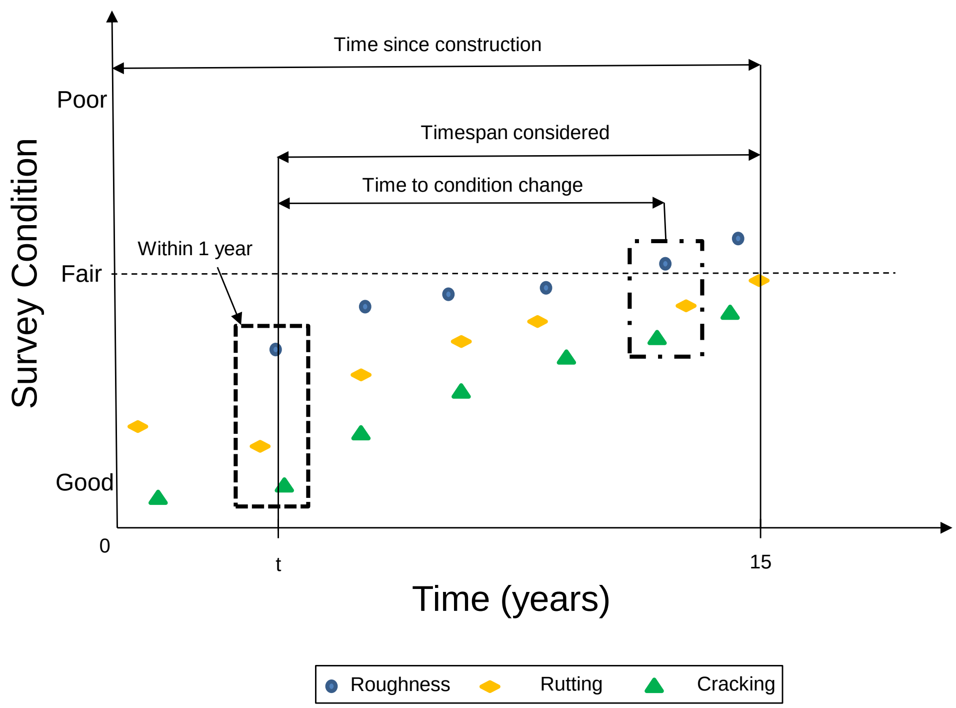
4. Calculate the time to change condition as the time between the last survey in one condition and the first survey in a different condition or the time that the condition remained constant as the time between the last survey and the first survey after the previous construction event.

> Note: Ideally, the time to change would be calculated using surveys done immediately after construction and immediately after change of condition from good to fair or fair to poor. However, the actual calculated time to change will be dependent on the actual timing of the surveys available.

Figure 11 depicts the various timespans referenced in this analysis and the meaning of each. For analysis of the LTPP data, a survey grouping was only formed provided each of the individual metric measurements was taken within 1 year of the others. As a result, many times there were surveys between the time of last construction (as designated by time equal to zero in figure 11) and the first grouping considered in the analysis. This often created a time lag between the time of construction and the time the first grouping was considered. Figure 11 shows the time the first grouping was considered as time "t," which changes for each pavement section. This time between construction and first survey grouping considered in this analysis was on average 1.5

years for AC pavements, which is a conservative estimate for JPCC pavements and CRCPs as documented in the research report that led to these guidelines.[(4)] Although this time was calculated by considering only sections that had a first grouping in good condition, this time between last construction and first grouping should not be added to the timespan considered, since the actual condition is not known but was assumed to be good over the timespan. This results in the timespans calculated under this analysis being conservative. For State DOTs that collect all data metrics concurrently using a single data collection vehicle, it is less likely for there to be measurements taken between the date of last construction and the first grouping, because there should not be a difference in time of measurement for the various metrics (i.e., the first survey measurements are available for all metrics). The timespan between last construction and first survey grouping will be dependent on State DOT data collection cycles and practices.

The timespan considered under this analysis was from the time of the first grouping until the time of the last grouping, which in figure 11 is shown to be from time “t” to 15 years. The time to change was calculated as the time between the first grouping and the first grouping where condition changes. For example, in figure 11, the first grouping (at time “t”) is in good condition, while the fifth grouping (prior to grouping at 15 years) is the first grouping to become fair, since the roughness survey is beyond the fair threshold. Therefore, the time between the first grouping and the fifth grouping is considered the time to change.



Source: FHWA.

Figure 11. Graph. Temporal groupings.

For example, an AC pavement section in fair condition is treated with a surface treatment. The overall condition after treatment is good. The time until the condition changes to fair is the time it takes to change from good back to fair condition. Similarly, if the overall condition remains fair after the treatment, this is also important, as it may have been the objective of the treatment, such as a preservation slowing the deterioration. Table 26 presents the average time to change from good to fair or that remained fair for AC pavement sections that received treatments when the overall condition was fair prior to treatment. The table shows that the average time in each category (e.g., good to fair and fair—no change) for surface treatments is less than both overlay and mill and overlay. Temporal considerations and expected lives of treatments are a key factor in a PMS.

Table 26. Temporal analysis by treatment and post-treatment trend.

Treatment Type	Good to Fair (Years)	Remained Fair (Years)
Mill and overlay	4.6	8.5
Overlay	4.4	10.0
Surface	3.1	4.9

State DOTs should conduct similar temporal analyses for the treatments and data maintained in their PMS. The temporal analyses produce the average time a treatment maintains a condition or the time until the condition changes after a treatment. These findings can be a key component of PMS forecasting and, ultimately, decisionmaking.

POTENTIAL M&R TREATMENTS TO IMPROVE OVERALL CONDITION

Based on the assessments presented in this chapter, the following presents a list of M&R treatments that improved the overall condition for the LTPP sections used in this study:

- AC pavements.
    - Mill and overlay.
    - Overlay.
    - Surface treatment.
- JPCC pavements.
    - Grinding.
- CRCPs.
    - PCC overlay.

Agencies should follow the procedures provided in these guidelines to develop, using their data, a similar list of treatments that improve the overall condition.

CHAPTER 5. SUMMARY, CHALLENGES, AND RECOMMENDATIONS

SUMMARY

The objective of these guidelines is to provide information and guidance to highway agencies on the following key pavement decisionmaking issues:

- Method to identify which condition metric is driving the performance measure.
- Temporal effects on performance measures.
- Effects of M&R treatments on performance measures.

The goal of the guidelines was to show agencies what needs to happen to move the overall condition from poor to fair to good. In meeting this goal, the guidelines will enable highway agencies to address critical questions, such as the following:

- What are the drivers of the performance measures?
- What are the effects of M&R treatments on condition metrics and overall condition?
- How can performance measures be improved from poor to fair, poor to good, and fair to good?

These guidelines have presented step-by-step approaches for the following:

- Developing performance measure drivers.
- Calculating the effects of M&R treatments.
- Combining the above findings to develop a list of M&R treatments that affect the condition.

Examples illustrating each of the above approaches were provided. These examples addressed all three pavement types—AC, JPCC, and CRCP. The guidelines also introduced important issues that should be considered by highway agencies, including measurement errors and temporal changes.

The examples and calculations presented were based on data from the LTPP dataset and developed for the purpose of the research study that led to these guidelines.[(4)] The LTPP database is available through LTPP InfoPave™ (https://infopave.fhwa.dot.gov/). These guidelines present examples that represent a starting point for agencies that could be used as default input if needed. However, agencies are encouraged to follow the processes in the guidelines using their own data to draw more representative conclusions for their agency. Once an agency has completed the steps presented in these guidelines, the next logical step to consider is to integrate the findings within the agency's PMS.

CHALLENGES AND RECOMMENDATIONS

An important consideration is the challenges agencies may face when integrating the performance measures within their practices. This section presents some of these challenges.

- **Different data sources.** The performance measures to assess pavement condition are to be based on HPMS data. Although State DOTs are required to submit HPMS data annually, the HPMS data submittal does not always match the data that an agency maintains in its PMS. In addition, the pavement segments in an agency's PMS are also likely different from that of the HPMS submittal. This presents a challenge, as agencies could potentially be faced with managing targets and goals based on two different datasets. If agencies integrate the performance measures into their PMS for monitoring and consideration, there could be differences from those reported to FHWA using the HPMS data due to the different data source. It is not known at this time the potential difference this may cause, but agencies need to be aware of the possible challenge. It is recommended that agencies assess whether they will face this challenge. If there are differences between the data sources, an agency should evaluate the potential effects and develop a plan to mitigate these effects. In addition, the Final Rule requires that the pavement condition metrics be collected annually for the full extent of the IHS and biennially for non-interstate NHS pavements.(3) Agencies may not currently be collecting PMS data at this frequency, which may also cause a difference in the performance measures determined using PMS data and HPMS data. This is another aspect that agencies will need to consider and reconcile between the HPMS and PMS datasets.

- **Change in optimization goals.** Agencies have various optimization goals for their PMS and treatment selection. For example, the objective of treatment selection for an agency may be to minimize agency cost while simultaneously maximizing the extension to pavement life. Agencies may have secondary goals or rules used in their optimization such as meeting friction thresholds for safety. Agencies should now also consider how to incorporate the performance measures within their optimization and how they plan to meet the targets. Agencies will need to decide the best method for accomplishing this. Some examples include the following:

    - Adjusting their optimization objective function to meet the performance measure targets.

    - Adding a secondary goal or rule to follow during optimization that considers the performance measure targets.

    - Adding a check of how the optimization recommendations affect the performance measures.

  Agencies will need to decide how the performance measures will affect their decisionmaking process. As a minimum, it is recommended that agencies consider how PMS outcomes (i.e., recommended M&R and project prioritization) affect the performance measures and determine whether the performance measures should be incorporated into the decisionmaking process.

- **Updating models within the PMS to consider the performance measures.** A key component of the PMS are the predictive models for the effect of various types of treatments and deterioration models. The data in these guidelines have shown that factors that affect treatment effectiveness include metric groupings and metric conditions. In order for agencies to incorporate the performance measures within the decisionmaking process, models used within the PMS would need to be updated or developed based on the performance measures and these factors to predict the effect of treatments on the performance measures. Advanced systems may be able to incorporate the performance measures within the forecasting models to predict the effects of delaying treatment changes in metric condition combination and effectiveness of treatments at different times. Work in this area has recently been or is currently being done under the National Cooperative Highway Research Program (NCHRP) Project 14-33, "Pavement Performance Measures That Consider the Contributions of Preservations Treatments," and Project 14-38, "Guide for Timing of Asphalt-Surface Pavements Preservation," which could be a good resource for addressing the challenge in question.(6,7) The former project was completed in the spring of 2017 and will be published as NCHRP Report No. 858, *Quantifying the Effects of Preservation Treatments on Pavement Performance,* while the latter project should be completed by the summer of 2018.

Agencies are required to meet the performance measures or face loss of flexibility for spending National Highway Performance Program funds until the minimum required condition levels are exceeded. Therefore, it is critical that agencies understand what metrics drive the performance measures and how performance measures are affected by M&R treatments and, based on that information, determine how the performance measures will be incorporated into their decisionmaking process. As a minimum, it is recommended that agencies add the performance measures to the output of the PMS and treatment selection optimization to monitor the values of the performance measures. It is also recommended that agencies perform similar analyses as those described in these guidelines and develop a list of potential M&R treatments that affect the performance measures or a treatment matrix. Furthermore, and to the extent possible, it is recommended that agencies incorporate these suggestions based on a long-term view of the overall health of their networks.

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