Approaches to Forecasting the Third Performance Management Rulemaking (PM3) Measures for Target Setting

August 2023

U.S. Department of Transportation
Federal Highway Administration

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-HOP-21-014		

4. Title and Subtitle Approaches to Forecasting the Third Performance Management Rulemaking (PM3) Measures for Target Setting	**5. Report Date** August 2023 **6. Performing Organization Code**
7. Author(s) Praveen Pasumarthy and Richard Margiotta	**8. Performing Organization Report No.**
9. Performing Organization Name And Address Cambridge Systematics Cambridge Systematics, Inc. 101 Station Landing, Suite 410 Medford, MA 02155	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** DTFH61-16-D-00051
12. Sponsoring Agency Name and Address Federal Highway Administration Office of Operations 1200 New Jersey Avenue, SE Washington DC 20590	**13. Type of Report and Period Covered** **14. Sponsoring Agency Code** HOP

15. Supplementary Notes
Task Order Contracting Officer's Representative (TOCOR) was Rich Taylor

16. Abstract
This document developed a step-by-step calculation guide for three forecasting methods in support of target setting for the third performance management rulemaking (PM3) travel time-based performance measures. The three forecasting methods covered in this document are:

- Extrapolation of past trends (macroscopic).
- Highway segments "at risk" for unreliability (microscopic; based on identifying segments that close to the reliability threshold).
- Model-based forecasting.

17. Key Words	18. Distribution Statement
Operations, performance measures, performance management, target setting, forecasting	No restrictions.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	56	N/A

Form DOTS F 1700.7 (8-72) **Reproduction of completed page authorized**

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 ACRONYMS

AAWDT	Annual Average Weekday Traffic
AAWET	Annual Average Weekend Traffic
BPR	Bureau of Public Roads
CFR	Code of Federal Regulations
CMAQ	Congestion Mitigation and Air Quality Improvement Program
DOT	Department of Transportation
FAST	Fixing America’s Surface Transportation
FHWA	Federal Highway Administration
ITS	Intelligent Transportation System
LOTTR	Level of Travel Time Reliability
LRTP	Long-Range Transportation Plan
MAP-21	Moving Ahead for Progress in the 21st Century Act
mph	Miles Per Hour
MPO	Metropolitan Planning Organization
MTTI	Mean Travel Time Index
NHS	National Highway System
NPMRDS	National Performance Management Research Data Set
pcphpl	Passenger Cars per Hour per Lane
PHED	Peak Hour Excessive Delay
PM3	Third Performance Management Rulemaking
RITIS	Regional Integrated Transportation Information System
SHRP 2	Strategic Highway Research Program 2
SOV	Single Occupancy Vehicle
STIP	Statewide Transportation Improvement Program
TDF	Travel Demand Forecasting
TDM	Travel Demand Model
TMC	Traffic Message Channel
TTI	Travel Time Index
TTTR	Truck Travel Time Reliability
v/c	volume-to-capacity
VDF	Volume-Delay Function
VDOT	Virginia Department of Transportation
VMT	Vehicle-Miles Traveled

EXECUTIVE SUMMARY

This document offers a step-by-step calculation guide for three forecasting methods in support of target setting for the Third Performance Management Rulemaking (PM3) travel time-based performance measures.[1]

The three forecasting methods covered in this document are:

- Extrapolation of past trends (macroscopic).
- Highway segments "at risk" for unreliability (microscopic; based on identifying segments that close to the reliability threshold).
- Model-based forecasting.

The methods described herein provide technical information on which targets can be determined, but ultimately State Departments of Transportation (DOT) and Metropolitan Planning Organizations (MPO) select final targets using a consensus-based process. Many factors outside of the technical information provided by these methods should be considered in target setting. Among them are funding availability and agency priorities across all program areas.

[1] 23 CFR 490.101 and 23 CFR 490.105.

CHAPTER 1. INTRODUCTION

BACKGROUND

The Moving Ahead for Progress in the 21st Century Act (MAP-21) (Pub. L. 112-141) and the Fixing America's Surface Transportation (FAST) Act (Pub. L. 114-94) transformed the Federal-aid highway and transit programs by establishing new performance-based planning requirements for State Departments of Transportation (DOT), Metropolitan Planning Organizations (MPO) and providers of public transportation services. Specific requirements for implementing the performance management provisions of MAP-21 and the FAST Act are codified in the Code of Federal Regulations (CFR) at 23 CFR part 490.

The national performance measures—Percent of the person-miles traveled on the Interstate that are Reliable (23 CFR 490.507(a)(1)); Percent of person-miles traveled on the non-Interstate National Highway System (NHS) that are Reliable (23 CFR 490.507(a)(2)); Truck Travel Time Reliability (TTTR) Index Measure (23 CFR 490.607); and Annual Hours of Peak Hour Excessive Delay (PHED) Per Capita Measure (23 CFR 490.707(a))—are collectively referred to as the "travel time-based performance measures" in this document.

Additional information on detailed calculation steps to compute travel time-based and Percent Non-Single Occupancy Vehicle (non-SOV) Travel performance measures can be obtained from FHWA-HIF-18-024 (Federal Highway Administration (FHWA) Computation Procedure for Travel Time-Based and Percent Non-Single Occupancy Vehicle (non-SOV) Travel Performance Measures).

INTRODUCTION

This report provides a step-by-step calculation approach for three forecasting methods in support of target setting for the travel time-based performance measures.

The three forecasting methods covered in this document are:

- Extrapolation of past trends (macroscopic).
- Highway segments "at risk" for unreliability (microscopic; based on identifying segments that close to the reliability threshold).
- Model-based forecasting.

ESTABLISHING TARGETS

The following key items are applicable for State DOTs and MPOs while establishing the targets for the Travel time-based performance measures.

- Establish two-year and four-year targets for each Performance Period:[2]
    - Targets for a Performance Period must be reported to FHWA by October 1 of the first year in that Performance Period.[3]
    - For the first Performance Period, only, two-year target reporting is NOT required for non-Interstate NHS Travel Time Reliability measure.[4]
- Establish a single, unified target (both two-year and four-year) for entire urbanized area for PHED measure:[5]
    - For the first Performance Period—applicable to State DOTs with NHS in the urbanized area with a population greater than one million containing any part of a nonattainment or maintenance area—2-year target reporting is NOT required for PHED measure.[6,7]
    - Beginning with the second Performance Period and beyond - applicable to State DOTs with NHS in the urbanized area with a population greater than 200,000 containing any part of a nonattainment or maintenance area.[8]
- Adjustment of four-year target allowed at the midpoint of performance period.

Table 1 summarizes the geographic extent, applicable roadways and timeframe for setting the targets for the Travel time-based performance measures.

METRICS AND MEASURES

The PM3 rule makes a distinction between metrics and measures in its computation guidance. Metrics are intermediate data elements that are computed between the data and the final measures. An example is the Level of Travel Time Reliability which is computed for each of four time periods for individual TMCs. These are then assessed to determine the Percent of the person-miles traveled on the Interstate that are Reliable and the Percent of person-miles traveled on the non-Interstate NHS that are Reliable measures.

[2] Defined in 23 CFR 490.101 and 23 CFR 490.105(e)(4) as a 4-year time period during which condition/performance is measured and evaluated to: assess condition/performance with respect to baseline condition/performance; and track progress toward the achievement of the targets that represent the intended condition/performance level at the midpoint and at the end of that time period. For example, the first Performance Period for the Travel time-based performance measures begins on January 1, 2018 and extends for a duration of 4 calendar years. Similarly, the second Performance Period starts on January 1, 2022 and ends on December 31, 2025.

[3] 23 CFR 490.107(b)(1).

[4] 23 CFR 490.105(e)(7).

[5] 23 CFR 490.105(e)(8)(iii) & (f)(5)(iii).

[6] 23 CFR 490.105(e)(8)(i) & (f)(5)(i).

[7] 23 CFR 490.105(e)(8)(vi) & (f)(5)(vi).

[8] 23 CFR 490.105(e)(8)(ii) & (f)(5)(ii).

TABLE 1. SUMMARY OF REQUIRED TARGETS UNDER 23 CFR 490.105

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Performance Measure	Geographic Extent	Applicable Roadways	Timeframe
Percent of person-miles traveled on the Interstate that are reliable	Statewide	Interstate System	2-year and 4-year targets
Percent of person-miles traveled on the non-Interstate National Highway System that are reliable	Statewide	Non-Interstate NHS	2-year and 4-year targets
Truck Travel Time Reliability Index	Statewide	Interstate System	2-year and 4-year targets
Annual Hours of Peak Hour Excessive Delay Per Capita[1]	Urbanized Areas	Entire National Highway System	2-year and 4-year targets

[1] State DOTs and applicable MPOs are required to collectively establish and report single targets for Annual Hours of PHED Per Capita and Percent of non-SOV Travel for applicable urbanized areas.

CHAPTER 2. USING HISTORICAL DATA FOR THE EXTRAPOLATION OF PAST TRENDS

The extrapolation of past trends is a common target setting method used by State DOTs and local agencies because it is simple to implement. A trend line of recent years is developed for the performance measure in question and the trend is extended into the future by inspection or by curve fitting. It is useful to track the performance of key external factors as well, especially vehicle-miles traveled (VMT), as these can influence the observed trend. Economic conditions also can be tracked, but even though these are likely to be strongly correlated with VMT, the lag between economic variables and VMT should be noted. Extrapolation of past trends is best suited when the horizon year for the target is short term in nature and there is a history of performance available for such areas as safety, pavement, bridge, or mobility.

DATA REQUIREMENTS

The data requirements for calculating the performance metrics and measures are outlined in FHWA publications FHWA-HIF-18-040[9] and FHWA-HIF-18-024[10], respectively. In general, the data required are continuously collected travel time data for relatively short one-way highway segments.

ANALYSIS TOOLS

FHWA provides detailed step-by-step guidelines on how to calculate the performance metrics in publications FHWA-HIF-18-040[9] and FHWA-HIF-18-024[10], respectively.

For forecasting the performance measure/metrics and setting targets, this "Extrapolation of Past Trends" approach uses a spreadsheet-based analysis.

FORECASTING MEASURES AND TARGET SETTING PROCESS

Following detailed steps are developed for forecasting measures/metrics and identifying a target using the "Extrapolation of Past Trends" approach.

Step 1. Using the data sources outlined in FHWA publications FHWA-HIF-18-040 and FHWA-HIF-18-024, gather all the relevant information to calculate the travel time-based performance metrics and measures.[9,10]

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9 Margiotta, Richard A., Turner, Shawn, and Taylor, Rich, *National Performance Measures for Congestion, Reliability, and Freight, and CMAQ Traffic Congestion: General Guidance and Step-by-Step Metric Calculation Procedures*, FHWA-HIF-18-040, June 2018, https://www.fhwa.dot.gov/tpm/guidance/hif18040.pdf.

10 Taylor, Rich; Purdy, Jeff; Roff, Thomas; Clarke, Justin; Vaughn, Ronald; Rozycki, Robert; and Chang, Christopher, *FHWA Computation Procedure for Travel Time Based and Percent Non-Single Occupancy Vehicle (non-SOV) Travel Performance Measures*, FHWA-HIF-18-024, April 2018, https://www.fhwa.dot.gov/tpm/guidance/hif18024.pdf.

Step 2. Using the detailed methodology provided in FHWA publications FHWA-HIF-18-040 and FHWA-HIF-18-024, calculate the travel time-based performance metrics and measures.

Step 3. Develop a trend line using monthly travel time-based performance metrics.

Step 4. Account for external factors that are typically outside of the control of State DOTs as well as internal factors that are under the control of State DOTs.

Step 5. Taking into account the impact of external and internal factors (step 4), as well as the forecasted performance (from step 3), a performance target could be selected based on the agency's (either State DOT or MPO) level of comfort.

Step 1: Gather Data

Using the data sources outlined in FHWA publications FHWA-HIF-18-040 and FHWA-HIF-18-024, respectively, gather all the relevant information to calculate the PM3 performance metrics and measures. Since probe speed data from the National Performance Management Research Data Set (NPMRDS) is available in a consistent format since 2017, gather all the data from 2017 onwards.

Step 2: Calculate Performance Metrics

Using the detailed methodology outlined in FHWA publications FHWA-HIF-18-040 and FHWA-HIF-18-024, respectively, calculate the PM3 performance metrics and measures.

Step 3: Conduct a Trend Line Analysis

Conduct a trend line analysis using the monthly PM3 performance metrics. Depending on the data, a linear or a best-fit polynomial trend line could be developed. This analysis will provide a lower and higher end range for a future performance period.

Step 4: Account for Additional Factors

External Factors

External factors (also called exogenous factors) are those influences that affect transportation system performance but are typically outside the control (at least operationally) of transportation agencies. Common examples of external factors include fuel prices, traffic volumes, economic conditions, and employment levels. The list of possible influential external factors can be grouped into the following general categories:[11]

[11] FHWA Publication No. FHWA-HOP-18-002: Approaches to Presenting External Factors with Operations Performance Measures.

- Travel demand.
- Truck demand.
- Economic trends.
- Population.
- Other trends

Internal Factors

Internal factors are those influences that affect transportation system performance, but which are under the control of transportation agencies. The Statewide Transportation Improvement Program (STIP) typically includes projects (both on Interstates and non-Interstates) which may potentially impact the system performance. The projects which may positively impact the system performance include capacity projects such as interchange improvements, intersection improvements and adding travel lanes, as well as transportation system management and operation (TSMO) strategies such as intelligent transportation systems (ITS), managed lanes, road weather management, and incident response. With major improvements, it is important to take into consideration that work zones will have short term impacts on system performance prior to realizing benefits of improvements.

Step 5: Set Targets

Analysts should assemble all the available information for the previous steps and use it, along with professional judgement, in setting the actual targets.

EXAMPLE

The following hypothetical example shows how to apply the extrapolation method. Figure 1 shows the historical trends in the Interstate System Reliability measure. Historical traffic growth on Interstates is assumed to be two percent. Assuming that future traffic growth will be roughly the same, figure 2 shows a simple extrapolation of the general downward trend in unreliable person-miles. If future traffic growth is expected to be higher and lower than historical trends, the trend line can be adjusted up or down. As shown, the preliminary targets would be the following:

- Two-year Target—73.0 percent.
- Four-year Target—67.0 percent.

This information serves as input to the consensus-based target setting used by a transportation agency. That is, the final targets are set using a combination of professional judgement and the results of the target setting analysis.

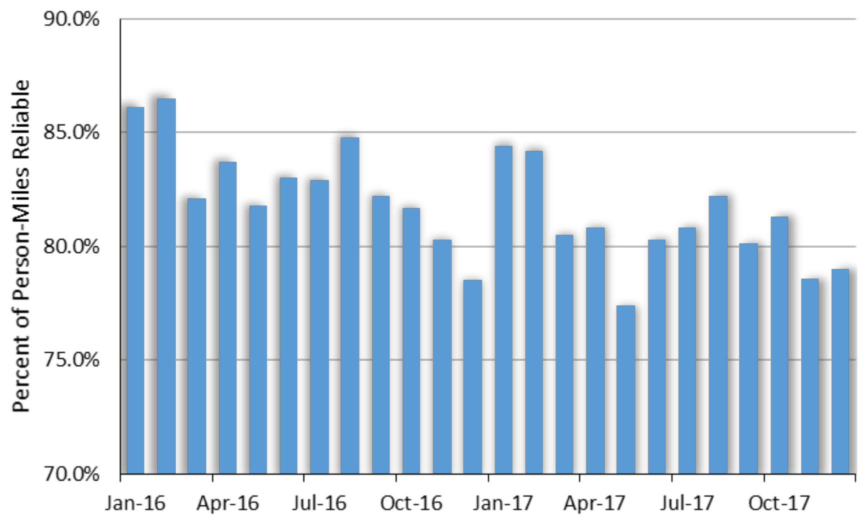

Figure 1. Chart. Historical trends in Interstate system reliability performance.
(Source: Federal Highway Administration.)

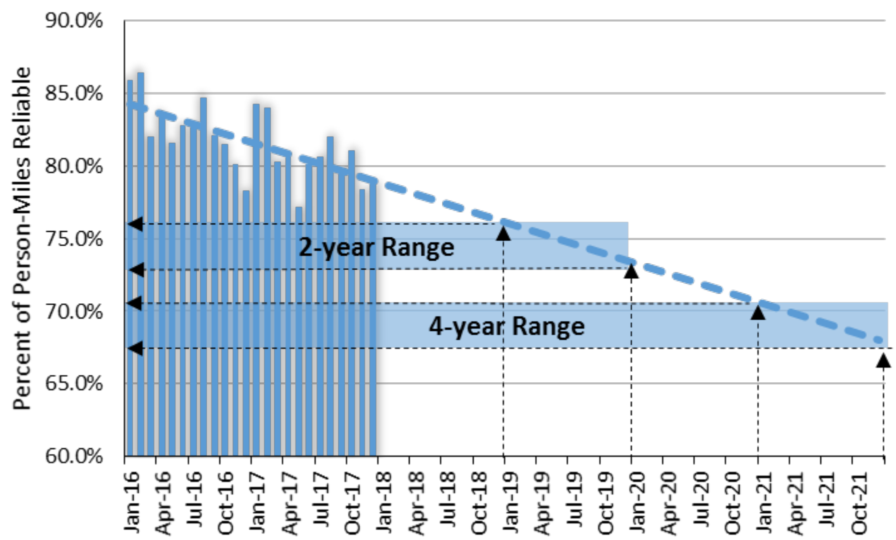

Figure 2. Chart. Extraopolated Trends for the Interstate travel time reliability measure.
(Source: Federal Highway Administration.)

CHAPTER 3. EMPIRICAL ANALYSIS: ASSESSING AT-RISK HIGHWAY SEGMENTS

Often, there are reporting segments on a state DOT's or MPO's transportation network that are "vulnerable" to failing to meet performance thresholds; this applies to the system reliability (Level of Travel Time Reliability (LOTTR)) and PHED measures which are threshold based. For example, an Interstate reporting segment with an LOTTR of 1.49 meets the 1.50 threshold for being reliable, but just barely. Similarly, the reporting segments with an LOTTR of 1.51 do not meet the 1.50 threshold. Because the definition of reliability depends on LOTTR metrics for 4 time periods, it also is useful to know how many of the time periods are vulnerable.

These reporting segments that are "on the cusp" may be viewed as vulnerable links for the next performance period. Different scenarios can be tested such as "what would happen if all the metrics' values close to the threshold, surpass the threshold in four years?" Identifying these vulnerable portions of the network and accounting for them in target setting is a challenge for DOTs as it involves analysis techniques not commonly found in commercial tools. As with trend extrapolation, VMT trends on the vulnerable segments should be considered, as well as any capacity or operational improvement projects that are being planned. Conversely, the decline in performance due to major planned work zones—such as bridge and interchange replacements—should also be considered in setting targets.

DATA REQUIREMENTS

The data requirements for calculating the performance metrics and measures are outlined in FHWA publication FHWA-HIF-18-024. In general, the data required are continuously collected travel time data for relatively short one-way highway segments.

ANALYSIS TOOLS

FHWA provides detailed step-by-step guidelines on how to calculate the performance metrics and measures in publication FHWA-HIF-18-024.

For forecasting the performance measure/metrics and setting targets, this "Assessing At-Risk Highway Segments" approach can be accomplished with a spreadsheet-based or similar analysis.

FORECASTING MEASURES AND TARGET SETTING PROCESS

The following detailed steps can be used for forecasting measures/metrics and identifying a target using the "Assessing At-Risk Highway Segments" approach.

Step 1. Using the data sources outlined in FHWA publication FHWA-HIF-18-024, gather all the relevant information to calculate the PM3 performance metrics and measures for system reliability, truck reliability, and peak hour excessive delay

Step 2. Using the detailed methodology outlined in FHWA publications FHWA-HIF-18-040 and FHWA-HIF-18-024, respectively, calculate the PM3 performance metrics and measures for system reliability, truck travel time reliability and peak hour excessive delay.

Step 3. Identify segments (Traffic Message Channel (TMC)) of the roadway network which can be considered as vulnerable. For the LOTTR metrics, time periods with values from 1.40 to 1.49 are a reasonable starting point for determining vulnerability. For the PHED measure, the threshold is determined based on speed limit. Vulnerable segments with 5 miles per hour (mph) over the TMC threshold can be considered as vulnerable; if the speed limit-based threshold is 27 mph, then the vulnerability threshold is 32 mph. Vulnerability can be used in multiple ways to provide more insight into system condition. For example, segments with an LOTTR value between both 1.40–1.49 and 1.45–1.49 can be identified.

Step 4. Account for external factors which are typically outside of the control of State DOTs as well as internal factors that are under the control of State DOTs. Expected VMT growth over the target time horizon is the main factor to consider.

Step 5. Reclassify the LOTTR and PHED metrics for each of the original segments by relaxing the original thresholds to the new vulnerability thresholds. In the above examples, these would be 1.40 and 1.45 for LOTTR. Also, keep track of number of time periods for each segment than fail the new thresholds. While not strictly relevant for the measure calculation, these numbers could be of value for other purposes, e.g., identifying off-peak times that have reliability problems.

Step 6. Considering the impact of external and internal factors (step 4), as well as the forecasted performance (from step 3), State DOT's will select a performance target based on their level of comfort.

EXAMPLE

The above step-by-step process for forecasting performance metrics and measures and setting target are implemented using NPMRDS data. In this section, the following measures were analyzed—Percent of Person-Miles Traveled on the Interstate that are Reliable and Percent of Person-Miles Traveled on the Non-Interstate NHS that are Reliable.

Step 1: Gather Data

Required data was gathered as indicated above.

Step 2: Calculate Performance Metrics

Percent of Person-Miles Traveled on the Interstate that are Reliable

Using the above-described methodology, the Interstate reliability measure was calculated for 2014, 2015, and 2016 (using NPMRDS Version 1 data), as well as for 2017 (using NPMRDS Version 2 data). Table 2 depicts the 2017 metric results breaking down the LOTTR values in six bins ranging from reliable to unreliable. The bin of interest for short-term forecasting is the 1.40–1.49 range.

Table 2. Percent of person-miles traveled on the Interstate that are reliable.

LOTTR Range	Percent of Reliable Person-Miles
1–1.24	65.0%
1.25–1.39	6.2%
1.40–1.49	5.5%
>= 1.50	23.3%

(Source: Federal Highway Administration, using National Performance Management Research Data Set data.)

Step 3: Conduct Analysis

The two measures addressing the percent of person-miles traveled that are reliable are peculiar in their treatment of what is considered reliable versus not. These measures assume a threshold of 1.50 LOTTR as the defining metric in which a segment is reliable. This presents a situation whereby small changes in roadway or travel conditions may cause segments that are barely less than 1.50 LOTTR to flip and become "unreliable." A sensitivity analysis was conducted to determine what would be the resulting measures under different scenarios.

The base scenario are the current conditions measured for 2017; scenario 1 assumes that TMC segments that currently have an LOTTR of 1.45 or more will reach an LOTTR of 1.50; scenario 2 assumes that TMC segments that currently have an LOTTR of 1.40 or more will reach an LOTTR of 1.50; and so on. The following scenarios continue progressively assuming lower thresholds for TMC segments, reaching the unlikely scenario 7, which assumes that TMC segments that currently have an LOTTR of 1.15 will reach an LOTTR of 1.50. This is shown in table 3 and figure 3 show how each of the performance measures changes under each progressive scenario.

Table 3. Sensitivity analysis for Interstate and non-Interstate National Highway System reliability.

Risk Scenario	Traffic Message Channel Level of Travel Time Reliability Threshold	% Interstate Reliable	% Non-Interstate National Highway System Reliable
Base	1.50	82%	86%
1	1.45	80%	82%
2	1.40	78%	76%
3	1.35	75%	66%
4	1.30	73%	56%
5	1.25	70%	46%
6	1.20	69%	37%
7	1.15	66%	29%

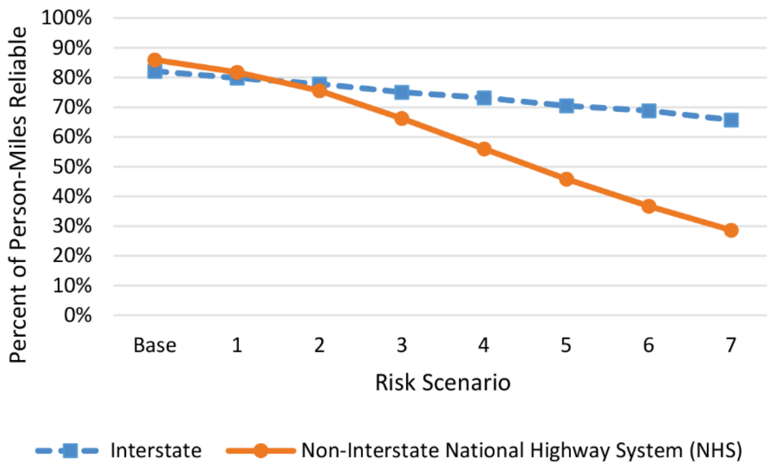

Figure 3. Chart. Sensitivity analysis for Interstate and non-Interstate National Highway System reliability.
(Source: Federal Highway Administration.)

Step 4: Account for Additional Factors

External Factors

The following external factors (also called exogenous factors) that are typically outside the control (at least operationally) of transportation agencies are considered—Travel demand; Truck demand; Economic trends; Tourism; and Population. The sensitivity analysis conducted above provides the range of possible outcomes. Examining external factors will help to narrow the range of possibilities.

- **Travel Demand:** Over the last few years, assume that the VMT has been increasing at a rate of 1.7 percent annually on rural facilities and 3.9 percent on urban facilities.
- **Economic Trends:** Assume that economic trends have been trending positive over the last few years. Nonfarm employment grew 2.5 percent annually, while the new housing permits issued grew 12.4 percent annually.
- **Population:** Assume that population has been steadily growing at an annual rate of 1.0 percent in rural and 1.3 percent in urban areas over the last few years.

Step 5: Set Targets

Increasing travel demand, improving economic conditions, and increasing population trends indicate that the system performance could potentially worsen in the future. Due to the lack of availability of extended historical data, targets for the performance measures could be selected using a conservative approach. **For 2-year targets, 1.35 was selected as the LOTTR threshold; and for 4-year targets, 1.25 was selected as the LOTTR threshold.**

Percent of Person-Miles Traveled on the Interstate that are Reliable

The estimated 2-year and 4-year targets using the analytic procedure for this measure are the following:

- Two-year Target—75.0 percent.
- Four-year Target—70.0 percent.

It is important to note that the process of target setting is consensus based. The results of technical analyses can inform the process, but ultimately analysts use their own judgment in establishing targets for both State DOTs and MPOs.

CHAPTER 4. MODEL-BASED FORECASTS OF TARGETS

As opposed to the previous methods identified, forecasting performance represents a mid- to long-term challenge that DOTs and local agencies must confront in order to transition from a performance measurement to a performance management approach. For mobility measures, while travel demand models (TDM) forecast performance measures such as volume-to-capacity (v/c) and vehicle-hours traveled, TDMs do not forecast any of the PM3 reliability or delay measures. A target setting approach utilizing such a tool would have the advantages of (1) being able to incorporate the effects of external factors that affect performance and are beyond a state DOT's or MPO's control or influence; and (2) accounting for the effects of improvements on progress towards targets.

A potential approach for forecasting mid and long-range mobility and PM3 performance measures is to adapt the reliability forecasting methods and tools developed under the Strategic Highway Research Program 2 (SHRP 2). While these tools were not explicitly designed to support target setting, they can be adapted for that use. Table 4 shows the SHRP 2 reliability tools that could be adapted to forecasting the PM3 measures. While several of the procedures can calculate the required metrics for system and truck reliability (50^{th}, 80^{th}, and 95^{th} percentile travel times), they would have to be produced for the multiple hours and day of week that comprise the time periods required. Therefore, in the sections below we present a hypothetical approach to forecasting the PM3 measures based on TDM output for a corridor. An issue that arises is that the links in the TDM network do not necessarily correspond to TMC segments, and they would have to be conflated with empirical data are to be used. Such a hybrid model—combining empirical data with forecasted demand—could be a powerful tool for predicting performance. For the purpose of demonstrating the method, though, we assume that empirical travel time data is not available.

Table 4. Strategic Highway Research Program 2 reliability tools.[12]

Strategic Highway Research Program 2 Project	Analysis Scale (in order of increasing complexity)
L03 and C11	Sketch planning; system or project level.
L07	Detailed sketch planning; mainly project level.
L02	Performance monitoring and project evaluations using empirical data.
L10	Performance monitoring and project evaluations using empirical data.
L08	Project planning using *Highway Capacity Manual* scale of analysis.
C05	Project planning using mesoscopic simulation scale of analysis.
C10	Regional planning using linked travel demand and mesoscopic simulation analysis.
L04	Regional planning using linked travel demand and mesoscopic or microscopic simulation analysis.

[12] More information on these tools and reports can be found at: https://www.fhwa.DOTs.gov/goshrp2/Solutions/Reliability/List.

DATA REQUIREMENTS

We assume that the TDM forecasts traffic by the following time periods (weekday):

- AM peak: 6:00 a.m.–9:00 a.m.
- Mid-day: 9:00 a.m.–4:00 p.m.
- PM Peak: 4:00 p.m.–7:00 p.m.
- Overnight: 7:00 p.m.–6:00 a.m.

Beyond the data requirements operating the TDM, data on hourly traffic distributions are required. These are required to split out the link volume forecasts into hours. Because most links in a TDM network are one way, the distributions need to be by direction, where direction is travel direction that peaks in either the morning or afternoon on weekdays. Links can be assigned to a "peaking direction" by examining speeds or v/c ratios; the AM or PM period with the highest value will indicate the peaking direction.

Table 5 shows an example of these hourly distributions. Because the System and Truck Reliability measures also consider weekend time periods, distributions for weekends also are required. Factors to compute annual average weekday traffic (AAWDT) and annual average weekend traffic (AAWET) also are needed.

TDMs predict single values for their performance measures meant to represent the average or typical condition. However, the System and Truck Reliability measures are based on the variability around this average condition. Therefore, some method of translating the average condition into the travel time percentiles for the performance metrics needs to be developed. The tactic used by SHRP 2 Project C11, where empirical data is used to develop relationships between the average condition and the percentiles can be used for this purpose. Figure 4 shows an example of this relationship developed from the NPMRDS data for Oregon. Note that the travel time index is used for this relationship in order to normalize the data for different section lengths.

Table 5. Example traffic distributions.

Hour	Weekday AM Peak Direction—Percent of Daily Traffic	Weekday PM Peak Direction—Percent of Daily Traffic	Weekend (both directions)—Percent of Daily Traffic
0	0.42	0.58	2.16
1	0.27	0.33	1.45
2	0.23	0.25	1.06
3	0.23	0.22	0.69
4	0.38	0.29	0.63
5	1.17	0.68	1.02
6	3.26	1.75	1.98
7	4.83	2.9	2.87
8	3.56	2.57	3.70
9	2.58	2.24	4.69

Table 5. Example traffic distributions (continuation).

Hour	Weekday AM Peak Direction—Percent of Daily Traffic	Weekday PM Peak Direction—Percent of Daily Traffic	Weekend (both directions)—Percent of Daily Traffic
10	2.46	2.33	5.66
11	2.56	2.56	6.45
12	2.65	2.71	7.06
13	2.7	2.77	7.06
14	2.93	3.12	7.09
15	3.26	4.01	7.19
16	3.47	4.81	7.19
17	3.42	4.85	6.90
18	2.66	3.23	6.22
19	1.95	2.23	5.15
20	1.54	1.78	4.24
21	1.4	1.63	3.77
22	1.14	1.3	3.27
23	0.79	0.98	2.50

ANALYSIS TOOLS

In addition to the TDM, code will have to be developed to perform the processing steps below. Spreadsheets are probably not adequate.

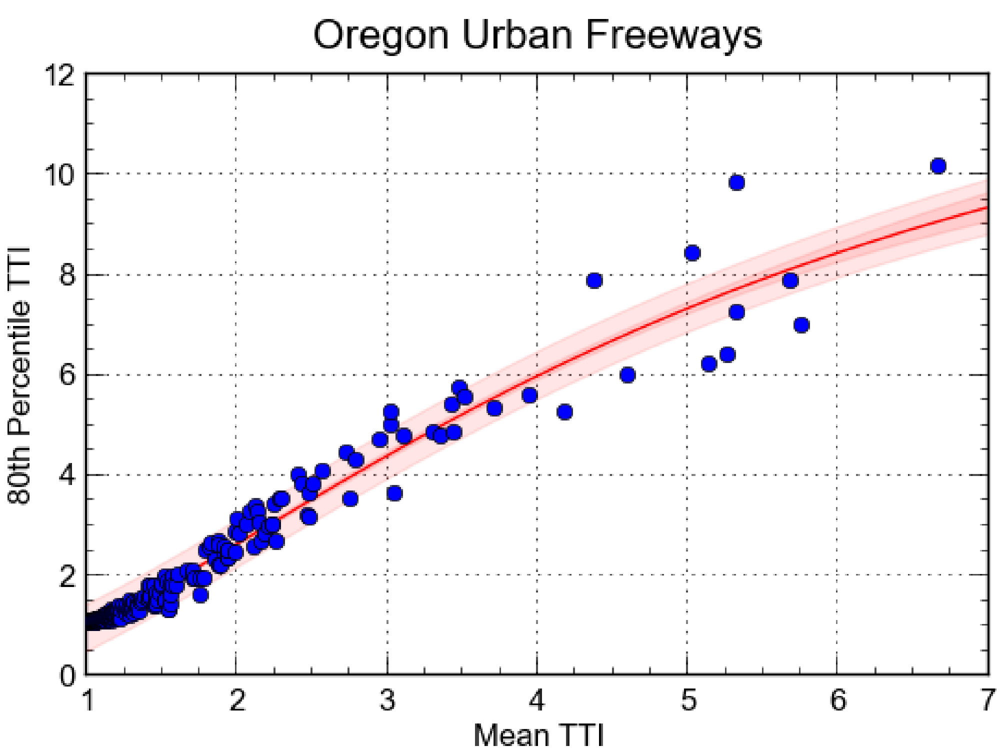

Figure 4. Chart. Empirical relationship for predicting the 80th percentile Travel Time Index.

(Source: Cambridge Systematics)

FORECASTING MEASURES AND TARGET SETTING PROCESS

The approach to developing the PM3 measures from TDM output involves the following processing steps:

1. Obtain the following link-level information from the output of the TDM:
   - Free-flow speed.
   - Number of lanes.
   - Assigned volumes for each time period.
   - Link capacity for each time period. The link capacity should correspond to the capacity as defined by the Highway Capacity Manual[13].

2. Develop hourly volumes for weekdays and weekends:
   - Sum the assigned volumes over all time periods to calculate AAWDT. Apply the hourly distributions to get weekday volumes by hour.
   - Repeat the process for weekend volumes, except that AAWDT must be converted to AAWET, which is usually lower, before applying the weekend hourly distributions.

3. Compute v/c ratios by hour.

4. Use a volume-delay function (VDF) to compute the travel time on the link. While TDM models also use a VDF as part of the traffic assignment process, it is applied for the entire period, not individual hours. The Bureau of Public Roads (BPR) function is a traditional VDF but many more exist. The BPR formulation is:

$$TT = TT_{ff} \times \{1 + 0.15 \times vcr^4\}$$

Figure 5. Equation. Predicted travel time on the link.

Where:

TT	=	the predicted travel time on the link.
TT_{ff}	=	the travel time at the free-flow speed.
vcr	=	the v/c ratio.

5. Compute the travel time for each hour in the LOTTR and Truck Travel Time Reliability (TTTR) time periods by link. Compute the metrics for the PHED delay measure as well.

6. Compute the average travel time for each LOTTR and TTTR time period by link, then the mean travel time index (MTTI) as the average travel time divided by the free-flow travel time.

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[13] Transportation Research Board, *Highway Capacity Manual 6th Edition: A Guide for Multimodal Mobility Analysis 2016*, https://www.nap.edu/catalog/24798/highway-capacity-manual-6th-edition-a-guide-for-multimodal-mobility

7. Compute the 50th, 80th, and 95th percentile travel times as a function of MTTI from the empirical relationships. From this point on, use the same calculation procedures for the system and truck reliability measures and the PHED measure as those used with empirical data.

The above procedure is a simplistic approach to the problem because the volumes and capacities used are static; since reliability is defined by how travel times vary, then its determinants also should vary. Two methods exist to extend the procedure to include variability in demand (volumes) and capacity.

The simplest adjustment is to increase the v/c ratio to account for increased demand and/or decreased capacity due to disruptions such as incidents and inclement weather. However, the development of the v/c adjustments must account for the fact that incidents and weather occur with variable severities, e.g., incidents do not occur every day on a highway section and when they do, their blockage and duration characteristics vary.) From a prediction standpoint, in addition to being probabilistic, incidents also are a function of VMT, so care must be taken in reducing capacity in the v/c ratio.

A second more complex method is to compute travel times stochastically. In this approach, the volume and capacity on a link are allowed to vary using Monte Carlo simulation techniques, and travel times for each level of volume and capacity are computed until a complete travel time distribution is obtained. Distributions for the factors being varied are required for the Monte Carlo simulation. The resulting synthetic distribution of travel times can then be used in the same way that empirical data are used for computing the PM3 measures. The procedure works as follows for incidents, but weather and volumes also can be addressed: The idea is to cycle through individual "days" where each day has distinct incident characteristics.

- Determine if an incident occurs during this hour by sampling from a Poisson distribution, where the lambda parameter is the VMT times the incident rate.
- Determine the blockage characteristics: shoulder or the number of lanes blocked by sampling from the incident blockage distribution.
- Reduce capacity to account for the incident blockage. The *Highway Capacity Manual* has information for capacity reduction factors due to incidents.
- Apply the VDF and store the travel time.
- Repeat over multiple "days" (replications) to create the travel time distribution.

Weather conditions can also be sampled using the above approach. Thus, each simulated "day" is a combination of incident and weather conditions.

EXAMPLE

An MPO wants to develop the PM3 measures for their region as part of their Long-Range Transportation Plan (LRTP). They have run their Travel Demand Forecasting (TDF) model for multiple scenarios and have developed code to process the TDF model output to develop the measures. The calculations follow the process below shown for a single freeway link one mile in length and three lanes wide for the first time period for the System Reliability measure.

- The free-flow speed is 60 miles per hour (mph) and the link has a calculated capacity of 2,200 passenger cars per hour per lane (pcphpl). To account for the effect of disruptions, the net effect is to reduce capacity by 10 percent, bringing the revised capacity to 1,980 pcphpl.

- One-way AAWDT for the link has been computed as 50,000 from the model output. Using a local hourly traffic distribution, the volume in each hour is determined:

  - 6:00 a.m.–7:00 a.m.: 4,800 vehicles per hour.
  - 7:00 a.m.–8:00 a.m.: 5,700 vehicles per hour.
  - 8:00 a.m.–9:00 a.m.: 5,200 vehicles per hour.

- The v/c ratios are calculated and the BPR VDF is used to compute the average travel times. Corresponding speeds and MTTIs also are computed (table 6).

- For the entire 6:00 a.m.–9:00 a.m. time period, the volume-weighted average travel time is computed as 1.095 minutes. The MTTI also is 1.095 (given that the link is 1 mile long and the free-flow speed is 60 mph).

- Using locally derived relationships similar to the one shown in figure 4:

  - 50th percentile travel time index (TTI) is 1.070.
  - 80th percentile TTI is 1.138.
  - 95th percentile TTI is 1.225.

- The LOTTR metric for this link and time period is 1.138/1.070 = 1.063.

- LOTTR metrics for all time periods and links are computed in the same manner as for empirical data. The System Reliability measure is then computed.

Table 6. Link calculations.

Time Period	Volume	Volume-to-Capacity	Travel Time (minutes)	Speed	Travel Time Index
6:00 a.m.–7:00 a.m.	4,800	0.808	1.064	56.4	1.064
7:00 a.m.–8:00 a.m.	5,700	0.960	1.127	53.2	1.127
8:00 a.m.–9:00 a.m.	5,200	0.875	1.088	55.1	1.088

CHAPTER 5. MACHINE LEARNING MODEL-BASED FORECASTS OF TARGETS

The Virginia Department of Transportation (VDOT) developed an analytical procedure to provide guidance in setting targets for the Interstate Travel Time Reliability Measure. It is hoped that the methodology can be extended to the other PM3 measures, as well as other travel time-based measures used by VDOT. The steps in the VDOT procedure are described below.

1. **Calculate Current Interstate Reliability.** VDOT used the NPMRDS data and the recommended procedure for calculating both the metrics (LOTTR) by TMC and time periods, as well as the overall system reliability measure. Virginia's Interstate Travel Time Reliability Measure in year 2019 was 83.55 percent.
2. **Examine Patterns in the 80th and 50th Percentile Travel Times.** To gain a deeper understanding of the Interstate system reliability measure, VDOT undertook a detailed analysis to explore the relationship between the 80th and 50th percentile travel times, the foundation of the metrics, and resulting measure. Figure 6 shows an example of the analysis that included multiple congested Interstates. The ratio between the 80th and 50th percentiles is shown in the bottom graph. Three regimes are shown:
    a. "Reliable" where average speeds are high and the ratio is close to 1.0.
    b. "Unreliable" where speeds are transitioning from high to low and the ratio is above 1.5.
    c. "Reliably Congested" where speeds are low and the ratio is within a few points of 1.5.

    While the term "Reliably Congested" may seem contradictory, it is a function of the two percentiles chosen for the LOTTR metric. In situations where a roadway segment experiences congestion just about every peak period, the 50th percentile (a measure of central tendency) is relatively high and not that greatly different from the 80th percentile. If the upper bound is changed to a higher percentile (e.g., 95th percentile travel time), it is possible that the same roadway would just be deemed "unreliable".

3. **Develop a Model to Predict Future Interstate System Reliability.** A machine learning model using the Random Forest algorithm was developed to predict the 80th and 50th percentile travel times on TMCs. There were 30 independent variables selected, including geometric features, weather conditions, incident characteristics, work zone characteristics, and traffic demand.[14] The model demonstrated very small (less than 1 percent) error when it was used to "predict" the reserved validation dataset.
4. **Forecast Key Independent Variables for Future Condition.** The following forecasts are made in order to apply the model:
    a. Number of lanes and acceleration/deceleration lane extensions: based capacity improvements in the on Six-Year Improvement Program Project Types.

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[14] Xiaoxiao, Z., M. Zhao, J. Appiah, and M. D. Fontaine, *Methods to Analyze and Predict Interstate Travel Time Reliability*, Report No. FHWA/VTRC 22-R2, July 2021.

b. Future year v/c ratio and future year crashes based on forecasted number of lanes, projected Average Annual Daily Traffic (AADT) using yearly growth factors, and safety performance functions for crashes.

The results of applying the model are shown in figure 7.

5. **Extend the Model to Include Other Reliability Measures.** The PM3 System Reliability measure is just one of several potential reliability measures. Other measures should be considered as well that do not have the limitations of the System Reliability measure:

a. Long time periods (4/6/10 hours) do not reflect peak-hour travel conditions and can “dilute” reliability measurements.

b. Seasonal fluctuations in travel demand are not addressed.

c. The pass/fail nature of the System Reliability measures does not indicate how strongly a roadway is reliable or unreliable.

The same methodology as used for the System Reliability measure can be used for other travel time-based measures, including reliability.

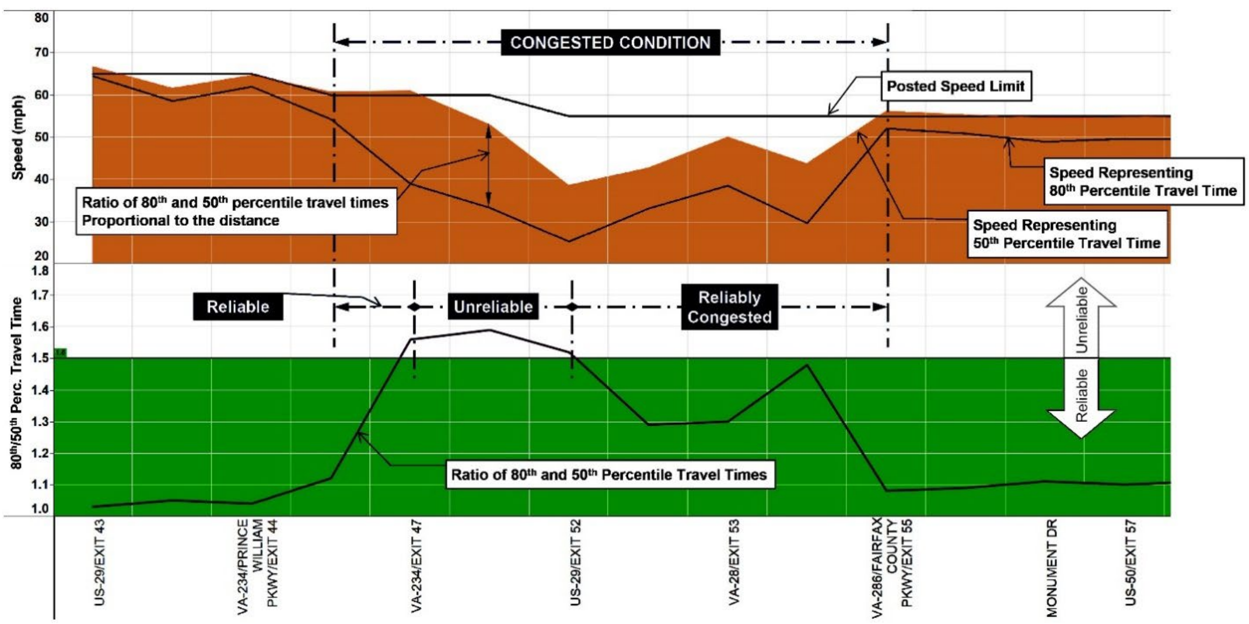

Figure 6. Chart. Example of reliability along a facility: I-66 Eastbound AM peak (6 AM–10 AM).
(Source: Virginia Department of Transportation.)

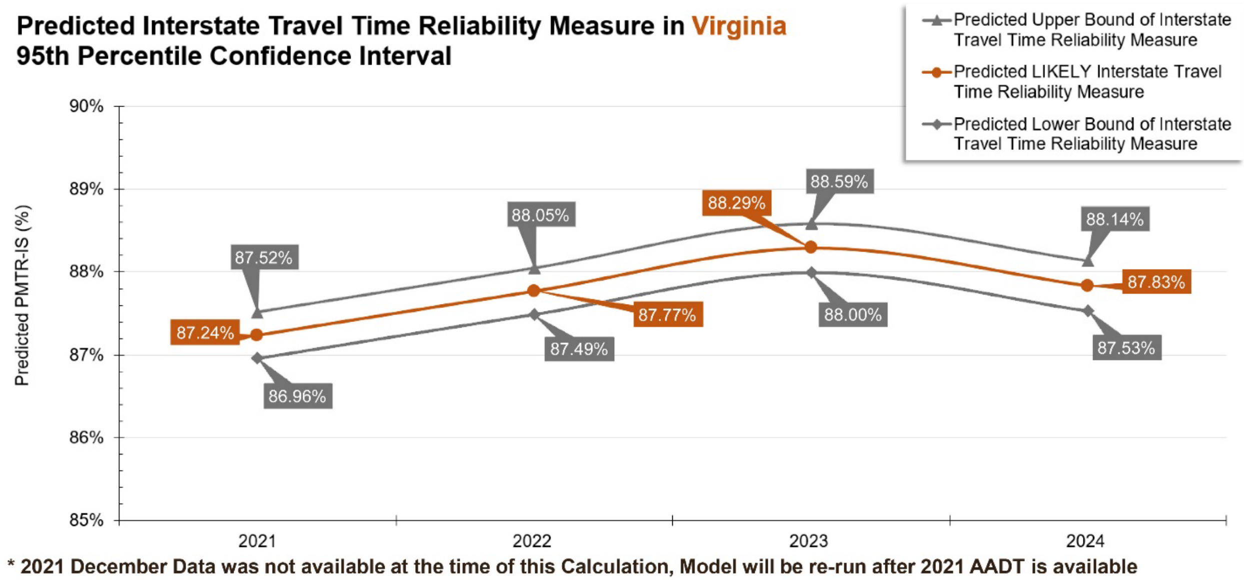

Figure 7. Chart. Interstate travel time reliability measure prediction—statewide.

(Source: Virginia Department of Transportation.)

SUMMARY

This document offered a step-by-step calculation guide for three forecasting methods in support of target setting for the travel time-based performance measures.

The three forecasting methods covered in this document were:

- Extrapolation of past trends (macroscopic). This approach requires multiple years of empirical travel time data. Additional multiyear data on VMT and other influencing factors are highly recommended.
- Highway segments “at risk” for unreliability (microscopic; based on identifying segments that close to the reliability threshold). This approach requires only a single year of travel time data.
- Model-based forecasting. This approach works in conjunction with a travel demand model and does not require travel time data, other to establish current conditions and developing relationships to predict the percentiles of the travel time distribution. Additional data on hourly distribution of traffic are also needed.

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August 2023

FHWA-HOP-21-014