Influence of Operations Strategies on Third Performance Management Rulemaking (PM3) and Other Travel Time-Based Measures Primer Part Two

Nonrecurring Congestion Strategies

September 2024

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-23-060		

4. Title and Subtitle	5. Report Date
Influence of Operations Strategies on Third Performance Management Rulemaking (PM3) and Other Travel Time-Based Measures Primer Part Two—Nonrecurring Congestion Strategies	September 2024
	6. Performing Organization Code
7. Author(s) Richard A. Margiotta, Eric Kocher, Jeff Dale, and Lisa Burgess	8. Performing Organization Report No.
9. Performing Organization Name and Address 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 U.S. Department of Transportation Federal Highway Administration Office of Operations (HOP) 1200 New Jersey Avenue, SE Washington, DC 20590	13. Type of Report and Period Covered Primer, January 2022 to March 2023
	14. Sponsoring Agency Code HOP

15. Supplementary Notes

The task order contracting officer's representative was Rich Taylor.

16. Abstract

The purpose of this Primer is to apply an evaluation methodology previously developed by the Federal Highway Administration to six real-world case studies, and to provide examples for successful application of the methodology and highlight relationships to third performance management rulemaking measures.

The methodology uses empirical data to track changes in travel times, as well as influencing factors: incidents, weather, and demand. The six case studies include two that address incident management; three that address adverse environmental events (snow and ice storms, dust storms, and rain); and one that addresses work zone management. Where indicated, traffic modeling was used to control for large variations in the influencing factors. Application of the methodology to six case studies revealed that, for the type of nonrecurring strategies implemented, little change in performance was observed using the empirical approach. The reason for this condition is that, by definition, nonrecurring strategies are narrowly focused on infrequent disruption events. In contrast, strategies that deal with recurring congestion will have an effect just about every day. As a result, travel time-based performance measures that accrue over an entire year may not be able to detect the infrequent effect of these strategies. Also, the effect of confounding by influencing factors for congestion—demand, crashes, and weather events—could mask the changes. To address this issue, modeling was used to hold these influencing factors constant for the before and after periods. Three of the case studies were used as examples and showed a highly positive net present value when the modeling results were obtained.

17. Key Words	18. Distribution Statement
Operations, evaluation, performance measures, performance management, transportation systems management and operations, strategic, data, data-driven policy, investment	No restrictions.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	74	N/A

Form DOT 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)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		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)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		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)

Please view an online version of the SI Conversion table.

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LIST OF ACRONYMS

AADT	average annual daily traffic
ADOT	Arizona Department of Transportation
AI	artificial intelligence
AID	advanced incident detection
ATM	Active Traffic Management
AWDT	average weekday daily traffic
AWEDT	average weekend/holiday daily traffic
CCTV	closed-circuit television
CMAQ	Congestion Mitigation and Air Quality Improvement Program
DMS	dynamic message sign
DOT	Department of Transportation
FHWA	Federal Highway Administration
HCM	*Highway Capacity Manual*
ICM	integrated corridor management
LOTTR	level of travel time reliability
MAP-21	Moving Ahead for Progress in the 21st Century
mph	miles per hour
MTTI	Mean Travel Time Index
NCDOT	North Carolina Department of Transportation
NCHRP	National Cooperative Highway Research Program
NPMRDS	National Performance Management Research Data Set
NPV	net present value
ODOT	Oregon Department of Transportation
PCPHPL	passenger car per hour per lane
PHED	peak hour excessive delay
PM3	third performance management rulemaking
PP&E	Preliminary Planning and Engineering
PTI	planning time index
PTSA	Preestablished Towing Service Agreements
RWIS	Road Weather Information System
SHRP2	Strategic Highway Research Program 2
SOV	single-occupancy vehicle
SQCG	Shared Quick-Clearance Goal
SSP	Safety Service Patrol
SWZ	smart work zone
TIM	traffic incident management

TIMS	traffic information management system
TIMS-BC	traffic incident management program benefit/cost
TMC	traffic message channel
TOPS-BC	Tool for Operations Benefit/Cost Analysis
TTI	travel time index
TTTR	truck travel time reliability
TxDOT	Texas Department of Transportation
VDF	volume-delay function
VHT	vehicle-hours of travel
VMS	variable message sign
VMT	vehicle miles traveled
VSL	variable speed limit

EXECUTIVE SUMMARY

This Primer presents an empirically based method for conducting before and after analyses of implemented operations strategies that deal with nonrecurring congestion. These strategies include Incident Management, Work Zone Management, Weather Management, and Special Event Management. The method is based on using probe vehicle-based travel time data; the National Performance Management Research Data Set is highlighted, but other probe vehicle data sources can be used. Additional data for incidents, weather, and demand are also used. The method assesses the effect that strategies have on the third performance management rulemaking (PM3) measures for system reliability, truck travel time reliability, and peak hour excessive delay, as well as other travel time-based performance measures. Examples of how the method is applied are given.

The purpose of this Primer is to: 1) summarize previous methods used to evaluate operations strategies; 2) document the nonrecurring congestion operational strategy implementation evaluation methodology developed for the project, including the performance measures needed to characterize benefits and costs and how to relate to PM3 measures; 3) report the results of the six real-world evaluations conducted with the methodology; and 4) provide examples for successful application of the methodology and highlight relationship to PM3 measures.

The methodology uses empirical data to track changes in travel times, as well as influencing factors: incidents, weather, and demand. The six case studies include two that address incident management; three that address adverse environmental events (snow and ice storms, dust storms, and rain); and one that addresses work zone management. Where indicated, traffic modeling was used to control for large variations in the influencing factors. Application of the methodology to six case studies revealed that, for the type of nonrecurring strategies implemented, little change in performance was observed using the empirical approach. The reason for this condition is that, by definition, nonrecurring strategies are narrowly focused on infrequent disruption events. By contrast, strategies that deal with recurring congestion have an effect nearly every day. As a result, travel time-based performance measures that accrue over an entire year may not be able to detect the infrequent effect of these strategies. Also, the effect of confounding by influencing factors for congestion—demand, crashes, and weather events—could mask the changes. To address this issue, the project team used modeling to hold these influencing factors constant for the before and after periods. Three of the case studies were used as examples and showed a highly positive net present value (NPV) when the modeling results were obtained.

The study found that commonly used travel time-based performance measures, including the PM3 measures, are not adequate for monitoring the effects that nonrecurring operations strategies have on congestion at the annual level. Other measures should be explored, including a delay measure with the threshold set at free flow conditions or the posted speed limit and analysis of the top 10 percent worst congestion periods throughout the year.

CHAPTER 1. INTRODUCTION

PURPOSE OF THIS PRIMER

The purpose of this Primer is to provide methods for conducting before and after evaluations of operational strategies implemented to address nonrecurring congestion. The focus is how these types of operational strategies affect the third performance management rulemaking (PM3) metrics and measures, as well as other travel time-based performance measures. This Primer documents: 1) the development of the evaluation methodology developed for the project; 2) the results of six case studies where the methodology was applied; and 3) examples of how agencies can apply the methodology for their own evaluations.

PRIMER OVERVIEW

In the following chapters, the Primer covers several topics:

- Chapter 1:
    - The purpose and benefits of conducting evaluations of operations strategies (especially with regard to the PM3 and other travel time-based measures
    - Types of operational strategies covered
    - Historical perspective on project evaluation
- Chapter 2: Evaluation methodology developed for operational strategies
- Chapter 3: Case studies: application of the evaluation methodology in the field
- Chapter 4: Examples of how to implement the methodology
- Chapter 5: Findings and recommendations

BACKGROUND

Types of Operations Strategies Covered by This Primer

Table 1 and table 2 show the broad types of operations strategies geared to nonrecurring congestion. Also covered in table 1 are the goals, objectives, and specific strategies associated with each category of strategies.

Table 1. Nonrecurring operational strategies and their performance contexts.

Operational Strategy Category	Goals	Objectives	Strategies	Primary Impact Category	Output Performance Measures	Possible Influence on Third Performance Management Rulemaking Measures	Unique Evaluation Characteristics
Road Weather Management	Reduce crashes	Warn motorists of unsafe conditions	Visibility, wind, pavement warning systems; variable speed limits	Safety	Crashes by type	Delay reductions due to crashes; also should lead to more reliable travel	Level of compliance by motorists
Road Weather Management	Reduce delay	Warn motorists not to travel	Traveler information	Demand: during extreme events, reduce amount of travel	Throughput: Vehicles per hour	Delay reductions; also should lead to more reliable travel	Level of compliance by motorists
Traffic Incident Management	Reduce delay	Reduce incident duration	Improved incident detection (from sensors or crowd-sourced)	Reduced delay	Incident timeline; lane hours of blockage	Delay reductions; also should lead to more reliable travel	Secondary crashes also possibly reduced
Traffic Incident Management	Reduce delay	Reduce incident duration	Closed-circuit television aerial surveillance	Reduced delay	Incident timeline; lane hours of blockage	Delay reductions; also should lead to more reliable travel	Secondary crashes also possibly reduced

Table 1. Nonrecurring operational strategies and their performance contexts. (continuation)

Operational Strategy Category	Goals	Objectives	Strategies	Primary Impact Category	Output Performance Measures	Possible Influence on Third Performance Management Rulemaking Measures	Unique Evaluation Characteristics
Traffic Incident Management	Reduce delay	Reduce on-scene management time	Removal laws, shared quick clearance goals; towing agreements	Reduced delay	Incident timeline; lane hours of blockage	Delay reductions; also should lead to more reliable travel	Secondary crashes also possibly reduced
Work Zone Management	Reduce delay	Reduce lane closure times	Maintain all traffic lanes; work zones designed for posted speeds; improved transportation management plans and actions	Reduced delay	Lane hours of closure	Delay reductions; also should lead to more reliable travel	Crashes also reduced
Work Zone Management	Reduce delay	Reduce work zone duration	Full, shoulder, partial, and/or ramp closure	Reduced delay	Delay that would have occurred	Net delay reductions; also should lead to more reliable travel	Increased delay will appear on alternative routes
All	Reduce delay	Change demand patterns	Traveler information	Demand	Throughput: Vehicles per hour	Changes in demand could lead to delay reductions	Difficult to measure demand shifts with field data

Table 2. Impact of Traveler Information Management System strategies.

Strategy	Methodology	Default Parameter Values
Safety Service Patrol (SSP)	Duration-based	• Average duration savings: 20 minutes • Apply to all types of lane blockage
Shared Quick-Clearance Goals (SQCG) Preestablished Towing Service Agreements (PTSA) Dispatch Collocation (DC) Traveler Incident Management Task Forces (TTF) Strategic Highway Research Program 2 (SHRP2) Training (ST)	Duration-based and proportion-based	• Proportion: 100% • Implementation: 100% • Average incident duration savings: 10 minutes • SQCG, TTF, ST—All types of blockages • PTSA—All types of blockages other than shoulder • DC—Two-lane blockage or greater
Driver Removal Laws (DRL) Authority Removal Laws (ARL)	Duration-based and proportion-based, with hypothetical incidents	• Proportion: 50% • Compliance rate: 30% • Average incident duration after DRL implementation on mainline: 5 minutes • Average incident duration after ARL implementation on mainline: 10 minutes • DRL applies only to one-lane blockage; ARL applies to all types of lane blockage except shoulder

Source: J. Ma, E. Miller-Hooks, M. Tariverdi, T. Lochrane, F. Zhou, D. Prentiss, K. Hudgins, P. Jodoin, Z. Huang, and M. Hailemariam. 2016. *User-Friendly Traffic Incident Management (TIM) Program Benefit-Cost Estimation Tool,* Report No. FHWA-HRT-16-055. Washington, DC: Federal Highway Administration.

Why Evaluate Operations Strategies?

Evaluations of completed projects is a key element of Operations Performance Management. Evaluating operations strategies provides valuable insight into the potential benefits and costs of investing in them. The general value of analysis is the extent to which it assists stakeholders implementing operational strategies to:

- Invest in the right strategies—Evaluation provides information for **determining which operational strategies are likely to be most effective and under which conditions:** The evaluation helps decisionmakers identify technical and implementation gaps and invest in the combination of strategies that would most minimize congestion and produce the greatest benefits. It provides an enhanced understanding of existing conditions and deficiencies, allowing for the improved ability to match and configure proposed strategies to the situation at hand.
- Highlight successes—Evaluations indicate if a project met its predetermined goals. When they do, publicizing the project will build support for future operations deployments within the agency, as well as with decisionmakers and the public.

PM3 Measures

On January 18, 2017, the Federal Highway Administration (FHWA) published the final rule that establishes a set of performance measures known collectively as the PM3 measures.[1] For the purpose of this Primer, four of the PM3 measures are considered because they are based on travel times:

1. National Highway System Performance: Travel Time Reliability for Interstate Highways (percent of the person-miles traveled on the Interstate that are reliable)
2. National Highway System Performance: Travel Time Reliability for Non-Interstate National Highway System Highways (percent of the person-miles traveled on the non-Interstate National Highway System Highways that are reliable)
3. Freight Movement on Interstate Highways: Truck Travel Time Reliability (TTTR) (truck travel time reliability index)

Peak Hour Excessive Delay (PHED)Guidance on the calculation of the PM3 measures has been developed by FHWA and these calculations are used throughout the example in this Primer.[2]

The immediate purpose of the PM3 measures was to implement the requirements in Title 23 of the U.S. Code (U.S.C.), which was updated by the Moving Ahead for Progress in the 21st

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[1] https://www.federalregister.gov/documents/2017/01/18/2017-00681/national-performance-management-measures-assessing-performance-of-the-national-highway-system.

[2] Taylor, R.; Purdy, J.; Roff, T.; Clarke, J.; Vaughn, R.; Rozycki, R.; and Chang, C. April, 2018. *FHWA Computation Procedure for Travel Time Based and Percent Non-Single Occupancy Vehicle (non-SOV) Travel Performance Measures*, Report No. FHWA-HIF-18-024. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/tpm/guidance/hif18024.pdf.

Century (MAP-21) legislation (Pub. L. No. 112-141 (2012)).[3,4] The intent of the performance component of the legislation is for State and local transportation agencies to report highway system performance on an annual basis and to establish performance targets against which agencies can measure their progress. The performance measures are reported at the system level, either statewide or for individual urban areas, depending on the measure.

Beyond the need to fulfill legislative requirements, the PM3 measures embody the principles of ***performance management***, whereby agencies use data to make informed investment decisions on an ongoing basis. With regard to this Primer, practitioners are concerned that, even though their operations projects are developed to improve operational performance in mind, they lack methods to demonstrate how the results of operations strategies “move the needle” on urbanized area or statewide performance measures. This Primer presents approaches for quantifying the impacts of operational strategy implementation and relating them to the PM3 measures and investment decisionmaking. Likewise, it’s possible that PM3 measures will influence investment decisions. The methodology presented herein demonstrates the connection between PM3 and operations strategies.

Past Evaluation Methodologies for Operations Strategies

Estimating the impacts of transportation projects—and of operations strategies specifically—can be achieved by either applying models or by conducting before and after analyses with empirically collected travel time data, which can be collected through a variety of technologies (e.g., roadway sensors, probe vehicles). The expected impacts of proposed projects should be ascertained through the use of some type of forecasting model, while before and after analyses are best conducted using empirical data (actual measurements of the impacts). The Primer developed for Part One of this project series discusses past evaluation strategies, as well as background on analytical methods and conducting evaluations at various stages of the project development lifecycle.[5]

SPECIAL CONSIDERATIONS FOR EVALUATING OPERATIONS STRATEGIES FOR NONRECURRING CONGESTION

By definition, nonrecurring congestion does not happen with regularity, and when it does, its effects are highly variable. For example, a traffic incident can block a shoulder or multiple lanes, and the traffic flow impacts are significantly greater for the latter. Consequently, operations strategies that target nonrecurring congestion are not in play every day, only when conditions warrant. Depending on the source of nonrecurring congestion, frequency of occurrence will vary:

- Traffic incidents are the most common form of nonrecurring congestion.

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[3]23 U.S.C. 150, https://www.govinfo.gov/content/pkg/USCODE-2019-title23/html/USCODE-2019-title23-chap1-sec150.htm.

[4]Office of the Federal Register. 2022. “Design Standards for Highways.” Federal Register 87, no. 1 (January 3, 2022): 32–42. https://www.govinfo.gov/content/pkg/FR-2022-01-03/pdf/2021-28236.pdf, last accessed April 21, 2023.

[5]Margiotta, R.; Hallenbeck, M.; Bullock, D.; Kulathintekizhakethil, M. (forthcoming) *Influence of Operations Strategies on Third Performance Management Rulemaking and Other Travel Time-Based Measures Primer Part One*, Report No. FHWA-HOP-24-001. Washington, DC: Federal Highway Administration.

- Inclement weather occurs periodically throughout the year and can have either localized or system-wide effects.
- Work zone locations and length of duration can vary, but both short- and long-term work zones might have a large impact on traffic flow if not set properly.
- Special events are the least frequent of nonrecurring sources, but some can have catastrophic traffic and societal impacts (e.g., natural disasters such as hurricanes and earthquakes).

The frequency of nonrecurring congestion occurrence has a major effect on how operations strategies can be evaluated. For recurring congestion, operations strategies operate continuously, at least during typical peak periods; and their impact can be detected over long periods (e.g., a year) with empirical data. Because of this continuous operation, baseline conditions can be easily established for comparing the postimplementation treatment. Further, long pre- and post-implementation time periods are required to establish the travel time reliability profile.

The frequency of nonrecurring congestion plays a role in how operations strategies can be evaluated. To conduct an evaluation, the background conditions should be roughly the same in pre- and post-implementation. Incident management is the nonrecurring congestion strategy that can be evaluated most like recurring strategies with empirical data because they occur frequently. However, consider a work zone management strategy that is implemented on a facility. For a pure empirical comparison, the same work zone—with and without the management strategy—would have to exist, but this is rarely the case. The missing component is "what would have happened in the absence of the treatment?", also known as the counterfactual condition. Another way to describe it is, "if we had not implemented the treatment, what performance level would have been attained?"

In the development of the evaluation methodology in Part One of this series of projects, control sites and modeling were used for special cases where background conditions were dissimilar in the pre- and post-implementation project phases.[6] For evaluating operations strategies targeting nonrecurring congestion, these methods take on a greater importance.

Other aspects of operations strategies for nonrecurring congestion that are vexing for evaluations include:

- Improved operating policies, such as changes in how on-scene management of incidents, have a low "signal" in terms of affecting the travel times that are the basis of the PM3 measures. That is, the effect of low-impact strategies can easily get overwhelmed by other factors in a before and after evaluation. Given this, an analyst should examine not only travel times, but also measures for influencing factors, such as incident and work zone duration and lane hours lost. These performance measures can be used in a modeling context to control for their influence on before and after travel times. Such a strategy is used by the recently released traffic incident management program benefit and cost (TIMS-BC) tool for forecasting the impact of proposed incident management strategies. First, incident

[6]Margiotta, R., Hallenbeck, M., Bullock, D., Kulathintekizhakethil, M. (forthcoming) *Influence of Operations Strategies on Third Performance Management Rulemaking and Other Travel Time-Based Measures Primer Part One*, Report No. FHWA-HOP-24-001. Washington, DC: Federal Highway Administration.

characteristics (duration and blockages) of a strategy are either set by the user or use default values. These are then used to estimate delay and other performance measures via equations.[7] Figure 1 shows the pathway for tracing influencing factors to measures of system performance. Operational strategies' effects are manifested in two basic outcomes: traffic flow and safety (crashes). Traffic flow, in turn, is defined by increases in capacity, changes in demand, and improvement in signal performance (better progression and phasing). In the case of incidents and work zones, capacity is "lost" by the blocking or removal of lanes and shoulders for the duration of the event. Hence, shortening the duration of these disruptive events improves travel times. All of these factors ultimately affect travel time, and therefore will affect the PM3 measures.

- Traveler information systems are a component of many nonrecurring operations strategies by shifting or eliminating demand. In the past, evaluating the impact of traveler information on system performance has been difficult. There is not a clear answer as to whether or not these changes in demand or travel times can be measured with empirical data.
- For some types of nonrecurring strategies, multiple actions are bundled together, such as in work zone transportation management and special event action plans. Accounting for all of the details of these plans, even in a modeling context, could be difficult.
- The availability of data on the factors influencing travel times will be a key consideration. Because the effect of nonrecurring operations strategies is more nuanced than that of recurring strategies, having detailed data on disruptive events is the only way to cull out an effect. For example, the lane- and shoulder-blocking characteristics of an incident or a work zone changes over time. An incident may start as a single lane blockage, change to two blocked lanes as needed by responders, then emergency vehicles may stay on the shoulder for some period of time. Some incident management systems capture this evolving nature of closures, but others just document the worst or most prevalent condition. Likewise, weather data from the National Oceanic and Atmospheric Administration is available nationwide, but only at selected locations (airports, even small ones, are common locations) and only at 1-hour reporting levels.

In summary, some nonrecurring strategies cannot be evaluated solely with empirical travel times. For some strategies, performance measures for influencing factors (based on empirical data) can be used to control for confounding effects. Other types of strategies could be difficult if not impossible to evaluate for their effect on travel times.

[7] *User-Friendly Traffic Incident Management (TIM) Program Benefit-Cost Estimation Tool*. (2022). Report No. FHWA-HRT-16-055, Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/operations/16055/003.cfm.

CHAPTER 2. BEFORE AND AFTER EVALUATION METHODOLOGY FOR OPERATIONAL STRATEGIES

OVERVIEW

Figure 1 presents the evaluation methodology. The team developed the methodology in Part One of this series of projects, which has a thorough discussion of each step.[8] It also contains details on the data needed to conduct evaluations and a review of past evaluation methodologies. Because modeling as a means of exerting experimental control is a major part of this project, a discussion of it follows.

APPLYING MODELING TO ESTABLISH CONTROLS IN EVALUATIONS

Using control sites—sites with similar characteristics that have not received a treatment—is a common method for establishing controls. For evaluations considering congestion, treatment and control sites would need to have similar intersection and interchange configurations, weather conditions, incident characteristics, and demand levels in the before and after periods. In lieu of using control sites, modeling can be used for control purposes. The idea is to create before and after scenarios based on the same demand, incident, and weather conditions as in the before case. This allows the analyst to answer the question "what would have happened without the treatment?"

A variety of modeling methods can be used for this purpose. The *Highway Capacity Manual*'s (HCM) freeway facilities or urban street methods that consider travel time reliability are examples of modeling methods that can be used for this purpose. A simpler (sketch planning) method is the HCM's Preliminary Planning and Engineering (PP&E) methodology.[9] While the data requirements are much smaller than for the regular HCM procedures, the methodology does consider queuing and travel time reliability.

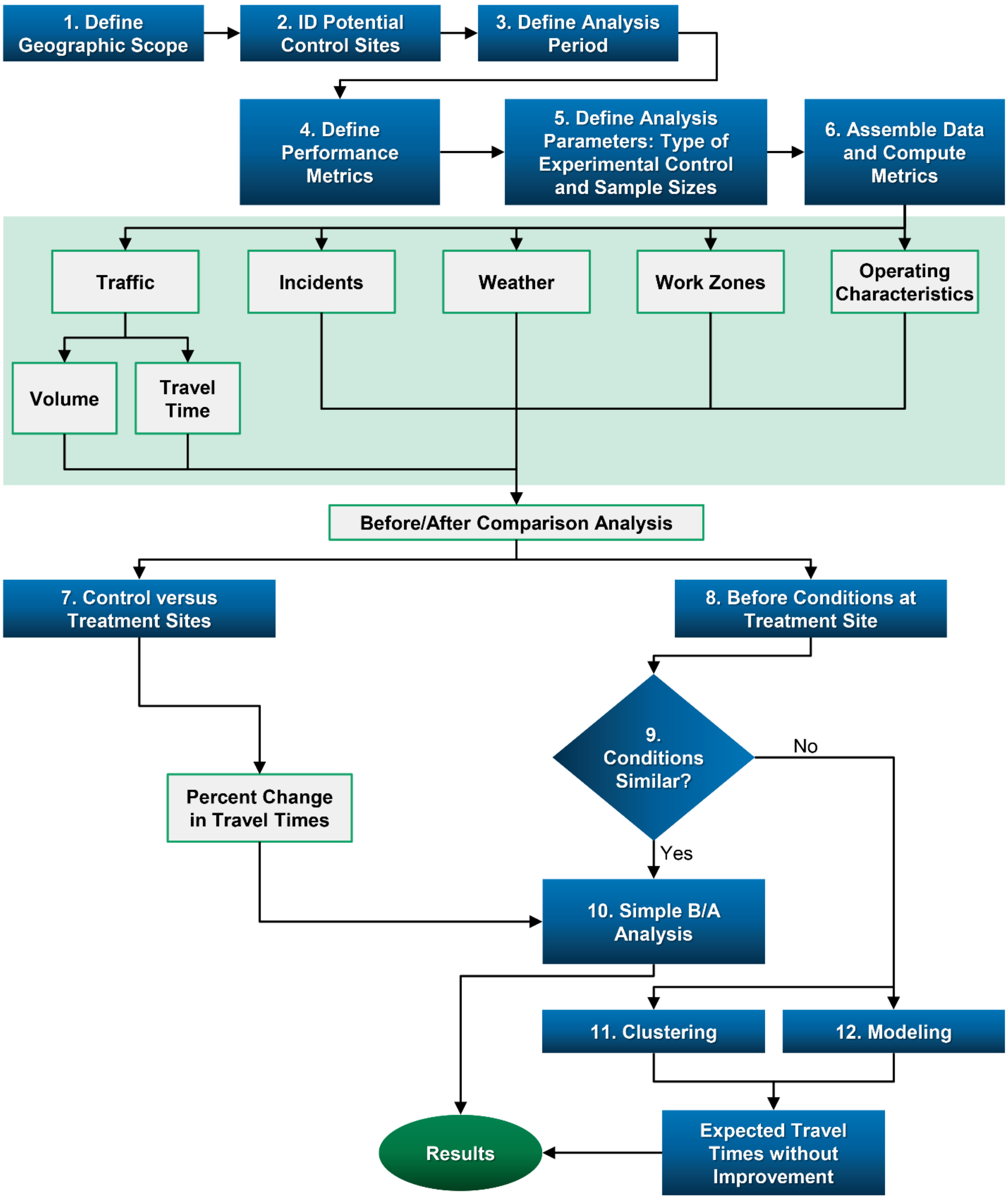
The steps in applying the PP&E process are as follows.

1. Use vehicle probe data, such as the National Performance Management Research Data Set (NPMRDS), to develop functions that relate reliability measures to the average measures commonly output from models and from roadways with similar characteristics in the region where the evaluation is taking place. Note the variances in the data for each relationship.
2. Use a volume-delay function (VDF) to predict the recurring-only predicted Mean Travel Time Index (MTTI) in the after case. A VDF that attempts to address queuing characteristics, such as modified versions of Davidson's function, should be used. Empirical volumes are used, and the capacity is the same as for the before period.
3. Apply the travel time or delay reduction factors for the operations treatment from the values presented in the task 2 matrix to get the revised predicted MTTI.

[8]Margiotta, R., Hallenbeck, M., Bullock, D., Kulathintekizhakethil, M. (forthcoming) *Influence of Operations Strategies on Third Performance Management Rulemaking and Other Travel Time-Based Measures Primer Part One*, Report No. FHWA-HOP-24-001. Washington, DC: Federal Highway Administration.

[9]Dowling, R. et al. *Planning and Preliminary Engineering Applications Guide to the Highway Capacity Manual*, (2016) National Cooperative Highway Research Program (NCHRP) Report 820, https://www.nap.edu/download/23632.

4. Apply the relationships developed in step 2 to obtain the predicted values for the rest of the travel time measures.



B/A = before and after. ID=identify

Source: FHWA.

Figure 1. Flow chart. Outline of the evaluation methodology.

Other sketch-planning level tools may also be used. The project team developed such a tool for this project and named it QSIM for its ability to model queuing. The appendix has more detail on this tool.

CHAPTER 3. CASE STUDIES AND SELECTED EXAMPLES

CRITERIA FOR SELECTING CASE STUDY SITES

The evaluation methodology was applied to six case study sites around the United States. The project team used several criteria in selecting the case study sites:

- The six sites should represent a variety of operations strategies.
- The implementation of the strategies should have been completed recently to increase the chances of finding relevant data and to allow full-year before and after analysis periods.
- The implementing agency should be a willing participant in the evaluation.

PERFORMANCE MEASURES USED IN THE EVALUATIONS

Table 3 presents the performance measures used in the examples. The analysis periods for the PM3 measures are strictly defined by the final rule. These analysis periods are as follows.

National Highway Performance Program Reliability (Level of Travel Time Reliability)

1. 6 a.m.–10 a.m., weekdays
2. 10 a.m.–4 p.m., weekdays
3. 4 p.m.–8 p.m., weekdays
4. 6 a.m.–8 p.m., weekends

Freight Reliability

1. 6 a.m.–10 a.m., weekdays
2. 10 a.m.–4 p.m., weekdays
3. 4 p.m.–8 p.m., weekdays
4. 8 p.m.–6 a.m., all days
5. 6 a.m.–8 p.m., weekends

Peak Hour Excessive Delay

1. 6 a.m.–10 a.m., weekdays
2. 4 p.m.–8 p.m., weekdays

All Other Performance Measures

Peak periods:

1. 7 a.m.–9 a.m.
2. 4 p.m.–6 p.m.

Table 3. Performance measures used in the evaluations.

Performance Measure	Type of Measure	Continuous or Binary?	Definition
Performance Measure Rule 3 (PM3) National Highway Performance Program Reliability (Level of Travel Time Reliability)	Reliability	Binary	Percent of person-miles deemed to be reliable, where "reliable" is travel below the ratio of the 80th percentile travel time and the median travel time for four time periods
PM3 Truck Reliability (Truck Travel Time Reliability; freeways only)	Reliability	Continuous	Index based on the ratio of truck travel times: 95th percentile divided by the median for five time periods; the index is the maximum of the ratio of the five periods; the system measure is the length-weighted average of all the individual indices
PM3 Peak Hour Excessive Delay	Average or Typical Condition	Continuous	Person-hours that occur below a threshold, where the threshold is either 60% of the speed limit or 20 mph, whichever is higher
Planning Time Index	Reliability	Continuous	95th percentile Travel Time Index (TTI) (95th percentile travel time divided by the free flow travel time)
80th Percentile TTI	Reliability	Continuous	80th percentile TTI (80th percentile travel time divided by the free flow travel time)
TTI	Average/ Typical Condition	Continuous	Ratio of average travel time to the free flow travel time
Average Speed	Average/ Typical Condition	Continuous	Space mean speed, calculated as the vehicle miles traveled-weighted harmonic mean speed
Delay	Average/ Typical Condition	Continuous	Excess vehicle hours incurred when speeds drop below the free flow speed

OVERVIEW OF CASE STUDY SITES

The project team identified the following locations and strategies for the case studies:

1. I-90 in Northeast Ohio ("Lake 90")—Variable speed limit (VSL) system enacted for adverse weather conditions, especially snow squalls from Lake Erie.
2. I–10 in Arizona—Dust detection and VSL system.
3. I-85 in Atlanta, GA—Advanced incident detection (AID) algorithm using artificial intelligence (AI).
4. I-26 in Asheville, NC, Integrated Corridor Management (ICM)—Traffic diversion system during incident and work zone created congestion, coupled with incentivized tow contracts.
5. I–35 in Central Austin, TX—Smart work zone (SWZ) technology, part of the Mobility35 program.
6. OR-217 in Portland, OR—Curve warning system for freeway ramps.

SUMMARY OF CASE STUDY RESULTS: KEY TAKEAWAYS

Table 4 shows some statistical results from the analyses for the six case studies.

Table 4. Summary of case study results, 2014–2021.

Location	Operations Strategy	Change in Performance	Performance Measure Rule 3 (PM3) Measures[1]	Comments
Lake 90 (I-90) Ohio	Variable speed limits and messaging linked with Road Weather Information System, primarily for winter weather events	Little change in PM3 measures	*Measure: Before and After* Sys Rel:[2] 100%/100% Truck Travel Time Reliability (TTTR):[3] 1.112/1.131 Peak Hour Excessive Delay (PHED):[4] 4/11	Crashes dropped by 30% for 3 years prior versus 3 years after. Modeling showed that this reduction would result in saving 8,760 vehicle-hours of delay per year.
I–10, Arizona, rural section between Phoenix and Tucson	Variable speed limit and dust detection system, primarily for dust storms during the annual monsoon	Little change in PM3 performance measures	<u>Measure: Before and After</u> Sys Rel: 100%/100% TTTR: 1.076/1.105 PHED: 6/8	Expected effect of deployment is on crashes, especially severe ones, but crash data were not available.
I-85, Northeast Atlanta, GA	Automated Incident Detection	Improvement in system reliability and excessive delay measures, but may be due to lower average annual daily traffic (AADT) in the after period	<u>Measure: Before and After</u> Sys Rel: 63%/74% TTTR: 2.086/2.104 PHED: 1,856/1,196	Modeling showed that under constant demand, 306,600 annual vehicle-hours of delay were saved.
I-26, Asheville, NC	Aggressive incident management during reconstruction	Two of the three PM3 measures indicate a moderate decrease in performance	<u>Measure: Before and After</u> Sys Rel: 87%/87% TTTR: 2.094/2.302 PHED: 166/200	AADT increased by 11% from before to after periods, leading to decrease in performance. Modeling showed that under constant demand, 869,000 annual vehicle-hours of delay were saved.

Table 4. Summary of case study results, 2014-2021. (continuation)

Location	Operations Strategy	Change in Performance	Performance Measure Rule 3 (PM3) Measures[1]	Comments
I–35, Austin, TX	Aggressive performance monitoring and travel information during major work zone activity	Improvement of PM3 measures primarily due to lower demand in after period	Measure: Before and After Sys Rel: 35%/41% TTTR: 2.948/2.453 PHED: 7,161/3,885	Evaluation focused on full closure impacts—no significant change in performance during full closures.
OR-217, suburban Portland, OR	Curve warning system primarily during wet weather conditions	The PM3 measures showed improvement; however, other strategies were being deployed during this period	Measure: Before and After Sys Rel: 60%/76% PHED: 186/179	Modeling was used to compute the delay savings at the OR 217/US-26 interchange due to the Oregon Department of Transportation reported crash reduction. The delay savings for the two warning systems combined is 106,580 vehicle-hours per year.

[1]In addition to the PM3 measures, other travel time-based performance measures also were used to arrive at the conclusions in this table. These measures include percentile-based travel time indices (mean and 80th and 95th percentiles) and average speed.

[2]System Reliability: percent of facility that is "reliable."

[3]TTTR (Freight Reliability).

[4]PHED, in thousands of person-hours.

CASE STUDY DETAILS

This section provides details on the evaluations of the six case studies. The last three case studies are used as more indepth examples of the analyses conducted.

I–10, Arizona, Dust Detection System

Background

The I–10 corridor between Phoenix and Tucson, AZ, experiences seasonal dust storms as a result of the monsoons that frequent the area during summer months. These dust storms drastically reduce visibility and can catch unsuspecting drivers by surprise, causing hazardous conditions on I–10 for freight traffic and for passenger vehicles.

To combat these hazardous conditions, the Arizona Department of Transportation (ADOT) developed and deployed a dust detection system that uses weather sensors to detect drops in visibility levels (figure 2). There are 13 visibility sensors that detect dust and automatically activates a series of system updates and alerts to operators at the ADOT Traffic Operations Center. The alert then triggers a reduction in the posted speed limit on permanently installed VSL signs through the corridor. The speed limit on I–10 is 75 miles per hour (mph), and this can change to 35 mph depending on severity of the visibility impacts. Dynamic message signs (DMSs) display warnings to travelers to slow down and alert them about reduced speeds. The system was implemented in early 2020 for the start of the monsoon season (mid-June).

Before and After Periods

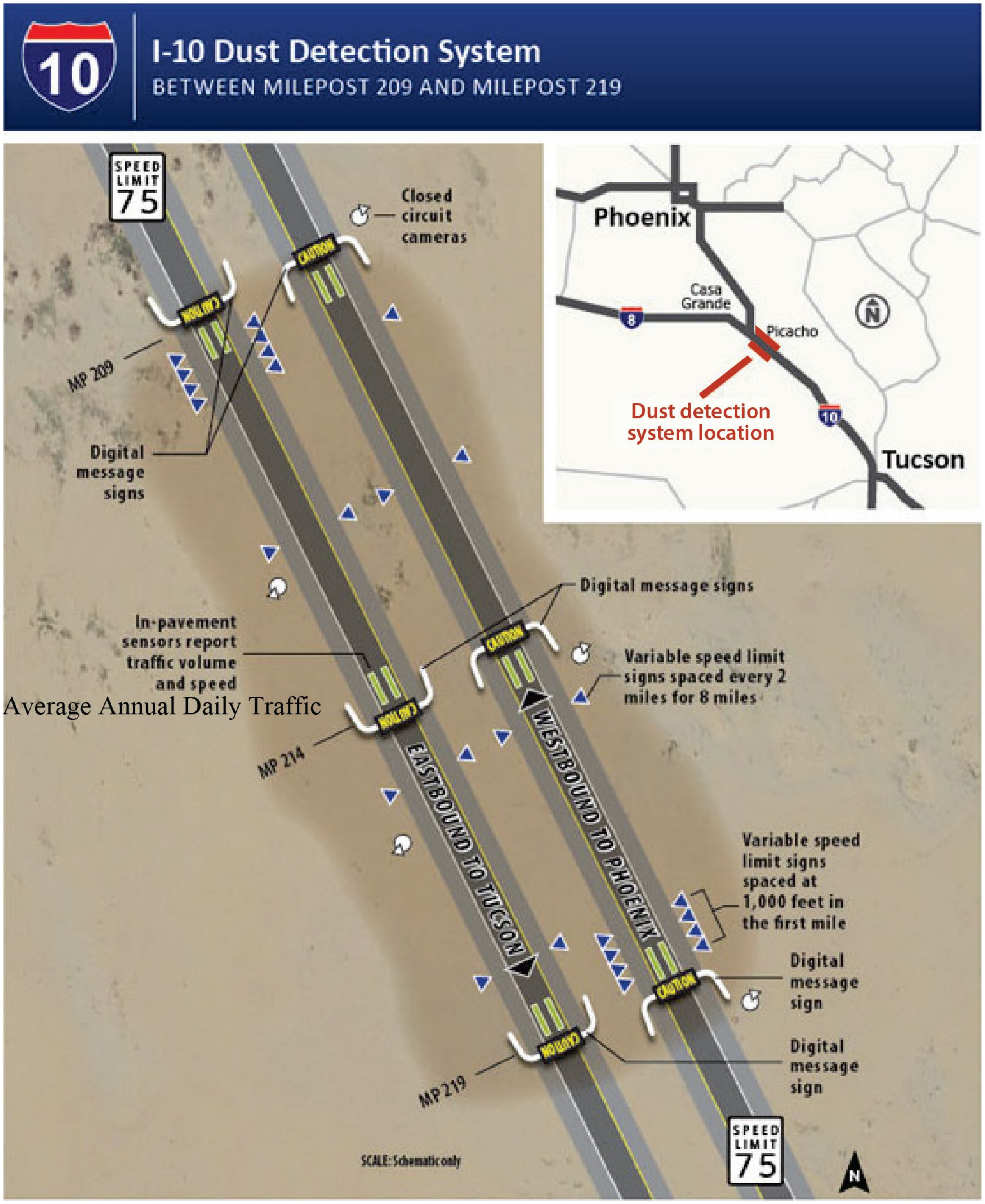
Analysis periods include complete years for the reliability measures plus the duration of the monsoon season when the dust detection system is expected to be highly active:

- Before: January 1, 2018–December 31, 2018
- After: January 1, 2021–December 31, 2021
- Before: June 15, 2018–September 30, 2018
- After: June 15, 2021–September 30, 2021, and June 15, 2022–September 30, 2022

Analysis

Congestion statistics are shown in table 5 and table 6. This section of I–10 is a rural Interstate with average annual daily traffic (AADT) around 50,000 and congestion is rare. Further analysis showed that the PM3 measures of system reliability and total excess delay do not reflect the occasional speed decreases observed during dust events as these are rare events over the course of a year. Focusing just on conditions during the monsoon season reveals the same uncongested pattern for the annual performance measures used (table 7).

In summary, the I–10 dust detection system is targeted on specific rare events that have the potential to be catastrophic from a safety viewpoint. As a result, annual travel time performance is not appreciably affected.



MP = mile post

Source: ADOT.

Figure 2. Map. Schematic and location of I–10 dust detection system.

Table 5. Congestion statistics on I–10.

Direction	Performance Measure	Year				
		2018	2019	2020	2021	2022
Eastbound AM Peak	Average speed	67.9	67.4	69.7	72.3	73.5
	Mean travel time index (MTTI)	1.119	1.127	1.091	1.051	1.035
	P80 travel time index (TTI)	1.135	1.158	1.110	1.060	1.042
	Planning time index (PTI)	1.154	1.182	1.132	1.084	1.063
	% congested	0.03	0.03	0.00	0.46	0.02
Eastbound AM Peak	Average speed	66.9	67.3	69.4	71.3	71.2
	MTTI	1.136	1.130	1.094	1.065	1.067
	P80 TTI	1.140	1.158	1.111	1.071	1.049
	PTI	1.172	1.187	1.133	1.100	1.081
	% congested	0.51	0.13	0.05	0.59	0.45
Westbound AM Peak	Average speed	67.5	67.3	69.7	72.9	73.5
	MTTI	1.126	1.130	1.090	1.042	1.034
	P80 TTI	1.145	1.159	1.112	1.056	1.038
	PTI	1.172	1.188	1.135	1.078	1.062
	% congested	0.00	0.02	0.02	0.00	0.00
Westbound PM Peak	Average speed	67.3	67.2	69.7	72.5	72.6
	MTTI	1.129	1.131	1.090	1.048	1.046
	P80 TTI	1.145	1.155	1.107	1.069	1.046
	PTI	1.179	1.182	1.130	1.098	1.077
	% congested	0.26	0.13	0.13	0.03	0.40

Table 6. Congestion modeling results on I–10.

Performance Measure	Year				
	2018	2019	2020	2021	2022
Average annual daily traffic	49,798	54,631	44,705	54,549	N/A
System reliability (%)	100.0	100.0	100.0	100.0	100.0
Freight reliability	1.076	1.093	1.069	1.090	1.105
Total excessive delay	5,629	1,718	1,425	4,128	7,774

Table 7. Congestion statistics during monsoon season on I–10.

Direction	Performance Measure	Year		
		2018	2021	2022
Eastbound AM Peak	Average speed	68.2	72.8	73.6
	Mean travel time index (MTTI)	1.115	1.044	1.032
	P80 travel time index (TTI)	1.132	1.058	1.035
	Planning time index (PTI)	1.148	1.084	1.055
	% congested	0.00	0.00	0.00
Eastbound AM Peak	Average speed	67.7	72.3	73.3
	MTTI	1.122	1.052	1.037
	P80 TTI	1.140	1.070	1.044
	PTI	1.166	1.097	1.076
	% congested	0.16	0.11	0.00
Westbound AM Peak	Average speed	67.8	72.9	73.6
	MTTI	1.122	1.042	1.032
	P80 TTI	1.139	1.056	1.036
	PTI	1.160	1.079	1.058
	% congested	0.00	0.00	0.00
Westbound PM Peak	Average speed	68.0	72.6	73.3
	MTTI	1.117	1.046	1.037
	P80 TTI	1.136	1.065	1.039
	PTI	1.161	1.095	1.074
	% congested	0.00	0.00	0.00

I–35 Capital Express Smart Work Zone (SWZ) Management in Austin, TX

Background

The I–35 corridor through Austin, TX, handles a significant volume of traffic and experiences congestion daily. Texas Department of Transportation (TxDOT) currently is widening I–35 through various projects[10], including preliminary projects to improve interchanges, and supporting overpasses to better accommodate detours and traffic management during later mainline construction. Through various projects, TxDOT is partnering with the city to develop alternate routing strategies for full-closure events and developing strategies to manage traffic during partial closures for active work zones. One of the critical components of this project is management of traffic during the roadway widening, as the corridor is already over capacity at

[10]This case study was conducted prior to any litigation regarding I–35.

peak hours during the day and construction has a well-documented negative impact on vehicle throughput.

To alleviate some of the congestion caused by traditional lane closures, TxDOT implemented work zone management techniques, including full road closures and SWZ devices (during full closures and partial closures). The deployment of SWZ technology allowed for TxDOT and its contractor to understand the effects of these closures on traffic, better plan for future closures, and present these data to decisionmakers and influential stakeholders in a simplistic way. This strategy is focused on significantly reducing the nonrecurring congestion associated with the multiyear construction program.

To ameliorate the delay and safety impacts of these work zones, TxDOT has implemented a comprehensive SWZ program that includes multiple strategies:

- Real-time queue warning
- Lane and road closure information
- Current travel time information: point-to-point travel times obtained via Bluetooth® technology, presented for short distances ahead throughout the corridor. Travel times are automatically updated every 5 minutes.
- Expected construction delay information
- Volume and spot speed data
- Traffic cameras at high incident locations
- Portable changeable message signs to display travel time and alerts

Before and After Periods

This deployment is unique for this study in that a before condition for comparing the effect of the SWZ is to a work zone with no active management. Also, the "after" period is really the construction period, not the postconstruction period as for the other types of nonrecurring operations strategies studied. A comparison can be made between preconstruction and construction conditions to understand the performance difference between the work zone ***with*** SWZ management techniques and no work zone, but that does not indicate how much more effective the SWZ is at improving performance compared with no active management. Therefore, the approach described in the following Analysis section was taken.

Analysis

The team took a two-pronged approach to analyze the Capital Express deployment. First, performance measures for the usual annual periods were computed. The team considered I–35 and two alternative routes, since traveler information was part of the Capital Express deployment: TX-1 Loop on the westside and US-183 on the east side. Second, the impact of the full freeway closures that occurred during the study period was examined. To do this, performance during the times of closures were compared with the same time periods for the previous weeks to see if a change in performance could be detected. The entire 25-mile study section was used, not just the area near the full closures, to gauge the system effects.

The anticipated effect of Capital Express is on the full-closure events. Seven events were studied (table 8 to table 14). No reliability measures were computed because of the limited times studied. For most cases, travel time performance during the full closures were similar to the previous weeks' performance; only one major exception was found on I–35. Part of the reason is that the closures were planned primarily for offpeak hours but would occasionally spill over to other parts of the day.

Table 8. I–35 full closure at St. Johns Bridge (9:00 a.m. May 31, 2019–-5:30 a.m. June 3, 2019).

Road	Direction	Before		During	
		Avg Speed Sum	Mean Travel Time Index (MTTI) Sum	Avg Speed Sum	MTTI Sum
I–35 North	Northbound	61.469	1.139	61.363	1.141
	Southbound	62.536	1.119	59.339	1.180
I–35 South	Northbound	64.111	1.092	65.314	1.072
	Southbound	63.089	1.110	63.974	1.094
TX-1 Loop	Northbound	62.036	1.128	62.477	1.120
	Southbound	56.112	1.247	53.546	1.307
US-183	Northbound	53.354	1.312	53.441	1.310
	Southbound	56.672	1.235	58.711	1.192

Avg = average

Table 9. I–35 full closure at St. Johns Bridge2 (9:00 p.m. December 4, 2018–5:00 a.m. December 5, 2018).

Road	Direction	Before		During	
		Avg Speed Sum	Mean Travel Time Index (MTTI) Sum	Avg Speed Sum	MTTI Sum
I–35 North	Northbound	62.363	1.122	63.733	1.098
	Southbound	62.168	1.126	65.480	1.069
I–35 South	Northbound	64.125	1.092	63.537	1.102
	Southbound	62.962	1.112	63.595	1.101
TX-1 Loop	Northbound	58.175	1.203	45.977	1.523
	Southbound	62.786	1.115	61.438	1.139
US-183	Northbound	51.781	1.352	52.409	1.336
	Southbound	55.976	1.251	42.579	1.644

Avg = average

Table 10. I–35 full closure at William Cannon (10:00 p.m. July 27, 2018–10:00 a.m. July 29, 2018).

Road	Direction	Before		During	
		Avg Speed Sum	Mean Travel Time Index (MTTI) Sum	Avg Speed Sum	MTTI Sum
I–35 North	Northbound	61.542	1.137	62.572	1.119
	Southbound	63.038	1.110	62.327	1.123
I–35 South	Northbound	63.032	1.111	58.635	1.194
	Southbound	61.948	1.130	53.641	1.305
TX-1 Loop	Northbound	60.228	1.162	54.345	1.288
	Southbound	57.141	1.225	58.073	1.205
US-183	Northbound	57.058	1.227	50.396	1.389
	Southbound	52.747	1.327	56.573	1.237

Avg = average

Table 11. I–35 full closure at William Cannon2 (11:00 p.m. May 11, 2018–4:00 a.m. May 12, 2018).

Road	Direction	Before		During	
		Avg Speed Sum	Mean Travel Time Index (MTTI) Sum	Avg Speed Sum	MTTI Sum
I–35 North	Northbound	61.372	1.141	62.982	1.111
	Southbound	61.622	1.136	62.899	1.113
I–35 South	Northbound	64.559	1.084	61.525	1.138
	Southbound	60.975	1.148	61.425	1.140
TX-1 Loop	Northbound	62.429	1.121	60.912	1.149
	Southbound	61.399	1.140	52.440	1.335
US-183	Northbound	53.087	1.319	55.208	1.268
	Southbound	55.409	1.263	56.210	1.245

Avg = average

Table 12. I–35 full closure at Ben White (Nightly 8:00 p.m. August 23, 2019–10:00 a.m. August 25, 2019).

Road	Direction	Before		During	
		Avg Speed Sum	Mean Travel Time Index (MTTI) Sum	Avg Speed Sum	MTTI Sum
I–35 North	Northbound	63.265	1.106	58.139	1.204
	Southbound	61.984	1.129	64.516	1.085
I–35 South	Northbound	63.841	1.096	57.954	1.208
	Southbound	64.285	1.089	60.209	1.163
TX-1 Loop	Northbound	56.422	1.241	54.801	1.277
	Southbound	57.549	1.216	54.588	1.282
US-183	Northbound	52.277	1.339	51.262	1.366
	Southbound	58.528	1.196	59.564	1.175

Avg = average

Table 13. I–35 full closure at Braker (10:00 p.m. December 2, 2019–5:00 a.m. December 3, 2019).

Road	Direction	Before		During	
		Avg Speed Sum	Mean Travel Time Index (MTTI) Sum	Avg Speed Sum	MTTI Sum
I–35 North	Northbound	62.314	1.123	41.629	1.682
	Southbound	64.402	1.087	55.933	1.251
I–35 South	Northbound	65.036	1.076	55.539	1.260
	Southbound	65.397	1.070	64.388	1.087
TX-1 Loop	Northbound	57.998	1.207	57.936	1.208
	Southbound	66.270	1.056	58.524	1.196
US-183	Northbound	56.012	1.250	53.465	1.309
	Southbound	56.240	1.245	56.869	1.231

Avg = average

Table 14. I–35 full closure at Oltorf (10:00 p.m. May 19, 2018–4:00 a.m. May 21, 2018).

Road	Direction	Before		During	
		Avg Speed Sum	Mean Travel Time Index (MTTI) Sum	Avg Speed Sum	MTTI Sum
I–35 North	Northbound	62.784	1.115	62.313	1.123
	Southbound	63.218	1.107	63.184	1.108
I–35 South	Northbound	65.012	1.077	63.087	1.110
	Southbound	63.320	1.105	62.505	1.120
TX-1 Loop	Northbound	60.248	1.162	65.794	1.064
	Southbound	62.345	1.123	56.681	1.235
US-183	Northbound	54.716	1.565	53.526	1.308
	Southbound	55.308	1.266	59.569	1.175

Avg = average

OR 217 in Portland, OR—Curve Warning System for Freeway Ramps

Background

The Oregon Department of Transportation (ODOT) has implemented a comprehensive Active Traffic Management (ATM) system on OR 217 in the Portland metropolitan area. The ATM strategies address both recurring and nonrecurring congestion issues. One of these strategies is the dynamic curve warning systems, which are activated when inclement weather affects safety of traffic navigating the ramp loops.

OR 217 is a 7.5-mile highway that connects I-5 and US-26 in the Portland metropolitan area. It is a highly congested corridor, particularly during peak periods, and there is limited right-of-way for capacity enhancements. ODOT implemented an ATM pilot in 2013 that includes a range of strategies, including advisory VSLs, adaptive ramp metering, and queue warning. Inclement weather causes additional safety issues. Advisory speed limits are automatically calculated and displayed for both congestion (in conjunction with queue warning), as well as during inclement weather. ODOT's evaluation of the OR 217 showed that motorist compliance was better with weather-related advisory speeds than with congestion-related advisory speeds.

The curve warning system activates flashers and a dynamic warning sign to indicate conditions on ramp loops are high risk due to pavement conditions (primarily rain and ice). A key objective for the curve warning system was to reduce crashes on ramp loops. ODOT studied before and after crash data, and a significant decrease in the number and severity of crashes occurred at the sites where the dynamic curve warning was deployed:

- 40–60 percent reduction in crashes overall
- 70–92 percent reduction in crash severity

ODOT's evaluation noted that there was an 11 percent overall reduction of crashes within the OR-217 corridor, but the curve warning system showed a significantly higher percentage of crash reduction in those specific ramp loop locations:

- 40–60 percent reduction in crashes overall
- 70–92 percent reduction in crash severity

Before and After Periods

- Before: January 1, 2013–December 31, 2013
- After: January 1, 2015–December 31, 2015; January 1, 2017–December 31, 2017

Analysis

The two curve warning systems are on loop ramps at the OR 217 and US-26 interchange, both of which are off-ramps from US-26. Thus, the effect of crash reductions will be primarily felt on US-26. Since the queues will spill back from the interchange, the effects will be felt in the westbound direction upstream to I-405 and in the eastbound direction from the interchange upstream to NW 185th Ave. Congestion conditions improved in the 2018–2022 period (eliminating 2020) compared with the 2014–2017 period on both US-26 (table 15) and OR-217.

For the effect of the curve warning systems at the US-26 and OR 217 interchange, the project team used modeling to compute the delay savings due to the ODOT reported crash reduction. The delay savings for the two warning systems combined is 292 vehicle-hours per day (106,580 vehicle-hours per year).

Table 15. Congestion statistics on US-26.

Direction	Performance Measures	Year								
		2014	2015	2016	2017	2018	2019	2020	2021	2022
Eastbound AM Peak	Avg speed	38.0	53.2	35.7	19.2	41.5	39.6	51.1	49.2	47.8
	Mean travel time index (MTTI)	1.736	1.240	1.849	3.434	1.592	1.665	1.292	1.343	1.380
	P80 travel time index (TTI)	1.711	1.248	2.151	4.593	1.906	2.015	1.233	1.404	1.537
	Planning time index (PTI)	4.527	2.368	4.319	10.353	2.750	2.969	2.129	2.215	2.295
	% congested	25.03	14.24	37.38	73.55	39.92	48.73	11.90	17.72	22.90
Eastbound PM Peak	Avg speed	35.1	54.6	35.9	32.5	37.6	32.4	44.6	42.4	38.0
	MTTI	1.882	1.209	1.841	2.029	1.755	2.037	1.481	1.557	1.735
	P80 TTI	1.912	1.138	1.955	2.401	2.188	2.579	1.842	1.914	2.216
	PTI	4.566	2.188	3.254	4.123	3.028	3.091	2.589	2.566	3.078
	% congested	28.79	11.12	36.02	66.24	57.71	76.80	34.01	41.99	53.02
	Average annual daily traffic (AADT) (1-way)	68,030	69,740	73,050	73,877	73,703	78,735	65,371	70,520	N/A
	System reliability (%)	100.0	100.0	22.0	12.1	47.5	40.5	95.2	100.0	68.1
	Total excessive delay	N/A	N/A	N/A	N/A	178,550	293,711	100,342	108,841	175,049
Westbound AM Peak	Avg speed	53.5	37.6	54.2	46.5	56.4	57.4	59.3	58.9	59.7
	MTTI	1.233	1.757	1.217	1.418	1.170	1.150	1.114	1.120	1.105
	P80 TTI	1.252	2.243	1.260	1.610	1.222	1.181	1.150	1.154	1.135
	PTI	1.405	3.098	1.440	2.237	1.343	1.288	1.223	1.215	1.199
	% congested	3.79	55.25	4.74	26.86	2.19	1.89	0.68	0.82	0.64
Westbound PM Peak	Avg speed	48.4	38.7	46.7	41.4	48.7	50.9	57.3	53.7	55.0
	MTTI	1.364	1.703	1.412	1.593	1.355	1.298	1.151	1.230	1.200
	P80 TTI	1.320	2.151	1.412	1.941	1.441	1.380	1.190	1.286	1.253
	PTI	1.738	3.421	1.940	2.640	1.786	1.758	1.366	1.479	1.412

Table 15. Congestion statistics on US-26. (continuation)

Direction	Performance Measures	Year								
		2014	2015	2016	2017	2018	2019	2020	2021	2022
	% congested	10.51	41.89	17.10	38.88	17.96	13.89	3.19	5.34	3.82
	AADT (1-way)	68,065	69,095	72,350	73,197	73,025	71,050	57,974	64,460	N/A
	System reliability (%)	100.0	66.2	100.0	76.6	100.0	100.0	100.0	100.0	100.0
	Total excessive delay	N/A	N/A	N/A	N/A	7,014	9,019	2,123	2,019	4,394

Avg = average

In this section, three examples of how operations strategies are analyzed across the project development continuum are presented, using the structure presented in figure 1 as a guide. Most of the project development stages are defined elsewhere. For example, researchers at FHWA have developed numerous guidance documents for incorporating operations into transportation planning[11] and traffic analysis tools.[12] Herein the project team offers only cursory guidance for these topics and instead focus heavily on the evaluation stage.

EXAMPLE 1: VARIABLE SPEED LIMITS DURING SNOW AND ICE EVENTS: THE LAKE 90 SYSTEM IN OHIO

Problem Identification

Planning Process

Lake-effect snow squalls on the eastern and southern end of the Great Lakes can form suddenly and drop copious snow. They form as bands of snow in otherwise fair weather when very cold air is blown across the unfrozen lakes. The edge of these bands is tightly defined: It can be clear at one point but snowing profusely several hundred yards away in the snow band. The intensity and unexpectedness of these lake effect snow squalls can be extremely hazardous for travelers, especially on interstates where speeds are high. As a result of a lake effect snow event in December 2016 that caused a 50-car pileup and a full closure for 14 hours, the Ohio DOT planned a deployment that combined Road Weather Information System (RWIS) detectors and VSLs to warn travelers and reduce their speeds to improve reaction time. The system was dubbed "Lake 90" because it covers I-90 on the southern shore of Lake Erie.

Models or Analytical Process Used: Ohio DOT did not use any modeling tools to deploy Lake 90. Rather, it reviewed winter crashes and available weather records to identify the extent of I-90 that should be covered by RWIS and VSL.

Congestion Monitoring

In addition to long-range planning, planners and operators also monitor current conditions and past trends to identify deficiencies of immediate concern. Deficiencies identified from current conditions may or may not match those identified by long-range forecasts. For this example, the same freeway segment identified in the long-range planning process is assumed to be also experiencing current congestion problems.

Data Used: Travel time data from vehicle probes have become nearly ubiquitous in the professions and are the data source of choice for congestion monitoring.

Benefit/Cost Analysis: This analysis is generally not performed at this stage.

[11] https://ops.fhwa.dot.gov/plan4ops/index.htm.
[12] https://ops.fhwa.dot.gov/trafficanalysistools/index.htm.

Project Level Goals and Objectives

Matching Deficiency to an Operations Treatment: At this stage, the particulars of individual projects are defined. In this example, a freeway segment has been defined as a current problem from crash and weather analysis. Therefore, a strategy specifically focused on reducing crashes during winter weather events is chosen.

Goals, Objectives, Strategies, and Tactics: For the ramp metering treatment, the project team defines:

- Goal—to improve safety on the freeway facility
- Objective—to reduce the occurrence of winter weather crashes, especially multiple car pileups
- Strategy—Variable Messaging System (VMS) warnings and VSL
- Tactics—applied when winter weather conditions are about to occur

Evaluation

Define Geographic Scope: A 12.5-mile segment of I-90 in Lake County, OH.

Define Analysis Periods: The PM3 measures have defined analysis periods. For the remaining performance measures, 7:00–9:00 a.m. and 4:00–6:00 p.m. on weekdays were defined as the two peak periods. The before and after periods for the comparison of results are:

- Before: October 1, 2016–September 30, 2017
- After: October 1, 2019–September 30, 2020, and October 1, 2021–September 30, 2022

Assemble Data: Data for the evaluation were assembled and appear in table 16. The NPMRDS data were used to develop performance measures at this stage. Computations for the PM3 measures are prescribed in the PM3 final rule. For the other performance measures from table 16, the starting point is the creation of a travel time distribution where each observation is travel time over the entire length of the facility.

Table 16. Data for Lake 90 evaluation.

Data Type	Source	Description
Travel time	National Performance Management Research Data Set	Probe-based travel times
Crashes	Ohio Department of Transportation (DOT)	From Ohio DOT crash system
Volume	Ohio DOT and Highway Performance Monitoring System	Continuous counter on I-90; short counts elsewhere
Weather	Ohio DOT	Road Weather Information System stations

For every timestamp in the data, travel times for Traffic Message Channels (TMCs) are summed. This step requires addressing TMCs with missing values for a time stamp. This procedure was used: if at least 75 percent of the facility length is present, factor up the travel times based on length. If not, delete the record.

Table 17 compares the performance measures for the before and after periods. Taken as a group, the naïve analysis indicates little change in performance due to the Lake 90 project, with most measures showing a small decrease in performance. As a rural Interstate (AADT = 44,000) congested conditions are rare. In terms of the PM3 measures, system reliability is computed as 100 percent and the total excessive delay is exceptionally low. The primary purpose of the VSL system is not to avoid traffic breakdowns due to smoother flow at high volume levels but rather to avoid crashes. In the case of Lake 90, crashes during lake effect snowstorms have the potential to be severe. During these events, drivers may be in bright sunshine one minute and in the middle of a fierce snow band a few minutes later.

Table 17. Performance measures on Lake 90, 2016–2022.

Direction	Performance Measure	Analysis		
		Before	After1	After2
Eastbound AM Peak	Avg speed	64.8	67.0	69.6
	Mean travel time index (MTTI)	1.111	1.075	1.035
	P80 travel time index (TTI)	1.130	1.094	1.043
	Planning time index (PTI)	1.184	1.141	1.096
	% congested	0.65	0.03	0.61
Eastbound PM Peak	Avg speed	63.0	66.9	70.1
	MTTI	1.144	1.076	1.027
	P80 TTI	1.123	1.086	1.022
	PTI	1.159	1.123	1.065
	% congested	0.92	0.41	0.86
	System reliability (%)	100.0	100.0	100.0
	Total excessive delay	3,705	9,252	12,482
Westbound AM Peak	Avg speed	64.9	67.0	70.2
	MTTI	1.109	1.075	1.026
	P80 TTI	1.120	1.092	1.019
	PTI	1.183	1.134	1.080
	% congested	0.93	0.27	0.93
Westbound PM Peak	Avg speed	64.4	66.8	69.3
	MTTI	1.118	1.078	1.039
	P80 TTI	1.122	1.092	1.036
	PTI	1.148	1.124	1.066
	% congested	0.16	0.21	0.67

Table 17. Performance measures on Lake 90, 2016–2022. (continuation)

Direction	Performance Measure	Analysis		
		Before	After1	After2
	System reliability (%)	100.0	100.0	100.0
	Freight reliability	1.112	1.098	1.131
	Total excessive delay	4,402	3,695	11,355

Avg = average

Traffic volumes (AADT) are relatively consistent between the periods. To understand how the Lake 90 system performed during times when crashes or winter weather disruptions were present, crash and weather data were compiled. The crash analysis revealed that crashes have declined on this section of I-90 over the past 8 years (table 18). Excluding 2020, the reduction in crashes from 2015–2017 to 2019–2021 is 24 percent. The effect of these reduced crashes did not appear in the annual congestion statistics.

Conduct Modeling if Conditions Warrant: To understand better the effect that crash reduction had on travel times, the QSIM model was used (see the appendix). QSIM models the cumulative impact of incidents over time by incident type. The project team only studied crashes and the 24 percent reduction was used for the after case. The team found the change in daily delay rate to be 0.049 hour per thousand vehicle miles, which translates to 24 vehicle-hours per day on average, or 8,760 vehicle-hours per year.

Table 18. Annual crashes and crash rates.

Year	Facility Length	Annual Crashes	Average Annual Daily Traffic	Rate per 100 Million Vehicle Miles
2014	12.507	140	N/A	—
2015	12.507	137	43,183	69.50
2016	12.507	151	42,487	77.85
2017	12.507	95	43,573	47.76
2018	12.507	N/A	N/A	N/A
2019	12.507	112	43,472	56.44
2020	12.507	72	36,693	42.98
2021	12.507	85	43,787	42.52

— = no data

Net Present Value Analysis: Table 19 presents the net present value (NPV) analysis, assuming a 10-year project life on the field equipment. Both travel time savings and crash reductions were studied. For crashes, the project team assumed that the crash rate was reduced from 65 per 100 million vehicle-miles to 55 per 100 million vehicle-miles based on the data in table 18. The NPV of the Lake 90 deployment is more than $14.5 million for the 10-year period.

Table 19 Net Present Value analysis for Lake 90.

Year	Average Annual Daily Traffic	Travel Time		Crashes		Construction Costs ($)	Operations & Maintenance Costs (+5% per Year) ($)	Net Present Value at 7% ($)
		Value of Savings ($)	Discounted Savings ($)	Value of Savings ($)	Discounted Savings ($)			
2018	43,000	–	–	–	–	3,040,500	–	-3,040,500
2019	43,472	164,688	153,914	2,557,746	2,390,417	–	135,000	2,409,331
2020	36,693	139,007	121,414	2,158,893	1,885,660	–	141,750	1,865,324
2021	43,787	165,881	135,409	2,576,280	2,103,012	–	148,838	2,089,583
2022	44,225	167,540	127,816	2,602,042	1,985,086	–	156,279	1,956,622
2023	44,667	169,216	120,648	2,628,063	1,873,772	–	164,093	1,830,327
2024	45,114	170,908	113,883	2,654,343	1,768,701	–	172,298	1,710,286
2025	45,565	172,617	107,497	2,680,887	1,669,522	–	180,913	1,596,106
2026	46,021	174,343	101,469	2,707,696	1,575,904	–	189,959	1,487,414
2027	46,481	176,086	95,779	2,734,773	1,487,535	–	199,456	1,383,858
2028	46,946	177,847	90,409	2,762,120	1,404,122	–	209,429	1,285,101
Total	–	–	–	–	–	–	–	14,573,452

– = no data

EXAMPLE 2: AUTOMATED INCIDENT DETECTION: I-85 IN ATLANTA, GA

Problem Identification

Planning Process

Agencies use several methods to identify incidents on routes covered by incident management. The majority of notifications come from motorist calls and reports, with additional notifications from police/911 and service patrol reports. A small percentage of incidents are initially identified by operators scanning the network for anomalies. However, monitoring and analyzing the overwhelming quantity of camera data without assistive automated methods can be unmanageable. Using AI, models can be trained to enhance images and provide robust detection and classification of traffic incidents, resulting in reduced duration of incidents.

Models or Analytical Process Used: Some models are used to study the impact of reduced incident detection times on total incident duration and the associated impacts on congestion. Microscopic traffic simulation models are the most accurate, but individual incidents may have to be studied at different demand levels and can be cumbersome to use. The HCM's reliability procedure, as a macroscopic approach, can provide the cumulative effect of reducing incidents across an entire year.

Performance Measures Used: Congestion measures developed by the HCM procedure include most of the measures shown in table 3. Notably, the PM3 measures are not developed directly by HCM.

Data Used: The operation of simulation models and their required data in support of planning activities are well documented in the profession. Observed volumes from field measurements are used as input, and field measured speeds are used for calibration.

Benefit/Cost Analysis for projects listed in planning documents are necessarily simple because little is known about project details. Benefits are generally derived from the change in delay predicted by the HCM for capacity expansion projects, but the benefits of operations strategies at this stage of the project development continuum may not be established. Costs are derived from general unit costs for diverse types of improvements rather than for the specifics of projects.

Congestion Monitoring

In addition to long-range planning, planners and operators also monitor current conditions and past trends to identify deficiencies of immediate concern.

Performance Measures Used: When empirical travel time data are used, agencies use a wide variety of performance measures, including the PM3 measures and the measures in table 6 to monitor congestion.

Models or Analytical Process Used: Data analysis software is used to compile performance measures from travel time data. A detailed look at the data indicates that queues routinely form at several on-ramp locations in both the morning and afternoon weekday peak periods, depending on direction.

Data Used: Travel time data from vehicle probes have become nearly ubiquitous in the professions and are the data source of choice for congestion monitoring.

Benefit/Cost Analysis is generally not performed at this stage.

Project Level Goals and Objectives

Matching Deficiency to an Operations Treatment: At this stage, the particulars of individual projects are defined. In this example, a freeway segment has been defined as a current problem (from congestion monitoring) that is expected to worsen over time (from long-range planning). In this example, aggressive operations deployments are preferred to capacity expansion.

Goals, Objectives, Strategies, and Tactics: For ramp metering treatment, the project team defines:

- Goal—to improve travel times on the freeway facility
- Objective—to reduce peak-period congestion by improving peak period speeds by 15 percent
- Strategy—automated incident detection
- Tactics—applied universally throughout the day

Design and Implementation

At the design stage, detailed traffic modeling is usually performed to quantify expected benefits.

Performance Measures Used: Delay, speed, and travel time are common performance measures for traffic analysis tools. The development of reliability measures is not yet routine, but several of the Strategic Highway Research Program 2 (SHRP2) research projects developed methods to produce reliability measures using traffic analysis tools. The PM3 measures are difficult to produce, primarily because they require mixing peak and offpeak conditions, whereas most traffic analysis tool applications focus on peak periods.

Models or Analytical Process Used: Macroscopic, mesoscopic, and microscopic traffic analysis tools are used for traffic modeling here.

Data Used: Traffic models require detailed data for inputs and calibration, and these data are the same as data used in evaluations: traffic volumes, travel times, and characteristics of incidents and weather. The data can be used in cluster analysis as an aid to calibration.

Evaluation

Before and After Periods

- Before: January 1, 2019–December 31, 2019
- After: January 1, 2021–December 31, 2021

Table 20 shows the high variability in traffic volumes over the study period, including the falloff of traffic during the COVID-19 pandemic and the recovery in 2021, which is still lower than prepandemic levels. (This pattern is common throughout the United States.)[13]

Table 21 to table 23 show the congestion statistics for the I-85 study section and the modeling results. The data indicate an improvement in travel time-related performance from the before period (2019) to the after period (2021). However, these results are confounded by the drop in both AADT and crashes over the analysis period. Table 24 shows more detail on the PM3 System Reliability measure, indicating that two TMCs (101+04256 and 101-04254, shown in *italics*) were responsible for the increase in system reliability from 2019 to 2021.

Table 20. Traffic volumes on I-85.

Traffic Metric	2021	2020	2019
Average Annual Daily Traffic (AADT)	295,000	274,000	306,000
Single Unit AADT	7,226	6,404	6,077
Combination Unit AADT	25,302	22,615	21,734
Truck %	11	11	9

Table 21. Congestion statistics on I-85.

Direction	Performance Measure	Year 2019	Year 2021
Northbound AM Peak	Avg speed	63.6	62.2
	Mean travel time index (MTTI)	1.195	1.222
	P80 travel time index (TTI)	1.211	1.211
	Planning time index (PTI)	1.270	1.362
Northbound PM Peak	Avg speed	30.6	34.2
	MTTI	2.485	2.224
	P80 TTI	2.791	2.574
	PTI	3.290	3.352
Southbound AM Peak	Avg speed	32.5	49.0
	MTTI	2.338	1.550
	P80 TTI	2.815	1.755
	PTI	3.700	2.355
Southbound PM Peak	Avg speed	55.7	51.4
	MTTI	1.366	1.479

[13] https://www.fhwa.dot.gov/policyinformation/travel_monitoring/22dectvt/figure3.cfm.

Direction	Performance Measure	Year 2019	Year 2021
	P80 TTI	1.414	1.527
	PTI	1.920	2.471

Avg = average

Table 22. Congestion modeling results on I-85.

Performance Measure	Year 2019	Year 2021
System Reliability (%)	62.9	74.3
Freight Reliability	2.086	2.104
Total Excess Delay	1,855,938	1,196,327
Number of Crashes	1,604	1,427
Crash Rate (per Million Vehicle-Miles)	1.48	1.28
Average Annual Daily Traffic	306,000	297,000

Table 23. Modeling of Automated Incident Detection results on I-85, 2019–2021.

Performance Measure	No Automated Incident Detection	With Automated Incident Detection
Average Incident Duration (minute)	34.0	25.1
Daily Speed	46.7	48.0
Peak Speed	28.8	30.0
System Reliability	50%	50%

Table 24. Performance of individual Traffic Message Channels on I-85, 2019–2021.

Traffic Message Channel	Metric	Before Period				After Period			
		AM	Midday	PM	Night	AM	Midday	PM	Night
101+04255	P50	16.0	17.3	48.6	16.0	15.7	17.0	35.2	15.7
101+04255	P80	16.5	31.9	68.1	18.2	16.5	29.2	53.8	18.6
101+04255	LOTTR	1.03	1.84	1.40	1.14	1.05	1.71	1.53	1.18
101P04255	P50	12.4	13.4	34.5	12.4	12.4	13.2	24.8	12.2
101P04255	P80	12.8	22.6	49.5	14.2	12.8	20.9	39.6	14.4
101P04255	LOTTR	1.03	1.69	1.44	1.14	1.03	1.58	1.60	1.18
101+04256	P50	92.7	100.7	224.6	92.7	92.7	100.7	166.9	94.2
101+04256	P80	95.8	162.2	292.0	114.5	97.4	146.0	243.4	119.2
101+04256	*LOTTR*	*1.03*	*1.61*	*1.30*	*1.24*	*1.05*	*1.45*	*1.46*	*1.27*
101P04256	P50	44.0	47.7	93.8	44.0	42.0	46.1	76.0	42.0
101P04256	P80	45.4	82.7	122.3	68.6	44.0	76.0	108.2	63.9
101P04256	LOTTR	1.03	1.74	1.30	1.56	1.05	1.65	1.42	1.52
101+04257	P50	82.9	89.9	160.7	82.9	81.6	89.9	132.6	82.9
101+04257	P80	85.5	117.8	204.0	104.0	85.5	115.3	176.8	104.0
101+04257	LOTTR	1.03	1.31	1.27	1.25	1.05	1.28	1.33	1.25
101P04257	P50	36.1	38.4	58.6	36.1	36.1	38.4	51.0	36.1
101P04257	P80	37.2	43.4	71.0	38.4	37.2	42.6	65.1	38.4
101P04257	LOTTR	1.03	1.13	1.21	1.07	1.03	1.11	1.28	1.07
101+04258	P50	26.5	27.8	38.6	26.5	26.5	27.8	33.3	26.5
101+04258	P80	27.4	31.4	45.9	28.3	27.8	30.9	43.5	28.3
101+04258	LOTTR	1.03	1.13	1.19	1.07	1.05	1.11	1.31	1.07
101P04258	P50	35.8	37.5	47.7	35.2	33.7	36.3	42.4	34.2
101P04258	P80	36.9	40.9	54.5	37.5	36.3	40.9	55.8	36.9
101P04258	LOTTR	1.03	1.09	1.14	1.07	1.08	1.12	1.32	1.08

Table 24. Performance of individual Traffic Message Channels on I-85, 2019–2021. (continuation)

Traffic Message Channel	Metric	Before Period				After Period			
		AM	Midday	PM	Night	AM	Midday	PM	Night
101+04259	P50	40.7	42.1	49.2	40.1	41.4	42.7	48.3	40.7
101+04259	P80	42.1	45.0	56.7	42.1	42.7	46.6	62.1	43.5
101+04259	LOTTR	1.03	1.07	1.15	1.05	1.03	1.09	1.29	1.07
101P04259	P50	25.1	25.5	28.2	24.3	25.1	25.9	29.3	24.7
101P04259	P80	25.9	27.3	32.3	25.5	26.4	27.8	34.4	26.4
101P04259	LOTTR	1.03	1.07	1.14	1.05	1.05	1.07	1.17	1.07
101+04260	P50	13.6	13.8	15.0	13.1	13.6	14.0	15.5	13.3
101+04260	P80	14.2	14.7	16.8	14.0	14.2	15.3	17.8	14.2
101+04260	LOTTR	1.05	1.07	1.12	1.07	1.05	1.09	1.15	1.07
101P04260	P50	36.8	37.4	39.9	36.3	36.8	37.4	39.9	35.7
101P04260	P80	38.0	39.2	42.7	38.0	38.0	39.2	42.7	37.4
101P04260	LOTTR	1.03	1.05	1.07	1.05	1.03	1.05	1.07	1.05
101-04259	P50	32.8	11.1	10.7	10.4	19.9	11.5	11.5	10.4
101-04259	P80	50.4	18.2	13.7	15.6	31.2	20.5	17.7	17.2
101-04259	LOTTR	1.54	1.64	1.27	1.50	1.57	1.78	1.54	1.66
101N04259	P50	62.3	23.9	23.5	22.4	38.7	24.7	24.7	22.4
101N04259	P80	95.5	34.1	28.1	29.2	59.7	37.7	33.3	32.6
101N04259	LOTTR	1.53	1.43	1.20	1.31	1.54	1.53	1.35	1.45
101-04258	P50	102.2	44.3	43.6	42.2	64.8	45.8	45.1	41.5
101-04258	P80	156.4	56.6	49.2	48.3	102.2	63.3	53.2	50.2
101-04258	LOTTR	1.53	1.28	1.13	1.15	1.58	1.38	1.18	1.21
101N04258	P50	96.4	46.6	45.8	44.4	59.5	45.8	44.4	42.4
101N04258	P80	139.7	57.0	49.9	48.2	84.7	59.5	50.8	47.4
101N04258	LOTTR	1.45	1.22	1.09	1.09	1.42	1.30	1.15	1.12

Table 24. Performance of individual Traffic Message Channels on I-85, 2019–2021. (continuation)

Traffic Message Channel	Metric	Before Period				After Period			
		AM	Midday	PM	Night	AM	Midday	PM	Night
101-04257	P50	37.2	18.0	17.4	16.9	24.0	18.0	17.4	16.6
101-04257	P80	51.4	22.0	18.9	18.3	33.7	24.0	19.3	18.6
101-04257	LOTTR	1.38	1.22	1.09	1.08	1.41	1.33	1.11	1.12
101N04257	P50	105.7	60.7	58.7	57.8	78.7	60.7	58.8	56.1
101N04257	P80	142.3	77.1	62.7	62.7	100.0	84.1	64.9	63.8
101N04257	LOTTR	1.35	1.27	1.07	1.08	1.27	1.39	1.11	1.14
101-04256	P50	112.3	81.3	79.9	76.1	89.0	81.3	79.9	73.7
101-04256	P80	157.2	94.3	92.5	81.3	102.5	100.4	90.7	82.8
101-04256	LOTTR	1.40	1.16	1.16	1.07	1.15	1.23	1.13	1.12
101N04256	P50	53.7	37.0	35.8	34.7	37.6	36.4	34.7	33.2
101N04256	P80	75.2	42.6	39.6	37.0	45.1	53.7	38.3	36.4
101N04256	LOTTR	1.40	1.15	1.11	1.07	1.20	1.48	1.10	1.10
101-04255	P50	139.1	100.8	91.3	91.3	106.2	119.3	92.8	89.9
101-04255	P80	194.8	157.9	97.4	108.2	149.8	194.8	102.5	139.1
101-04255	LOTTR	1.40	1.57	1.07	1.19	1.41	1.63	1.11	1.55
101N04255	P50	19.4	15.2	12.7	12.7	15.5	19.9	12.9	12.7
101N04255	P80	28.7	24.2	13.8	18.0	21.5	25.8	15.5	22.1
101N04255	LOTTR	1.48	1.59	1.09	1.42	1.39	1.30	1.20	1.74
101-04254	P50	23.1	19.8	16.1	16.4	19.0	22.5	16.4	16.4
101-04254	P80	34.6	26.9	17.6	21.5	23.6	26.9	19.8	23.1
101-04254	*LOTTR*	*1.50*	*1.36*	*1.09*	*1.31*	*1.24*	*1.19*	*1.20*	*1.41*
101N04254	P50	80.8	77.0	71.4	71.4	74.7	74.7	70.4	69.4
101N04254	P80	91.2	85.0	75.8	77.0	78.2	82.1	75.8	73.5
101N04254	LOTTR	1.13	1.10	1.06	1.08	1.05	1.10	1.08	1.06

LOTTR = level of travel time reliability

Conduct HCM Modeling if Conditions Warrant: To control for the confounding effects noted above, the project team used modeling. The project team used the QSIM model for this purpose by reducing the mean incident duration by 10 minutes to account for AID deployment.[14] Daily average speeds increased from 46.7 mph to 48.0 mph, which translates into a total delay reduction of 840 vehicle-hours saved per day (306,600 vehicle-hours annually). During peak periods, the model indicated that speeds also increased slightly from 28.7 mph to 30.0 mph.

Benefit/Cost Analysis: Table 25 shows the NPV analysis for the AID deployment on I-85. A 10-year project life is assumed. Because of the large travel time savings, almost $43 million in benefits accrue over the 10-year period.

Table 25. Net Present Value analysis for I-85 Automated Incident Detection deployment.

Year	Average Annual Daily Traffic	Travel Time		Construction Costs ($)	Operations and Maintenance Costs (+5% per Year) ($)	Net Present Value at 7% ($)
		Value of Savings ($)	Discounted Savings ($)			
2018	295,000	–	–	500,000	–	-500,000
2019	274,000	5,764,080	5,386,991	–	200,000	5,186,991
2020	306,000	6,437,257	5,622,550	–	210,000	5,412,550
2021	309,060	6,501,630	5,307,267	–	220,500	5,086,767
2022	312,151	6,566,646	5,009,663	–	231,525	4,778,138
2023	315,272	6,632,313	4,728,747	–	243,101	4,485,646
2024	318,425	6,698,636	4,463,584	–	255,256	4,208,327
2025	321,609	6,765,622	4,213,289	–	268,019	3,945,270
2026	324,825	6,833,278	3,977,030	–	281,420	3,695,610
2027	328,073	6,901,611	3,754,019	–	295,491	3,458,528
2028	331,354	6,970,627	3,543,513	–	310,266	3,233,248
Total	–	–	–	–	–	42,991,074

– = no data

EXAMPLE 3: ENHANCED TRAFFIC INCIDENT MANAGEMENT: I-26 IN ASHEVILLE, NC

Problem Identification

Site Description: The North Carolina Department of Transportation (NCDOT) implemented the I-26 ICM route in Asheville, NC, to mitigate impacts of a large widening project. The I-26 widening project stretches approximately 17 miles and includes the demolition of five bridges.

[14] Based on information from this document: https://www.itskrs.its.dot.gov/its/benecost.nsf/ID/0b3c3881ace7dcb18525853b0062a21f

Median crossovers were initially planned to accommodate traffic during bridge demolition, with each structure removal requiring approximately 2 weeks.

To prevent the negative consequences associated with longer duration lane closures, NCDOT chose to deploy an ICM strategy in place of the median crossovers.

Planning Process: NCDOT had been planning for improvements to this corridor for a number of years. This planning included detailed traffic modeling of alternatives.

Project Level Goals and Objectives

Matching Deficiency to an Operations Treatment: Congestion was expected to worsen when I-26 was under construction. NCDOT took a two-pronged approach to alleviating congestion: provide traveler information on alternative routes so that demand on I-26 was reduced and aggressively manage incidents. For this example, the aggressive incident management component is the focus.

Goals, Objectives, Strategies, Tactics: The goals and objectives of the project relate to minimizing disruptions to traffic caused by incidents. ICM strategies deployed on this project included a dedicated incentivized tow contract, increased Safety Service Patrol presence, activating specific signal timing plans on arterial detour routes, implementing coordinated response plans with preplanned DMS scenarios, and sharing closed-circuit television feeds with local partners. ICM strategies also were used for work zone management on I-26 to reduce construction timelines. The ICM strategy would allow for a full nighttime closure, directing motorists off the interstate and onto the selected alternate route with DMS and dynamic trailblazer signs, which were installed as a low-cost solution.

Additionally, the ICM strategy was paired with an incentivized tow contract for incident management in the construction zone. The incentivized tow contract allows responders to stage at appropriate locations, arrive on-scene more quickly, and prioritize clearing the lane once they are instructed to. This strategy is focused on significantly reducing the incident and roadway clearance time to mitigate impacts to the travel time reliability due to incidents in the construction zone.

Evaluation

Before and After Periods

- Before: January 1, 2018–December 31, 2018
- After: January 1, 2021–December 31, 2021

(Construction Start Date: October 28, 2019)

Data Available

- Travel time data from NPMRDS
- Incident data from NCDOT's Traveler Information Management System (TIMS)
- Continuous count data on I-26 from NCDOT

Analysis

Table 26 through table 28 present the empirically based travel time measures and the modeling results. Key points from these data are listed below.

- Traffic grew substantially in the corridor from 2019 to 2021 (6 percent).
- The number of crashes almost doubled. One possible reason is the change in reporting practice.
- Based on data from the NCDOT TIMS, the average incident duration dropped from 40 to 24 minutes after enhanced management strategies were implemented.
- Considering the PM peak period, which is the most congested period for both directions, travel time performance changed only slightly from the before to after periods; sometimes it was slightly worse, sometimes slightly better depending on the measure used.
- Additional details on the System Reliability measure are shown in table 29. Only one TMC was responsible for the slight improvement in System Reliability in 2021.

The relatively stable congestion levels suggest that even with higher traffic volumes, the enhanced TIM strategies had a positive effect on performance. We modeled the impact of the drop in incident duration from 2019 to 2021 and found that both daily and peak speeds increased. The delay savings was 2,382 daily vehicle hours (869,380 annual vehicle-hours). For this analysis, we assumed that no shoulders exist due to the work zone. Combined with the empirical evidence, the enhanced TIM made a substantial improvement in conditions.

Table 26. Congestion statistics and modeling results on I-26.

Direction	Performance Measure	Year 2018	Year 2021
Eastbound AM Peak	Average speed	62.5	61.3
	Mean travel time index (MTTI)	1.152	1.175
	P80 travel time index (TTI)	1.168	1.196
	Planning time index (PTI)	1.233	1.279
	% congested	0.77	1.24
Eastbound PM Peak	Average speed	51.7	49.3
	MTTI	1.391	1.459
	P80 TTI	1.604	1.618
	PTI	2.059	2.204
	% congested	20.26	21.09

Table 26. Congestion statistics and modeling results on I-26. (continuation)

Direction	Performance Measure	Year 2018	Year 2021
Westbound AM Peak	Average speed	61.2	62.3
	MTTI	1.176	1.157
	P80 TTI	1.186	1.185
	PTI	1.318	1.246
	% congested	1.73	0.56
Westbound PM Peak	Average speed	41.5	42.2
	MTTI	1.736	1.705
	P80 TTI	2.081	2.005
	PTI	3.087	3.231
	% congested	43.69	37.83

Table 27. Congestion modeling results on I-26.

Performance Measure	Year 2018	Year 2021
System Reliability (%)	86.5	87.3
Freight Reliability	2.094	2.302
Total Excessive Delay	166,147	199,655
Number of Crashes	332	610
Average Annual Daily Traffic	80,418	85,210
Mean Incident Duration, Lane-Blocking Crashes (minute)	55.7	32.8
Mean Incident Duration, All Incidents (minute)	40.2	24.3

Table 28. Modeling of standard versus enhanced Traffic Incident Management on I-26, 2018–2019.

Performance Measure	Traveler Incident Management	Traveler Incident Management+
Daily Speed	38.1	42.7
Peak Speed	22.6	24.7
System Reliability (%)	0	0

Table 29. Performance of individual Traffic Message Channels on I-26, 2018–2019.

Traffic Message Channel	Metric	Before Period				After Period			
		AM	Midday	PM	Night	AM	Midday	PM	Night
125N05200	P50	11.7	12.0	12.3	11.7	11.9	12.6	12.2	12.0
125N05200	P80	12.6	14.9	19.7	12.9	12.6	14.9	14.8	13.4
125N05200	*LOTTR*	*1.08*	*1.24*	*1.61*	*1.11*	*1.06*	*1.18*	*1.21*	*1.12*
125-05199	P50	235.8	237.4	243.6	232.9	243.9	252.8	251.8	239.6
125-05199	P80	245.9	247.7	313.7	247.5	256.1	268.1	320.3	254.3
125-05199	LOTTR	1.04	1.04	1.29	1.06	1.05	1.06	1.27	1.06
125N05199	P50	28.1	28.3	29.0	27.7	29.1	30.1	30.0	28.5
125N05199	P80	29.3	29.5	37.4	29.5	30.5	31.9	38.2	30.3
125N05199	LOTTR	1.04	1.04	1.29	1.06	1.05	1.06	1.27	1.06
125-05198	P50	149.1	150.9	154.8	149.9	155.3	162.6	164.4	154.3
125-05198	P80	154.3	157.8	211.2	160.4	162.3	177.8	238.3	168.9
125-05198	LOTTR	1.03	1.05	1.36	1.07	1.05	1.09	1.45	1.09
125-05197	P50	164.2	163.1	162.7	158.7	165.2	169.6	169.0	161.6
125-05197	P80	169.0	168.1	169.6	166.9	171.8	177.1	178.3	169.8
125-05197	LOTTR	1.03	1.03	1.04	1.05	1.04	1.04	1.06	1.05
125N05197	P50	22.7	22.6	22.5	22.0	22.9	23.5	23.4	22.4
125N05197	P80	23.4	23.3	23.5	23.1	23.8	24.5	24.7	23.5
125N05197	LOTTR	1.03	1.03	1.04	1.05	1.04	1.04	1.06	1.05
125P05197	P50	19.2	19.2	18.9	18.5	19.2	19.7	19.4	18.6
125P05197	P80	20.0	19.9	19.8	19.3	19.9	20.6	20.4	19.5
125P05197	LOTTR	1.04	1.04	1.05	1.04	1.04	1.05	1.05	1.05
125+05198	P50	164.0	163.6	164.1	159.5	164.6	169.4	168.8	159.5
125+05198	P80	169.4	170.0	180.7	167.7	171.7	181.2	195.3	169.9
125+05198	LOTTR	1.03	1.04	1.10	1.05	1.04	1.07	1.16	1.07
125P05198	P50	22.8	22.8	22.8	22.2	22.9	23.6	23.5	22.2
125P05198	P80	23.6	23.7	25.1	23.3	23.9	25.2	27.2	23.6
125P05198	LOTTR	1.03	1.04	1.10	1.05	1.04	1.07	1.16	1.07
125+05199	P50	149.9	150.1	155.4	147.3	153.1	159.2	159.7	150.1
125+05199	P80	156.6	160.8	277.7	157.6	159.7	187.8	273.8	160.2
125+05199	LOTTR	1.04	1.07	1.79	1.07	1.04	1.18	1.71	1.07

Table 29. Performance of individual Traffic Message Channels on I-26, 2018–2019. (continuation)

Traffic Message Channel	Metric	Before Period				After Period			
		AM	Midday	PM	Night	AM	Midday	PM	Night
125P05199	P50	26.7	26.8	27.7	26.3	27.3	28.4	28.5	26.8
125P05199	P80	27.9	28.7	49.6	28.1	28.5	33.5	48.9	28.6
125P05199	LOTTR	1.04	1.07	1.79	1.07	1.04	1.18	1.71	1.07
125+05200	P50	261.5	263.4	288.6	256.6	262.6	276.8	280.0	259.2
125+05200	P80	276.0	316.7	420.8	296.2	275.0	341.4	366.2	286.6
125+05200	LOTTR	1.06	1.20	1.46	1.15	1.05	1.23	1.31	1.11
125P05200	P50	10.4	10.5	11.5	10.2	10.5	11.0	11.2	10.3
125P05200	P80	11.0	12.6	16.8	11.8	11.0	13.6	14.6	11.4
125P05200	LOTTR	1.06	1.20	1.46	1.15	1.05	1.23	1.31	1.11
125+05201	P50	47.2	48.0	49.1	46.6	46.1	47.8	47.8	45.8
125+05201	P80	49.3	50.8	53.2	49.8	48.0	50.1	51.0	48.3
125+05201	LOTTR	1.04	1.06	1.08	1.07	1.04	1.05	1.07	1.05

Benefit-Cost Analysis: Table 30 shows the NPV analysis for the I-26 aggressive incident management deployment. A 5-year project life was assumed to cover the duration of widening project. Because of the large travel time savings, the NPV of the I-26 deployment is $66 million over the 5-year period.

Table 30. Net Present Value analysis for I-26.

Year	Average Annual Daily Traffic	Travel Time		Crashes		Construction Costs ($)	Operations and Maintenance Costs (+5%/year)[1] ($)	Net Present Value at 7% ($)
		Value of Savings ($)	Discounted Savings ($)	Value of Savings ($)	Discounted Savings ($)			
2019	85,000	–	–	–	–	0	–	$0
2020	85,850	16,344,344	15,275,088	0	0	–	3,500,000	11,775,088
2021	86,709	16,507,787	14,418,541	0	0	–	3,600,000	10,818,541
2022	87,576	16,672,865	13,610,025	0	0	–	3,933,333	9,676,691
2023	88,451	16,839,594	12,846,846	0	0	–	4,130,000	8,716,846
2024	89,336	17,007,990	12,126,462	0	0	–	4,336,500	7,789,962
Total	–	–	–	–	–	–	–	48,777,127

[1]Cost of towing contract.

– = no data

CHAPTER 4. FINDINGS AND RECOMMENDATIONS

SUMMARY OF CASE STUDIES

Lake 90 Variable Speed Limit Corridor in Ohio

Deployment Objective: To reduce crashes during snow and ice precipitation events by combining RWIS with VSL.

Performance Impacts: The number of crashes on days when snow or ice fell was 50 percent lower in the 2019–2022 period than for the 2016–2018 period, a strong indication of the effect of the Lake 90 system. Modeling revealed that the crash reduction decreased delay on the study section by 24 vehicle-hours per day on average or 8,760 vehicle hours per year. No appreciable change was seen in the PM3 performance measures.

I–10 Dust Detection and Variable Speed Limit System in Arizona

Deployment Objectives: To reduce crashes due to visibility-reducing dust events by combining a dust detection system with VSL. Dust events mainly occur during the Arizona monsoon season, June 15–September 20.

Performance Impacts: During dust events, which for the most part were short-lived, speeds dropped. The duration of these drops was also short, indicating that crashes most likely did not occur during these events. No appreciable effect on travel time-based performance measures was seen.

Automated Incident Detection on I-85, Northeast Atlanta, GA

Deployment Objective: To reduce the time needed to detect incidents, thereby, reducing total incident duration.

Performance Impacts: Detecting the impact of AID using the travel time performance measures was not possible due to confounding with other influencing factors. Modeling revealed that if AID reduces incident detection by 10 minutes, 300,600 vehicle hours of annual delay could be saved on the study section.

Enhanced Traffic Incident Management on I-26, Asheville, NC

Deployment Objective: To reduce the impact of incidents during major reconstruction activities by reducing incident duration.

Performance Impacts: Analysis of NCDOT incident management log data revealed that the average incident duration dropped from 40 to 24 minutes after enhanced traffic incident management was implemented. However, the effect of this reduction was not detected in the travel time performance measures due to confounding: both traffic level and crashes increased after the implementation. Modeling revealed that, all things being equal, 869,380 annual vehicle-hours of delay were saved by the implementation.

Capital Express Smart Work Zone (SWZ) Management on I–35, Austin, TX

Deployment Objective: To mitigate the impacts of a major work zone, including short-term full closures, by using offpeak scheduling and traveler information.

Performance Impacts: The impact of full closures was analyzed by considering travel times on the facility during the closure and for 5 weeks before the closure; the same day of week and times were used. The analysis showed no difference in the during and prior times in terms of the travel time measures, indicating that the implementation was successful.

Curve Warning System on OR-217 and US-26, Portland, OR

Deployment Objective: To reduce crashes on tight radius freeway interchange loop ramps, especially during inclement weather.

Performance Impacts: Previous analysis by ODOT revealed that crashes had been reduced by approximately 50 percent after the curve warning system was introduced. This information was used in modeling the travel time effects of the system. The delay savings for the two warning systems combined is 292 vehicle-hours per day (106,580 vehicle-hours per year).

Three of these case studies are highlighted in this report as examples: Lake 90, AID on I–85, and aggressive incident management on I-26. NPV analysis was conducted for these three deployments and found that all were highly cost effective.

DISCUSSION AND RECOMMENDATIONS

The primary purpose of this evaluation project is to assess the effect that operations strategies, geared to addressing nonrecurring congestion, have on the PM3 performance measures. Three of the six case studies (Lake 90, OR-217 curve warning, and I–10 dust detection) were designed and implemented to address primarily safety concerns; Lake 90 and I–10 are rural sections with low traffic volumes (less than 50,000 AADT) and virtually no recurring delay. These three strategies did not have an appreciable impact on the PM3 or other travel time performance measures used in the study. In both cases, the safety issue was related to infrequent environmental conditions that have the potential for severe consequences, namely, multiple vehicle pileup crashes. Capturing the benefit of avoiding these catastrophic events is problematic as they are so rare.

Although the types of strategies are categorized as affecting nonrecurring congestion, these and many more can be better categorized as safety mitigation strategies. A new classification of operations strategies is recommended, where the classifications are based on the *primary expected impact* of the strategy: recurring congestion, nonrecurring congestion, or safety. Most operations strategies affect multiple problem areas (e.g., congestion, safety, reliability), but in all cases a primary impact can be identified. Alternately, the nonrecurring congestion category could be renamed to “disruptive events.” This renaming is a semantic exercise, but it removes the stigma that all operations strategies need to address congestion.

Additionally, as operations strategies focused on disruptive events will not be beneficial in showing agencies’ efforts for congestion mitigation, the project team recommends that they be highlighted in safety-oriented processes, such as Highway Safety Improvement Programs and Strategic Highway Safety Plans.

The project team purposely aimed the other three operations strategies toward congestion reduction through improving incident management (I-26 and I-85) and work zone congestion (I–35). Also in these cases, the annualized travel time-based performance measures (including the PM3 measures) did not capture the congestion impacts of these strategies, either because the effect was small or confounded by influencing factors. That is, the PM3 and other travel time-based measures showed minor changes from the before to the after period. Sometimes these changes suggested an improvement in performance; in other cases a degradation in performance was indicated. This result is a common issue with many nonrecurring congestion-focused operational strategies; small improvements could be masked by conditions such as increases in demand or changes in crash history. As a result, the project team developed a modeling framework to control for influencing factors. In most cases, at least a modicum of delay savings was indicated by the modeling.

These findings indicate that evaluations also should include summarizing how well the deployment met their intended objective in addition to conducting congestion-based analyses using annualized travel time measures.

The case studies indicate that other metrics may be more effective than the suite of PM3 and other travel time-based performance measures when measuring minor changes in performance that occur during infrequent events. This situation is especially relevant for rural conditions. For example, the events that are addressed by nonrecurring operations strategies may have travel times that reside in the upper portion of the travel time distribution, above both the 80th and 95th percentile travel times. As the System and Freight Reliability PM3 measures are based on the travel time distribution (as well as other performance measures), the change in performance can be subdued. The Total Excessive Delay measure may be better suited to capturing this effect, but its delay threshold can be too stringent to capture minor changes in congestion. For example, if an urban facility is already operating well below the threshold, the effect of a strategy may improve performance, but still be below the threshold. Accordingly, the project team offers the following recommendations for tracking the performance of nonrecurring operations strategies:

- Use a delay measure, similar to one used in this report, where the threshold is based on free flow travel time. This approach is used in many benefit and cost analyses (e.g., FHWA Highway Economic Requirements System model and the Tool for Operations Benefit/Cost Analysis [TOPS-BC] procedure) and is consistent with the delay definition in the HCM.
- Focus analysis changes for the 30–35 worse congestion days of the year (about 8–10 percent of days). Note changes in delay and average speeds, and compute metrics that indicate how much “worse” these days are than the rest of the year.

APPENDIX A. DESCRIPTION OF THE QSIM SKETCH-PLANNING MODEL FOR ESTIMATING TRAVEL TIME, SPEEDS, AND DELAY

INTRODUCTION

QSIM was developed to integrate results obtained from simulation runs for congested and uncongested conditions and to produce estimates of the overall effect of AADT/C on average delays due to congestion over the course of a year. QSIM analyzes the effects of temporal variations in traffic and queuing on an hour-by-hour basis for weekdays and for weekends and holidays. Weekday travel is analyzed separately in each direction—the "home-to-work" peak direction, for which the peak occurs in the morning, and the "work-to-home" direction, for which the peak occurs in the afternoon, QSIM considers both freeways and signalized. The study also considered unsignalized streets, which were not modeled with QSIM.

Set Test Section Capacity

The procedure starts by defining a test section for QSIM to analyze. The capacity of the section is determined using HCM procedures. For the research reported herein, the project team used the following basic capacity values:

- **Freeways—**2,300 passenger car per hour per lane (PCPHPL), based on the 1994 HCM for 6+ lane facilities.
- **Signalized Arterials—**900 PCPHPL, based on the HCM's saturation flow rate of 1,800 PCPHPL and a 50-percent green time.

The test section length also is set at this time; this is a key factor in QSIM as the speed and delay of vehicles are measured over the length of the section. For this study, segment length was fixed at 1.5 miles (7,920 feet) for freeways. For signalized arterials, the length of the segment is equal to the signal spacing. Setting a variable segment length for arterials is believed to capture the effect of queuing more realistically than a fixed one. Thus, high signal densities imply a shorter segment length; therefore, a higher percentage of the link will be consumed by queuing.

Temporal Distributions and Peak Spreading

Once the AADT/C level is set, AADT is determined by multiplying AADT/C by the (two-way) capacity. Average Weekday Daily Traffic (AWDT) and Average Weekend/Holiday Daily Traffic (AWEDT) are determined by applying factors to AADT: 1.0757 for AWDT and 0.8393 for AWEDT. From these daily volumes, temporal distributions are used to determine "target" volumes by hour. Separate distributions exist for freeways and nonfreeways; three AADT/C ratios (AADT/C less than or equal to 7, AADT/C between 7 and 11, and AADT/C greater than 11); and peak direction (morning and afternoon).

Directly applying these distributions would lead to problems for AADT/C ratios on the boundary values. For example, the high AADT/C range's distribution is flatter than the middle range; this result could possibly lead to predicting congestion in an hour for the middle range while not predicting congestion in the same hour for the high range. This procedure accounted for problems at the boundary values and further spread out traffic throughout the day as AADT/C ratios increased above 13.

STOCHASTIC VARIATION IN TRAFFIC VOLUMES

To account for day-to-day variability in traffic flows, QSIM stochastically determines what the test volume in a given hour should be from the "target" hourly volume (determined above) and information on hourly variability, where the "target" volumes are the mean of normal distribution, and the variance is defined in Figure 3 as:

$$\text{Variance} = (\text{Coeff. of Variation} * \text{Mean})^2$$

Figure 3. Equation. The variance as a function of the mean and coefficient of variation.

Random sampling is then used to select the test volume from this distribution.

UNCONGESTED SPEED FUNCTION FOR FREEWAYS

The speed estimation procedure for unsaturated freeway sections from the HCM is used.

PERFORM QUEUING ANALYSIS

1. **Determine percentage of link under queuing.** If test volume exceeds capacity, a queue is assumed to form. For simplicity, the program assumes that the bottleneck point from which the queue builds is at the downstream end of the segment. The program accumulates total travel time on the segment. If the length of the queue exceeds the length of the segment, total delay due to the bottleneck will naturally exceed total delay on the segment itself. (This additional delay can be estimated by increasing segment length.) For freeways, once volumes exceed capacity, vehicles are assumed to move through the bottleneck point at a flow rate less than capacity. Therefore, 2 basic freeway capacity values are used: 2,300 PCPHPL for unsaturated conditions and 2,000 PCPHPL for oversaturated conditions.
2. **Queues are estimated for the beginning and ending of each hour.** If the demand volume plus any leftover queue is greater than the capacity of the section, the queue at the end of the hour is calculated in Figure 4 by:

$$Q2 = Q1 + V - C$$

Figure 4. Equation. Calculation of queue length and the end of a time period.

Where:

Q1 = Queue at the beginning of the hour (vehicles)

Q2 = Queue at the end of the hour (vehicles)

V = Demand (test) volume for the hour (vehicles)

C = Bottleneck capacity of the section (vehicles)

3. **Calculate queue speed.** For both freeways and signalized arterials, if the volume to capacity ratio is greater than 1.0, queuing is assumed to take place. Queuing also will affect traffic if there is a standing queue at the end of the preceding hour. If travel in the hour under consideration is affected by queuing, the program analyzes the growth (or decline) in queue length over the hour. Vehicle hours of travel are estimated separately for those portions of the segment that are affected by queuing and those that are not. The formulation is shown in Figure 5:

$$\text{Link Speed} = [\text{Queue Speed} * (\text{Queue Length}/\text{Link Length})] + [\text{Nonqueue Speed} * (1 - \text{Queue Length}/\text{Link Length})]$$

Figure 5. Equation. Calculation of link speed as a weighted average of queue speed and nonqueue speed.

In the current formulation, the speed on the segment is based on estimating total vehicle-hours of travel (VHT) and vehicle miles traveled (VMT) first, then computing speeds as VMT divided by VHT.

VMT and VHT are tracked separately for queued and unqueued portions of the test segment as shown in Figure 6:

$$\text{VMT} = \{(\text{UQL} * \text{DVOL}) + (\text{AQL} * \text{CAP})\}/5{,}280$$

Figure 6. Equation. Calculation of vehicle miles traveled from queued and unqueued vehicles.

Where:

UQL = Length of the segment that is not queued in feet

DVOL = Demand volume for this hour (determined stochastically from the temporal distributions), in vehicles

AQL = Average queue length during the hour in feet

CAP = The bottleneck capacity, in vehicles

The first term counts the number of vehicles that are entering the segment at the back of the queue. When the entire segment is consumed by a queue, this term becomes zero. The second term counts the number of vehicles in the queue that are processed through the bottleneck. Queue length is found by multiplying the number of queued vehicles by the calculated queue spacing (Figure 8).

$$\text{VHT} = (\text{UQL} * \text{DVOL} * \text{UQDEL}) + (\text{AQL}/\text{QSPACE})$$

Figure 7. Equation. Calculation of vehicle-hours of travel from queued and unqueued vehicles.

Where:

UQDEL = Unqueued delay, in hours per vehicle foot, calculated using the uncongested delay function

QSPACE = spacing of vehicles in the queue, in feet per vehicle

$$= \text{Queue Speed}/\text{CAP}$$

Figure 8. Equation. Calculation of vehicle spacing in a queue.

The first term is the number of vehicle-hours experienced by vehicles on the unqueued portion of the segment. The second term calculates the number of vehicles that (on average) are in the queue during the hour. Note that QSPACE depends on the assumed queue speed, which for freeways was determined empirically from freeway data to be 15.5 mph. For arterials, queue speed was determined analytically as capacity (vehicles per hour) times vehicle spacing (feet per vehicle) and is roughly 8–9 mph. The second term is equivalent to estimating queued VHT (QVHT) as a function of queued VMT (QVMT) and queue speed as shown in Figure 9 and Figure 10:

$$\text{QVHT} = \text{QVMT}/\text{Queue Speed}$$

Figure 9. Equation. Calculation of queued vehicle-hours of travel, method 1.

Letting:

QVMT = AQL * CAP (the second term in figure 6)

Queue Speed = CAP * QSPACE

produces:

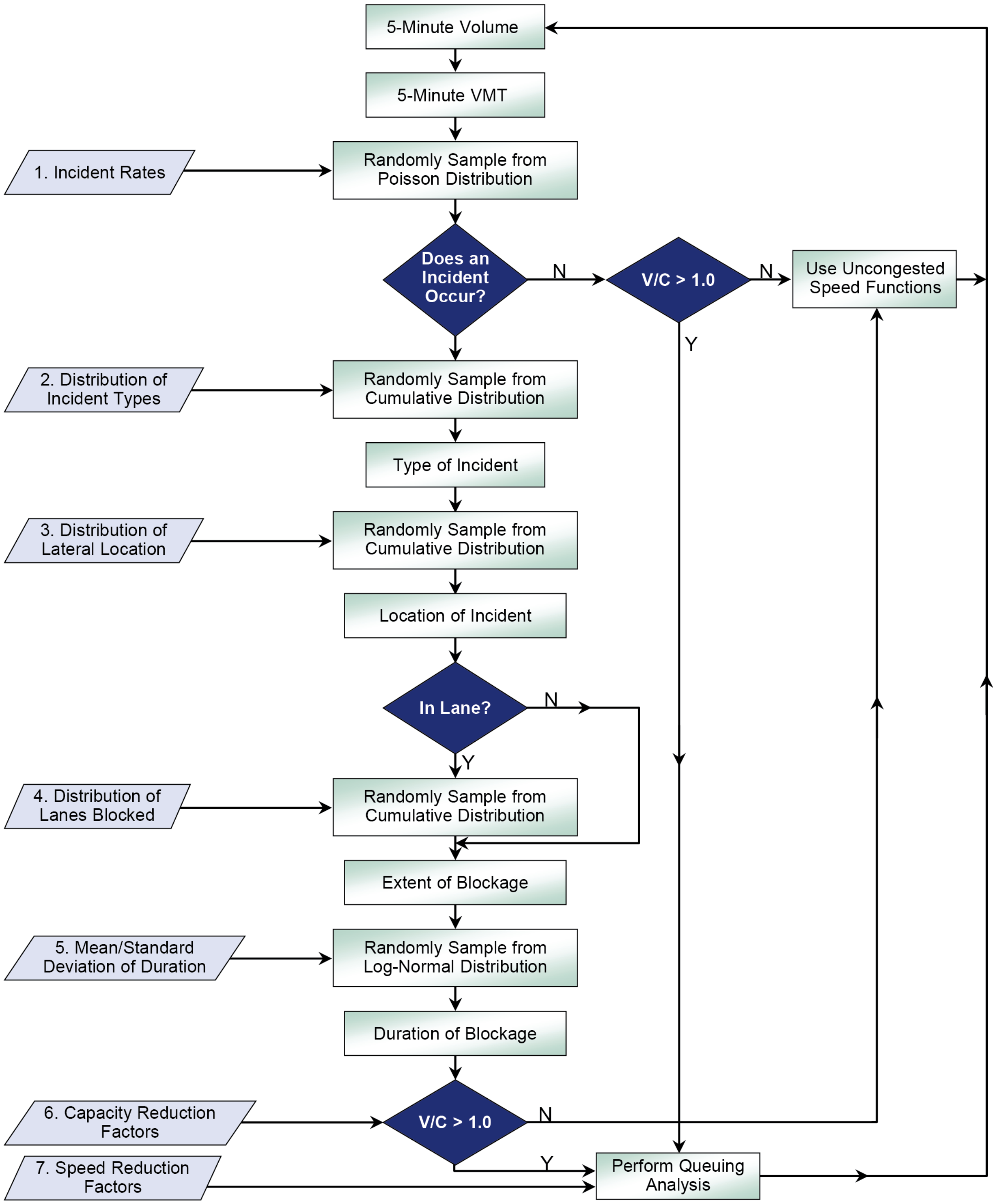
$$\text{QVHT} = (\text{AQL} * \text{CAP})/(\text{CAP} * \text{QSPACE})$$

Figure 10. Equation. Calculation of queued vehicle-hours of travel, method 2.

Note that in the methodology, the traditional speed–flow–density relationships are used. There is some evidence that in the congested (unstable) traffic flow regime these relationships do not apply. The assumed freeway queue speed of 15.5 mph is felt to be representative of an onramp bottleneck; therefore, the current research applies to this situation only.

Adding the Effect of Incidents

Figure 11 shows the methodology for including incidents in QSIM.



Source: FHWA.

Figure 11. Flow chart. Details of incident modeling within QSIM.

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September 2024

FHWA-HOP-23-060