Transportation Management Center Performance Dashboards

Final Report

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This document, a product of the Transportation Management Center Pooled Fund Study, examines the use of dashboards in the transportation management center environment. Dashboards display data in a user-friendly format. The project team conducted an outreach exercise to determine the current state of the practice for use of dashboards and summarized the results. Different end users have different data needs, and developers of successful dashboards customize them for those needs. This report presents a process for planning and developing a successful dashboard, including the data needs and analysis process.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°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)

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LIST OF ACRONYMS

API	Application programming interface
ATMS	Advanced transportation management system
CCTV	Closed-circuit television
DMS	Dynamic message sign
DOT	Department of Transportation
ETL	Extract, transform, and load
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FSP	Freeway Service Project
ITS	Intelligent transportation systems
JSON	JavaScript Object Notation
LOS	Level of Service
MPO	Metropolitan Planning Organization
ODOT	Oregon Department of Transportation
ORBP	Ohio River Bridges Project
PFS	Pooled fund study
PII	Personally identifiable information
PTI	Planning time index
RITIS	Regional Integrated Transportation Information System
RTMC	Regional Transportation management center
SLD	Straight-line diagram
SQL	Structured Querying Language
SRTMC	Spokane Regional Transportation Management Center
TMC	Transportation Management Center
TOC	Traffic Operation Center
TRIMARC	Traffic Response and Incident Management Assisting the River City
TSMO	Transportation systems management and operations
TTI	Travel time index
TTR	Travel time reliability
UTC	Coordinated Universal Time
VDOT	Virginia Department of Transportation

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EXECUTIVE SUMMARY

Every year advances in technology, data management, and data availability are rapidly improving and dynamically transforming the way transportation agencies monitor and support roadway traffic. The growth in data provides transportation agencies operating roadway networks with an unprecedented level of detail, which they can use to make proactive decisions and support the monitoring of the network. With Transportation Management Centers (TMCs) serving as the critical hub of this management, the ability to turn this influx of data into actionable information is imperative to the success of the TMC and overall support of the transportation network. Dashboards and the data that support them empower the TMC with information, enabling data driven decision-making, and more exact and successful results from operations.

Having access to these large and robust data sources is only a first step. Understanding how to collect, store, manage, and ultimately provide analysis and metrics of this data enables agencies to transform the data into powerful information and quantifiable metrics. Through these quantifiable processes, agencies can report highly detailed information across billions of individual data records and explore the information in the most granular way possible. While TMCs can view, interact, and use this information in many ways, a TMC dashboard or data interface is one of the most universally recognizable ways to distribute this information.

In very simple terms, a TMC dashboard is a tool that displays information about the roadway and events occurring on that roadway; however, the complexities of data, technology, and available performance measures cannot be understated. Agencies can take advantage of the wide variety of performance measures and reporting information available to display through the TMC dashboard when agencies understand the data and the data management principles.

A key theme throughout this report, a product of the TMC Pooled Fund Study (PFS), is that data is the key element that enables a TMC dashboard to function. Thus, each section of this report uses a data-first perspective, seeking to establish the entirety of the process and environment needed to successfully carry out a TMC dashboard project. By the end of the report, readers should have a comprehensive understanding of TMC dashboards, data needs, and principles, and the steps for how to carry out a TMC dashboard project at their own agency. The report concludes with a current state of the practice, trends, and recommendations for TMC dashboards.

TMCs are now using dashboards to display increasingly robust presentations of real-time information. Key trends include incorporating data and analytical products into the dashboards and moving towards decision support and decision automation. The most effective dashboards deliver key information to different TMC stakeholders. These products include dashboards that display the benefits of TMC operations and other transportation investments. The stakeholders with an interest in TMC dashboards include, for example, elected officials and decision-makers, general public, and public agencies that need transportation information to serve their mission.

CHAPTER 1. INTRODUCTION

This introduction provides background information on the concepts of Transportation Management Center (TMC) dashboards.

BACKGROUND

TMCs are the hub of most traffic management systems. TMCs serve as a centralized location through which information about the roadway network flows, perform operational tasks designed to keep the network performing efficiently.

There is a wide array of tools available for TMC operators and managers to monitor roadways, one of which is a TMC dashboard.

Dashboards benefit the operation of TMCs in several ways. They primarily communicate the status and performance of an operation. This unifies a team within a TMC working together towards a common vision, which, in transportation, encompasses safety and mobility. TMCs dissect the operation into several components, each having specific objectives that may use specific dashboards to communicate the status and performance to smaller, more specialized teams.

Dashboards also communicate the benefits of traffic operations to the public, media, Departments of Transportation (DOTs), decision makers, and legislators. Dashboard quarterly and annual roadway performance reporting shows how TMC traffic monitoring and managing efforts reduce average travel time and improve travel time reliability, reduce response time and roadway clearance time in response to incidents, lower secondary crash rates, and present operations costs and return on investments. These dashboards and their quantifiable data outputs are strong proponents for added and continued funding of TMC operations.

In many cases, dashboards show near real-time metrics, allowing TMC operators, managers, and support staff to make decisions and initiate control strategies, where appropriate, to keep the system operating. A variety of data coming from both near real-time and historical sources provide TMC staff more information to make educated decisions. Understanding these data sources and how the TMC collects, stores, and makes information ready for analysis is critical in the design and implementation of a successful TMC dashboard and support of the larger mission of the TMC.

The TMC PFS identified a need to document, in detail, these important steps to design and carry out a TMC dashboard project, and the TMC PFS funded this report as a result. This document explores the need to include a review of existing TMC dashboards and needs, understand the current state of the practice and ongoing trends related to TMC dashboards, and the recommended steps and processes to not only develop a TMC dashboard, but also to ensure that a robust data management system is in place to support the mission of the TMC into the future.

PURPOSE OF RESEARCH

The evolution of technology and data is continually providing more data that previously may not have been readily available or easily pulled together for complex analysis. The first step of this report involved outreach to nine TMCs as well as a review of literature and TMC websites to gain an understanding of the use of TMC dashboards and the various types of data sources and other needs the project team identified.

The research served to scan and synthesize current practices and identify practices for developing and using TMC performance dashboards for evaluating the performance of traffic operations (including TMC operations, service patrols, traffic incident management) and for communicating the benefits of traffic operations to the public, media, DOT, decision makers, and legislators.

This research also provided valuable insight into the data use and the various data sources upon which TMCs often rely. A key component to the success of a TMC dashboard is the underlying data and data management practices. This report documents these efforts throughout, including practices needed to support these data environments and dashboards to provide the reader with a complete picture of all aspects a TMC should consider when developing a successful dashboard.

PURPOSE OF THE REPORT

This report synthesizes major data flows, performance measures, dashboard presentation schemes, concepts, and practices for the use of dashboards within a TMC. Key audiences include personnel in transportation agencies that are responsible for or involved in research, planning, and operation of intelligent transportation systems (ITS), TMCs, or transportation management with basic knowledge of how those components work together. After reading this report, the user should walk away with an understanding of why this information is critical and how to plan for a TMC dashboard, as well as how to make key decisions that affect the dashboard project. Dashboard designers should make some of the decisions, such as identifying data sources and formats, early in the TMC dashboard project process. With this knowledge, the user can work with their partners to successfully execute a TMC dashboard development process.

Readers will gain the largest amount of knowledge by reading the entire report front-to-back, however different pieces of the report will likely be useful for different user groups. Chapter 2 (research process and results) and Chapter 3 (summary of existing practices, including TMC dashboard examples) contain information about the existing state of the practice. Chapter 3 also has a wealth of information about key practices observed from the research that will be beneficial in the development of new TMC dashboards. Chapter 3 determines the type of dashboard that is desired and answers key questions in the planning process for a dashboard project. Chapters 4 and 5 focus on the future of TMC dashboards and where the industry is heading. These chapters contain information about current trends and potential practices for the development of new dashboards as well as the key information for executing the project. Ultimately, the target audiences can use the information presented in the report to determine which dashboard types are most beneficial in terms of data, presentation, which performance measures to track, how to process the data, and develop the most useful dashboard concept in their TMC.

STRUCTURE OF THE REPORT

This report provides the reader with a direct understanding and approach of the steps needed to successfully create and deploy a TMC dashboard. The report contains the following chapters:

- **Chapter 1: Introduction** – This chapter introduces the concept of TMC dashboards and the research project's purpose.
- **Chapter 2: Data Collection Process** – This chapter describes the approach and results of the literature review and data collection conducted as part of this project.
- **Chapter 3: Current State of the Practice for TMC Dashboards** – This chapter expands on the results from chapter 2 and combines results from the literature to discuss the current state of the practice concerning TMC dashboards.
- **Chapter 4: Current Trends for Planning and Use of TMC Dashboards** – This chapter focuses on the direction that the industry is moving with respect to TMC dashboards, both planning and using them. Chapter 4 focuses more on the future, whereas chapter 3 focuses on the present.
- **Chapter 5: Practices** – This chapter discusses practices for the planning, design, and use of TMC dashboards. This chapter also combines information uncovered through the targeted outreach (chapter 2) and literature review of the current state of the practice (chapter 3), along with integrating the current trends (chapter 4) to develop the practices.
- **Chapter 6: Summary and Recommendations** – This chapter summarizes the key themes from the report and highlights several important practices for inputs, dashboard functionalities, and dashboard development.

CHAPTER 2. DATA COLLECTION PROCESS

This chapter presents the results of the literature review that was conducted, information collected, and examples of identified TMC dashboards.

INFORMATION SOLICITATION

The project team developed a list of the top 50 United States metropolitan areas by population and the appropriate TMC for each was determined. The project team then determined which ones are TMC Pooled Fund Study (PFS) members (or covered by them), and nine of those TMCs were contacted based on their participation in the PFS. The project team studied research literature, project reports, and websites to identify the state of practice with TMC dashboards.

The project team called the nine TMCs to explain the project, inform them of the ultimate benefit to the TMC community and the project team's ability to adapt to each TMC's interest. The project team identified the appropriate person and offered a range of submission options. The project team offered a download link to TMCs who wished to submit examples of their dashboard displays. The project team received information, then followed up with the TMC operators to thank them for their input and to seek clarification if necessary.

The multiple contacts with the TMCs helped ensure that each felt invested in this project and was willing to provide helpful information to the project team that would ultimately benefit the interests of TMCs.

OVERVIEW OF RESPONSES

This section provides an overview of the following three topics:

- Basic agency information.
- Goals and objectives of dashboards within a TMC.
- Planning, design, and implementation of dashboards.

Basic Agency Functions, Data, and Performance Measures in Transportation Management Centers

TMCs are collaborations of agencies, functional groups, people, and technologies that have evolved over the past several decades and will continue to do so as capabilities and resources change and expand.

All TMCs include representation from State DOTs – usually a combination of operations and maintenance personnel – with State police being the next most common staffing.

Almost all TMCs are focused on the traditional operations topics of freeway management, recurring and non-recurring congestion, and planned special event management activities. TMCs respond to debris removal, crashes and stalled vehicles, and provide information to travelers and freight shippers, frequently with roadside changeable message signs. Many TMCs use social media channels such as Facebook and Twitter, and other channels such as WAZE and 511 systems, which highlights the relatively rapid uptake in new communication mechanisms.

TMCs provide a common information communication platform between agencies. Many TMCs are moving into arterial traffic management operations using advanced signal software and real-time network communication and analysis tools that not only provide better data for signal timing but also better visual evaluation and presentation information. Managed lane operations are a special form of active transportation management that requires effort at the TMC to monitor and respond to changing conditions.

Transportation Management Center Dashboard Goals and Objectives

The processes and attributes used to create an existing dashboard are worth studying for what they might tell dashboard developers about how to create successful dashboards in the future, even when a TMC's initial dashboard was developed in a different technology generation. Most of the literature refers to accommodating changing user needs and technology enhancements as the dashboards evolve. TMC dashboards have seen the same sort of evolution as performance measurement reporting; as views, reports and awareness increases, the number of requests for more or different information also grows. A greater variety of requests has allowed the stakeholder feedback and user testing processes to evolve.

The user groups for TMC dashboard information are most frequently the TMC operators and other internal State agency groups such as planners, traffic operations, maintenance, and other departmental staff. These groups were the initial stakeholders of most of the TMC designs and operating practices. The initial goal of most of the TMC operations was to identify the status and condition of major roads, the monitoring devices, and responder staff. Emergency operations center and first responder personnel are also a primary customer for the TMC dashboard information – either through direct views or alerts from the TMC operators.

Data Analysis and Presentation

With more than half of the larger TMC dashboards being mature (operating more than five years), most have an automated process for data collection and analysis, and many have access to historical data to create trends in information and performance measurements.

The typical TMC data uses fairly conventional data sets that can be obtained from the operators, the databases or sensors they monitor, or information that is relatively easily obtained from other sources – such as weather websites. TMCs should archive weather, event, crash, and 'messages deployed' information as explanatory information so that the speed, volume, and other operating and performance statistics can be understood in future analyses.

TMCs, the reviewed literature and websites identify the following elements as part of the analysis process:

- Traffic speed or travel time (roadside sensors, Bluetooth, probe data).
- Traffic volume (roadside sensors, loops, video detection).
- Crash or incident data.
- Event management activity log.
- Work zone and maintenance information.
- Weather information.
- Special event information.
- Video or still images from traffic cameras.
- Messages deployed on Dynamic Message Signs.

TMCs provided reports, dashboard views, and other displays they use. Figures 1 to 5 illustrate some views of operational status and performance reporting from dashboards.

The simplest dashboards or reports are tables of status or "uptime" – the amount of time that a device or service is operating. The Louisville Traffic Response and Incident Management Assisting the River City (TRIMARC) system has a detailed dashboard that monitors camera downtime during weekdays to assist operators and identify maintenance needs.

Many operational reports and dashboards seek to illustrate the current or recent past performance on a range of activities or equipment. The Louisville TRIMARC report has monthly values and a comment section that is used to describe the measure or identify the source or distribution channel of the information.

North Carolina DOT uses pie charts to compare regional distributions of various operational elements; these are presented for each quarter in figure 1 and figure 2 but could also be presented in annual view format. The reader, analyst, or leadership can compare experiences across the regions and compare those to resource allocations and operating practices.

Some reports—like the one from TRIMARC—provide a quick view of the services or events in that month for a single TMC.

Maryland's Coordinated Highways Action Response Team system status dashboard has an at-a-glance feature that displays key attributes of the operational system (figure 3). Users can toggle each major 'button', and the map will display the events; users can click on those events for more information.

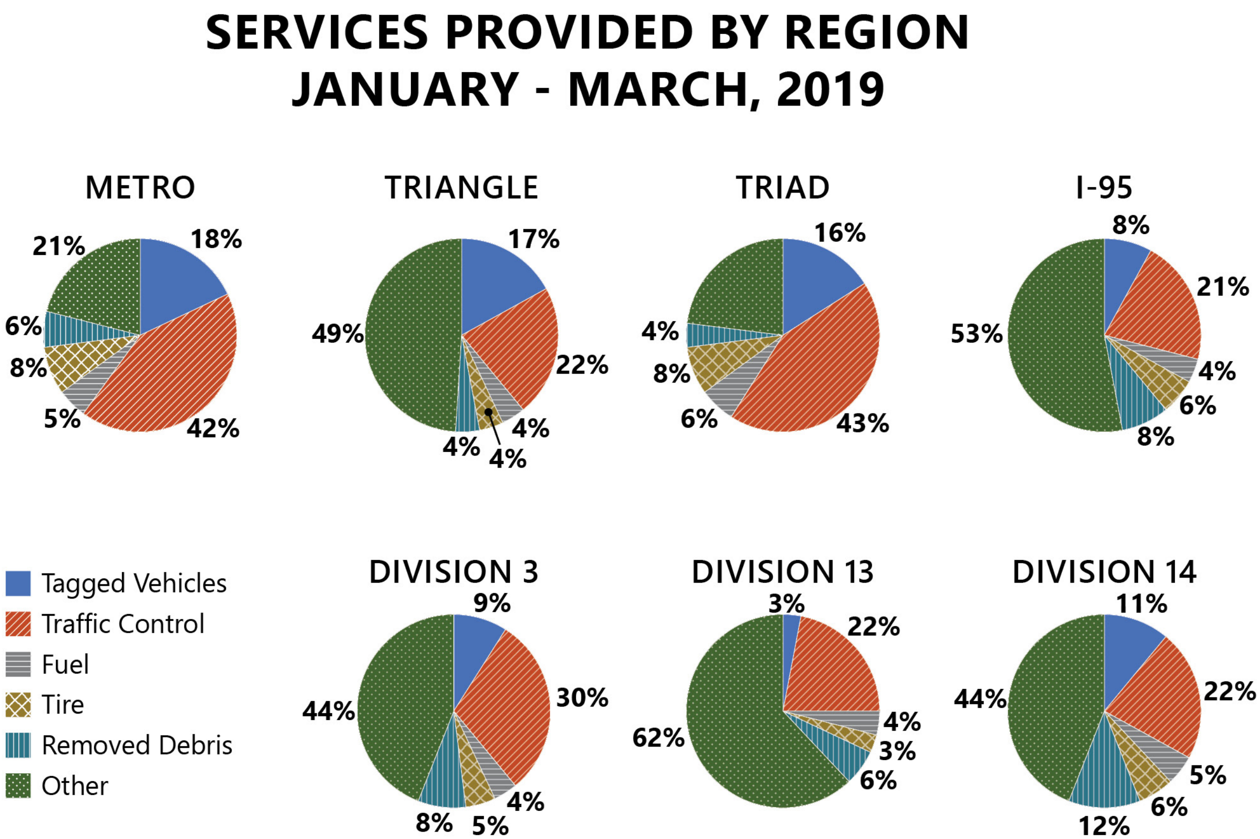


Figure 1. Chart. North Carolina Department of Transportation services provided by region.(1)

Source: *North Carolina Department of Transportation.*

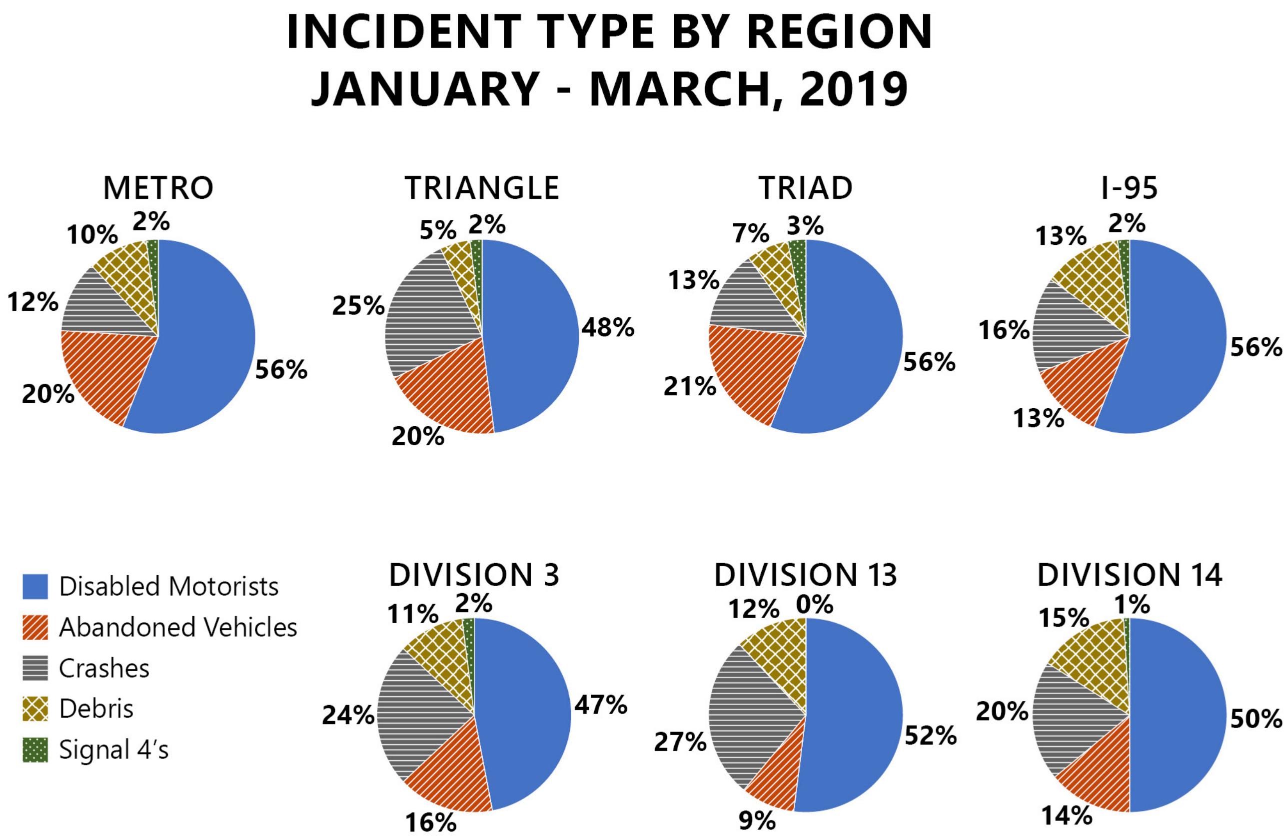
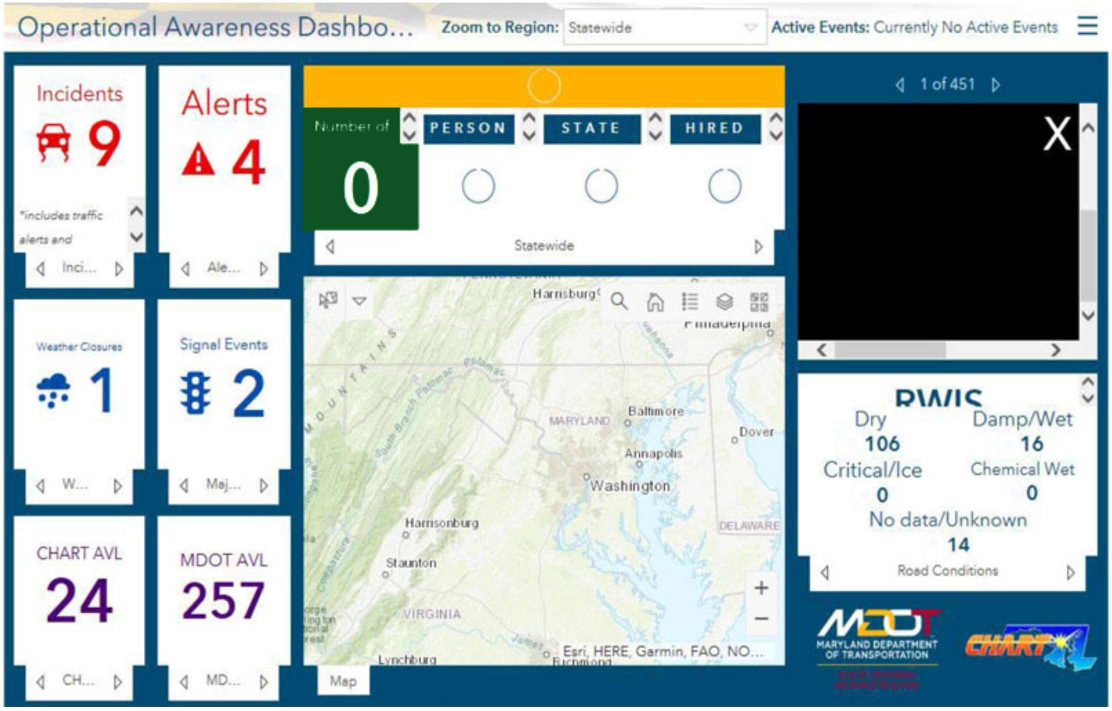


Figure 2. Chart. North Carolina incident type by region.[(1)]

Source: *North Carolina Department of Transportation.*



Note: AVL = automated vehicle location; MDOT = Maryland Department of Transportation.

Figure 3. Photo. Coordinated Highways Action Response Team dashboard.(2)

Source: *Maryland State Highway Administration.*

The North Carolina DOT comparisons of crash volume and crash clearance times provides relevant comparisons from one year to another (using the same quarter) as well as connecting the causes with the results. The statewide crash count, shown in figure 4, increased more than 10 percent from 2018 to 2019. Figure 5 demonstrates the average clearance time declined slightly from 2018 to 2019, suggesting the resource allocation in 2019 was appropriate for maintaining the performance at the target level.

Advanced displays use mapping software to illustrate concentrations of freeway service patrol activity over a month. These help gauge the resource allocation decisions, and power changes to the patrol schedules and staffing levels. These “heat maps” can also display different factors – showing monthly or year-to-year changes.

North Carolina’s bottleneck dashboard identifies the top congestion problem locations (figure 6). The color coding helps the reader navigate the list and “why is this section in the top 10?” issues. One issue noted by the leadership is that the list does not change very much from month-to-month. The construction-caused sections are also very important – those will presumably drop off or down the list, and therefore do not need new projects to address their problems.

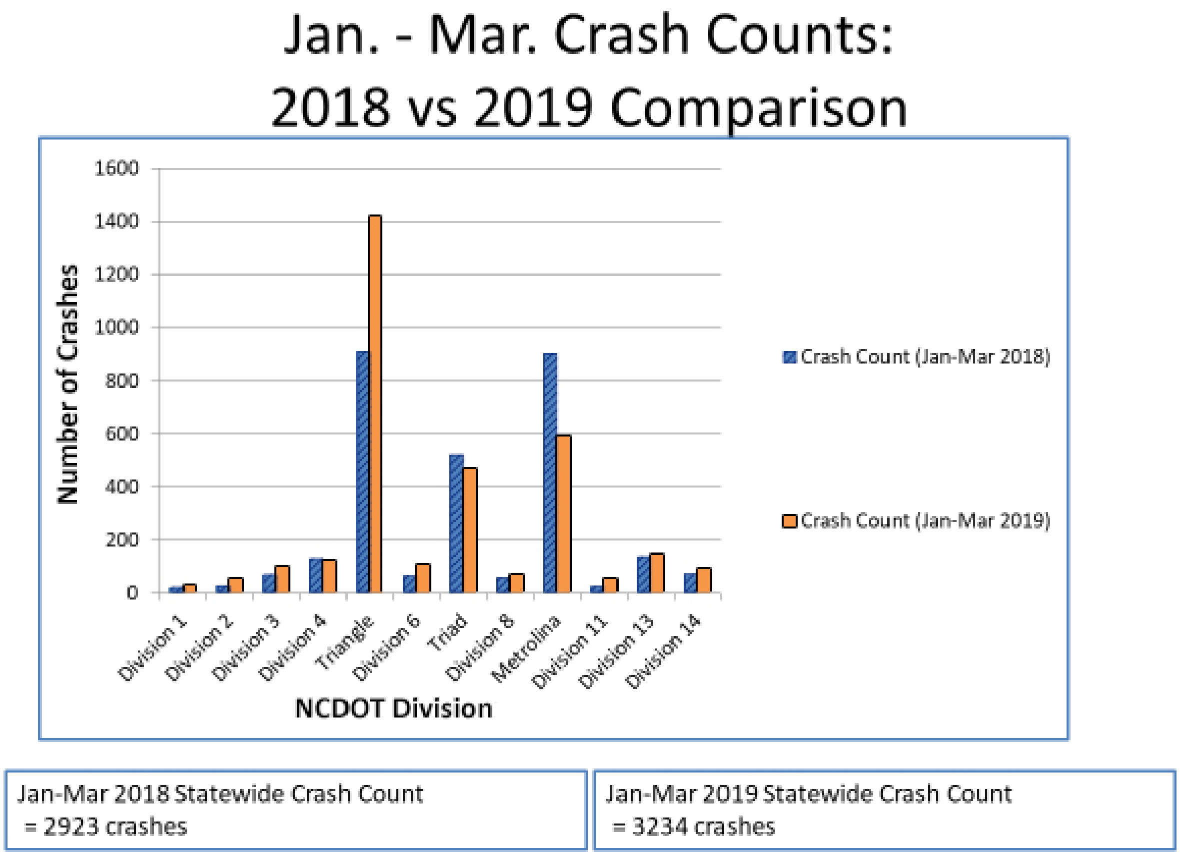
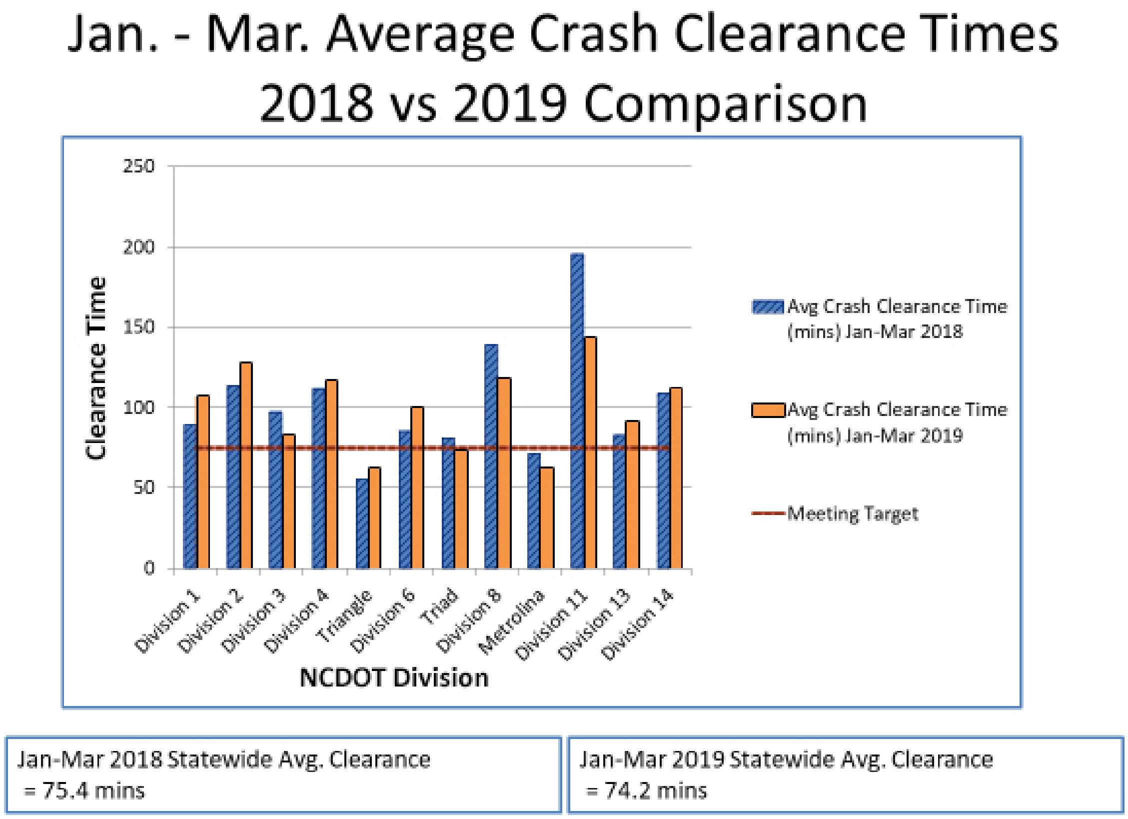


Figure 4. Graph. North Carolina crash counts.[(1)]

Source: *North Carolina Department of Transportation.*



Note: Avg = average.

Figure 5. Graph. North Carolina crash and clearance time.[(1)]

Source: *North Carolina Department of Transportation.*

Fewer agencies are integrating this information into a public-facing dashboard. Most TMCs use traffic speed, volume, weather, crash, and incident information in an internal dashboard and refer to it in TMC practice reports and on their websites. These are the standard traffic operations information with logical connections to the core mission of a TMC, and direct uses in the deployment and operation of management functions and staff and are the basic logical components of the before/after analyses.

Delay Bottleneck Report March 2019

Rank	Location	Division
1	(I-85 S @ MM 26 - 31)	12/10
2	[I-485 CCW @ PROVIDENCE RD MM 57 - 64]	10
3	[I-77 N @ CLANTON RD MM 7 - 2]	10
4	[I-40 E @ HARRISON AVE MM 287 - 280]	5
5	[I-77 S @ WESTINGHOUSE BLVD MM 1 - 10]	10
6	[I-485 CW @ PROVIDENCE RD MM 57 - 52]	10
7	(I-26 W @ NC-191 MM 33)	13
8	[I-485 CW @ GARRISON RD MM 6 - 1]	10
9	*I-40 E @ HARMON DEN RD MM 7 - 1	14
10	[I-540 E @ CREEDMOOR RD MM 9 - 2]	5

[Normal Top 10- Non Construction]
(Sometimes Top 10)
*New

Note: N = north; E = east; S = south; w = west; CCW = counterclockwise; CW = clockwise; RD = road; BLVD = boulevard; AVE = avenue; MM = mile marker.

Figure 6. Photo. North Carolina bottleneck list report.[(3)]

Source: *North Carolina Department of Transportation.*

Transportation Management Center Dashboard Planning, Design, and Implementation

Dashboard development may involve a variety of data challenges, but the most difficult are those that involve combining data sets from different agencies or even different elements of a single agency. Correctly identifying data needs is typically the first step in constructing a dashboard data set. TMCs should consider audiences, use cases, performance measures, and communication channels before finalizing the data items; and even after the initial roll-out, all these lists will grow. In many cases, the listing begins with the available data; the best systems also consider data needed to support the mission, even if those data are collected by other agencies or must be estimated for some time before data collection can be arranged. Ensuring that the data are of high quality, are available when needed, accessible, and shared with the appropriate agencies are important elements of the data solution.

Those involved in the dashboard planning steps should include maintenance resources and staff expertise as factors. Most TMCs use in-house staff or consultants to do the maintenance, and TMCs use a combination of system diagnostics and user feedback to address the issues and develop more capabilities.

Dashboard Evolution

A relatively constant element of TMC dashboards is change. Some changes derive from new data sources such as third-party data and information providers and other changes spring from new agency goals or desired attributes. User feedback, public comments, and stakeholder meetings are other common sources of change for dashboards. Internal change often begins with operators – either as a need or as an improvement suggestion. New analytic platforms or data integration services are also frequent change agents. When asked for other goals for the performance dashboards, the most frequently mentioned improvement objectives were the following:

- Display of real-time events, understandable for systems primarily designed to serve internal TMC operations.
- Dashboard attributes or other operational improvements, including greater flexibility for use across the agencies.
- Geographic displays of active events and customizable features.

Dashboard Enhancements

TMCs should consider the following topics for future enhancements and envisioned changes:

- Data sources – Traffic speed and traffic signal data are commonly used data elements.
- New analysis capabilities – More complex information queries are a common analytical element. TMCs should also explore predictive analysis capability.
- Information sharing – The dashboard provides information to other stakeholders most frequently, supporting the goal of providing a common communication platform. TMCs should consider coordinating data to improve traffic management, but very few TMCs share data with the public.
- Visualization or presentation capabilities – A real-time dashboard with a visual display in the control center is a common goal for TMCs with a dashboard.
- Other enhancements – Real-time tracking of the transportation operations center performance is a common "other" dashboard enhancement. Making report preparation easier and integrating the TMC data with other data sets – in essence, functions with a longer time horizon – is also a frequent response of TMCs.

CHAPTER 3. CURRENT STATE OF THE PRACTICE FOR TRANSPORTATION MANAGEMENT CENTER DASHBOARDS

This chapter discusses the current state of the practice for Transportation Management Center (TMC) dashboards presently in use based on the results of the literature review.

DASHBOARDS CURRENTLY IN USE

This section outlines the variety of dashboards that TMCs use across the United States. While the purposes of dashboards may vary between interfaces, outputs, data, and targeted users, dashboards often fit into the following categories:

- Planning dashboards that compare performance measures, viewing metrics based on the selected date and time ranges, and comparing long term trends in data. Planning dashboards have a variety of users and can fit many needs allowing users to explore historical trends and perform data analytics. Decision makers can use dashboards to monitor system performance against set targets and generate required reporting (e.g., for Transportation Performance Management for the Federal Highway Administration [FHWA]).
- Operations dashboards that respond with low latency, delivering near real-time information, performance measurements, and monitoring capabilities. TMC operators use these dashboards in real-time decision making and monitoring functions.
- Reporting dashboards combine elements of both planning and operational dashboards to deliver user-friendly visualizations of performance measures in a convenient and report formatted output template. In many cases reporting dashboards are print-ready and designed to fulfill reporting requirements of local, State, and federal agencies.
- Maintenance dashboards present the operational status of devices and system components to technicians and managers to help coordinate their activities to restore normal operations and maintain the system. These are like operational dashboards but are more targeted to operating, maintaining, and supporting the infrastructure and assets of a system.
- Advanced Traveler Information Systems dashboards present traveler information to the motoring public. The dashboards typically display current traffic conditions and events, like operations dashboards, but are simpler and are read-only. These dashboards can be as simple as a line of information displayed on a dynamic message sign (DMS) or information pushed as a text update to travelers.

Agencies and organizations use some or all of these dashboard types for both internal and external needs and purposes. Dashboards may be standalone products or designed to complement existing processes and procedures. The following examples showcase the flexibility of dashboards to serve multiple purposes.

Regional Integrated Transportation Information System – Planning, Operation, Advanced Traveler Information System Dashboard

The Regional Integrated Transportation Information System (RITIS) is a nationally recognized data management system that shares, disseminates, and archives data, integrating a variety of tools such as performance measurement, dashboards, and visual analytics. RITIS users include transportation engineers, planners, and TMC operators at the local, regional, and State levels, in addition to first responders and other public agency personnel. The data collected and stored in RITIS includes real-time traffic data, as well as supporting data to give operators and responders a full picture of the conditions such as weather, transit, incidents, video feeds, radio scanners, live events, and other similar data sources (figure 7). Approved RITIS users can disseminate data to the general public and media, as needed.

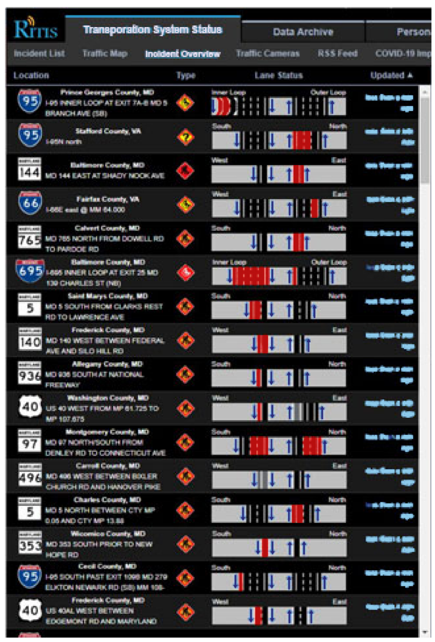


Figure 7. Photo. Regional Integrated Transportation Information System transportation system status.[(4)]

Source: *University of Maryland Center for Advanced Transportation Technology Laboratory.*

Florida Department of Transportation District 5 Regional Transportation Management Center (TMC) Facility and Regional TMC Map – Operations Dashboard

In 2019, the Florida Department of Transportation (FDOT) District 5 opened a new regional TMC (RTMC) facility to serve the nine counties of the District serving the Orlando area in Central Florida. This state-of-the-art facility includes multiple video screens, allowing RTMC operators to view hundreds of closed-circuit television cameras, dynamic message signs, and sensors across the roadway network. In addition to these resources, FDOT District 5 has an RTMC map displaying information from the Department’s SunStore, a big data management environment continuously collecting millions of data records a month in near real-time. Through specialized application programming interfaces (API) the RTMC map receives performance measures of the roadway system, including both the interstate and arterial network. Displayed on the map are a series of colors depicting the departure from expected or normal traffic along with the ability to interact with roadway segments to view current preference trends based on data within the last five minutes and expected performance measurements, including congestion and travel times. The RTMC map visually alerts operators as conditions change and provide a quantifiable review of potential alternative routes.

Virginia Department of Transportation Performance Reporting System for Projects and Programs – Planning, Reporting, Maintenance Dashboard

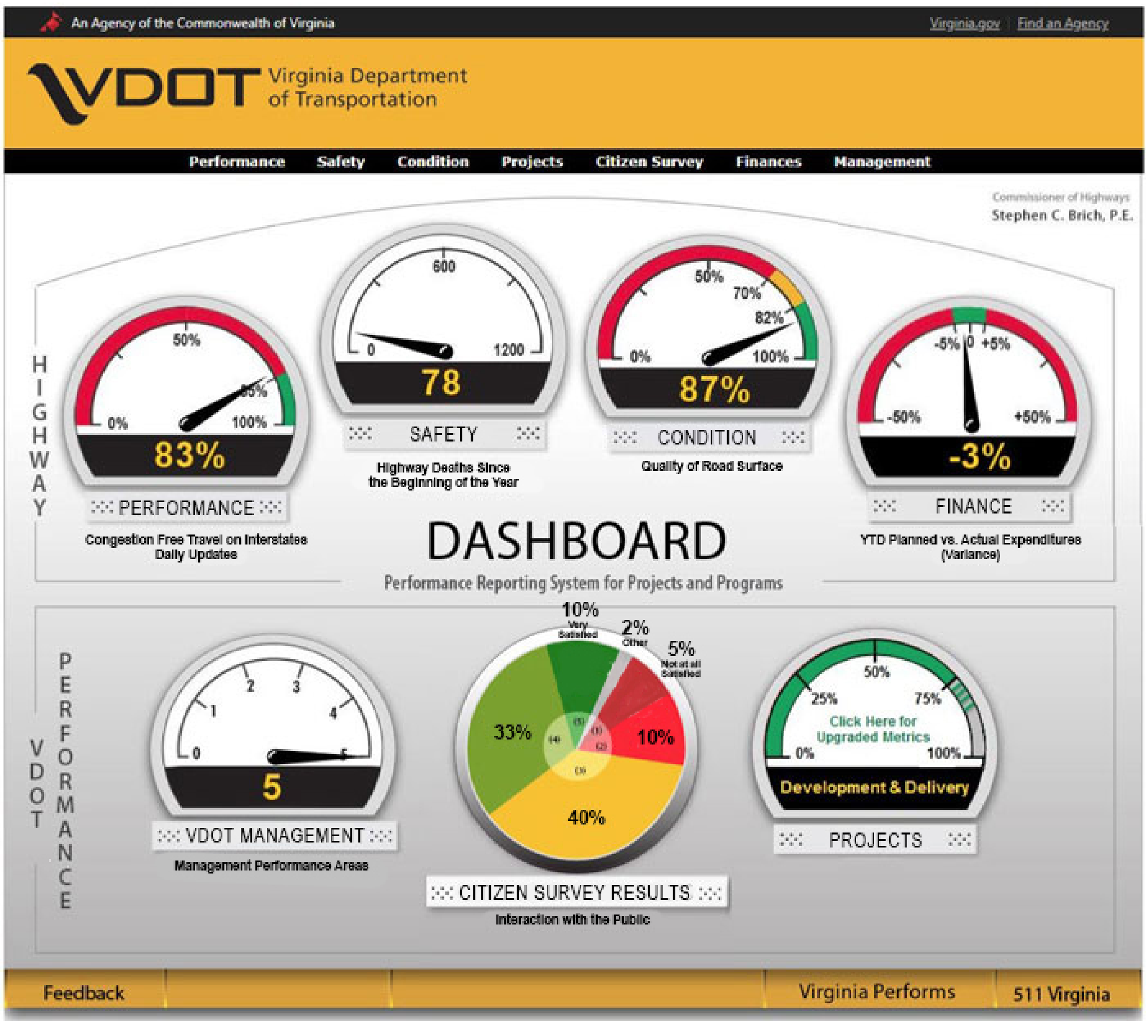


Figure 8. Photo. Virginia Department of Transportation Performance Reporting System for Projects and Programs.(5)

Source: *Virginia Department of Transportation.*

The Virginia Department of Transportation (VDOT) created a dashboard (figure 8) to allow travelers to access performance reporting across the system and provide a user-friendly interface where users could quickly view the overall status and performance of VDOT's roadways. Combining several data sources, this dashboard presents a starting point for users to fully explore the wealth of system performance measures available. After selecting a focus area, users can dive into the data on the dashboard and further explore the performance measures. The dashboard provides a direct connection to and shares information with the Virginia Performs Initiative, helping display how the Department is furthering the overall goals and initiatives of the agency.

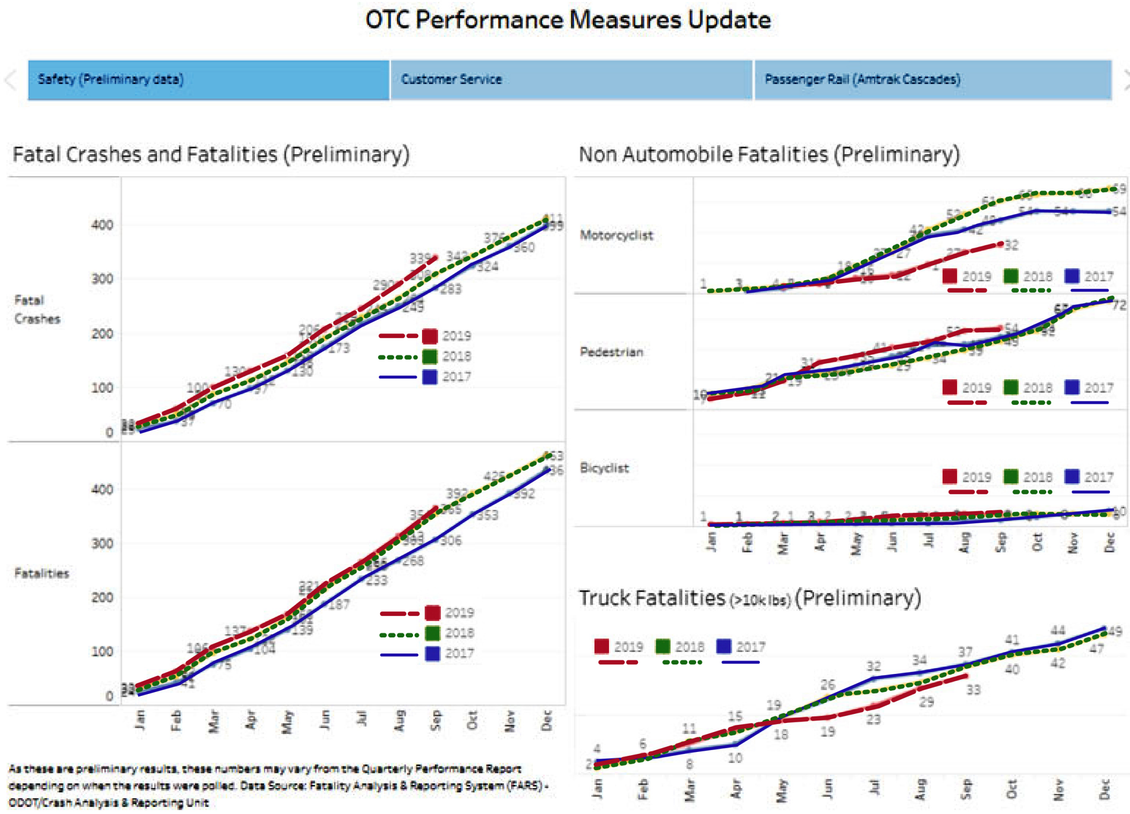
Oregon Department of Transportation TrickCheck Map – Planning & Maintenance Dashboard

Incorporating in a mapping component, the TripCheck Map from Oregon Department of Transportation (ODOT) provides a quick view of activity across the roadway network (figure 9). Included in the map are layers representing incidents, live traffic conditions, local events, and special information entered by ODOT and local agencies, the location of intelligent transportation systems (ITS) devices, and many more ready to access features. This highly detailed view of the network can provide fast insight into what is occurring by providing users a variety of different data sources and metrics.

Figure 9. Photo. Oregon Department of Transportation TripCheck map and dashboard.[(6)]

Source: *Oregon Department of Transportation.*

Also available from ODOT is the Oregon Transportation Commission Dashboard (figure 10), a nightly updating system that provides a quick look at performance measures across the system.



Note: OTC = Oregon Transportation Commission.

Figure 10. Photo. Oregon Department of Transportation Oregon Transportation Commission dashboard.(7)

Source: *Oregon Department of Transportation.*

Spokane Regional Transportation Management Center Performance Measurement System – Operations & Advanced Traveler Information System Dashboard

For the past 10 years, the Spokane Regional Transportation Management Center (SRTMC) has used the Performance Measurement System to display real-time traffic information across multiple jurisdictions both locally and regionally (figure 11). Combining real-time volume and speed detectors, more than 100 live streaming camera feeds, variable message signs, and many other technologies the SRTMC serves as the hub of the region's transportation management system.

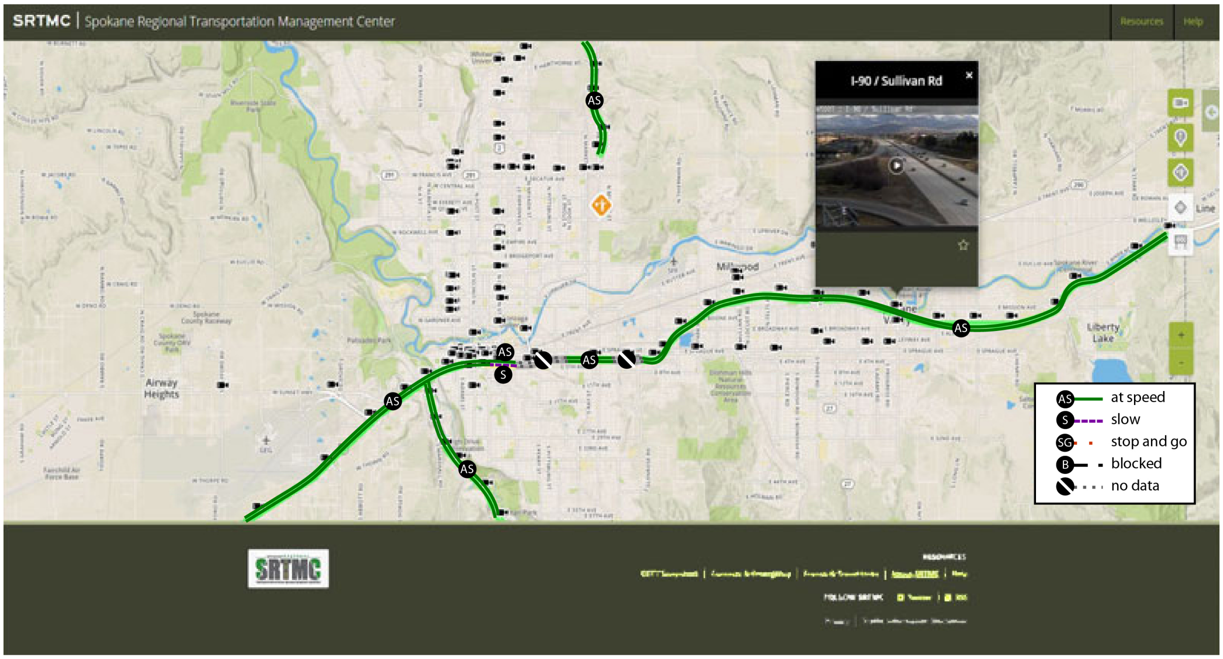


Figure 11. Photo. Spokane Regional Transportation Management Center dashboard.(8)

Source: *Spokane Regional Transportation Management Center.*

Florida Department of Transportation District 4 Regional Transportation Management Center – Operations and Advanced Traveler Information System Dashboard

In FDOT District 4, which serves the east coast of the State between Fort Lauderdale and Vero Beach, the RTMC uses their display wall for shared status, not just for video. The RTMC developed systems to monitor the status and uptime of their ITS components, present the uptime performance, and flash alerts for items that are unavailable or need maintenance. Similarly, RTMC's display wall shows a straight-line diagram whose x-axis indicates distance along a facility and the y-axis indicates current travel time. This allows the RTMC operators and managers to have a common vision of monitoring and responding to the status of their system.

DASHBOARD STAKEHOLDERS AND USER NEEDS

This section examines who the end users of TMC dashboards are, why each user group benefits from the dashboards, and what user needs are met as a result. At a high level, the intended functionality of a TMC dashboard is to achieve safety and mobility through planning and operations using performance measures and dashboards as the enabling technologies. Two key user needs are to facilitate data-driven decisions and to facilitate real-time decisions. Data-driven decisions allow for the understanding of the impacts of decisions, the quantification of return on investments, and overall performance gains for the network. Data-driven decisions also allow for the use of performance measures in the prioritization of future investments by providing a quantifiable and data-driven approach. It allows the discovery of relationships, patterns, and trends that contribute to safety and mobility goals, identifies innovative approaches for improvements, and reveals the impact of combinations of factors on the network.

While the TMC operators and managers are the primary users of the TMC dashboard, the platform could present value to other transportation and non-transportation professionals. With more datasets and minor enhancements, transportation planners, engineers, transit personnel, executive leadership, and others could use the TMC dashboard to enhance their short- and long-term deliverables. The ability to use real-time decision-making allows an agency to be proactive rather than reactive, as dashboards can present data in a way that allows users to take real-time action. Many agencies using dashboards are taking advantage of this proactive approach as seen in the Dashboards Currently in Use section and many more agencies are beginning to explore this opportunity.

Top-level decision makers, including executive and legislative branch government officials at the State and local level are key users of TMC dashboards. These officials make high-level decisions about allocation of resources and funding for projects. The officials want to know that the resources are spent wisely and effectively, and they want to show that the outcome of traffic operations activities achieves benefit to the public. A TMC dashboard can allow officials and their staff to monitor progress towards key transportation goals and non-transportation goals supported by transportation (e.g., equitable access to jobs). The TMC dashboard should provide an opportunity to increase transportation system and agency transparency, while reducing the workload for busy transportation professionals who would otherwise have to answer government officials' requests for data by creating reports. The TMC dashboard is thus an effective tool in communicating the benefits of traffic operations by visually showing progress towards achieving goals and benefits.

The general public, who are the users of the transportation system, are also stakeholders. Taxpayers have a vested interest in tax revenue spending on many services including transportation. Taxpayers want to know the effectiveness of the transportation system and the projects that improve it. A dashboard can provide information transportation system users need about their transportation options, including real-time information such as traffic speeds, roadway closures, park and ride lot occupancy, and other real-time traffic and transit information. This information can help transportation system users make effective use of the transportation network by empowering their decision-making.

The below table identifies these key stakeholders, the agency they typically represent, and the roles or responsibilities associated with the professional.

PLANNING FOR DASHBOARDS

This section discusses the state of the practice for planning TMC dashboards. Many dashboards are a component of other larger advanced transportation management systems (ATMS), groups of ITS field device deployment projects, or TMC operations service contracts. These larger efforts follow the systems engineering process due to State DOT policy, 23 CFR Part 940 (commonly referred to as FHWA rule 940), or both. However, successful dashboards follow a detailed process during planning that is dashboard specific to avoid the common pitfall of only focusing on the higher-level objectives of the containing contracted project, service, or system. Not outlining a comprehensive plan for the creation of a dashboard may result in development moving forward without adequate planning, stakeholder engagement being minimal or completely absent, and an end product that does not meet the needs or satisfy the goals of the project.

Dashboard developers should answer several basic questions over the course of planning for a dashboard including the following:

- Who will use the dashboard?
- What will the dashboard look like?
- What will the dashboard do?
- How often will the dashboard update?
- Which datasets are necessary to have these outputs?
- What platform will the dashboard use?
- Will the data in the raw form be acceptable or will there be a new data metric calculated?
- What will happen to the information displayed on the screen?
- Will the project undergo an AGILE style of development or follow traditional waterfall development?

The planning stages of a dashboard development project should address these questions. Planning for dashboards includes several steps, ranging from regional connections to highly technical details about data availability.

Regional Intelligent Transportation Systems Architecture

Under 23 CFR Part 940, the ITS architecture is a required part of the systems engineering process to establish the agencies with which information and services are exchanged. The dashboard is often the endpoint that enables users from other agencies to view the shared information, and thus plays a critical role in fulfilling that requirement between agencies. This level of architecture is typically part of the regional ITS architecture and is useful in reviewing to determine existing needs as well as added opportunities for helpful information sharing between agencies. Agencies sharing data typically establish a formal memorandum of understanding that details data collection, ownership, availability, accessibility, usage, and redistribution through a formal agreement between the agencies. By sharing data and dashboard services, agencies can avoid duplication of efforts and identify cost-saving opportunities where collaboration between agencies may be possible.

Stakeholder Outreach

Dashboard developers can use the regional ITS architecture to identify stakeholders, stakeholder needs, and potential opportunities for collaboration. Dashboard developers typically perform stakeholder outreach to elicit added details of needs and opportunities, further engage stakeholders to establish a collaborative group moving towards a common goal, and to outline a roadmap of implementation to fulfill the identified goals and needs.

The planning stage can benefit from having many different levels of stakeholders involved in the project. Each stakeholder brings a different valuable point of view, operators and those who will use the dashboard on a daily basis understand the importance of quickly finding the answers they need; planners and engineers approach from a more planning centric view of the performance measures that can be made available from the data and dashboard; while managers can understand the value of both. Dashboard developers should consider more external stakeholders where appropriate as these external partners may use the dashboard to answer questions, not always commonplace to those within the TMC structure. Table 1 provides a list of stakeholders.

One example of how to represent these multiple stakeholder levels is the inclusion of user scenarios, often developed within Concept of Operation documents, which depict various real-world scenarios of how different users may interact with the dashboard and the various impacts that these interactions may have in the decision-making process of both operational and planning decisions.

Stakeholder outreach can provide access to practitioners who may participate in the testing and validation of the dashboard, ultimately helping to ensure that the overall goals are met.

Finally, the TMC dashboard can be an invaluable tool in relaying the benefits of various projects and traffic operations to the public and to elected officials who provide taxpayer funding for those projects. For example, the TMC dashboard could generate an automated monthly or quarterly report for executive leadership or the general public. Such a report could outline the traffic operations conducted during the reporting period and include a summary of estimated benefits to the traveling public such as cost or time savings. Alternatively, a public-facing dashboard provides similar cost and time savings data for the public and elected officials to examine directly.

While large expansion or widening projects are recognized for their potential benefit to the transportation network and user experience, many traffic operations efforts go unseen, but provide great benefit to the transportation network. By generating consistent reports that describe the various traffic operations efforts in a region and how they positively impact the traveling public, TMC dashboards can communicate the importance of traffic operations to a community, region, or State.

Dashboard Goals

Generally, the first step to develop a dashboard is to identify and prioritize the key goals for the TMC dashboard. The dashboard should provide specific information to satisfy a need. This forms the basis of the rationale for creating a dashboard, as without clearly articulated goals, a dashboard project runs a high risk of being unsuccessful.

Goals should be SMART. That is: **S**pecific, **M**easurable, **A**ttainable, **R**ealistic, and **T**imely.

Goal development should not occur in a vacuum. Involvement from the development team, stakeholders, and end product owners is critical to create a collaborative process and clearly define what success will be. Goals should not conflict and should center on completing identified needs in measurable ways. Goals should not be overly broad, unreachable, or unable to provide a clear measure of success. The establishment of goals sets the stage for the remaining steps of the project and provides a clear horizon for dashboard development.

Project Level Architecture

The project level architecture should specify how components within a system are structured. At this level, an architecture diagram of how to organize components in the system logically documents the decisions. This architecture should fit within the established Regional ITS Architecture and contain enough detail to verify that the required components are in place or made available during the life of the project.

The project level architecture can help in identifying the following:

- Developing efficiencies in designing a standalone dashboard with complete customizable control versus utilizing an existing and established architecture to leverage prior work that may not allow the same level of flexibility.
- Organizing components to use the intermediate output from a data source or existing resource versus creating dedicated API resource components for a single dashboard purpose.

Along with guiding the decision-making process, the project level architecture serves as input to the dashboard or system designer to further dissect into design and implementation.

Table 1. Stakeholders, roles, and responsibilities.

Stakeholder	Agency	Key Roles and Responsibilities	Dashboard Roles and Responsibilities
Traffic Operator	State Department of Transportation (DOT) Local Agency	Monitor the transportation network in real-time using Transportation Management Center (TMC) dashboards and available information. Coordinate notifications and responses to traffic incidents, monitor events, activate appropriate responses to detected or reported incidents. Pushes messages via advanced traveler information system dashboards or other traveler information mechanisms.	Support operator activities and decisions: • Aggregate and communicate various health and status attributes in real-time. • Present notifications and input data for actions and decisions. • Display organizational performance metrics and targets.
Traffic Operations Manager / Engineer	State DOT Local Agency	Oversee real-time management of the transportation network; ensure the quality and evaluate the performance of real-time operational deployments. Serve as stakeholder or project manager in TMC Dashboard development.	Support management oversight: • Show performance of operations. • Show anomalies in system operations. • Compare current conditions to historical conditions to gauge improvement or worsening trends.
Transportation systems management and operations (TSMO) Planner / Engineer	State DOT Regional Agency Local Agency	Identify and carry out a TSMO/ intelligent transportation systems (ITS) solution within the transportation network. Serve as a stakeholder in TMC Dashboard development to guide the needs and goals of the dashboard. User of planning and reporting dashboards to identify trends and perform analysis.	• Support identification of future TSMO needs through presentation of data-driven forecasting. • Show benefits of prior TSMO investments through presentation of improvements before and after a project.
Transportation Planner / Engineer	State DOT Regional Agency Local Agency	Identify transportation-related issues, challenges, and opportunities within the jurisdiction; plan and program short-, medium-, and long-term improvements to account for these issues, challenges, and opportunities; conduct corridor planning and engineering studies. User of planning and reporting dashboard.	• Support identification of future transportation needs through presentation of data-driven forecasting. • Show benefits of prior investments through presentation of improvements before and after a project.

Table 1. Stakeholders, roles, and responsibilities (continuation).

Stakeholder	Agency	Key Roles and Responsibilities	Dashboard Roles and Responsibilities
Transit Planner / Manager	Transit Agency	Identify transit-related issues, challenges, and opportunities within jurisdiction; plan and program short-, medium-, and long-term improvements to account for these issues, challenges, and opportunities; conduct transit studies; identify and pursue funding opportunities.	Show needs and benefits of transit operations: • Ridership data. • Ridership trends. • Congestion information. • On-time performance. • Origin-destination analysis.
Top-Level Decision Maker / Government Official	State Government Local Government metropolitan planning organization	Make key decisions regarding funding of transportation projects and allocation of transportation resources; monitor the performance of transportation systems; use transportation data to support initiatives not directly related to transportation.	Show benefits of traffic operations and transportation system investments: • Safety analysis of crashes and injuries. • Congestion and bottleneck analysis. • Simulated improvements from future investments in transportation projects and operations.
Transportation System Users	General Public	See how effective the transportation system is; see where and how effective public transportation expenditures are; obtain information about their transportation options; obtain real-time information about the transportation system's operation that may affect their trip.	Show benefits of traffic operations and transportation system investments: • Real-time tools for transportation users. • Safety analysis of crashes and injuries. • Congestion and bottleneck analysis. • Simulated improvements from future investments in transportation projects and operations.

Project Development Process

During the project development process, the dashboard developer should determine the project development methodology of either Agile, waterfall, or hybrid. Each of the styles has advantages and disadvantages that play a role in the project development lifecycle, described below:

- Waterfall methodology follows a linear approach to the development of the dashboard, moving through the various software development lifecycle phases completing one phase before moving to the next. The user needs are dissected into system requirements, system architecture, system design, further dissected into subsystem level requirements and design, followed by implementation, component testing, integration, system testing, and product delivery. This methodology provides a highly structured approach but may not allow a high level of flexibility for changes to the system specification after the development plan has been finalized and initiated.
- Agile methodology implements a variety of approaches but centers on the concept of smaller development processes, iterating multiple times to incorporate stakeholder feedback between each iteration. This allows the overall development process to remain flexible and allow requirements and solutions to evolve throughout the project. The target system is available for stakeholder review much sooner, and the stakeholder feedback and subsequent iterations allows continual improvement; however, this methodology does require clear and frequent communication and will be available among all parties.
- A hybrid methodology approach combines both of these methodologies, allowing for a relatively robust and structured approach but with flexibility built in. A large majority of dashboard development tends to follow this hybrid approach. The hybrid approach leverages the advantages of both methodologies by combining defined system requirements with multiple iterations and meeting and validating high-level technical requirements while remaining flexible.

A typical project lifecycle has four distinct phases: initiation, planning, implementation, and closing. The initiation phase identifies dashboard project goals that reflect stakeholders' outreach.

The planning phase establishes the scope, schedule, budget, and implementation plan for the dashboard project. This planning accounts for key details such as the architecture, timeline, and schedule for implementation. Discussing and documenting the project requirements happens during the planning stage; the use of these project requirements can be used in later stages during testing to verify requirements have been met.

Project requirements may vary but should follow these general suggestions:

- Identify the technology needed to complete the dashboard. Including the following:
  - Database.
  - User interface dashboard or specialized software.
  - Licensing requirements.
- Establish roles and responsibilities for staff involved with the project, such as key functionality and technical requirements of the dashboard.

During the planning phase dashboard, developers should consider any known security or operational policies and constraints which may need more time to accommodate before implementation can proceed. These added steps should be documented and built into the schedule. For instance, if the hosting server for the dashboard will require added configuration of server ports or firewall settings that may be managed by an external department, added time should be planned for coordination.

TMCs should make as much data as possible accessible to the public while still maintaining data security. During this phase, the front-end language and software of the user interface should be identified and discussed. Some advantages and disadvantages should be weighed before selecting the front-end language. Considerations include the following:

- What technology does the organization support?
- Does staff have the technical expertise to successfully deliver a dashboard in the desired language/platform?
- Is there a data management platform in place that can support the dashboard's data?
- Where will the data and dashboard reside?
- Does the organization support a cloud solution?
- How customizable does the user interface need to be?

The TMCs need answers to these considerations to help drive the selection of the software language and platform they should consider for the dashboard. The Data Analysis, Technology, Toolsets, and Dashboarding section includes examples of front-end software packages for TMC Dashboards and analysis.

The implementation phase performs activities needed to synthesize the dashboard product. This includes, but is not limited to, the following activities:

- Allocating the requirements to specific development activities or staff.
- Retrieving resources identified in the architecture (e.g., data streams, data sets, hardware, and pre-built software products that form components of the dashboard).
- Developing code and integrating components together to satisfy requirements.
- Developing testing routines to verify the organization meets requirements.
- Integrating components to work together that realize larger and larger system functions.
- Developing related product parts (e.g., documentation, installation packages or scripts. operations and maintenance tools to help detect and diagnose issues).

These technical requirements should include checks and verification for accessibility needs and for compliance with the Americans with Disabilities Act (ADA), which prohibits discrimination against individuals with disabilities. Although no federally enforceable standards for web access currently exist under the ADA, TMCs can look to resources such as the standards issued by the U.S. Access Board under Section 508 of the Rehabilitation Act (applicable to federal agencies) or the World Wide Web Consortium's June 2018 Web Content Accessibility Guidelines 2.1 as references for providing uniform access to ensure that individuals with disabilities can access and interact with websites. Dashboard developers should follow such reference tools to ensure that all users can perceive, operate, and understand the content and components of the dashboard. The final phase is the closing phase, sometimes referred to as the deployment phase, where the developer releases the final project for the TMC's and other stakeholder's use. Having followed the outlined phases is critical to a TMC dashboard process as this sets the direction for the entire project. Meaningful goals and a robust planning process ensure that the TMC obtains the greatest value from the final product and translates to a successful dashboard.

DATA MANAGEMENT

This section discusses many concepts related to data management, including data types, data formats, data storage, access, retention concepts, and begins exploring methods of data security. This section focuses on available methods necessary for data management serving TMC dashboards.

TMCs can use a high variability of data inputs, types, and formats for dashboards. These include the following:

- Traditional static data.
- High velocity and high volume sources such as probe collected data or field deployed sensors.
- Valuable and sometimes sensitive data provided from other departments and agencies including law enforcement or incident response systems.
- Transit agency data.
- Crowd sourced information containing unstructured data.
- Nationally provided data.
- Developer-identified data sources.

At a high level, dashboard developers can split data into two different data input types, static or slow changing and dynamic. Dashboard developers require static and dynamic input types for a successful dashboard.

Static inputs are typically items that provide context and do not change over time, and include the following:

- Locations of physical TMC assets (traffic signals, utility poles, DMS signs).
- Physical limits and characteristics of a roadway (speed limit, median type, functional classification).
- Slow changing data elements. This refers to items that are essentially static but have a non-zero probability of changing without the need for a major project. For example, a transit route is typically fixed, but transit planners can modify it on a relatively infrequent basis (typically measured in months or years, as opposed to minutes for dynamic inputs).

Dynamic data inputs are data sources that continually update and reflect conditional changes, and include the following:

- Average traffic speeds or travel time of a roadway segment (collected via sensors, Bluetooth, or probe data).
- The number of vehicles (volume) that pass a location (collected via roadside sensors, loops, other detectors, or video detection).
- Location and duration of crash events.
- Presence of rainfall along a corridor or other weather information.
- Event management activity log.
- Work zone and maintenance information.
- Special event information.
- Video or still images from traffic cameras.
- Messages deployed on dynamic message signs.

These data drive the dashboard, with the dashboard using the information to present real-time context and rapidly update performance metrics. A successful data management platform (covered in the Data Management Platform section) provides the foundation for the storage and external partner-provided data retrieval or through third party providers that the TMC houses. The dashboard developer should carefully discuss scale and complexity of this data at the outset of dashboard scoping to adequately understand and plan for the influx of data that may be available and needed for use in the dashboard. Many dynamic datasets can quickly enter the realm of “big data” with collection, storage, and analysis working across billions of records.

While there are many definitions of “big data” in use, the most recognizable is that big data is a tipping point in which traditional mechanisms to manage data are no longer able to perform at the level needed. A volume of data being collected, the rate in which the data is collected (velocity), the value that the data holds, the variety of data types being collected, or the veracity (trust) of the data are all big data identifiers. The main takeaway of this definition and understanding of big data is that the term is highly relative and dashboard developers should carefully consider on a case by case basis if a source represents big data.

Data management presents several unique opportunities and challenges. The availability of data can greatly expand how various dashboards communicate with users and the information that is represented; however, the availability of these large datasets present unique challenges in how to best manage, analyze, and access this information within a dashboard. To navigate this complexity, one of the first steps in constructing a dashboard is to ensure that dashboard developers can correctly identify the data needs and viable sources for the data. TMCs should consider audiences, use cases, performance measures, and communication channels before identifying the data needs. Once identified, the data needs should be satisfied and made available through the data management platform before the dashboard can undergo development.

In many cases, the data listing usually begins with data immediately available to the TMC while the best systems also consider data that is needed to support the mission, even if other agencies collect those data or the TMC must estimate the data element for some time before arranging for data collection. Ensuring that data integrity remains high, is available as needed, and the agency can obtain or share with appropriate agencies are fundamentally important in the design of a data management platform.

When considering data for use in a dashboard, the following questions can aid in understanding the maintenance resources and required staff expertise to keep a dashboard relevant and operating efficiently:

- How is the data formatted? Are adequate data dictionaries available to allow users to verify values and collection information?
- Is there a clear relationship between data and its context? Can the relationship be properly represented spatially?
- Who is responsible for maintaining the data?
- What is the frequency of update to the data? Does this update frequency satisfy identified needs?
- What is the latency of the data? How reliable is this information in making real-time decisions?
- How often will the dashboard access the data? Is there a threshold where the frequency of use may allow data archival to occur?
- Does the data require any modification or extract, transform, and load (ETL) procedures prior to use in the dashboard?
- Does the data need to be saved, stored, and made available for historic analysis? Are there data retention laws that the TMC must adhere to in data storage?
- Are there license or other agreements that limit the sharing or ETL processes of a dataset?
- Is the data considered sensitive? Are added security measures required to protect data and access?

The answers to each of these questions expand the knowledge base of available data and details the necessary steps to make the data available for use. Best practices recommend establishing data dictionaries for each dataset as these documents provide a guided layout and form in which the above questions can be answered. Data dictionaries typically contain data descriptions, field structures, update frequencies, data source information, and other details. FDOT District 5's SunStore data dictionaries provide this information in a consistent and easy to follow format.

Not to be understated, the format in which the dashboard presents data is critical to the data planning process, as some data are transferred from one format to another to be combined with other datasets to provide the proper outputs and performance measures for the dashboard's use.

Achieved through ETL processes, the dashboard project team should understand the data and account for all limitations and caveats before use in a dashboard. A common spatial constraint dashboard project teams commonly encounter in the development of performance measures is occurrences in which data from two different sources do not match in reported segmentation. For example, a probe data source may report the average speeds of a corridor from the off ramp from an interstate to the next major intersection, while a Bluetooth sensor may report from a minor intersection to an on ramp located on the opposite side of the interstate. In this case, the ETL process may require a process of conflation to compare these two different data sources and properly represent for visualization in the dashboard. ETL processes may also need to adjust for the difference in time interval segmentation, and other data attributes such as converting local time to the date and time established using a Coordinated Universal Time (UTC) format.

In the context of making data readily available for use in dashboards or other programming interfaces, dashboards project teams often use ETL processes in data management to convert different data formats into a single comprehensive format. Developers primarily use JavaScript Object Notation (JSON), a language-independent open standard data format. This format is highly likely to be the preferred data type for dashboard developers. Extensible markup language is a data format used for dynamic datasets. Comma-separated values is a third data format typically used for tabular datasets and will require additional analytics to bring the data into a more useful format for dashboard integration.

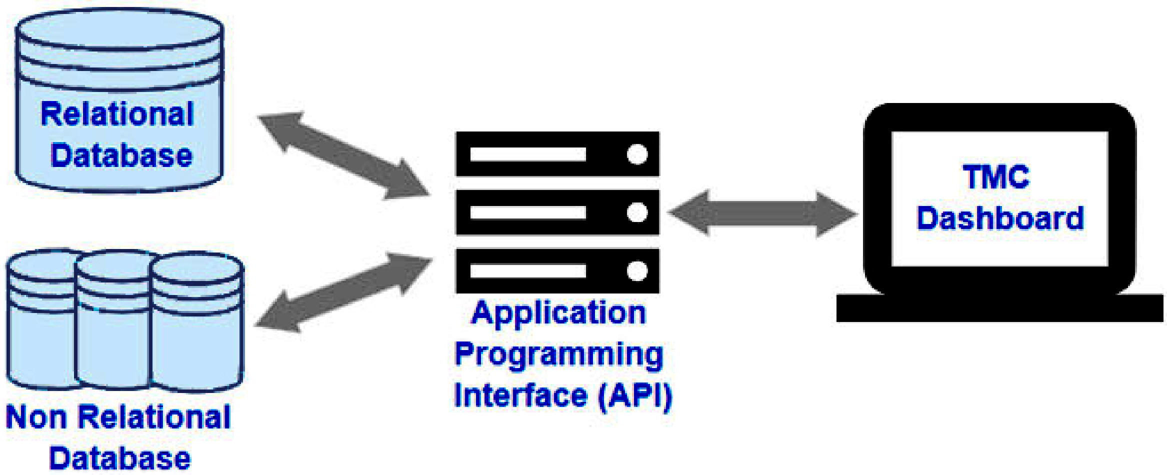
The use of a single comprehensive format can greatly streamline data storage, retrieval, and provide consistently repeatable mechanisms to estimate data growth and future needs of the system. In the planning of a dashboard, dashboard developers should consider data storage requirements to ensure adequate storage space will be available for the lifetime of the dashboard. Data storage may take many forms but is primarily centered around two concepts, relational and non-relational databases. While sharing similarities, these two concepts use different approaches for data storage and retrieval.

Relational Database

Relational databases are highly structured and organized into tables of rows and columns, with each row containing a unique key identifier. These tables link to many other tables in established relationships. Structured Querying Language (SQL) is the language for querying relational databases. SQL is a powerful language that can use the structure of the tables, allowing the query to include analytic expressions performed by the database server before returning the information to the user submitting the query. Examples of relational databases include Microsoft SQL Server, Oracle database, or MySQL. SQL provides a robust and relatively straightforward approach to data structure; however, these inner relationships can establish complex query paths as each table and row connect in multiple ways, and such complex, large datasets may suffer performance lags in relational databases.

Non-Relational Database

Often referred to as non-relational databases NoSQL, ElasticSearch, MongoDB, or Hadoop provide a different approach to the storing of data. These non-relational databases store information in Key-value pairs or JSON documents which offer high scalability and an approach to dealing with unstructured data. Data management platforms prefer non-relational databases when dealing with a variety of data sources. Many incoming datasets are unstructured or semi-structured and require flexibility to store these varied data sources quickly without requiring a transformation into a structured data model. However, the use of unstructured formats does not readily allow for the establishment of complex relationships between data items, instead, relationships are stored and established within the data record.



Note: TMC = Transportation Management Center.

Figure 12. Illustration. Data workflow for relational and non-relational databases connected via an application programming interface to a dashboard.

Source: *Federal Highway Administration.*

Data used in TMC dashboards are often a combination of data from both relational and non-relational databases (figure 12). As is the case with many aspects of data, there is rarely a one size fits all approach for data management. Dashboard project teams should carefully evaluate each dataset against the questions at the start of this section to determine how to best manage data and in which format or database type the data should be stored. This concept of a data management plan may expand to a tiered approach for storage of information, introducing the concepts of hot and cold storage of data.

Hot and cold storage refers to data accessibility, where hot storage is more accessible, but may be more expensive to provide, and cold storage is less accessible, and less expensive to provide. Dashboard developers can apply hot and cold storage to any dataset regardless of the type of selected database. Dashboard developers use hot storage for data which needs to be most readily available and is generally represented by the data that is queried the most often. In most TMC dashboards, data in hot storage is the most recent data received. How long data remains in hot storage is highly dependent on data relevance; for example, many dashboard visualizations use data that is a representation of near real-time information. As that data becomes historic the data may still hold a high relevance in the establishment of trends or baseline performance measures necessitating the need for the data to remain in hot storage. Hot storage environments are typically memory and resource intensive with larger allocations provided to greatly increase performance and response time.

Cold Storage refers to data which is still accessible but has less resources dedicated to query and analytics. This does not mean that cold storage is not valuable, only that in the context of relevance, the dashboard does not query at the same rate as other data. This data is still available for users but with the understanding that queries and analytics may take longer to complete as the system designed to serve cold storage may have less computational resources readily available.

Determining when to use hot or cold storage is highly dependent on the needs of the dashboard and the data management platform that is used. A TMC dashboard and data management environment could use a single system to serve as both hot and cold storage where the appropriate resources are available or if the technical expertise to carry out this concept is available. The dashboard project team should evaluate the use of cold storage in terms of data and records retentions in which State or federal laws may require the storage and availability of data long after data relevancy has passed. Continuing to provide access via cold storage mechanisms allows for data requests to be automated and ensures legal requirements are met.

While the Data Management Platform section should manage data security and access, dashboard developers should clearly define and understand any restrictions or privacy concerns that may arise related to the data used in a TMC dashboard. Dashboard developers should consider and take steps to anonymize data where appropriate or to limit access to data and dashboard components where personally identifiable information (PII) can be revealed to protect and alleviate privacy concerns. When PII is present, a best practice, and sometimes mandated depending on the agency or governing jurisdiction, is for agencies to follow accepted suggestions and standards in securing the data. An example provided by the United States Department of Commerce is the SP 800-122 *Guide to Protecting the Confidentiality of PII.* Dashboard developers also must comply with applicable law with respect to their collection and use of PII.

DATA ANALYTICS APPROACHES

This section focuses on the data analysis that occurs between the raw data inputs and the output in a dashboard format, as well as the delivery of information to the end user. This section answers the question of how the information is translated from traditional TMC data sources to the dashboards using the datasets discussed in the previous section. The focus of this section is on what is now used in TMC applications; the section also discusses tools for future applications.

Data Analysis Techniques

Dashboard developers can employ various data analysis techniques to prepare data for use in dashboards to create an end product that meets the goals of the TMC dashboard project. These techniques include the transformation of the input data format, the transformation of the information into a derived analytic output, the fusion of multiple data sources or outputs into a single data stream, ensuring the quality of a data stream, the detection and notification if certain events occur in the data stream or if data elements are not available, the classification of data elements, and the prediction of future events. Dashboard developers can stack the data analysis techniques as a pipeline, from the simplest case of displaying information in as close to the original format as possible, to more complex network of transformations and even predictions occurring between the input and the output.

Dashboard analytic techniques start with the connection handling and decoding to get information from a raw input source format to a representation appropriate format for the next stage in the analytic pipeline. An ATMS often generates the data source and an API makes the data available. The dashboard then transforms the information from the format provided by the data source to a format suitable for rendering on the dashboard.

After the dashboard achieves initial visibility of data, data quality is often the next highest priority concern to address. Dashboard developers can use analytics to transform the input to a higher quality information set before passing along to other stages of analytics or to the output dashboard. Dashboard developers can compare input data against validation rulesets to classify the data as invalid or to assign a qualitative confidence metric to the data. The dashboard developers can also impute data at this stage to fill in missing information. This is often done by a combination of analytical rules (such as a value from an adjacent road section, or an adjacent time period) and average historical data; however, machine learning could also be used to generate missing data values for a given input sequence. Texas Transportation Institute published a set of validation criteria in 2004 still in use by RITIS and Intelligent Transportation Systems Integration Quality and Analysis for assigning quality to traffic detection data.(9)

Data fusion is another technique to combine multiple data input streams into a single output stream. Different data sources often overlap in the information coverage they provide.

For example, an agency may have access to radar detector data along a portion of the roadway network as well as access to a third-party speed data feed derived from cell phones or fleet vehicles’ on-board systems traveling throughout the network. The well-maintained and calibrated radar detectors may be the more accurate of the two, but there are times when the data collection goes down for maintenance and the detectors may not include some roadways. An agency can use the third-party data feed to fill these gaps. Furthermore, the radar detectors may have a limited deployment and may not cover every roadway. However, the third-party data feed is dependent on having a sufficient volume of vehicles, and thus a sufficient sampling, before the third-party data feed can be considered a complete data set.

All of these scenarios can be generalized as a data fusion of the best coverage from all available input data sets to maximize coverage. Dashboard developers can accomplish this by using the data source having the highest confidence or through an aggregation of the values from each data source weighted by the confidence of each value. Within the fusion technique, before a dashboard can compare multiple datasets against each other, the datasets should be normalized in space and time. An architectural approach to this stage in the analytics pipeline is to make the pre-processed data available as an interim output to multiple systems that may benefit from it. The TMC dashboard may be only one of several systems that would use the quality processed and fused output data source as an input. Other real-time decision support capabilities or future planning and analysis projects may also benefit from data at this stage. Thus, this data should be stored as a derived data source in the data management platform discussed in the Data Management Platform section.

Note: ITS = intelligent transportation system; CAD = computer-aided design.

Figure 13. Photo. Image Number of incidents by detection source from 2019 Michigan Department of Transportation performance measures.(10)

Source: *Michigan Department of Transportation.*

Dashboard developers can perform some analytic calculations on input data to provide valuable information for a dashboard. Travel time reliability is a measure commonly calculated based on the input speed data. Device and system uptime is a simple calculation based on whether or not a device or system is available, or equivalently, a log of when the device or system goes online or offline for a given period of time. Analytics that use multiple, different data sources are also providing valuable insights, particularly of interest to safety and planning efforts. Many universities and academic institutions have conducted research projects that combine a plethora of different datasets including travel times, crash reports, lighting, sidewalk gaps, demographics, transportation projects, property values, to determine factors contributing to pedestrian crash severity and to determine which factors contributed to increased property values. As an example, figure 13 is taken from Michigan DOT’s Performance Measures report in which incidents are detected by various sources. This graphic quickly conveys the number of incidents and how that information was collected, allowing for multiple sources to provide users a more comprehensive picture of events that occurred.(10)

Dashboards combine data properly for visualization, which is the most critical step. Several tools slice and overlay data to support visualization. The end user performs the calculation of the analytical output intuitively once the datasets are visualized together. Dashboards can also aggregate multiple datasets for a given analysis. Machine learning is an area that is receiving an increasing amount of attention. While the full impacts and applicability of machine learning will continue to evolve in the coming years, machine learning presents a unique opportunity to allow computers to explore data to find trends, patterns, and answers that are not feasible at the same scale with traditional methods. The use of machine learning allows input data to be provided to servers to train and test data such that the computers can develop and learn what the probable outcome is as a result of data inputs. Dashboard developers can incorporate machine learning and predictive analytics into dashboards to model the future, given certain data inputs. Through this emerging technology, TMCs may have the opportunity to receive alerts and take proactive steps to better manage the network.

For example, TMCs can use machine learning to monitor the following types of conditions:

- Detect changes in roadway speeds that may indicate an incident has occurred.
- Identify bottlenecks in traffic as they begin and alert operators how impactful the bottleneck may become, including monitoring adjacent arterials that may become affected.
- Alert of congestion events in real-time that could increase the likelihood of a traffic incident occurring.

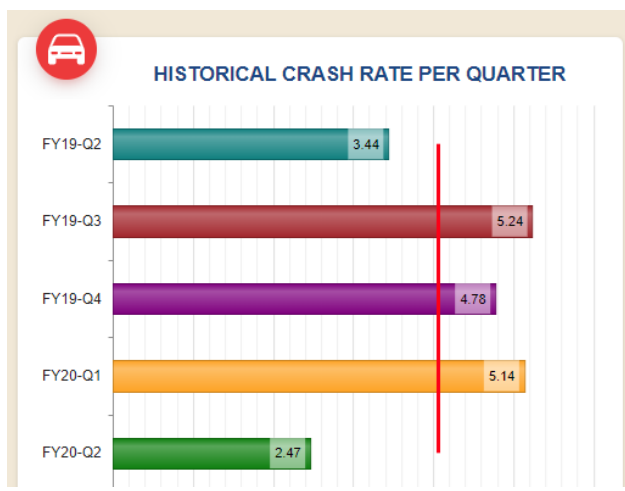
Data Analysis Outputs

The expected data outputs from the data analysis process can be categorized as follows: roadway status and performance, operations status and performance, transportation operations/planning programmatic information, and data analysis.

Roadway Status and Performance

There are many performance metrics available to evaluate roadway and status performance. Congestion is a derived measure that is typically based on a threshold of reduced average speed along a stretch of roadway and is one of the most common metrics used to report roadway status and performance. An agency can review congestion itself in many ways, including reviewing reported speed against trend speeds, evaluation of roadway travel times or using metrics of travel time index (TTI) or planning time index for comparisons or monitoring changes in volumes across a corridor.

Traffic events or incidents are similar. Dashboards attribute traffic events or incidents to a specific location and display additional attributes for additional analysis. The Traffic Incident Management Handbook defines an incident as "any non-recurring event that causes a reduction of roadway capacity or an abnormal increase in demand."[1] This includes crashes, construction, large sporting events, and concerts. Analysis outputs include the existence, location, duration, and other attributes of traffic events. A traffic management operation may generate many attributes of incidents for later analysis and output, including timestamps for each activity associated with an event, duration of the event, type of event, and information for how the event was initially discovered and



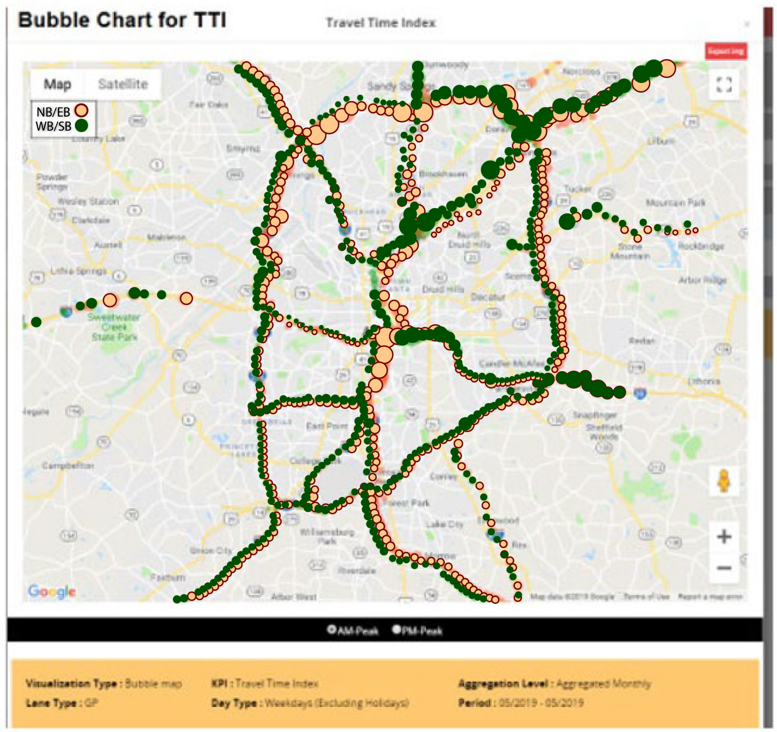
Note: FY = fiscal year; Q1 = quarter 1; Q2 = Quarter 2; Q3 = Quarter 3; Q4 = Quarter 4.

Figure 14. Graph. Florida Department of Transportation District 1 historical crash rate per quarter example for reporting incidents as performance measures.[11]

Source: *Florida Department of Transportation District 1.*

responded to. These results can be represented through performance measures in several ways, including daily, monthly, quarterly (see figure 14), or yearly.

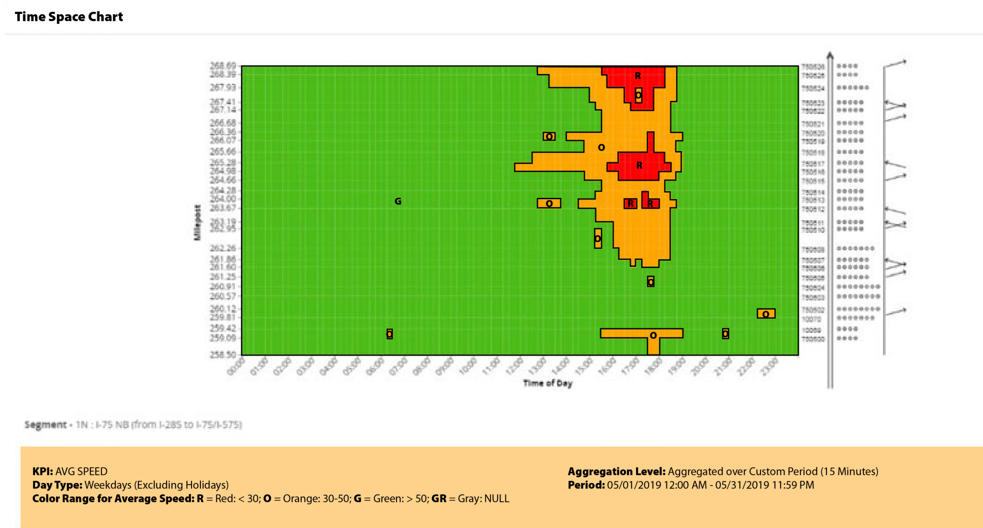
The Atlanta TMC uses a series of performance measures to view the roadway status and monitor performance measures across the system. Figure 15 shows a representation of TTI across the Atlanta region with varying size bubbles representing the differences in TTI experienced on these sections of the system while figure 16 represents changes in speed over time along a corridor which produces a thematic representation of congestion that visualizes the impacts of congestion building along a corridor.



Note: TTI = Travel Time Index; GP = general purpose; KPI = Key Performance Indicator.

Figure 15. Photo. Atlanta Transportation Management Center bubble chart for Travel Time Index.(12)

Source: *Georgia Department of Transportation.*



Note: Avg = average; KPI = Key Performance Indicator.

Figure 16. Photo. Atlanta Transportation Management Center time-space chart of average speeds (time of day versus location on the axes, and color representing speed).(12)

Source: *Georgia Department of Transportation.*

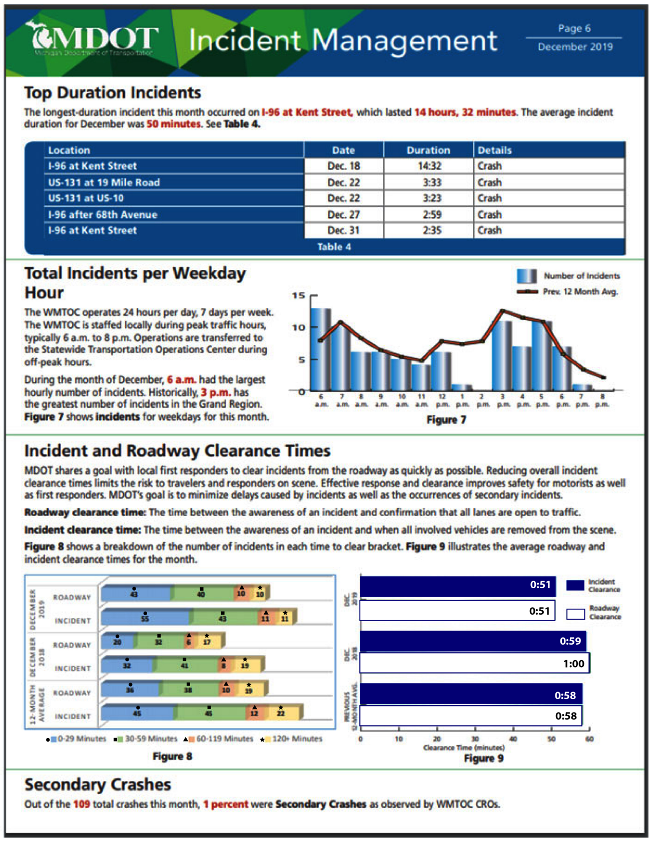
As the TMC operation matures, an agency can use additional information related to events to improve the performance of the event response and the overall performance of the roadway. This includes the following:

- Roadway Status and Performance:
    - Travel Time – Speeds and travel times are the fundamental status of a roadway network and are typical output measures displayed on a dashboard.
    - Travel Time Reliability – Derived from daily travel time values over at least six months to measure reliability, or the variance of the travel time from day to day. Motorists can use this information to plan how much extra time to allow to ensure with a certain probability that the traveler will arrive on time. The reason this is important is because the motoring public remembers the infrequent awful experience, so reducing the negative effects of this variability will improve the motorist experience. Included with travel time and travel time reliability are derived Travel Time Index and Planning Time Index performance measures.
    - Traffic Incidents – Industry professionals traditionally view incidents as occurring at a specific location but could be attributed to a larger area. Dashboard output rendered is either related to a specific incident or is aggregated information for a set of incidents over a span of time and space (i.e., over a set of roadway segments).
    - Congestion – Congestion is one effect of traffic incidents, where roadway characteristics change and capacity, traffic volume, and speed are different than normal conditions. Industry professionals typically identify congestion when the speed drops below a threshold, and spans along a roadway segment or network

rather than being associated to a single point along the roadway. Congestion lends itself well to roadway performance analysis since end users typically ignore the other attributes in traffic incidents.

- Operations Status and Performance:
  - Event Management – Event management output includes details regarding the attributes of the event described earlier and the process of managing and responding to the events. When agencies consistently collect the data, the dashboard can aggregate performance and provide it as an output.
  - Courtesy Patrol – Courtesy Patrol supports the event management on-scene, particularly for limited access facilities. The dashboard can use their real-time location, status changes, time spent helping an event versus patrolling, and other measures to output and used for real-time operations and performance evaluation.
  - TMC Operators – The dashboard can record and timestamp each activity of the TMC. This includes the time to invoke a response plan in response to a traffic event, and other activities that the TMC consistently tracks.
- Transportation Operations/Planning of Programmatic Information:
  - Current and future projects and status.
  - Financial information.
- Data Status:
  - Device update.
  - Systems update.
  - Systems alerts.

Signed into law in 2012, MAP-21, the Moving Ahead for Progress in the 21st Century Act (P.L.112-141) mandated the use of performance measures to address many changes facing the U.S. transportation system. MAP-21 requires these performance measures when developing certain transportation plans, such as a Statewide Transportation Improvement Program, and other studies with the goal of providing a more efficient investment of federal transportation funds and the ability to provide data-driven qualitative metrics.



MDOT Incident Management

Page 6

December 2019

Top Duration Incidents

The longest-duration incident this month occurred on **I-96 at Kent Street,** which lasted **14 hours, 32 minutes**. The average incident duration for December was **50 minutes**. See **Table 4.**

Location	Date	Duration	Details
I-96 at Kent Street	Dec. 18	14:32	Crash
US-131 at 19 Mile Road	Dec. 22	3:33	Crash
US-131 at US-10	Dec. 22	3:23	Crash
I-96 after 68th Avenue	Dec. 27	2:59	Crash
I-96 at Kent Street	Dec. 31	2:35	Crash

Table 4

Total Incidents per Weekday Hour

The WMTOC operates 24 hours per day, 7 days per week. The WMTOC is staffed locally during peak traffic hours, typically 6 a.m. to 8 p.m. Operations are transferred to the Statewide Transportation Operations Center during off-peak hours.

During the month of December, **6 a.m.** had the largest hourly number of incidents. Historically, **3 p.m.** has the greatest number of incidents in the Grand Region. **Figure 7** shows **incidents** for weekdays for this month.

Figure 7

Incident and Roadway Clearance Times

MDOT shares a goal with local first responders to clear incidents from the roadway as quickly as possible. Reducing overall incident clearance times limits the risk to travelers and responders on scene. Effective response and clearance improves safety for motorists as well as first responders. MDOT's goal is to minimize delays caused by incidents as well as the occurrences of secondary incidents.

Roadway clearance time: The time between the awareness of an incident and confirmation that all lanes are open to traffic.

Incident clearance time: The time between the awareness of an incident and when all involved vehicles are removed from the scene.

Figure 8 shows a breakdown of the number of incidents in each time to clear bracket. **Figure 9** illustrates the average roadway and incident clearance times for the month.

Figure 8

Figure 9

Secondary Crashes

Out of the **109** total crashes this month, **1 percent** were **Secondary Crashes** as observed by WMTOC CROs.

Note: MDOT = Michigan Department of Transportation; WMTOC = West Michigan Transportation Operations Center.

Figure 17. Photo. Michigan Department of Transportation performance measure report.[13]

Source: *Michigan Department of Transportation.*

Dashboard developers should design dashboard outputs with these performance measures in mind as these will form the basis for evaluating transportation infrastructure and are needed for reporting performance of the roadway system by many agencies at the federal, State, and local level. TMC dashboards provide operators with many of the required performance measures for reporting. As an example, the Michigan DOT (figure 17) releases a Monthly Performance Measure report of the performance of the roadway network. This monthly report includes a series of performance measurements covering incident clearance times, roadway speed performance, weather advisories, and device uptime in a clear and user-friendly report. These types of outputs can be fully automated either as a separate product or built directly into a TMC dashboard as an automated reporting function. The automation of these reports can be a time saver on the staff hours needed to gather the information, provide leadership with ready to go snapshot reports, and help satisfy several of the requirements related to MAP-21

Data Analysis Delivery

The delivery of the data to the end user on the dashboard interface can occur in several ways. Data delivery, including visualization, user interaction, and end user devices, can address several topics. Visualization refers to tables, charts, annotations, maps, infographics, and reports such as the example (figure 17) from Michigan DOT. User interaction could involve display only, navigation, filtering, voice activation (i.e., like 511 systems), or data export for offline analysis. End user device examples include browsers, tablets, mobile phones, or simpler methods such as voice/text/e-mail. This section further expands on these delivery methods with an emphasis on how the data is presented.

Visualization

Tables, charts, and graphs all display data series information and almost all users are familiar with these visualization styles and can quickly understand the data by reviewing the different data axes. This is a technique that has existed for decades across multiple disciplines and still provides one of the most reliable methods for communicating information to users. The increase in the use of smart phones, GIS, and navigation apps has greatly expanded the use of maps for everyday visualization. Almost all users now have access to maps to view information and are increasingly familiar with viewing live metrics directly from a map interface. Some visualizations can be extended from maps including the following:

- Coloring the roadway to indicate the status of the road in terms of speed or travel time reliability.
- Labeling the roadway with icons to indicate the existing, location, and status of traffic incidents.
- Indicating roadway assets with customizable messages such as DMS that provide a quick glance of relevant information about the road network.
- Overlaying other relevant spatial information and landmarks such as community features, restaurants, or other points of interest.
- Displaying navigation routes to guide users to or from a location.

A map-based dashboard interface may be appropriate for tasks where observing the entire network under a TMC's control is necessary. This allows the operators to view the entirety of the system and quickly view adjacent roadways to identify potential conflicts or opportunities for managing traffic. Map centric dashboards provide the ability for users to zoom or key on specific areas, allowing the user to view the same dashboard at a zoomed-out level to view a larger region or be zoomed in to a specific area to view highly detailed information. This is a great benefit as some users may be interested in a specific location, but the TMC handles reporting on an entire region. Using the map-centric dashboard provides the opportunity to meet both needs through the same dashboarding application. Figure 18 depicts the New England 511 dashboard which shows information across the region while allowing users to zoom to specific areas for more details.

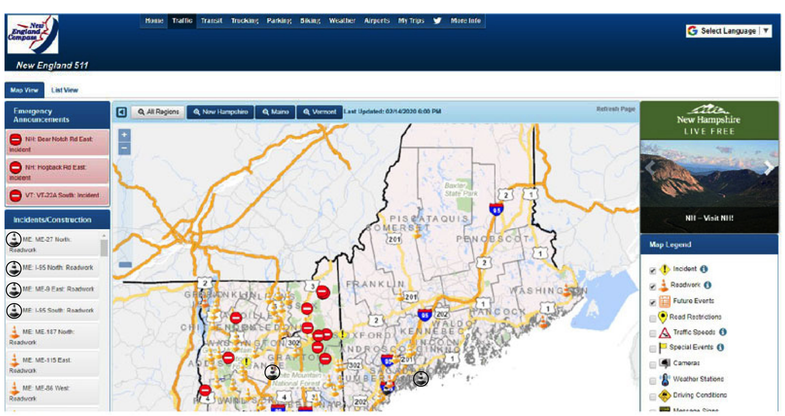


Figure 18. Photo. New England 511 dashboard.(14)

Source: *New Hampshire Department of Transportation.*

To a map-centric dashboard, the use of a straight-line diagram (SLD) is another spatial platform that simplifies the linear nature of a roadway. The SLD created a linear view of the roadway, avoids the use of curves easily representing the roadway in a 2-dimensional chart. This can be a great resource for displaying roadways and corridors that have geometries which would otherwise be difficult to fit into an interface. Similarly, a map-centric dashboard can make these SLD representations available as a clickable pop-up attribute or chart.

In addition to maps and SLD representations of a roadway or corridor, infographic representations bring together multiple elements to display performance measurements through charts, tables, and graphics. These infographics combine to create a rich, contextual presentation to facilitate insight into how various individual data elements support each other. These infographics often display aggregations that represent a complete time period such as figure 19 displaying quarterly performance, within the figure aggregations of the traditional 7-9 AM or 4-6 PM peaks and a histogram of variations in speed over the course of the 24 hours. These aggregations provide the users with an opportunity to view trends as they occur by displaying near real-time data with recent data and are a great resource in communicating Return on Investment (ROI) or changes in performance between months, quarters, or years.

Note: PTI = Planning time index; TTI = travel time index; AVG = average.

Figure 19. Photo. Examples of infographics reporting on various changes in performance measures along a roadway segment.[11]

End User Device

One of the rationales for creating a dashboard is to use technology to answer a question. The choice of which device platform to use to pass information to the end user should be based on the end goal and the most efficient and effective method of communicating that information to the end user. The end user’s device and experience should be paired appropriately. For example, a fancy interactive display requiring focused navigation and control is not appropriate if the end user is driving a vehicle, but this type of display may be very helpful as part of a long-term planning application. A full-screen monitor, keyboard, and mouse are ideal for more complex analysis that requires user interaction and more details. The user typically completes planning, research, performance reviewing, and managing operations using a full-screen monitor, keyboard, and mouse.

Mobile devices are useful for less detailed, less complex, or for more operational information. Examples include the following:

- Notification of an event.
- Travel time network performance at a glance.
- Pulling up traffic cameras from a map view.
- Navigation or route planning.

Shared displays are useful for collaborative information. This can include real-time status that can warrant a response, as well as performance metrics that are shared goals among staff in the TMC. Examples include the following:

- Monitoring video of the scene of a traffic incident.
- Straight line diagram showing the status of the roadway.
- Status and uptime of devices and systems.
- Alerts for status values that go below a threshold and warrant a TMC response, such as speeds and device availability.

Data Analysis Technology, Toolsets, and Dashboarding

This section covers the different software technologies and tools that dashboard developers use to create dashboards and to analyze data for dashboard output.

Users should carefully weigh the unique advantages and challenges of each platform and technology before determining which to use for a TMC dashboard. TMCs around the country often use a combination of technologies, as the selection of technology for a dashboard within the complex TMC environment is not a one size fits all approach.

The following technologies, toolsets, and dashboarding platforms illustrate the variety of options available for data visualization and analysis but developers are not limited to these options.

HTML & JavaScript Custom Solutions include ReactJS, Angular, and JQuery. These are a complete and often custom solution, in which HTML5 and JavaScript combine to form a dashboard. In this solution, customization is highly available and requires developers with specific skillsets. There are multiple packages available for the enhancement of charts, graphs, and reports. This option is generally flexible allowing the stakeholder to have customization control. Through APIs, the dashboard can select, retrieve, perform complex analysis and queries, and display information to the user. HTML & JavaScript is widely used with several additional packages available for advanced query and analysis including the ESRI JavaScript API for spatial analysis.

Microsoft .NET Custom Solutions are a platform and language that allows the dashboard developer to create a dashboard within the Microsoft environment and services. Customization is available however the specific Microsoft stack and services may limit the functionalities. Dashboard developers require technical expertise to develop and support the dashboard. The

.NET platform provides the ability to perform queries and directly interact with data including performing complex analysis.

PowerBI is a dashboard tool available from Microsoft that specializes in the display and analytics of data. This dashboard tool joins various structured data either by direct load of tables, Microsoft suite, or APIs. PowerBI is an interactive dashboard creator that allows design and analysis of data without requiring a highly technical staff to implement (figure 20), though configurable widgets may limit customization. A Kibana dashboard operates on top of the ElasticSearch big data platform, providing dashboard and analytics that directly interface with the ElasticSearch data cluster, a big data non-relational database technology. This interaction allows the dashboard to operate at very high speeds while returning queries into interfaces and graphics. The configuration of Kibana dashboards require at least a moderate technical expertise within the Elasticsearch stack.

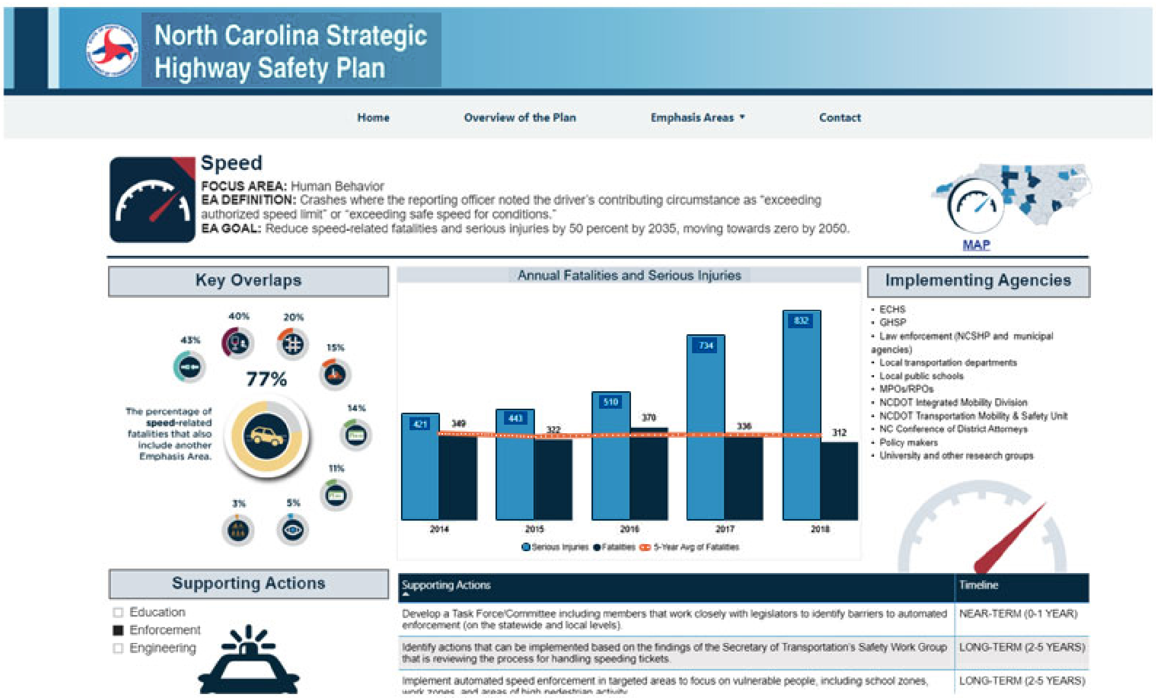
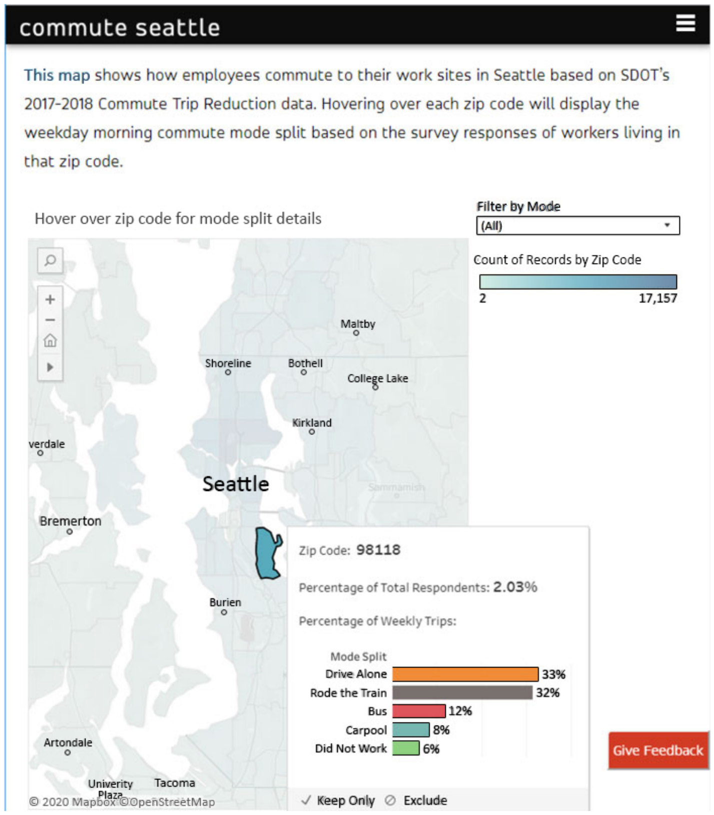


Figure 20. Photo. PowerBI example.[(15)]

Source: *North Carolina Department of Transportation.*

Tableau has many similarities to Microsoft's PowerBI, allowing users to interface with data and explore analytics (figure 21). The Tableau platform allows dashboards to take advantage of big data and return fast analytics. Users can customize within the Tableau platform using available tools and widgets. The Tableau platform while not requiring a specific technical skillset for use does require a properly configured environment.



Note: SDOT = Seattle Department of Transportation.

Figure 21. Photo. Tableau example.[16]

Source: *Commute Seattle.*

ESRI's ArcGIS platform allows for the creation of dashboards using data and tools shared through the ESRI platform. These dashboards are highly spatial and allow users to configure basic tools and widgets to search, filter, and perform some analysis. Users needing to perform deeper level analysis can enable advanced tools using spatial analysis. ESRI dashboard can be used via cloud services using ArcGIS online or locally through ArcGIS Portal with varying levels of technical expertise required to configure and set up the platform environment.

Dashboard Communication and Messaging Objectives

Dashboards, as a primary function, communicate specific messaging to stakeholders. Dashboard developers frame this messaging during the high-level design of the dashboard for the desired outcome and develop the technical architecture of the dashboard to support the desired messaging. The data and analytics populate specific placeholders, values, and data visualizations within the dashboard and deliver the quantitative component of the intended message. This allows users to design different dashboards to accomplish a variety of different goals from informing operators of situational information supporting real-time decisions, to helping planners evaluate project success and needs for future investments, and to communicating the benefits of traffic operations to external stakeholders such as elected officials.

Transportation agencies may desire to send each stakeholder custom messaging. This allows stakeholders to support the agency through their role after receiving an account of the agency's operations in a format that is relevant to the particular stakeholder. The Dashboard Stakeholders and User Needs section includes a table of stakeholders and how a TMC dashboard should support each stakeholder. Table 2 details the stakeholders with the framing of messaging and how a dashboard might carry out the communications goals. Note that the statements include a placeholder for specific metrics and values for quantification within the frame of the message, which the data, analysis, and visualizations (discussed elsewhere in this document) will fill.

Table 2. Stakeholders, dashboard messaging, and framing.

Stakeholder	Agency	Dashboard Messaging and Framing
Traffic Operator	State Department of Transportation (DOT) Local Agency	A specific transportation component needs the operator’s attention and action immediately. The operator’s recent action had a specific impact. The operator’s specific performance metric is meeting their goal. General encouragement that the operator’s contribution is having a positive impact.
Traffic Operations Manager / Engineer	State DOT Local Agency	The team’s specific performance metric is exceeding or falling short of a performance goal. The operation team needs higher staffing levels during specific times or due to specific quantities of phone calls or due to the quantity and duration of any standard operating procedures.
Transportation systems management and operations (TSMO) Planner / Engineer	State DOT Regional Agency Local Agency	The operations of multiple agencies each have available capacity that could be shared, shown by specific metrics. There is room for improved performance within specific transportation agencies, as shown by specific metrics in comparison with other network assets. The anticipated benefit-cost ratio for this roadway project is a given value.
Transportation Planner / Engineer	State DOT Regional Agency Local Agency	The operations of multiple teams each have available capacity that could be shared, shown by specific metrics. There is room for improved performance on specific transportation network assets, as shown by specific metrics in comparison with other network assets. The anticipated benefit-cost ratio for this roadway project is a given value.
Transit Planner / Manager	Transit Agency	The transit vehicles are ahead or behind schedule by specific amounts of time. The transit vehicles are moving too few or too many / more or fewer passengers by a specific amount based on historical norms. Transit is having a specific impact on congestion in the transportation network where transit routes are moving passengers.

Table 2. Stakeholders, dashboard messaging, and framing (continuation).

Stakeholder	Agency	Dashboard Messaging and Framing
Top-Level Decision Maker / Government Official	State Government Local Government Metropolitan Planning Organization	These projects are meeting or falling behind schedule. These project and operations investments have improved the transportation network by a specific amount. There is room for improvement and additional investment in transportation operations that would provide specific benefits with a specific return on investment. The constrained corridors identified here may be candidates for intelligent transportation systems and other TSMO deployments. The specific number of tax dollars spent on transportation operations and project have returned benefits in the following areas with specific performance metrics values. The anticipated benefit-cost ratio for this roadway project is a given value.
Transportation System Users	General Public	The transportation project near my community and commute is falling ahead or behind schedule by a specific amount. The transportation project and operations near my community and commute has improved the transportation network by a specific amount. The specific number of tax dollars spent on transportation operations and project have returned benefits in the following areas with specific performance metrics values. Links, contact information, or both provided for pertinent traveler information sites, including 511, transit agency websites, and project update websites. Anticipated work zone locations for the day/week within the area.

CHAPTER 4. CURRENT TRENDS FOR PLANNING AND USE OF TRANSPORTATION MANAGEMENT CENTER DASHBOARDS

This chapter covers the direction in which the industry is moving with respect to Transportation Management Center (TMC) dashboards. This chapter focuses on the future-facing side of TMC dashboard development.

DATA TRENDS

The key data-related trend is the availability of data from more sources than have ever existed previously. Real-time sources provide much of the data that continues to emerge. Policymakers and public awareness of the availability of the data and the power of the information it contains will likely lead to a greater number of requests and requests for more types of data. This chapter will discuss and identify a variety of performance measures and metrics suitable for and meaningful to various audiences to meet the dashboards' intended goals and objectives.

Developers have access to more data sources from comprehensive datasets than ever before. Formerly, one had to perform statistical sampling and modeling exercises as the tools to collect, analyze, and report as a comprehensive dataset did not exist. Now, dashboard developers use various software and data sources to produce very large datasets. Many transportation agencies, local, county, and State organizations, and private companies are starting to implement technologies and software that are greatly expanding the amount of data that is available to find more efficiencies. These big data sources are continually expanding as the cost of deploying many data solutions continues to decrease and new innovative opportunities to collect data arise.

Probe devices collecting big data such as cellular phones, connected devices, and sensors such as traffic signals, or the emergence of connected vehicles, will continue to expand the amount of data available and the demand for the use of this valuable information. Planners, engineers, TMC operators, general users, and executive leaders use these highly detailed datasets to access information that in the past would have been cost prohibitive to obtain. These resources are enabling such professionals to collect, analyze, and make available many performance measures in near real-time, which provides practitioners the tools to make decisions and take action that can benefit users across the network.

In addition to many of the near real-time datasets that are continuing to emerge, many agencies and organizations have taken advantage of asset management which carefully detail the location and attributes of every asset owned by the agency including the service records, maintenance logs, precise locations, and connections to other assets. These assets in many cases serve an important spatial relationship, allowing users to quickly tie real-time data to a physical location for display in dashboards or evaluate performance measurements.

Dashboards using these data driven performance measures serve an important connection to providing various audiences access to this information. As discussed in previous sections a dashboard with established goals is an important step to ensure that target audiences receive meaningful information. While TMC dashboards should identify performance measurements on a per dashboard level, the Data Analysis Outputs section established several of the types of performance measurements that can be successfully facilitated through a dashboard with these performance measures continuing to expand as data availability grows. Performance measures consist of both data collected directly from field devices and from machine learning and predictive algorithm data.

Examples of these performance measures may include the following:

- Real-time analysis of roadway speed, congestion, travel time, TTI, planning time index against known performance to establish trends such as:
  - Comparison of the latest retrieved data against an aggregate of the past 15-minute data to establish a data-driven trend indicator.
  - Comparison of the past hour to past comparable hours by day of week over a year to establish a baseline for comparison.
- Predictive algorithms using real-time data and recent trend data to evaluate potential near-term congestion points or conflict areas:
  - Evaluation of trend data with known values to determine roadway segments which may reach congestion thresholds.

The inclusion of these data requires that TMC dashboard designs consider not only a multitude of users but also how data within the dashboard environment may represent temporally as trend data. Predictive analytics present even more analytical options. As a result of this expansion, the planning process will continue to be much more critical than in the past. The availability of data will present new challenges related to the ability to process and store data, making data management an even more critical and intensive task. Today's users have become accustomed to having immediate data and information available, a trend that will continue and place emphasis on a dashboard's ability to remain current while presenting a highly user-friendly interface. A positive result of this growth is that dashboards are poised to play an important role in displaying, analyzing, and distributing access to these data and performance measures. Dashboards are ideally suited to the task of performing pre-determined analysis functions with real-time data inputs. Due to the greater complexity inherent to using larger datasets, dashboards with logical user interfaces are important to presenting these large amounts of data clearly and concisely.

USER TRENDS

Building on trends in data, similar user growth trends continue to emerge. For users, there will be a greater number wanting access to data, and the users are less likely to be in the traffic management industry. There will be far more policymakers and members of the general public looking to access data for various purposes; some highly complex, and others relatively simple, ranging from large research projects to simple one-time questions (e.g., why a certain roadway segment is congested). These users expect that the transportation agencies will respond to requests for data quickly and that the data they receive will be accurate and complete. TMCs will need to plan new dashboards for a large variety of users, including transportation agency internal traffic operations staff, agency senior executive management, policy decision makers and legislators, the media, the general public, and environmental planners.

As a result of the user base expanding beyond traffic management professionals, dashboards need to present data in a way that a non-professional user can easily understand what is being shown. Dashboards are an ideal tool that can be used to visualize different data sets in many different ways and can be customized to the end user's needs. TMCs can design dashboards to present data in a format that people outside the industry, including decision-makers, can understand. Industry professionals who need access to data quickly to make precise, real-time, data-driven decisions are the target audience for complex dashboards. Users want to access data on their own devices, many times on mobile devices. While there are limits as to the amount of information that a mobile device can display, a dashboard should consider that some users will be accessing the dashboard on mobile devices, tablets, or other smaller units. With a wider variety of users and usages, more developers desire customizable dashboards. A one-size fits all solution will not work for the variety of needs but maintaining multiple dashboard deployments is not feasible either – both from a maintenance standpoint as well as a shared user experience/community standpoint. Dashboard project teams should consider customizable, configurable widgets and components that can be plugged into a dashboard based on the user's unique information and location of interest. A current trend in the industry is for dashboard developers to create dashboards that serve a specific need for a specific end user group instead of creating an all-encompassing complex dashboard. Dashboards that provide direct and more straight forward use consistently maintain higher levels of use compared to their more complex counterparts.

As systems become more and more user friendly and intelligent, users will expect dashboards to provide information based on their needs, or intended, not just if the user typed in the perfect syntactical query. Users will expect intellitype or autocomplete in search boxes, and expect the output to recommend related objects alongside the information displayed initially.

DASHBOARD SCOPE TRENDS

A TMC's scope of operations is expanding quickly, with more arterial management (based on new signal system capabilities) and integrating those arterials with the freeways that were more traditionally part of the TMC's realm. Many TMCs are also integrating transit into their operating capabilities, with connected vehicles and vehicle to infrastructure applications being a new area as well. All of these represent new areas where TMCs are collecting data to store, report, and feed into dashboards.

TMCs are trending beyond just reporting and moving towards support for data-driven decisions and automation in operations. If control of the operations is more automated, the TMC will require more monitoring capability to ensure that the operations are running smoothly. TMC staff will use dashboards more often to organize and display the operational information and to receive alerts to any concerns or problems. Dashboards of this type may include user interface features to allow operators to override the automated control if operations degrade.

In addition to providing more data for public consumption, the public may have specialized requests for the TMC to develop additional capabilities to support individual data needs. The public knows that the TMC has a significant amount of useful data stored, and thus will want help in obtaining data that meets their needs. TMCs may program dashboards to allow access to raw data or can streamline certain analysis functions that an end user can perform. These changing needs and technology enhancements are likely to accelerate in the future.

Lastly, there is a trend towards using a service model, or subscription model, rather than a design-build model for procuring and building dashboards. This can allow for greater flexibility in developing and creating dashboards while allowing more seamless vendor servicing and updating of the dashboard. However, dashboard developers should ensure that data is interoperable with other software products and that the use of proprietary tools is minimized to avoid an agency being locked into a particular vendor.

CHAPTER 5. PRACTICES

This chapter presents practices for Transportation Management Center (TMC) dashboards, including the planning, design, data management and analytics, and user interface. The chapter also highlights replicable practices from the literature and the targeted outreach.

LITERATURE REVIEW TO BUILD UPON EXISTING PRACTICES

Although this document contains practices that were known at the time of writing, new developments are likely to occur in this fast-growing field. Agencies should perform a literature review at the start of a project to learn about any new trends, practices, and other lessons learned that may be newer than this document. Following this step can ensure that agencies are building upon recent practices and progress of performance measures and dashboard development. A literature review at the beginning of a project does not need to be extensive and may include contacting peer TMCs to obtain technical details about their previous dashboard projects.

SOLVE THE CORRECT PROBLEM CORRECTLY

The systems engineering process supports the successful TMC dashboards development through clear identification and validation of the correct problem, thorough dissection and verification that the problem was solved correctly, and systematic management of project risk throughout the project development process. Oftentimes, users employ a dashboard as a means to validate and verify other traffic operations and TMC operations projects; however, the dashboard development project itself warrants its own systems engineering process.

A comprehensive practice of using performance measures to evaluate project benefits and the need for future investments can help ensure that TMCs solve the correct problem. This applies to transportation investments in traditional intelligent transportation systems (ITS) technology as well as dashboards that display information obtained from and about the roadway network. A common traffic operations goal for TMC dashboards is to provide real-time operational status and performance measures to support real-time data-driven decisions that realize an improvement in traffic operations at a reduced operational cost. However, TMCs should consider a wide range of stakeholders and future needs. This holistic approach ensures that investments provide synergistic value to multiple stakeholders and towards the future vision rather than being limited to the value produced from serving a single purpose. However, this can add complexity in the planning and funding of the dashboard, when incorporating additional stakeholders, data ownership and usage agreements, and funding constraints.

The following actions can help ensure that the dashboard provides useful information to the end user.

- Continuing on with the familiar steps of the systems engineering process may uncover additional challenges.
- Ensuring data availability becomes more of an agency responsibility rather than a contractor's responsibility as it would be for projects with fewer external data dependencies.

It is important for data to be properly validated, however this becomes more difficult to measure for several reasons:

- Increasing the variety of stakeholders and needs requires additional user scenarios to test.
- Furthermore, dashboards may not have quite as direct of an immediately measurable impact on transportation performance as other physical roadway improvements. Some dashboards merely provide users with information on system performance.

DATA MANAGEMENT PLATFORM

A dashboard is only as good as the data and information inputs that outside sources provide. It is therefore critical to ensure that data is of sufficiently high quality and dashboards can store and access the data in a timely fashion. As discussed in the Data Management section, there are many concepts that TMCs should consider related to each data element that the dashboard will use. However, a well configured and architected data management platform is needed to properly serve and make data available. This environment can serve as the central hub of data management expanding beyond a single-use or singular TMC dashboard, as much of the data that is needed to successfully operate a TMC dashboard is highly desired for other dashboarding, analytical, and reporting efforts across most organizations. Dashboard developers should approach data management platforms with this concept in mind and, whenever possible, fulfill a larger need for data management. There are many benefits to using a data management platform which this section explores.

When discussing and planning a data management platform, TMCs should consider the following key concepts and capabilities.

Centralized Data Storage

The concept of centralized data storage does not refer to a singular system, instead, it refers to an interconnected series of systems that are able to interact and present users a singular entry point to accessing data. This can be a combination of technologies and can expand across servers located in different departments, databases, or even ones provided by external organizations.

The key concept centers on access, which allows users with different needs to use the same data and information for different purposes. Automated protocols from the primary data custodians coordinate and ingest stored data through automated protocols as the data updates. Centralized data storage can provide TMC dashboards with the ability to deliver user-friendly interfaces which can perform highly complex analysis behind the scenes. The use of the centralized data also accounts for data variability by incorporating access to data stored in disparate environments allowing a single point of access to be used for real-time analysis and historical data review simultaneously without the user being required to go to a different platform.

This can greatly reduce or nearly eliminate data silos and duplication, as well as solve concerns of, "Do I have the most recent data available?" or "Did another department use a different data set in their analysis?" as the data is directly provided by the data custodian or source. Data stored in the centralized data location is highly recommended to be stored in the rawest or purest format of the data available. This will allow different users with different needs to leverage these same centralized datasets.

The use of big data as a component within the TMC dashboard and centralized data storage platform has become a pillar on which these environments rely. By combining relational and non-relational database structures in the environment with securable centralized application programming interfaces (APIs), users can quickly take advantage of retrieving data, gathering analytics, and determining performance measurements without having to go through the difficult task of coordinating access to different systems. The APIs of the centralized data storage environment act as brokers, sending requests to the appropriate location to retrieve information in a consistent data format that users can programmatically use.

Design a System That Can Support Both Internal and External Users

Developers should consider making the data platform and underlying big data technology available by internal and external users' consumption. The primary focus of the TMC dashboard and data platform should be to fulfill the needs of the TMC. As a byproduct, when appropriate, the design of the platform should consider methods to allow both internal and external users access to the data and information available in the platform. To provide this access while maintaining dedicated support for the TMC, it may be necessary to set up separate API channels with specialized access constraints to ensure that prioritization and resources are constantly available for primary use. This prioritization will enable the TMC operators to have dedicated resources to increase efficiency and remove barriers that could increase the latency of requests.

Allowing internal departments, external organizations such as Metropolitan Planning Organizations (MPOs), counties, transportation agencies, and the public to view, query, and interact with data has multiple benefits including the following:

- Support multiple dashboards, reporting tools and applications as departments and organizations can leverage the centralized system.
- Provide consistent and repeatable reporting and analytics from all partners.
- Provide opportunities to create stakeholder engagements and build consensus.

As use increases with these internal and external stakeholders, TMCs should review additional data and use options that may become available. For instance, a local agency may have valuable data that could enhance the function of a dashboard in the TMC. That agency, once able to take advantage of the platform, may understand the value in sharing local data, ultimately helping to increase the overall effectiveness and availability of data within the platform. In some cases, this ability may help fulfill a need of a local jurisdiction to share data into a larger data platform that would not be feasible for a smaller organization to attempt to support and manage on their own.

Remain Highly Flexible, Scalable, and Modular

To remain current and grow with expanding needs, the data platform must remain highly flexible in the technologies it can interface with, provide adequate scalability that can quickly and easily grow with data needs, and be designed with modularity that allows sections of the platform to be independently updated and avoid singular points of failure.

Open-source technologies, especially in the realm of big data, provide a great deal of flexibility and can help in avoiding vendor lock-in, allowing the platform to remain highly dynamic to the fast-changing technology world. This flexibility continues to remain imperative as technology advances continue to emerge and provide even more techniques to lower latency in data collection, ingestion, and retrieval.

Allowing the system to scale as needed to meet demands in both storage and performance provides a future-ready system that can grow with data needs. Scaling should consider both vertical and horizontal scaling alternatives that dashboard owners can leverage across database technologies and server configurations for load balancing. In cases where necessary, the platform should be able to incorporate existing relational or Structured Querying Language (SQL) databases and migrate this information into big data or non-relational technologies to take advantage of performance and storage gains.

The platform design should have no single point of failure. A modular approach ensures that if one component has a problem the rest of the system continues normally. Modularity in the platform is critical to allow dashboards to incorporate and make available new technologies, connections, and data.

Maintain Low Latency and High Retrieval Rates

Dashboard developers should design the data platform to minimize the latency of data collection and ingestion while providing high rates of data retrieval. The use of TMC dashboards in an operational capacity places a high value on the ability to return data and information in as near real-time as possible. Platforms developed with this consideration in mind can achieve the best performance and response possible.

Developers should make efforts to streamline data collection, ingestion, and retrieval processes within the platform. Data staging should be avoided unless necessary; instead, the dashboard developers should architect platforms to constantly be aware of incoming data and information that can be picked up and processed into the platform with as minimal latency as possible. When dealing with the number of records that are often being collected in sub-minute intervals, the dashboard should process this incoming information quickly as a small delay can start a chain reaction of delay that renders the system incapable of completing an ingestion process before the next data records arrive. Though small in record size, it is not uncommon for the data generated in the transportation world to easily reach billions of individual records for a month or year.

Equally important for TMC dashboards is the ability to retrieve data and information back from the platform. Non-relational big data environments are designed to handle requests that provide performance measures and aggregations across hundreds of millions of records in seconds or less. Through the process of Map-Reduce, a platform can quickly filter and aggregate hundreds of millions of records in parallel over a clustered environment by first mapping or sorting information and then reducing the results down in an incredibly fast and efficient way. Dashboard managers can return the reduced results or aggregations, such as the average speed on a roadway for the past 3 weeks in 15-minute increments, to the dashboard for further use or to calculate additional performance measures.

Design an Architecture That Accepts Any Data Structure

Data platforms should be dynamic and flexible to the type of data and information that the TMC provides. Technology innovations mean that incoming data may take a wide variety of data formats and types. A successful data platform remains flexible and accepts multiple types of data. Following the concept of a centralized solution, this does not require that each component be capable of accepting all data formats but rather that the overall environment has the flexibility to store data and information regardless of the data type.

Use Big Data and Artificial Intelligence to Enhance Transportation Management Center Capabilities

These relatively new sources of information can strongly enhance a TMC's capabilities by providing large historical datasets that allow machine learning and predictive algorithms to predict future conditions. While this is an emerging opportunity, it is important to recognize the opportunity to take advantage of these technological innovations that may help TMC operators in making better-informed decisions. As this technology is a continually evolving target, planning for this in the context of a TMC dashboard may be difficult. However, keeping this future enhancement on the horizon is important to ensure that the TMC considers a flexible architecture and is poised to take advantage of this technology once ready to explore its application.

Select the Correct Tool for the Job

The use of an appropriate application stack is critical in fulfilling the objectives of a dashboard system and ensuring that the dashboard and underlying data platform will remain valid over the lifetime of the dashboard product. There are a wide variety of application stacks that are now available which specialize from heavily detailed data analytics to highly user-friendly data visualizations. Various vendors provide these stacks with various trade-offs and advantages existing for each.

The industry commonly uses several recognized components to support dashboards and data platforms, including the following:

- Development platform: Microsoft ASP.NET, Angular, Node JS, JavaScript, ArcGIS for JavaScript, PHP.
- Visualization components: ChartJS, Telerik Kendo, matplotlib, QT, PowerBI.
- Geographical information systems: ESRI, OpenStreet, Google.
- Data management: Microsoft SQL, Oracle, MYSQL, Elasticsearch, MongoDB, Hadoop.

Incorporating these key concepts into the architecture of the data platform enables the platform to be future ready and capable of evolving as needs change.

CUSTOMIZED OUTPUT DISPLAYS BY USER GROUP

There are many more groups of possible stakeholders in today's TMC environment than in the past. Many TMCs are now housing multiple units and dispatch teams that take advantage of the collaborative environment to share data and information. As such these different user groups have different needs of the dashboard and a one-size fits all approach may not be effective when designing the dashboard user interface. For example, a developer could program a dashboard system such that TMC operators see roadway performance and status data, traffic engineers see traffic signal timing and delay-related performance metrics, while maintenance staff can access system health and system status information. Each of these different users are reviewing similar types of information but are using that data for very different purposes. It is important to understand the audience of the dashboard and how they may use the dashboard (table 3).

When communicating tailored performance information to the appropriate user, the TMC can summarize and aggregate performance information to present to the public, elected officials, and planners. Dashboard outputs provide information about the operational performance of roadways, courtesy patrol, and operators to TMC management with the roadway performance and traffic condition information aggregated so operators can identify and respond to incidents. Device uptime, availability, and health status is available for those responsible for maintaining the system. It is important to clearly define the user audience and account for how these different user groups may interact with the dashboard and with the goals of the TMC dashboard.

How the user will view the dashboard is an important consideration, as dashboards will scale differently depending on the intended use. Accounting for the responsiveness of the dashboard on different devices will allow users to view the dashboard in a variety of ways. While considering responsiveness to fit phones and tablet devices, owners should review TMC dashboards for the applicability of using it on a video wall. In some cases, large video walls present unique opportunities to display dashboards which transportation management staff need to easily interpret from across the room.

Table 3. Sample datasets by user group within a dashboard.

Stakeholder	Sample Data Needs
Traffic Operator	Real-time traffic volumes (from Bluetooth, third-party datasets, Automated Traffic Signal Performance Measurement; crash locations and queue length; near-miss hotspots; work zone locations; corridors operating below historic trends)
Traffic Operations Manager / Engineer	Real-time traffic volumes (Bluetooth, intersection/turning movement counts); crash locations and queue length; near-miss hotspots; work zone locations; corridors operating below historic trends
Transportation systems management and operations Planner / Engineer	Level of Service (LOS); Planning Time Index (PTI)/Travel Time Index (TTI), travel time reliability (TTR); intelligent transportation systems infrastructure locations; near-miss hotpots; crash locations (short-term); work zone locations; constrained corridors
Transportation Planner / Engineer	LOS; PTI/TTI, TTR; near-miss hotspots; crash locations (short-term); work zone locations; constrained corridors
Transit Planner / Manager	Automatic Vehicle Location points; General Transit Feed Specification real-time; existing bus routes and bus stops; crash locations (short-term); work zone locations; demographic data relating to low-income, mobility constraints, and limited vehicle access; ridership by route

FORM PARTNERSHIPS WITH INDUSTRY DATA PROVIDERS

Forming partnerships between the agency and data providers can smooth the processes of sharing data seamlessly for multiple user groups and may give the opportunity to discuss gaps or needs that providers could directly fill. The more data that is available for use by all parties will help to increase reliability in mapping and analysis. In many instances, these data providers are already using data from public organizations to better refine the information they make available.

Data available from providers, such as probe data, crowd-sourced incident data, and the future data from connected and autonomous vehicles, are all highly valuable data sources which can greatly enhance the analytical capabilities of dashboards, providing overlapping sources of truth for validation and increasing the possibilities of incorporating machine learning into future analysis.

By establishing data-sharing agreements, it may be possible for an agency to obtain data at no cost or reduced cost by sharing their data with partner organizations. For example, the Florida Department of Transportation (FDOT) purchased an agreement with HERE for access to the real-time feed of the probe data for all roadways available in Florida. Under this agreement all FDOT departments and partnering agencies can use the data, including regional partners such as MPOs and county or local jurisdictions. Through this agreement, partnering agencies can take advantage of this data availability without the need to contract individually. This allows FDOT to serve as the data steward allowing partners access to the valuable analytics without requiring the technical knowledge needed to manage an environment capable of storing this data.

It is also possible that through partnerships with data providers that partner agencies may have opportunities to perform pilots with providers to test new technology and become included in the evaluation process. This serves both the data provider and the agency, as the agency can understand the capabilities of emerging data and technology while the provider gains valuable real-world test case knowledge of how the data will be used.

COORDINATION WITH PEER TMC OPERATIONS

Forming partnerships between various TMCs is worthwhile, as this facilitates information sharing and may lead to cost-saving opportunities. TMCs should coordinate dashboard projects with other TMCs to share ideas and lessons learned, but also to allow TMCs to share modular components of dashboards. When TMCs share reusable solutions it eliminates the need to reinvent the wheel.

Many TMCs experience very similar concerns and issues. These similarities provide an opportunity for TMCs to learn from shared experiences of success and work collaboratively to avoid pitfalls. The frequency of coordination may vary across geographies and the type of operations supported but TMCs should make efforts to establish and regularly discuss ongoing efforts and lessons learned.

ENSURE PROPER PROJECT MANAGEMENT WHEN DEVELOPING DASHBOARDS

Proper project management is an important component of successful dashboard development. As outlined and discussed in the Planning for Dashboards section, it is important dashboard developers discuss several items before undertaking a dashboard project.

In addition to the establishment of goals, an agency should perform value/cost analysis to ensure the cost of the dashboard is worthwhile. In many cases, the dashboard will provide significant value to an agency, however high development costs may require that an agency alter some functionality to ensure high value is received. Dashboards can be susceptible to over-design beyond the user needs which is another factor that can inflate the expense. An agency should carefully consider ongoing maintenance and support, especially in the case where ongoing data management (Data Management section) is required to understand the cost that will be required once the dashboard is deployed. When negotiating a contract with a vendor, it is important to successfully draft a contract that covers the entire project’s needs. Before proceeding, it is critical that data input is available and planned for. If not, failed dependencies can disrupt future projects.

Using a modular approach to dashboard construction will allow for dashboard developers to build the dashboard in phases. Thus, TMCs can acquire new inputs and functionality and later add to the dashboard to allow for more complex analytics and outputs. From a project management perspective, this does not imply considering all potential uses but that where possible the use of modularity be implemented to allow for further expansion in the future with the minimal changes needed.

Building upon the complex nature of dashboards and the data, it is important to recognize that as software, there can be development bugs and failures, as “perfect” engineering with zero errors is unlikely. A dashboard needs robust quality assurance and quality control process to track and address these software related issues. The tracking of these issues should expand beyond the development of the dashboard as unforeseen changes in data and structure may cause the dashboard to display incorrectly. The ability to quickly review prior code and view steps the agency took during development and maintenance offers project managers an important first step in identifying potential causes and corrections.

It is critical to recognize that dashboarding, and ultimately the trend towards data driven decisions and automation is extremely complex. Furthermore, in the transportation industry, there is an extremely low tolerance for public safety risks. For these reasons, the systems engineering process is critical to help reduce project risks in transportation technology.

ENSURE STAKEHOLDER BENEFITS ARE DELIVERED AND COMMUNICATED

The Data Analysis Technology, Toolsets, and Dashboarding section outlines the various stakeholders and their messaging needs from the dashboard. Operators and managers generally need information to support their actions with data input, status, and performance information to show the dashboard’s benefit to the organization. Planners are not as concerned with real-time data; they need more aggregate and post-analysis information to understand needs and what investments would deliver benefits to those needs. Elected officials, executive management, and the general public need the dashboards to communicate the benefits of taxpayer dollar investments in traffic operations. The dashboard, comprised of the messaging framework and the data to quantify the metric in the message, is the interface between each of the stakeholders and those needed communication products of real-time information, encouragement, correction, accountability, and investment value.

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CHAPTER 6. SUMMARY AND LEADING PRACTICES

This final chapter brings together all of the information, lessons learned, and research from the previous chapters. This chapter summarizes key issues and practices for agencies to consider in the planning and development of a Transportation Management Center (TMC) dashboard.

TRENDING CAPABILITIES AND FUNCTIONALITIES OF TRANSPORTATION MANAGEMENT CENTER DASHBOARDS

TMC dashboards have undergone a metamorphosis from providing visual clues about a roadway performance to dynamic and highly interactive systems with powerful analytics and the ability to deliver performance measures across billions of data records. The findings of the outreach exercised in Chapter 2 and the expanding state of the practice in Chapter 3 reveals a definite trend in the use of analytics throughout TMC dashboards. Many variations of TMC dashboards are in use across the United States in agencies of different size, regional geographic profile, traffic management support needs, and level of technology implementation. These dashboards provide users the ability to see a wide variety of information, quickly going from real-time operational support to providing planning and executive leadership with metrics and reporting that show quantifiable returns on investment, are capable of identifying complex trends, and can help with federal and State reporting requirements.

One theme is agency desires for the dashboard to include more detailed roadway information. Today more users across many organizations are expecting to have access to performance metrics and expect to see these presented in a user-friendly dashboard interface. Dashboard developers traditionally design dashboards around a highly technical need and user. Dashboard development in the future should approach with the understanding that a multitude of other users may have a desire to access and analyze this information.

Chapter 4 further expanded these current trends, spotlighting the importance of data and the overall management of information made available to agencies. This research cannot overstate the importance of properly managing data, as TMC dashboards act as the conduit to convey this information. Agencies who can properly manage data are best positioned to explore the benefits of having highly granular data across the roadway network readily available. Many of these organizations that take a data-first approach often find that they can create targeted TMC dashboards much faster and serve a much larger user base.

In addition to providing data visualization and analytics, a majority of dashboard users now expect to have the ability to export or report data and analytics directly from TMC dashboards. While this is not necessarily a required step for TMC dashboards agencies should consider end user expectations as appropriate. As described in the Dashboards Currently in Use section, some TMC dashboards are expressly meant for reporting, however many users expect to be able to extract data and information from planning and operational dashboards.

As more data becomes available from sources such as connected vehicles, TMC dashboards will continue to expand to provide even more detailed analysis. While this is a great advantage, agencies establish the main use for a TMC dashboard during the planning for the dashboard. When an agency desires a dashboard that does all things for all users, it will often fail. Focused dashboards that serve a specific purpose are less complex for users and generally provide for a more user-friendly experience.

Expansions in data availability and granularity in the future will also provide TMC dashboards an opportunity to leverage machine learning and artificial intelligence to improve proactive decision making. While this particular innovation is the front edge of technology, the use of this type of higher-level analytics is being monitored for ways to further improve TMC dashboards and the overall performance of the transportation network.

KEY DASHBOARD DEVELOPMENT PRINCIPLES

This section highlights the most important TMC dashboard planning concepts and takeaways, starting with identifying the correct problem dashboards will solve and addressing the key stakeholder needs. This section provides a summary of the key steps to planning a dashboard project to help an agency to follow the process to create a TMC dashboard. The following provides each key principle and a brief summary of the corresponding sections in this document.

Failing to Plan is Planning to Fail - Planning the Dashboard – Planning for Dashboards Section

Building upon Benjamin Franklin's famous quote of "Failing to plan is planning to fail," TMC dashboards and the underlying data function best when agencies properly plan and organize. The extra time taken to organize the needs of the dashboard, coordinate with stakeholders, and design the overall workflow of the dashboard are proven keys to success. While there are always additional challenges that arise throughout a project, these principles help guide an agency around many of the common pitfalls with development.

Communicate Constantly – Chapter 2, Dashboard Stakeholders and User Needs Section, Stakeholder Outreach Section, and User Trends Section

Avoiding silos in communication is critical to creating a well-rounded dashboard that will meet the needs and objectives identified during the planning process. The involvement and communication between stakeholders are key in any project and the development of dashboards is no different. It is through this insight that stakeholders can express the various ways in which the dashboard will be used and the types of functionality that are considered of core importance.

No One Size Fits All - Selecting the Right Dashboard – Current Use

There are some dashboard variations that serve a TMC with each having focus areas in which that type of dashboard excels. During the planning for a dashboard, an agency identifies goals, needs, and objectives. These objectives drive the type of dashboard and functionality that the agency should consider. This fundamental idea drives directly at the importance of following best planning practices to ensure that the end product meets the needs of the user.

Manage the Data – Data Management Section, Data Analytics Approaches Section, and Data Trends Section

Data management provides the foundation for successful TMC dashboards and in many cases opens additional opportunities for analysis. Following best practices positions an agency to further leverage the data and information needed for TMC dashboards elsewhere, which can result in many great benefits.

Simple is Best

In terms of overall design and functionality, TMC dashboards function best when directly addressing a need or objective. It is important to avoid a common pitfall that arises with unneeded complexity or use of technology that does not best fulfill the identified needs and objectives.

For example, if the need being addressed is to represent the average hourly speed of a roadway on a video wall at the TMC, the inclusion of a 3-Dimensional representation of the roadway with minute by minute reporting for each lane of the roadway may not be the best approach. While highly valuable information, this display does not necessarily meet the need of the dashboard. If the need had been to provide a TMC operator with an operational or real-time view of the network from a web application, then this level of detail would be highly valuable.

Transportation Management Center Dashboard Checklist

The following dashboard checklist provides an outline that can assist agencies with the creation of a TMC dashboard:

- Meet with stakeholders.
    - Identify a communication plan and meeting schedule.
- Define goals and objectives.
- Define the project approach.
    - How will the agency develop the TMC dashboard (what methodology)?

- Define project requirements.
  - Determine acceptable data availability, data latency, and data format.
  - Identify additional data extract, transform, and load processes needed to make data available.
  - Establish core functionality of the TMC dashboard including data analytics, performance metrics, and reporting.
  - Identify TMC dashboard hosting and deployment location including firewall and IT aid.
- Identify data and data management.
  - Is data storage established?
  - Are additional partnerships, data purchase, or equipment deployments required?
- Determine how the agency will develop the TMC dashboard.
  - Identify considerations in the project requirements.
  - Identify testing procedures and who will participate.
  - Identify any special considerations for TMC Dashboard deployment.
- Stakeholder follow-up and TMC dashboard outreach.
  - Meet with stakeholders after deployment.
  - Establish a maintenance plan.

Did it work? Use the following scenarios to test the TMC dashboard plan:

- What is the intention of the dashboard in one sentence?
  - This ability means the agency has defined a need and the objective is to the point; it does not mean the process is not complex or that multiple data will be needed. For example, "The dashboard will provide TMC operators a real-time view of the roadway with triggered alerts for incidents and congestion".
- What level of data latency is acceptable in the TMC dashboard?
  - Communication and stakeholder involvement is paramount to understanding what is required to make the dashboard successful.
  - Discuss data latency and overall needs during the planning and requirements phase.
- What performance measures will be available in the TMC dashboard?
  - Agencies establish many metrics and may use them in meeting State and federal reporting requirements.
- Who will access the TMC dashboard?
  - Is the dashboard available to all users? Does it have a password protection area or is it public?
- Is the same true for all of the data needed to make the dashboard function?

INPUTS FOR SUCCESSFUL DASHBOARD IMPLEMENTATION

TMC dashboard success is influenced by communication and data management. As with the success of most projects, communication is key. Throughout the planning and development of the TMC dashboard agencies are recommended to establish a communication plan with the development team and stakeholders to allow engagement throughout the project.

Covered in the Data Management Platform section, the data management platform serves as the central hub for a TMC dashboard by providing access to data and analytics for use in the dashboard. Agencies should establish these inputs early in the process so that the inputs support project requirements. Data management details of the system include the following:

- Storage needs.
- Specific access constraints.
- Data analytical processes and interactions via application programming interfaces.
- Data sources required for metrics and performance measures.

Following these established best practices will help an agency in creating a TMC dashboard that meets identified needs, completes objectives, and serves as a powerful support tool.

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