18 TRANSPORTATION SYSTEMS MANAGEMENT & OPERATIONS

18.1 Purpose

The purpose of this chapter is to provide an overview of transportation system management and operations (TSMO) program elements, methods, strategies and analysis tools. The chapter guides users on integrating established TSMO procedures, analytical tools and data into existing planning processes and project development.

FHWA defines TSMO as "an integrated program to optimize the performance of existing multimodal infrastructure through implementation of systems, services, and projects to preserve capacity and improve the security, safety, and reliability of our transportation system". This section includes an overview of the content of the chapter and background information on the policy basis and rationale for TSMO.

Technology related to TSMO is changing rapidly and will continue to evolve in the coming decades. With accelerated change as the norm, this chapter represents a snapshot of current conditions and trends that will need to be updated frequently. For more details on many of the methods in this chapter also refer to FHWA's Planning for Operations website.

18.1.1 Overview of Chapter Sections

This chapter covers a range of TSMO topics:

- Policy Basis and Rationale for TSMO – State and federal policy foundation for TSMO
- TSMO and Data – Considerations and procedures for obtaining and processing TSMO-related data for performance measurement
- Planning and Programming for TSMO – Considerations for objectives-driven, performance-based operations planning, TSMO strategies, programming, multi-modal system performance measures, ITS architecture, systems engineering, and analysis tools
- Corridor Management – Considerations and analytical procedures for incorporating TSMO into corridor management
- System Management – Planning-level sensitivities and considerations for operations strategies related to incident and emergency management, road weather operations, special events management, traveler information, transportation demand management, and connected/automated vehicles

18.1.2 Policy Basis for TSMO

ODOT has established transportation goals that are both supportive of and supported by TSMO. The overarching goal of the 2006 Oregon Transportation Plan (OTP) is "a safe, efficient and sustainable transportation system that enhances Oregon's quality of life and economic vitality." OTP Goal 2, Management of the System, is specific to TSMO and states "improve efficiency of the transportation system by optimizing the existing infrastructure with improved operations and management." OTP Key Initiatives A and B reflect the desired direction of the OTP to maximize existing system assets and to optimize capacity using TSMO strategies.

Other state transportation policies that are supportive of TSMO include the Oregon Highway Plan (OHP) Policy 1G, Major Improvements, which states "maintain highway performance and improve safety by improving system efficiency and management before adding capacity"; OHP Action 1G.1, which establishes an investment hierarchy that prioritizes strategies that "protect the existing system" above all others; and Policy 2E, Intelligent Transportation Systems, which states "consider a broad range of TSMO services to improve safety and efficiency in a cost-effective manner." Operational Notice PB-03 issued to ODOT personnel provides direction for developing financially feasible ODOT facility plans and local Transportation System Plans consistent with OTP and OHP policies for managing and maintaining ODOT's existing transportation system.

Beyond the ability to advance many key transportation goals in the state, TSMO also provides a platform for implementing a performance-based approach to planning, designing, operating, and maintaining a transportation system. The federal surface transportation legislation, Moving Ahead for Progress in the 21st Century Act (MAP-21), laid the groundwork for a paradigm shift in planning and programming transportation improvements with the establishment of a performance-based program. The need for on-going data to support a performance-based program is acute and TSMO technologies provide a way to automate the collection and archiving of large amounts of operational performance data. The TSMO program also offers an objectives-driven, performance-based approach for planning and programming that effectively applies data in the decision-making process.

18.1.3 Rationale for TSMO

> *This section is intended as a high level overview of TSMO. For a more in depth understanding of TSMO refer to FHWA Planning for Operations web page.*

TSMO offers a performance-based approach to managing the multimodal transportation system in support of the OTP and OHP goals and policies. The many strategies that fall under the TSMO umbrella address one or more of ODOT's key policy goals of safety, efficiency and sustainability.

Safety

Safe travel is ODOT's highest priority for the transportation system. TSMO can help address system safety for all users through technology and operational strategies that focus on minimizing conflicts. This can take the form of traffic signals with dedicated phasing for different movements and modes; traffic incident management programs that quickly clear incidents to increase safety for responders and reduce the risk of secondary crashes; road weather information systems to notify travelers of adverse weather conditions; or variable speed signs that adjust advisory travel speed based on traffic conditions ahead.

Efficiency

The economic health and prosperity of Oregon and its communities depend on a well-functioning transportation system. TSMO's contribution is considered in two ways: the efficient use of the existing transportation system and efficient use of resources.

With regard to efficient use of the existing transportation system, many TSMO strategies address non-recurring events that cause travel delay in both urban and rural settings such as ineffective traffic control operations, traffic incidents and inclement weather. These strategies support reliable travel for people and goods by actively managing the existing transportation system. The intent is to maximize the function and performance of current transportation networks to reduce delay and improve reliability for all modes. The TSMO strategies applied vary based on the modes, facility types, and land use context. For example, strategies like transit signal priority or pedestrian signal phasing can help keep travelers moving in busy urban environments while in rural locales strategies like smart work zones or incident or event based traveler information can address those unique needs.

The expected growth in population, freight tonnage, and total vehicle miles traveled will place an enormous burden on the existing transportation infrastructure into the future. As fewer funds are available for adding capacity, optimizing the existing transportation system has become a critical and practical approach. TSMO strategies generate resource efficiency by enhancing system capacity for less money, time, and disruption than traditional approaches. It optimizes resource use by allocating financial and personnel resources to cost-effective programs, such as reducing incident response times or maintaining traffic signal timings that have proven effective in increasing performance of the transportation system.

Another dimension to TSMO's resource efficiency is the opportunity to share resources across agencies. TSMO is most effective when multiple partners coordinate or collaborate to deliver a service like traveler information; or share infrastructure like fiber optic cable network; or establish interagency agreements like joint traffic signal operations and maintenance.

Sustainability

Transportation has an integral role in protecting and preserving livable and sustainable communities. Livability is described by ODOT as "the attributes of a community that affect its suitability for human living". The ODOT Sustainability Act of 2001(ORS 184.421) defines sustainability as "using resources in a manner that enables people to meet their current needs while allowing future generations to meet their needs." Managing how the transportation system operates is a vital aspect of livability and sustainability.

The broad suite of TSMO strategies actively contribute to both goals of meeting community needs today and managing resources for the future. In addition to the livability benefits to transportation safety and efficiency, TSMO can also facilitate multimodal travel choices, optimize on and off-street parking, or provide route options to avoid delay-inducing events. It helps to preserve mobility by implementing operational solutions like bike signals, transit signal priority, and personalized trip planning that support safer and more sustainable travel choices.

A significant environmental benefit of TSMO centers on optimizing the efficiency of vehicles to save fuel and reduce vehicle emissions. Several categories of TSMO strategies such as congestion management (ramp meters) or speed management (variable speed signs) can smooth traffic flow and bring down vehicle speeds. Multiple studies have documented the reductions in fuel use and harmful emissions as a result of reducing vehicle acceleration and deceleration events. With the growing efforts to address climate change in Oregon, TSMO strategies offer near-term, lower cost, efficiency-focused approaches to transportation-related greenhouse gas reduction and for adaption to a changing climate.

The overall benefits attributed to TSMO strategies typically include:

- Reduced travel delay
- Reduced travel times
- Improved travel time reliability
- Reduced number of crashes
- Reduced instance of secondary crashes
- Reduced fuel consumption
- Improved air quality
- Improved agency operational efficiency

18.2 TSMO and Data

This section provides an overview of the relationship between TSMO and data. While the use of data has long been a key element in the practice of planning, designing and operating the transportation system, the use of technology to actively manage the transportation system has given rise to new data sources and new applications of those data in operating the transportation system.

Data are an integral element of TSMO. The rapid and dynamic changes in transportation technology are delivering a wealth of new data sources that are being generated by both roadside and mobile sensors that register changes in motion, temperature, light, air quality, and the list goes on. These data can be collected and transferred in real-time to end users and it can be captured and stored for later use in evaluation or research. Sensor-based technologies are delivering the data necessary to support active operation of the system and objectives-driven, performance-based decision-making for investments, as described in Section 18.3, Planning and Programming for Operations.

While there is overlap with Chapter 3, Transportation System Inventory, the focus of this section is on sensor-based data and its relationship to managing and operating of the transportation system. The section discusses the following topics:

- Data Management lists considerations for collecting, processing and interpreting sensor-based data.

- Agency TSMO Data describes sources of sensor-based transportation-related data available through ODOT and partner agencies.

- Third-Party TSMO Data describes sources of sensor-based transportation-related data available from private sources.

- Portal Transportation Data Archive provides an overview of the publicly accessible transportation data archive housed at Portland State University.

- TSMO Performance Evaluation and Monitoring discusses the use of before and after analysis and system monitoring in deploying TSMO.

> *ODOT is in the process of preparing a TSM&O Performance Measures Plan. The outcomes of the planning effort will be incorporated in this section.*

18.2.1 Data Management

Data management encompasses the organization and use of data. The first step to good data management is a clear understanding of how data will be used. Clarity in the application of data helps to inform decisions about collecting, processing, and interpreting data. The following list includes common components and considerations for managing data.

- Collection is the systematic process of gathering and measuring data. Traffic data can be collected using either automated or manual methods. Automated data collection methods are designed to continuously record data in discrete time periods. Some examples of automated collection methods are traffic counters, portable traffic recorders, Bluetooth or Wi-Fi recorders, and weigh-in-motion devices. Manual collection refers to visually observing and recording data using tally sheets, counting boards, or manually reported data such as crash data.[1]

[1] https://www.fhwa.dot.gov/policyinformation/tmguide/tmg_fhwa_pl_13_015.pdf

- Data Quality refers to the strength, trustworthiness, and validity of data. A specification can be used to ensure data quality is preserved. There are five key factors to consider when assessing data quality:

    - The *Validity* of the data is the relevance of collected data to the performance measure or goal being studied.
    - The *Completeness* of the data indicates whether there is enough information to draw a reasonable conclusion about the data.
    - *Data Consistency* considers whether data are collected using the same processes and procedures in every instance and by every individual or agency collecting the data.
    - The *Accuracy* of the data refers to whether the data make sense and are free from significant errors.
    - The *Verifiability* of the data considers whether there are ways to verify the data were reported and collected according to accepted procedures.[2]

- Data Monitoring is the practice of routine checking of data against quality control factors. Monitoring data can assist with design, maintenance, operations, safety, environmental analysis, finance, engineering economics, and performance management.[3] As an example, sensor failures can be detected through data monitoring practices. Data monitoring can also provide feedback to inform planning, such as whether planning goals for implementation and effectiveness of TSMO program investments are being met. For more information see section 18.2.5.

- Calibration is the process of performing a variety of tests on equipment to ensure that it functions as intended and correctly collects, processes, and reports data. The calibration process can identify errors such as failed or improperly set up sensors or incorrect algorithms that can result in collecting, processing, storing, and disseminating inaccurate statistics.[4]

- Storage – Data storage can be a major challenge as the volume of data being collected is increasing drastically. However, the per gigabyte storage cost of data continues to decline as technology advances. There are also many alternate data storage methods available through the private sector, including cloud storage and data warehouses.[5] With the volumes of collected sensor data, established retention policies provide guidelines for how long data are kept and for what purposes.

- Data Fusion is the process of synthesizing data from several different sources to obtain more meaningful information than gained from a single source. The data are gathered, cleaned to remove inconsistencies, and exported to a centralized

[2] http://www.nationalservice.gov/sites/default/files/resource/Data_Quality_Elements_Performance_Measures_LearningAidFinal7.23.pdf
[3] https://www.fhwa.dot.gov/policyinformation/tmguide/tmg_fhwa_pl_13_015.pdf
[4] https://www.fhwa.dot.gov/policyinformation/tmguide/tmg_fhwa_pl_13_015.pdf
[5] https://www.fhwa.dot.gov/asset/dataintegration/if10019/dip06.cfm

database. A detailed analysis of the characteristics of the data is necessary to mitigate issues with merging different sources of data. Fusing highly incompatible data sources can be extremely painstaking work, but some of this work can be minimized with software tools.[6]

- Interoperability is an approach in which a number of databases are linked through a communications network so that they appear to be from a single source. Interoperable databases allow users from multiple agencies to make a query without concern for where the data reside or how they are organized. An interoperable database provides easier access to resources, improved availability, and greater ability to share data than a fused database. However, the interface for an interoperable database is much more difficult to configure and the maintenance needs are much more complex.[7]

- Sharing – Data collected by agencies may be useful to other agencies or the general public through traveler information systems. Considerations for data sharing include establishing procedures for access and dissemination. The Federal Highway Administration has developed a Data Exchange Format Specification (DXFS) to facilitate the development of interoperable traveler information systems between agencies and with private entities. [8]

- Granularity refers to the level of depth or detail in a set of data. The finest level of granularity is the smallest pieces of information a dataset can be subdivided into. Courser levels of granularity may include more summarized or aggregated representations of data.

- Communication – Traffic systems use communication systems to transmit data between field equipment and traffic management centers. These systems consist of agency-owned cable, leased privately owned cable, or wireless systems. Communication between field devices is standardized based on National Transportation Communications for Intelligent Transportation System Protocol (NTCIP) specifications. Data sharing and storage are important considerations for data communication.

- Security – In the past, transportation agencies relied on security through obscurity for protection of their communication system. Now that more conventional technologies such as Wi-Fi and Ethernet are commonly used in field devices, communications systems are more vulnerable to attack. It is important for agencies to use current best practices and industry standards to improve security. [9] The FHWA has developed a National Institute of Standards and Technology Framework for Improving Critical Infrastructure Cyber Security: https://www.fhwa.dot.gov/asset/dataintegration/if10019/dip05.cfm.

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[6] https://www.fhwa.dot.gov/asset/dataintegration/if10019/dip06.cfm
[7] https://www.fhwa.dot.gov/asset/dataintegration/if10019/dip05.cfm
[8] http://www.ops.fhwa.dot.gov/publications/fhwahop13047/seces.htm
[9] https://www.fhwa.dot.gov/publications/publicroads/16sepoct/01.cfm

- Privacy – Agencies must take into account any privacy issues that may arise as a result of disclosure of traffic data. Both federal and state laws recognize a certain degree of privacy with respect to driver information. For this reason, traffic data that a public agency collects or purchases should be anonymous in nature.

- Metadata are data that provide information about other data, often how the data were collected. An example of metadata is the location and timestamp data associated with a photograph. Metadata can also include elements such as the person who collected the data, the title of the dataset, file size, date created, date modified, timeframe, accuracy, collection method, and information about the collection device.

18.2.2 Agency TSMO Data

Agency data services are critical for successfully managing Oregon's transportation system. ODOT manages datasets on both freeways and arterials, including vehicle, pedestrian, bicycle, and transit data. More information about many of these data sources can be found in Chapter 3, Transportation System Inventory.

Freeway Data

ODOT shares live video feeds from the State's traffic cameras as well as weather, incident, closures, delays, and construction data on the Trip Check website – https://www.tripcheck.com/.

On Oregon's freeways, ODOT collects speed, volume, classification, and occupancy data with both loops and radar through Automatic Traffic Recorder (ATR) stations, ramp meters, and temporary counting stations. ODOT also collects travel time data using Bluetooth stations. These data are gathered and managed by the Transportation Data Section (TDS). Volume data are shared through the TDS web site through the Transportation Volume Tables.[10] Volume and classification data are also publicly available through ODOT's TransGIS web site.[11]

ODOT records and logs every message displayed by a Variable Message Sign (VMS) or Variable Advisory Speed (VAS) sign through its data acquisition system, managed by the ITS Unit.

Weigh in Motion (WIM) devices capture and record axle weights and gross vehicle weights as drivers drive over a measurement site. ODOT currently operates 22 WIM stations that pre-clear an average of 4,400 trucks a day.[12] WIM data are managed by TDS.

Multimodal Arterial Data

Many of the same methodologies for data collection on ODOT's freeways can also be applied to arterial corridors. Count stations gather volume, speed, and lane occupancy

[10] https://www.oregon.gov/ODOT/Data/Pages/Traffic-Counting.aspx
[11] https://gis.odot.state.or.us/transgis/
[12] https://www.oregon.gov/ODOT/MCT/Pages/GreenLightProgram.aspx

data. Some traffic signals are also equipped with detectors that can gather vehicle counts by lane and time period. Bluetooth sensors gather travel time and origin-destination data to help measure and optimize arterial performance. Additionally, pedestrian and bike data can be collected on arterial corridors. Pedestrian volumes can be estimated using pushbutton actuations at signals and enhanced pedestrian crossings such as Pedestrian Activated Beacons (PABs). Bicycle volumes and travel times can be determined using many of the same methods used to count motor vehicles.

Arterial traffic data are also used to operate adaptive traffic signal control systems. Adaptive signal control systems continuously monitor and evaluate data and adjust signal timings every few minutes to improve travel time and reduce delay.

Transit Data

TriMet, C-TRAN, and many other transit agencies provide real time data for buses and trains in General Transit Feed Specification (GTFS) format. TriMet also publishes monthly ridership and performance statistics.[13,14] ODOT is starting a project to standardize ridership data and formats from transit agencies around the state. The project will seek to develop an ecosystem of open source software tools around the new data standard.

Incidents

Automated incident detection and management data are available through the Highway Traffic Operations Center System (TOCS). The system collects, analyzes, disseminates and archives data in the transportation areas of operations, traffic, incident, and emergency management. The TOCS will include traffic surveillance, road/weather condition monitoring, incident detection and reporting, signal control, and emergency call taking.

The Highway Travel Conditions Information System (HTCIS) includes the status updates that are shared with the public on the ODOT TripCheck website, through 511, and ODOT's TripCheck Traveler Information Portal (TTIP), which allows external sources to access ODOT's data for redistribution. It includes which lanes are affected and what the expected impact is to travelers (i.e., delay experienced). Each incident usually has multiple status updates throughout the duration of the incident. These database also include weather related information (atmospheric and the resulting road conditions) at the various weather stations throughout the State. The ITS Unit manages these data sources.

ODOT also collects crash data from individual driver and police crash reports through its Crash Data System (CDS) managed by the Crash Analysis & Reporting Unit.

Weather Data

ODOT has weather stations installed across the state that continuously record temperature, dew point, humidity, wind direction, wind speed, visibility, and

[13] https://developer.trimet.org/
[14] https://trimet.org/about/performance.htm

precipitation. The public via TripCheck can access weather data.[15] ODOT also has several roadway weather surface state sensors that monitor grip factor (or relative friction) of the roadway. ODOT's ATM systems currently use these data in adjusting advisory speeds in variable speed corridors and activing advanced curve-warning systems. The data are captured in the data acquisition system (DAC), managed by ODOT's ITS Unit.

Additional weather data are available from the Oregon Department of Environmental Quality, which monitors air quality and reports an air quality index based on the concentration of pollutants in the air.

ODOT also has a pilot program that collects data from a subset of agency-owned snowplows. Data collected by the pilot program include road temperature, air temperature, location, speed, vehicle diagnostics, plow position, and details about the surface treatments applied to the road.

18.2.3 Third-Party TSMO Data Sources

Third-party data comprise an increasingly important source of transportation data for ODOT, providing the agency data types, resolution, locations, and date ranges not otherwise available from agency-owned data collection systems. This subsection provides a general overview of the types of data that can be acquired from third-party sources, with a focus on the third-party data providers with whom ODOT has developed agreements for use of real-time data that have been archived and made available for secondary use.

Travel Time, Speed, and Congestion Data

In the absence of strategically installed Bluetooth readers, Wi-Fi sensors, or similar infrastructure elements, travel time data are most commonly obtained from GPS probe vehicles runs. The prevalence and low-cost of GPS-enabled mobile devices makes private crowdsourced travel time, speed, and congestion data collection an attractive offering to third-party developers.

Location referencing for the third party transportation data is enabled by the Traffic Message Channel (TMC), the commercial industry standard used by HERE and TeleAtlas mapping firms. Use of third party data by public agencies requires the integration of the TMC referenced road network with the agency road network. The basic data elements provided with third party data are date, timestamp, roadway link identifier, roadway link length, and roadway link travel time or speed.[16]

Major third-party travel time, speed, and congestion data providers include HERE, TomTom, INRIX, and Google-owned Waze. Each data provider utilizes a driver network, comprising vehicles, smartphones, or other GPS-enabled devices, to monitor basic location and speed attributes of the vehicle. The provider often utilizes a data analytics capability to derive useful information from these attributes, including travel

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[15] https://www.tripcheck.com/textpages/RWISreport.asp?curRegion=0
[16] https://ops.fhwa.dot.gov/publications/fhwahop11029/ch2.htm

time and congestion levels. Incorporating a large probe user base with sufficient distribution across a given geographic region, a third-party data provider can generate detailed segment-based speeds and travel times for all the primary roadways in the region.

ODOT Partnership Highlight – INRIX Travel Time Data

ODOT partnered with INRIX to acquire raw segment speed information for major Oregon roadways for the years 2008 to 2013. As part of this agreement, ODOT received access to RITIS, the INRIX online analytical tool used to perform data visualization, reporting, and analytics on the raw datasets. Note - As of 2016 ODOT does not have a current contract with INRIX and therefore cannot access the RITIS analytics capabilities for the archived raw data.

INRIX data collection does not differentiate between passenger vehicles and freight vehicles, so any freight traffic analysis using this dataset requires making assumptions about the vehicle mixes. The Transportation Planning Analysis Unit (TPAU) oversees access to this dataset.

ODOT Partnership Highlight – National Performance Management Research Dataset (NPMRDS) Travel Time Data

Made available by the FHWA Office of Freight Management and Operations to all state DOTs and MPOs, the NPMRDS contains raw travel time data for all National Highway System routes. This dataset is provided in 5-minute periods and differentiates between auto, truck, and combined travel times. Although freely available, NPMRDS does not include an analytical component. ODOT utilizes the data analysis and visualization tools, JMP and Tableau, to analyze, filter, and visualize the data. TPAU oversees access to this dataset.

ODOT Partnership Highlight – HERE

Beginning in 2016, ODOT has access to raw HERE travel time data that expand upon the NPMRDS-provided coverage to include a large number of non-NHS routes. The dataset includes historical data (as far back as 2012) in five-minute increments and current data available in one-minute increments. The contract with HERE includes the Iteris analytics tool, iPeMS, to be used to analyze, filter and visualize the data. Like with the NPMRDS, the HERE travel time dataset can be differentiated between passenger and freight vehicles. TPAU oversees access to this dataset.

Incident Data

Most roadway incident data is generated by public agencies, typically by highway patrol or transportation management center systems. However, some crowd-sourced mobile traffic and mapping applications support an active user interaction component in addition to using GPS to report the location of the vehicle. A well-known and well-used example is Waze, which provides users the ability to submit en route reports on roadway conditions, including incidents, road hazards, traffic jams, and police presence.

Some public agencies are beginning to partner with traffic data companies to acquire their user-generated reports on incidents and other conditions to supplement their own detection and reporting systems. Examples include Florida DOT, which in 2014 entered into a data-sharing agreement with Waze to share its traffic detection data in exchange for Waze's user road conditions reports. In 2015, the city of Los Angeles entered into a partnership with Waze to provide the company information about construction, film shoots, planned closures, and events occurring on L.A. streets. In return, the city receives Waze user-generated incident reports. Additionally, the city can use the Waze application as a broadcast platform to send out hit-and-run and child abduction alerts to Waze users. Public agencies may also purchase data from Waze or other crowd-sourced mobile traffic mapping applications.

Currently, Waze consumes data through the TripCheck Traveler Information Portal (TTIP) on road closures, incidents and construction supplied by ODOT and local agencies using the TripCheck Local Entry (TLE) Tool).

Bicycling and Pedestrian Data

Similar to third-party vehicular travel time data providers, third-party bicycling data providers utilize a GPS device-enabled crowdsourced approach to generate bike trip data that can be purchased by public agencies. Available data types include bicycle volumes, locations (including cut-through pathways), speeds, time of day, direction of travel, route choice for given origins and destinations, and user-generated conditions observations.

Some platforms, like Strava, are geared toward fitness users who use the application to track training rides and compare their results against others in the Strava community. Other app platforms, like Ride Report (https://ride.report/) and Portland State University and ODOT sponsored ORcycle (https://www.pdx.edu/transportation-lab/orcycle), encourage users to report on their perceived stress level of routes and to provide feedback on crash, safety, or infrastructure issues observed on a ride.

Third-party pedestrian data are a relatively unexplored area of third-party data sources to date. Potential sources include GPS device-enabled fitness tracking apps, similar in function to Strava, in which users run the application in order to track their workouts or monitor their overall movement and activity level. Examples include Human (http://human.co/ & http://cities.human.co/details/United_States/Portland) and Nike+ Running (https://www.nike.com/us/en_us/c/nike-plus/running-app-gps). Most household travel surveys also incorporate GPS tracking as part of monitoring the daily travel by all modes on a select survey day.

Another emerging approach to obtaining pedestrian movement data is through installed detectors that infer pedestrian activity within the system's field of detection. These systems are most commonly deployed in retail environments to help businesses monitor foot traffic for operational improvements.

For example, Navizon (https://www.navizon.com/product-navizon-analytics) utilizes a small hardware device to detect and count Wi-Fi enabled devices within a defined target area. Placemeter (http://www.placemeter.com/) analyzes camera footage to detect pedestrians and obtain pedestrian traffic volumes and walking direction.

ODOT Partnership Highlight – Strava Bicycle Data

In 2014, ODOT became the first public agency in the nation to license bicycling trip data from Strava, a leading app developer and social platform for users to track their bike rides via GPS. Strava data relates to TSMO because it provides a representation of bicycle volumes that can be used to inform both operational and planning decisions. Strava data can also be used to compare one route to another. TPAU oversees access to this dataset.

The motivation for the partnership was to supplement the limited bicycle travel information collected by the agency through travel surveys and strategically located fixed counters. The lack of information on bicycle travel information makes it more difficult to track the success of statewide biking efforts and to target future investments appropriately.

The Strava dataset provides statewide minute-by-minute bike traces (i.e., the presence and direction of travel of a Strava user) mapped to link segments on the Open Streets Map base map. Aggregating these traces reveals not just how many Strava users are using the system, but how, when, and where they are riding.

For the 2014 year, the Strava dataset included travel data for 20,400 Oregon users, who logged 540,000 bike trips (averaging 26 trips per year each), for a total of 5.6 million bike miles traveled.

Comparing Strava data records for a given time period and location against fixed location bicycle counter readings (for example, at Hawthorne Bridge in Portland and various locations in Eugene), ODOT has determined that Strava users represent roughly 1 - 10% of the total bicycle volume. While the share of Strava trips varies by location, the percentage has remained consistent over time at each location. Further analysis by ODOT has indicated that Strava data are representative of which routes are popular with users overall and identify non-auto pathways used by cyclists.

Key use cases proposed by ODOT that make use of Strava data include:

- Identify and validate high-demand areas in which to locate bicycle counters, especially in non-urban areas
- Inform the deployment and placement of highway rumble strips to identify locations where high bicycle volumes may warrant different installation approaches
- Justify and target seasonal maintenance efforts
- Supporting county and other non-ODOT jurisdictions with cycling data to inform bike path plans and designs

Transit Data

Third-party sources of transit data are uncommon since transit providers are typically public agencies. However, there are third-party data analytics companies, like Urban Engines (https://www.urbanengines.com/), that specialize in ingesting raw data generated by the transit agency (like fare card data and GPS traces) and performing various analytics functions to visualize travel patterns, identify delays and congestion, platform crowding, and wait times.

NextBus (http://nextbus.cubic.com) is another example of a third-party data analytics company that provides added value to the data generated by transit agency. NextBus uses GPS location information from the transit vehicle and a proprietary algorithm that incorporates historical travel data to track transit vehicles and predict their arrival time.

Weather Data

In addition to the publicly available National Weather Service weather data, several third-party providers offer weather data services. An example is Weather Underground (https://www.wunderground.com/), which provides forecasts generated by a proprietary forecasting system that draws from a network of tens of thousands of neighborhood and personal weather stations across the country. Weather Underground offers an API that provide layers such as radar and satellite and a variety of weather data features, including alerts, conditions, forecasts, and astronomy.

18.2.4 Portal Transportation Data Archive

Portal Transportation Data Archive, formally known as PORTAL the Portland Oregon Regional Transportation Archive Listing (https://portal.its.pdx.edu/home), is a publically funded data archive hosted and maintained by Portland State University. Started in 2004, Portal is the region's archive for many different types of transportation related data for the Portland and southwest Washington metropolitan areas.

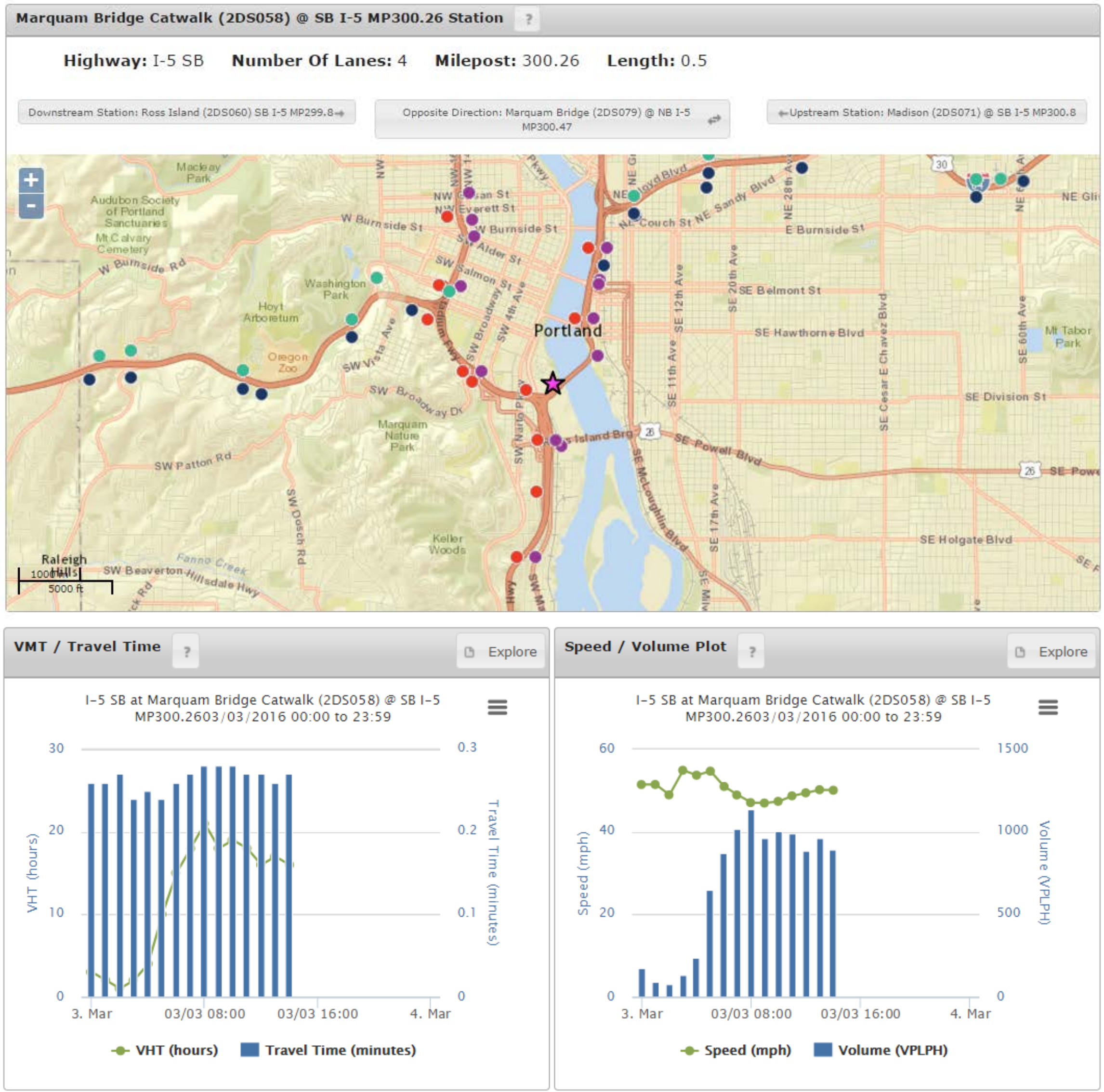
Currently, Portal archives freeway detector data from ODOT and WSDOT, travel time data from ODOT and PBOT, VMS/VAS messages from ODOT, Weigh-in-Motion data from ODOT, arterial detector data from Clark County and PBOT, traffic signal data from PBOT, bike and pedestrian counts from PBOT, automatic vehicle location (AVL) and automated passenger counter (APC) data from TriMet, air quality data from DEQ, and weather data from NOAA.

While Portal archives all of the above mentioned data, a graphical user interface is also available for viewing and downloading some of the data described. The Portal website offers maps, graphs, and data downloads related to the following:

- Detector data on OR and WA highways in the Portland and Vancouver areas
- Detector data on Portland and Vancouver Arterials
- Travel time data in Portland
- Transit performance metrics in Portland and Clark County

Examples of some of the Portal visualizations are shown below in Exhibit 18-1.

Exhibit 18-1: Portal Stations Map and Subsequent VMT/Travel Time and Speed/Volume Graphs[17]



In addition, the information available through the Portal website, additional data available upon request. A complete list of data archived is listed below in Exhibit 18-2.

[17] http://portal.its.pdx.edu/stations/view/id/3186/

Exhibit 18-2: Data Archived at Portal including Resolution and Date Ranges

Type of Data	Agency	Detection	Resolution	Date Range(s)	Location	Collection Frequency
Speed Volume Occupancy	ODOT	Loops Radar	20-sec 5-min 15-min Hour	2004- (loops) ~2014- (radar)	Portland freeways, Beltline in Lane Co.	Every 2 minutes
Speed Volume Occupancy	WSDOT	Loops Radar	20-sec 5-min 15-min Hour	~2012	Vancouver freeways	Every 20 seconds
Travel Times	ODOT	Bluetooth	Individual Traversals	~2014-	Portland freeways & selected arterials	Every 2 minutes
VMS/VAS Messages	ODOT	N/A	On sign change	~2014	Where installed	Every 2 minutes
WIM	ODOT	In-road sensors	Hour	~2011-2013	WIM stations in Oregon	Monthly
Travel Time	PBOT	Bluetooth	Individual detections	~2012-	Various locations in Portland	Hourly
Arterial Speed, Volume	Clark County	High Definition Radar	5-min	~2014-	Various locations in Clark County	Daily
Traffic Signal Data	PBOT	TransSuite, MOE & SCATS	5-min	~2014-	City of Portland	Hourly
Passenger Counts, On-time Performance	TriMet	AVL/APC	Quarter	~2012	TriMet service area	Quarterly
Weather	NOAA	NOAA detection	Hour	~2004-	Airports (PDX, Hillsboro, Aurora)	Hourly
DEQ Air Quality	DEQ	Weather and Air Quality data	Hour	~2014	DEQ site near Powell Blvd.	Hourly
Bike counts	PBOT/ LCOG	Loops	Unknown	~2014	Various locations in Portland	Hourly

Type of Data	Agency	Detection	Resolution	Date Range(s)	Location	Collection Frequency
Bike counts	LCOG	Loops, pneumatic tubes, infrared, manual	Short duration	~2012	Various locations in Eugene, Springfield, and elsewhere in Lane County	
Pedestrian Pushbutton Actuations	PBOT/LCOG	Pushbutton	Individual actuations			

18.2.5 TSMO Performance Evaluation and Monitoring

Most TSMO deployment projects involve evaluating, adjusting, and improving the performance of the system. Performance evaluation informs the effectiveness of specific TSMO strategies and can aid decision makers in project selection for future capital investments. Performance evaluation can also identify problems or failures, identify fixes to implement, or determine parameters to adjust to optimize performance. Often, the performance evaluation component of a project takes the form of a before and after study, where baseline "before" transportation data are compared to "after" data collected post-deployment.

Before and after study designs can be used to assess the impacts from TSMO deployments on efficiency, reliability, safety, and travel behavior. Data needs are dictated by intent of the evaluation. For example, a before and after evaluation of impacts to travel time reliability from a TSMO project require collecting travel time data during the periods before and after deployment. It is important to collect sufficient data ahead of a project implementation and after completion to statistically measure factors like reliability. The cost of performing before and after studies, which has been a barrier, is greatly reduced with technology-based methods.

Evaluation should define in the project planning phase. Depending on the study design, performance evaluation can be set up as a one-time before period vs. after period analysis, or as a comparison of before data to after data collected over time. A study design with multiple after periods allows for observations of trends over time. After periods typically occur at specified intervals (e.g. annually). The initial after period typically does not occur until a duration of time passes beyond project construction (e.g. six months). This is so data are not skewed by abnormal behavior that may occur upon installation of new transportation devices in the system. It is important that the before period and after period occur during the same time of year so seasonal differences in traffic and travel conditions do not skew the results.

Analysis methods can vary depending on the goals of the evaluation, data structure, and data availability. In the ideal case, a simple matched pairs comparison[18] can highlight whether significant changes occurred in the data between before and after periods due to a TSMO project. **Examples of some before and after studies completed in Oregon** are shown below in Exhibit 18-3.

Exhibit 18-3: Example Before and After Evaluations

Project Name	Description	Performance Measures	Data Used	Findings
OR 217: Active Traffic Management	Evaluated effectiveness of Active Traffic Management System	Crashes Travel Time Travel Time Reliability	Transportation Data Services Crash Reports Washington County Consolidated Communications Agency Data HERE Data PORTAL	Reduction in travel time, improvement in travel time reliability
Beltline Highway Ramp Metering	Evaluated system performance of Beltline Highway in Eugene, Oregon before and after implementation of ramp meters	Incidents Volumes Speeds Travel Times Reliability	ODOT Incident logs ODOT ATR Data ODOT INRIX™ Analytics Suite	Reduction in incidents, negligible change in speeds, travel times, and travel time reliability
Cornell Road InSync Evaluation	Comparison on operations between TOD signal timing plans and InSync adaptive signal system operation	Travel Time Delay	Bluetooth MAC address data Percent Arrival on Green Traffic Counts	Reduction in travel time during high volume periods, small increase in overall delay
911 CAD Integrated Dispatch Project	Evaluation of 911 dispatch interconnect system between Deschutes County 911 call center, OSP call center, and ODOT incident response system	Notification Time Dispatch Response Time Incident Duration Responder Arrival Time Percentage of Highway-Related Notifications Received by	ODOT Incident Logs OSP Call Center Logs Deschutes County 911 Call Center Logs	Reduction in dispatch response time, incident response time, and incident duration

[18] See Dalgaard, P. (2008). *Introductory Statistics with R*. Springer Science & Business Media, or another introductory statistics text.

Project Name	Description	Performance Measures	Data Used	Findings
		ODOT		
District 8 Incident Response Evaluation	Evaluation of pilot program for a dedicated incident response service patrol	Clearance Time Average Incident Response Time Maintenance Calls	ODOT Highway Traffic Operation Center System (HTOCS) Highway Travel Conditions Information System (HTICS)	Reduction in response time, incident duration, clearance time, and maintenance calls

Key considerations for evaluations include collecting quality baseline (before) data, accounting for external factors that may affect data collected in the future, and developing analysis tools for reproducibility.

Collecting quality baseline (before) data

Issues with baseline before period data are frequent in before and after studies, and often include incomplete or missing data, structures and formats that don't correspond to after data, and inadequate sample sizes for comparisons. These issues are difficult to overcome because once project deployment occurs, one cannot simply go back and collect more data for the before period. Before data should match the after data in structure, and therefore should be collected by the same or similar methods. Before period data should be examined and verified for quality and accuracy prior to project deployment. This can be done through testing and creating a baseline report. Statistical tools like power analysis can help analysts determine minimum sample sizes needed to make appropriate comparisons.

Accounting for external factors

After period data are subject to influence by external factors beyond the TSMO deployment. Examples include a reduction in vehicle miles traveled due to a spike in fuel costs, a downturn in the economy, or weather conditions that change travel patterns. Therefore, performance evaluations should anticipate normalizing or scaling after period data by also collecting traffic volumes on nearby facilities or other variables. In the case of controlling for traffic volumes, annual ATR data could be used as a potential data source. The nature of the particular study can inform the types of external variables that may be of interest.

Developing analysis tools for reproducibility

Before and after performance evaluations can benefit greatly by employing reproducible analysis tools. Reproducible tools allow analysts to reach the same results given a set of data and include clear documentation. Reproducible tools can expedite the analysis task in cases when after data are collected at specified intervals. Employing traditional analysis tools may lead to more opportunity for problems in the future. For example, complex spreadsheets in Microsoft Excel may be hard to reproduce when an extended period of time has passed between reporting periods or when employee turnover occurs.

Many open-source scripting languages like R and Python are well suited for creating reproducible analysis tools.

Performance monitoring differs from performance before and after evaluation in that it is the periodic measurement of progress in meeting operational objectives. Monitoring includes a set of agreed upon measures that are reported out at regular intervals. For TSMO application, performance monitoring can be used to support day to day operational decision making, such as winter road operations or incident management. It also applies to the planning for operations process as described in Section 18.3.

18.3 Planning and Programming for TSMO

The section introduces the concept of planning and programming for TSMO. It begins with an overview of the objectives-driven, performance-based approach that supports integration of TSMO into ODOT's planning and programming processes. Key elements of the objectives-driven, performance-based approach are described in this section including stakeholder collaboration, operational objectives and performance measures, TSMO strategies, programming, intelligent transportation system (ITS) architecture and system engineering requirements, and analysis tools.

The intent of this section is to provide guidance for developing and incorporating TSMO into ODOT planning processes including transportation system plans, corridor plans, and modal plans. As noted in Section 18.1, the OTP and the OHP have established the policy basis for TSMO in planning, designing, and operating Oregon's transportation system. Additionally, ODOT has completed a statewide ITS plan and numerous regional ITS plans that serve as resources for planning processes.

18.3.1 Objectives-Driven, Performance-Based TSMO Planning

The basic tenet of the objectives-driven, performance-based approach is to maximize the performance of the existing transportation system. To accomplish this, the approach relies on a collaborative process to establish measurable operational objectives that are supported by system and demand management strategies focused on improving near-term travel conditions for all modes. For comparison, the traditional approach to transportation planning focuses on addressing issues and problems with a set of infrastructure projects that extend into the distant future. The difference between approaches is the focus on near-term measurable outcomes and solutions. While the objectives derive from issues and problems, the solutions are matched to future-focused objectives and monitored for performance over time. The objectives-driven, performance-based approach is a cyclical process of objectives setting, strategy development, implementation, and performance measurement to manage the transportation system.

Exhibit 18-4 demonstrates the process flow for the objectives-driven, performance-based approach. It is important to note that this approach has points of integration with the broader community planning processes to ensure TSMO is incorporated. Integral to the process is the coordination and collaboration with a broad range of stakeholders that occurs at every step. The implementation and operation of TSMO strategies often requires partnership among multiple business units within an agency and across modes and jurisdictions in a region. Applying an objectives-driven, performance-based approach to operations planning further broadens the circle of collaboration to include transportation planners and non-transportation entities such as public safety officials, special interest groups, key attractions, and major employers. Coordination and collaboration among planners and operators is necessary across all steps in the approach, and is particularly important in defining operations objectives that feed into long-range transportation plans.

Exhibit 18-4: Objectives-driven, Performance-based Approach

Source: *Advancing Metropolitan Planning for Operations: An Objectives-Driven, Performance-Based Approach – A Guidebook*, FHWA

Establishing TSMO goal(s) focused on the safe, efficient and reliable management and operation of the transportation system is where the process begins. This is a point of integration with broader corridor, regional or statewide planning processes. A transportation plan may identify a single overarching TSMO goal or a set of goals that are broad but address different aspects of TSMO, such as reliability, efficiency, quality of service, and travel options.[19] As noted in Section 18.1.2, ODOT has established TSMO goals and objectives in the OTP and the OHP. It is important to note that TSMO and ITS plans will often include a vision for TSMO. However, when TSMO is integrated into broader planning processes including RTPs and TSPs, TSMO should be reflected in the vision created for these plans.

Operations objectives are the bridge between goals and actions and help determine the selection of and investment in TSMO strategies. These objectives focus on the desired operational performance of the transportation system and address issues related to system

[19] Regional Goals, https://ops.fhwa.dot.gov/plan4ops/focus_areas/integrating/regional_goals.htm, FHWA

reliability, congestion, safety, incidents, weather, work zones, and major events. The process for setting operations objectives relies heavily on stakeholder participation and an understanding of the needs and interests of the traveling public. Section 18.3.2 provides further detail on developing operations objectives and associated performance measures.

The process for identifying and selecting TSMO strategies begins with an analysis of needs in a study area. Here, operations objectives and baseline performance measurement provide the criteria for determining operations needs. Stakeholder input is also critical to ascertaining and verifying needs. Potential TSMO strategies are matched to operations objectives they help to achieve. Strategy evaluation assesses the benefits and costs for each strategy and identifies any co-benefits to other goals and operations objectives. Analysis tools, such as sketch planning tools, travel demand forecasting model post-processors, and simulation modeling may be used to help forecast system needs and analyze the potential benefits of operations strategies.[20] Section 18.3.3 describes common TSMO strategies and considerations for their application. Section 18.3.6 provides an overview of analysis tools commonly used in assessment of operational needs and benefit-cost analysis.

With the selection of operations objectives, associated performance measures, and supportive TSMO strategies, the process shifts to integrating these elements into long-range transportation plans and funding programs, such as the OTP or ODOT's Statewide Transportation Improvement Program (STIP). It is important to note that TSMO strategies can be implemented as standalone projects or programs or they can be incorporated into the implementation of other projects types like preservation, modernization, and safety. The benefit of on-going collaboration across a diverse set of stakeholders is the opportunity to partner on implementation of TSMO strategies. Section 18.3.4 delves into more detail on programming for TSMO.

Given the diversity of geography that ODOT serves, it is important to note that the objectives-driven, performance-based process is highly scalable to the planning context and can evolve over-time. Large urban regions may develop a robust plan with several TSMO-related goals and supporting operations objectives that address a variety of issues. In contrast, smaller rural regions can apply the same process that results in a single TSMO goal with a few operations objectives that address critical system performance issues. The cyclical nature of the process means that initial TSMO planning can be refined and expanded upon over time.

[20] Advancing Metropolitan Planning for Operations: The Building Blocks of a Model Transportation Plan Incorporating Operations – A Desk Reference, FHWA 2010

18.3.2 Multimodal System Performance Measures

> *To learn more about establishing operations objectives and performance measures including examples refer to* [Advancing Metropolitan Planning for Operations: The Building Blocks of a Model Transportation Plan Incorporating Operation - A Desk Reference]().

Operations objectives are the bridge between goals and actions and help determine the selection of and investment in TSMO strategies. These objectives focus on the desired operational performance of the transportation system and address issues related to system reliability, congestion, safety, incidents, weather, work zones, and special events. The process for setting operations objectives relies heavily on stakeholder participation and an understanding of the needs and interests of the traveling public.

Operations objectives should exhibit S-M-A-R-T characteristics:

- **Specific** The objective provides enough detail (e.g., decrease travel time delay) to identify actions that will achieve the objective.
  Criteria: What is the target issue? What will be accomplished?

- **Measurable** The objective is quantifiable (e.g., by 10 percent) defining how many or how much should be accomplished. Tracking progress against the objective enables an assessment of the effectiveness of an action or set of actions.
  Criteria: Is the objective quantifiable? Can it be measured? How much change is expected?

- **Agreed Upon** Stakeholders come to a consensus on a common objective. This is most effective when the planning process involves a wide range of stakeholders to facilitate regional collaboration and coordination.
  Criteria: Does the objective address an issue of importance to stakeholders? Does it have broad support from stakeholders?

- **Realistic** The objective can reasonably be accomplished within the limitations of resources and other considerations. The objective may require substantial coordination, collaboration, and investment to achieve. To be achievable, it may need to be re-evaluated and adjusted once strategies and costs are defined.
  Can the objective be accomplished with available resources and support?

- **Time-bound** The objective identifies an achievable timeframe (e.g., within five years). As with the Realistic characteristic, the timeframe may need to be adjusted once strategies and costs are defined.
  Can the objective be accomplished within the proposed timeframe?

A basic sentence structure for operations objectives looks like this:

(Action verb) + (the target subject) + (descriptor) by X (unit of measure) by (year).

- Common Action verbs show directionality and include words like *increase, achieve, reduce,* and *decrease*.
- The Target Subject is the activity being measured such as *mode share* or *delay.*
- Descriptors provide detail about the subject such as time period of interest (e.g. peak hour, average weekday), geographic focus (e.g. region, neighborhood), mode (e.g. transit, trucks) facility type (e.g. bus route, corridor), and user type (e.g. freight carriers, single-occupancy vehicle drivers).
- Unit of measure defines the standard for a quantity such as *percent* or *miles.*
- Year is the target timeframe such as by *2040.*

Below are some examples of S-M-A-R-T operations objectives:

- *Reduce the number of freeway miles at level of service F in the PM peak by 5% by 2040.*
- *Increase the percent of major employers actively participating in transportation demand management programs by 20% within 10 years.*

There are two general categories of operations objectives: *outcome-based* and *output-based*. Outcome-based operations objectives address whether strategies resulted in overall improvement. These objectives are high-level, crosscutting and user-focused. These characteristics mean that plans will include fewer outcome-based measures. Examples of outcome-based objectives are delay reduction, travel time reliability, and increases in non-single occupancy vehicle mode share.

Output-based operations objectives are focused on the quantity or magnitude of output. They are focused on the operational activities of organizations and support desired system performance outcomes. Output-based objectives tend to be more abundant in plans because organizations more readily monitor outputs and have data to support measurement of the objective. Examples of output-based operations objectives include the frequency of signal re-timing, average incident response time, and share of transit stops with real-time traveler information.

Performance measures quantify operations objectives. They are indicators of the extent to which the transportation system is achieving desired operations objectives. Performance measures also help identify transportation system issues and needs; assess potential impacts of TSMO strategies; communicate progress in achieving goals and objectives; and provide accountability. Exhibit 18-5 provides a table of common operations objectives, associated performance measures, and relationship to modes.

Exhibit 18-5: Example Operations Objectives and Performance Measures Reference Table[21]

Operations Objectives	Performance Measures	Modes Potentially Affected by Objectives and Performance Measures Auto = A; Transit = T; Freight = F; Bike = B; Pedestrian = P				
		A	**T**	**F**	**B**	**P**
System Efficiency						
Extent of Congestion	• Percent of intersections operating at LOS F or V/C > 1.0 • Rate of increase in facility miles operating at LOS F or V/C > 1.0	●	●	●		
Duration of Congestion	• Hours per day at LOS F or V/C > 1.0 (or other threshold)	●	●	●		
Vehicle Miles Traveled	• Average VMT per capita per day, per week, or per year	●	●	●	●	●
Safety	• Traffic fatalities and injuries per 100 million vehicle miles traveled • Traffic incident clearance time	●	●	●	●	●
Delay	• Hours of delay per capita or per driver	●	●	●	●	●
Energy Consumption	• Total fuel consumed per capita for transportation	●	●	●	●	●
System Reliability						

[21] Source: Adapted from Table 3.2.1: *Cross-Reference Table in* *Advancing Metropolitan Planning for Operations: The Building Blocks of A Model Transportation Plan Incorporating Operation - A Desk Reference*, FHWA

Operations Objectives	Performance Measures	Modes Potentially Affected by Objectives and Performance Measures Auto = A; Transit = T; Freight = F; Bike = B; Pedestrian = P				
		A	T	F	B	P
Non-recurring Delay	• Travel time delay per capita during scheduled and/or unscheduled disruptions to travel	●	●	●	●	●
Travel Time	• Average travel time during peak periods (minutes)	●	●	●	●	●
Transit On-time Performance	• Arrival and departure times (if different) from a select number of stops on transit facilities of interest		●			
System Options						
Mode Share	• Share of trips by each mode of travel	●	●	●	●	●
Modal Options for Individuals with Disabilities	• The percent of intersections with ADA provisions • The percent of individuals with disabilities that can access transit		●			●
Bicycle and Pedestrian Mobility	• Average delay for pedestrians and bicyclists on primary routes • Average pedestrian or bicyclist comfort level measured by survey				●	●

There are limitations that must be considered when developing operations objectives and performance measures. The availability of data needed for performance measures and the difficulty in agreeing upon an appropriate target or timeframe for achievement are obstacles for agency use of this approach. Developing operations objectives requires data on baseline conditions and often requires information on historical conditions and forecasts of future conditions in order to determine a reasonable target and timeframe. These limitations should be factored into consideration and selection of operations objectives and performance measures. It is advisable to begin with a select number of agreed upon objectives and performance measures and develop a process for data management, evaluation, reporting, and decision-making. The cyclical nature of the planning process provides ample opportunity for the refinement over time.

Chapter 9 includes more information about performance measures.

18.3.3 TSMO Strategies

Numerous TSMO strategies can be applied to support operations objectives and should be considered and evaluated as part of any planning effort. Appendix 18A provides an extensive list of strategies with a description, key benefits, order of magnitude cost, geographic application, influencing factors, data needs, and level of staffing associated with each one. The strategies are grouped by category:

- Regional Traffic Control
- Traveler Information
- Maintenance and Construction
- Road Weather Operations
- Incident Management
- Emergency Management
- Public Transportation
- Freight
- Archived Data Management
- Transportation Demand Management
- Complementary Strategies
- Strategies that Require Political and Policy Changes
- Emerging Strategies

Exhibit 18-6 provides a list of TSMO strategies to consider based on operations objectives.

Exhibit 18-6: TSMO Strategies to Consider Based on Operations Objectives

<table>
<tr><th>High-Level
Operations Objectives*</th><th colspan="2">TSMO Strategies to Consider</th></tr>
<tr><td colspan="3">System Efficiency</td></tr>
<tr><td>Extent and Duration of Congestion
• Reduce recurring congestion (extent and duration)
• Improve intersection LOS</td><td>(see right)</td><td rowspan="8">Applicable to all system efficiency objectives:
• Traffic network surveillance
• Transportation operations centers
• Enhanced traffic signal operations
• Transit signal priority
• Incident management
• Travel demand strategies that encourage shifts in travel mode, time, or route
• Congestion pricing strategies that encourage shifts to off-peak periods
• Roadside truck electronic screening/clearance
• Traveler information
• Archived data management
• Connected/autonomous vehicles
• Ramp metering
• Freeway/arterial integrated corridor management (ICM)</td></tr>
<tr><td>Intensity of Congestion (Travel Time Index)
• Reduce travel time index</td><td>(see right)</td></tr>
<tr><td>Travel Time
• Improve travel time</td><td>(see right)</td></tr>
<tr><td>Delay
• Reduce hours of delay
• Reduce control delay at traffic signals
• Improve roadway LOS</td><td>• Access management
• Managed lanes
• Bottleneck removal
• Ramp closures</td></tr>
<tr><td>Energy Consumption
• Reduce energy consumption
• Reduce fuel consumption</td><td>(see right)</td></tr>
<tr><td>Cost of Congestion
• Reduce cost of congestion</td><td>(see right)</td></tr>
<tr><td>Vehicle Miles Travel
• Reduce vehicle miles traveled</td><td>• Transportation demand management: trip elimination, trip chaining, mode shifts, increasing vehicle occupancy, land use strategies
• Improve transit travel times and reliability</td></tr>
<tr><td>Trip Connectivity
• Reduce door-to-door trip time
• Reduce cost of transfer fees</td><td>• Transportation demand management for end users: minimize trip transfers, fare integration</td></tr>
<tr><td colspan="3">System Reliability</td></tr>
<tr><td>Non-Recurring Delay
• Reduce person hours of delay caused by scheduled events, work zones, system maintenance, unscheduled disruptions, and traffic incidents</td><td>(see right)</td><td rowspan="5">Applicable to all system reliability objectives:
• Traffic network surveillance
• Transportation operations centers
• Active traffic management
• Freeway/arterial integrated corridor management
• Safety applications
• Incident management
• Emergency management
• Special event management
• Work zone management
• Maintenance and construction activity coordination
• Road weather operations
• Traveler information
• Archived data management
• Connected/autonomous vehicles</td></tr>
<tr><td>Travel Time Buffer Index
• Reduce travel time buffer index</td><td>• Managed lanes
• Freight only lanes</td></tr>
<tr><td>Planning Time Index
• Reduce average planning time index</td><td>• Ramp metering
• Managed lanes
• Public transportation improvements</td></tr>
<tr><td>Travel Time 95th/90th Percentile
• Reduce the 90th (or 95th) percentile travel time</td><td>(see right)</td></tr>
<tr><td>Variability
• Reduce travel time variability</td><td>(see right)</td></tr>
</table>

High-Level Operations Objectives*	TSMO Strategies to Consider
On-Time Performance • Improve average on-time performance for transit and freight	• Advanced transit operations management • Transit signal priority • Truck traffic signal priority • Managed lanes (including transit and freight options) • Electronic fare collection • Roadside truck electronic screening/clearance
System Options	
Mode Share • Reduce per capita single occupancy vehicle commute trip rate • Increase alternative (non-SOV) mode share • Increase active (bicycle/pedestrian) mode share	• Travel demand management • Parking management • Traveler information • Congestion pricing (with electronic toll collection and automated enforcement)
Transit Use • Increase transit mode share • Increase average transit load factor • Increase passenger miles traveled	• Advanced transit operations management • Electronic fare collection • Transit surveillance and security • Traveler information • Travel demand management: marketing, rider incentive programs, transit ease of use
Travel Time – Transit Compared to Auto • Reduce the travel time differential between transit and auto	• High performance transit • Queue jump lanes at signalized intersections • Transit lanes/managed lanes • Transit signal priority
Bicycle and Pedestrian Accessibility and Efficiency • Decrease average delay for pedestrians and bicyclists • Increase the number of intersections with pedestrian features	• Bicycle and pedestrian operations and safety (e.g. pedestrian countdown signals, bicycle detection, timing)

* For numerous SMART objectives, see *Advancing Metropolitan Planning for Operations: The Building Blocks of A Model Transportation Plan Incorporating Operation - A Desk Reference*, FHWA.

18.3.4 TSMO Programming

Programming is the process of selecting projects for funding (based on long-range planning efforts and a prioritization process), identifying funding resources, and scheduling project implementation. This section provides an overview of long-range planning, project selection, TSMO funding sources, and additional TSMO programming resources.

Long-Range Planning

The [Oregon Transportation Plan (OTP)] and the six associated mode/topic plans (e.g. Oregon Highway Plan) provide the foundation for long-range planning for regional and local transportation system plans in Oregon. The OTP is a 25-year plan that sets statewide goals for mobility and accessibility, management of the system, economic vitality, sustainability, safety and security, funding the transportation system, and coordination/communication/cooperation. The Transportation Planning Rule (OAR 660-012) requires regional and local transportation system plans to be consistent with the OTP.

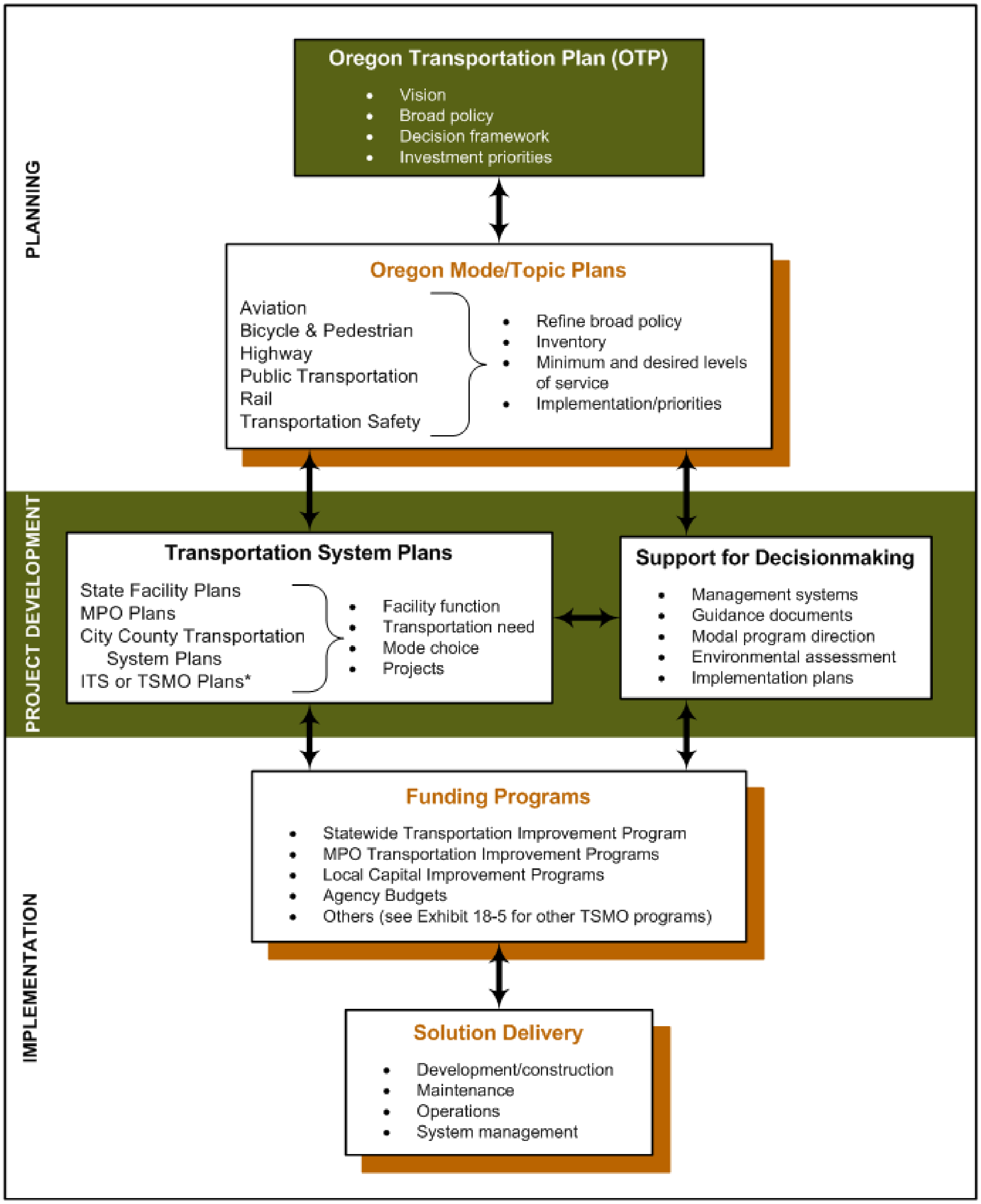
Exhibit 18-7 illustrates the relationship between the OTP, statewide mode/topic plans, and regional and local transportation system plans. The project development and funding programs shown in the exhibit are discussed in the following sections.

TSMO Project Selection for Programming

Projects are typically identified as part of the development of regional or local transportation system plans. These plans use the OTP and state mode/topic plans as policy guidance and develop a list of long-range projects to meet the objectives and goals of the transportation system plan. In the context of the objectives-driven, performance-based approach to planning for operations, measurable operations objectives should be used to support funding decisions as well as to monitor and evaluate projects so that prioritizations can be modified as necessary. Other measures are also used in the project selection process such as benefit/cost analysis or ODOT's least cost planning method.

To date many ITS or TSMO plans have been developed separately from regional or local transportation system plans. [Note: TSMO is broader than ITS as previously defined at the beginning of this chapter. Until recently most agencies focused on ITS plans instead of TSMO plans.] However, the ITS or TSMO plans are often referenced in the applicable transportation system plan or adopted as an appendix. ITS or TSMO plans typically include a phased implementation plan of projects that often compete for funding with projects from the transportation system plans. More work is needed to bridge the gap between traditional planning and operations planning.

Exhibit 18-7: Integrated Transportation Planning and Programming



Source: *Oregon Transportation Plan*, 2006, Figure 7

* Regional or local ITS or TSMO plans are often referenced in or adopted as an appendix to MPO, city, or county transportation plans.

TSMO Funding Sources

Successfully funding TSMO projects or a TSMO program depends on a combination of capital, operations, and maintenance investments to support active management and operations of the transportation system. The funding sources identified in Exhibit 18-8 primarily identify funds that could be used for capital investments; however, funding is also critical for ongoing operations and maintenance. Often operations and maintenance budgets are funded through each agency's own budget.

Exhibit 18-8: Potential TSMO Funding Sources and Application Cycles

Potential Funding Program	Applicable Project Types	Application Cycle
Oregon Statewide Transportation Improvement Program (STIP) *(Note: Prior to the current programs, most TSMO projects received funding through the STIP Operations Program)*	Enhance: Activities that enhance, expand, or improve the transportation system Fix-It: Activities that fix or preserve the transportation system; currently each region receives an allocation of funds specifically for ITS as a subcategory under Operations.	Process begins in odd-numbered years and results in a 4-year funding program
ConnectOregon	Non-highway freight, transit projects, and active transportation projects	Roughly every 2 years
U.S. DOT Transportation Investment Generating Economic Recovery (TIGER) Discretionary Grants	Projects that generate economic development and improve transportation safety, reliability, and affordability	Yearly (typically May)
FTA State of Good Repair (SGR) Grant Program	Transit projects	Varies; part of a 4-year program
U.S. DOE Energy Efficiency and Conservation Block (EECBG) Program	Projects that improve energy efficiency (e.g. signal timing)	Yearly
Homeland Security Funding	Traffic surveillance, CAD integration with 911 centers	Varies
Metropolitan Transportation Improvement Program (MTIP)	Any regional or local TSMO project within an MPO	Varies by MPO and results in a 4-year program
Local Funding (e.g. gas tax, property tax, system development charges)	Any TSMO project; Local match for other funding programs	Varies

Agencies have developed creative solutions for obtaining TSMO funding or reducing costs through practices such as these:

- System sharing (e.g. central signal system shared by multiple agencies)
- Communications infrastructure sharing with other departments within an agency, other transportation agencies, emergency management agencies, or the private sector (e.g. PGE)
- Installing conduit underground as part of capital improvement projects that have been identified as future fiber optic communications corridors
- Staff sharing between agencies for TSMO activities
- Local flexible fund for TSMO that can be used as the local match for STIP, MTIP, or other funding sources
- Purchase of spare parts or back-ups as part of capital construction projects

TSMO Programming Resources

Additional information about programming for TSMO projects is available at:

- FHWA Integrating Operations into Planning and Programming
- FHWA Performance-Based Planning and Programming Guidebook
- FHWA Programming for Operations: MPO Examples of Prioritizing and Funding Transportation System Management & Operations Strategies (includes a Portland case study)
- NCHRP 20-07/345 Program Planning and Development for TSM&O in State Departments of Transportation
- SRHP2/TRB Guide to Incorporating Reliability Performance Measures into the Transportation Planning and Programming Processes
- Oregon Statewide Transportation Improvement Program
- Metro Regional TSMO Plan 2010 – 2020, Appendix F: Finance Report

18.3.5 ITS Architecture and Systems Engineering

This section describes how the ITS architecture and a systems engineering approach can be used in the planning process.

ITS Architecture

An ITS architecture provides a common framework for planning, defining, and integrating ITS within a region. The U.S. Department of Transportation developed the National ITS Architecture so that intelligent transportation systems deployed around the country, and within a region, can communicate with one another and share information to maximize the return on investment for ITS. For example, if a transportation agency wants to clear incidents faster, the architecture defines a function to monitor roadways and identifies the interconnection and information flows between roadway devices, the traffic operations center, and the emergency management center needed to provide responders with incident information. The architecture provides the framework for the process, but does not define the technology or management techniques used to provide the information flows. More details on the National ITS Architecture are available at https://local.iteris.com/arc-it/.

The FHWA published a Final Rule policy (FHWA Docket No. FHWA-99-5899) that requires all agencies using federal highway trust funds for ITS projects develop a regional or statewide architecture that is compliant with the National ITS Architecture. The FTA published a similar policy (FTA Docket No. FTA-99-6147) that applies to federal funding from the mass transit account of the highway trust fund. For more details on the Final Rule refer to https://ops.fhwa.dot.gov/its_arch_imp/archrule_final_1.htm.

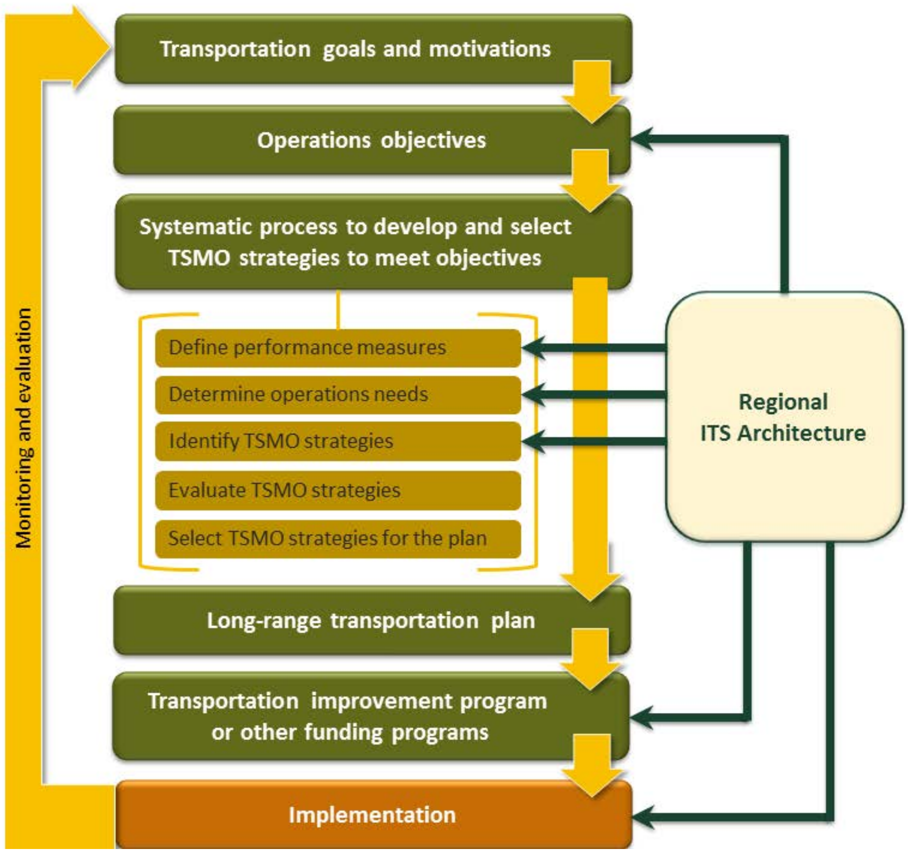
In Oregon, ITS architectures have been developed for the following regions (documentation at https://www.oregon.gov/ODOT/Maintenance/Pages/ITS-Operations.aspx):

- Oregon Statewide
- TransPort (Portland area)
- Salem-Keizer
- Central Willamette Valley
- Eugene-Springfield
- Rogue Valley
- Deschutes County

Exhibit 18-9 shows how a regional ITS architecture can provide support for an objectives-driven, performance-based approach to planning for operations. The regional ITS architecture helps answer important questions such as:

- What existing or planned TSMO strategies may be available to help achieve operations objectives?
- What stakeholders and collaborative relationships can be leveraged as part of the planning process?
- What data are available to monitor transportation system performance and track progress toward operations objectives?
- What parts of the architecture’s operational concepts, functional requirements, or other contents can be used to support project development?

Exhibit 18-9: Regional ITS Architecture Use in Planning for Operations



Source: *Applying a Regional ITS Architecture to Support Planning for Operations: A Primer*, FHWA

Systems Engineering

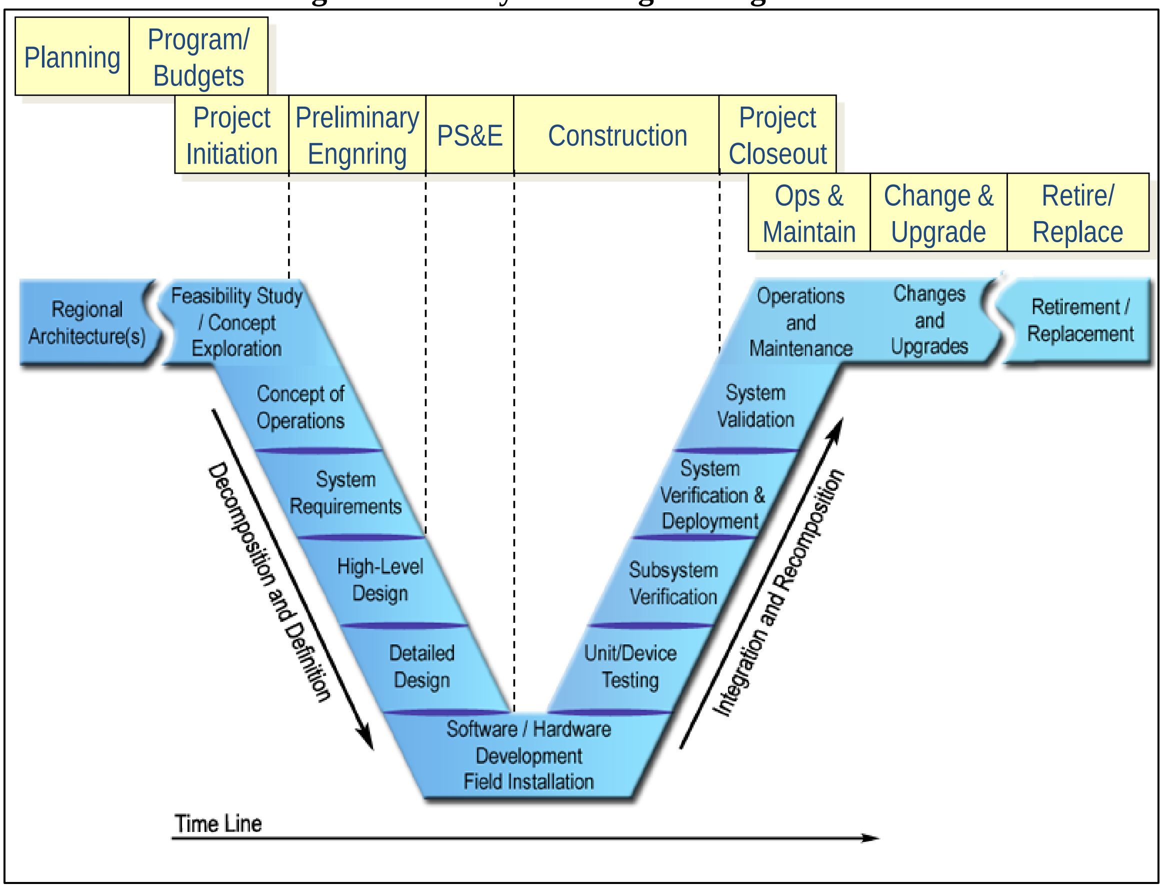
Systems engineering is an organized approach intended to improve the success rate of systems projects by clearly communicating user needs and providing a logical organization that ties all aspects of the implementation cycle to those user needs and requirements. The approach can be applied to any of the TSMO strategies related to systems that are described in this manual. Systems engineering analysis is required for all ITS projects using federal funds per the Final Rule described in the ITS Architecture section above. The Final Rule requires a systems engineering analysis that includes, at a minimum:

- Identification of portions of the regional ITS architecture being implemented (or if a regional ITS architecture does not exist, the applicable portions of the National ITS Architecture)
- Identification of participating agencies' roles and responsibilities
- Requirements definitions
- Analysis of alternative system configurations and technology options to meet requirements
- Procurement options

- Identification of applicable ITS standards and testing procedures
- Procedures and resources necessary for operations and management of the system

Although there are many ways to represent the systems engineering process, the winged "V" (or "Vee") model diagram shown in Exhibit 18-10 has been broadly adopted in the transportation industry. The left wing of the "V process shows the regional ITS architecture, feasibility studies, and concept exploration that support initial identification and planning for a project. Transportation planning fits within the left wing. The operations objectives and performance measures identified during the planning phases should be applied throughout the systems engineering process and actually validated once the project reaches the deployment phase in the right wing of the "V" diagram. This approach provides a systematic method to plan and design systems to achieve the desired operations objectives.

Exhibit 18-10: Planning within the Systems Engineering "V" Model



Source: *Systems Engineering Guidebook for ITS*, ver. 3.0, FHWA CA Division

ITS Systems Engineering and Architecture Compliance Checklist

The ODOT ITS Unit developed a systems engineering and architecture compliance checklist, which essentially forms a Systems Engineering Plan for an ITS project or a project with ITS/TSMO elements. The checklist can be used to define how a project will comply with federal requirements and identify which systems engineering tasks need to be completed as part of the project scope of work. This checklist is required for all federally funded ITS projects in Oregon but is also useful for ITS projects funded through other sources. The checklist is available at https://www.oregon.gov/ODOT/Maintenance/Pages/ITS-Operations.aspx.

18.3.6 Analysis Tools

This section describes the scoping and selection of TSMO planning-level analysis tools and methods, which include a full range of analytical level of detail from sketch models through simulation. See Chapter 2, Section 2.4 for additional information on planning tools.

There is a wide selection of tools and methods that can be used during the various stages of the TSMO planning process. The analysis tools are generally broken out into these categories:

- Sketch-planning tools
- Deterministic tools
- Traffic signal optimization tools
- Simulation tools

Sometimes classified as tools and methods, these items are also used as inputs to many of the before mentioned tools:

- Travel demand models
- Crash modification factors
- Archived operations data

These tools, methods, and inputs range from easy to use to very complex. Exhibit 18-11 lists basic advantages and challenges of each tool or method.

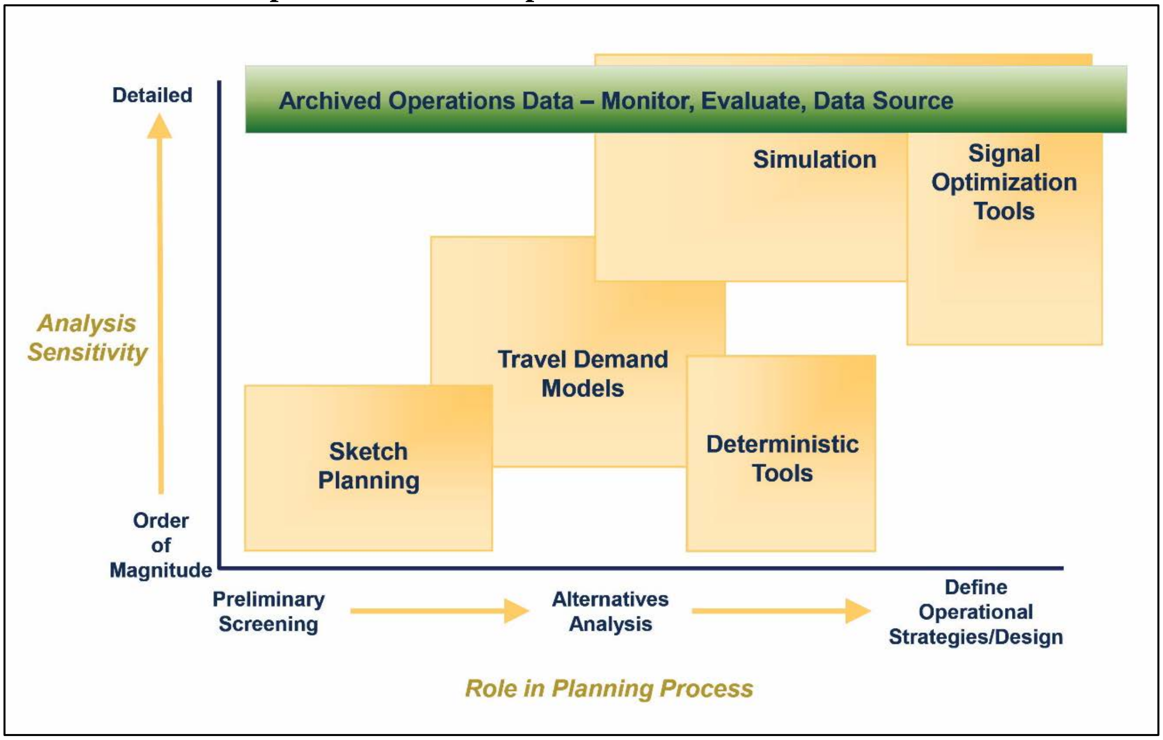
Exhibit 18-11: Advantages and Challenges of TSMO Analysis Tools/Methods

Tool/Method	Advantages	Challenges
Primary Tools and Methods		
Sketch-planning tools *Used to produce general order of magnitude estimates of impacts*	• Low cost • Fast analysis times • Limited data requirements • View of the "big picture" • Efficient initial screening	• Limited in scope, robustness, and presentation capabilities
Deterministic tools *Used to predict impacts based on inputs*	• Quickly predict impacts for an isolated area • Widely accepted	• Limited ability to analyze broader network impacts • Limited performance measures
Traffic signal optimization tools *Used to develop optimal signal phasing and timing plans*	• Effective tool for testing plans prior to field implementation • Proven operational benefits	• Calibration process can be time consuming
Simulation tools *Used to observe the effects of inputs in a modeled environment*	• Detailed results, particularly microsimulation • Dynamic analysis of incidents and real-time diversion patterns • Visual presentation opportunities	• Demanding data and computing requirements, particularly microsimulation • Research requirements may limit network size and number of analysis scenarios • Requires substantial experience working with models
Supplementary Tools and Methods		
Travel demand models	• Validated models available for most metro areas • Evaluation of the regional impacts • Consistent with current planning practices	• Limited ability to analyze operational strategies • Typically does not capture nonrecurring delay
Crash modification factors	• Low cost • Fast analysis times • Limited data requirements	• Quality of factors can be low • Factors not present for many countermeasures
Archived operations data	• Quick data collection • Current/up-to-date data • Provides detailed response to public officials based on real-world data	• Limited availability of quality data • Requires access to data/privacy concerns

Adapted from Table 2 in *Applying Analysis Tools in Planning for Operations*, FHWA

The detail and complexity of a tool can vary between quick and easy (sketch-planning) to time intensive and complex (simulation). Tools also have different uses depending on the stage of the planning process. Preliminary screening would typically involve sketch-planning tools while simulation would start during the alternatives analysis process and potentially continue through design. Exhibit 18-12 shows the comparison of tool capabilities as they relate to the TSMO planning process and their respective analysis sensitivity.

Exhibit 18-12: Comparison of Tool Capabilities



Source: *Applying Analysis Tools in Planning for Operations Participant Workbook,* FHWA Workshop Series

Throughout the planning process, archived operations data and crash modification factors/countermeasures may be used as inputs for a variety of tools. For example, historical vehicle volumes may be used to calibrate travel demand models or simulations while a crash modification factor might be used in a benefit/cost analysis.

There are many tools and methods that can be used to evaluate TSMO strategies throughout the planning process. This section describes some of these tools in more detail and Exhibit 18-13 provides an overview of what category applies to each tool or method and the level of effort to apply it regarding data needs, staffing, and time. See Section 2.4.2 for detailed descriptions of the High (H), Medium (M), and Low (L) rankings.

Some of the tools previously developed by FHWA for operational analysis have been phased out for newer models. Screening Analysis for ITS (SCRITS), Surface Transportation Efficiency Analysis Model (STEAM), and IMPACTS are no longer available online.

Exhibit 18-13: TSMO Analysis Tools/Methods

Tools/Methods	Sketch-Planning	Deterministic	Traffic Signal Optimization	Simulation	Input to Other Tools	Data Needs	Staffing	Time
	Category					Applications		
Tool for Operations Benefit Cost Analysis (TOPS-BC)	X					L	M	L
SHRP2 Analysis Tools	X					L	M	L
ITS Benefits/Cost Database and Before-After Studies	X				X	L	L	L
Mesoscopic/Dynamic Traffic Assignment				X		M	M	M
Travel Demand Model		X			X	M	M	M
Crash Modification Factors (CMFs)/Countermeasures					X	L	L	L
Regional Strategic Planning Model (RSPM)					X	H	H	H
Traffic Signal Optimization			X			M	M	M
Microscopic Simulation				X		H	H	H

Tool for Operations Benefit Cost Analysis (TOPS-BC)
(https://ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm)
TOPS-BC is a sketch-planning tool that was developed in parallel with the FHWA Operations Benefit/Cost Analysis Desk Reference. This spreadsheet-based tool has four key capabilities:

1. Allows users to look up the expected range of TSMO strategy impacts based on a database of observed impacts in other areas
2. Provides guidance and a selection tool for users to identify appropriate benefit/cost methods and tools based on the input needs of their analysis
3. Provides the ability to estimate life-cycle costs of a wide range of TSMO strategies
4. Allows for the estimation of benefits using a spreadsheet-based sketch-planning approach and the comparison with estimated strategy costs.

In addition to the four key capabilities, local weather station data can be used in evaluation of non-recurring events and to calibrate to local conditions. TOPS-BC can also be used to evaluate emissions for Congestion Mitigation and Air Quality (CMAQ) funds assuming that there is a local emissions model/tool that can also be used. The most common tool used for emissions modeling is MOVES, which was developed by the US EPA.

SHRP2 Analysis Tools

(https://www.fhwa.dot.gov/goshrp2/Solutions/Operations/List)
The SHRP2 analysis tools are a repository of different solutions designed to meet various challenges. These tools are the result of over 100 research projects that address various transportation challenges. The SHRP2 solutions are broken out into the following disciplines:

- Planning and Environment
- Safety
- Design
- Risk Management
- System Management and Operations
- Bridges
- Utilities and Railroads
- Pavement and Materials
- Construction

Under the discipline of system management and operations, the focus areas include capacity, reliability, and renewal. Some examples of solutions include advanced travel analysis tools for integrated travel demand modeling, freight demand modeling and data improvement, validation of urban freeway models, and incorporating travel-time reliability into the highway capacity manual.

Incorporating travel-time reliability into the highway capacity manual is one tool that is part of a suite of tools to help transportation planners and engineers improve monitoring and analysis of data to achieve more consistent, predictable highway travel. In order to implement the methodology of the freeway reliability analysis, a Java-based tool with a graphical user interface was created call FREEVAL-RL (FREeway EVALuation ReLiability).

The FREEVAL-RL tool analyzes freeway segments for both undersaturated and oversaturated conditions. For oversaturated conditions, demand, volume, and vehicle queuing are tracked over time and space. Using outputs from the FREEVAL-RL tool, reliability can be estimated over various scenarios.

Other Sketch-Planning Tools

Additional sketch-planning tools include:

- ITS Benefits/Cost Database (https://www.itskrs.its.dot.gov/its/itsbcllwebpage.nsf/KRHomePage)
    - This website-based tool developed by the US DOT provides a database of previous studies for numerous TSMO strategies. The user must sort through data to find similar benefits or costs to apply, which can be time consuming.

- Results from other before and after studies
  - Results from other studies with similar TSMO strategies or project elements can be useful in a quick evaluation of potential benefits and costs.

These methods are limited to available data and studies and may be more time intensive to sort through. However, these methods may be more cost-effective for smaller projects or for projects evaluating emerging TSMO strategies or TSMO strategies not available for analysis in other tools.

Mesoscopic/Dynamic Traffic Assignment

Mesoscopic/dynamic traffic assignment falls under the category of a simulation tool. This tool is one of the more complex tools and requires a higher cost and more staff training to use; however, it provides a higher level of resolution than the other tools discussed. Per Chapter 8 (Mesoscopic Analysis), a mesoscopic model is defined as:

> *A hybrid model that includes combinations or approximations of elements from both macroscopic and microscopic models. Mesoscopic models may include a routable network similar to a macroscopic model (with a supplementary origin-destination matrix), while also incorporating more detailed operational elements of the transportation network to better estimate travel time based on traffic operations similar to a microscopic model. Elements from either the macroscopic or microscopic models may be generalized or simplified.*

One piece of mesoscopic modeling is Dynamic Traffic Assignment (DTA). DTA considers traffic routes and travel times that can vary by time of day whereas the more traditional travel demand models use a static assignment of routes during a time interval. The advantage of DTA models is they come close to achieving the same detail that microsimulation models achieve while maintaining elements of macro-simulation models. DTA is a further level of effort and refinement of model assignment between the typical travel demand model and micro-simulation. Common DTA software tools used are DynusT and Dynameq.

More details on DTA including general concepts, scoping, and tool selection can be found in Chapter 8, Section 8.5.

Travel Demand Model

The Travel Demand Model is typically a system-level tool that is generally limited to the facility level. Details include basic characteristics such as number of lanes and speed limits. Travel demand models are used to compare scenarios or help screen alternatives by using origin and destination patterns, demand to capacity ratios, differences in percent volumes, and rough estimates of travel times. They are also used as input to other tools when design hour volumes are needed.

While travel demand models typically do not include the level of detail (e.g., intersection performance) or specific components/modules (e.g., intelligent transportation systems) to directly assess TSMO strategies, there may be methods for manipulating the travel demand model tool in an indirect manner that serves as a proxy for TSMO strategies. For example, the analyst could consider increasing the capacity of a corridor in order to emulate the potential corridor benefits related to improved access management or signal control system enhancements.

Additional information regarding TDM can be found in Chapter 17 (not yet written).

Crash Modification Factors (CMFs)/Countermeasures

Crash Modification Factors and countermeasures can be used as a simple tool on its own but more often than not, is used as an input to other more detailed tools. A CMF is a multiplicative factor, that when used in conjunction with a countermeasure, provides the long-term expected number of crashes. In a benefit/cost analysis that incorporates safety, there are two sources that can be used to estimate the impact of a particular countermeasure: the CMF Clearinghouse and the All Roads Transportation Safety (ARTS) program. If available, the list through the ARTS program should be used prior to other sources because ARTS was developed for Oregon through collaboration with ODOT, the League of Oregon Cities (LOC), and the Association of Oregon Counties (AOC). Funding for crash countermeasures is also available through the ARTS program.

Chapter 4 (Safety) provides additional information regarding crash analysis. In particular, Section 4.4 provides detail on predictive crash analysis with a thorough explanation of crash modification factors in Section 4.4.2.

Regional Strategic Planning Model (RSPM)

(https://www.oregon.gov/ODOT/Planning/Pages/Strategic-Assessment-Tools.aspx)
The Regional Strategic Planning Model (RSPM, formally known as GreenSTEP) is used for strategic planning preceding an RTP or TSP goal-setting process. As such, it can be helpful in setting a vision, as it quantifies the regional benefit of several TSMO strategies, against competing non-TSMO policy actions/investments. RSPM was initially developed for state and regional greenhouse gas emissions reduction planning and helped establish MPO emissions targets. It has one of the most detailed understandings of future vehicle types and fuels, per collaboration with sister state agencies Department of Environmental Quality (DEQ) and Department of Energy (DOE). RSPM has no network to shorten run-times, but uses demand to capacity relationships and congestion approach by functional class to evaluate the impact of various freeway and arterial ITS (ramp metering, incident response, signalization, and access management) and other speed smoothing policies. Other policies addressed include Transportation Options programs (e.g., workplace TDM and individualized marketing programs). Recent applications have used a broader set of transportation and land use outcomes such as household travel costs, walk and bike travel, and delays. Estimations are done at the household level for a metropolitan planning area or larger. RSPM is being implemented in Oregon MPOs, and typically reports at a region or jurisdiction level.

Chapter 7 includes more information about scenario planning assessment and RSPM.

Traffic Signal Optimization Tools

Traffic signal optimization tools are primarily used to develop optimal signal timings for corridors, networks, and individual intersections. These tools can incorporate items such as intersection capacity, cycle lengths, splits, and signal coordination and offset. The most common traffic signal optimization tool used in Oregon is Synchro.

Microscopic Simulation

Microscopic Simulation tools can simulate the individual movement of vehicles and pedestrians. These tools are typically complex and require the highest cost and staff training; however, they provide a high level of confidence. Two examples of microscopic simulation tools are VISSIM and Paramics.

VISSIM is a tool that involves microscopic traffic simulation for multimodal traffic and can handle congested conditions under different traffic scenarios. It is capable of handling dynamic route choice and realistic differences in driver behavior. VISSIM can analyze capacity, traffic control, signal systems and re-timing, and public transit. VISSIM can handle adaptive traffic control (such as SCATS). It has the capabilities to handle multimodal networks, including pedestrians, bicyclists, and transit. It can be linked to various emissions models as well.

Paramics is a tool that involves microscopic traffic simulation and can handle congested conditions under various traffic scenarios. Paramics can be applied on freeways, intersections, roundabouts, for ITS applications, public transportation, pedestrian modeling and environmental/emissions. Paramics can evaluate various ITS strategies, such as variable speed limits, high occupancy tolling, vehicle actuated signals, and incident management.

18.3.7 Incorporating TSMO in Planning Statements of Work

ODOT conducts many different types of planning activities: regional and local transportation system plans, corridor/facility plans, and topical or area specific refinement plans. Exhibit 18-14 lists the typical tasks performed under a planning work scope and identifies considerations for incorporating TSMO.

Exhibit 18-14: TSMO Considerations in Planning Work Scopes

Planning Tasks	TSMO Considerations
Stakeholder/Public Involvement	Broaden stakeholders to include internal and external operations staff on the project advisory committee. If a standing operations committee exists in the area, notify them of the planning process and seek their input at key points in the planning process.
Vision, Goals, and Objectives	TSMO is an element supporting the broader planning vision. Include a TSMO-related goal and supporting SMART objectives and performance measures.
Evaluation Criteria	Operational performance measures provide useful information on how well the existing transportation system is functioning. Carry forward performance measures for system efficiency, system reliability, and system options into the evaluation criteria.
Existing Plans, Policies, Regulations, and Standards	A number of regions along with the state of Oregon have completed ITS and/or TSMO plans and architectures. The OTP and OHP include TSMO policies. Incorporate these references when documenting supporting plans and policies.
Current Conditions, Deficiencies, and Transportation Needs	Capture ITS infrastructure and TSMO program activities such as TIM and TDM as part of the transportation system inventory. If available, existing ITS/TSMO plans are a resource for this information.
Solution Alternatives	The OHP 1G1 Policy requires ODOT to maintain highway performance and improve system efficiency and management before adding capacity. Include TSMO strategies as part of the solution alternatives. See Appendix18A for list of TSMO strategies.

18.4 Corridor Management

This section provides considerations and analytical procedures for incorporating TSMO into planning for corridor management. A corridor is typically considered a linear system of multimodal facilities where an existing roadway or transit facility serves as the spine. Some corridors may also include a broader travel shed with parallel facilities or connections to major activity centers or logical destinations. Corridor limits can range from a few miles long in urban areas to tens or hundreds of miles long for state or multi-state corridors. Corridor planning typically includes a combination of modes and the modal focus can vary by corridor (e.g. freight route, high capacity transit route, limited access highway).

TSMO strategies used for corridor management are grouped into four categories in this document:

- **Arterial Management** is the use of strategies on arterial-type facilities to improve the efficiency, safety, and capacity of the facility, without increasing its size.[22]Arterial management generally applies to roadways that have signalized intersections and carry a combination of vehicles (autos, transit, and freight), pedestrians, and bicyclists.
- **Freeway Management** is the management of freeway-type facilities for safety and mobility improvement. Mobility improvement addresses congestion (recurrent and non-recurrent) in response to prevailing and predicted traffic conditions. Freeway management generally applies to roadways that have uninterrupted flow and only carry vehicles (autos, transit, and freight).
- **Demand Management** is the dynamic management of travel demand to influence traveler behavior in real-time to achieve operational objectives.
- **Integrated Corridor Management (ICM)** is an approach to managing the transportation network that encourages multi-agency coordination and combines arterial and freeway strategies to balance and manage travel demand across networks (freeway, arterial, transit, and parking). ICM plays an important role during events such as incidents, planned special events, inclement weather, and through work zones.

The first three groups are all elements of Active Transportation and Demand Management (ATDM). FHWA defines ATDM as "the dynamic management, control, and influence of travel demand, traffic demand, and traffic flow on transportation facilities."[23] FHWA's definition of ATDM includes three components: 1) Active Traffic Management, 2) Active Demand Management, and 3) Active Parking Management. In this document the active traffic management element is divided into arterial and freeway management categories, and the demand management category encompasses both the active demand management and active parking management components.

Appendix 18A includes a more detailed list of TSMO strategies, benefits, cost magnitude, and implementation factors.

Exhibit 18-15 provides a list of corridor TSMO strategies to consider based on facility type and surrounding area. In some cases, there is a clear distinction between the strategies applied to an arterial versus a freeway. However, there are many strategies that may apply to both types of facilities, such as dynamic warning signs and variable speeds. The following subsections provide an overview of each of the four categories of corridor TSMO management as well as analysis considerations and procedures for evaluation as appropriate.

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[22] Oregon Transportation Planning Rule, Oregon Administrative Rule (OAR) 660-012-0005

[23] Definition according to FHWA Office of Operations https://www.its.dot.gov/index.htm

Exhibit 18-15: TSMO Strategies to consider based on Facility Type and Area

Corridor TSMO Strategies	Facility Type*					Area*		
	Interstate	Freeways & Expressways	Ramps	Principal Arterial	Minor Arterial & Major Collector	Urbanized	Small Urban	Rural
Arterial Management (Section 18.4.1)								
Traffic signal enhancements (updates, phasing, advanced)				●	●	●	●	●
Dynamic lane use			●	●	●	●	●	●
Queue jumps (ramp meter or signal)			●	●	●	●		
Transit signal priority			●	●	●	●	❍	
Truck signal priority			●	●	●	●	❍	●
Bicycle signals				●	●	●	●	●
Automated enforcement			●	●	●	●	●	●
Added capacity for critical movements (Section 10.3.2)			●	●	●	●	●	●
Improved traffic control schemes (Section 10.3.2)			●	●	●	●	●	●
Freeway Management (Section 18.4.2)								
Variable speed control	●	●		●		●	●	●
Automated speed enforcement	●	●	●	●	●	●	●	●
Dynamic lane use control	●	●		●		●	❍	
Dynamic lane reversal	●	●		●		●	❍	❍
Managed lanes (HOT/HOV)	●	●	❍	❍		❍	❍	
Adaptive ramp metering			●			❍		
Dynamic merge control	●	●				●	●	●
Dynamic warning	●	●	●	●	●	●	●	●
Hard shoulder running	●	●				●	●	❍
Dynamic re-routing	●	●	●	●	●	●	❍	●
Dynamic truck restrictions	●	●	●	●	●	●	●	●
Demand Management Strategies (Section 18.4.3)								
Corridor monitoring	●	●	●	●	●	●	●	●
Corridor specific traveler information	●	●	●	●	●	●	●	●
Active transit management	●	●	●	●	●	●	❍	❍
Active parking management						●	❍	
Congestion pricing	●	●		●		●		
Gamification	●	●	●	●	●	●	●	●
Shared-use mobility	●	●	●	●	●	●	❍	❍
Employer based transportation demand management	●	●	●	●	●	●	❍	❍
Neighborhood based transportation demand management	●	●	●	●	●	●	❍	❍
Integrated Corridor Management (Section 18.4.4)								
Corridor management strategies above	●	●	●	●	●	●	●	●
System Management (Section 18.5)	●	●	●	●	●	●	●	●
● Strategy applies to facility								

Corridor TSMO Strategies	Facility Type*					Area*		
	Interstate	Freeways & Expressways	Ramps	Principal Arterial	Minor Arterial & Major Collector	Urbanized	Small Urban	Rural
❍ Strategy MAY apply to facility								

* For facility type and area by highway and milepost, see:
https://www.oregon.gov/ODOT/Data/Documents/FC_NHS_State_Highway_List.pdf

18.4.1 Arterial Management

The arterial management strategies are part of a broader category of Active Traffic Management (ATM) strategies. Active Traffic Management (ATM) is "the ability to dynamically manage recurrent and non-recurrent congestion based on prevailing and predicted traffic conditions."[24] Additional information is available on FHWA's Active Traffic Management website.[25]

This document divides active traffic management into two categories: arterial management and freeway management. Arterial management focuses on facilities that have traffic signals, interrupted flow, and carry a combination of vehicles, pedestrians and bicyclists. On the other hand, freeway management focuses on facilities that mainly carry vehicles (a combination of autos, transit, and freight) and have limited access points. As shown in Exhibit 18-15, some of the freeway strategies can also apply to arterials, yet arterial strategies generally do not apply to freeways.

The arterial management strategies discussed in this section aim to improve the efficiency, safety, capacity of an arterial-type transportation facility without increasing its size.

This section focuses on seven types of arterial strategies:

- Traffic signal enhancements
- Dynamic lane use
- Queue jumps
- Transit signal priority
- Truck priority
- Bicycle signals
- Automated enforcement

Traffic Signal Enhancements

These strategies can be implemented by making improvements to traffic signal timing. This may include updating the base signal timings to accommodate multi-modal users, modifying the phasing to improve efficiency, or implementing advanced signal control

[24] FHWA Office of Operations, https://ops.fhwa.dot.gov/atdm/approaches/atm.htm
[25] FHWA website: https://ops.fhwa.dot.gov/atdm/approaches/atm.htm

strategies such as adaptive signal control. The strategies also include upgrading the existing signal system infrastructure to facilitate implementation of the operational improvements.

- Base Signal Timing – Reviewing and updating the basic signal timings, such as minimum and maximum green, walk, flashing don't walk, yellow and red clearance intervals and vehicle detector settings can improve the safety and efficiency of the intersection operation. It is not uncommon for the basic signal timings to remain unchanged from the first day a signal is turned on. It is good practice to review and update the base timings on a routine basis as standards for clearance intervals and detector settings may change.

- Traffic Signal Phasing – Modifying the traffic signal phasing, such as adding a protected left turn phase, converting a protected left turn phase to protected/permissive left turn phase or installing a right turn overlap can improve the safety and efficiency of the intersection operation. Depending on the traffic volumes, changes to the phase sequence (lagging a left turn phase) may improve the efficiency of an intersection. Changes to the traffic signal phasing may require minor equipment changes to the traffic signal indications.

- Advanced Features – Implementing advanced features of the traffic signal software, including phase re-service, dynamic phase length, or ped-friendly flashing yellow arrow (FYA) can improve the safety and efficiency of an intersection. Some of the signal timing parameters may work better in free (not coordinated) operation and others may work better in coordinated operation. The advanced features should be explored if there is a unique operating condition, and not implemented everywhere, since some of the features may work against others.

- Coordinated Timings – Coordinated signal timings require a group of signals to operate on a common cycle length. Coordinated signal timings are best used on corridors where the intersections are regularly, closely spaced (within one half mile), or where platoons of vehicles do not disperse too much from one signal to the next and where there is a predominate movement that needs to be progressed between multiple intersections. A well timed corridor (or group of signals) can serve traffic efficiently using Time-of-Day coordination without the need for advanced signal timing. To get the most effective operation, the timings must meet the operational goals of the corridor (favor main street flow, balance delays on all approaches, promote transit, etc.). Typically, signals operate coordinated timing plans based on the time of day for set time periods (am peak, midday and pm peak), without much attention paid to the weekend timing plans. A simple way to improve the operation of a corridor is to evaluate the weekend operations of the signals and implement weekend timings if needed. A common rule of thumb is for agencies to update the coordinated timings every three to five years, however using performance measurement data as a trigger allows agencies to use their resources more efficiently. Doing this will require the agency to monitor operations on a more on-going basis in order to see trends in the performance measures that need to be addressed.

- Event/Incident Timings – Event and incident timings are special timing plans that are developed to serve traffic associated with an event (sporting event/concert or adverse weather) or an incident (crash, either on the arterial being controlled or on parallel facility). The timings are developed based on assumptions from previous events and can include operating special coordinated timing plans or operating one or more intersections in free mode. Typically, the event/incident timings are manually turned on and off using a command from the central signal system, but they can also be enabled using a trigger, like volumes from a system detector or weather sensor.

- Traffic Responsive Signal Timing – Traffic Responsive (TR) signal timing operates similar to traditional coordinated timings, but instead of using the time of day, it uses volume and occupancy as the trigger to change the previously developed timing plans. For example, under traditional time-of-day operation, the p.m. peak plan starts at 4:00 p.m., but under traffic responsive, it may start at 3:30 p.m. (ex. school or work shift ends) or not at all (ex. holiday). It is best used on corridors with predictable and distinct traffic patterns (ex. heavy inbound in the a.m. and heavy outbound in the p.m.) where adjusting the start times of the existing plans is needed. Traffic responsive plan selection normally occurs in a field master or a central signal system. It uses the detection data to calculate the most appropriate timing plan and then sends a command to the local signal controllers to tell them which plan to operate. TR requires additional system detectors to be installed along the corridor and can be time consuming and complex to set up and monitor.

- Traffic Adaptive Signal Control – Traffic Adaptive signal control uses special algorithms to optimize the signal timings along a corridor. Typical adaptive systems adjust the cycle, split, and offsets every cycle to match the fluctuation in traffic. Adaptive systems show benefit at locations where the traffic conditions are unpredictable and/or volumes are high, as adaptive systems can delay the onset of oversaturation and can recover more quickly from a saturated condition. The adaptive algorithms are typically calculated in a central system and the cycle, splits and offsets for each intersection are commanded from the central system. However, some systems provide the processing power at a field "master" location along the corridor. Adaptive systems require robust vehicle detection and reliable communications between the field controllers and the master/central system. Each corridor/group of signals should be evaluated before deploying an adaptive signal system to ensure it is the best operational/management choice.

- Traffic Signal Controllers – In the state of Oregon, agencies operate two types of traffic signal controllers (with various firmware), including the Model 170 and the Model 2070. In recent years, agencies have been replacing the Model 170 controllers with Model 2070 controllers, as they provide additional operational features, extra computing power and more data storage. ODOT has recently decided to install ATC controllers at some intersections and is expected to make the ATC controller a standard in the near future. These new controllers provide even more computing power, collect more performance data, and are compatible with future connected vehicle technology. Upgrading the traffic signal controllers to the current standard 2070 or to the ATC will improve the intersection operation because of the additional operating features and computing power available.

- Central Signal System – The central signal system manages the local traffic signal timing databases, provides remote access to the local controllers, and collects/disseminates performance measurement data. A central system allows an agency to monitor the operations of their traffic signals and make adjustments if necessary, such as during an incident. Multiple agencies within a region can benefit by sharing a single central system.

- Communications – Communications between traffic signals provides the ability for the signals to talk to each other and is most beneficial for keeping the time clocks synchronized. Communications between the traffic signals and a central system allows an agency to remotely manage and monitor traffic signal operations. Reliable communications is very important when operating traffic responsive or adaptive operations, as the computing is done by the central system or by a field master with the commands being sent in real-time from the central or master location to the local controller.

- Detection – A traffic signal system needs robust detection in order to operate in the most efficient manner. Detection is necessary for all signal operations, except fixed-time control, yet it is the one thing that is often not maintained as well as it should be. Traditional vehicle detection uses inductive loops cut into the pavement. They are a very reliable form of detection, but they are susceptible to damage by poor pavement conditions or accidentally being cut. Once they are installed, there is no flexibility to move them to a different location and it is sometimes challenging to detect motorcycles and bicycles with them. Video detection is a non-intrusive form of detection as it uses cameras mounted above the pavement. Video detection can detect vehicles and bicycles and allow agencies to adjust the zones if needed. This form of detection is susceptible to false calls due to fog and shadows and can sometimes miss vehicles because of occlusion. It also has a limited range of how far it can see in advance of the intersection. Video detection requires more frequent maintenance than loop detection. Radar detection is a non-intrusive form of detection as it uses a radar detector mounted above the pavement. Radar detection can detect vehicles and bicycles and allow agencies to adjust the zones if needed. This form of detection is not susceptible to false calls due to fog and shadows, but requires different units for advance and stop bar detection. The choice of type of detection at an intersection should be evaluated considering the physical condition of the site and the operational objectives, with the most appropriate type installed.

- Closed Circuit Television (CCTV) Cameras – CCTV cameras, in conjunction with a central traffic signal system, help an agency assess operational issues quickly from a remote location. The central signal system tells the agency what the traffic signals are doing and a CCTV camera allows the agency to see what may be causing a problem (crash, power outage, etc.). CCTV cameras help the agency to monitor signal operations if timings are changed. For example, if additional green time is added to a left turn phase, the agency can watch how the other phases operate with less green time. CCTV cameras should be installed at most major intersections to allow the agency to view traffic operations along the major corridors. CCTV cameras are also used for identifying incidents and dispatching responders.

Dynamic Lane Use

Modifying intersection approach lane uses may be done with dynamic lane use signing. For example, an intersection may have two approach lanes (left/through and through/right), but during the p.m. peak, the left turn movement is restricted. The restriction can be conveyed to the driver by using a blank-out sign that uses the time of day or a volume threshold to turn on/off. The appropriate lane assignments should be based on a traffic analysis to ensure that the intersection works well throughout the various peak periods. This type of operation requires additional signing to be installed on the signal mast arm and in advance of the intersection along with special logic programmed in the controller.

Queue Jumps

A queue jump is a special phase for an intersection approach that is only used under certain conditions. One common application of a queue jump is for transit, where, if a bus is detected at a certain location, the traffic signal will provide a special indication for the bus so it can proceed through the intersection ahead of the adjacent through traffic. A queue jump can also be used for bicycle traffic. It is an effective solution if there is an existing source of delay at the intersection. A queue jump requires that the bus has a dedicated lane and specific detection. It can work during Free and Coordinated operation, however queue jumps may not be beneficial where there are high volumes of right turning vehicles. A queue jump may also be employed at a ramp meter where transit or other high occupancy vehicles are provided a special lane to avoid the queue on the ramp. This may require additional right-of-way to implement.

Transit Signal Priority

Transit signal priority (TSP) provides additional green time to the approaches at an intersection that serve buses. TSP can be implemented on any corridor that has transit service, with more benefit going to corridors with higher number of buses and corridors that are not over capacity. Most TSP systems require that the bus be equipped with an emitter and the controller cabinet be equipped with a detector unit. This can be done using infrared, wireless communication (such as Wi-Fi) and GPS, or connected vehicle technology. Once a bus is detected, the traffic signal will determine if and how much extra time the bus approach can be given. The time can either be a green extension (hold bus phase green longer) or an early green (bring up bus phase earlier) depending on which phase of the cycle the traffic signal is when the priority request is detected. Typically, TSP provides an additional 2-10 seconds for a bus approach, which is taken from other approaches at the intersection.

Truck Priority

Truck priority is similar to transit signal priority in that it provides additional green time to an approach where a heavy vehicle is detected. The additional green time is only provided as green extension, since the goal of truck priority is to minimize the stops (and subsequent start-ups) for heavy vehicles. Truck priority works well on corridors with a high percentage of heavy vehicles, speeds above 35 mph, on roads with no major curves, and where the traffic signals operate in free mode. The traffic signal needs to receive an input that indicates the presence and speed of a heavy vehicle. This can be accomplished via inductive loop detectors in the pavement or connected vehicle technology on the truck. Based on the data, the traffic signal will provide additional green time when a heavy vehicle is detected and it does not have enough time to enter the intersection before it turns yellow. Typically, truck priority provides an additional 5-10 seconds to the truck approach.

Bicycle Signals

Most traffic signals are capable of providing priority to multi-modal traffic including bicycles, buses, and heavy vehicles. For example, bicycles can be detected using specific detectors and the bicycle rider can be shown a special bicycle phase, separate from cars.

Automated Enforcement

Automated red light enforcement and automated speed enforcement are two somewhat controversial techniques to improve safety. Both have been shown to be effective in improving compliance with red lights or speed limits. In the correct location, where there is a history of crashes related to red-light running or speed, the technologies can be effective at reducing the crashes related to poor driver behavior. The use of these devices should be carefully weighed and used only where the results would yield a reduction in crashes. These technologies require statutory authority to implement and participation from law enforcement.

18.4.2 Freeway Management

With a focus on trip reliability, freeway management works to maximize the efficiency and effectiveness of facilities by using automation to quickly respond to conditions to influence travel behavior with respect to lane and facility choices. This section describes freeway management strategies and how they may be applied to facilities in Oregon.

Variable Speed Control

Variable speed control (aka variable speed limits, variable advisory speeds, speed harmonization, or dynamic speed limits) is a management strategy to actively manage the posted or advisory speeds at a location or throughout a corridor. On multilane facilities, speeds can also be managed for individual lanes. The speeds are adjusted in real-time to respond to roadway traffic and weather conditions and can be regulatory speed limits or advisory speeds. Variable speed control can be used virtually anywhere including rural or urban settings and can be applied to different modes of travel (autos, bikes, buses, trucks).

The common goals and objectives of agencies considering the development and deployment of variable speed control is improved safety, increased mobility, and reduced environmental impacts. Speed harmonization is a term that is used synonymously with variable speeds in urban areas with recurring congestion. Speed harmonization refers to bringing everyone's speed into "harmony" or reducing the variability between the high and low speeds. Reducing this variability improves safety by reducing starting and stopping of congested traffic and the potential number of rear end collisions. By improving safety and harmonizing speed, mobility in a corridor can be increased through higher average speeds and increased capacity. With less congestion and less starting and stopping, environmental impacts can also be reduced.

Variable speed control is typically applied to interstates, freeways, expressways, or principal arterial highways and is most commonly used to address congestion, inclement weather, or construction. Congestion applications should be considered for corridors where there is frequent queuing at bottleneck locations or a history of rear-end crashes. While congestion applications are more commonly applied to urban corridors, they can also be applied to rural corridors to address seasonal congestion. Inclement weather applications should be considered for corridors with a history of crash issues related to inclement weather (e.g. ice, snow, rain, high winds). Work zone applications can be considered for any work zone, particularly for larger projects with a longer duration where work is being done in close proximity of travel lanes. For ODOT facilities, coordinate with the ITS Unit, who developed an *Oregon Statewide Variable Speed System Concept of Operations* and can help with planning.

Input from the State Traffic Engineer, law enforcement, local jurisdictions, and elected officials should be considered in the planning process.

Automated Speed Enforcement

This strategy requires statutory authority to use and participation of law enforcement. The strategy may involve fixed mounted cameras or cameras that can be stationed at different places along the roadway. The cameras are often installed at locations where there have been a history of speeding violations and/or crashes associated with speeding. The camera records violators and issues citations that are reviewed by law enforcement officials. While this strategy can be applied on any facility, it has been found particularly effective to support variable speed control and in work zones.

Dynamic Lane Use Control

Lane use control is the dynamic control of lanes typically through opening or closing them as conditions warrant. Lanes will typically be closed due to incidents or work zones with the goal of safely merging traffic into adjoining lanes. By closing lanes due to an incident or work zone, the goal is to reduce rear end and secondary crashes. Dynamic lane control is typically applied to urban interstates, freeways, expressways, or principal arterials.

Dynamic Lane Reversal

This strategy dynamically reverses the travel direction for one or more lanes to better allocate capacity based on traffic demand. This strategy should only be considered where lane reversal can be done safely, such as a lane separated by barrier on a high-speed facility or a clearly marked lane on a low-speed facility. Dynamic lane reversal may also be considered for facilities adjacent to or near event centers where there is a large imbalance in travel directions, such as a large ingress pre-event and a large egress post-event and minimal traffic in the opposing direction.

Managed Lanes (HOT/HOV)

Managed lanes refer to travel lanes dedicated to a particular use, most commonly to high occupancy vehicle (HOV), high occupancy toll (HOT), and electronic toll lanes. HOV lanes require passenger vehicles to have a minimum number of occupants in order to use a specific lane, while HOT lanes allow single occupant vehicles to pay a toll in order to drive in a specific lane, while HOVs travel free or at a discount. Electronic toll lanes may require all vehicles using the lane to pay a toll. The pricing of HOT lanes and electronic toll lanes may vary depending on the demand (higher price when demand is higher).

HOV and HOT lanes both improve the air quality by reducing the congestion on a facility. HOT lanes have actually proven to be more efficient than traditional HOV lanes because more vehicles are able to use the reserved lane, while continuing to encourage drivers to use transit or carpool. HOT lanes produce revenue that can be used to supplement the cost of construction, maintenance and enforcement.

Adaptive Ramp Metering

Adaptive ramp metering is the dynamic turn on, turn off, and adjustment of ramp metering rates that respond to real-time traffic conditions. Ramp metering uses signals at ramps to control the rate at which vehicles are allowed to enter the facility (typically an urban interstate, freeway, or expressway). Adaptive ramp metering takes into account current roadway conditions and varies the metering rate depending on those conditions. Other features of adaptive ramp metering may include bottleneck identification, incident detection, and integration into neighboring traffic signals.

The objective of adaptive ramp metering is to prevent a high-speed, low-access network or corridor from being inundated with vehicles and causing a heavily congested network. An adaptive ramp metering system can assist in keeping all vehicles moving, by regulating the number and frequency of vehicles entering a facility.

Considerations for adaptive ramp metering include:

- Corridor wide implementation
- Density of detection
- Length of ramps

In order for adaptive ramp metering to be successful, all entrances to a corridor should be regulated by a ramp meter signal. If some entrances are not controlled by ramp meters, users may try to use those entrances instead and the system would have a harder time regulating the density of vehicles on the facility.

Having reliable detection throughout the corridor is necessary for the successful deployment of adaptive ramp metering. At a minimum, detection should be present near each on-ramp with additional detection desired near off-ramps and in sections between ramps. Detection is also needed at the ramp meters themselves and further up the ramp.

The length of a ramp can also dictate how fast or slow a ramp metering rate might be. If a ramp is not sufficiently long and a queue builds up, there is a potential for the queue to spill onto nearby local streets. If a ramp is long and the ramp metering rate is very slow, it can take a vehicle a significant amount of time to enter the facility. Balancing these two items can be a challenge.

Although dynamic ramp metering has been implemented in several corridors in Oregon, it has been controversial with the public. Implementation of this strategy needs to include a public education component to facilitate understanding of its benefits and acceptance.

Dynamic Merge Control

Dynamic merge control is also known as dynamic lane merge or dynamic early merge. Using a dynamic message sign, information on an upcoming merge and expected behavior can be displayed during congestion conditions. Dynamic merge typically closes an upstream lane that neighbors a downstream merge point. This can improve the speed in which the downstream traffic is able to merge while maintaining a higher vehicle throughout.

Typical installations are in places where there is recurrent congestion and significant merging vehicles, particularly for urban interstates, freeways, or expressways. The mainline should have sufficient capacity upstream of the merge point and may be better suited for locations where peak periods of the mainline and merging roadway are at different times.

Dynamic Warning

Dynamic warning signs notify drivers of a specific condition ahead based on real-time traffic conditions. Dynamic queue warning automatically notifies drivers of a queue of stopped or slowed vehicles ahead. Additional information such as distance to the queue and queuing lane(s) is desirable.

The objectives of dynamic queue warning are to reduce rear-end crashes and smooth traffic flow. By notifying drivers of slowed or stopped vehicles ahead, drivers will be less likely to be surprised by the end of a queue. In addition, if a queue is caused by a crash, secondary crashes can also be reduced. Queues are determined by comparing the speed, volume, and occupancy from one detection location to another.

Dynamic queue warnings can be used in spot locations or throughout a corridor. A spot location installation may be applicable where there is recurrent queuing or throughout a corridor where recurrent congestion occurs at multiple locations.

Dynamic warning signs may also warn drivers of adverse pavement conditions based on weather sensors or about wildlife close to the roadway based on animals in the detection zone. The signs would advise drivers of the condition and recommend an action, such as a slower speed. Dynamic warning signs may be applicable on both freeways and arterials.

Hard Shoulder Running

Hard shoulder running, also known as dynamic shoulder lanes, is the use of shoulders as a travel lane or lanes. To be considered an "active" traffic management option, this strategy needs to be implemented, when conditions warrant, with the use of real-time information. Hard shoulder running can be set up for all travelers or be for special purpose only (e.g. transit only). The goal and objective of hard shoulder running is to increase capacity, improve speeds, and improve volume of a segment when conditions warrant.

If the hard shoulder is on the right side, corridors with a higher number of ingresses and egresses may not be a good candidate for hard shoulder running unless ramp tapers can provide smooth merging operations. Hard shoulder running also requires a sufficiently wide shoulder to adequately function as a lane of traffic.

Dynamic hard shoulder running is often implemented with the use of variable speed and lane use control. The lane use control signs over the shoulder provide frequent real-time reminders of the status of the hard shoulder (open or closed). The variable speed displays can reinforce any reduced speeds needed in the corridor, particularly if the shoulder lane requires a lower speed. Like with lane use control, a typical distance between over lane signs is generally in the half-mile range in the U.S.

Currently, an interpretation of Oregon statutes has determined that hard shoulder running is not legal and would require enabling legislation to apply it. For more information on use of freeway shoulders see Use of Freeway Shoulders for Travel — Guide for Planning, Evaluating, and Designing Part-Time Shoulder Use as a Traffic Management Strategy, FHWA, February, 2016.

Dynamic Re-Routing

This strategy provides alternate route information to travelers in response to increasing congestion on a corridor at bottlenecks or due to events such as incidents (on the corridor or a parallel facility). This is an emerging strategy that will likely advance further as connected vehicles advance with broadcast traveler information and dynamic mapping features. In the meantime, traveler information systems can be used to provide dynamic re-routing information that travelers can check pre-trip or passengers can check en-route.

Dynamic Truck Restrictions

This strategy limits trucks to certain ramps, lanes, or routes based on traffic demand so that at least one lane of traffic is available exclusively for passenger traffic. The goal of this strategy is to allow passenger traffic to flow more freely without having to brake or slow down for less agile truck traffic. In turn this helps improve safety, support uniform speed, and improve traffic flow. Dynamic truck restrictions should be considered for highways with high truck volumes and major arterials and collectors that serve both freight and passenger traffic. This strategy requires enabling legislation as well as political support and support from the freight community.

18.4.3 Demand Management

Demand Management strategies dynamically manage travel demand to influence traveler behavior in real-time to achieve operational objectives such as preventing or delaying bottleneck conditions, improving safety, promoting sustainable travel modes, reducing emissions, and maximizing system efficiency. Specific demand management strategies and how they may be applied to facilities within Oregon are discussed herein. Additional information on Demand Management strategies can be found on FHWA's websites for Active Demand Management and Active Parking Management.

Corridor Monitoring

Continuous multimodal monitoring of corridors is a fundamental requirement for deploying other multimodal strategies because it provides a current snapshot of transportation conditions and can be used with archived data and predictive methods to maintain or achieve system performance. While monitoring is often done at Traffic Operations Centers for larger agencies like ODOT, it can also be done from single workstations at smaller agencies or at ODOT district or maintenance offices. The most common forms of monitoring include:

- Camera monitoring systems provide a visual means for observing traffic operations and identifying unplanned events. For interstates, freeways, and expressways, cameras are often installed at major interchanges, at regularly spaced intervals in urbanized areas, or at known trouble spots (e.g. winter conditions, geometric curvature). For arterials and collectors, cameras are often installed at traffic signals due to the availability of power, communications, and available mounting locations. When additional coverage is needed in urbanized areas, street light poles or separate camera poles are also used.
- Detection systems (e.g. radar, video, inductive loops, Bluetooth) collect a variety of data such as volume, speed, occupancy (vehicle density), and travel times. Data collected by the detection system(s) is used to produce performance measurement reports. Detection systems should be considered for all facilities. Extensive coverage is typically needed in urbanized areas. Pedestrian and bicycle specific detection should be considered in urbanized and small urban areas.
- Transit Operations Data can be used to inform system operators about transit ridership, service routes, service frequency, current transit vehicle availability, and other data to improve the efficiency of the system. This type of data may be especially important to coordinate integrated corridor management when transit is brought into the equation.

- Third party data (e.g. INRIX, Waze) is also a good source of information for monitoring corridors. This type of data is often captured by tracking mobile phones or from crowd-sourced information.
- Automated system performance or alerts should be used and considered when acquiring new transportation management systems. For example, central signal systems can provide alerts when traffic signals go into flash or a transit management system can provide alerts when a bus route is running behind schedule.
- Predictive algorithms can be developed using archived data to generate corridor travel forecasts based on real-time data.

Corridor Specific Traveler Information

Although providing traveler information is often a system wide effort (see Section 18.5), traveler information can also be tailored to specific corridors. This is done by providing travelers with existing or predictive travel times for parallel corridors through roadside dissemination (e.g. dynamic message signs) or broadcast through other systems (e.g. mobile apps, multimodal trip planners, websites). This can help travelers decide which travel route and mode to take. For example, if both a parallel freeway and arterial are congested, the parallel bus rapid transit or light rail line may be a much faster option.

Active Transit Management

Several strategies are available for actively managing demand for transit services:

- Dynamic fare reduction can be used to reduce the fare for the transit system in a particular corridor as congestion or delay increases to encourage travelers to select transit.
- Dynamic transit capacity assignment involves reorganizing schedules or reassigning assets (e.g. buses) based on real-time and anticipated demand patterns on a particular corridor.
- On-demand transit allows travelers to make real-time requests for transit services with flexible routes and schedules.
- Transfer connection protection works to improve the reliability of transfers between a high frequency transit service (e.g. light rail) to a low frequency transit service (e.g. bus). For example, a bus departure at a transfer point may be delayed to allow passengers to make the connection from a light rail train that is running late.

Active Parking Management

Active parking management involves actively optimizing performance and utilizing parking facilities to affect travel by influencing trip timing choices, mode choice, and parking facility choice at trip ends. Active parking management strategies include:

- Dynamic overflow transit parking uses overflow parking facilities (e.g. large retail parking lots) near transit stations or park-and-ride facilities when existing parking facilities are at or near capacity. Agreements are often needed with other entities for this strategy. This strategy helps encourage transit use on corridors over automobiles.

- Dynamic parking reservation allows travelers to reserve a parking space at their destination facility on demand to ensure availability. In a corridor context, the availability of parking at a traveler's final destination may influence them to travel by automobile (alone or with other occupants) or the availability of parking at a popular transit park-and-ride near the beginning or mid-point of their trip may encourage them to take transit along the corridor instead.
- Dynamic wayfinding provides real-time parking information about space availability and location to optimize the use of parking facilities and minimize the time spent searching for parking. This strategy helps travelers choose which corridor to use.
- Dynamically priced parking uses variable parking fees based on demand and availability to influence trip timing choice and parking facility choice in an effort to balance parking supply and demand. This strategy has an impact on mode choice, which corridors travelers select, and when they travel.

These strategies are typically applied in urbanized or small urban areas but can also be used in rural areas where there is high parking demand at special event facilities such as fairgrounds or amphitheaters.

Congestion Pricing

Although not currently used in Oregon, congestion pricing is a strategy that can be used to manage demand on congested facilities by time of day or day of week. For corridors, congestion pricing is typically applied to the entire corridor, a segment of the corridor, or by certain lane(s) within the corridor. The use of variable pricing by lane, segment, time of day, or day of week influences travel demand by encouraging travelers to consider alternate corridors or travel modes during peak demand periods. Pricing can be pre-set by time of day or can be updated dynamically based on current travel conditions. In the US, congestion pricing is typically used on interstates, freeways, or expressways in urbanized areas. Internationally, many cities have designated a "cordon" around the central business district that charge for the entry of private vehicles on a time-of-day basis. Often, variable pricing is used for specific lanes during peak periods so that traffic in those lanes continues to flow for high occupancy vehicles, transit, emergency services, and those willing to pay the higher prices. In other parts of the world, such as downtown London, congestion pricing is also extended to arterials and collectors in urbanized areas. For more information on congestion pricing, see https://ops.fhwa.dot.gov/congestionpricing/.

Caveat: The use of congestion pricing in Oregon requires legal authority and integration with ODOT's road user charging initiatives. Also, it typically requires political and public support.

Gamification

There are numerous applications (apps) that travelers can use to earn points or even monetary rewards for delaying travel or using a route that avoids peak congested areas.

This gamification process manages demand by rewarding travelers to use routes and travel times to make the transportation system as a whole more efficient.

Shared-Use Mobility

Shared-use mobility includes any transportation services that are shared among users such as traditional public transit, ridesharing, carsharing, ridesourcing, or bikesharing. Shared-use mobility services can be provided by public agencies, private entities, or through public-private partnerships. Although typically a broader system wide transportation demand management effort (see Section 18.5), shared-use mobility can also be applied to corridors. Ridesharing services can be targeted to provide carpool or vanpool options along particular corridors (typically interstates, freeways, or expressways but also for principal arterials) to provide high occupancy travel between outlying areas of a city to employment centers or between urban areas (e.g. service on I-5 between Wilsonville and Salem). In urbanized areas, shared-use mobility can be achieved on arterial and collector corridors by providing travel options such as bikesharing or parking spaces for carsharing. Visit Drive Less Connect to find links to many ride matching services currently available in Oregon.

Employer Based Transportation Demand Management

Although typically a broader system wide transportation demand management effort (see Section 18.5), employers can help influence travel demand on corridors by:

- Adjusting shift times to start and end during non-peak periods of the adjacent corridor
- Providing incentives to use modes such as transit, bike, or walking
- Providing shuttle services to provide employee transportation between the nearest transit center and the employment center

These strategies are often used in urbanized areas but can also be applied in rural areas. For example, when a large employment center is located at an interstate interchange, adjustments to shift time may reduce delay for employees and travelers at the nearby interchange.

Neighborhood Based Transportation Demand Management

Another TDM strategy may target specific neighborhoods with incentives to travel via carpools, car-shares, walking, biking, or other non-single occupancy vehicle modes.

18.4.4 Integrated Corridor Management

The vision of Integrated Corridor Management (ICM) is to optimize the movement of people and goods within the corridor, balancing travel demand across all networks. ICM requires proactive management and collaboration between partner agencies, allowing for real-time operational decisions that benefit the corridor as a whole. ICM strategies focus on balancing travel demand across networks (freeway, arterial, transit, and parking) and providing multi-agency management of events such as incidents, special events, inclement weather, and work zones[26].

The ICM approach is based on three key concepts:

1. Corridor-level focus on operations
2. Agency integration
3. Active management of corridor assets and facilities

The first concept is a corridor-level focus on operations. As described earlier in Section 18.4, a corridor is a system of multimodal facilities that link travelers to a variety of destinations and services. A corridor also includes cross-network connections that allow travelers to connect to other corridors. ICM focuses on optimizing operations within the corridor to balance travel demand as much as possible.

Integration is the second key concept of ICM and includes three levels: institutional, operational, and technical. The overarching theme of integration is sharing information and infrastructure between agencies. The path to full integration can progress in steps. Initial steps may be sharing data and information with other agencies, and eventually pave the way to sharing full communication infrastructure and central system critical to managing the transportation system.

- Institutional integration involves collaboration between agencies within and across corridor boundaries and is necessary for successful implementation of ICM. The collaboration efforts might include sharing responsibilities and traffic operation functions, dissemination of traveler information, or sharing analysis information.

- Operational integration involves implementing multi-agency management strategies across the corridor. The multi-agency management strategies often require real-time information sharing to maximize corridor capacity. For operational integration to work smoothly, there are three key factors that need to be considered:

    - Assets – all of the transportation facilities and capabilities along the corridor
    - Availability – whether or not the assets are available
    - Scale of Response – whether the response needs to be conservative, medium, or aggressive

- Technical integration provides the means, such as communication links and system interfaces for agencies to collaborate and see the impact of operational decisions in real-time.

[26] Note that ODOT's Mobility Procedures Manual (April 2015) provides detailed information about coordinating with the freight industry for a variety of corridor work zone conditions.

Active management of the corridor assets and facilities is the third concept of ICM. With active management, an action is implemented, the results are monitored and assessed, then additional actions are evaluated and recommended, and (if necessary) another action is implemented. This active management cycle is continuous. This process can be fully automated or developed to include human input at key decision points.

Once all of these concepts are adopted and in place, corridor management can be optimized during planned and unplanned events. To understand how all these pieces might come together, take an example of a major freeway blocking event. With this scenario ICM could be used to inform drivers via variable message signs or personal devices to shift to a different route. Active traffic management strategies can be implemented or modified and ramp metering rates can be adjusted to facilitate traffic movement to avoid the incident. ICM could be used to help inform emergency responders how best to reach the scene, as well as adjusting signal timing on arterials handling an unexpected spike in traffic. If the event is severe enough, drivers can even be advised to use transit, and transit partners can increase transit service temporarily.

18.4.5 Analysis Procedures

This section provides analysis procedures for evaluating TSMO strategies at the corridor level using:

- Tool for Operations Benefit Cost Analysis (TOPS-BC)
- Crash Modification Factors (CMFs) – also see Chapter 4 in APM Version 2
- Dynamic Traffic Assignment (DTA)

Each tool includes discussion on steps, input parameters and settings, output, results interpretation and reporting, sensitivities, and caveats and cautions.

In addition to the tools discussed in depth in this chapter, there are several additional analysis tools that can be used to evaluate TSMO strategies. Synchro and SimTraffic are most appropriate for optimizing traffic signals. VISSIM and Paramics are more powerful microsimulation tools that can be used to evaluate many types of TSMO strategies including but not limited to adaptive signal systems, ramp meters, transit signal priority, variable speed limits, and hard shoulder running. Chapter 8 of the APM Version 1 provides information on how to use these tools.

Tool for Operations Benefit Cost Analysis

The Tool for Operations Benefit Cost Analysis (TOPS-BC) was created by the FHWA Office of Operations as a sketch-planning analysis tool for TSMO related strategies. It is meant to provide a preliminary screening and initial prioritization of TSMO strategies and replaces the ITS Deployment Analysis System (IDAS). As described in Section 18.3 the TOPS-BC tool provides four key functions:

1. Allows users to look up the expected range of TSMO strategy impacts based on a database of observed impacts in other areas nationally and internationally

2. Provides guidance and a selection tool for users to identify appropriate benefit/cost methods and tools based on the input needs of their analysis
3. Provides the ability to estimate life-cycle costs of a wide range of TSMO strategies
4. Allows for the estimation of benefits using a spreadsheet-based sketch-planning approach and the comparison with estimated strategy costs.

As a sketch planning level tool, TOPS-BC allows users to quickly understand typical benefits for a range of TSMO strategies and then estimate the benefit-cost ratio of those TSMO strategies. The tool also provides a suggested list of analysis tools for TSMO strategies depending on user-selected criteria such as: the level of confidence required, which TSMO strategies are being investigated, key measures of effectiveness, and a few other filters.

The tool exists as a Microsoft Excel spreadsheet with several tabs and color coded cells that clearly identify where the user needs to provide information. Before getting into a detailed description of TOPS-BC, it is worthy to note that since the tool is an Excel spreadsheet, the user does have the ability to modify it as needed. The Excel file for TOPS-BC can be found here: https://ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm

Exhibit 18-16 provides a list of the TSMO strategies included in the TOPS-BC tool, and whether typical impacts/benefits are provided for the strategy, as well as more detailed tabs to calculate costs and benefits.

Exhibit 18-16: TSMO Strategies Included in TOPS-BC

TSMO Category	TSMO Strategy	Typical Impacts	Cost	Benefit
Traveler Information	Dynamic Message Signs (DMS)	Yes	Yes	Yes
	Highway Advisory Radio (HAR)	Yes	Yes	Yes
	Pre-Trip Traveler Information	Yes	Yes	Yes
	Web/Internet Multi-Modal Traveler Info	Yes	No	No
	In Vehicle – traveler info or route guidance	Yes	No	No
Traffic Signal Coordination Systems	Preset Timing	Yes	Yes	Yes
	Traffic Actuated	Yes	Yes	Yes
	Central Control	Yes	Yes	Yes
	Transit Signal Priority	Yes	Yes	No
	Emergency Signal Priority	Yes	No	No
Ramp Metering Systems	Central Control	Yes	Yes	Yes
	Traffic Actuated	Yes	Yes	Yes
	Preset Timing	Yes	Yes	Yes
Incident Management	Traffic Incident Management (general)	Yes	Yes	Yes
	Incident Detection/Verification	Yes	Yes	No
	Incident Response/Management	Yes	Yes	No
	Incident Detection and Response	Yes	Yes	No
	Freeway Service Patrols	Yes	Yes	No
Advanced Traffic Demand Management (ATDM)	Speed Harmonization	No	Yes	Yes
	Employer Based Traveler Demand Management	No	Yes	No
	Hard Shoulder Running	Yes	Yes	Yes
	High Occupancy Toll (HOT) Lanes	Yes	Yes	Yes
	Road Weather Management	Yes	Yes	Yes
	Work Zone	Yes	Yes	Yes
	Advanced Public Transit Systems	Yes	No	No
	Congestion Pricing (HOT lanes and variable tolls)	Yes	No	No
Public Transit	Fixed Route Transit (various features)	Yes	No	No
	Paratransit (various features)	Yes	No	No
Supporting Strategies	Traffic Management Center	No	Yes	No
	Loop Detection	No	Yes	No
	CCTV Cameras	No	Yes	No

The cost and benefit components of TOPS-BC each calculate costs and benefits on an annual basis, and provide an overall benefit/cost ratio for the strategy.

TOPS-BC calculates an annualized cost for each strategy by incorporating the useful life of the equipment, the replacement cost, and the annual operations and maintenance cost. The net present value of implementing the strategy is also provided, and while default values for the discount rate and time horizon are provided, the user can change those values.

The cost components for each strategy are broken down into two categories: the one-time costs to create the backbone structure for the strategy such as software and system integration; and the incremental cost of each additional installation such as additional loops, weather stations, and dynamic message signs. Default costs are included in the spreadsheet for all of the cost components. The user simply needs to enter the number of infrastructure deployments (typically one), and the number of incremental deployments.

If better cost data are available, the user can easily modify the spreadsheet with project specific costs or add components to the spreadsheet. One cost component that is not captured in the cost estimating tool is right-of-way acquisition, which should not be ignored.

Exhibit 18-17 provides an example of how TOPS-BC calculates the cost of dynamic message signs. Again, the tool provides default unit costs for capital equipment and operations and maintenance annual costs, as well as the useful life of the equipment. These values can all be changed if the user has more precise information relevant to the specific project. However, for a quick planning level cost analysis, the user simply needs to provide information in the green cells:

- The number of infrastructure deployments (typically one as is the case in this example)
- The number of incremental deployments, shown as five in this example
- The year of deployment.

Based on this example, the average annual cost to implement and maintain this strategy over a 25-year lifespan is $88,400.

Exhibit 18-17: Example Cost Calculation of Dynamic Message Signs

FHWA Tool for Operations Benefit/Cost (TOPS-BC): Version 1.1

PURPOSE: Estimate Lifecycle Costs of TSM&O Strategies

WORK AREA 1 - ESTIMATE AVERAGE ANNUAL COST

Traveler Information: DMS

Equipment	Useful Life	Capital / Replacement Costs (Total)	O&M Costs (Annual)	Annualized Costs
Basic Infrastructure Equipment				
TMC Hardware for Information Dissemination	5	$ 7,500	$ 375	$ 1,875
TMC Software for Information Dissemination	5	$ 20,000	$ 1,000	$ 5,000
TMC System Integration	20	$ 100,000	$ 5,000	$ 10,000
TOTAL Infrastructure Cost		$ 127,500	$ 6,375	$ 16,875
Incremental Deployment Equipment (Per Sign Location)				
Communication Line	25	$ 750	$ 900	$ 930
Variable Message Sign	25	$ 92,500	$ 4,400	$ 8,100
Variable Message Sign Tower	25	$ 125,000	$ 275	$ 5,275
TOTAL Incremental Cost		$ 218,250	$ 5,575	$ 14,305
INPUT Enter Number of Infrastructure Deployments	1			**$ 16,875**
INPUT Enter Number of Incremental Deployments	5			**$ 71,525**
INPUT Enter Year of Deployment	2016			
Average Annual Cost				**$ 88,400**

The annual benefits calculated by TOPS-BC focus on travel time savings for both recurring and non-recurring congestion, energy/fuel savings, and savings due to reduced crashes. A tab marked "Parameters" includes all of the assumptions used to calculate the benefits such as the cost of fuel, fuel economy of autos and trucks, the cost of hourly travel for autos and trucks, the typical percent of trucks on the facility, the cost of crashes by severity, typical emissions, typical crash rates by facilities, speed-flow relationships, and typical incident delay factors. Exhibit 18-18 shows a section of the parameters tab. If local information is known, in particular the percent of trucks on the facility and crash rates on the facility by severity, those should be modified to provide a more accurate benefits assessment. However, if local factors are not known, the default values make the tool ready to use for an approximation of the benefit for the desired TSMO countermeasure.

Exhibit 18-18: Parameter Tab in TOPS-BC

Benefit Estimation Parameters

General Parameters

Year of Dollars Displayed	
Year of Dollar Display	2014
Inflation Rate	3%
Adjustment Factor	1.13
Annualization Factor	
Number of Periods per Year	250
Net Present Value Calculation	
Default Time Horizon (Years)	20
Traffic Mix	
Percentage Trucks	10%
Percentage "On-the-Clock" Travel Purpose (Autos)	20%
Average Auto Occupancy	1.67
Discount Rate	
Discount Rate (for 20 year analysis)	7.0%
Analysis Time Horizon	
Years	20

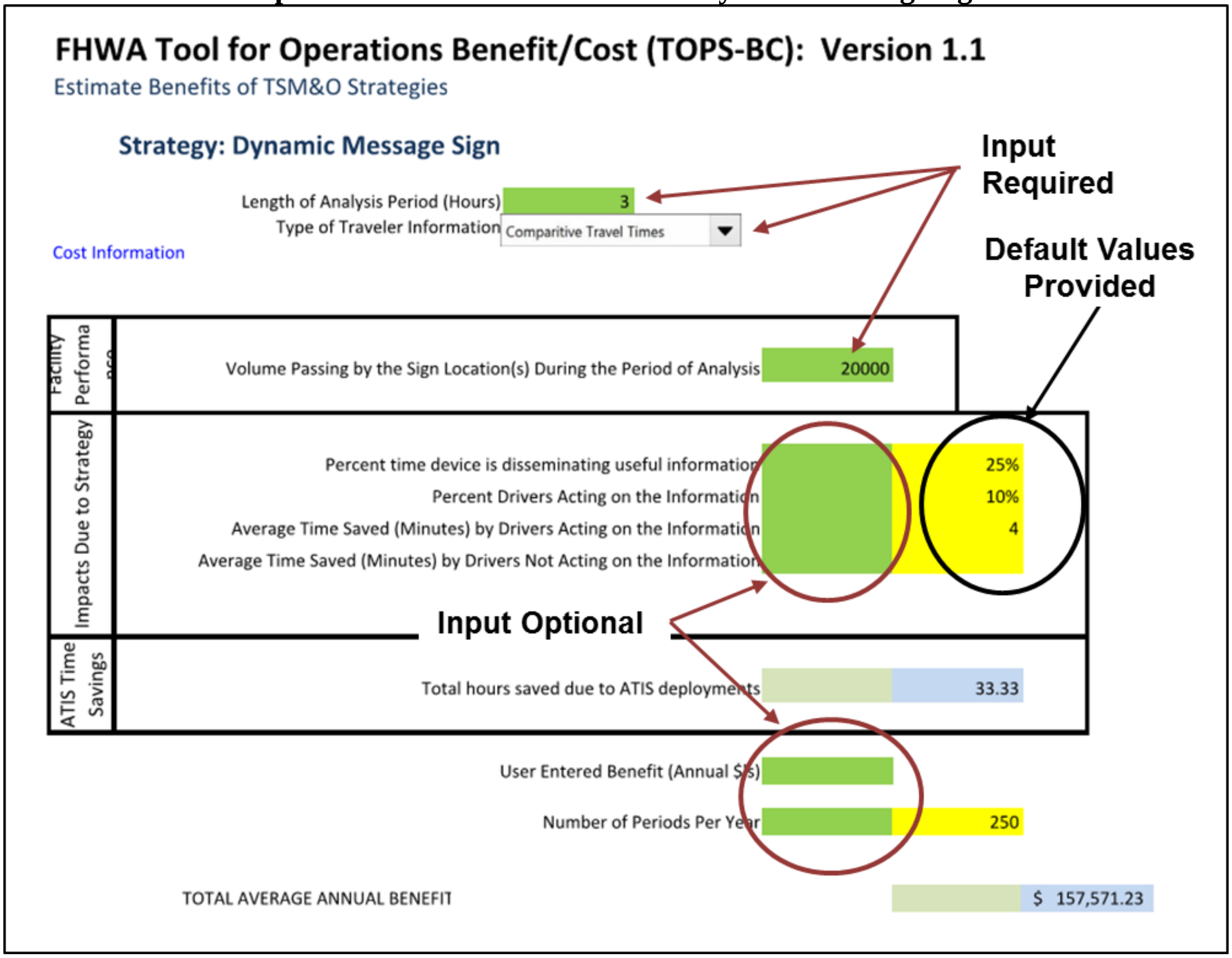
Benefit Valuations

Recurring Travel Time (per hour)		
"On the Clock" Travel Time	$	31.51
Other Auto Travel Time	$	15.76
Truck Travel Time	$	31.51
Non-Recurring Travel Time (per hour)		
"On the Clock" Travel Time	$	31.51
Other Auto Travel Time	$	15.76
Truck Travel Time	$	31.51
Crashes (per occurrence)		
Fatality	$	10,129,579
Injury	$	75,409
Property Damage Only (PDO)	$	2,589
Fuel Use		
Per Gallon (Excluding Taxes)	$	4.13
Non-fuel Operating Costs (per VMT)		
Auto		0.25
Truck		0.37
Emission Cost (per ton)		
CO	$	79
CO2	$	42
NOx	$	18,346
PM10	$	148,342
VOC	$	1,283
Noise (per VMT)		
Auto	$	0.0012
Truck	$	0.0371

Similar to the cost component in this tool, each strategy has its own tab to calculate benefits. Again, color coded cells are used to easily identify where input is required. Green cells indicate user defined input; however, not all green cells require user input. Often a default value will be used, as is the case when a yellow (default) cell is adjacent to a green one. In the Exhibit 18-19, there is also a green cell at the bottom that can be used to add additional benefits not represented by the TOPS-BC sheet, but input there is not required. For the dynamic message sign shown in Exhibit 18-16, the user is required to provide three pieces of information:

- Length of the analysis period
- Type of traveler information (three options are provided on a pull down menu). In the example shown below the “Comparative Travel Times” option is selected. The other two options include “Congestion Warning” and “Alternative Route Recommendation”
- Traffic volume passing the sign location(s) during the period of analysis

Exhibit 18-19: Example of the benefits calculated for dynamic message signs

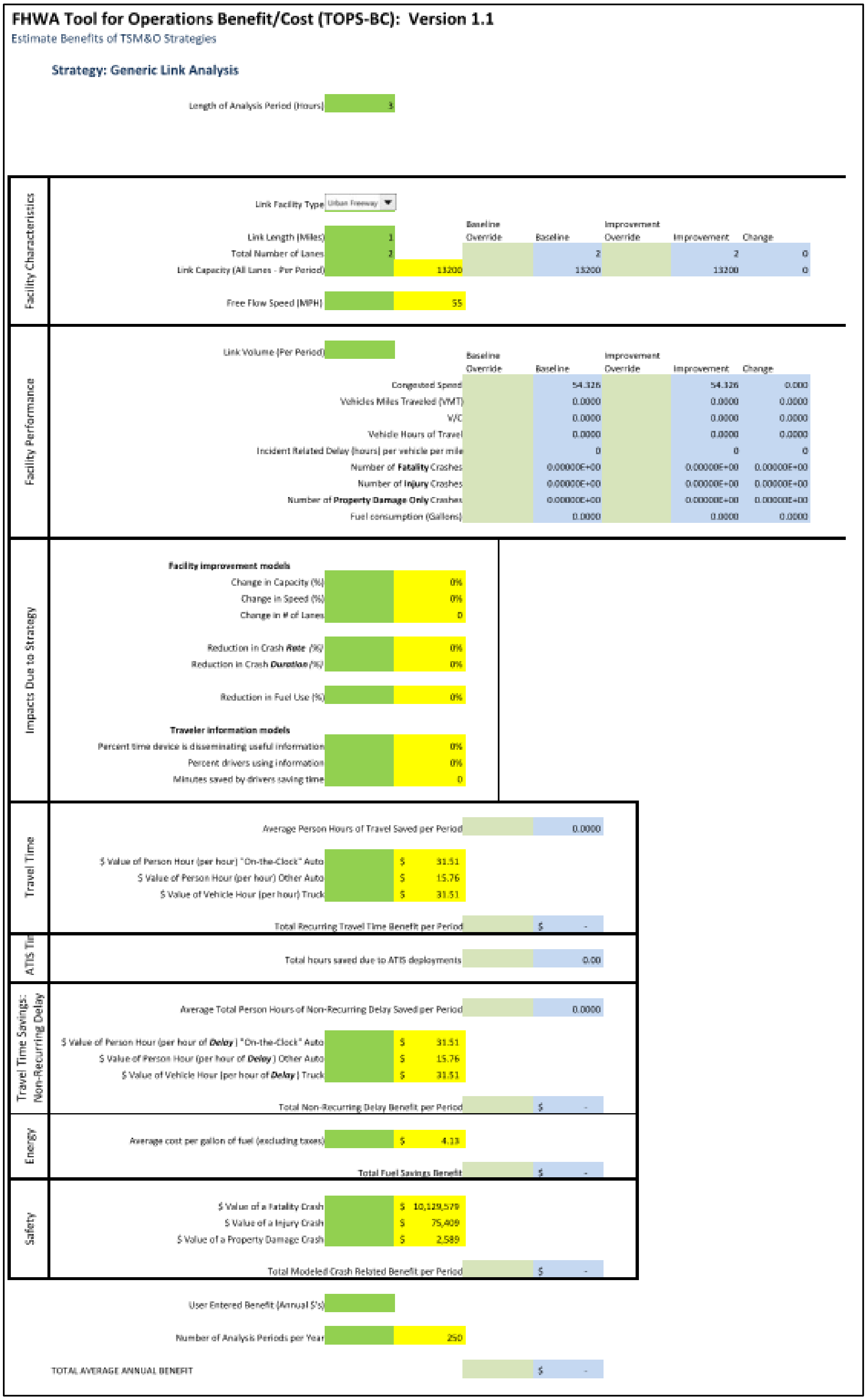


There are additional categories where default values are provided or the user can override those values when location specific information is known. For example, in Exhibit 18-19, default values are provided in the yellow cells for four items. The user can input their own values in the adjacent green cells if more precise information is known, or opt to use the default values.

Using the information from the benefit and cost tabs, the user can easily create a benefit-cost ratio since both elements are provided in terms of an annual cost and annual benefit. Based on the DMS example, the benefit-cost ratio is 1.78.

In addition to the benefit tabs for each strategy, the tool provides a "generic link based" analysis tab that can be used to enter benefits related to a TSMO strategy not specifically identified, as shown in Exhibit 18-20. This tab allows the user to customize a benefits calculation that may not fit precisely into any of the other categories. In this tab, the user must input information about the facility characteristics, and expected impacts of the strategy such as changes in capacity, crash rates, delay, speed, and energy.

Exhibit 18-20: Link Based Benefits Tab



The TOPS-BC tool also provides a summary tab that allows the user to select some or all of the strategies for a total benefit-cost summary.

For more information and access to the TOPS BC tool, refer to FHWA TOPS BC website.[27]

Crash Modification Factors

Crash modification factors (CMFs) are used to determine the effect a specific countermeasure will have on future crashes at a given location or along a corridor. In terms of TSMO related strategies, CMFs apply directly to the objectives-driven, performance-based approach, by providing the likely quantifiable change in crashes. Section 18.3 introduces CMFs and Chapter 4 also goes into great detail on using CMFs, especially related to predictive crash analysis.

In most cases the CMF targets a specific type of crash, severity, or type of facility. When calculating benefits for a strategy at a specific location, it is important to ensure that the CMF is applied to those same types of crashes and severity categories. For example, if a countermeasure has a CMF that reduces fatal crashes by 20 percent, and the location where it is being applied had an annual average of five fatal crashes and 15 non-fatal injury crashes, the benefit from that CMF would be the reduction of one fatal crash per year. That CMF would not apply to the non-fatal crashes.

In general when two countermeasures are being applied to a location, the CMFs are not additive. For example, if both variable speeds and ramp metering are installed along a freeway segment, you should use either the CMF related to variable speeds or the CMF related to ramp meters, but not both. The only time you might use two (or more) CMFs for combined countermeasures are when the CMFs each target different types of crashes or severity of crashes at a given location. However, even then, one should use judgement to minimize any sort of exaggerated additive benefit from using more than one CMF.

Dynamic Traffic Assignment

While this section provides an overview of DTA relative to corridor management, APM Chapter 8.5 provides a broader overview of DTA concepts and tools, as well as publication by the Transportation Research Board[28].

DTA models can provide a tool for measuring corridor management within the context of the broader (subarea or regional) travel network. Many attributes or variables in DTA models provide an enhanced ability to measure operational impacts at the corridor level. While such impacts could also be assessed in microsimulation models, such models do not provide the routable nature of "trips" present in a DTA network (which are typically replaced with pre-defined intersection-level turn movements). Further, microsimulation

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[27] TOPS-BC website: https://ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm

[28] *TRB Transportation Research E-Circular E-C153: Dynamic Traffic Assignment: A Primer*, Transportation Research Board, Washington DC, June, 2011. https://www.trb.org/Publications/Blurbs/165620.aspx

models typically require more effort to prepare than DTA models (for a given size network).

While there are many differences between different DTA platforms, the following general characteristics are common:

- Time-dependent paths where the path through the network is influenced by travel times that vary depending on when travelers arrive at a given network link, as opposed to assuming that travel times are constant throughout the period being simulated.
- Travel routes typically change at shorter intervals than static models (typically minutes instead of hours).
- Network congestion estimates, which are often based on traffic operations, are typically more detailed than a static model to account for travel time difference between routes.
- Vehicles queue on the network and are not forced through over-capacity conditions due to a timer interval constraint. Thus some demand may remain unserved during the analysis period.
- Individual vehicle "simulation" (whether visualized or not) is generally present to account for vehicle interaction and operational impacts.
- Like static assignment, multiclass assignment (including trucks) can be captured in DTA tools, which allow for different path sets and attributes among classes.
- Transit elements are included in varying degrees based on each DTA tool, but may include the ability to include service information including routes, stop locations, and schedules. Next generation DTA tools are starting to model individual transit persons as well.

A key differentiator among DTA models is the overall fidelity and detail for which traffic flows are captured along a road. The two types of models are referred to as "link-based" and "lane-based:"

- Link-Based Models – Traffic flow along a roadway is analyzed macroscopically, where the total number of lanes is considered as an overall link capacity. Differences among individual lanes (including the amount of traffic demand for an individual lane), interactions among individual vehicles, and friction related to movement and lane changing are not directly modeled. Examples: Visum Dynamic User Equilibrium (DUE), DTALite/NeXTA, and DynusT.

- Lane-Based Models – Traffic flow along a roadway is analyzed for each lane, using car-following algorithms that account for interactions among vehicles and flow differences in each lane. Storage of vehicles related to turn bay lengths and other differences between lanes along a given link may influence operations at the adjacent node/junctions/intersections. Examples: Dynameq and Vissim DTA.

In general, lane-based DTA platforms will provide additional detail needed to evaluate corridor operations, including the following considerations:

- Intersection control (approach geometry and signal timing)

- Transit stop treatment

- Lane-changing friction caused by weaving between intersections or access density
- Time of day lane management (such as reversible lanes or closures)
- Bottleneck impacts can be better captured with the additional operational detail

18.5 System Management

This section provides an overview, considerations, and analytical procedures for a collection of TSMO strategies that are programmatic and applied systemically. Whereas corridor management focuses on TSMO strategies applied to a specific facility or set of parallel facilities, system management addresses programs that are implemented across the transportation system in a given geography (i.e. city, county, regional or state). This section discusses seven system management program areas including:

- **Traffic Incident Management** is the practice of coordinating resources across partner agencies and the private sector to quickly detect, respond to, and clear traffic incidents to reduce impacts on safety and congestion.
- **Emergency Operations** is the planned, coordinated response to man-made or natural events causing or threatening injury or loss of life, property damage, human suffering, or financial loss.
- **Road Weather Operations** is the use of strategies to minimize or eliminate the impacts of weather events such as rain, snow, high winds, or flooding on safe and reliable travel.
- **Work Zone Management** is the practice of managing traffic impacts during construction to maximize traveler and worker safety, minimize traffic delay, maintain access for adjacent land uses, and support timely completion of construction.
- **Planned Special Event Management** is the advanced planning and coordination to manage travel before, during and after an event.
- **Traveler Information** includes strategies to deliver pre-trip and en-route information about travel options and conditions.
- **Transportation Demand Management** is the policies and strategies aimed at enhancing travel opportunities and choices that make more efficient use of the transportation system.
- **Connected and Automated Vehicles** is the emerging technology in vehicles that will enable the communication between vehicles, infrastructure and mobile devices to make travel safer and more efficient.

18.5.1 Traffic Incident Management

Traffic Incident Management (TIM) is the practice of planned and coordinated detection, response, and clearance of traffic incidents. TIM is a multi-disciplinary effort among incident responders to manage and clear traffic incidents as quickly as possible while maximizing responder safety and minimizing traffic impacts during the incident. Exhibit 18-21 lists several examples of hazardous traffic incident events. Traffic incidents are said to account for up to one-quarter of congestion on US roadways[29]. Swift clearance of

[29] http://ntimc.transportation.org/Documents/Benefits11-07-06.pdf

incidents has two main benefits: safety and system efficiency. Clearing an incident as quickly as possible limits the amount of time incident responders and travelers are exposed to dangerous conditions, decreases the chances of a secondary crash, and more quickly restores the roadway to normal capacity.

Exhibit 18-21: Examples of Hazardous Traffic Incident Events

Abandoned Vehicle – Hazard	Downed Power Lines	Pedestrian in Roadway
Animal on Roadway	Fatal Crash	Pothole
Animal Struck – Hazard	Hazard Tow (minor)	Rock Fall
Closure	Hazardous Debris	RR Crossing Equipment Failure
Crash	Hazardous Tree/Vegetation	Signal Not Working
Crash Investigation	Hazmat Spill (minor)	Spilled Load
Damaged ODOT Property	High Water	Vehicle Fire
Disabled Vehicle – Hazard	Obstruction on Roadway	

Oregon adopted its first TIM Strategic Plan in 2011 and recently completed a 2015 update[30]. Oregon's TIM Strategic Plan identifies and prioritizes actions to implement statewide over the next five years. The updated plan identifies over sixty actions in the areas of technology integration, agency and stakeholder collaboration, public outreach, policy and regulatory, system evaluation, and responder training.

Successful TIM programs and strategies rely on cooperation and coordination across a broad range of partners. The Oregon TIM Strategic Plan identifies over twenty stakeholders. A multi-agency approach ensures that all response agencies are acting toward a common goal while understanding each partner's unique roles and responsibilities.

Traffic incidents can severely reduce the capacity of roadways, even when incidents occur in the shoulder area. Exhibit 18-22 demonstrates the loss of freeway capacity due to lane blocking incidents. For example, on a two-lane freeway if one lane is blocked, the freeway is limited to just 35% of its normal capacity (not 50% as one might linearly assume).

[30] Oregon Traffic Incident Management Strategic Plan. Prepared by DKS Associates, in cooperation with ODOT and Oregon State Police (OSP). 2015. Web link: *https://www.oregon.gov/ODOT/Maintenance/Pages/Traffic-Incident-Management.aspx*

Exhibit 18-22: Proportion of Freeway Segment Capacity Available Under Incident Conditions

Number of Lanes (One Direction)	Shoulder Disablement	Shoulder Accident	One Lane Blocked	Two Lanes Blocked	Three Lanes Blocked
2	95%	81%	35%	0%	N/A
3	99%	83%	49%	17%	0%
4	99%	85%	58%	25%	13%
5	99%	87%	65%	40%	20%

Source: *Highway Capacity Manual 2010*, Exhibit 10-17

When considering which strategies are most appropriate for a given area, there are numerous factors to consider. The following list documents a number of the key factors including:

- Crash data (see Chapter 4 for safety and crash analysis procedures)
- Traffic volumes
- Geographic context
- Facility type
- Existing capital infrastructure
- Existing ITS infrastructure
- Proximity to detour routes
- Available resources and resource sharing between agencies
- Status of integrated corridor management

Common Traffic Incident Management Strategies

The following list includes common traffic incident management strategies currently in place in Oregon. For a complete list of TIM Strategies Oregon is pursuing, Oregon's TIM Strategic Plan should be referenced.

- Safety Service Patrols arrive at the scene and provide preliminary traffic control, assist the motorist to the side of the road, or other safety measures to improve safety. Oregon has a total of 23 Dedicated Incident Responders that cover key state roadways in regions 1, 2, 3, and 4. The service patrol hours of operation vary by district and may also vary seasonally.

- Driver Removal Laws require drivers to remove their vehicles out of travel lanes after a traffic incident if there are no serious injuries or fatalities. Drivers can then exchange information in a safe location and wait for law enforcement assistance. Oregon's Move It Law requires drivers involved in an incident to remove their vehicle from the travel lanes as long as there are no serious injuries.

- Authority Removal Laws allow a pre-designated set of public agencies to remove damage or disables vehicles (and/or spilled cargo) from the roadway that is safety concern for travelers. Typically, these laws include liability protection for the designated agencies. Oregon's Authority Removal Law allows law enforcement to remove vehicles or debris so the incident is not blocking traffic.

- Move Over Laws require drivers approaching a scene where incident responders are present to either change lanes or reduce speeds. The exact requirements and penalties vary from state to state. In Oregon, the current law requires drivers to either move to a lane not adjacent to that of the response vehicle, or, if changing lanes is not possible, reduce the speed to five miles per hour under the speed limit. Note that in Oregon's TIM Strategic Plan, there is an action to determine whether the Oregon law should be stricter (requiring a larger speed reduction), and if so, to begin the required legislative process.

- Shared Quick Clearance Goals sets a specific clearance time target that the incident must be cleared from the roadway. Oregon legislature established a 90-minute quick clearance goal for all incidents in 2013.

- Pre-established Towing Service Agreements set the requirements for tow companies to meet in order to be on a tow rotation list. When a tow is needed for a traffic incident, these agreements allow the agency to easily contact the appropriate tow company using a central point of contact.

  In Oregon, the Oregon State Police (OSP) set the requirements tow companies must meet to be on the tow rotation list. When an incident occurs, either ODOT or OSP will initiate a tow request if necessary. The tow company called to the scene depends on which agency initiates the request.

  The Portland region is unique in regard to towing regulations in the state. In the Portland region, several agencies coordinate to allow for a central point of contact when an incident requires a tow. Those agencies include Portland Police, Multnomah County, City of Portland, TriMet, and ODOT. The vetting to get on the Portland tow list is different than the statewide list, so the list of tow companies is different, although some tow companies may be on both lists. Creating a formal process that unites all transportation agencies under a single Tow Board in the Portland area allows for a forum to present and implement new towing strategies much easier than other areas in the state.

- Incentivized Towing offers a financial incentive for tow companies to clear an incident in an allotted time period, and can institute a penalty if the tow company takes longer than that time period. Oregon does not currently have any incentivized towing contracts in place.

- Instant Towing or Staged Towing Contracts initiate a tow request as soon as an incident is reported. If it turns out the tow is not necessary, the tow company receives a "no service" fee. Staged towing strategically stations tow trucks near areas of frequent accidents, and tow companies are paid for the full time they are stationed, regardless of whether they are actually called to a tow incident.

  In Oregon, the Portland region participates in Instant Towing year round, and during winter events the Portland region has Staged Towing contracts where tow companies locate trucks at specific pre-determined locations and are ready as incidents occur. An action in Oregon's TIM Strategic Plan is to identify if there are other regions in the state that could benefit from tow contract plans.

- Dispatch Co-location can improve communication between response agencies and transportation agencies.

- TIM Task-Force is an organization of first responder agencies that convene on a regular basis to discuss TIM challenges, procedures, resources, and other TIM areas to improve upon. In Oregon, there is a statewide TIM Task Force, and TIM teams that meet regularly in the Portland area, Rogue Valley area, and Central Oregon area, as well as an annual statewide winter operations meeting. Oregon's TIM Strategic Plan identifies other regions along the I-84 and I-5 corridors where additional TIM Teams may be beneficial.

- Strategic Highway Research Program (SHRP2) Training created a coordinated, multi-disciplinary training program for all emergency responders, which helps put all incident responders on the same page, leading to a safer, faster, integrated responder team.

- After Action Reviews are incident debriefing sessions where all involved response agencies discuss the incident and determine what worked well and what can be improved.

After TIM projects are selected and implemented, monitoring TIM performance measures is critical for agencies to demonstrate accountability and program effectiveness in order to support future TIM planning.

FHWA identified three national TIM performance measures:

- Roadway clearance time – the amount of time between the first recordable awareness of the incident by a responsible agency to the time that all lanes are available for traffic flow

- Incident Clearance time – the amount of time between the first recordable awareness of the incident by a responsible agency to the time that all responders have left the scene
- Number of secondary incidents **–** the number of unplanned incidents beginning with the time of detection of the primary incident where an incident occurs as a result of the original incident either within the incident scene or within the queue in either direction.

Oregon currently collects and monitors the first two performance measures, as well as roadway closure time and the number of responders trained in the National TIM training program. Oregon legislature set the current goal for incident clearance – clear 100 percent of all lane-blocking crashes within 90 minutes. Tracking the number of secondary incidents is marked as a high priority action in the 2015 Oregon TIM Strategic Plan. Developing a method to track incident responder fatalities and struck-bys is also noted in the plan.

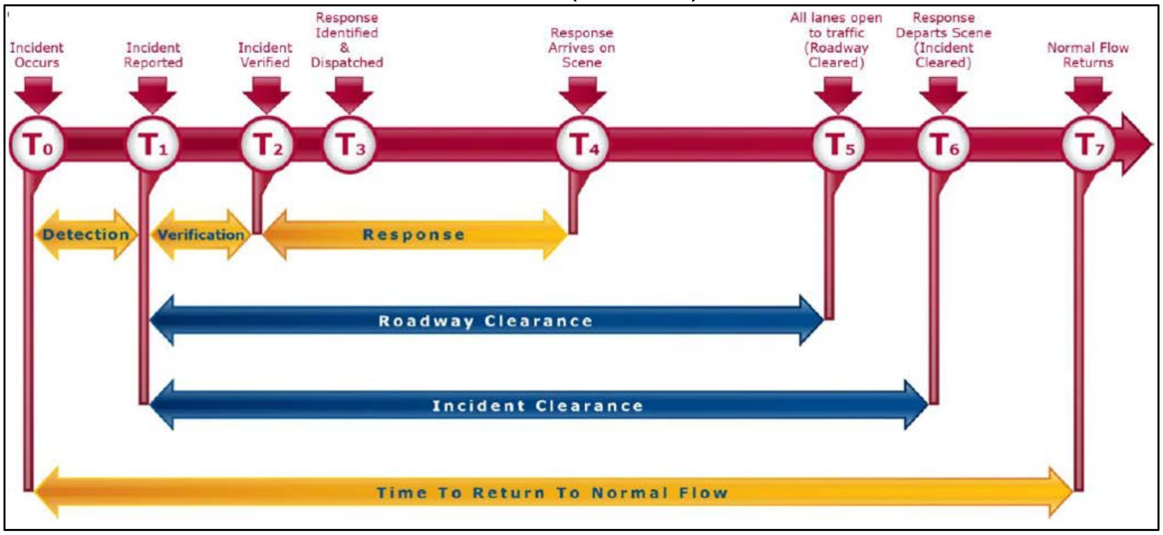
The National Cooperative Highway Research Program (NCHRP) advanced the TIM performance measure element and recently created a website to help guide performance measurement related to TIM: http://nchrptimpm.timnetwork.org/. The purpose of the website is to provide guidance on consistent use of TIM performance measures and to support the overall efforts of TIM program assessment. NCHRP website goes beyond the three national TIM performance measures by recommending other key performance measures, listing common sources of TIM data, and identifying challenges in collecting and analyzing TIM data. The NCHRP website also provides recommendations for developing TIM databases and model scripts.

As shown in Exhibit 18-23, NCHRP recommends tracking six key time intervals during incident response:

- Detection time
- Verification time
- Response time
- Roadway clearance time (also recommended by FHWA)
- Incident clearance time (also recommended by FHWA)
- Time to return flow to normal

A seventh time interval not captured by the NCHRP timeline but worth considering, is the time for upstream platoons caused by the incident to dissipate. In some cases, the flow at the scene of the incident may return to normal while long platoons are still present upstream.

Exhibit 18-23: View of Incident Timeline (NCHRP)



NCHRP highlights other performance measures to consider including: number of secondary incidents involving first responders, percentage of fatal crashes that are secondary, queue lengths, travel delay, service patrol statistics, and several others. Oregon already tracks incident data involving the crash location, severity, fatalities, type, involved vehicles, and others information captured in the crash database.

For incidents, the following three databases provide information: Transportation Data Section (TDS) Crash Reports, Highway Traffic Operations Center System (HTOCS), and Highway Travel Conditions Information System (HTCIS). The information within these systems includes:

- <u>TDS Crash Reports</u> – This database is compiled from individual driver and police crash reports submitted to ODOT. The reports in this crash database include information about the crash (such as location, time, type, and severity), information about the vehicle (such as ownership, type of vehicle, and vehicle movement), and information about the participants (such as age, sex, injury severity, and drug or alcohol use).
- <u>HTOCS Events and Unit Status</u> – This database includes most of the information about each incident such as time, location, primary unit in charge, description of incident, and response result. It also contains status timestamps for each unit (i.e., person) as they are notified and respond to incidents.
- <u>HTCIS Traveler Information</u> – This database includes the status updates that are shared with the public on the ODOT TripCheck website, through 511, and ODOT's Traveler Information Portal (TTIP), which allows external sources to access ODOT's data for redistribution. It includes which lanes are affected and what the expected impact is to travelers (i.e., delay experienced). Each incident usually has multiple status updates throughout the duration of the incident. This

database also includes weather related information when available (atmospheric and the resulting road conditions).

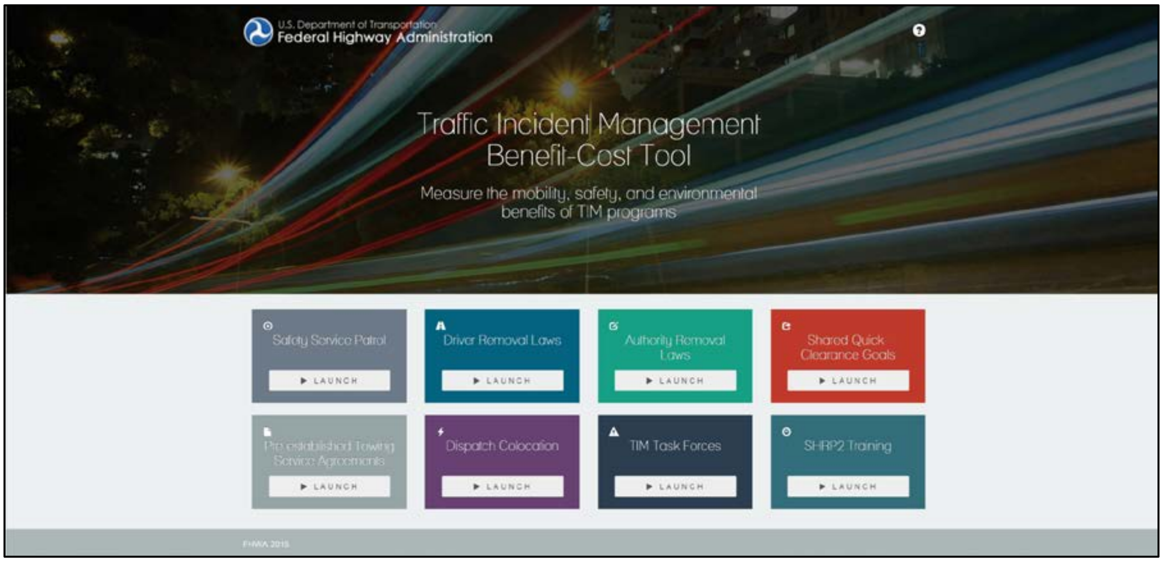
Traffic Incident Management Analysis Tools

The USDOT ITS Knowledge Resources website, described in Section 18.3.6, is a useful tool for identifying benefits and costs for a wide variety of TIM strategies under the categories of surveillance and detection; mobilization and response; information dissemination; and clearance and recovery. The website compiles evaluation findings about TIM-related projects from across the globe and documents benefits, costs, and lessons learned. The benefit and cost sections can be easily searched by application, specific goals, and geographic location. The USDOT ITS Knowledge Resources website can be found at https://www.itskrs.its.dot.gov/its/itsbcllwebpage.nsf/KRHomePage

FHWA's Office of Operations and Research Development recently developed a tool, the Traffic Incident Management Benefit-Cost (TIM-BC) tool, which can be used to evaluate the benefits of TIM strategies as shown in Exhibit 18-24. It is a web-based software tool (https://www.fhwa.dot.gov/software/research/operations/timbc/) that evaluates eight of the most common TIM strategies:

- Safety Service Patrols
- Driver Removal Laws
- Authority Removal Laws
- Shared Quick Clearance Goals
- Pre-established Towing Service Agreements
- Dispatch Co-location
- TIM Task-Force
- Strategic Highway Research Program (SHRP2) Training

Exhibit 18-24: FHWA's TIM-BC Tool



FHWA's Incident Management Benefit Cost Tool allows the user to customize project information and obtain benefit cost information. For optimal results the tool requires the user to have a considerable amount of data for each roadway segment the strategy targets. For example, the user needs to enter the average incident duration and number of incidents categorized as shoulder blockage or one lane blockage, as well as the percentage of estimated secondary incidents for each roadway segment. In some cases, default values are available. There is also an element of subjectivity in the data entry area for "Project Savings", requiring the user to input the proportion of incidents in which clearance times would decrease by implementing the strategy.

Once all of the information is entered, the program calculates savings for delay, fuel, secondary accidents, and emissions. The tool also produces a formatted pdf report of the analysis.

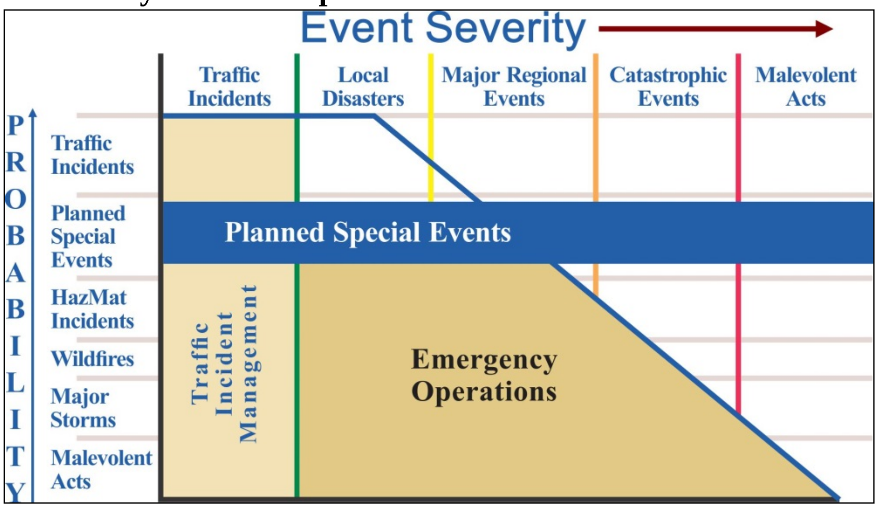
18.5.2 Emergency Operations

Emergency operations is broadly defined as the response and management of the transportation system during a wide range of non-recurring events including major traffic incidents, special planned events, and disasters such as flooding or evacuations. For the context of this sub section, emergency operations refer to less probable and more severe types of non-recurring events such as natural disasters, evacuations, and large-scale hazardous materials events. Exhibit 18-25 lists examples of emergency events and Exhibit 18-26 illustrates the relation of event probability with event severity, with the shaded region indicating the type of event addressed in this section. Both traffic incident management and planned special events are covered in other sections (18.5.1 and 18.5.5 respectively).

Exhibit 18-25: Examples of Emergency Operation Events

Air Crash	Explosion	Other Disaster
Avalanche	Evacuation	Rail Crash
Bomb	Flood	Road Surface Collapse
Earthquake	Landslide	Tsunami
Erosion	Major Hazmat	Wildfire

Exhibit 18-26: FHWA's Emergency Transportation Operations – Severity and Probability Relationship



The federal government provides extensive guidelines and recommendations for emergency operations through FHWA's Emergency Transportation Operations website,[31] and through FEMA's National Incident Management System (NIMS) website.[32] Additionally, Oregon has its own Emergency Operations Plan[33] that provides the framework to respond and recover from major emergencies and disasters. Oregon's plan documents the roles and responsibilities of state agencies while managing emergency response efforts.

Successful emergency operations rely heavily on TSMO strategies and multi-agency coordination to ensure mobility is maintained and that real-time data are accurately communicated to both the public and transportation operators.

[31] FHWA website accessed on December 9, 2015: http://www.ops.fhwa.dot.gov/eto_tim_pse/about/eto.htm
[32] FEMA website for NIMS access on December 10, 2015: https://www.fema.gov/national-incident-management-system
[33] State of Oregon Emergency Operations Plan. Oregon Office of Emergency Management. Publication date: July 2010; Latest Revision Date: March 2014.

FHWA describes three phases of emergency response, with most of the TSMO related strategies linked to the first two phases.

1) Preparation and Activation. Emphasized TSMO strategies include ITS infrastructure investments and creating transportation management centers.
2) Response. Emphasized TSMO strategies include communication systems, information sharing, and resource management.
3) Re-entry and Return to Readiness. This phase is more about debriefing and documentation, and does not have much emphasis on TSMO strategies.

Overview of TSMO Emergency Operation Strategies

Key TSMO strategies to successfully implement Emergency Operations include:

- Integrated Corridor Management. When emergencies close transportation facilities, require a detour, or even a mass evacuation, integrated corridor management can ensure that all transportation facilities within and across corridor boundaries are being used at maximum efficiency. For example, if a segment of freeway is closed, integrated corridor management can be used to modify traffic signal timing on surface streets to accommodate a sudden spike in traffic or unexpected direction of flow. See Section 18.4.4 for more information about Integrated Corridor Management.
- Real-Time Traveler Information. During an emergency it is critical to share current and accurate information with the public. Agencies need to be able to connect to a traveler information system and quickly update the information as it changes. See Section 18.5.6 for more information about Traveler Information strategies.
- Communication between Agencies. In the case of emergency operations, the scale is likely large enough that multiple transportation facilities and services will be impacted. For optimum mobility, it is critical that agencies communicate plans before implementing. For example, if a freeway segment needs to be closed, it is critical to notify the agencies whose facilities will be impacted. Notifying the appropriate agencies ensures that available resources can be optimized (detour routes, variable message signs, signal timing adjustments, etc.).
- Integration of ITS into Emergency Response Plans. On the planning spectrum, agencies should integrate ITS/TSMO strategies into emergency response plans. See Sections 18.4.1 and 18.4.2 for Arterial and Freeway Management strategies.
- Statewide Communication Interoperability Plan (SCIP)[34]. This plan establishes protocol to communicate with agencies across the state and enables a unified approach to enhance interoperable communications.

Considerations for Effective Emergency Operations

Effective emergency operations are closely related to integrated corridor management requiring institutional, operational, and technical integration. Institutionally, there needs to be collaboration between agencies. Operationally, agencies need to share assets and

[34] Website: *https://www.oregon.gov/siec/Pages/SCIP.aspx*

communicate asset availability to all involved agencies. Technically, the means to communicate and interface with agencies and traffic devices needs to be available.

Benefits of Fully Integrated Emergency Operations

When Emergency Operations are fully integrated, there are several benefits to the transportation system and the general public:

- Improved mobility during large scale emergencies
- Improved safety of the public and responders
- Ability for the public to make well informed decisions

Emergency Operations Analysis Tools

The USDOT ITS Knowledge Resources website, described in Section 18.3.6, has a limited database of studies that identify benefits and costs for Emergency Operations strategies such as freeway lane reversal and hazmat technologies. The USDOT ITS Knowledge Resources website can be found at https://www.itskrs.its.dot.gov/its/itsbcllwebpage.nsf/KRHomePage.

18.5.3 Road Weather Operations

Adverse weather can have many negative impacts on travel in the areas of safety, mobility, productivity, and operational decisions. FHWA, through their Road Weather Management Program, summarizes the most common impacts weather can have on roads, traffic, and operational decisions as shown in Exhibit 18-27.[35]

[35] https://ops.fhwa.dot.gov/weather/q1_roadimpact.htm

Exhibit 18-27: Weather Impacts on Roads, Traffic and Operation Decisions

Road Weather Variables	Roadway Impacts	Traffic Flow Impacts	Operational Impacts
Air temperature and humidity	N/A	N/A	• Road treatment strategy (e.g., snow and ice control) • Construction planning (e.g., paving and striping)
Wind speed	• Visibility distance (due to blowing snow or dust) • Lane obstruction (due to wind-blown snow or debris)	• Traffic speed • Travel time delay • Crash risk	• Vehicle performance (e.g., stability) • Access control (e.g., restrict vehicle type, close road) • Evacuation decision support
Precipitation (type, rate, start/end times)	• Visibility distance • Pavement friction • Lane obstruction	• Roadway capacity • Traffic speed • Travel time delay • Crash risk	• Vehicle performance (e.g., traction) • Driver capabilities/behavior • Road treatment strategy • Traffic signal timing • Speed limit control • Evacuation decision support • Institutional coordination
Fog (smoke and dust also limit visibility in some parts of Oregon)	• Visibility distance	• Traffic speed • Speed variance • Travel time delay • Crash risk	• Driver capabilities/behavior • Road treatment strategy • Access control • Speed limit control
Pavement temperature	• Infrastructure design	N/A	• Road treatment strategy
Pavement condition	• Pavement friction • Infrastructure damage	• Roadway capacity • Traffic speed • Travel time delay • Crash risk	• Vehicle performance • Driver capabilities/behavior (e.g., route choice) • Road treatment strategy • Traffic signal timing • Speed limit control
Water level	• Lane submersion	• Traffic speed • Travel time delay • Crash risk	• Access control • Evacuation decision support • Institutional coordination

The first step in setting up a road weather operations strategy is to determine the adverse weather situation that needs to be addressed. A corresponding strategy can be selected to reduce or eliminate the impacts of the adverse road weather condition.

Road weather operations strategies are typically separated into three main categories:

- Advisory strategies aim to inform users and managers of a facility of current and future road weather conditions. These strategies may be directed to users of a system by way of radio, variable message signs, social media, or the Internet.
- Control strategies actively manage a facility to restrict, permit, or regulate operations based on weather conditions. Control strategies can be in the form of variable speeds, highway closures, chain requirements (chain-up laws, chain-up areas, and checkpoints, or altered traffic signal timing.
- Treatment strategies aim to reduce the impact on weather events to users or maintainers of a roadway or facility. In a winter weather situation, this might be by plowing the roadway, applying sand or salt to a highway, or applying liquid deicer during icy conditions. It may also include asset tracking such as snow plow tracking that may also be used to provide traveler information under advisory strategies.

FHWA has compiled a list of road weather management best practices used throughout various states called the Road Weather Management (RWM) Best Practice Library (BPL). Version 3 of the BPL was released in 2012 that provides 27 innovative mitigation strategies and practices for varying adverse weather situations. The most recent version of the RWM BPL can be found at https://ops.fhwa.dot.gov/weather/mitigating_impacts/best_practices.htm.

Some strategies, like variable speed control, variable message signs, and altered traffic signal timing require new or existing infrastructure to be in place to support their operation. Having reliable power and communications infrastructure, especially during inclement weather, is necessary for their operation. Other strategies require a support structure to facilitate their operations. This can be in the form of social media like Twitter or updated traveler information via the Internet. ODOT operates TripCheck (https://tripcheck.com) that provides up-to-date information and camera images of road weather travel conditions in Oregon.

Road Weather Operations Analysis Tools

The analysis tools described in Section 18.3.6 may be considered for analyzing the potential effectiveness of road weather operations strategies. In particular, the TOPS-BC tool provides sketch level planning support for road weather operations and the crash modifications factors clearinghouse also provides guidance. Crash analysis (see Chapter 4) can also be used to help identify crash rates where there is a correlation to the weather. Analysis of maintenance logs and other agency asset tracking tools can be done to analyze how and where maintenance resources are allocated to help determine locations or activities that may benefit from road weather strategies.

Factors to consider when evaluating the applicability of road weather operations strategies:

- Known locations that impact travel during adverse weather conditions (e.g. mountain passes, low water crossings, bridges with high winds)
- Crash data with a correlation to weather conditions
- Weather conditions (weather service information, data from road weather information systems)
- Maintenance resource allocation (e.g. locations, activity types, frequency)

18.5.4 Work Zone Management

Work zone management includes all policies and practices related to minimizing travel delays and maintaining the safety of all travelers and workers from construction or maintenance work zones and associated detour routes. This section provides an overview of TSMO strategies for work zone management, evaluation considerations, and a summary of tools for work zone analysis. FHWA's Work Zone Mobility and Safety Program website provides a wealth of information and resources to support work zone management: https://ops.fhwa.dot.gov/wz/index.asp. ODOT also provides work zone management resources:

- Work Zone Safety: https://www.oregon.gov/ODOT/Safety/Pages/Work-Zone.aspx
- Traffic Control Plans Unit: https://www.oregon.gov/ODOT/Engineering/Pages/Work-Zone.aspx

The most comprehensive set of work zone management strategies is included in FHWA's Work Zone Operations Best Practices Guidebook, 3rd edition, at https://ops.fhwa.dot.gov/wz/practices/best/bestpractices.htm, which covers approximately 40 topics and numerous subtopics grouped in these overarching categories:

Policy and Procedures

- Public Relations, Education, and Outreach (Program-Level)
- Modeling and Impact Analysis
- Planning and Programming
- Project Development and Design
- Contracting and Bidding Procedures
- Construction/Maintenance Materials, Methods, Practices, and Specifications
- Traveler and Traffic Information (Project Related)
- Enforcement
- ITS and Innovative Technology
- Evaluation and Feedback

This guidebook includes 12 best practices from Oregon such as 20-minute maximum delay specifications, media and public outreach, and work zone incident management.

Some of the most commonly used TSMO strategies for work zone management include closure policies, stakeholder coordination and planning, public outreach and traveler information, work zone incident management, dynamic warning systems, and traffic control as described in the following sub-sections.

Closure Policies

Minimizing closures of lanes, ramps, and roadways during peak travel times goes a long way towards maintaining travel mobility. All travel modes should be considered when developing closure policies. For example, freeway work zone projects should consider Interstate design vehicles, over-dimension vehicles, and bus routes. Alternatively, an urban work zone projects should consider accommodations for pedestrians, bicycles, transit, passenger vehicles, and the appropriate types of freight vehicles.

ODOT has a standing policy for all freight routes that any lane closure that is expected to cause traffic delays triggers a mandatory coordination process with mobility stakeholders. For this purpose, delay is expected when the hourly volumes during construction exceed an established free-flow threshold. These thresholds are defined in the corridor-specific Traffic Management Plans that were established during the OTIA-III bridge rehabilitation efforts.

The work zone analysis tools discussed later in this subsection provide input on procedures for analyzing closures.

Stakeholder Coordination and Planning

Planning efforts for work zone management should include a variety of stakeholders such as transportation agencies, construction management divisions within agencies, contractors, transit agencies, traffic management centers, 911 centers, law enforcement, fire and rescue agencies, emergency medical agencies, utility agencies/companies, area businesses, freight community, freight distribution centers, event centers, school districts/school bus operators, and neighborhood associations. Transportation Management Plans (TMPs) can be used to identify strategies for work zone management. TMPs are required for significant federally funded projects but can also be scaled to any size project. ODOT uses three levels of TMPs: program-level (overarching statewide safety and mobility policies), corridor-level (targeted for high-volume freight and passenger travel routes), and project-level (as needed for individual projects). See the FHWA and ODOT TMP websites for more information: https://ops.fhwa.dot.gov/wz/resources/tmp_factsheet.htm and https://www.oregon.gov/ODOT/Engineering/Documents_RoadwayEng/Transportation_Management_Plan.pdf.

ODOT's TripCheck Local Entry (TLE) feature allows transportation agencies within Oregon to share information about construction and maintenance projects between one another. This system also feeds pertinent traveler information to the media and the public. ODOT strongly recommends all transportation agencies in Oregon actively use TLE. Contact ODOT to get started: https://www.tripcheck.com/Pages/ATCU.asp.

Public Outreach and Traveler Information

Key components of successful work zone management include public outreach during design, public outreach immediately preceding work zone activities, and traveler information while construction is underway. Public outreach can be done through many forums such as workshops, websites, social media, and partnerships with the media. Traveler information systems (see Section 18.5.6) can be used to provide work zone schedules, travel impacts, real-time or predictive travel times through work zones or alternate routes, and estimated delay.

Work Zone Traffic Incident Management

Traffic incident management (TIM) strategies (see Section 18.5.1) can be applied to specific work zones, particularly for longer-duration construction projects. This may include TIM teams for the work zone as well as incident detection sensors and camera surveillance to quickly identify incidents so a coordinated response can be initiated. Although TIM teams have not specifically been established for Oregon construction projects to date, ODOT does work closely with construction teams and is available to provide incident response as needed.

Some ODOT projects include a full-time traffic control supervisor to periodically patrol the work zone (mostly to supervise the temporary traffic control procedures) and who can also be on-call 24 hours per day. This traffic control supervisor coordinates with ODOT incident responders as needed. Some ODOT regions pre-position tow vehicles in or near work zones to support incident management and have maintenance personnel work overtime to support incident management.

Some states, such as Utah, are experimenting with performance incentives for keeping traffic moving safely and efficiently. This includes incentives for quick clearance of incidents.

Dynamic Warning Systems

A variety of dynamic warning systems can be used to detect existing traffic, vehicle, or road weather conditions and provide warnings via roadside dynamic message signs or emerging connected vehicle technologies:

- Queue or congestion warning
- Over dimension vehicles
- Work space intrusion

- Construction vehicle activities (e.g. merging, crossing, exiting)
- Hazardous road weather conditions (e.g. ice/water on road, visibility)
- Geometric conditions (e.g. curves)

Traffic Control

Beyond traditional work zone traffic control measures, these strategies may also be considered:

- Speed management (e.g. driver feedback speed advisory signs, variable speed control, automated speed enforcement)
- Dynamic merge control (see Section 18.4.2)
- Temporary ramp metering
- Adaptive or traffic responsive temporary traffic signals

ODOT has developed a mobile speed management system for stationary and moving maintenance activities that uses driver feedback speed advisory signs. Future applications aimed at improving worker safety include applications such as automated truck-mounted impact attenuators.

A variety of factors should be considered when evaluating what strategies to apply to a work zone:

- Planned construction/maintenance activities and duration:
    - For the work zone under evaluation
    - For any nearby projects that impact area mobility
    - For any projects on the same corridor that impact regional or statewide mobility
- Transportation conditions of the work zone roadways and areas of influence (e.g. parallel routes where travelers may detour):
    - Average daily traffic (including freight presence)
    - Seasonal traffic variations/factors
    - Posted speed
    - Peak period travel speeds
    - Travel time reliability
    - Average daily hours of congestion
    - Intersection traffic control devices (e.g. stop signs, traffic signals)
- Existing systematic or local TSMO strategies in place (e.g. TIM program, roadside traveler information, dynamic speed or warning systems)

Work Zone Analysis Tools

This section provides a summary of work zone analysis tools that can be used at the program level (SWIM2, WISE, CA4PRS, dynamic traffic assignment) or when analyzing specific projects (ODOT Work Zone Analysis Tool, Highway Segment Analysis, QuickZone).

Statewide Integrated Model, 2nd Generation (SWIM2)

SWIM2 is an Oregon model that allows testing of regional and statewide policies and potential projects to inform decision makers on the complex interactions between land use, the transportation network, and the economy. The SWIM2 model can be used for a bigger picture evaluation of the impacts of significant work zones and other closures. A work zone example is provided in Chapter 7 along with more details about the SWIM2 model. Additional SWIM2 information is available at https://www.oregon.gov/ODOT/Planning/Pages/Technical-Tools.aspx#SWIM. Contact TPAU for SWIM2 analysis applicability and requests.

Work Zone Impact and Strategy Estimator (WISE)

WISE was created by FHWA to support work zone planning and scheduling at the regional program level to minimize delays to the traveling public and costs to the agency. The WISE tool builds on existing traffic simulation software used by transportation agencies and MPOs. It uses basic network geometry (link/node and number of lanes) and basic traffic volume information along with a user-defined library of demand-based and duration-based strategies to determine project sequencing based on user and agency costs. Optimized project sequencing can be developed using the Operation Module, which uses TransModeler from the DynusT dynamic traffic assignment model. More information on WISE is available at https://www.fhwa.dot.gov/goshrp2/Solutions/Reliability/R11/WISE_Work_Zone_Impacts_and_Strategies_Estimator_Software

Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS)

Caltrans developed CA4PRS to help state transportation agencies and paving contractors develop construction schedules that minimize traffic delay, extend pavement service life, and reduce agency costs. The tool takes into consideration project alternatives for different pavement design, construction logistics, and traffic operations options. More information on CA4PRS is available at http://www.dot.ca.gov/research/roadway/ca4prs/index.htm

Dynamic Traffic Assignment

Some dynamic traffic assignment programs (see Sections 9.5 and 18.4.5) can be used to support decision making for regional work zone management.

ODOT Work Zone Analysis Tool

ODOT has developed a Work Zone Traffic Analysis Tool and User's Guide to determine lane closure restriction recommendations and construction delay estimates for ODOT roadways. It also includes a section for analyzing non-ODOT facilities. This tool determines when highway segment lane closures should be allowed based on traffic volumes (see Chapter 5 for developing design volumes) and free flow thresholds. Lane closures are discouraged when traffic volumes exceed free flow thresholds. Note- this tool is not designed to analyze intersection operations. The User's Guide is available at https://www.oregon.gov/ODOT/Engineering/Pages/Work-Zone.aspx

The tool can also be used to estimate delay, or the average additional travel time as a result of the work zone activities. These estimates are based on traffic microsimulation tools and regression analysis. The estimated delays can be used to help determine work zone staging and detours. ODOT has a maximum delay standard of 20 minutes. Exceptions are sometimes granted for exceeding the delay threshold.

Highway Segment Analysis

Chapter 6 includes analysis procedures for highway segments, ramps/ramp junctions, merging, diverging, weaving, and passing and climbing lanes that can be used for analysis of work zones as applicable.

QuickZone

QuickZone is a spreadsheet-based traffic analysis tool that compares the traffic impacts of work zone management strategies (e.g. project phasing, diversions, travel demand measures) for both urban and rural work zones. It looks at each strategy's impact on traffic delays, potential queues, and costs. QuickZone is available at https://ops.fhwa.dot.gov/wz/traffic_analysis/quickzone/index.htm.

18.5.5 Planned Special Event Management

Planned special events can have major impacts on travel based on when and where the event is held, how many people are in attendance, and what travel modes are available. This section describes special event management, the TSMO strategies that may be applied, and the evaluation considerations. Additional information can be found on FHWA's Traffic Management for Planned Special Events website: https://ops.fhwa.dot.gov/eto_tim_pse/about/pse.htm

The list of special events held in Oregon is a long one but typically includes happenings such as sporting events, concerts, conventions, fairs, festivals, motorcades/parades, public/political events, or heavy shopping days (e.g. Thanksgiving through Christmas). Venues can be as varied as arenas, stadiums, theaters, fairgrounds, recreational facilities, public open spaces, and public roadways closed to vehicular traffic. Event frequency also varies. Some events are one-off events (e.g. political rallies) while others occur annually (e.g. state and county fairs), seasonally (e.g. sporting events), or frequently (e.g. venues that hold a variety of events year-round).

Special event management is the application of coordinated operations strategies to inform the traveling public about travel conditions, monitor changing travel conditions, and manage travel demand associated with the planned special event. The level of effort from both a staffing and investment standpoint varies and can be scaled to the level of traffic impacts. For instance, a venue with year-round events may require more capital investments in parking systems, transit infrastructure, and traffic signal operations whereas smaller, less frequent events may have more of a focus on traveler information and smaller day-of-event traffic control (e.g. police on hand directing traffic).

The evaluation of special event management is similar to analyzing TSMO strategies for a sub-region with the primary difference being the origin-destination pairs and the time-of-day/day-of-week. A typical sub-region analysis uses home-employment origin-destination pairs whereas special events have a venue as the destination and the origin depends on when the event is held. Special event analysis also varies by both time-of-day and day-of-week whereas sub-region analysis focuses on the weekday AM and PM peak commute periods. Any of the tools in Section 18.3.6 used for TSMO evaluation can be applied to special event management. Often existing models (e.g. travel demand, simulation, traffic signal optimization) have already been developed for the area surrounding a venue for weekday commute conditions and these models can be tailored to reflect special event conditions.

The evaluation of special event management should take into consideration:

- Venue size and typical attendance
- Time-of-day and day-of-week of planned special event
- Mode split of available travel options
- Capacity impacts to roadways and transit systems for event ingress and egress
- Capacity impacts to venue parking facilities and nearby parking facilities (on-street, public facilities, and privately operated facilities)
- Impacts to traffic signals on event travel routes
- Availability of existing TSMO strategies (e.g. traveler information, surveillance systems, traffic signal systems, dynamic traffic control)
- Staff availability for events during non-standard work hours

TSMO strategies that may be considered for special event management include the following:

Stakeholder Coordination

Coordination between all applicable stakeholders can greatly improve the management of special event travel demand. Stakeholders may include transportation agencies, transit agencies, law enforcement, 911 centers, special event promoters, venue management teams, parking facility operators, media, and any sectors of the public affected by event traffic. Face-to-face meetings to coordinate in advance of the event are key and a post-event meeting to review best practices and areas for improvement is helpful for events held with some regularity. Staffing considerations are also important for all affected agencies since many events are held outside non-standard hours and special accommodations may need to be made to allow for staff support.

Temporary Traffic Control

Several temporary traffic control strategies may be considered:

- Temporary traffic control devices (e.g. temporary traffic signals, portable VMS, tubular markers, barricades) may be used to modify roadway traffic control near an event venue.
- Flaggers or law enforcement personnel may be used to help direct traffic at bottlenecks.
- Detours around the event venue may be used for commercial vehicles and other non event-related traffic.
- The standard ODOT special provisions boilerplates provide a place for construction projects to list special events that will prohibit the use of lane closures or sidewalk closures.

Surveillance

Existing and temporary systems may be used to monitor travel conditions before, during, and after a planned special event:

- Vehicle detection systems
- CCTV cameras
- Event service patrol- by foot, vehicle, or aerial surveillance

Consider making surveillance video and data available in a central location for all stakeholders.

Traffic Management Center (TMC)

An existing TMC, a satellite TMC (e.g. room at the venue), or portable TMC (e.g. traveling vehicle set up with TMC systems) may be used to manage operations for an event. This may require additional staff or the use of existing staff after hours.

Traffic Signal Operations

Many of the traffic signal strategies discussed in Section 18.4.1 may be considered for special events. In particular, special timing plans may be developed to handle event traffic that may be turned on manually from a central signal system or enabled using a trigger, such as volume thresholds from a system detector.

Dynamic Traffic Control

A variety of dynamic traffic control may be considered:

- Reversible lanes or changeable lane assignment on corridors with a dominant travel direction during event ingress or egress
- Dynamic trailblazer signs to route travelers to and from an event

- Existing dynamic traffic control already in place near the event such as variable speed control, adaptive ramp metering, dynamic merge control, dynamic warning systems, and dynamic re-routing

Transit Management

For less frequent events at venues without transit infrastructure, transit shuttle service may be considered. This service could use existing park-and-ride lots or new ones could be negotiated at public or private parking facilities, including retailers with large under-utilized parking lots. Shuttle stops or dedicated transit lanes should be considered at the venue. For venues with year-round events, permanent transit infrastructure (e.g. bus routes and stops) may be considered. Service frequency may need to be increased before and after an event to handle demand.

Parking Management

On-site and off-site parking capacity should be evaluated to determine what is needed to meet parking demand for motor vehicles and bicycles. Parking traveler information and electronic payment systems help make parking operations more efficient. Active parking management strategies (see Section 18.4.3) may also be considered: dynamic overflow transit parking, dynamic parking reservation, dynamic wayfinding, and dynamically priced parking.

Traveler Information

All available traveler information systems (see Section 18.5.6), including permanent and portable roadside VMS, should be used to provide travel impacts in advance of special events as well as to provide real-time travel conditions on the day of the event. This also includes close coordination with the media.

18.5.6 Traveler Information

Traveler information systems provide relevant information on travel options and conditions before and during travel. The intent of these services is to give travelers actionable information that can change their behavior in ways that improve the efficiency of the transportation system.[36] Traveler information strategies support many of the TSMO strategies described in this chapter, particularly the transportation demand management strategies (also called transportation options) discussed in Section 18.5.7. An overview of the types of information delivered to travelers and the various media used to do so is presented below. A discussion of considerations for implementation, and summaries of safety benefits and operational impacts of traveler information systems

[36] Chorus, C.G., Molin, E.J. and Van Wee, B., 2006. Use and effects of Advanced Traveler Information Services (ATIS): a review of the literature. *Transport Reviews*, *26*(2), pp.127-149.

follows the overview. Additional information on traveler information systems is available at:

- FHWA Real-Time Travel Information website: https://ops.fhwa.dot.gov/travelinfo/
- NCHRP Web-only Document 192: https://www.trb.org/Publications/Blurbs/168370.aspx
- NCHRP Synthesis 399: https://www.trb.org/Publications/Blurbs/161865.aspx

Overview of Information Types and Media

Common types of traveler information include:

- Alternate routes can aid travelers in making real-time route choices. Alternate routes go hand-in-hand with construction zones, special events, traffic incidents, abnormal travel times, and adverse weather.
- Congestion information can notify travelers of levels of congestion relative to normal traffic, the lanes affected, and congested roadway segments.
- Live traffic cameras record traffic conditions visually at specific camera locations. They allow travelers to see roadway conditions and make decisions accordingly.
- Parking availability information allows drivers to save time and fuel by knowing where parking options are available. It is useful primarily in dense urban areas and parking garages.
- Public safety information can include Amber alerts, Silver alerts, and evacuation information. These types of information prompt travelers to attend to or do something, for example look for a certain type of vehicle from an Amber alert.
- Road work/construction zones allow travelers to change plans by avoiding a particular area or allowing for extra travel time. Examples include locations of tree trimming, bridge closures, lane closures, and construction activities.
- Special events can disrupt normal traffic. Large events can cause road closures, traffic diversions, traffic volume changes, and changes to parking options. Recurring events like sports games can have similar effects as well. Information pre-trip and during trips can help travelers make according travel decisions.
- Traffic incident information includes incident type, times of occurrence, location, number of lanes affected, and when lanes will reopen.
- Travel times aid travelers in route, departure time, and mode decisions prior to a trip. During a trip, information on travel times to certain points can help travelers with route choices.
- Weather information includes severity of weather conditions, road closures, alternate routes, evacuation routes, and advisories to travelers (e.g. snow chains required).

Traveler information is disseminated in many ways. Some information sources are more established and readily available (e.g. radio, television) while others are newer and less widely available (e.g. smartphone apps). Sources vary in their ability to reach travelers as well. Sources like radio and television may provide information passively; travelers receive information relevant to their trip while not actively seeking it. Other sources, like websites and apps, require the user to actively seek out information. Technology innovations continue to expand the sources and flow of information. Many common information sources are described below.

- 511 phone systems allow users to simply dial 5-1-1 on the phone to hear travel information. In Oregon, most of this information is the same as displayed on TripCheck and includes roadway conditions by highway, roadway conditions for mountain passes, roadway conditions for major cities, commercial vehicle restrictions, and chain requirements.

- Mobile smartphone apps can provide a wide range of information to users to help trip planning and decision making. There is a trend toward agencies allowing private developers to access real time data to develop apps and solutions. ODOT offers the TripCheck Traveler Information Portal (TTIP) for this purpose. Example applications include Waze providing incident and detour information, Google Maps providing travel times and trip planning options, and Pango providing parking information and reservations. Smartphone technology continues to evolve: hardware improvements enhance their capabilities, and software improvements in non-transportation apps like calendars and scheduling create opportunities for traveler information to integrate with these products.

- On-board devices like TomTom, Garmin, and OnStar provide information such as alternate routes and congestion. Some of these services require a paid subscription.

- Radio is available in almost every vehicle and in some areas has more reliable coverage than cellular networks. Many radio stations broadcast travel information like closures, delays, emergencies, and adverse weather as part of news content. ODOT also utilizes Highway Advisory Radio (HAR) to broadcast warnings, advisories, directions, and other non-commercial information of importance to motorists on dedicated radio stations. ODOT provides the Guidelines for the Operation of Highway Advisory Radio and Travelers Advisory Radio on State Highways document to aid operators of HAR. The document can be found at http://library.state.or.us/repository/2007/200710231322182/index.pdf For example, HAR messages are intended to be under one minute in duration and repeated continuously so that travelers can hear the message at least twice while passing through a station's coverage area.

- Social media provides agencies with a venue to interact with travelers directly. The ODOT twitter feed (@OregonDOT) posts updates on advisories, delays, incidents, weather, road closures, and photos. There are also several TripCheck Twitter accounts that provide similar information for certain corridors (e.g.

@TripCheckUS97A). Social media also allows user-to-user exchanges of traveler information.

- Subscription-based email and short message service (SMS) messaging services allow users to receive email or text messages about weather and roadway conditions. The Amber alert and Silver alert systems use SMS messaging to disseminate information.
- Television is similar to radio in that it is widely accessible and travel information is broadcast as part of regular news coverage. But, it is limited to providing pre-trip information.
- Websites, from both public agencies and private entities, can provide every type of travel information listed above. ODOT's award-winning TripCheck website (https://www.tripcheck.com) provides summarized information by roadway and by category, real-time photos from CCTV cameras, and offers an interactive map-based platform for users to retrieve data. The TripCheck Local Entry (TLE) tool allows local agencies to input information about their roadway network to the TripCheck system. TripCheck Mobile (https://www.tripcheck.com/mobile) also provides a platform optimized for low-bandwidth and mobile phone users. TripCheck TV (https://www.tripcheck.com/tv/) provides camera images, alerts, and delays and is designed for display on televisions at public locations where travelers are waiting such as lobby areas and transit stops. Data collected on roadways are sent to the TripCheck system, and is then shared via TTIP with other information outlets like 511, the ODOT Twitter feed, and smartphone apps.
- Variable message signs (VMS) are traffic control devices along roadways that display dynamic messages containing traveler information to motorists. VMSs can be temporary (located on trucks or trailers parked along the side of roadways) or permanent (affixed to permanent supports or bridge structures). Along with variable advisory speed signs and travel time signs, permanent VMSs comprise the ODOT Real Time system. VMSs should be placed strategically at locations that allow motorists to change travel plans depending on the message, where there is sufficient sight distance, and where access to power and communications is available. ODOT provides recommendations for VMSs in the Guidelines for the Operation of Permanent Variable Message Signs document: https://www.oregon.gov/ODOT/Engineering/Docs_TrafficEng/PCMS-Handbook.pdf Connected vehicle technology is an emerging area for traveler information. As vehicle-to-vehicle and vehicle-to-infrastructure technology matures, opportunities for in-dashboard and in-vehicle travel information alerts will arise.

Considerations for Effective Deployment

NCHRP Web-only Document 192 (available at http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w192.pdf) presents results of a study on the use and deployment of traveler information systems across six regions of the US. The study provides many recommendations for successful implementation of traveler information systems. Primarily, traveler information "should be targeted, easy to use, relevant, clear, trustworthy, reliable, and accurate." The report emphasizes four main features for successful deployment:

1. Provision of information on non-recurring events in real time. Non-recurring events like traffic incidents and special events disrupt the transportation system substantially, and providing relevant information can lessen their negative impacts.
2. Dissemination across a wide array of media. Travelers have varying levels of access to information and needs, so providing many options to obtain information is beneficial. A central agency need not control all information streams, and information sharing with private entities and third parties can aid in circulation. ODOT's TripCheck Traveler Information Portal (TTIP) is a prime example of information sharing in action.
3. Aligning information with the needs and wants of the traveling public. Information providers must be aware that different travelers have different needs and wants. Trip purposes (e.g. commuting, business travel to a meeting, leisure, etc.), departure/arrival time constraints (e.g. the need to travel during peak hours), familiarity with the geographic area of travel, mode options, and market penetration of smartphones are all examples of factors that affect wants and needs for information of travelers.[37]
4. Evaluation. Traveler information programs should be evaluated to ensure they are producing desired and intended results. Data collection efforts like surveys, usage statistics, and focus groups can inform agencies about effectiveness of traveler information systems. However, a critical first step is to define performance measures that can assess whether traveler information systems meet goals.

Traveler Information Analysis Tools

The benefits of deployment of traveler information systems are well documented. The sketch planning tools described in Section 18.3.6 may be used to screen traveler information strategies. In particular, the USDOT ITS Knowledge Resources website is a repository of benefit summaries from traveler information systems. Case studies are organized by types of information sources and whether information is related to pre-trip information, en-route information, tourism, and special events. The TOPS-BC tool also provides analysis of pre-trip and en-route traveler information.

18.5.7 Transportation Demand Management

Transportation demand management (TDM), also called transportation options, includes actions or programs aimed at reducing the motor vehicle demand for transportation infrastructure, which often improves the efficiency of transportation systems. Example TDM strategies include rideshare programs, transit fare discount programs, telecommuting, and individualized trip planning. TDM strategies have long been a part of transportation planning in Oregon. Goal 2 of the *Oregon Transportation Plan* is "to

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[37] Chorus, C.G., Molin, E.J. and Van Wee, B., 2006. Use and effects of Advanced Traveler Information Services (ATIS): a review of the literature. *Transport Reviews*, *26*(2), pp.127-149.

improve the efficiency of the transportation system by optimizing the existing transportation infrastructure capacity with improved operations and management." The target strategies for achieving this goal come from TDM and transportation system management (TSM). The Oregon Transportation Planning Rule (OAR 660-012) requires urban areas with a population greater than 25,000 people to evaluate TDM and TSM strategies as part of their transportation system planning efforts. It also encourages urban fringe areas to consider low-cost TDM and TSM strategies as applicable. The Oregon Transportation Options Plan provides an overview of existing transportation options programs in use in Oregon, challenges/trends/opportunities, and policies and strategies for 10 goals to support the state's vision for transportation options. It also includes an implementation section with guidance for integrating transportation options into the planning process.

Additional information and a comprehensive description of the many available TDM strategies may be found at:

- Oregon Transportation Options Plan: https://www.oregon.gov/ODOT/Planning/Pages/Plans.aspx#OTOP
- FHWA Travel Demand Management: https://ops.fhwa.dot.gov/tdm/
- FHWA Integrating Demand Management into the Transportation Planning Process: A Desk Reference: https://ops.fhwa.dot.gov/publications/fhwahop12035/index.htm
- Victoria Transport Policy Institute's Online TDM Encyclopedia: http://www.vtpi.org/tdm/
- Drive less. Connect. (Oregon's ride-matching tool): http://www.drivelessconnect.com/
- Commuter Choice: http://www.commuterchoice.com/

The full menu of available TDM strategies is too long to list here. TDM strategies can generally be grouped as:

- Physical measures (e.g. transit or parking infrastructure)
- Operational measures (e.g. active transportation and demand management, see Section 18.4)
- Institutional measures (e.g. sustainable travel planning)
- Financial/pricing measures (e.g. congestion or parking pricing).

TDM strategies can also be grouped by type of travel choice: mode, time, location, and route. Exhibit 18-28 provides an overview of the effectiveness of the most common TDM strategies in addressing key policy objectives (mobility, congestion relief, air quality, economic development, land use interaction, goods movement, and livability). Appendix 18A includes some of the high-level TDM strategies most commonly used in Oregon. Marketing and outreach to individual travelers, businesses, and transportation agencies are all typically part of successful TDM programs.

Exhibit 18-28: TDM Strategies and Their Relative Effectiveness in Addressing Key Policy Objectives

Strategies	Mobility	Congestion Relief	Air Quality	Economic Development	Land Use Interaction	Goods Movement	Livability
Traditional TDM							
HOV/HOT Managed Lanes	◐	○	○	○	◔	◔	◔
Employer Trip Reduction Programs	◐	◔	◐	x	-	◔	◔
Alternative Work Arrangements	◐	◔	◐	◔	◔	◔	●
Individualized Marketing*	◐	◐	◔	◔	-	◔	◔
School-Based Trip Reduction	◐	◔	◐	○	○	-	●
Event-Based Trip Reduction	◐	◔	◔	○	○	◔	◔
Recreation-Based Trip Reduction	◐	◔	◔	○	○	◔	◔
Car-Sharing	◐	x	◐	◔	◔	-	◐
Ridesharing*	◐	x	◐	◔	◔	-	◐
Vanpool Programs	◔	◔	●	◔	○	◔	◔
Land Use/Active Transportation							
Developer Trip Reduction	◔	◔	◔	x	◐	-	◔
Land Use Strategies	◐	◔	◔	◔	◐	-	●
Access Management*	◐	x	x	◔	◐	◔	◔
Car-Free or Access-Restricted Zones	◔	◐	◐	x	◐	◔	●
Bicycle Facilities and Programs	◐	◔	◐	◔	◐	○	●
Pedestrian Facilities and Continuity	◐	◔	◐	◔	◐	○	●
Transit							
Transit Service Improvements	◔	◔	◐	○	◔	○	◔
Transit Prioritization/ BRT	◐	◔	◐	◔	◔	x	◔
Transit Fare Discounts	◔	◔	◐	◔	◔	x	◔

Strategies	Mobility	Congestion Relief	Air Quality	Economic Development	Land Use Interaction	Goods Movement	Livability
Parking							
Parking Information	◐	◔	◔	◔	◔	◔	◔
Parking Supply Management	x	◐	◐	x	◐	-	◐
Parking Pricing	x	◔	◐	x	◐	◔	◐
Pricing							
Cordon Pricing	x	●	●	○	◔	◐	○
Congestion Pricing	x	●	●	○	◔	◐	○
General Financial Incentives	●	◔	●	◐	◔	◐	◔
Vehicle Miles Traveled (VMT) Tax	x	●	●	x	◐	◐	○
Systems Management							
Traffic Signal Optimization*	◐	◐	◔	x	-	◔	x
Ramp Metering	x	◐	x	-	-	◔	x
Traffic Incident Management*	◐	◐	◔	-	-	◔	x
Integrated Corridor Management	◔	◔	○	○	-	◐	-
Traveler Information	◐	◐	◔	◔	-	◔	◔
Eco-Driving	-	x	◔	x	x	◐	◐

Key: ● = highly effective; ◐ = moderately effective; ◔ = nominally effective; ○ = likely effective (but undocumented);
x = minimal to no impacts; - = not applicable

Source: *Integrating Demand Management into the Transportation Planning Process: A Desk Reference*. FHWA-HOP-12-035. Table 10.6

* Strategy was not evaluated in the FHWA Desk Reference but is commonly used in Oregon.

The evaluation of TDM strategies should take into consideration:

- Mode split
- Person throughput on key facilities or corridors
- Ratio of travel times on all travel options to one another
- Vehicle miles traveled and vehicle trip reduction
- Emission reduction

- Transit ridership
- Rideshare program usage
- Parking utilization
- Breakdown of employment by location
- Enrollment in employee incentive programs
- Demand estimates based on parking or tolling costs
- Satisfaction with travel options and incentives to use them

TDM Analysis Tools

The typical tools for analyzing TSMO strategies discussed in Section 18.3.6 have limited ability to evaluate TDM strategies. Emerging TDM strategies, such as rideshare programs, may have a big impact on transportation demand but the extent of that impact are still unknown.

Tools that may be used to evaluate TDM:

- Travel Demand Models: Some planners in Oregon apply trip reduction factors in travel demand models based on data from the Oregon Department of Environmental Quality's *Guidance for Estimating Trip Reductions from Commute Options* (1996) to represent TDM strategies.
- Trip Generation Rates: Section 6.6 of this APM talks about incorporating TDM into trip generation rates. Sections 9.4.3 and 10.3.2 discuss considering TDM strategies as a part of the future transportation alternatives analysis.
- Regional Strategic Planning Model (RSPM) (See Sections 7.6 and 18.3.6): The RSPM may be used as a screening tool to understand the tradeoffs and first order average day impacts of non-auto modes.
- Worksite Trip Reduction Model (WTRM) (https://www.nctr.usf.edu/pdf/473-14.pdf): This sketch-planning tool uses either an online worksheet or look-up tables to predict the changes in vehicle trip rates or parking rates for TDM strategies.
- EPA COMMUTER Model (http://www.nctr.usf.edu/clearinghouse/software.htm): This basic computer model is 20 years old and calculates the transportation and emissions benefits based on TDM incentives (e.g. public transportation service improvements) and disincentives (e.g. parking charges). This program relies heavily on professional judgment.
- Trip Reduction Impacts of Mobility Management Strategies (TRIMMS) (http://trimms.com/): This tool is a visual basic application spreadsheet that estimates the impacts of TDM strategies, including their benefit-cost ratios.
- Business Savings Calculator (https://www.bestworkplaces.org/resource/calc.htm): This web-based calculator helps employers considering commuter options to calculate the financial, environmental, traffic-related, and other benefits.

18.5.8 Connected and Automated Vehicles

Rapidly emerging connected and automated vehicle technologies are posed to disrupt long-standing practices in planning, designing, maintaining and operating the transportation system. While ODOT is taking initial steps to understand and prepare for the coming changes, the state of the practice for analysis procedures related to this new transportation paradigm is thin. This sub-section provides an overview of Connected and Automated Vehicles (CAV) as currently understood. For more information on connected and automated vehicle, see USDOT ITS Joint Program Office website.

Connected vehicles include on-board technology that enables communication with their environment using a variety of different wireless communication technologies as appropriate to the level of communication needed. Depending on the application, dedicated short range communication (DSRC), cellular, or Wi-Fi communications may be appropriate. Connected vehicles can “talk” to:

- Other vehicles on the road, termed Vehicle to Vehicle (V2V)
- Roadside infrastructure, like traffic signals, termed Vehicle to Infrastructure (V2I)
- Everything else, like mobile devices, termed Vehicle to Everything (V2X)

Automated vehicle technology is focused on removing the driver (partially or entirely) from controlling the vehicle’s operations. National Highway Transportation Safety Administration (NHTSA) identifies five levels of automation[38]:

- **No-Automation (Level 0):** The driver is in complete and sole control of the primary vehicle controls – brake, steering, throttle, and motive power – at all times.
- **Function-specific Automation (Level 1):** Automation at this level involves one or more specific control functions. Examples include electronic stability control or pre-charged brakes, where the vehicle automatically assists with braking to enable the driver to regain control of the vehicle or stop faster than possible by acting alone.
- **Combined Function Automation (Level 2):** This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions. An example of combined functions enabling a Level 2 system is adaptive cruise control in combination with lane centering.
- **Limited Self-Driving Automation (Level 3):** Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time. The second-generation Google car is an example of limited self-driving automation.

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38 http://www.nhtsa.gov/About+NHTSA/Press+Releases/U.S.+Department+of+Transportation+Releases+Policy+on+Automated+Vehicle+Development

- **Full Self-Driving Automation (Level 4):** The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles. The third-generation Google car is an example of full self-driving automation. **Vehicles with level 4 automation may also be referred to autonomous vehicles.**

CAV aim to benefit transportation in three areas:

- Safety: CAV may reduce crashes and injuries by providing tools to drivers and vehicles to better anticipate and prevent a crash, or if a crash is imminent, the technology could provide adjustments to minimize injuries.
- Mobility: CAV technology can provide information to transportation system users and operators that allow them to make informed choices and reduce travel delay. Automated vehicles may open more mobility options for disabled and aging populations, and expand last mile connections for transit. The automated parking feature may reduce the number of vehicles circulating in search of parking and potentially decrease the allocation of space for vehicle parking.
- Environment: CAV technology can enable drivers (and vehicles) to use real time information to operate more efficiently to reduce energy use and emissions.

These are developing technologies, and although the systems are not yet mature, agencies should begin preparing for the impacts of CAV technologies on the transportation system. Ways to prepare include but are not limited to:

- Assessing the impacts on planning practices and processes:
    - How will travel demand models consider CAV effects?
    - How will longer term road capacity needs be re-assessed?
    - What are the effects to funding and programming?
    - What are the equity impacts of CAVs?
    - How will vehicle ownership patterns change?
- Assessing impacts on infrastructure
    - What are the impacts on signing and striping?
    - Do lane widths change?
    - What are the effects on traffic control systems?
    - What road side infrastructure, including communications, is needed in the future?
    - How is the design and use of curb space impacted?
    - How are transit, bicycles and pedestrian facilities impacted?
- Assessing the impacts on agency operations:
    - What workforce skills are needed?
    - How does this change licensing, regulations, and enforcement policies and procedures?
    - How are procurement processes updated to support new public-private partnerships?

Connected Vehicle Analysis Tools

USDOT is supporting research and developing guidance to help agencies consider and plan for connected and automated vehicles. The Connected Vehicle Reference Implementation Architecture (CVRIA) tool is directed at incorporating CAV into ITS architectures.[39] The tool includes information about the many CAV applications being developed such as eco-traffic signal timing, eco-multimodal real-time traveler information, and eco-smart parking. It identifies the various categories of information flows; standards necessary for implementation; and other resources to support integration into ITS architectures. USDOT has also supported the development of a software tool, Systems Engineering Tool for Intelligent Transportation (SET-IT)[40], which links drawing and database tools with the CVRIA to visualize the architecture elements and information flows.

Appendix 18A – Summary of TSMO Strategies

[39] https://local.iteris.com/cvria/html/about/about.html
[40] https://local.iteris.com/cvria/html/resources/tools.html