Transportation Systems Management & Operations

Study Guidebook

April 2020

Prepared for:
Ohio Department of Transportation

Prepared by:
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1 Introduction

The mission of the Ohio Department of Transportation (ODOT) is to provide the easy movement of people and goods by making the system work better and improving safety. Fundamental to achieving that mission is ODOT’s Transportation Systems Management and Operations (TSMO) Program. TSMO is an evidence-based process for identifying issues and applying the most effective countermeasures. This Guidebook covers that process. The intended audiences include ODOT’s Office of Traffic Operations, Office of Traffic Management, Districts and consultants supporting efforts to improve safety and mobility throughout Ohio.

The objective of a TSMO Study is to develop a high-level assessment of needs and solutions. The study results are then used in the prioritization process. This leads to funding the most effective improvements.

A basic TSMO Study must clearly outline the issues and present alternative improvements (not just a single idea). The expectation is for roughly eight to 12 person-hours of effort to prepare. For those familiar with ODOT Safety Studies, this is analogous to an “abbreviated” study, versus a “full” study. While there is no requirement to produce a “full” TSMO Study, there are no arbitrary restrictions on the volume of additional alternatives or analyses that may be included in a TSMO Study.

1.1 TSMO Study Components

There are five major components for TSMO Studies decision-making. Figure 1 summarizes these components. A key part of needs identification is the Traffic Operations Assessment Systems Tool (TOAST). The TOAST has been central to the genesis of this overall process since its initial development in 2018; the TOAST will be explained further in the following chapter.

Figure 1. TSMO Study Components

<table>
<thead>
<tr>
<th>Guidebook</th>
<th>Explains process</th>
<th>Provides details and guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needs Identification</td>
<td>TOAST</td>
<td>Other considerations</td>
</tr>
<tr>
<td>Countermeasures</td>
<td>List of 15 viable TSMO tactics</td>
<td>Incorporated into Guidebook and benefit-cost (B/C tool)</td>
</tr>
<tr>
<td>Assessment</td>
<td>B/C tool (new)</td>
<td>Other available tools</td>
</tr>
<tr>
<td>Resourcing</td>
<td>Project prioritization</td>
<td>Funding allocation</td>
</tr>
</tbody>
</table>

The TSMO Study process begins with accurate identification of safety and operational needs, leveraging a wealth of available data. It culminates with an improvement (countermeasure) targeted at a specific road segment or corridor, with resources identified for implementation.
Highway Safety Funding

A TSMO Study presumes that any segment with an apparent safety issue has already been evaluated for funding through ODOT’s Safety Program. This is especially true if the TOAST safety metric scored poorly for any segment within the TSMO Study boundaries has scored poorly. Separate safety evaluations for safety - prior to a TSMO Study - should follow ODOT’s Division of Planning Safety Analysis Guidelines and should use ODOT’s Geographic Information Systems (GIS) Crash Analysis Tool (GCAT) and/or Economic Crash Analysis Tool (ECAT). See ODOT’s Highway Safety Improvement Program (HSIP) for current guidance and tools.

An overview of the TSMO Study process is shown in Figure 2 below. Along the top, in orange, key inputs and new resources are shown, which feed into the process shown left to right along the bottom.

Figure 2. TSMO Study Process Overview

The process always begins with identifying operational needs on segments or corridors. These needs may already be apparent from observation or feedback. They may also be revealed (e.g., via TOAST) or supported through data-driven analysis. The upper left two boxes in Figure 2 show a non-exclusive list of considerations for needs identification.
Two new important resources are this Guidebook and the TSMO B/C Evaluation Tool, each shown with a red outline in the figure above. In addition to covering the entire TSMO study process, the Guidebook contains information on some of the most viable TSMO countermeasures that should be considered. The guidebook also introduces the B/C Tool.

The B/C Tool is a new high-level decision support resource to help assess alternative countermeasures. It is not meant to exclude more detailed B/C analysis, e.g., using Tool for Operations Benefit Cost Analysis (TOPS-BC); nor exclude related evaluations with other tools or for other improvements not included within the B/C Tool. This is explained further in the chapter on B/C analysis.

TSMO Studies, like their safety study counterparts, will in most cases satisfy the Planning Phase of ODOT’s Project Development Process (PDP). This is due to the alternative analysis that has been included in the study process outlined in Chapter 5. Depending on the complexity of the recommendation, it is likely to satisfy feasibility study requirements. All TSMO studies are different therefore it is important to include the District environmental coordinator or a representative from the Office of Environmental Services in any discussions before moving a recommendation beyond the Study. In some cases, recommendations may require further detailed study of alternatives or additional public involvement in order to move further through the PDP. In all cases, this coordination will yield a more complete scope of services for implementation.

1.2 Guidebook Overview

The remainder of this guidebook is organized as follows:

- **Chapter 2. Needs Identification** - the next chapter provides an overview of identifying operational needs, with an emphasis on TOAST, its inputs and its outputs
- **Chapter 3. TSMO Countermeasures** - introduces a curated set of TSMO technologies and strategies that may be considered for application
- **Chapter 4. Prioritization & Resourcing** - outlining the application and prioritization process that leads to funding specific TSMO improvements
- **Chapter 5. TSMO Study Process** - further defines the TSMO Study process, the Study outline and components
- **Chapter 6. Economic Evaluation** - overview of the TSMO B/C Tool that is provided as a separate Excel workbook
- **Appendices** - containing more detail on the TOAST metrics, TSMO countermeasures and examples for TSMO Studies

1[https://ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm](https://ops.fhwa.dot.gov/plan4ops/topsbctool/index.htm)

2TOAST segments are based on ODOT’s Roadway Information System and are subdivisions of Network Linear Feature Identifier (NLF_ID) segments
2 Needs Identification

Many roadway and operational conditions will benefit from TSMO improvements. The process described in this Guidebook does not preclude ODOT from identifying needs other ways. The TOAST is the most prominent and data-driven mechanism, but other situations will also call for attention. For example, a weather-related concern (e.g., fog or ice) on a specific segment may not score high in TOAST but may benefit substantially from new weather monitoring and motorist warning technologies. Another example is adjacent traffic signals in neighboring jurisdictions that are not operating well together and can benefit from better timing or coordination. ODOT District staff are not limited to the TOAST rankings and are encouraged to leverage local knowledge for proposing TSMO improvements.

2.1 TOAST

The chief motivation for ODOT developing TOAST in 2018 was to provide a consolidated measure of operational needs at the segment level across highways throughout Ohio. The State Priority System included with TOAST covers several hundred routes in all 88 Ohio counties. The 2019 version of TOAST has over five thousand segments. The median length of these segments is about two miles, though they may be as short as a tenth of a mile or as long as dozens of miles. This Guidebook and the TSMO countermeasures are intended to target specific trouble spots. TSMO Studies are not amenable for very long roadway sections or more systematic issues. TOAST currently (in 2018 and 2019) brings in seven different inputs, described below. Values within each metric have 11 possible scores, zero to 10. Lower scores are worse. If an input value is missing, the score is assigned a 10 (perfect score). Each input category is given a fixed weight, ranging from 7.5% to 25%, summing to 100%. For each of the roughly 6,000 bi-directional segments statewide, a single consolidated measure is presented as a percent, with lower values being worse. The histogram in Figure 3 shows a summary of the resulting consolidated scores from 2019.

Figure 3. TOAST Consolidated Score
The operational issues identified by TOAST follow an expected spatial pattern, as depicted in the maps shown in Figure 4. The red segments (left) and the larger circles (right) correspond to lower aggregate TOAST scores. Each of the seven input metrics have a different pattern.

Figure 4. Example View of Statewide TOAST Summary Scores
Table 1 summarizes the seven input metrics. Each row includes a range and average for the input data, the weighting (“Wgt”) applied and an availability (“Avail”) percent (i.e., the number of segments with data) the remaining segments without data are assumed to mean there are no operational issues and are given a perfect score.

Table 1. TOAST Input Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
<th>Range</th>
<th>Avg</th>
<th>Wgt</th>
<th>Avail</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottlenecks</td>
<td>Minutes x length x annual occurrences when speeds below 65% of free-flow for at least two minutes</td>
<td>0 to 596k</td>
<td>8,817</td>
<td>25%</td>
<td>87%</td>
<td>92% of segments have perfect scores</td>
</tr>
<tr>
<td>Travel Time</td>
<td>% of time motorists can travel within 90% of free-flow speed; data from Inrix</td>
<td>0% to 99.9%</td>
<td>82.2%</td>
<td>20%</td>
<td>80%</td>
<td>26% of segments have perfect scores</td>
</tr>
<tr>
<td>Safety</td>
<td>Crashes per year per mile; Potential for Safety Improvement by Density (PSID)</td>
<td>0 to 1,221</td>
<td>18.0</td>
<td>15%</td>
<td>100%</td>
<td>45% of segments have PSID=0</td>
</tr>
<tr>
<td>Volume</td>
<td>Average annual daily traffic (AADT) per lane</td>
<td>0 to 38,890</td>
<td>5,033</td>
<td>15%</td>
<td>100%</td>
<td>39% receive score of 15 (low volume)</td>
</tr>
<tr>
<td>Freight Corridor</td>
<td>% truck traffic</td>
<td>0% to 51%</td>
<td>10.0%</td>
<td>10%</td>
<td>100%</td>
<td>Segments with 20%+ given score of 0</td>
</tr>
<tr>
<td>Incident Clearance</td>
<td>Average elapsed time (minutes) from report to cleared scene</td>
<td>11 to 744</td>
<td>78.7</td>
<td>7.5%</td>
<td>82%</td>
<td></td>
</tr>
<tr>
<td>Secondary Crashes</td>
<td>% of total crashes occurring due to previous incident</td>
<td>0% to 50%</td>
<td>5.3%</td>
<td>7.5%</td>
<td>71%</td>
<td>73% of segments have perfect scores</td>
</tr>
</tbody>
</table>
TOAST results are primarily made available in an Excel workbook, allowing users to explore and filter results for their own purposes. Figure 5 shows an excerpt. Multiple reports are also furnished, presenting results by ODOT District, urban vs. rural and functional class.

Figure 5. Excerpt Example TOAST Results Table

Improvements are underway to improve mapping and visualization of TOAST results. For each TOAST segment, included hyperlinks let users click through to see the location on Google Maps or via PathWeb. Hyperlinks are included shows an excerpt for each segment to see the location on Google Maps or via PathWeb. Figure 6 shows an example of the PathWeb.

Figure 6. Example PathWeb View for a TOAST Segment

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3See results and more information at http://www.dot.state.oh.us/Divisions/Operations/Traffic-Management/Pages/TOAST.aspx

4https://PathWeb.pathwayservices.com/ohiopublic/
The TOAST Excel workbook provides users with all of the metrics. Users can also filter and sort by need in the workbook. The results can also be brought into other programs for analysis or combined with other datasets for more in-depth assessment (e.g., joining with GCAT results on segment IDs).

Supporting the results table is a statewide map as well as a series of maps for each district and county. All segments are color coded according to their summary TOAST score (percentage), with those below 55% colored red (for 2019). Figure 7 shows District 7 and Shelby County.

Figure 7. Example TOAST Maps (District 7, Shelby County)

Deciding what a “good” TOAST result is versus a “bad” result is somewhat subjective, but the numbers provide guidance. For the overall score, referring back to Figure 3, observe that half of all segments fall within a range of 65% to 85%. Therefore, if a segment in question is scoring below 65%, it is already among the worst performing quarter of segments.

Results, maps, and all TOAST resources at http://www.dot.state.oh.us/Divisions/Operations/Traffic-Management/Pages/TOAST.aspx

5Results, maps, and all TOAST resources at http://www.dot.state.oh.us/Divisions/Operations/Traffic-Management/Pages/TOAST.aspx
For reference, sets of results distributions (histograms) are provided and broken down for each TOAST metric in Appendix A. These are important to refer to because, in some cases, a result just less than the maximum value may still be very good (e.g., freight corridors or incident clearance) and in other cases already quite poor (e.g., bottlenecks or safety). Figure 8 shows two examples.

Figure 8. Example TOAST Metric Distributions (Statewide)

How the TOAST metrics are included in the TSMO Study is left largely to district discretion and may be guided by the nature of the safety or operational issue. There is additional guidance in Chapter 5 and Appendix B.
3 TSMO Countermeasures

TSMO includes a wide range of strategies, tactics and other potential improvements. The curated set of countermeasures included here are those that have been refined through ODOT staff input, existing and emerging implementations and vetting by advisory committees.

The countermeasures generally exclude:

- Temporary strategies (e.g., for work zones)
- Those primarily for security (e.g., infrastructure monitoring) or safety (e.g., rumble strips or wrong way driver detection)
- Improvements restricted by current policy (e.g., tolling or automated enforcement)
- Technologies not yet widely available (e.g., many connected vehicle applications)
- Non-localized process or programmatic approaches

Those that fall into statewide or programmatic approaches include traffic incident management (TIM) training, freeway service patrol (FSP) coverage expansion, general traffic signal maintenance and detection and surveillance technologies. While these should always remain viable strategies for consideration, they are often targeted at spot locations of the nature assumed for TSMO Studies.

The items listed in this chapter are neither exhaustive nor intended to preclude consideration of other TSMO strategies. For example, high occupancy vehicle lanes are sometimes a viable TSMO strategy. However, the context is specific and the implications often more complex than what would be considered for a typical TSMO Study. Similarly, there will inevitably be locally specific options worth proposing, e.g., minor or specific infrastructure improvements to improve operations, intersection movement control by time of day or adjacent to a rail crossing and innumerable other possibilities.

Although ramp metering is included in the list of countermeasures, metering is not viable as an isolated application and is subject to corridor metering and ODOT policy, guidance, and warrants (forthcoming).

Table 2 shows that the countermeasures fall into one of a handful of TSMO categories. The table includes a column noting key TOAST metrics that - if poorly scoring - indicate this category of countermeasures should be considered, while recognizing that any countermeasure can potentially improve any TOAST metric.
### Table 2. TSMO Countermeasure Categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Countermeasure</th>
<th>TOAST Metrics</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traveler Warning and</td>
<td>Destination Dynamic</td>
<td>Travel Time</td>
<td>Monitoring conditions and vehicles, providing real-time alerts or</td>
</tr>
<tr>
<td>Information Systems</td>
<td>Message Signs</td>
<td></td>
<td>guidance to motorists</td>
</tr>
<tr>
<td>(TWIS)</td>
<td>Detection Based Driver</td>
<td>Secondary Crashes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Warning - Curve and Intersection</td>
<td>Safety</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dynamic Message Sign</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Environmental Detection and Warning</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Queue Warning System</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic Flow Management</td>
<td>Managed Lanes / Hard Shoulder Running</td>
<td>Travel Time</td>
<td>To maximize use of availability capacity, improve throughput, reduce delay</td>
</tr>
<tr>
<td></td>
<td>Speed Harmonization</td>
<td>Volume</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Variable Speed Limits</td>
<td>Freight Corridors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ramp Metering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roadway Improvements</td>
<td>Reversible Lanes</td>
<td>Travel Time</td>
<td>Adapting or modifying infrastructure for changed usage by time of day,</td>
</tr>
<tr>
<td></td>
<td>Truck or Bus Only Lanes</td>
<td>Bottlenecks</td>
<td>direction or vehicle type; this category</td>
</tr>
<tr>
<td></td>
<td>Auxiliary Lanes</td>
<td>Volume</td>
<td>may also include other minor infrastructure improvements</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal Operations</td>
<td>Traffic Signal Improvements - Retiming, Rephasing</td>
<td>Any, but specific to</td>
<td>Specific attention to improving intersection flow through a variety of tactics</td>
</tr>
<tr>
<td></td>
<td>Traffic Signal Improvements - Coordination</td>
<td>signalized intersections</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interagency Signal Operations / Coordination</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Remember, that if the TOAST metric for safety is particularly poor (e.g., a score less than 7.5 out of 15, which puts it in the bottom quarter), the segment should have already been evaluated via a Safety Study and proposed for improvement funding from the Safety Program.

Table 3 on the following pages summarizes the countermeasures, primary characteristics and considerations for applicability. The last two columns indicate what additional, but optional, capacity or safety evaluation may be considered for different countermeasures. These evaluations should be performed to ensure the identified countermeasure will successfully mitigate the known safety or capacity concerns at the study location. For more information regarding how to perform the required analyses, please refer to ODOT’s Analysis and Traffic Simulation (OATS) Manual or Safety Analysis Guidelines. While the additional capacity and safety analyses are not required to be performed at the TSMO study phase, the analysis will be required as part of a feasibility study before implementation of the proposed countermeasure.
<table>
<thead>
<tr>
<th>TSMO Countermeasure</th>
<th>Description</th>
<th>Key Benefits</th>
<th>Order of Magnitude Cost</th>
<th>Geographic Application</th>
<th>Influencing Factors</th>
<th>Data Needs</th>
<th>Possible Capacity Eval.</th>
<th>Possible Safety Eval.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination Dynamic Message Signs (DDMS)</td>
<td>A hybrid subtype of DMS dedicated to alternate route travel times, installed prior to decision points or freeway entries (see p. 36)</td>
<td>• Improved mobility • Increased traveler satisfaction</td>
<td>Low</td>
<td>• Urban • Rural</td>
<td>• Multi-agency partnerships • Commitment to keeping information up to date</td>
<td>Varies by system • As many data sources that are available</td>
<td>None</td>
<td>Basic</td>
</tr>
<tr>
<td>Detection Based Driver Warning - Intersection Warning</td>
<td>Local monitoring for speeds, obstructions, limited sight distance, ice, animals, etc., with alerts to drivers and others at risk</td>
<td>• Improved safety</td>
<td>Low - Medium</td>
<td>• Rural, high right-angle intersection crash locations • In time, urban via CV</td>
<td>Manual of Uniform Traffic Control Devices compliance</td>
<td>Crashes of nature influenceable by warnings</td>
<td>None</td>
<td>Basic (No dependable CMF)</td>
</tr>
<tr>
<td>Dynamic Message Signs (DMS)</td>
<td>Permanent overhead or roadside sign, for real-time traveler information and warnings, controlled from TMC (see p. 39)</td>
<td>• Improved mobility • Increased traveler satisfaction</td>
<td>Medium</td>
<td>• Urban spot locations • Rural spot locations • Near alternate routes where events regularly impact route choice</td>
<td>Right-of-way often hard to obtain for urban arterials • Power and communications not always nearby communications not always nearby</td>
<td>Direct communications to a TOC or leased cellular connection</td>
<td>None</td>
<td>Basic</td>
</tr>
<tr>
<td>Environmental Detection and Warning</td>
<td>Installation of sensors in shoulders or using video detection to monitor flooding or other spot weather impacts, warning motorists via signs and other traveler information (see p40)</td>
<td>• Improved safety</td>
<td>Low - Medium</td>
<td>• Locations with frequent fog, snow, or ice • Low-water crossing</td>
<td>High crash/incident locations related to weather</td>
<td>Air and road weather conditions</td>
<td>None</td>
<td>Basic</td>
</tr>
<tr>
<td>Hard Shoulder Running (HSR)</td>
<td>Includes inside/outside hard shoulder running or part time shoulder use, installation of dynamic lane control signs (see p42)</td>
<td>• Improved safety • Improved mobility</td>
<td>High</td>
<td>• Urban facilities • Rural facilities</td>
<td>Sufficient and accurate data collection is important for bottleneck analysis and mitigation</td>
<td>Inputs for capacity analysis</td>
<td>Transmodeler</td>
<td>ECAT</td>
</tr>
<tr>
<td>Queue Warning System (QWS)</td>
<td>Temporary, portable, or truck - mounted dynamic message signs for traveler warning of queues ahead (see p43)</td>
<td>• Improved safety</td>
<td>Medium</td>
<td>• Urban facilities • Rural facilities</td>
<td>Crash history • Analysis</td>
<td>Vehicle demand volume, speed, and occupancy</td>
<td>None</td>
<td>ECAT CMF 76 0.84 for Rear End A,B,C crashes</td>
</tr>
<tr>
<td>TSMO Countermeasure</td>
<td>Description</td>
<td>Key Benefits</td>
<td>Order of Magnitude Cost</td>
<td>Geographic Application</td>
<td>Influencing Factors</td>
<td>Data Needs</td>
<td>Possible Capacity Eval.</td>
<td>Possible Safety Eval.</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>--------------------------------</td>
<td>-------------------------</td>
<td>------------------------</td>
<td>--------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Ramp Metering</td>
<td>New or expanded ramp metering coverage, upgraded ramp control, e.g., coordinated, or from static to dynamic (see p44)</td>
<td>• Improved mobility</td>
<td>Low - Medium</td>
<td>Urban freeway</td>
<td>• Public perception • Queue mitigation on metering</td>
<td>• Vehicle demand volume, speed, and occupancy</td>
<td>Transmodeler</td>
<td>Basic</td>
</tr>
<tr>
<td>Reversible Lane</td>
<td>Adding reversible lanes, arterials or freeways (see p45)</td>
<td>• Improved safety • Improved mobility</td>
<td>High</td>
<td>Urban • Rural</td>
<td>• Multi-agency coordination • New technology capabilities and limitations</td>
<td>• Vehicle demand volume, speed, and occupancy</td>
<td>High - Medium</td>
<td>ECAT</td>
</tr>
<tr>
<td>Speed Harmonization</td>
<td>Promoting consistent speed limits through corridor, either posted speed limit adjustments or harmonization strategies, regulator or advisory (see p46)</td>
<td>• Improved mobility</td>
<td>Medium - High</td>
<td>Urban limited access facilities</td>
<td>• Enforcement • Driver education</td>
<td>• Volumes • Hours of operation</td>
<td>Transmodeler</td>
<td>ECAT</td>
</tr>
<tr>
<td>Traffic Signal Improvements (Retiming)</td>
<td>A range of possibilities, e.g., coordination, communication, phasing changes, adaptive control, dual red signal heads, flashing yellow arrow (FYA), new or upgraded detection, actuation, etc. (see p48)</td>
<td>• Improved mobility</td>
<td>Low</td>
<td>Urban traffic signals</td>
<td>• Understanding new technology, capabilities, and limitations</td>
<td>• Vehicle demand volume, speed, and occupancy</td>
<td>HCS</td>
<td>Basic</td>
</tr>
<tr>
<td>Traffic Signal Improvements (Coordination)</td>
<td>Installation of or adaptation for bus only or truck only lanes, includes modification for truck lane restrictions (see p49)</td>
<td>• Improved safety • Improved mobility</td>
<td>Medium - High</td>
<td>Urban (bus) • Rural (truck) • High bus or truck volumes or crash rates</td>
<td>• Available right-of-way • Enforcement • Grades</td>
<td>• Volumes, by class • Crash rates</td>
<td>Transmodeler</td>
<td>Basic</td>
</tr>
<tr>
<td>TSMO Countermeasure</td>
<td>Description</td>
<td>Key Benefits</td>
<td>Order of Magnitude Cost</td>
<td>Geographic Application</td>
<td>Influencing Factors</td>
<td>Data Needs</td>
<td>Possible Capacity Eval.</td>
<td>Possible Safety Eval.</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------------</td>
<td>--------------</td>
<td>-------------------------</td>
<td>------------------------</td>
<td>---------------------</td>
<td>------------</td>
<td>------------------------</td>
<td>----------------------</td>
</tr>
</tbody>
</table>
| Variable Speed Limit (VSL) | Enables lower regulatory speeds during adverse conditions or congestion, permanent installation (see p50) | • Improved safety
• Improved mobility | Medium | Urban
Rural | • Multi-agency coordination
• New technology capabilities and limitations | • Vehicle demand volume, speed, and occupancy
• Incident information
• Air and road weather conditions
• Event times and information | Transmodeler
CMF 8730
0.71 for all urban crashes |
| Auxiliary Lanes | Full width lane extending an on or off ramp, or continuous between interchanges, improving operations from speed changes, weaving, maneuvering, or queuing (not included with B/C Tool) | • Improved safety
• Improved mobility | Medium | Limited access facilities, where demand, congestion, or grades are an issue | Available right-of-way | • Vehicle demand volumes for exits, entrances, and through traffic
• Lane geometry | HCS
ECAT |
4 Prioritization & Resourcing

In 2019, ODOT created a dedicated funding source for TSMO projects and project development. The initial funding was small, meant to seed several pilot efforts and intended to test the overall process and program’s results. It is important to note that if the identified issue is a safety issue or involves a large safety component, then Safety Integrated Project (SIP) maps should be reviewed to check for any already identified safety priority. A Highway Safety Improvement Program (HSIP) application should be pursued prior to TSMO funding as shown in Figure 10. Depending on the TOAST output or other available data, Districts should either perform a safety study including TSMO considerations or TSMO Study.

4.1 Objective

The primary objective of TSMO Program funding is to fund and quickly deploy capital improvements to congested segments of roadway. As described in Chapter 2, these are often roadway segments or locations identified by the TOAST but can also be hot spots or needs identified by District staff.

4.2 Eligible Activities

Example projects and project development activities that the program is currently targeting include:

- ITS Devices and Incidentals
- Preliminary Engineering
- Environmental
- Detailed Design
- Right of Way
- Construction

4.3 TSMO Funding Cycle Timeline

Figure 9 illustrates key points in the annual TSMO process and funding cycle. Of note is that application deadlines have been purposely set to follow the announcement of the HSIP - funded projects. This will allow applicants to attempt to fund their project through HSIP first and then the TSMO Program, recognizing that TSMO will be actively considered in all Safety Studies.

http://www.dot.state.oh.us/Divisions/Planning/ProgramManagement/HighwaySafety/HSIP/Pages/MapRoom.aspx
4.4 TOAST/TSMO Location Evaluation Process

As the primary identifier of operations related deficiencies, the TOAST will be run annually each August. The resulting list of locations will be published each September. Figure 10 outlines the following process that will be followed to evaluate the priority locations identified by TOAST and the District staff. District TSMO Coordinators are members of each District Safety Review Team (DSRT) and will be involved in the process from segment identification through countermeasure evaluation.

Figure 10. TOAST/TSMO Location Evaluation Process

- **Annual TOAST List Released**

- **Segment Has High Crash Rate, Severity or on SIP Map?**
  - **YES**
    - Apply for HSIP
  - **NO**
    - District TSMO Coord Performs Abbreviated Studies

- **District TSMO Group DSRT Evaluates Countermeasures**

- **Programmed Project Scheduled?**
  - **YES**
    - Include TSMO in that Project
  - **NO**
    - Apply For TSMO Capital Funding
4.5 TSMO Capital Funding Application Review Process

TSMO capital funding requests will be screened for two initial thresholds:

1. Applications for device purchase or construction $\leq$ $100k may be evaluated by the Program Manager and any subject matter expert (SME). They may happen at any time during the annual cycle. These are meant to be quick fixes or enhancements.

2. Applications $\geq$ $12M and that add capacity shall be evaluated by the Transportation Review Advisory Council (TRAC).

All requests that fall between the above thresholds will be evaluated by the process outlined in Figure 11:

Figure 11. Funding Application Review Process

- District Submits Project Prior to Deadline
- District Presents Projects to Committee
- Committee Ranks and Prioritizes Projects for Funding
- Fund Project and Implement Improvements
- One page project summary abbreviated TOAST study supporting documentation
- Brief presentation/Q&A similar to safety applications
- Committee Members:
  - District TSMO Coordinators
  - TSMO PM
  - Office of Traffic Management Admin
  - Office of Roadway Engineering Admin
  - Highway Safety
  - Construction Alternative Del
- Criteria:
  - Benefit: Cost TOAST
  - Ranking TOAST Metric(s)
  - Volume: Capacity Expected
  - TOAST Improvement
5 TSMO Study Process

The following subsections outline the components that should be included in a TSMO Study. Examples of each of the following components can be found in Appendix C.

5.1 Title Page
The report shall have a title page that identifies the district, county, route, section, study completion date, a location map and the name of the consultant or others preparing the report.

5.2 One-Page Project Summary
The report shall have a one-page project summary including basic project information, site map, the overall TOAST score and its year and the individual TOAST scores (there are seven as of 2019). The one-page summary will capture the issues or needs, and the identified countermeasures to improve operations at the location using TSMO or other strategies. The benefit-to-cost ratios for the improvements should also be identified on the summary sheet.

5.3 Existing Conditions
5.3.1 Purpose & Need
This part of the report is used to identify the location being studied and give the reasons for conducting the study. Reasons for conducting the study can include the TOAST scoring and the ranking from TOAST within the state and district.

5.3.2 Facility Description
This section of the report is used to identify the location being studied (county/city/township, route, and intersection or segment), type of facility (functional classification, number and direction of lanes) existing traffic control and TSMO strategies in place. If applicable, information summarizing previous or planned improvements to mitigate congestion should be documented.

5.3.3 Performance Measures
This section of the TSMO Study should summarize the TOAST scoring. The meaning of the performance measures need not be described in detail in the study. Rather, the scoring information should be summarized, with local contributing factors explained.
5.4 Countermeasures

Based on the output of the TOAST, supplemented with local knowledge and possibly the aforementioned safety and capacity analyses, countermeasures should be identified for consideration. Refer to Chapter 3 and Chapter 6 for more details regarding potential countermeasures. Given TOAST results, specific countermeasures may be applicable to the study site. These countermeasures should be discussed in this section of the report. Other information for the countermeasures, such as estimated construction costs and supporting safety and capacity analyses should be included.

Improvements beyond the countermeasures included in this Guidebook should be dismissed. The more standardized evaluation of TSMO alternatives is intended to allow TSMO to be compared to traditional or other non-TSMO options so that the most beneficial and cost-effective countermeasure ultimately gets selected for improvement.

5.4.1 Benefit-Cost Results

For the countermeasures being recommended, a benefit-cost calculation should be performed. The TSMO B/C Tool has been developed to aid with this calculation. This section of the report should detail the benefit-cost results for all recommended countermeasures. The ratio of benefits to costs must be reported (not more precise than one decimal place in this context); and optionally the net present value (NPV) may be included. NPV is simply the difference of benefits minus costs. Each countermeasure should be evaluated and reported independently.

5.5 Recommendations

Based on existing analyses and improvement evaluations, the recommended countermeasures should be summarized in this section of the report. They should be divided into short-, medium- and long-term countermeasures, if applicable. Table 4 shows an example summary.

<table>
<thead>
<tr>
<th>Countermeasure</th>
<th>Timeframe (S, M, L)</th>
<th>Costs ($000s)</th>
<th>Benefits (10 yrs)</th>
<th>B/C</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>QWS</td>
<td>Short</td>
<td>$675</td>
<td>$1,618</td>
<td>2.4</td>
<td>Preferred, low risk</td>
</tr>
<tr>
<td>Lane Add</td>
<td>Long</td>
<td>$25,150</td>
<td>$20,250</td>
<td>0.8</td>
<td>Right-of-way uncertain</td>
</tr>
<tr>
<td>VSL</td>
<td>Medium</td>
<td>$550</td>
<td>$1,150</td>
<td>2.1</td>
<td>Can be combined with QWS</td>
</tr>
<tr>
<td>HSR</td>
<td>Medium</td>
<td>$2,200</td>
<td>$2,900</td>
<td>1.3</td>
<td>Less efficient over short distance</td>
</tr>
<tr>
<td>DMS</td>
<td>Short</td>
<td>$450</td>
<td>$755</td>
<td>1.7</td>
<td>Can be combined with others</td>
</tr>
</tbody>
</table>
6 TSMO Economic Evaluation

Economic evaluation is a central component of the TSMO Study process. This chapter provides guidance on developing an estimated benefit to cost ratio (B/C or BCR). TSMO is very competitive with other options from a B/C standpoint, given sizeable benefits for relatively smaller cost. However, careful analysis and documentation is necessary for defensible B/C estimates, even among competing possible TSMO countermeasures.

ODOT’s TSMO Plan\(^7\) outlines the need for a consistent B/C framework to help guide policy and prioritization of TSMO proposals, and a new tool for high-level economic evaluation of alternatives. The Plan includes a recommendation under Systems & Technology to, “implement consistent benefit-cost analysis for all project alternatives that allows assessment of TSMO strategies.” This chapter describes that analysis. It is also addressed by the accompanying Excel workbook.

6.1 The TSMO B/C Tool

The TSMO B/C Tool was developed as a standalone Excel workbook for use by ODOT Districts and their consultants. It is intended for high-level assessment for the set of TSMO countermeasures identified by ODOT and introduced in Chapter 3. Every attempt is made to keep it simple, understandable and self-contained. ODOT recognizes that there are innumerable other tools, software, and methods for more detailed evaluation that should be utilized as needed for any proposed improvement.

The TSMO B/C Tool is in its first iteration, as of 2019. As it currently exists it is primarily an information reference. ODOT’s intentions is to develop it into a more fully-featured spreadsheet tool that accepts inputs, performs calculations, and provides summary outputs in a manner analogous to ECAT and other tools currently in use.

Figure 12 shows a snapshot of the first tab of the B/C Tool workbook. Each countermeasure is shown on its own row, followed by typical costs, typical benefits, B/C values, and an indicator of certainty.

\(^7\)http://www.dot.state.oh.us/Divisions/Operations/Traffic-Management/Pages/TSMO.aspx
## TSMO Countermeasures Benefit-Cost Summary Table

<table>
<thead>
<tr>
<th>Countermeasures</th>
<th>Typical Cost</th>
<th>Typical Benefits</th>
<th>Typical B/C</th>
<th>B/C Range</th>
<th>Availability of Supporting Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Destination Dynamic Message Signs (DDMS)</td>
<td>$5,000 /site</td>
<td>Safety/Crash</td>
<td>(See Details)</td>
<td>4.0</td>
<td>1.4 to 16.9 Medium</td>
</tr>
<tr>
<td>Detection Based Warnings - Curves</td>
<td>$14,000 /site</td>
<td>20.0%</td>
<td>-</td>
<td>3.0</td>
<td>2.8 to 5.6 High</td>
</tr>
<tr>
<td>Detection Based Warnings - Intersections</td>
<td>$24,500 /site</td>
<td>15.0%</td>
<td>-</td>
<td>-</td>
<td>High</td>
</tr>
<tr>
<td>Dynamic Message Signs (DMS)</td>
<td>$200,000 /site</td>
<td>16.6%</td>
<td>-</td>
<td>2.1</td>
<td>2.1 to 3.8 Medium</td>
</tr>
<tr>
<td>Environmental Detection and Warning</td>
<td>$90,000 /site</td>
<td>20.0%</td>
<td>-</td>
<td>4.0</td>
<td>2.8 to 22.8 High</td>
</tr>
<tr>
<td>Freeway Service Patrol (FSP)</td>
<td>$200,000 /veh</td>
<td>-</td>
<td>20.0%</td>
<td>4.0</td>
<td>10.0 to 36.2 High</td>
</tr>
<tr>
<td>Hard Shoulder Running (HSR)</td>
<td>$2,000,000 /mile</td>
<td>-</td>
<td>15.0%</td>
<td>4.5</td>
<td>4.5 Medium</td>
</tr>
<tr>
<td>Queue Warning System</td>
<td>$200,000 /mile</td>
<td>20.0%</td>
<td>-</td>
<td>0.0%</td>
<td>2.0 to 1.6 to 2.4 High</td>
</tr>
<tr>
<td>Ramp Metering</td>
<td>$20,000 /site</td>
<td>20.0%</td>
<td>5.0%</td>
<td>7.0</td>
<td>5.6 to 15.1 Medium</td>
</tr>
<tr>
<td>Reversible Lane</td>
<td>$237,000 /mile</td>
<td>-</td>
<td>30.0%</td>
<td>6.5</td>
<td>6.1 to 21.0 Medium</td>
</tr>
<tr>
<td>Speed Harmonization</td>
<td>$300,000 /mile</td>
<td>-</td>
<td>15.0%</td>
<td>8.0%</td>
<td>7.0 to 6.8 to 62.2 Medium</td>
</tr>
<tr>
<td>Traffic Cameras</td>
<td>$75,000 /site</td>
<td>-</td>
<td>12.0%</td>
<td>8.0%</td>
<td>10.0 to 3.9 to 16.6 Medium</td>
</tr>
<tr>
<td>Traffic Signals - Retiming</td>
<td>$3,000 /int</td>
<td>-</td>
<td>15.0%</td>
<td>9.0%</td>
<td>60.0 to 55.0 to 175.0 Medium</td>
</tr>
<tr>
<td>Traffic Signals - Coordination</td>
<td>$7,000 /int</td>
<td>-</td>
<td>12.0%</td>
<td>9.0%</td>
<td>-</td>
</tr>
<tr>
<td>Truck/Bus Only Lane</td>
<td>$75,000 /mile</td>
<td>-</td>
<td>20.0%</td>
<td>-</td>
<td>Low</td>
</tr>
<tr>
<td>Variable Speed Limits (VSL)</td>
<td>$150,000 /mile</td>
<td>10.0%</td>
<td>17.5%</td>
<td>7.5%</td>
<td>2.0 to 0.6 to 14.0 High</td>
</tr>
</tbody>
</table>

This summary table may be referred to as a quick reference for the set of TSMO countermeasures included in this Guidebook. The Tool provides a rough order of magnitude estimate of costs, benefits, and the ratio of benefits to costs. This is done without delving into details such as analysis years, salvage values, discount rates, inflation, and so forth.

The red and green shaded bars in the cost and benefits columns provide a visual indication of the magnitude of the number shown. For example, some countermeasures have much lower costs (e.g., DDMS, traffic signal improvements) compared to countermeasures involving infrastructure (e.g., HSR, reversible lanes).

The three most common categories of benefits are included in the Tool: safety, delay, and operating costs. Other benefit categories (e.g., reliability, emissions, accessibility, security, etc.) may be added into any TSMO Study if warranted. They may be considered for inclusion in the Tool in a future iteration.

Taken together, the total benefits form the numerator, and the total costs are the denominator. A typical range is shown in the next to last column. The last column indicates the certainty in the estimates. For example, a TSMO Study could claim with confidence that a proposed curve warning system (in a location with prevalent curve-related crashes) would have a B/C of about three. In some cases on the summary table, values are absent. For those, the user should refer to the specific countermeasure sheets.
Figure 13 is an example sheet (workbook tab or pages in Appendix B) for a countermeasure. The callouts summarize what each section includes.

Queue Warning System

What is it?
Queue warning’s basic principle is to inform travelers of the presence of downstream stop-and-go traffic (based on real-time traffic detection) using warning signs and flashing lights. Drivers can anticipate an upcoming situation of emergency braking and slow down, avoid erratic behavior, and reduce queuing-related collisions. Dynamic message signs (DMS) show a symbol or word when stop-and-go traffic is near. Variable speed limits and lane control signals that provide incident management capabilities can be combined with queue warning. The system can be automated or controlled by a traffic management center operator.

Relevant Deployment Conditions
- Frequently congested freeways or roads.
- Facilities with frequent queues in predictable locations.
- Facilities with sight distance restricted by vertical grades, horizontal curves, or poor illumination.
- Power must be available to site or able to be installed at cost-effective rate.
- Right of way to install QWS signs and/or overhead sign gantries must be available.
- Communications to TOC must be available.
- CCTV monitoring of the site should be present to monitor system performance.
- Signs should be placed to contain end of queuing fully at site.
- Sensors to support QWS operation must be installed at close spacings. Sensors should be located before and after ramp entrances.

Range of Researched Benefits:

<table>
<thead>
<tr>
<th>Benefit Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility</td>
<td>No expected direct mobility benefits.</td>
</tr>
<tr>
<td>Safety</td>
<td>44% reduction in crashes</td>
</tr>
<tr>
<td></td>
<td>22% reduction in crashes, 54% reduction in near misses</td>
</tr>
<tr>
<td></td>
<td>18% to 45% reduction in crashes</td>
</tr>
<tr>
<td></td>
<td>14% reduction in crashes (work zones)</td>
</tr>
</tbody>
</table>

Vehicle Operating Costs
- No expected direct operating cost benefits.

Benefit/Cost Data
- 1.6:1 - 2.4:1

Conditions Supporting Success
- Locations with high rates of secondary crashes, recurring congestion/queuing, and limited sight distances.
- Public outreach to familiarize the public with the goals and benefits of the system.
- Lane control signals upstream of lane blockages.
- Frequent analysis (e.g., once per minute) of speed and occupancy data for improved system responsiveness.
- Different types of warnings activated depending on the severity of the congestion ahead.
- Work zones also benefit from queue warning with portable dynamic message sign units placed upstream of expected queue points.

Generalized Deployment Costs
- Finland: $30 million.
- Scotland: $630,000.
- Virginia: $25,000 at two weigh stations.
- West Virginia: $85,000 for fog warnings.
- Minnesota: $15 million, or $3.75 million per mile, on I-94.
- Florida: $26 million for a mobile warning system.
- California: $2.5 million for reduced visibility warnings.

Inputs
- Annual Number of Crashes (along applicable direction for the proposed segment)

Basic BCR Calculation Steps

Annual Benefit\textsubscript{5} = ((((AADT - Truck AADT) x $15.29) + (Truck AADT x $29.96)) x (% Traffic Present During Non-Recurrent Congestion) x (Operating Area Length / 55) x 20% x 365)

BCR\textsubscript{4} = (Annual Benefit \times Countermeasure Lifespan) / Cost
As an example, consider a segment scoring “poorly” among safety, travel time, and secondary crashes. Given the unpredictable nature of non-recurring backups, back of queue crashes are a particular concern. The District therefore wants to consider a queue warning system (as shown in Figure 13).

As noted, the costs of QWS varies a lot by situation, but the District estimates a $450k installation covering about two miles of expressway. Add to this 5% of capital installation per year for operations and maintenance over, say, 10 years, which totals $675k.

On this two-mile segment, in one direction, there are 16 crashes per year. The District estimates a full 25% of these can be helped by a QWS, for 4 crashes per year.

As noted at the bottom of the information sheet:

\[
\text{Annual Benefit} = \text{Annual Number of Crashes} \times 20\% \times $202,264
\]
\[
\text{Annual Benefit} = 4 \times 20\% \times $202,264
\]
\[
\text{Annual Benefit} = $161,112
\]

Next, consider the 10-year lifecycle for the B/C, returning $1.62M in benefits over 10 years, divided by $675k, gives an estimated B/C = 2.4.

6.3 Further Resources for Economic Evaluation

A more in-depth evaluation of the economic benefits or costs a small selection of other tools or resources:

- Transportation Benefit-Cost Analysis, Transportation Research Board Committee on Transportation Economics, broad guidance (all transportation, not just TSMO) and state of the practice resources, [http://bca.TransportationEconomics.org/](http://bca.TransportationEconomics.org/)
- ITS Benefits Database, USDOT Research and Technology, a large collection of evaluations and assessments of operational strategies, [https://www.itsbenefits.its.dot.gov/its/benecost.nsf/BenefitsHome](https://www.itsbenefits.its.dot.gov/its/benecost.nsf/BenefitsHome)
Appendix A - TOAST Score Distributions

**Bottlenecks**

- Frequency distribution graph showing the number of bottlenecks for different scores.

**Travel Time**

- Frequency distribution graph showing the number of travel times for different scores.
Incident Clearance

![Incident Clearance Score vs Frequency](image1)

Secondary Crashes

![Secondary Crashes Score vs Frequency](image2)
Appendix B - Countermeasure Details

Each of the following pages gives details on the countermeasures introduced in Chapter 3. The same content is also contained in the accompanying TSMO B/C Tool (Excel workbook) and is provided in both places for convenience.

Destination Dynamic Message Signs

What is it?
Destination Dynamic Message Signs (DDMS) are a countermeasure that provide travel time guidance to various destinations. This countermeasure can utilize a static sign with a variable matrix to publish the travel time in minutes. By providing travel times to motorists, they can make informed decisions on whether the route’s trip time is acceptable for their needs or if an alternate route should be sought. In the context of this countermeasure, only destination-focused travel times are provided. Other DMS features are detailed separately.

Relevant Deployment Conditions
• Corridors that experience frequent non-recurrent congestion or high travel time variability.
• Corridors that experience inclement weather conditions or high weather-related crashes.
• Corridors that serve as key routes for special events that impact traffic operations.
• Corridors with known alternative routes that can sufficiently handle some re-routing traffic.

Range of Researched Benefits:

<table>
<thead>
<tr>
<th>Mobility</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.8 minutes of delay reduced, on average, with 3.7% divergence.</td>
<td>No expected direct safety benefits.</td>
</tr>
<tr>
<td>10 to 15% diversion to alternate route.</td>
<td></td>
</tr>
<tr>
<td>10% diversion to alternate routes.</td>
<td></td>
</tr>
<tr>
<td>12 to 14% diversion to alternate routes.</td>
<td></td>
</tr>
</tbody>
</table>

Vehicle Operating Costs
• No expected direct operating benefits.

Benefit/Cost Data
• 1.38:1 - 16.95:1

Conditions Supporting Success
• Corridors should be instrumented with sufficient ITS sensor equipment to generate an accurate travel time.
• Destination DMS should be reliably connected via network communications to the Traffic Operations Center to provide timely updates to motorists.
• Presence of alternative routes.
• Coordination with local agencies that manage the alternative routes (such as cities or counties) to help foster regional collaboration with traffic management.

Generalized Deployment Costs
• USDOT: $2,000 Cost per Unit - Roadside static signage, purchase and installation.

Inputs
• AADT (for applicable direction)
• Truck AADT (for applicable direction)
• % Traffic Present during congestion (for applicable direction)
• Alternate Route Travel Time Savings (during periods of congestion) (in hours)

Basic BCR Calculation Steps

\[
Annual\ Benefit = (((AADT - Truck \ AADT) \times 15.29) + (Truck \ AADT \times 29.96)) \times \\
(% \ Traffic \ Present \ During \ Congestion) \times (Alternate \ Route \ Travel \ Time \ Savings) \times 10\% \ Diversion \times 365
\]

\[
BCR^4 = \frac{Annual\ Benefit \times \ Countermeasure\ Lifespan}{Cost}
\]

Vehicle Operating Costs
• No expected direct operating benefits.
## Detection-Based Driver Warning (Intersection Warning)

### What is it?
Detection-based driver warning are technologies that improve motorist awareness of an inclement condition when that condition is present. It includes curve warning systems that measure a vehicle’s speed in advance of a curve and, if exceeding the curve’s advisory speed, will notify the vehicle by flashing beacons. These strategies tend to be applied in isolated parts of the network that has a particular crash history type.

### Relevant Deployment Conditions
- Curves with higher crash rates.
- Curves with poor sight lines.
- Curves with high average speeds.

### Range of Researched Benefits:

<table>
<thead>
<tr>
<th>Category</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mobility</strong></td>
<td>No expected direct mobility benefits.</td>
</tr>
<tr>
<td><strong>Safety</strong></td>
<td>77% reduction in crashes</td>
</tr>
<tr>
<td></td>
<td>18% reduction in crashes</td>
</tr>
<tr>
<td><strong>Vehicle Operating Costs</strong></td>
<td>No expected direct operating cost benefits.</td>
</tr>
</tbody>
</table>

### Benefit/Cost Data
- 2.79:1 - 5.57:1 (curve warning)

### Conditions Supporting Success
- Deployment of flashing beacon sufficiently upstream of curve to allow for proper deceleration.
- Use of recognizable signs, preferably those that are compliant with the MUTCD.

### Generalized Deployment Costs
- Minnesota DOT: $14,000 for a dynamic curve speed warning sign with solar power and radar detection
- Iowa State University: Dynamic speed signs cost from $2,000 to $11,000 per display. (2014 dollars)
- FHWA: Dynamic Speed Feedback Signs on Curves costs less than $10,000 per sign including installation, support, and maintenance. (2015 dollars)

### Inputs
- Annual Number of Crashes (along applicable direction)

### Basic BCR Calculation Steps
- \( \text{Annual Benefit} = \text{Annual Number of Crashes} \times 20\% \times 202,264 \)
- \( \text{BCR2} = \frac{\text{Annual Benefit} \times \text{Countermeasure Lifespan}}{\text{Cost}} \)
Dynamic Message Signs

What is it?
Dynamic Message Signs (DMS) are large electronic signs along a corridor that provide changeable messages to motorists. These signs are typically used to display information about travel conditions so that drivers can make informed travel choices. In the context of this countermeasure, the messages posted on the signs include general travel messages, including information on traffic conditions, inclement weather, construction, and road incidents.

Relevant Deployment Conditions
- Corridors that experience frequent non-recurrent congestion or high travel time variability.
- Corridors that experience inclement weather conditions or high weather-related crashes.
- Corridors that serve as key routes for special events that impact traffic operations.

Range of Researched Benefits:

Mobility
- No expected direct mobility benefits.

Safety
- 16.6% reduction in crash rates
- 18% reduction in crashes

Vehicle Operating Costs
- No expected direct operating cost benefits.

Benefit/Cost Data
- 2.1:1 (with equipment costs), 6.9:1 (without)
- 3.81:1

Conditions Supporting Success
- Presence of alternative routes.
- Agency capability to monitor for inclement travel conditions downstream of DMS.
- Public outreach to familiarize the public with the goals and benefits of the system.
- Ability to use common terminology for conveying messages, only use acronyms when widely understood.
- Sufficient distances between DMS and adjacent signing, 800 feet or more.

Generalized Deployment Costs
- Caltrans: $200,000 Large DMS display support structure includes purchase and installation. (2018 dollars)
- Caltrans: $100,000 per Unit for Large DMS includes purchase and installation of sign on existing mounting structure. (2018 dollars)
- USDOT: $108,500 per Unit for Large DMS includes purchase and installation. (2016 dollars)
- North Carolina DOT: $330,000 per DMS installation. (2004 dollars)
- South Carolina DOT: $185,300 cost per DMS with structure and equipment only. (2010 dollars)
- New Hampshire DOT: $223,000 cost per DMS. Includes installation, power runs (ditching), UPS back up for four hours, microwave communication equipment (Canopy), equipment cabinets, all necessary equipment, device testing, connection to network management system and subsystem integration testing. (2010 dollars)

Inputs
- Annual Number of Crashes (along applicable direction)

Basic BCR Calculation Steps

\[
\text{Annual Benefit} = \text{Annual Number of Crashes} \times 16.6\% \times \$202,264
\]

\[
\text{BCR2} = \frac{\text{Annual Benefit} \times \text{Countermeasure Lifespan}}{\text{Cost}}
\]
### Environmental Detection and Warning

#### What is it?
Environmental detection and warning systems utilize meteorological instruments to measure for travel conditions that could be hazardous to a vehicle. These notifications are typically issued by activating flashing beacons on roadside signs to bring attention to an advisory message, such as “pavement slippery when wet,” when the system detects that the pavement is wet.

#### Relevant Deployment Conditions
- Corridors with inclement weather and high crash rates due to that weather.
- Corridors with weather that changes rapidly.

#### Range of Researched Benefits:

<table>
<thead>
<tr>
<th>Category</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility</td>
<td>No expected direct mobility benefits.</td>
</tr>
<tr>
<td>Safety</td>
<td>18% reduction in crashes (icy curve warning)</td>
</tr>
<tr>
<td></td>
<td>39% reduction in wet-pavement crashes</td>
</tr>
</tbody>
</table>

#### Vehicle Operating Costs
- No expected direct operating cost benefits.

#### Benefit/Cost Data
- 5.8:1 (high water)
- 2.8:1 - 7.0:1

#### Conditions Supporting Success
- Deployment of flashing beacon sufficiently upstream of the location of concern to allow for proper warning and response.
- Use of recognizable signs, preferably those that are compliant with the MUTCD.

#### Generalized Deployment Costs
- TXDOT: $75,000 per location to install high water detection systems to avoid flooding disasters.
- Caltrans: $100,000-150,000 Roadway Weather Information Systems (RWIS) Stations. Annual O&M Cost: $5,000.

#### Inputs
- Annual Number of Crashes (along applicable direction)

#### Basic BCR Calculation Steps

\[
\text{Annual Benefit} = \text{Annual Number of Crashes} \times 20\% \times \$202,264
\]

\[
\text{BCR}^2 = \frac{\text{Annual Benefit} \times \text{Countermeasure Lifespan}}{\text{Cost}}
\]
Freeway Service Patrol

What is it?
Freeway Service Patrol (FSP) is a program, typically operated by a road operator. Its goals are to reduce traffic congestion and improve highway safety by having specially marked and equipped vehicles patrol designated sections of roadway and provide incident management and/or motorist assistance. Unlike other strategies, the FSP on its own requires no permanent in-field infrastructure, but rather represents the mobile service of tow trucks and qualified personnel to provide services. FSP is generally supported by the road operator’s ITS program and, depending on the situation, state or local police. Despite inclusion in the National ITS Architecture, there is no standardized way in which FSP is operated.

Relevant Deployment Conditions
- Corridors with moderate rates of lane-obstructing crashes or vehicle breakdowns that result in traffic congestion.
- Urban facilities with long incident clearance times.

Range of Researched Benefits:

<table>
<thead>
<tr>
<th>Mobility</th>
<th>Vehicle Operating Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 36% to 66% reduction in travel costs to motorists.</td>
<td>• 3.43% to 5.28% reduction in fuel consumption</td>
</tr>
<tr>
<td>• 7.45% reduction in delay.</td>
<td></td>
</tr>
<tr>
<td>• 15% to 30% reduction in incident time, given one minute of blockage for four minutes of delay.</td>
<td></td>
</tr>
<tr>
<td>• 70.7% reduction in incident duration, given one minute of blockage for four minutes of delay.</td>
<td></td>
</tr>
<tr>
<td>• 13% to 41% reduction in roadway clearance time, given one minute of blockage for four minutes of delay.</td>
<td></td>
</tr>
</tbody>
</table>

Safety
- 12.8% reduction of secondary crashes for every minute of incident clearance reduction.

Conditions Supporting Success
- Public outreach to familiarize the public with the goals and benefits of the system.
- Sufficient patrols to reduce incident response clearance times to desirable levels.
- Personnel with skills to appropriately clear incidents in a hazardous roadway environment.
- Good coordination with local police and first responders.

Generalized Deployment Costs
- Michigan DOT: Freeway Courtesy Patrol statewide service is $2.3 million annually. (2013 dollars)
- Florida DOT: $40.36 Per Hour for Emergency Response Labor / Safety service patrol. (2013 dollars)
- Virginia DOT: $20.63 Per Hour - Average burdened hourly wage rate for the patroller of a Safety Service Patrol in Virginia. (2006 dollars)
- Virginia DOT: $28.37 Per Hour - Average burdened hourly wage rate for the foreperson of a Safety Service Patrol in Virginia. (2006 dollars)
- Virginia DOT: $51.49 Per Hour - Average burdened hourly wage rate for the manager of a Safety Service Patrol in Virginia. (2006 dollars)
- Florida DOT: $500,000 O&M Cost per Severe Incident Response Vehicle. (2006 dollar)

Inputs
- AAADT
- Truck AAADT
- % Traffic Present during Non-Recurrent Congestion
- Operating Area Length (in miles)

Basic BCR Calculation Steps

\[ \text{Annual Benefit} = (\text{AAADT} - \text{Truck AAADT}) \times 15.29 + (\text{Truck AAADT} \times 29.96) \times \text{(\% Traffic Present During Non-Recurrent Congestion)} \times (\text{Operating Area Length} / 55) \times 20\% \times 365 \]

\[ \text{BCR} = (\text{Annual Benefit} \times \text{Countermeasure Lifespan}) / \text{Cost} \]
Hard Shoulder Running

What is it?
Hard Shoulder Running (HSR) is also known as temporary shoulder use. The underlying principle of HSR is to take advantage of the additional roadway space occupied by the shoulder as a means of increasing the facility’s capacity. It is often used to address capacity constraints that arise as a result of incidents or other unusual circumstances during non-peak periods. Furthermore, it is used also during congested periods to alleviate the duration and severity of recurrent congestion. In some cases, access to the shoulder may be limited to only a subset of vehicles, such as transit buses or carpools.

Relevant Deployment Conditions
- Sufficient right of way must be available to accommodate shoulder travel throughout the section.
- Roadside should be reviewed to determine if an additional guardrail or barrier needs to be installed if travel is permitted on shoulder.
- Shoulders should be as wide as a travel lane to facilitate movements when lane is open to travel.
- Shoulder pavement depth should be sufficient to handle projected traffic on lane.
- Shoulder should have no adverse superelevation.
- Methods to accommodate shoulder travel through interchanges safely should be developed and provided.
- Power must be available to site or able to be installed at cost-effective rate.
- Right of way to install overhead sign gantries must be available so lane control signs can be installed, if deploying an actively managed facility.
- Communications to Traffic Operations Center must be available.
- CCTV monitoring of site should be present to monitor system performance and incidents.
- Lane control sign gantries must be placed so that at least one is visible at all times.
- Sensors must be installed on the shoulder at close spacings (e.g., every 100 meters) to detect disabled vehicles.
- Upgrades to allow shoulder to handle vehicular traffic should not compromise road drainage.

Range of Researched Benefits:

Mobility
- 10% to 25% travel time reduction
- Up to 21% reduction in travel times (ATM, simulated)

Safety
- 25% to 40% reduction in crashes

Vehicle Operating Costs
- No expected direct operating cost benefits.

Benefit/Cost Data
- 4.5:1

Conditions Supporting Success
- Where HSR begins or ends at a ramp junction, junction control is often required to maintain lane continuity and safe operations.
- For improved safety, a Variable Speed Limit system should be used to slow freeway traffic down when hard shoulder running is active.
- Public outreach to familiarize the public with the goals and benefits of the system.
- Regularly spaced emergency pulloffs (e.g., every 500-1,000 meters) are desirable for use when shoulder lane is open to travel.
- Continuous roadway lighting may provide safety benefit when hard shoulder running is operational.
- Retractable barriers may be used to open and close shoulders to general vehicular traffic.

Generalized Deployment Costs
- United Kingdom: $18 million per mile on the M42 roadway.
- Birmingham, Alabama: $2.2444 million per mile.
- United Kingdom: $47.4 million per mile on the M62 roadway.
- Frankfurt, Germany: $2.125 million per mile on the A5 roadway.
- Minnesota: $5.2 million per mile.
- Washington State: $50,000 per mile.
- Virginia: $1.2 million per mile.

Inputs
- AAADT (for applicable direction)
- Truck AAADT (for applicable direction)
- % Traffic Present during Non-Recurrent Congestion (for applicable direction)
- Improvement Length (for applicable direction, in miles)

Basic BCR Calculation Steps

Annual Benefit = (((AAADT - Truck AAADT) x $15.29) + (Truck AAADT x $29.96)) x (% Traffic Present when HSR is active) x (Improvement Length / 70) x 15% x 365)

BCR = (Annual Benefit * Countermeasure Lifespan) / Cost
Queue Warning System

What is it?
A queue warning system’s basic principle is to inform travelers of the presence of downstream stop-and-go traffic (based on real-time traffic detection) using warning signs and flashing lights. Drivers can anticipate an upcoming situation of emergency braking and slow down, avoid erratic behavior, and reduce queuing-related crashes. Dynamic message signs (DMS) show a symbol or word when stop-and-go traffic is near. Variable speed limits and lane control signals that provide incident management capabilities can be combined with queue warning. The system can be automated or controlled by a traffic management center operator.

Relevant Deployment Conditions
- Frequently congested freeways or roads.
- Facilities with frequent queues in predictable locations.
- Facilities with sight distance restricted by vertical grades, horizontal curves, or poor illumination.
- Power must be available to site or able to be installed at cost-effective rate.
- Right of way to install QWS signs and/or overhead sign gantries must be available.
- Communications to Traffic Operations Center must be available.
- CCTV monitoring of the site should be present to monitor system performance.
- Signs should be placed to contain end of queuing fully at site.
- Sensors to support QWS operation must be installed at close spacings. Sensors should be located before and after ramp entrances.

Range of Researched Benefits:

**Mobility**
- No expected direct mobility benefits.

**Safety**
- 44% reduction in crashes
- 22% reduction in crashes, 54% reduction in near misses
- 18% to 45% reduction in crashes
- 14% reduction in crashes (work zones)

**Vehicle Operating Costs**
- No expected direct operating cost benefits.

**Benefit/Cost Data**
- 1.6:1 - 2.4:1

Conditions Supporting Success
- Locations with high rates of secondary crashes, recurring congestion and queuing, and limited sight distances.
- Public outreach to familiarize the public with the goals and benefits of the system.
- Lane control signals upstream of lane blockages.
- Frequent analysis (e.g., once per minute) of speed and occupancy data for improved system responsiveness.
- Different types of warnings activated depending on the severity of the congestion ahead.
- Work zones also benefit from queue warning with portable dynamic message signs placed upstream of expected queue points.

Generalized Deployment Costs
- Finland: $30 million.
- Scotland: $630,000.
- Virginia: $25,000 at two weigh stations.
- West Virginia: $85,000 for fog warnings.
- Minnesota: $15 million, or $3.75 million per mile, on I-94.
- Florida: $26 million for a mobile warning system.
- California: $2.5 million for reduced visibility warnings.

Inputs
- Annual Number of Crashes (along applicable direction for the proposed segment)

Basic BCR Calculation Steps

\[
\text{Annual Benefit} = (((\text{AADT} - \text{Truck AADT}) \times 15.29) + (\text{Truck AADT} \times 29.96)) \times (\% \text{ Traffic Present During Non-Recurrent Congestion}) \times (\text{Operating Area Length} / 55) \times 20% \times 365
\]

\[
\text{BCR} = (\text{Annual Benefit} \times \text{Countermeasure Lifespan}) / \text{Cost}
\]
Ramp Metering

**What is it?**
Ramp metering is a strategy that regulates the flow of on-ramp traffic entering the freeway with a goal of maintaining the freeway flow at, or below, capacity. This strategy also reduces congestion by helping break up platoons of vehicles that are entering the freeway from an on-ramp, typically at ramps that are served by an upstream traffic signal. Ramp metering systems generally operate only during periods of congestion, typically during the peak periods, and service traffic through a fixed release rate (e.g. one vehicle every four seconds) or a dynamic release rate (e.g., a rate determined by the traffic state on the freeway).

**Relevant Deployment Conditions**
- On-ramps that serve freeways with frequent congestion, either recurrent or non-recurrent.
- On-ramps that serve freeways with a known downstream bottleneck.
- On-ramps with sufficient length to permit queue storage behind the ramp meter (based on ramp traffic demand and the metering rate).
- On-ramps with sufficient acceleration length to permit vehicles to accelerate from a stopped position at the ramp meter to freeway speeds at the merge point.
- On-ramps that have access to ITS network communications architecture.

**Range of Researched Benefits:**
- **Mobility**
  - 25% reduction in delay
  - 1% to 4% reduction in travel times
- **Safety**
  - 22% reduction in crashes
  - 64% reduction in crashes
- **Vehicle Operating Costs**
  - No expected direct operating cost benefits.

**Benefit/Cost Data**
- 5.6:1 - 7.9:1
- 15:1

**Conditions Supporting Success**
- Public outreach to familiarize the public with the goals and benefits of the system.
- Sufficient ITS infrastructure to allow for real-time monitoring and operation.
- Sufficient ramp sensor infrastructure to avoid queue spillback when conditions are detected.
- Frequent analysis (e.g., once per 30 seconds) of freeway and on-ramp travel conditions to assess a proper metering rate.

**Generalized Deployment Costs**
- Kansas DOT: $30,000 per Adaptive Ramp Metering system that includes a roadside warning beacon and a stop bar used to trigger the ramp meter signal. (2009 dollars)
- Arizona DOT: $4,300 per Ramp Meter Signal and Support Assembly. (2009 dollars)
- Arizona DOT: $7,978.63 per Control Cabinet (Type 341A) - Ramp Meter. (2009 dollars)

**Inputs**
- AAADT (for applicable direction)
- Truck AADT (for applicable direction)
- % Traffic Present During Ramp Meter Activation (for applicable direction)
- Improvement Length (length of mainline that is influenced by ramp meter, in miles)
- Annual Number of Crashes (along applicable direction)

**Basic BCR Calculation Steps**

\[
\text{Annual Benefit} = ((\text{AADT} - \text{Truck AADT}) \times 15.29) + (\text{Truck AADT} \times 29.96) \times (% \text{ Traffic Present During Ramp Meter Activation}) \times (\text{Improvement Length} / 70) \times 0.01 \times 365 + \left( \frac{\text{Annual Number of Crashes}}{20} \times 202,264 \right)
\]

\[
\text{BCR} = \frac{\text{Annual Benefit} \times \text{Countermeasure Lifespan}}{\text{Cost}}
\]
**Reversible Lane**

**What is it?**
A reversible lane is a strategy that improves traffic flow by allowing a particular lane to operate in the direction of higher traffic volumes. Typically, this strategy is used in an urban area with some degree of separation (either barrier of pavement markings) from the general purpose lanes. There also is signing to convey which direction of travel is permissible. By allowing the lane to flow with the direction of higher traffic volumes, more capacity is offered to that travel direction. This is often more cost effective (in terms of pavement and right-of-way) because it leaves the dynamic lane to be used on-demand, which cuts down on infrastructure requirements. Reversible lanes can be used on freeways and arterial roadways.

**Relevant Deployment Conditions**
- Corridors with high directional traffic volumes in one direction that change direction depending on time of day.
- Corridors with limited right-of-way for widening.
- Corridors with the capability of being instrumented with lane control signals and sufficient pavement markings (or separation).

**Range of Researched Benefits:**

**Mobility**
- 30% reduction in delays
- 14 minutes per trip saved over up to 13.8 miles

**Safety**
- No expected direct safety benefits.

**Vehicle Operating Costs**
- No expected direct operating cost benefits.

**Benefit/Cost Data**
- 6.5:1
- 6.8:1
- 6:1 - 21:1

**Conditions Supporting Success**
- Public outreach to familiarize the public with the goals and benefits of the system.
- Sufficient ITS infrastructure to allow for real-time monitoring and operation.
- Dedicated maintenance to provide upkeep to these assets.

**Generalized Deployment Costs**
- Caltrans: $1.9M for eight mile section for ITS components. (2007 dollars)
- Colorado DOT: estimated $22.2 million one-time capital cost with $710,000 annual costs for 13-mile reversible lane system pilot program with movable barriers on I-70 in Denver for 12.7 miles. (2011 dollars)
- Phoenix: $18.3 million to add overhead beacons and lane-control signs to their existing reversible lane system. (2009 dollars)
- City of Arlington: $3 million for a reversible lane system on two major and one minor arterial roads. The system uses signage and dynamic overhead lane control signs.

**Inputs**
- AAADT (for applicable direction)
- Truck AAADT (for applicable direction)
- % Traffic Present when reversible lane is open (for applicable direction)
- Improvement Length (for applicable direction, in miles)

**Basic BCR Calculation Steps**

\[
\text{Annual Benefit} = (((\text{AAADT} - \text{Truck AAADT}) \times 15.29) + (\text{Truck AAADT} \times 29.96)) \times (\% \text{ Traffic Present When Reversible Lane is Open}) \times (\text{Improvement Length} / 70) \times 30\% \times 365
\]

\[
BCR4 = (\text{Annual Benefit} \times \text{Countermeasure Lifespan}) / \text{Cost}
\]
Speed Harmonization

What is it?
Speed harmonization is a countermeasure that sets variable speed limits along a congested corridor with the goal of maximizing capacity flow. This strategy is often paired with Variable Speed Limits (VSL), which are very comparable; however, they differ in that Variable Speed Limits tend to be set uniformly in response to an inclement meteorological condition at any given time, whereas speed harmonization is exclusively used during congested periods to reduce the stop-and-go nature of congested traffic.

Relevant Deployment Conditions
- Locations with high congestion, large speed differentials, recurrent back of queues and high crash rates are desirable to offset the high costs associated with the system.
- Reliable line power should be available to site or able to be installed at-cost-effective rate in order to ensure available operation.
- Right of way to install VSL signs and/or overhead sign gantries must be available.
- Reliable communications to the Traffic Operations Center must be available.
- CCTV monitoring of site should be present to monitor system performance and verify messaging.
- VSL signs should be placed at frequent intervals to help maintain motorist awareness of the changed condition.
- Agency should adopt policy for speed harmonization and explore opportunities for enforcement in order to improve success.

Range of Researched Benefits:

<table>
<thead>
<tr>
<th>Mobility</th>
<th>Vehicle Operating Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>28% to 32% reduction in travel time</td>
<td>12% to 17% reduction in fuel consumption</td>
</tr>
<tr>
<td>7.6% reduction in delay</td>
<td>6.3% reduction in fuel consumption</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Safety</th>
<th>Benefit/Cost Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>No expected direct safety benefits.</td>
<td>6.81:1 - 62.2:1</td>
</tr>
</tbody>
</table>

Conditions Supporting Success
- There must be sufficient space on shoulder to permit enforcement officers (if used) to pull over violators.
- Outreach to the judicial system regarding the legal aspects of VSLs for speed harmonization can strengthen enforcement efforts.
- Public outreach to familiarize the public with the goals and benefits of the system.
- Due to potential driver confusion regarding signage, VSLs for speed harmonization should be deployed with caution when a dynamic lane management system is in place.

Generalized Deployment Costs
- Virginia DOT: $3.2 million VSL system (hardware, software, training and operational support included) for two years on a 7.5 mile section. (2008 dollars)
- Utah DOT: $173 - $329 (per day) Equipment rental cost for portable variable speed limit system. (2018 dollars)
- Washington State: $3.2 million per mile on a 3-lane section.
- Washington State: $4 million per mile on a 5-lane section.
- Germany: $1.2 million to $1.7 million per mile.
- United Kingdom: $18 million per mile.
- Michigan: $67,000 per mile for a portable system.
- Virginia: $425,000 per mile.
- Oregon: $560,000 per mile.
- Seattle: $3.6 million per mile on I-5.
- Minnesota: $2.15 million per mile on I-35W.
- Wyoming: $28,000 per mile.

Inputs
- AAADT (for applicable direction)
- Truck AADT (for applicable direction)
- % Traffic Present during VSL Activation (for applicable direction)
- Improvement Length (for applicable direction, in miles)

Basic BCR Calculation Steps
\[
\text{Annual Benefit} = (((\text{AADT} - \text{Truck AADT}) \times 15.29) + (\text{Truck AADT} \times 29.96)) \times (\% \text{ Traffic Present During VSL Activation}) \times \frac{\text{Corridor Length}}{70} \times 15\% \times 365
\]

\[
\text{BCR}^4 = \frac{\text{Annual Benefit} \times \text{Countermeasure Lifespan}}{\text{Cost}}
\]
## Traffic Signal Improvements (Retiming)

### What is it?
Traffic signal retiming is a countermeasure that updates the timing plan using the latest available traffic volumes. This typically establishes timing plans with new splits and offsets for the traffic volumes in question. Retiming can be done locally at one intersection or along a corridor of intersections. The mobility improvements tend to scale with how much variance exists between the old and new timing plans, as the older timing plans were set to accommodate traffic volumes that could be very different from the current traffic volumes.

### Relevant Deployment Conditions
- Traffic signals that have timing plans that are more than a few years old.
- Traffic signals in areas that have undergone land use changes.
- Traffic signals in areas that have experienced indirect changes to traffic operations, such as the addition of a new freeway.
- Traffic signals in areas that are indirectly affected by medium-term network disruptions, such as adjacent road construction projects on a parallel corridor.

### Range of Researched Benefits:

#### Mobility
- 7% to 25% travel time improvement (retiming)
- 7.4% reduction in travel time (retiming)
- 23% reduction in delay (retiming)
- 5% to 20% reduction in travel times (retiming)

#### Safety
- 31% reduction in crashes (retiming)

#### Vehicle Operating Costs
- 2% to 9% fuel reduction (retiming)
- 10% to 15% (retiming)
- 7.8% reduction in fuel costs (all measures)

### Benefit/Cost Data
- 62:1 (retiming)
- 55:1 - 175:1 (retiming)
- 57:1 (retiming)

### Conditions Supporting Success
- Retiming efforts use representative traffic volumes or forecasts that align closely with reality.
- Retiming efforts consider adjacent traffic signals and evaluate whether the corridor benefits from adjusting their timing as well.
- Retiming efforts use or upgrade existing infrastructure, such as detection or flashing-yellow arrows (where allowed).

### Generalized Deployment Costs
- Costs to update signal timing range from $2,500 to $3,100 per signal per update. (2005 dollars)
- The average cost to retime signals under the MTC (California) program is $2,400 per intersection. (2006 dollars)
- NTOC: $3,000 per signal. Signal retiming interval is every three to five years. (2007 dollars)

### Inputs
- AADT
- Truck AADT
- Corridor Length (in miles)
- Number of Intersections

### Basic BCR Calculation Steps

\[
\text{Annual Benefit} = (((\text{AADT} \times \text{Truck AADT}) \times \$15.29) + (\text{Truck AADT} \times \$29.96)) \times (\text{Corridor Length} / 55) \times 15\% \times 365
\]

\[
\text{BCR}^* = \frac{(\text{Annual Benefit} \times \text{Countermeasure Lifespan})}{(\text{Cost} \times \text{Number of Intersections})}
\]
# Traffic Signal Improvements (Coordination)

**What is it?**
Traffic signal coordination is a countermeasure that sequences traffic signal operations along a corridor to allow for a “green wave” of vehicles that can sequence through progressive green lights. This typically establishes timing plans along the corridor that follow a common cycle length while optimizing the split/offset to allow for progressive traffic flow. Mobility improvements tend to scale with how uncoordinated the old timing plans were.

**Relevant Deployment Conditions**
- Traffic signals in areas that have undergone land use changes.
- Traffic signals in areas that have experienced indirect changes to traffic operations, such as the addition of a new freeway.
- Traffic signals in areas that are indirectly affected by medium-term network disruptions, such as adjacent road construction projects on a parallel corridor.
- Traffic signals that are along a primary travel route with many minor cross-streets that are not served by coordination.

**Range of Researched Benefits:**

<table>
<thead>
<tr>
<th>Category</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility</td>
<td>30% reduction in travel time (coordination)</td>
</tr>
<tr>
<td></td>
<td>11.4% reduction in travel time (coordination)</td>
</tr>
<tr>
<td>Safety</td>
<td>No expected direct safety benefits.</td>
</tr>
<tr>
<td>Vehicle Operating Costs</td>
<td>7.8% reduction in fuel costs (all measures)</td>
</tr>
</tbody>
</table>

**Benefit/Cost Data**
- Limited B/C Data Available

**Conditions Supporting Success**
- Signal timing efforts occur using representative traffic volumes or forecasts that align closely with reality.
- Traffic signals along the corridor have network communications or some other reliable data source (i.e., GPS times) to follow a “common clock.”

**Generalized Deployment Costs**
- Michigan DOT: $2,645 to add wireless backhaul
- Michigan DOT: $4,452 to add wireless backhaul
- Michigan DOT: $3,110 to add wireless backhaul
- Costs to update signal timing range from $2,500 to $3,100 per signal per update. (2005 dollars)
- The average cost to retiming signals under the MTC (California) program is $2,400 per intersection. (2006 dollar)
- NTOC: $3,000 per signal. Signal retiming interval is every three to five years. (2007 dollars)

**Inputs**
- AADT
- Truck AADT
- Corridor Length (in miles)

**Basic BCR Calculation Steps**

Annual Benefit = (((AADT - Truck AADT) x $15.29) + (Truck AADT x $29.96)) x (Corridor Length / 55) x 12% x 365

BCR = (Annual Benefit * Countermeasure Lifespan) / Cost
Truck-Bus-Only Lane

**What is it?**
Truck-Bus-Only Lanes are lanes designated for the use of larger vehicles, such as trucks or buses. The goal is to separate them from other mixed-flow traffic to enhance safety and/or stabilize traffic flow. Truck-only lanes are not very common in the United States, but there are bus-only lanes on some urban interstates and in central business district areas.

**Relevant Deployment Conditions**
- Corridors with high volumes of larger vehicles that create congestion when mixed with general purpose vehicles.
- Corridors with high truck- or bus-related crashes.
- Corridors with steep grades that result in slow-moving larger vehicles.
- Corridors with high community push to segregate certain transportation modes, particularly buses or trucks, from general traffic, such as for Bus Rapid Transit.

**Range of Researched Benefits:**

<table>
<thead>
<tr>
<th>Mobility</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>19% to 30% reduction in travel time (Bus Lane)</td>
<td>20% reduction in travel time (Bus Lane)</td>
</tr>
<tr>
<td>Safety</td>
<td>Safety</td>
</tr>
<tr>
<td>24% reduction in crashes (Bus Lane)</td>
<td></td>
</tr>
</tbody>
</table>

**Vehicle Operating Costs**
- No expected direct operating cost benefits.

**Benefit/Cost Data**
- Limited B/C Data Available

**Conditions Supporting Success**
- Public outreach to familiarize the public with the goals and benefits of the system.
- Sufficient enforcement to maintain compliance with posted regulations.
- Clearly marked differentiators, such as colored pavement, to indicate that a particular lane is reserved for trucks or buses only.

**Generalized Deployment Costs**
- National Capital Regional Transportation Planning Board: (2017 dollar)
  - $100,000 Standard Bus Lane - White Pavement Striping Capital Cost per Mile
  - $10,000 Standard Bus Lane - White Pavement Striping Maintenance Cost per Mile per Year
  - $308,000 Red Paint Bus Lane Capital Cost per Mile
  - $10,000 Red Paint Bus Lane Maintenance Cost per Mile per Year
  - $9,500 Bus-Mounted Automated Enforcement Per Bus
  - $11,250 Bus-Mounted Automated Enforcement Maintenance Cost per Year
  - $64,945 Stationary Camera Enforcement Per Camera
  - $12,375 Law Manual Enforcement per Year
  - $49,500 Moderate Manual Enforcement per Year
  - $99,000 Maximum Manual Enforcement per Year

**Inputs**
- AADT (for applicable direction)
- Truck AADT (for applicable direction)
- Improvement Length (in miles)

**Basic BCR Calculation Steps**

Annual Benefit = (((AADT - Truck AADT) x $15.29) + (Truck AADT x $29.96)) x (Corridor Length / 55) x 15% x 365

BCR = (Annual Benefit * Countermeasure Lifespan) / (Cost * Number of Intersections)
Variable Speed Limit

What is it?
A variable Speed Limits (VSL) are systems that provide flexible speed limits for motorists to drive on the road, as opposed to traditional fixed speed limit. VSLs allow a road operator to post speed restrictions—regulatory or advisory, depending on local policy—that are based on real-time information that may not be available to the motorists, such as congested conditions ahead, a major incident or a hazardous environmental condition (e.g. icy road). Most VSL programs use roadside or overhead signage to notify motorists. In the connected-vehicle environment, this information may be transmitted directly into the driver’s onboard equipment. Although the technology may be different, the expected benefits are anticipated to be comparable.

Relevant Deployment Conditions

- Locations with high congestion, large speed differentials, recurrent back of queue, and high crash rates are desirable to offset the high costs associated with the system.
- Locations with recurrent inclement weather, such as icy roads, snow, fog or other visibility-impairing elements, that would benefit from motorists with reduced speeds are desirable.
- Reliable line power should be available to site or able to be installed at cost-effective rate in order to ensure available operation.
- Right of way to install VSL signs and/or overhead sign gantries must be available.
- Reliable communications to the Traffic Operations Center must be available.
- CCTV monitoring of site should be present to monitor system performance and verify messaging.
- VSL signs should be placed at frequent intervals to help maintain motorist awareness of the changed condition.
- Agency should adopt policy for VSL activation.

Range of Researched Benefits:

Mobility
- 20% reduction in travel time
- 17.6% reduction in travel time
- 2% to 7.6% reduction in travel time
- 15% reduction in delay

Safety
- 8% to 30% reduction in crashes
- 55.7% reduction in personal injury crashes
- 8% to 25% reduction in crashes
- 4.5% to 8% reduction in crashes
- 9% to 35% reduction in crashes
- 18% reduction in crashes

Vehicle Operating Costs
- 5% to 16% reduction in fuel use
- 6.3% reduction in fuel use

Benefit/Cost Data
- B/C Range of 7:1 to 14:1
- B/C Range of 0.6:1 to 1.6:1
- B/C Range of 1.1:1 to 1.9:1

Generalized Deployment Costs

- Washington State: $3.2 million per mile on a three-lane section.
- Washington State: $4 million per mile on a five-lane section.
- Germany: $1.2 million to $1.7 million per mile.
- United Kingdom: $18 million per mile.
- Michigan: $67,000 per mile for a portable system.
- Virginia: $425,000 per mile.
- Oregon: $560,000 per mile.
- Seattle: $3.6 million per mile on I-5.
- Minnesota: $2.15 million per mile on I-35W.
- Wyoming: $28,000 per mile.

Inputs

- AADT (for applicable direction)
- Truck AADT (for applicable direction)
- % Traffic Present during VSL Activation

Basic BCR Calculation Steps

\[
\text{Annual Benefit} = (((\text{AADT} - \text{Truck AADT}) 	imes \$15.29) + (\text{Truck AADT} \times \$29.96)) \times (\% \text{ Traffic Present During VSL Activation}) \times (\text{Improvement Length} / 70) \times 17.5 \times 365) + (\text{Annual Number of Crashes} \times 10 \times \$202,264)
\]

\[
\text{BCR} = \frac{\text{Annual Benefit} \times \text{Countermeasure Lifespan}}{\text{Cost}}
\]

Conditions Supporting Success

- There must be sufficient space on shoulder to permit enforcement officers (if used) to pull over violators.
- Outreach to the judicial system regarding the legal aspects of VSL can strengthen enforcement efforts.
- Public outreach to familiarize the public with the goals and benefits of the system.
- Due to potential driver confusion regarding signage, VSL should be deployed with caution when a dynamic lane management system is in place.
- An accompanying Queue Warning System can contribute to the success of a VSL deployment by justifying the speed limits to drivers.

Right of Way to Install VSL Signs
- Washington State: Right of way to install VSL signs and/or overhead sign gantries must be available.
- Reliable communications to the Traffic Operations Center must be available.
- CCTV monitoring of site should be present to monitor system performance and verify messaging.
- VSL signs should be placed at frequent intervals to help maintain motorist awareness of the changed condition.
- Agency should adopt policy for VSL activation.
Title Page

FPO
One Page Project Summary

FPO
**Existing Conditions**

**Purpose & Need**

**Example 1**

I-77 between SR 821 (Exit 16) and the Noble County Line (WAS-77-16.40-17.64) was identified as the highest; in need of capacity improvement in DIO, freeway segment in District 10 in need of capacity improvement, based on the output generated by TOAST. This section of freeway had an overall TOAST Score of 58.7%. The purpose of this study is to identify improvements and recommend countermeasures to mitigate the congestion along this segment.

**Example 2**

The purpose of this study is to evaluate the existing operation and to identify potential countermeasures at the study location of US Route 20 (Fremont Pike) between I-75 SB ramps to Lime City Rd. This location was selected by the District 2 TSMO Committee based on data from the 2018 TOAST analysis with an Urban Non-Freeway ranking of #2 for District 2 and #30 Statewide.

A review of the TOAST data revealed that this segment has some issues with travel time performance, with a score of eight out of 80; and safety performance, with a score of zero out of 30. In addition, traffic characteristics show low performance due to the volume per lane, with a score of six out of 20, and Freight Corridors, with a score of 8 out of 20.

This section of the report is used to identify the location being studied (County/City/Township, Route and Section), type of facility (Functional Classification, number and direction of lanes) and existing traffic control. If applicable, information summarizing previous or planned improvements to mitigate congestion should be documented.
Facility Description

Example 1

This section of SR 149 has two, 12-foot lanes with two-foot shoulders. There are left turn lanes on SR 149 at the Bond Drive/Union Local School Drive intersection. The pavement surface is asphalt. The functional classification is a major collector and the posted speed limit is 45 mph. There are three signalized intersections within this section of SR 149; IR 70 eastbound ramps, IR 70 westbound ramps and at Bond Drive/Union Local School Drive.

Per MS2 (Transportation Data Management System), table 1 this section of SR 149 has an AADT of 8,150. Below are the historical AADT and truck percentages.

Table 1. SR 149 AADT & Truck Percentages

<table>
<thead>
<tr>
<th>Year</th>
<th>SR 149 (SLM 23.93)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>QWS</td>
</tr>
<tr>
<td>2018</td>
<td>8,150</td>
</tr>
<tr>
<td>2017</td>
<td>10,123</td>
</tr>
<tr>
<td>2016</td>
<td>10,023</td>
</tr>
<tr>
<td>2015</td>
<td>9,769</td>
</tr>
<tr>
<td>2014</td>
<td>7,493</td>
</tr>
<tr>
<td>2013</td>
<td>7,368</td>
</tr>
<tr>
<td>2012</td>
<td>7,280</td>
</tr>
<tr>
<td>2008</td>
<td>6,840</td>
</tr>
</tbody>
</table>

This section of SR 149 is experiencing significant congestion due to the recent addition of a Pilot Flying J truck stop in 2014 (south of the interchange with IR 70), Union Local High School, numerous businesses and the continued growth in the oil and gas industry in Belmont County.

A traffic monitoring camera was installed in 2018 at the SR 149 interchange to monitor the truck stop and ramp traffic at this interchange.

Example 2

The study area is US 30 in eastern Wayne County near the Village of Dalton, between Wooster to the west and Massillon to the east. US 30 is a rural four-lane divided roadway with several at-grade intersections and drive access points with median crossovers. To the east and west of the study area, US 30 is either an expressway or freeway look-alike roadway as it approaches Wooster and Massillon.

There are several residential and commercial drives on this section of US 30, as well as several intersections. The table summarizes the intersections in the study segment.
Table 1. US 30 Intersection Information

<table>
<thead>
<tr>
<th>Intersection*</th>
<th>SLM</th>
<th>Control Type</th>
<th>Access Type</th>
<th>Legs</th>
<th>Side Road AADT</th>
<th>Median Width (ft)</th>
<th>Turn Lanes (R, L)</th>
<th>Drives to Next Intersection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kansas</td>
<td>19.64</td>
<td>Stop</td>
<td>RIRO</td>
<td>3</td>
<td>790</td>
<td>45</td>
<td>R</td>
<td>8</td>
</tr>
<tr>
<td>SR 57</td>
<td>20.15</td>
<td>Signal</td>
<td>Full</td>
<td>4</td>
<td>7,882</td>
<td>40</td>
<td>R, L</td>
<td>9</td>
</tr>
<tr>
<td>Kohler</td>
<td>20.68</td>
<td>Stop</td>
<td>Full</td>
<td>4</td>
<td>708</td>
<td>40</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Kidron</td>
<td>21.15</td>
<td>Stop</td>
<td>Full</td>
<td>3</td>
<td>4,178</td>
<td>15</td>
<td>R</td>
<td>4</td>
</tr>
<tr>
<td>Lake</td>
<td>21.72</td>
<td>Stop</td>
<td>Full</td>
<td>3</td>
<td>277</td>
<td>90</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Pres Vannes</td>
<td>21.96</td>
<td>Stop</td>
<td>Full</td>
<td>3</td>
<td>-</td>
<td>105</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Kurzen</td>
<td>22.26</td>
<td>Stop</td>
<td>Full</td>
<td>4</td>
<td>478</td>
<td>50</td>
<td>R, L</td>
<td>8</td>
</tr>
<tr>
<td>Old Lincoln</td>
<td>22.77</td>
<td>Stop</td>
<td>Full</td>
<td>3</td>
<td>1681</td>
<td>50</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Wenger</td>
<td>23.33</td>
<td>Stop</td>
<td>Full</td>
<td>4</td>
<td>301</td>
<td>55</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>SR 94</td>
<td>24.02</td>
<td>Signal</td>
<td>Full</td>
<td>4</td>
<td>4094</td>
<td>50</td>
<td>2R,2L</td>
<td>2</td>
</tr>
<tr>
<td>Cochran</td>
<td>24.35</td>
<td>Stop</td>
<td>Full</td>
<td>3</td>
<td>-</td>
<td>50</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Eckard</td>
<td>24.86</td>
<td>Stop</td>
<td>Full</td>
<td>4</td>
<td>448</td>
<td>50</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Old Lincoln</td>
<td>25.04</td>
<td>Stop</td>
<td>Full</td>
<td>3</td>
<td>2123</td>
<td>50</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Lebanon</td>
<td>25.38</td>
<td>Stop</td>
<td>Full</td>
<td>4</td>
<td>521</td>
<td>50</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Old Lincoln is being counted as a drive where it intersects US 30 west of Lake

Based on the table above, there are 14 intersections in the study area - two signalized and 12 stop-controlled - as well as 41 drives. This yields an intersection density of 2.11 intersections per mile and a drive density of 6.19 drives per mile. Due to the density of driveways and intersections, the posted speed limit on US 30 is 55 miles per hour through the entire study area. Also based on the table above, the median width varies, with a minimum width of approximately 10 feet and a maximum width of 105 feet. In general, the median width is 40 feet west of Kidron Road and 50 feet east of Kurzen Road.

The typical section of US 30 is two 12-foot lanes in each direction with a 4-foot inside shoulder and 8-foot outside shoulder. Edge lines and lane lines are striped on the roadway, and there are raised pavement markers on the lane lines. There are also inside and outside shoulder rumble strips.

Traffic counts on US 30 have slightly increased from around 18,000 - 20,000 vehicles per day in 2000 to around 21,000 - 23,000 vehicles per day in 2018. The AADTs on US 30 since 2000 are shown in the table below.

Table 2. IR 71 AADT & Truck %ages

<table>
<thead>
<tr>
<th>Year</th>
<th>AADT (Truck %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SLM 19.77 W. of SR 57</td>
</tr>
<tr>
<td>2018</td>
<td>20,989 (21%)</td>
</tr>
<tr>
<td>2015</td>
<td>20,318 (18%)</td>
</tr>
<tr>
<td>2013</td>
<td>18,080 (21%)</td>
</tr>
<tr>
<td>2009</td>
<td>18,320 (21%)</td>
</tr>
<tr>
<td>2006</td>
<td>16,900 (23%)</td>
</tr>
<tr>
<td>2003</td>
<td>19,040 (20%)</td>
</tr>
<tr>
<td>2000</td>
<td>19,840 (19%)</td>
</tr>
</tbody>
</table>
There is currently a safety project planned for the eastern portion of this section of US 30, to be constructed in 2019. The project, PID 102109, will close the median at the Wenger Rd intersection, add an eastbound left turn lane at the US 30A (Old Lincoln) intersection west of Wenger Rd, and replace the traffic signal at the SR 94 intersection. There is also a safety study underway that will study a section of US 30 near the SR 57 intersection. In addition, there is a resurfacing project planned for almost the exact limits of this study in fiscal year 2023 (PID 87746, SLM 19.80 - 26.47).

Example 3
Interstate 480 in central Cuyahoga County is an interstate urban freeway with relatively level terrain. There are four lanes along I-480 eastbound with an auxiliary lane between State Rd (SR 94) and SR 176. The lanes are 12-feet wide and with full shoulders for all of the eastbound direction. There are four lanes westbound between State Rd. (SR 94) and SR 176. The pavement is asphalt with striped edge lines, lane lines and raised pavement markers. The median of I-480 is a concrete barrier wall.

Currently, the southbound traffic from SR-176 has an acceleration lane into a merge condition to enter I-480 westbound. The State Road (SR 94) exit westbound is a deceleration lane. The speed limit on this section of I-480 is 60 miles per hour.

The traffic counts on I-480 in this section have steadily increased since 2008. The AADT on I-480 in this section since 2008 is shown in the table below.

Table 1. I-480 AADT

<table>
<thead>
<tr>
<th>Year</th>
<th>IR 480 (SLM 14.32 - 15.59)</th>
<th>SR 176 SB Ramp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AADT</td>
<td>WB</td>
</tr>
<tr>
<td>2017</td>
<td>140,190</td>
<td>71,309</td>
</tr>
<tr>
<td>2016</td>
<td>138,562</td>
<td>69,994</td>
</tr>
<tr>
<td>2015</td>
<td>136,653</td>
<td>68,434</td>
</tr>
<tr>
<td>2014</td>
<td>133,203</td>
<td>n/a</td>
</tr>
<tr>
<td>2013</td>
<td>132,540</td>
<td>n/a</td>
</tr>
<tr>
<td>2012</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>2010</td>
<td>135,220</td>
<td>n/a</td>
</tr>
<tr>
<td>2009</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>2008</td>
<td>133,830</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Example 4
The segment of I-75 between straight line mile 16.27 and 17.24 in Allen County was identified on the 2018 TOAST list. The segment runs north of the Napoleon Rd. overpass to the southern end of the SR-696 overpass near the Village of Beaverdam. Interstate 75 is a four-lane divided highway with approximately 12-foot-wide lanes and 4-foot inside and 10-foot outside shoulders at this location. There are edge line rumble strips present on the inside and outside shoulders of the roadway in the northbound and southbound directions. The speed limit is 70 miles per hour. I-75 along this segment location carries approximately 34,676 total vehicles per day, 10,992 of which are trucks. The current Pavement Condition Rating (PCR) of I-75 in this segment is 71 for the northbound lanes and 72 for the southbound lanes.
Table 1. 1-75 AADT & Truck Percentages

<table>
<thead>
<tr>
<th>Year</th>
<th>I-75 Traffic SLM 16.64</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AADT</td>
</tr>
<tr>
<td>2017</td>
<td>34,676</td>
</tr>
<tr>
<td>2016</td>
<td>32,077</td>
</tr>
<tr>
<td>2015</td>
<td>32,279</td>
</tr>
<tr>
<td>2013</td>
<td>32,096</td>
</tr>
<tr>
<td>2011</td>
<td>30,921</td>
</tr>
<tr>
<td>2008</td>
<td>32,540</td>
</tr>
<tr>
<td>2005</td>
<td>39,060</td>
</tr>
<tr>
<td>2002</td>
<td>34,780</td>
</tr>
<tr>
<td>1999</td>
<td>31,600</td>
</tr>
<tr>
<td>1994</td>
<td>26,820</td>
</tr>
<tr>
<td>1990</td>
<td>20,850</td>
</tr>
</tbody>
</table>

The highest volumes are on Friday afternoons; and the lowest volumes are on Sundays and Saturdays.

A minor rehabilitation project is scheduled for FY2022 (PID 94214) that will repair the mainline pavement, reestablish the grass median and replace concrete barrier sections with cable rail. Drainage concerns along the median barrier will also be addressed with the project to alleviate standing water along the inside shoulder. This TOAST segment is fully included with the proposed project. The pavement was most recently replaced in 2010 and had sections milled out along the curve to enhance the pavement friction.

Performance Measures

Example 1

The TOAST Score for the segment of US Route 20 (Fremont Pike) between I-75 SB ramps to Lime City Road is summarized in Table 1.

Table 1. TOAST Data for WOO-20-(2.79-4.96)
Looking at the existing conditions, traffic volume, and crash patterns for this segment, the causes for some of the poorer performing TOAST categories were analyzed.

- Travel Time Performance (8 out of 80): This west end of the corridor in the area of the I-75 ramps performs poorly throughout most of the day. The main cause of this poor performance is the large volume of vehicles heading SB on I-75 from the east, resulting in a very large WB left turn movement at the intersection of US 20 & I-75 SB ramps. The traffic from this movement spills back out of the left turn lane storage, through the next intersection of US 20 & I-75 NB ramps and past the intersection of US 20 & Carronade. The demand of the large WB left turn movement onto the I-75 SB ramp also adds significant delay to the EB US 20 through movements from the west, especially in the PM peak hours. A review of INRIX data confirms that the congestion at the I-75 interchange in both directions throughout the day. Sample INRIX data and the Turning Movement Counts for both ramp locations and Carronade are in Appendices A & B.

- Safety Performance (0 out of 30): A large source of the poor safety performance is also believed to be caused by the congestion listed above. Rear-end crashes attribute to almost 50% of the crashes for this corridor. It is believed that drivers are not anticipating stopping for the extensive queues that form during peak hours. Additional crash analysis can be found in the next section.

- Volume Per Lane (6 out of 20) and Freight Corridor (8 out of 20) also produce low scores but just reinforce the high traffic volumes and large %age of truck traffic along this roadway segment.

- Based on the TOAST analysis, bottlenecks, incident clearance and secondary crashes are not shown as significant issues. However, future refining of the TOAST data may show that bottlenecks would score lower based on the regular reoccurring queuing near the interchange.

Example 2

The 2018 TOAST list was developed for this location using data from Fiscal Year 2018, which is July 1, 2017 to June 30, 2018. The TOAST score for this segment is summarized in Table 1. In general, the higher the score, the better the segment is performing. A lower score indicates that the segment is performing poorly and may benefit from TSMO strategies.

<table>
<thead>
<tr>
<th>Category</th>
<th>Metric</th>
<th>Value</th>
<th>Score</th>
<th>Max Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Time Performance</td>
<td>Free Flow Speed</td>
<td>98.1%</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Bottlenecks</td>
<td>Impact Factor</td>
<td>51,667 minute-miles/year</td>
<td>7</td>
<td>70</td>
</tr>
<tr>
<td>Incident Clearance</td>
<td>Clearance Time</td>
<td>77 minutes</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>Secondary Crashes</td>
<td>% Secondary</td>
<td>15.6%</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>Safety Performance</td>
<td>PSI Density</td>
<td>0</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Volume per Lane</td>
<td>Number of Vehicles</td>
<td>19,430 veh / lane / day</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Freight Corridor</td>
<td>Truck %age</td>
<td>8.6%</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>OVERALL SCORE</td>
<td>% Total Score</td>
<td>52.9%</td>
<td>164</td>
<td>310</td>
</tr>
</tbody>
</table>
Example 3
The overall TOAST score for I-75 from the Napoleon Road Overpass to the SR 696 Overpass is 52.9% (164/310). The details of the score are summarized below.

**Travel Time Performance = 80/80**
For the majority of the day, motorists can travel at or near (90%) the free flow speed. The travel time does not appear to be an issue for this segment.

**Bottlenecks = 42/70**
A potential bottleneck is detected when speeds on a segment drop to 65% of reference speeds and cause at least a two-minute delay. I-75 is separated into 131 different segments; this corridor had the 17th highest score. Bottlenecks do not appear to be an issue for this segment.

**Incident Clearance = 20/50**
The time from report of an incident until the entire scene is cleared. The score reflects an average clearance time of 86 minutes. The average clearance time statewide along I-75 was 80 minutes. The incident clearance does not show to be an area of concern.

**Secondary Crashes = 20/40**
This score represents that 10.4% of the total crashes for the area are secondary crashes which occurred because of a previous incident. Further review into the crashes individually was done to confirm the data and determine types of crashes that most lead to secondary crashes. It was determined that from 2015-2017, of the 41 total crashes, only one was a secondary crash and appeared to be related to snowy weather conditions. This would alter the score for the metric to a 40/40.

**Safety Performance = 3/30**
The low score shows a high potential for safety improvement by traffic density. Utilizing the Economic Crash Analysis Tool to determine areas of greatest potential, it was determined that the crash types with the greatest potential for safety improvement were sideswipe-passing, animal and fixed object. This correlates to the crashes experienced with the presence of the entrance ramp, median concrete barrier and the rural nature of the segment.

**Volume Per Lane = 4/20**
The segment has one of the lowest volumes for segments of I-75 across Ohio. However, because it is classified as a freeway it still carries more traffic than the majority of District One highways.

**Freight Corridors = 0/20**
Nearly all I-75 segments (96.2% statewide) scored below a 10 in this category. This segment carries 31.7% trucks. This is enough to prompt investigating truck traffic and the effect it has on overall travel speeds, crashes, bottlenecks, etc.
Optional Supporting Information

Basic Crash Analysis

Example 1

Looking at the segment from a safety perspective, a review of crash data yielded 511 relevant crashes within the study area during the five-year period of 2013-2017. During this time 104 (20%) of the crashes resulted in injury. There was one fatal crash within the study area during the study period. In addition, the segment from I-75 to Oakmead Dr. has been selected for study by the FY 2019 Highway Safety Program and is listed as Urban Non-Freeway Rank #46.

<table>
<thead>
<tr>
<th>Year</th>
<th>Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>113</td>
</tr>
<tr>
<td>2014</td>
<td>84</td>
</tr>
<tr>
<td>2015</td>
<td>80</td>
</tr>
<tr>
<td>2016</td>
<td>86</td>
</tr>
<tr>
<td>2017</td>
<td>148</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crash Severity</th>
<th>Pavement Condition</th>
<th>Light Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>79.4% Property Damage Only</td>
<td>76.9% Dry</td>
<td>75.9% Day</td>
</tr>
<tr>
<td>20.4% Injury</td>
<td>19.2% Wet</td>
<td>13.3% Dark - Lighted Roadway</td>
</tr>
<tr>
<td>0.2% Fatal</td>
<td>3.3% Snow</td>
<td>4.7% Dark - Not Lighted</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Light Condition</th>
<th>Pavement Condition</th>
<th>Crash Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>75.9% Day</td>
<td>76.9% Dry</td>
<td>79.4% Property Damage Only</td>
</tr>
<tr>
<td>13.3% Dark - Lighted Roadway</td>
<td>19.2% Wet</td>
<td>20.4% Injury</td>
</tr>
<tr>
<td>4.7% Dark - Not Lighted</td>
<td>3.3% Snow</td>
<td>0.2% Fatal</td>
</tr>
<tr>
<td>3.7% Dusk</td>
<td>0.2% Unknown</td>
<td>0.2%</td>
</tr>
<tr>
<td>1.6% Unknown</td>
<td>0.2%</td>
<td>Unknown</td>
</tr>
<tr>
<td>0.8% Dawn</td>
<td>0.2%</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Crash</th>
<th>Contributing Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear End</td>
<td>56.0% Following too Close</td>
</tr>
<tr>
<td>Sideswipe-Passing</td>
<td>9.6% Failure to Yield</td>
</tr>
<tr>
<td>Left Turn</td>
<td>8.2% Improper Lane Change</td>
</tr>
<tr>
<td>Fixed Object</td>
<td>6.1% Failure to Control</td>
</tr>
<tr>
<td>Right Turn</td>
<td>3.5% None-Motorist</td>
</tr>
<tr>
<td>Angle</td>
<td>3.1% Improper Backing</td>
</tr>
<tr>
<td>Backing</td>
<td>2.9% Ran Red Light</td>
</tr>
<tr>
<td>Head On</td>
<td>2.3% Improper Turn</td>
</tr>
<tr>
<td>Animal</td>
<td>2.2% Other Improper Action</td>
</tr>
<tr>
<td>Overtaking</td>
<td>2.0% Unknown</td>
</tr>
<tr>
<td>Sideswipe-Meeting</td>
<td>2.0% Improper Start</td>
</tr>
<tr>
<td>Unknown</td>
<td>1.2% Improper Start</td>
</tr>
<tr>
<td>Parked Vehicle</td>
<td>0.6% Defective Equipment</td>
</tr>
<tr>
<td>Other Object</td>
<td>0.4% Left of Center</td>
</tr>
<tr>
<td>Pedalcycles</td>
<td>0.4% Ran Stop Sign</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>0.2% Improper Crossing</td>
</tr>
<tr>
<td>Exceeded Speed Limit</td>
<td>0.2%</td>
</tr>
<tr>
<td>Unsafe Speed</td>
<td>0.2%</td>
</tr>
<tr>
<td>Failure to Obey Signs/Signals/Officer</td>
<td>0.2%</td>
</tr>
<tr>
<td>Wrong Side/Wrong Way</td>
<td>0.2%</td>
</tr>
<tr>
<td>Operating Vehicle in a Negligent Manner</td>
<td>0.2%</td>
</tr>
<tr>
<td>Load Shifting</td>
<td>0.2%</td>
</tr>
<tr>
<td>Swerving to Avoid</td>
<td>0.2%</td>
</tr>
</tbody>
</table>
A review of the crash data revealed two main findings:

- Rear-end: 300 crashes - 58.7% compared to the state non-freeway system of 31.1%
- Crashes increased by 72% in 2017 over the previous year and are 45% higher in 2017 than the five-year average of the analysis period.

The high percentage of rear-end crashes is consistent with a heavily congested corridor. Drivers are often following too closely and may not be anticipating other drivers stopping for queues or pulling into business drives.

The significant increase in the 2017 crashes is a concern. The corridor did have a recent signal retiming project. New clearance intervals and modified timings were implemented in July 2016. There is the possibility that modified timings could be associated with an increase in crashes. The new timings, especially the clearance interval changes, can change drivers' habits and expectations. As previously indicated, the segment from I-75 to Oak Mead (MM 3.31) has been selected for study as part of the FY2019 Highway Safety Program. The more in-depth safety analysis may provide additional findings.

**Example 2**

The evaluation of this segment indicates a poor safety performance. Compared to similar segments of roadway, this 0.84 mile stretch of US 35 has 61 crashes per mile per year more than what is expected.

The analysis shows that there were 59 crashes from 2013-2017. There were zero fatalities. The majority of crashes were rear-end collisions and the second most were fixed object. Rear-end collisions are not expected to be a primary type of accident on a freeway. This condition may be caused by either ramp traffic backing up into the freeway’s driving lane or due to an incident that has stopped or slowed traffic. Fixed object crashes would indicate that vehicles are departing from the roadway and striking a roadside object. There are various factors which could lead to vehicles departing a roadway.

**Table 1. US 35 Crash Types**

<table>
<thead>
<tr>
<th>Type of Crash</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear End</td>
<td>24</td>
<td>40.7%</td>
</tr>
<tr>
<td>Fixed Object</td>
<td>17</td>
<td>28.8%</td>
</tr>
<tr>
<td>Sideswipe - Passing</td>
<td>9</td>
<td>15.3%</td>
</tr>
<tr>
<td>Backing</td>
<td>3</td>
<td>5.1%</td>
</tr>
<tr>
<td>Right Turn</td>
<td>2</td>
<td>3.4%</td>
</tr>
<tr>
<td>Animal</td>
<td>2</td>
<td>3.4%</td>
</tr>
<tr>
<td>Head On</td>
<td>1</td>
<td>1.7%</td>
</tr>
<tr>
<td>Other Object</td>
<td>1</td>
<td>1.7%</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>59</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Crash</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury Crash</td>
<td>14</td>
<td>23.7%</td>
</tr>
<tr>
<td>Property Damage Crash</td>
<td>45</td>
<td>76.3%</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>59</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>
Example 3

The intersection of US 33 and Sharp Road was ranked the 125th rural intersection location statewide on the 2017 HSIP Priority List. The segment FAI-US-33-23.62 to 23.72 was ranked the 288th rural non-freeway location. Crash data observations include:

- 22 of the total 30 crashes (73%) that occurred on the segment from 2015 to 2017 occurred at the intersection of US 33 and Sharp Road.

- Rear-end crashes were the most common crash type accounting for 22 of the 30 (73%) crashes.
  - 13 of the 22 rear end crashes (59%) occurred in the northbound direction while the other nine rear-ends crashes occurred southbound.
    - At least two of the southbound rear-end crashes happened during a bridge maintenance work zone lane closure upon approach to the intersection during August and September 2017.

- 8 of 30 crashes (27%) were injury crashes.

Figures 2 through 5 illustrate crash data summaries for the segment.

Figure 2: 2015-2017 Crash Severity Frequency

- 8 (27%) Injury Crash
- 22 (73%) Property Damage Crash

Figure 3: 2015-2017 Crash Type Frequency

Frequency of Crashes by Type of Crash
Detailed Crash Analysis

Example 1

The segment of SR 72 (Limestone Street) from Leffel Lane to Selma Road has a Potential for Safety Improvement (PSI) of over seven crashes per year. This indicates that the segment has seven more crashes per year than other similar locations. The detailed results are in the chart below.
Example 2

The results of the safety analysis for existing mainline SR 8 between I-76 and the Tallmadge Bridge are summarized in Table 1. In addition to an annual crash frequency, the crash frequency per mile per year is also reported in parenthesis.

Table 1. 2018 HSM Analysis Results - Mainline SR 8

<table>
<thead>
<tr>
<th></th>
<th>Fatal and Injury</th>
<th>Property Damage Only</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Between I-76 Ramps and Carroll Street Ramps</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted Crash Frequency</td>
<td>6.05 (14.1)</td>
<td>13.89 (32.3)</td>
<td>19.94 (46.4)</td>
</tr>
<tr>
<td>Expected Crash Frequency</td>
<td>4.82 (11.2)</td>
<td>15.80 (36.7)</td>
<td>20.62 (47.9)</td>
</tr>
<tr>
<td>Potential for Safety Improvement</td>
<td>-1.23 (-2.9)</td>
<td>1.91 (4.4)</td>
<td>0.68 (1.5)</td>
</tr>
<tr>
<td><strong>Between Carroll Street Ramps and Buchtel Avenue Ramps</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted Crash Frequency</td>
<td>5.25 (9.9)</td>
<td>12.23 (23.1)</td>
<td>17.48 (33.0)</td>
</tr>
<tr>
<td>Expected Crash Frequency</td>
<td>7.00 (13.2)</td>
<td>24.34 (45.9)</td>
<td>31.34 (59.1)</td>
</tr>
<tr>
<td>Potential for Safety Improvement</td>
<td>1.75 (3.3)</td>
<td>12.11 (22.8)</td>
<td>13.86 (26.1)</td>
</tr>
<tr>
<td><strong>Between Buchtel Avenue Ramps and Southern Perkins Street Ramps</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted Crash Frequency</td>
<td>0.66 (8.3)</td>
<td>1.50 (18.8)</td>
<td>2.16 (27.1)</td>
</tr>
<tr>
<td>Expected Crash Frequency</td>
<td>1.23 (15.4)</td>
<td>2.97 (37.1)</td>
<td>4.20 (52.5)</td>
</tr>
<tr>
<td>Potential for Safety Improvement</td>
<td>0.57 (7.1)</td>
<td>1.47 (18.3)</td>
<td>2.04 (25.4)</td>
</tr>
<tr>
<td><strong>Between Southern Perkins Street Ramps and Northern Perkins Street Ramps</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted Crash Frequency</td>
<td>3.51 (10.0)</td>
<td>8.17 (23.3)</td>
<td>11.68 (33.3)</td>
</tr>
<tr>
<td>Expected Crash Frequency</td>
<td>5.66 (16.2)</td>
<td>30.22 (86.3)</td>
<td>35.88 (102.5)</td>
</tr>
<tr>
<td>Potential for Safety Improvement</td>
<td>2.15 (6.2)</td>
<td>22.05 (63.0)</td>
<td>24.20 (69.2)</td>
</tr>
<tr>
<td><strong>Between Northern Perkins Street Ramps and Glenwood Ramps</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted Crash Frequency</td>
<td>10.26 (14.7)</td>
<td>22.67 (32.4)</td>
<td>32.93 (47.1)</td>
</tr>
<tr>
<td>Expected Crash Frequency</td>
<td>7.06 (10.1)</td>
<td>17.59 (25.1)</td>
<td>24.65 (35.2)</td>
</tr>
<tr>
<td>Potential for Safety Improvement</td>
<td>-3.20 (-4.6)</td>
<td>-5.08 (-7.3)</td>
<td>-8.28 (-11.9)</td>
</tr>
<tr>
<td><strong>Between Glenwood Ramps and Southern Tallmadge Ramps</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted Crash Frequency</td>
<td>3.22 (11.5)</td>
<td>7.76 (27.7)</td>
<td>10.98 (39.2)</td>
</tr>
<tr>
<td>Expected Crash Frequency</td>
<td>8.51 (30.4)</td>
<td>34.98 (124.9)</td>
<td>43.49 (155.3)</td>
</tr>
<tr>
<td>Potential for Safety Improvement</td>
<td>5.29 (18.9)</td>
<td>27.22 (97.2)</td>
<td>32.51 (116.1)</td>
</tr>
<tr>
<td><strong>Between Southern Tallmadge Ramps and Tallmadge Bridge</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predicted Crash Frequency</td>
<td>1.59 (9.4)</td>
<td>3.90 (22.9)</td>
<td>5.49 (32.3)</td>
</tr>
<tr>
<td>Expected Crash Frequency</td>
<td>4.81 (28.3)</td>
<td>25.88 (152.2)</td>
<td>30.69 (180.5)</td>
</tr>
<tr>
<td>Potential for Safety Improvement</td>
<td>3.22 (18.9)</td>
<td>21.98 (129.3)</td>
<td>25.20 (148.2)</td>
</tr>
</tbody>
</table>

The analysis indicates that the segment between the Southern Tallmadge Ramps and the Tallmadge Bridge is performing the worst of all the segments by experiencing 148 more crashes per year per mile than other similar segments.
Capacity Analysis

To come...
Benefit-Cost Results

To come...
Countermeasures

To come...
Recommendations

Example 1

Based on the analysis of the US Route 20 corridor between I-75 and Lime City Road, the following countermeasures are proposed at this location:

Short Term Countermeasures

I. Revisit signal timings along the corridor, especially near the west end of the corridor. This can be accomplished through in-house traffic analysis. This countermeasure has a benefit-cost ratio of X.X.

II. Modify EB right turn only lane at the I-75 SB ramp to a thru/right lane for increased intersection capacity. This improvement would only require minor guardrail, pavement marking and signing modifications. The estimated cost for this improvement is $10,000 with a benefit-cost ratio of X.X.

The total estimated cost for the short-term countermeasures are $10,000 plus in-house efforts for the signal retiming.

Medium Term Countermeasures

I. Modify the US 20 & I-75 SB ramp intersection to provide for dual WB left turn lanes. The work would require the removal of the median wall just west of the I-75 overpass to make room for the additional left turn lane, on and off ramp modifications, a new traffic signal and other associated improvements. The estimated cost of this improvement is $800,000 with a benefit-cost ratio of X.X.

Long Term Countermeasures

I. Reconfigure the interchange to improve traffic flow. The interchange has exceeded its capacity. The reconfiguration would likely require the replacement of the I-75 overpass bridge. Because this is a long-term and costly solution, the construction costs and resulting benefit-cost ratio were not calculated for this countermeasure.
Appendix D - Supporting Analyses

Optional Supporting Analyses

Safety and/or capacity analysis may be conducted to provide supporting information for the resulting TOAST scores and identified potential causes. The level of safety and capacity analyses to be performed is dictated by the countermeasures being considered. See Chapter 3 for details on the countermeasures and the level of additional analysis that may be needed.

Supplemental Crash Analysis

a) Basic Crash Analysis

Regardless of the countermeasure being considered, TSMO Studies may include a basic level of safety analysis. This analysis should include a review of the most recent three calendar years of crash data for the study location. At a minimum, a summary of the existing crash patterns and trends should be documented. In some cases, a collision diagram may be helpful to explain the safety performance of the study location. The decision to develop a collision diagram is left up to the District Coordinators and should be based on an initial review of the crash data, the size of the study segment, and the Safety Performance score from the TOAST output. For longer segments, in lieu of a crash diagram, a chart illustrating the locations of crashes could be used to summarize the crash data. Alternatively, if a smaller portion of a larger study area has a high concentration of crashes, the crashes for only that area may be diagrammed.

b) Detailed Crash Analysis

Based on the countermeasures being considered, a more detailed safety analysis may be required. See Chapter 3 for more information on the level of safety analysis required for each countermeasure. The detailed safety analysis involves evaluating existing and future conditions using the Economic Crash Analysis Tool (ECAT). For more information regarding how to perform this analysis, please consult ODOT’s Safety Analysis Guidelines.

In this section of the report, the ECAT results for the existing conditions should be summarized in as tabs or graphs. The future conditions results may be summarized in later chapters after the countermeasures are detailed.

c) Capacity Analysis

The level of capacity analysis required differs based on the countermeasures being considered. For some countermeasures, only a simple HCS or Synchro analysis is required, while in other situation, a microsimulation using Transmodeler may be necessary. Please refer to ODOT’s Operational Analysis and Traffic Simulation (OATS) Manual to find more information on how to properly perform analyses in accordance with ODOT standards. In this portion of the report, the results for the existing condition should be presented as tabs or graphs displaying at a minimum the Level of Service and corresponding delays or densities for all study elements.