Development of Network-Level Evaluation Tool for Managing ITS Infrastructure

Final Report

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16. Abstract The research team developed a methodology and implementation tool for the evaluation of Intelligent Transportation System (ITS) projects. The tool enables users to define packages of ITS improvements and provides a planning-level benefit/cost analysis output based on roadway data (such as delay and safety).		
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Executive Summary

The Michigan Department of Transportation (MDOT) is responsible for nearly 10,000 miles of trunk line highways, including some of the most heavily traveled routes in the State. MDOT is challenged to manage highway and transportation assets to efficiently and continually improve the safety and convenience of all travelers within the State of Michigan.

Intelligent transportation systems (ITS) offer a menu of options available to MDOT to improve the safety and efficiency of the transportation system. Leveraging ITS investments can reduce the need for infrastructure expansion by making better use of existing assets. Managing these assets is increasingly challenging as rapidly advancing technology complicates investment decisions. MDOT's extensive ITS coverage and adoption of advanced ITS technology provides an opportunity to support future decisions with enhanced data sources and techniques.

The objectives of the *Development of a Network-Level Evaluation Tool for Managing ITS Infrastructure* study are to: 1) define the ITS network and identifiable limits; 2) complete an evaluation of existing system performance; and 3) deliver a user-friendly network-level performance evaluation tool.

As part of this project, a performance assessment methodology was created for ITS deployments in Michigan to provide a "snapshot" of benefits provided by current ITS deployments. The assessment found Michigan incurs approximately 1.3 billion dollars per year in costs arising from delay on roadways and 3.9 billion dollars in costs associated with crashes (fatalities, injuries, property damage, etc.). Current ITS deployments reduce these disbenefits by roughly 251 million and 176 million dollars, respectively. This represents an approximate savings of 18.6 percent in delays on major roads and savings of 4.0 percent in costs associated with safety issues.

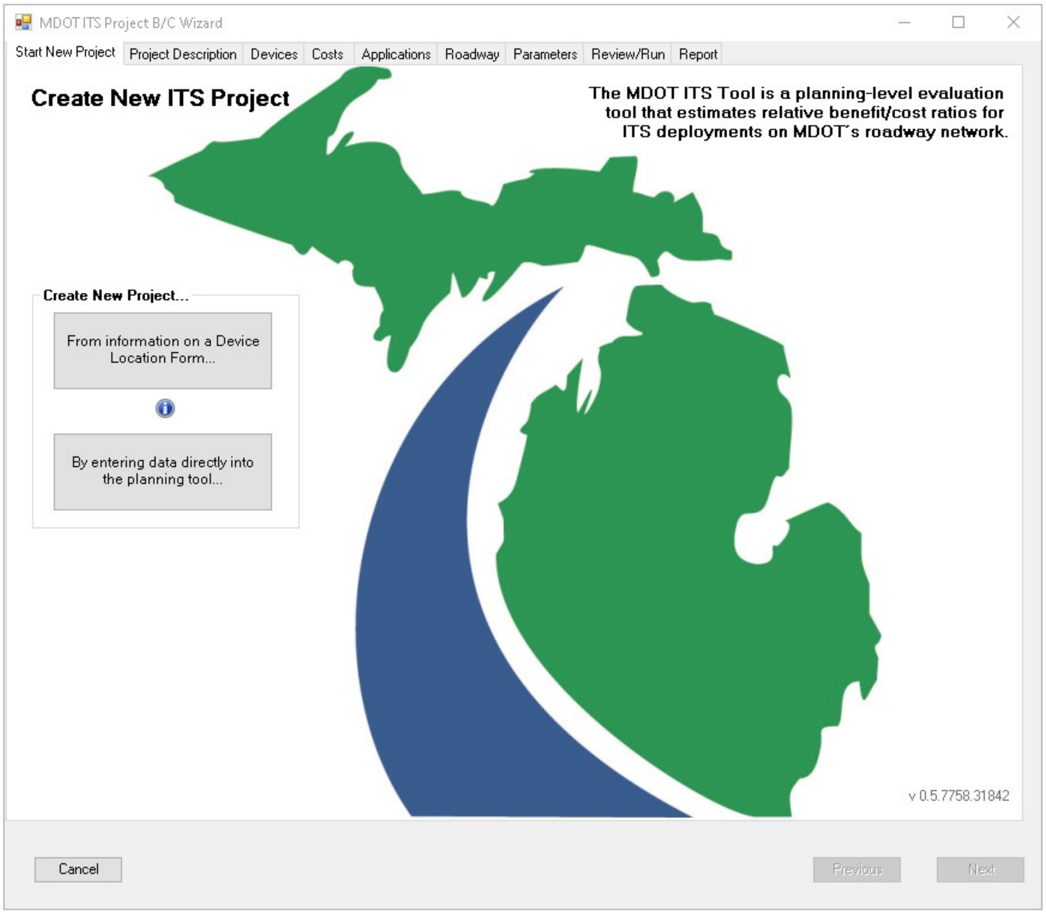
The ITS evaluation tool focuses on generating planning-level benefit/cost results for ITS projects. A review of available input data found that on the roadway side, there is comprehensive data available for AADT and safety. Congestion data is available for a limited portion of the State trunk network. For the ITS devices, while there are some limits to MDOT's ITS database, it is comprehensive enough to reliably support a high-level benefit/cost evaluation for existing and new ITS devices.

A robust planning-level benefit/cost calculation methodology is presented in Section 4. It relies on existing roadway data resources, benefit parameters based on national and local research, costs from MDOT's Device Location Form, and a calculated Gap Score which factors in the presence of existing and overlapping ITS devices.

A series of sample ITS project applications were conducted using the tool's methodology and were found to be reasonable and in-line with expectations. The results ranged from 0.7 to 16.7 across a variety of project types and applications.

The tool was developed as an ESRI AddIn to be used with the ArcGIS platform. The tool calculates the benefit/cost ratio for ITS deployments on Michigan State trunklines.

Figure 1 MDOT ITS Tool Device Location Form Tab



The MDOT ITS Tool is a planning-level evaluation tool that estimates relative benefit/cost ratios for ITS deployments on MDOT's roadway network.

A User Guide including installation instructions is provided in Section 6 of the full report and Section 7 includes discussion of opportunities to update the tool with new data or revised parameters.

1.0 Introduction

The Michigan Department of Transportation (MDOT) is responsible for nearly 10,000 miles of trunk line highways, including some of the most heavily traveled routes in the State. MDOT is challenged to manage highway and transportation assets to efficiently and continually improve the safety and convenience of all travelers within the State of Michigan.

Intelligent transportation systems (ITS) offer a menu of options available to MDOT to improve the safety and efficiency of the transportation system. Leveraging ITS investments can reduce the need for infrastructure expansion by making better use of existing assets.

MDOT has been deploying ITS technology for decades now. The most heavily traveled corridors in the State are well-covered by ITS technology, including environmental sensor stations (ESS), closed circuit television (CCTV) cameras, microwave vehicle detection stations (MVDS), dynamic message signs (DMS), and many other novel systems and programs.

While the wide variety of available ITS investment options provides valuable opportunities for MDOT to improve the performance of the statewide transportation system, it also imposes a challenge to assess the investment strategy that will best support MDOT’s mission and vision. Managing these assets is increasingly challenging as rapidly advancing technology complicates investment decisions. MDOT’s extensive ITS coverage and adoption of advanced ITS technology provides an opportunity to support future decisions with enhanced data sources and techniques.

1.1 Objectives

The *Development of a Network-Level Evaluation Tool for Managing ITS Infrastructure* project has been commissioned by the MDOT Office of Research. The project is overseen by the ITS Program Office, and the objectives of the project include delivery of a user-friendly performance evaluation tool for use on existing or proposed ITS programs.

The objectives of this study are to: 1) define the ITS network and identifiable limits; 2) complete an evaluation of existing system performance; and 3) deliver a user-friendly network-level performance evaluation tool.

The following section summarizes the vision for the evaluation tool, which guides the tool development process by organizing anticipated tool functions into questions that it will answer, listing required elements and where they will come from, and outlining the functional and format requirements of the final product.

1.2 Questions the Tool Answers and How These Support Decision-Making

The tool is intended to answer the following questions for the benefit of users:

- **What is the anticipated benefit/cost ratio and performance impacts for a specific ITS project?**

  Users will be able to enter proposed ITS projects into the tool and receive an estimate of benefit/cost and performance impacts. This application will enable project developers to identify projects that have potentially high value. Where possible, the tool will consider the network impacts of ITS projects (as opposed to considering each project in isolation).

  Example: A regional engineer is considering a DMS deployment project on her busy State route. She is able to quickly input the location and project details into the tool. Using available traffic data and other MDOT resources that are behind the scenes, the tool provides her a favorable benefit/cost estimate. The information supports her development of the ITS Project Request Form's Section 4. Performance Measures.

- **Among a specific set of ITS projects, which projects have the highest benefit/cost and anticipated impacts?**

  Users will be able to compare planning-level benefit/cost and performance impacts across a set of project candidates, providing support for project prioritization. This application will enable Regions to advance high-performing projects for funding consideration and Central Office to identify high-performing projects among all the regions to prioritize funding.

  Example: The MDOT ITS Program Office receives more requests for ITS projects in FY2021 than funding allows. Using the tool, they are able to evaluate the projects and identify those with lower anticipated benefit/cost, which can be another factor among many others in project selection.

- **What benefits does the existing ITS network generate?**

  Users will be able to identify the benefit/cost and performance impacts associated with existing ITS deployments and, by extension, identify the impacts of removing (or failing to maintain) ITS infrastructure. This application will allow the Regions and the ITS Program Office to prioritize maintenance and reinvestment.

  Example: The MDOT ITS Program Office is asked by MDOT leadership to evaluate the impacts of the CCTV network across all State-maintained roadways. The tool enables staff to select the CCTV network and receive an estimate for the benefits generated by the CCTV and the costs to maintain the CCTV network. High-value CCTV assets at key locations are identified as being most useful, and maintenance funding is committed to that device to ensure it continues providing service.

1.3 Required Tool Elements and Where They Come From

To achieve the listed functions, the tool relies on the following elements, shown in Table 1.

Table 1 Required Tool Elements and Sources

Required Element	Primary Sources
Existing	
Current ITS deployments with relevant data (type, details/functions, age, condition, geospatial locations).	MDOT Asset Management Database.
Roadway inventory (classification, speed limits).	MDOT existing roadway inventory shapefiles.
Roadway performance (volumes, congestion/delay, safety issues).	MDOT existing roadway inventory shapefiles.
ITS device cost estimates.	MDOT Device Location Form.
New	
ITS device benefit estimates/calculations.	Developed by project team—drawing from national research, case studies, and MDOT input.
ITS useful life estimates.	Developed by project team—drawing from national research, case studies, and MDOT input.

1.4 Functional Requirements

The tool must:

- Answer the identified questions for the benefit of users.
- Generate easily understandable outcomes, including estimated benefit/cost ratios and performance impacts.
- Provide consistency across different ITS device and project types to allow for comparison.
- Allow for consideration/evaluation of network effects of ITS projects.
- Work effectively with existing ITS project request and selection process.
- Be easy to operate with minimal training.

1.5 Format Requirements

The tool must:

- Be accessible to key user groups with existing MDOT software/hardware.
- Be built on a platform that allows for MDOT's ongoing usage.
- Have minimal maintenance requirements that allow for update of inventory data and calculation parameters.

Given these format requirements, the decision was made to develop the tool as an add-on to desktop ArcGIS.

2.0 Review of ITS and Roadway Data Analysis Methodology

This section summarizes a review of available data on current and planned ITS devices and services and roadway performance data. These elements are the major inputs into a decision-support tool.

2.1 ITS Devices Analysis

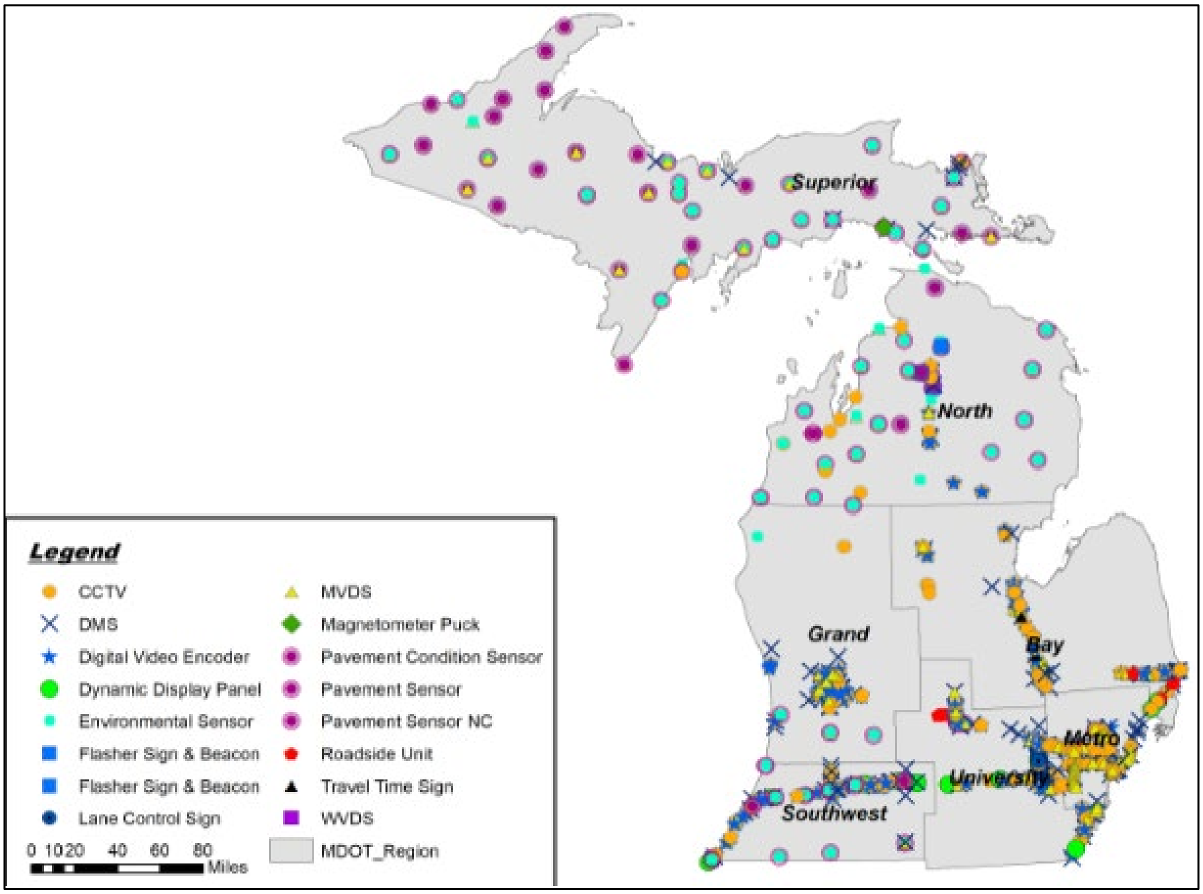
The research team coordinated with MDOT to review available ITS device data and produce a geo-referenced catalog of ITS devices.

ITS Devices Data Source

ITS device data was obtained from MDOT by downloading a.csv file representing the MDOT ITS Data Asset Management Database as of September 2019. The raw data file contained 29,119 unique devices, divided into 72 unique device types. The device locations are shown in Figure 2, though note there is limited visibility when viewed at a statewide scale as many devices are tightly clustered.

The majority of device types included in the complete MDOT ITS database are assets that support the functionality of ITS devices but are not ITS devices themselves. For example, this includes power supply, switches, networking infrastructure, utility poles, and so on. The research team worked with MDOT to identify the core ITS devices of interest for this project. The final working geodatabase omits most of the support ITS devices.

Figure 2 MDOT ITS Devices from Database



ITS Data Gaps

It is important to note that there are some gaps in the available ITS data from the database:

- Planned and programmed deployments would potentially add value to the tool, but there is not a comprehensive and available dataset.
- Data availability in some fields imposes potential complications. For example, there is a "Status" field that includes categories such as Active," "Installed," and "Inventory." Initial conversations with MDOT did not identify any reason to make hard distinctions based on any data gaps in these subfields. Unless otherwise noted, for this project, the fields of interest of the ITS database are limited to device type and location. Other fields, such as "Status," remain in the geodatabase but currently are not used for anything and do not affect which assets were included.
- The MDOT ITS Database did not associate specific cost data with each device.

Device Type and Count Summary

The device types and counts that are being included in the post-processed ITS device database are shown below, in Table 2.

Table 2 ITS Device Database Type and Count Summary

Database Type	Count
Closed-Circuit Television (CCTV) Camera[1]	670
Microwave Vehicle Detection Station (MVDS)	717
Environmental Sensor	563
[DSRC] Roadside Unit (RSU)	251
Dynamic Message Sign (DMS)	235
Pavement Sensor	140
Lane Control Sign	93
Wireless Vehicle Detection Station (WVDS)	43
Dynamic Display Panel	68
Flasher Sign + Flashing Beacon	40
Travel Time Sign	12

[1] Associated with this category are 571 digital video encoder (DVE) devices. According to feedback from MDOT, the presence of a DVE with a CCTV device indicates that the CCTV camera is an older (analog) model. MDOT did not specify how this information might be used within the evaluation process, but did request that this category be included in the refined geodatabase.

Details of these devices are provided below.

Closed-circuit TV (CCTV)

The MDOT ITS database lists 670 CCTV installations. CCTV is perhaps the most critical of devices in the MDOT ITS catalogue as it allows for ground-truth verification of traffic conditions in real-time.

The MDOT ITS database also contains a device-type category for digital video encoders (DVEs) that are associated with CCTV devices. The combination of DVE with CCTV implies that the camera is an older analog model. The MDOT project management (MDOT PM) team indicated that DVE devices should be included in the refined geodatabase to indicate the type of CCTV device. The working map files include a DVE layer that can be integrated as appropriate by the tool-building team.

MDOT noted a CCTV device has practical 360-degree vision[1] with an effective range of ½ mile (though in many locations it can see up to a mile). This information may support identifying coverage gaps.

CCTV devices that are collocated with remote processing units (RPUs) or environmental sensors are not included in the tool's final geodatabase. This pairing indicates that the CCTV is associated with an environmental sensor station rather than the video feeds used by MDOT traffic control centers. In the working project database, all CCTV devices that are within 10 feet of an RPU have been removed.

Microwave Vehicle Detection Stations (MVDS)

MVDSs are used to provide data on vehicle speed, traffic volume, and lane occupancy. Unlike CCTV cameras, MVDS data is automatically converted into machine-readable data, making MVDS coverage essential for certain aspects of MDOT traffic condition reporting.

One MVDS station frequently captures data from only one location of a roadway—though it does usually log data from all lanes.

According to MDOT, the devices associated with HERE (previously contracted with MDOT to obtain traffic data) may or may not actually exist in the field. Some of these were turned over to MDOT, while others were removed. If the core MDOT ITS database includes other devices such as power provision, this indicates that the MVDS has been turned over to MDOT and is still active. If not, it has likely been removed or abandoned.

MDOT suggested that if any HERE MVDS devices are collocated with MDOT-owned equipment (e.g., power provision), they be carried over to the working geodatabase. If they appear to stand alone, they can be removed. The research team found that all MVDS devices were collocated with other equipment. Thus, no MVDS devices were removed and the owner field was updated to assign ownership to MDOT for all devices.

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[1] There is a coverage gap associated with the support pole, which should not affect roadway coverage.

A 2018 MDOT research report concluded that MVDS could be used as a replacement for more expensive methods of traffic counting (i.e., the State continuous count program), but *only* if the MVDS were maintained to a stricter standard of calibration than MDOT currently uses. Further, the study found that there were many data gaps in the data recorded from MVDS devices. It was proposed that part of the data unavailability issue was due to a software transition during the study period, thus it is possible that MDOT now better utilizes data from MVDS than they did during 2015–2016.[2]

Environmental Sensors

The MDOT ITS database includes a category for "Environmental Sensors" that includes multiple subcategories of sensor types that might be included in an environmental sensor station. The refined database includes 559 individual environmental sensors distributed among 98 Environmental Sensor Stations (ESS). The exact sensor suite at any individual ESS can vary but includes some combination of the following:[3]

- Air (ESAR).
- Atm Pressure (ESBP).
- Control Unit (ESS).
- Humidity & Temp (EHST).
- Precip (ESP).
- Sub-Surface (ESSS).
- Visibility (ESVS).
- Wind (ESWD).

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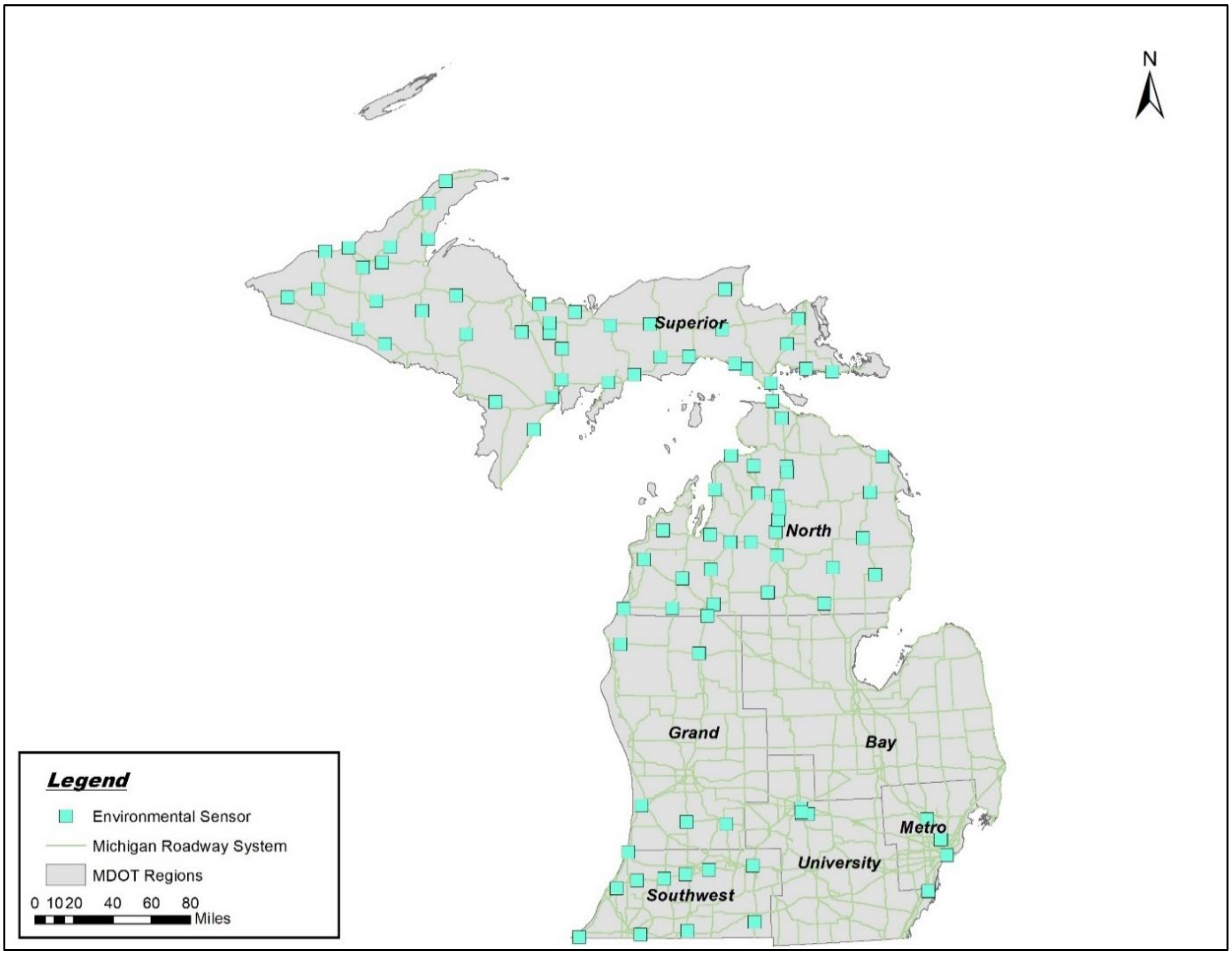
[2] Jun-Seok Oh et al. "An Evaluation of Michigan's Continuous Count Station (CCS) Distribution. Final Report. Western Michigan University Transportation Research Center for Livable Communities. MDOT OR 15-187. April 30, 2018. (Chapter 7 of this report includes an MDVS cost/benefit analysis with respect to CCS.)

[3] The original MDOT ITS database also includes a subcategory called Solar Radiation Shield (ESSRS). This subcategory should be removed from the final geodatabase per MDOT direction.

Figure 3 Environmental Sensor Station Locations



MDOT has stated that for evaluation purposes, it likely is not necessary to worry about which subtypes are considered. There was agreement that all ESS device subtypes could be collapsed into an environmental sensor station ESS category. However, there is some possibility that a closer look at the data could highlight a reason to evaluate ESS device subtypes separately, and so they remain individually listed in the geodatabase.

Roadside Units (RSU/DSRC)

The geodatabase includes 251 Roadside Unit (RSU) wireless communication transponders using dedicated short-range communications (DSRC) technology.

MDOT has noted that there were a few RSUs in the Southwest region that are unusual in that they are associated specifically with the truck parking information system. Reportedly, these can be identified as RSU devices that are collocated with a dynamic display panel. MDOT suggested a possibility of treating these differently—perhaps associating them together with the dynamic display panels, or considering the entire truck parking information system as a single application distinct from the rest of the MDOT ITS program. This function should be considered during tool development.

Dynamic Message Signs (DMS)

Dynamic Message Signs can be used to post information such as estimated travel times, road conditions, pertinent warnings, or any other short message as determined by MDOT's traffic operations centers. DMS are used for both automated messaging (triggered by devices, pre-canned response plans for events), and hand-entered messages. The geodatabase lists 235 of these devices.

Pavement Sensors

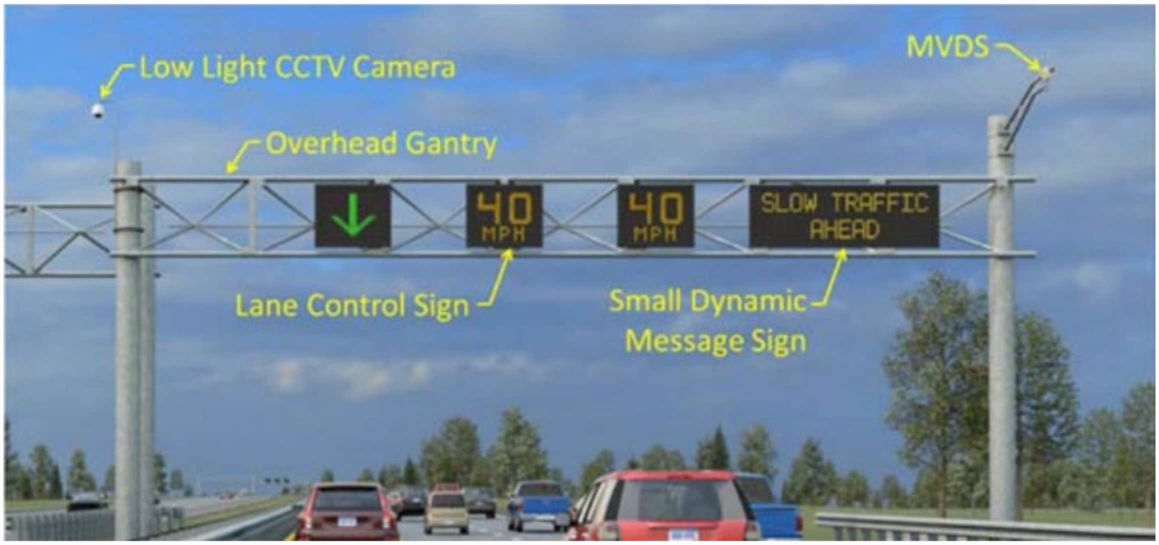
The original MDOT ITS database included three similar device types, *Pavement Sensor*, *PCS*, and *Pavement Sensor NC*. Per MDOT direction, these three device types have been collapsed into a single layer file. However, the type attributes remain in the geodatabase so can be distinguished later if there is a need.

This category includes traffic sensing devices embedded in roadway pavement. Each device can detect traffic conditions at one location in one travel lane. One hundred and forty (140) individual devices are listed, though these are usually located in groups of two or more to obtain full lane coverage at a location.

Lane Control Signs

MDOT's lane control sign type ITS devices are currently all associated with the "FlexRoute" portion of U.S. 23 north of Ann Arbor. FlexRoute provides for a shoulder that becomes open to traffic in response to high-traffic conditions, as well as dynamic speed limit recommendations. As such, each lane control sign is paired with a series of other ITS devices on an overhead gantry, shown in Figure 4.

Figure 4 MDOT US23 FlexRoute Gantry



Wireless Vehicle Detection Stations (WVDS)

The MDOT ITS database uses the WVDS category exclusively to detect parking occupancy for the truck parking program. MDOT directed that the WVDS items with subcategory types other than “puck” be removed from the working geodatabase. After data cleansing, 43 WVDS devices remain in the map file.

Dynamic Display Panel

Dynamic display panels typically display one to three digits. The MDOT ITS database lists 68 dynamic display panels. These are often found in combination.

One potential complication in evaluating the benefits of this device in aggregate is that dynamic display panels are used to display various kinds of information. For example, the benefit/cost analysis for a dynamic display panel that is providing the number of available truck-parking spots is likely much different than one displaying estimated travel times.

Flasher Sign + Flashing Beacon

A flasher sign in the MDOT ITS database refers to any sign modified with a yellow flashing light to help draw attention to the sign. The database does not include the message on the sign that the flasher is amplifying.

Per MDOT, the *flashing beacon* category differs from the *flasher sign* category in that flashing beacons are connected to an environmental sensor station (ESS) and begin flashing when the ESS data determines it would be appropriate (e.g., when weather conditions may facilitate ice buildup on bridge surfaces). The database does not specify the message on the sign that the flasher is amplifying.

Travel Time Sign

The MDOT ITS database has a category called *travel time signs*. The actual devices in this category appear very similar to dynamic display panels in that they are a dynamic digital sign capable of displaying a two-digit number. However, all travel time signs are dedicated to specifically providing travel time. There are 12 of these devices listed. These are always listed in pairs because they are intended to provide *relative* travel times as options to motorists.

2.2 Road Network Analysis

The attributes of the roadway network are another key input into evaluation of the benefits of ITS devices. Inputs, including traffic volumes, safety issues, and congestion levels help quantify where and how devices are giving travelers safer, more efficient, and more reliable options.

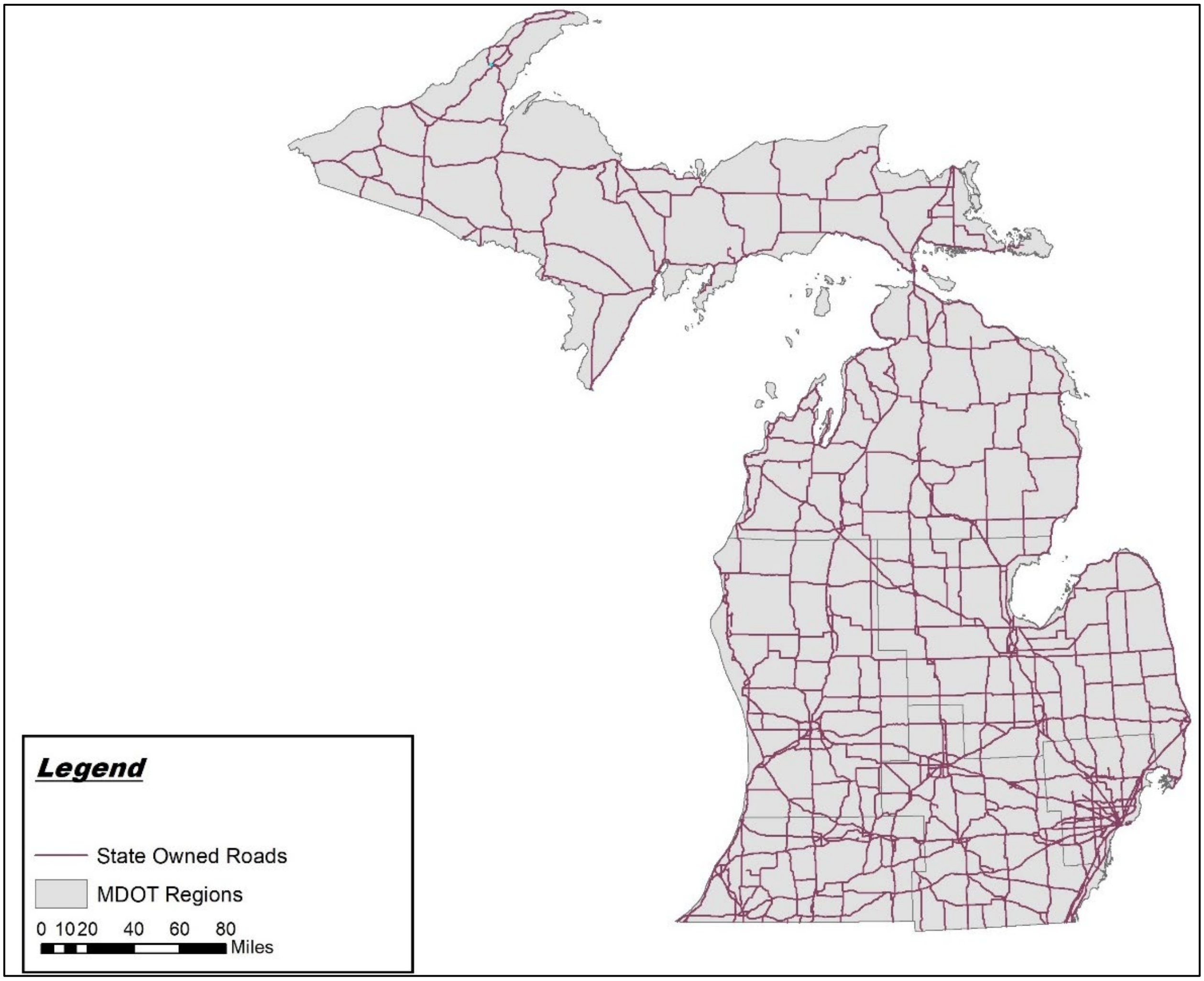
The research team worked with MDOT project team to establish the context in which ITS devices are evaluated. The ArcGIS files compiled to evaluate the efficacy of ITS devices include all MDOT-controlled routes in a shapefile as well as attributes that are pertinent to each road section.

MDOT expressed a preference that the tool use only data that is readily available to MDOT ITS planners. The research team built on the foundation of annual average daily traffic (AADT) data to incorporate additional data layers representing congestion data and crash data. Congestion data includes only partial coverage of the MDOT network; however, it is believed that congestion is not problematic for segments for which data is not available. Crash data is believed to be complete from 2017–2019.

State Road Network

The MDOT (State trunklines) road network was obtained via the MDOT Data Portal in September 2019.[4] The MDOT trunkline shapefile includes all State-owned, MDOT-managed roads. The trunkline system includes less than 10 percent of the overall State road network (by segment length). The remainder of roads in Michigan are owned and managed by local authorities. ITS assets on locally controlled roads are not within the scope of this project.

Figure 5 MDOT-Controlled State Trunkline Roads



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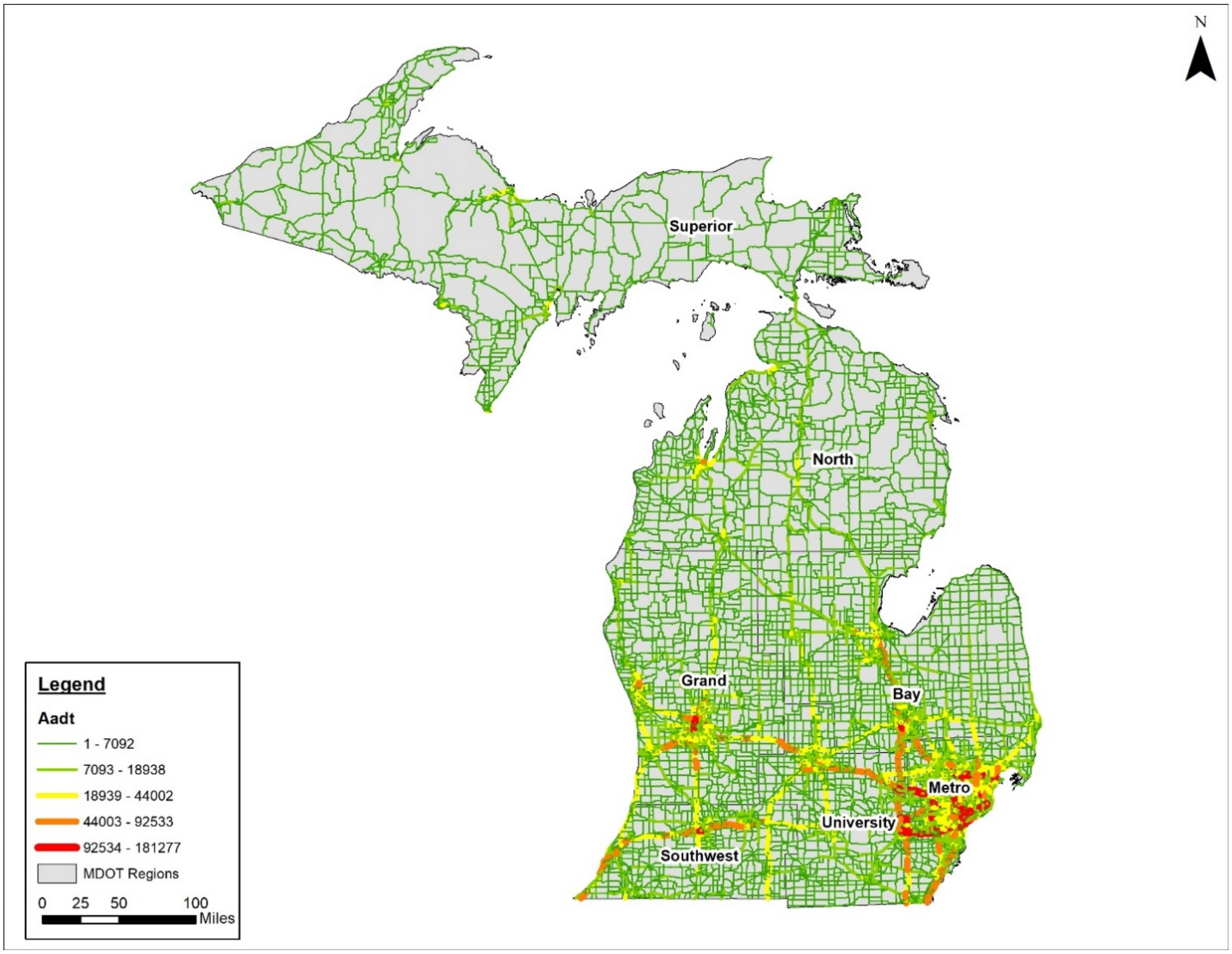
[4] MDOT Data Portal, State Trunklines: http://gis-mdot.opendata.ArcGIS.com/.

Traffic (AADT) Data

The primary evaluation metric currently used in MDOT ITS planning is AADT. The 2018 values for AADT have been obtained from the Michigan Open GIS Data Portal.[5] Raw AADT values are given with precision to the single digit, differentiating between overall and commercial AADT. It may be advantageous for the ITS evaluation tool to represent traffic volumes within discrete bins (e.g., low, medium, and high volume roads). MDOT does not have pre-determined traffic volume bins that should be considered in such decisions when designing the final evaluation tool.

Figure 6 Statewide AADT



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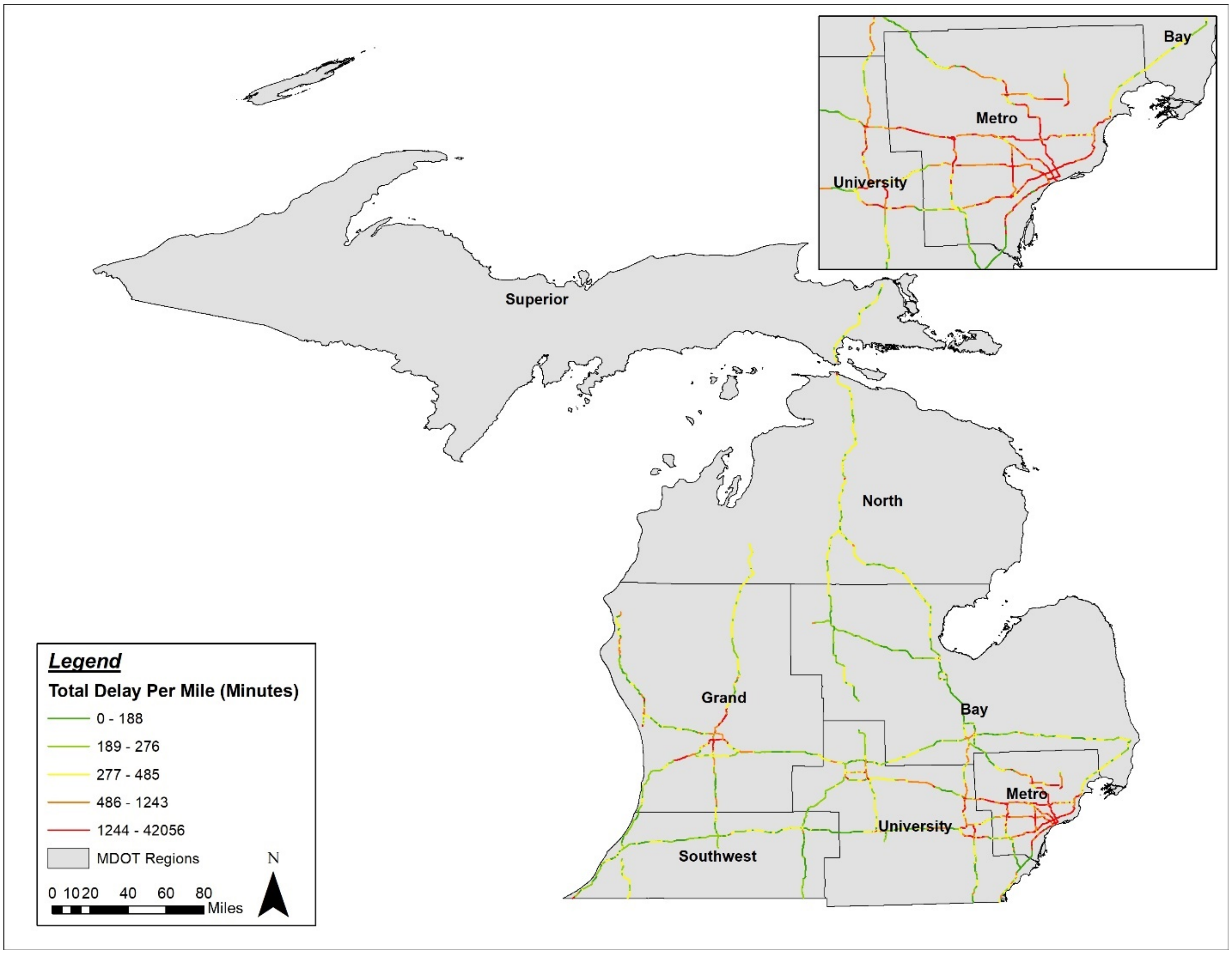
[5] MDOT Open Data Portal, AADT: https://gis-mdot.opendata.ArcGIS.com/datasets/mdotaadtcaadt2018.

Congestion Layer (Total delay per mile in minutes per year)

The research team worked with MDOT's Congestion and Reliability Section to obtain an INRIX dataset representing total delay per mile, in minutes from Wayne State University. This dataset is typically processed in support of the Michigan Congestion & Reliability Performance Report.

Delay data is not available for the entirety of the MDOT trunkline system. For segments that do not have available delay data, this research project operates under the assumption that delay is negligible for ITS device planning purposes.

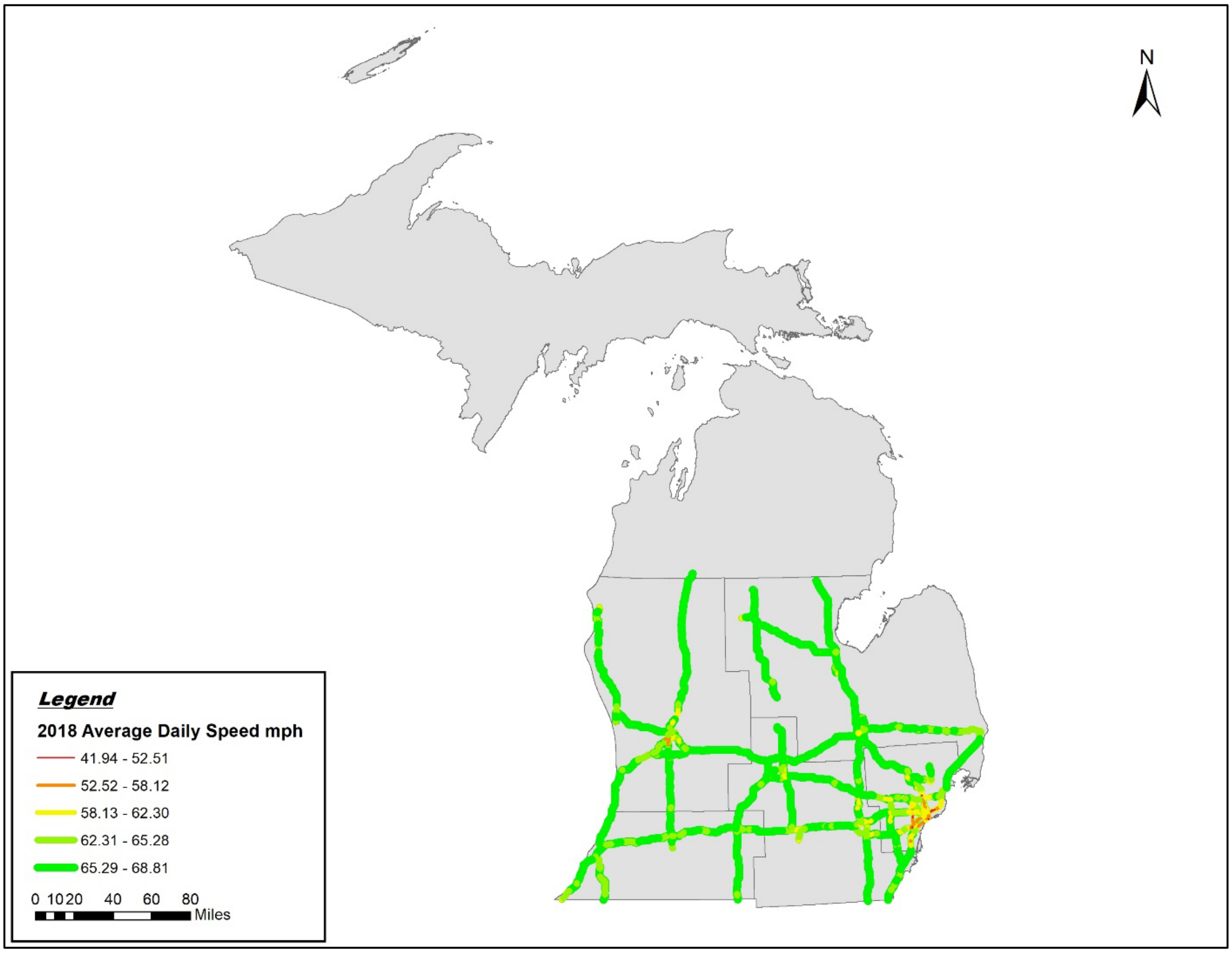
Figure 7 Total Delay per Mile



Average Speed Layer

The TMC average daily speed map was created by joining the INRIX 2018 Average Speed table to the INRIX TMC shapefile (provided by WSU). The research team calculated the average daily speed from the existing entries and symbolized the average daily speed map based on the results.

Figure 8 Average Daily Speed (mph)

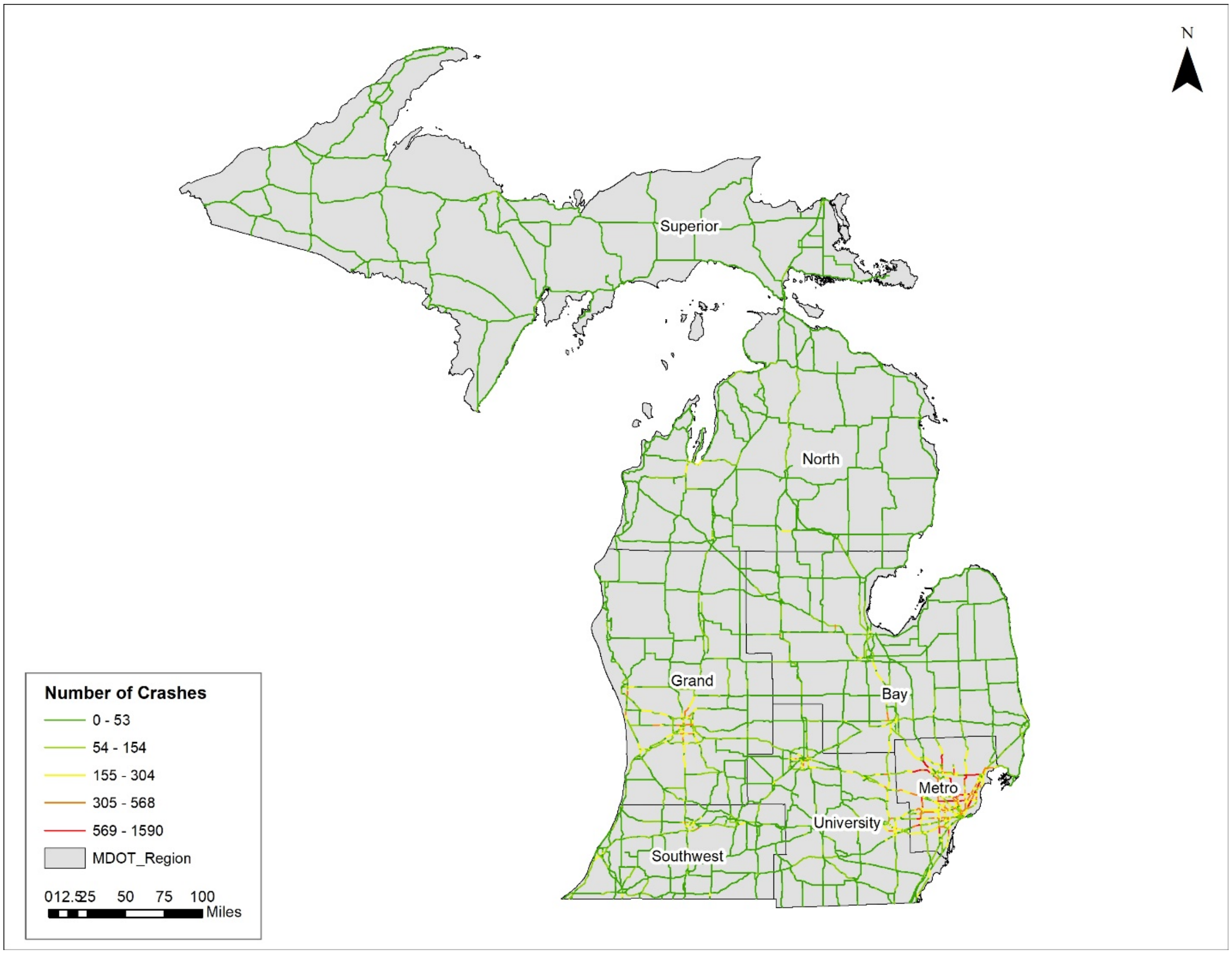


Crash Safety Layer

Traffic crash data in Michigan is shared with the public through the Michigan Traffic Crash Facts (MTCF) website. MDOT provided the research team with a spreadsheet that included coordinates of crash locations for the years 2017, 2018, and 2019. These data omitted crashes listing the cause as animal, drinking, or drugged, where presumably the use of conventional ITS strategies would have limited impact.

Crash volume data was mapped for 2017–2019. With the State AADT shapefile as the base layer, the crash points were combined using Spatial Join tool, with a 0.1-mile buffer. This process joined each crash to the nearest roadway segment. The result is a count of the number of crashes on each road. To produce a more accurate metric, the number of crashes was divided by the segment length, in miles, to produce Crashes per Mile. The final shapefile contains fields for Count and CrashPerMi.

Figure 9 Crashes, 2017–2019



2.3 Review Findings

There is a solid foundation for ITS device data inputs into the tool. While there are some limitations to the specifics within available data, the dataset does provide location, device type, and other critical inputs to the decision-support tool. The current database has been refined and will serve as the initial input into the tool. The research team will develop and discuss and explore options for ensuring the database can be updated with new data when available.

On the roadway side, there is comprehensive data available for AADT and safety. Congestion data is available for a limited portion of the State trunk network. As with the ITS devices, while there are some limits to the database, it is comprehensive enough to reliably support a high-level benefit/cost evaluation for existing and new ITS devices.

3.0 ITS Performance Assessment Methodology

As a companion to the ITS benefit/cost tool, a performance assessment methodology also was created for current ITS deployments in Michigan. The performance assessment differs from a benefit/cost analysis in several important ways, and is not meant to be a strictly comparable "alternative" approach to benefit/cost calculations. Among the major differences are:

- The performance assessment seeks to give a "snapshot" of benefits provided by current ITS deployments. It does not consider the costs of deployments.
- The performance assessment uses a "top down" approach to calculations by first estimating the total disbenefit incurred by crashes and delays, then calculates a reduction based on assumptions about ITS deployment's effects on disbenefits.
- The roadway segmentation model used for the ITS gap analysis also is used for the performance analysis. All state-jurisdiction roadways are divided into one-mile segments for the assessment. The benefit/cost model uses the same segmentation that is used for delay data reporting, which includes segments of varying length.
- The performance assessment uses the same initial model assumptions about the effect of ITS devices on crashes and delays as the benefit/cost tool, but it segments and normalizes the data differently and as such will not produce the same aggregate values.
- The benefit/cost tool examines values at a project level, the performance assessment examines values based on geographic constraints, such as along or corridor or within a region.
- The value of the performance analysis is in its ability to use a simplified underlying data management structure, and be "re-run" at different times to provide an index of the benefits provided by ITS deployments overtime, if desired.

3.1 Performance Assessment Methodology

With the goals of being data-driven and simple to replicate, the performance assessment was extensively based on the ITS gap assessment geospatial structure and the underlying assumptions of costs used in the cost benefit tool.

Geospatial Structure

The ITS gap assessment analyzed roadway characteristics (roadway class, traffic volumes, proximity to population centers, etc.) to determine a "reference" level of ITS deployments for each one mile segment of roadway. Roadways were classified into a simple, 4-level system to identify the appropriate reference level. The classifications are shown in Table 3.

Table 3 Performance Assessment Roadway Classifications

Category	Criteria
A: Urban Interstate, Freeway or Expressway **NFC 1 and 2**	1. Roadway class of Interstate or U.S. Trunk Highway or comparable. 2. In or within one mile of a Minor Civil Division with a population density greater than 1,800 per square mile. 3. AADT >= 12,000
B: Rural Interstate, Freeway or Expressway **NFC 1 and 2 (below AADT)**	1. Roadway class of Interstate or U.S. Trunk Highway or comparable. 2. Greater than one mile from the boundary of a Minor Civil Division with a population density greater than 1,800 per square mile. OR 3. AADT <=3,000
C: Urban Major **NFC 3, 4, 5 and 6**	1. Roadway class NOT Interstate or U.S. Trunk Highway or comparable. 2. Contained within or within two miles of a Minor Civil Division with a population density greater than 2,000 per square mile. 3. AADT >=5,000
D: Rural Major **NFC 3, 4, 5 and 6**	1. Roadway class NOT Interstate or U.S. Trunk Highway or comparable. 2. NOT Contained within or within two miles of a Minor Civil Division with a population density greater than 2,000 per square mile. 3. AADT <=5,000

The reference level was then applied to the roadway segments and compared to the existing inventory. The difference between the reference and current inventory was given a score as a "gap."

The same one-mile roadway segmentation was retained for the performance assessment. In addition to the locations of ITS devices, traffic volume data (passenger and commercial average daily traffic), crash and delay data were normalized to one mile increments and assigned to the one mile gap analysis segments.

Model Assumptions

The cost or "disbenefit" values resulting from delays and crashes are identical to those used in the benefit/cost analysis tool. While crash data are reported for all roadways in Michigan, delay information is only compiled for certain roadways, generally Category A, B, and C roadways. As a result, Category D roadways do not have an ITS performance assessments. These generally do not have devices installed other than to address specific, localized conditions.

For the remaining categories, the following disbenefit values are used in the performance analysis are shown below, in Table 4.

Table 4 Performance Assessment Disbenefit Values

Item	Value
Value of Crash (Category A and B roadways)	$83,110.08
Value of Crash (Category C roadways)	$79,886.27
Value of Time (Passenger vehicles)	$16.60 per hour
Value of Time (Commercial vehicles)	$29.50 per hour

To calculate performance, each ITS device type was assumed to have an effect of reducing the disbenefit encountered on the segment. For these calculations, the assumptions shown in Table 5 were used.

Table 5 Performance Assessment Benefit Assumptions

Item	Road Category	Value
“Basic ITS” (CCTV, vehicle detection, DMS)	A, B, C	10% reduction in crashes
“Basic ITS” (CCTV, vehicle detection, DMS)	A, B	7 person-minute/mile reduction in total delay
“Basic ITS” (CCTV, vehicle detection, DMS)	C	4 minute/person reduction in total delay
Connected Vehicle Roadside Units	A, B, C	15% reduction in crashes
Weather Monitoring (ESS)	A, B, C	7% reduction in crashes
Weather Monitoring (ESS)	A, B	5% reduction in delay
Weather Monitoring (ESS)	C	3% reduction in delay
Lane Control (LCS)	A, B, C	7% reduction in delay
Lane Control (LCS)	A, B, C	10% reduction in crashes
Active Traffic Management	A, B, C	20% reduction in crashes
Active Traffic Management	A, B, C	15% reduction in delay

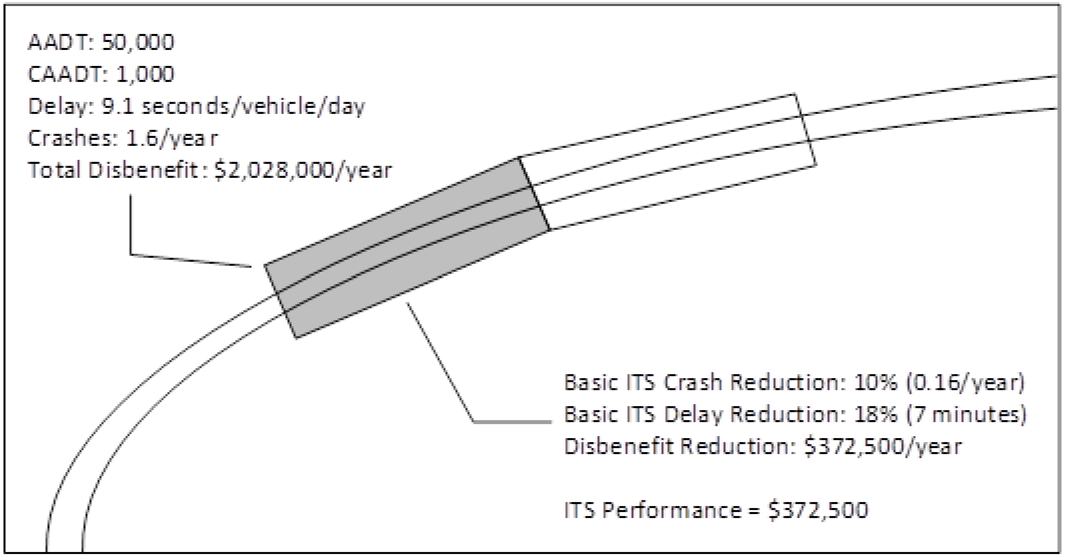
While values were assigned for each of the ITS device types shown in Table 5, note that not all device types are deployed in significant numbers, and not all devices are deployed on all roadway categories.

Performance Calculation

The ITS performance calculation is fundamentally calculating a total disbenefit for each one mile segment and subtracting the cumulative reduction provided by the ITS devices on that segment.

An example is shown in Figure 10.

Figure 10 Performance Assessment Example Segment



In the example, a roadway segment has an AADT of 50,000 with Commercial Vehicles (CAADT) of 1,000 per day. Congestion over the 1 mile segment is an average of 9.1 seconds per vehicle per day and there are an average of 1.6 vehicle crashes per year. Using the assumptions from the benefit/cost analysis, at total annual disbenefit of $3,028,000 is incurred on this high-delay, high crash segment.

By reducing the average number of crashes by 10 percent and delay by 18 percent (proportionally distributed by passenger and commercial vehicles) and overall reduction or ITS performance value of $372,000 is realized.

Repeating this process over all the segments on A, B, and C category roadways gives a statewide view of ITS performance.

Performance Assessment Analysis

A significant difference between the ITS performance assessment and other benefit/cost analyses is that while most other approaches tend to isolate the geographic context to where ITS deployments are located, the performance analysis considers the roadway network as a whole. This has two important effects on the numerical output of the analysis:

- The disbenefit costs (total delays and crashes) will be much higher than if only costs from the area of a deployment are considered.

- The larger disbenefit costs will tend to show a smaller effect of the ITS deployments as a percent reduction or ratio than other methods.

For these reasons it is important to interpret performance assessment data as internally compatible, but not necessarily comparable to other methodologies.

Part of the unique value of the performance assessment is its ability to perform post hoc aggregations of cost and performance data. After a statewide segmentation and analysis was completed, MDOT regions were overlaid to produce the aggregation shown in Table 6.

Table 6 ITS Performance by Region

Region	Delay Costs	Delay Savings	Percent Savings	Crash Costs	Crash Savings	Percent Savings
Bay	$55,619,399	$7,282,296	13.1%	$396,805,790	$6,053,916	1.5%
Grand	$158,225,138	$24,896,383	15.7%	$561,249,845	$2,991,690	0.5%
Metro	$917,190,068	$180,067,898	19.6%	$1,976,302,576	$123,080,523	6.2%
North	$12,705,480	$685,059	5.4%	$29,463,671	$353,295	1.2%
Southwest	$35,531,948	$9,352,881	26.3%	$252,054,352	$5,363,942	2.1%
Superior	$1,326,374	$124,682	9.4%	$6,148,811	$59,450	1.0%
University	$172,898,777	$28,929,994	16.7%	$703,694,679	$18,648,199	2.7%
TOTAL	$1,353,497,184	$251,339,193	18.6%	$3,925,719,724	$156,551,015	4.0%

From Table 6, Michigan incurs approximately 1.3 billion dollars per year in costs arising from delay on roadways and 3.9 billion dollars in costs associated with crashes (fatalities, injuries, property damage, etc.). Current ITS deployments reduce these disbenefits by roughly 251 million and 176 million dollars, respectively.

The percent reduction shown (18.6 percent) is a reduction in total delay on all category A, B, and C roadways. While the percent reduction initially appears to be a substantial portion of total delay, the oldest and most dense ITS deployments are generally targeted at the areas that have historically had the most congestion and therefore delay.

In comparison, the crash savings are 4.0 percent of the total crash disbenefits across the entire state, indicating that value of ITS for improvements in safety.

Performance Assessment Tool Use

The ITS performance assessment provides a view of the total value of ITS deployments, both in dollar terms and as a percentage reduction in the disbenefit of delays and crashes. Specific benefit/cost analysis tools should be used to evaluate individual projects and help guide investment decisions.

The performance assessment should be used to give an overall view of the current value of ITS assessments and to give an indication of the change in value over time. In this way, the performance assessment can be considered as an “index” of performance as opposed to a raw valuation.

Periodic revisiting of the performance assessment and development of more specific (metro area or roadway-based) aggregations is recommended as one way to display the value of ITS investments.

4.0 ITS Benefit/Cost Evaluation Methodology for Tool

This section summarizes the approach for conducting benefit cost analysis within the evaluation tool. It includes the ITS devices included in the tool, an overview of the benefit parameters, cost components, ITS gap score, and sample ITS projects.

4.1 ITS Device Categories

This section provides a list of the devices incorporated into the evaluation tool for managing ITS infrastructure. There were a variety of possible categorization schemes and several key issues which were addressed in selecting the devices included:

- For installation and maintenance purposes, devices may include a number of subcomponents and supporting technologies that are not relevant for the purposes of calculating benefits. For example, the communications technology that supports CCTVs should be subsumed under a CCTV category. While these components may be relevant for costing purposes, they were not included as a separate item in calculating benefits.
- Benefits of ITS are derived from applications of the devices, not the equipment itself. Thus, it is important to identify the relationship between devices and applications. Vehicle detectors, for example, are used to provide speed and travel time estimates that can help mitigate congestion and reduce travel time. Devices can support multiple applications.
- Benefit/cost analysis requires that data be readily available on the inventory of devices, as well as the ability to move information from existing MDOT data into the tool.

A number of sources were utilized to develop the device recommendations. These included:

- The evaluation of existing data availability and characteristics of candidate devices for the benefit/cost tool discussed in Section 2. The 72 original device types from the MDOT ITS Data Asset Management Database were mapped and consolidated. The Memo included a discussion of MDOT's process for maintaining and updating the database.
- Western Michigan University conducted an ITS benefit/cost research project for MDOT in 2015. That study included a categorization of ITS devices and applications for use in benefit/cost analysis.

- MDOT uses a Device Location Form to summarize the components and costs of ITS projects across the State as part of the current project selection and prioritization process. The form serves as the primary cost input for the benefit/cost tool.

Table 7 below compares the devices identified in each of these three sources. The different terminologies were used to describe the devices were maintained in the table, but the devices across each row are considered to be basically the same.

Table 7 Device Terminology and Grouping Across Key Sources

ITS Data Asset Management Database	MDOT ITS Benefits Research Report	MDOT Device Location Form
Closed Circuit TV (CCTV)	CCTV	CCTV
Dynamic Message Signs (DMS)	DMS	DMS (Large and Small)
Microwave Vehicle Detectors (MVDS)	Vehicle Detectors	MVDS
Wireless Vehicle Detectors (WVDS)	Vehicle Detectors	
Environmental Sensors		Environmental Sensors Station
Roadside Unit (RSU) / Dedicated Short-Range Communication (DSRC)		RSU
Pavement Sensors		
Lane Control		Lane Control System
Dynamic Display	Dynamic Trailblazers	Dynamic Message Panel (DMP)
Flashing Sign/Beacon		Curve Warning, Queue Warning
Travel Time Sign	Travel Time Signs	DMP—Travel Time
	Ramp Meters	Ramp Meters
		Active Traffic Management (ATM) Corridor
		Over-height Vehicle Detection System (OHVDS)

As noted above, calculation of benefits requires knowledge of both the devices involved and the specific applications they are supporting. The research team reviewed the sources cited above as well as the applications identified in the Device Location Form and applications identified in various TSMO projects, including Michigan.

Based on this review and the status of various device data, the research team developed a recommendation for which devices are included in the benefit/cost tool and which applications they support. Flexibility is an important characteristic of the tool, as both new devices and applications will need to be added in the future. Table 8 presents the set of devices considered for inclusion in the tool, the set of applications, and the relationship between the two. Devices considered essential for the application are marked as primary (with a "P"), while devices that support the application, but are not essential, are marked as secondary (with an "S"). Overview definitions of the applications follow the table.

Table 8 Recommended ITS Device Categories and Application Support

Recommended ITS Device Categories	Application: Incident Management	Application: Traffic Conditions (Recurring)	Application: Traffic Conditions (Non-Recurring)	Application: Safety	Application: Weather	Application: Lane Control	Application: Ramp Metering
CCTV	P	S	P	S	S	S	
DMS	P	P	P	P	P	P	
Microwave Vehicle Detectors	P	P	P	S	S	P	P
Environmental Sensors Station				S	P		
RSU	S	S	S	P	S		
Dynamic Message Panel			S	P	S		
Lane Control System	S	S	S	S		P	
Travel Time Signs	S	P	P				
Ramp Meters		S	S				P
ATM Corridor	P	P	P	P	S	P	
Curve Warning				P			
Queue Warning		S		P			

Notes: P = Primary; S = Secondary

- The two categories of Vehicle Detection Station, Microwave and Wireless, are lumped together. As they perform the same functions, benefits will not vary, although costs may differ.
- Incident management refers to activities that support first responders in the field, who must service the incident and direct traffic around it.

- Traffic conditions recurring includes traveler information on key routes, as well as operational strategies such as variable speed limits or traffic signal coordination strategies.
- Traffic conditions non-recurring refers to traffic delays caused by incidents, construction, special events, or similar occurrences. The main objective is to provide traffic information to motorists so that they can anticipate the slowdown or take an alternate route.
- Weather applications can provide data on locations subject to hazardous weather events, such as flooding, icing, fog or whiteouts. Other weather stations across the State provide MDOT with more general weather information that can help in planning winter maintenance activities.
- Lane control refers to strategies that require opening and closing of lanes, such as reversible lanes or hard shoulder running.
- Safety covers a range of sub-applications designed to address safety hot spots in the system. These may include curve warning systems, queue warning systems, or connected vehicle safety applications at intersections.
- Ramp meters help manage recurring and non-recurring congestion on highways.

4.2 ITS Devices Applications

A set of ITS devices for the benefit/cost tool were recommended in the previous section and matched with likely applications. Applications were identified as either primary, where the device is considered essential to the application or secondary, where a device may add benefits but is considered optional for the application. Estimated costs for the devices may vary depending on the application, supporting technologies and required and location. However, costs are relatively well-established based on MDOT’s extensive ITS deployments across the State. Estimates of benefits, however, require knowledge of the specific applications proposed as well as other data which may include traffic volumes, roadway characteristics and crash rates/ frequency. Benefit estimates have been compiled by FHWA in the TOPS-BC tool and U.S. DOT in the ITS Benefits Database and that documentation was used to develop parameters appropriate to the MDOT system. TOPS-BC and the ITS Benefits Database include benefit parameters derived from real-world studies and simulations of ITS deployments across the country. The table below summarizes for each device, the primary applications, primary data required to estimate benefits and the types of benefits that apply to each device/application combination.

Table 9 ITS Device Types, Applications, and Key Data Needs and Benefits

Equipment Types	Subcategories	Application Use Primary	Data	Benefits
CCTV	• CCTV • CCTC—Arterial • CCTV—Traffic Signal	• Traffic conditions (non-recurring) • Incident management	• Traffic volume • Crash rate	• Crash reduction • Vehicle operating costs (VOC) savings
DMS	• Large • Small	• Traffic conditions (non-recurring) • Traffic conditions (recurring) • Safety • Weather • Lane Control • Incident Mgmt	• Traffic volume • Crash rate	• Travel time savings • Crash reduction • VOC savings
MVDS		• Incident management • Traffic conditions (non-recurring) • Traffic conditions (recurring)	• Traffic volume • Crash rate	• Crash reduction • VOC savings
Environmental Sensor	• ESS • ESS with DMS	• Weather	• Traffic volume • Delay • Crash rate	• Delay savings • Crash reduction • VOC savings
RSU	• RSU • RSU—Traffic Signal	• Safety	• Crash rate	• Crash reduction
Lane Control System	• Single Panel • 3 Panel • 3 Panel with DMS • 4 Panel • 4 Panel with DMS	• Lane Control	• Traffic volume • Delay • Crash rate	• Delay savings • Crash reduction • VOC savings
Dynamic Message Panel/Travel Time Signs	• Single Panel • 2 Panel • 3 Panel	• Travel Times • Traffic conditions (non-recurring) • Traffic conditions (recurring)	• Traffic volume	• Travel time savings
Ramp Meters		• Ramp Metering	• Traffic volume • Delay • Crash rate • Congestion data	• Delay savings • Crash reduction • VOC savings

Equipment Types	Subcategories	Application Use Primary	Data	Benefits
ATM Corridor	3-Lane 4-Lane	Incident management Traffic conditions (non-recurring) Traffic conditions (recurring) Safety Lane Control	Traffic volume Delay Crash rate	Delay savings Crash reduction VOC savings
Curve Warning[1]		Safety	Crash rate	Crash reduction
Queue Warning[1]		Safety Traffic Conditions (non-recurring)	Crash rate	Crash reduction

[1] This application should only be analyzed independently within the tool. If the user is deploying this in combination with other devices the user should conduct two separate analyses with this device separate from the other device type(s) with benefits and costs combined after to calculate the benefit/cost ratio.

In summary, the primary benefits incorporated into the tool include travel time or delay savings, reduced fuel consumption (calculated as vehicle operating costs) and reduced crashes. Primary data inputs are traffic volumes, delay, and base crash rates. The next section provides the methodology for how the benefits are calculated.

4.3 Benefit Calculation and Parameters

The benefits incorporated into the evaluation tool include travel time or delay savings, reduced crashes, reduced vehicle operating costs, and reduced winter maintenance costs and are calculated in terms of annualized monetary benefits. Methodologies for estimating benefits are generally consistent with the FHWA's Tool for Operations Benefit Cost Analysis (TOPS-BC), a sketch-planning level benefit/cost analysis (BCA) decision support tool for a wide range of Transportation System Management and Operations (TSMO) strategies.

To minimize user input requirements, the tool utilizes readily available data to the extent possible. Primary benefit data inputs are strategy use, roadway classification, area type, distance, AADT and CAADT, delay, and crash rates. Some of the applications require specific user inputs as needed. The capability is provided for the user to add or modify input values as needed. The following contains the sources for the primary data inputs for estimating benefits:

- Strategy—Device(s) from the Device Location Form.
- Strategy use—Primary and secondary use from the Device Location Form and user input for additional use(s).
- Road classification—F-System field from AADT/Crash HPMS geodatabase.
- Distance—User input or calculated depending on Strategy.
- Traffic volume:
  - Auto AADT—AADT minus CAADT from the AADT/Crash HPMS geodatabase.
  - Truck AADT—CCADT from the AADT/Crash HPMS geodatabase.
- Hours of delay—Total delay per mile from the Delay 2018 geodatabase.
- Crash rate—CrashPerMi divided by 3 years from the AADT/Crash HPMS geodatabase.
- Existing ITS equipment—Gap score as described in the ITS Gap Score Calculations section below.
- Benefit monetization values—value of time, value of crashes, and vehicle operating costs from U.S. DOT guidance and MDOT studies.

Benefits are estimated as follows:

- Annual travel time benefit[6] = Average daily traffic X average vehicle occupancy X (number of signs / 2 directions) X percent time providing useful information X percent drivers acting on information X (number of minutes saved / 60 minutes per hour) X 365 days per year X monetary value of time
- Annual delay benefit[7] = Delay / 60 minutes per hour X area of impact X number of devices (if applicable) X average daily traffic X average vehicle occupancy X percent bad weather (if

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[6] Either travel time or delay savings are estimated, not both. Approach depends on the strategy selected. Calculations are performed for autos and commercial vehicles.

[7] Either travel time or delay savings are estimated, not both. Approach depends on the strategy selected. Calculations are performed for autos and commercial vehicles.

applicable) X percent time activated/operational (if applicable) X reduction in delay X monetary value of time

- Annual crash benefit = Crash rate X distance X percent bad weather (if applicable) X market penetration (if applicable) X percent reduction in crashes X monetary value of crashes
- Annual vehicle operating costs savings benefit[8] = Average daily traffic X distance X 365 days per year X percent time providing useful information (if applicable) X percent drivers acting on information (if applicable) X percent bad weather (if applicable) X percent time activated/operational (if applicable) X percent reduction in vehicle operating costs X monetary value of vehicle operating costs
- Annual winter maintenance costs savings benefit = Distance X number of days of = >1 inch of more of snow per year X percent reduction in winter maintenance costs X winter maintenance cost per mile
- Average annual benefit = annual travel time benefit (or annual delay benefit) + annual crash benefit + annual vehicle operating costs savings benefit + annual winter maintenance cost savings benefit

Benefit parameter maximums for combinations of devices include:

- Maximum delay savings = 25 percent.
- Maximum travel time reductions 7 minutes
- Maximum crash savings = 15 percent, except ATM, curve, or queue warning where the maximum is their respective defaults
- Maximum vehicle operating costs savings = 5 percent

If the user is interested in analyzing a strategy not available within the tool, one of the existing device types could be used as a proxy. Select an existing device type that is anticipated to have similar benefit types and adjust the parameters accordingly.

Table 10 presents the benefits parameter default values used to estimate the benefits within the evaluation tool.

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[8] Calculations are performed for autos and commercial vehicles.

Table 10 Default Benefits Parameters

Benefits	Default	Source/Notes[1]
Basic ITS Equipment (CCTV, DMS, MVDS)		
Reduction in crashes (DMS)	10%	TOPS-BC
Reduction in crashes (if only CCTV or detectors)	5%	TOPS-BC potential impacts literature indicates 5-15% reduction in fatal accidents, international studies 30-80% reduction incidents
Percent time DMS providing useful information	17%	TOPS-BC, weekday peak hours (6 hours per day, 250 days per year)
Percent time DMP providing useful information	2.8%	TOPS-BC, weekday peak hours (1 hour per day, 250 days per year)
Percent people act based on DMS or DMP information	10%	TOPS-BC
Time saved for people acting on DMS information (large)	7 minutes	TOPS-BC (4 min for comparative travel times, 3 min for congestion warning, and 7 min for alternative route/mode recommendation)
Time saved for people acting on DMS information (small) or DMP	4 minutes	TOPS-BC (4 min for comparative travel times)
Reduction in vehicle operating costs (traffic management and/or incident management)	5%	TOPS-BC potential impacts literature indicates 15% reduction in fuel use for incident management strategies
Reduction in vehicle operating costs (traveler information or travel times or other non-traffic or incident management applications)	2%	TOPS-BC potential impacts literature indicates 1-2% reduction in fuel use for traveler information strategies
Safety Treatment (RSU, Curve Warning, Queue Warning)		
Market penetration (RSU)	5%	
Reduction in crashes (RSU)	10%	NCHRP Project 03-101 has 10-26% for V2I. Ohio TSMO (2019) has 15% reduction.
Reduction in crashes (Curve Warning)	30%	FHWA ITS Benefits Database: 50% reduction single vehicle crashes (2015), 77% reduction crashes (2015). Ohio TSMO (2019) has 20% reduction.
Reduction in crashes (Queue Warning)	25%	FHWA ITS Benefits Database: MN 22% reduction along Interstate segment and 54% reduction near-crashes (2018), TX 44% reduction crashes (2017), Ohio TMSO 20% (2019)

Benefits	Default	Source/Notes[1]
Weather Monitoring (ESS)		
Reduction in crashes (no DMS)	7%	TOPS-BC. MIDOT Regional Deployment Plans (2006-2013) used 10%. Ohio TSMO Framework has 20% if includes warning system (2019).
Reduction in crashes (with DMS)	10%	TOPS-BC. MIDOT Regional Deployment Plans (2006-2013) used 10%. Ohio TSMO Framework has 20% if includes warning system (2019).
Area of impact for crashes (ESS)	5 miles	
Percent time bad weather	6-14%	See weather factors below by region
Reduction in delay (no DMS)	3%	MIDOT Regional Deployment Plans (2006-2013)
Reduction in delay (with DMS)	5%	TOPS-BC
Reduction in vehicle operating costs	2%	
Reduction in winter maintenance costs	7%	MIDOT Regional Deployment Plans (2006-2013)
Lane Control (LCS, LCS with DMS/DMP)		
Reduction in delay (LCS only)	3%	
Reduction in delay (with other components, e.g., DMS, DMP, RSU, CCTV, MVDS, etc.)	7%	15% from Ohio TSMO Framework (2019) for hard shoulder running, 15% for speed harmonization, and 17.5% for variable speed limits.
Reduction in crashes (LCS only)	5%	TOPS-BC
Reduction in crashes (with other components, e.g., DMS, DMP, RSU, CCTV, MVDS, etc.)	10%	Florida I-75 TSMO study 12% for mostly hard shoulder running. Ohio TSMO (2019) has 10% reduction.
Percent time activated	8.6%	TOPS-BC, weekday peak hours (3 hours per day, 250 days per year)
Reduction in vehicle operating costs (LCS only)	2%	TOPS-BC potential impacts literature indicates 1-2% reduction in fuel use for traveler information strategies
Reduction in vehicle operating costs (with other components, e.g., DMS, DMP, RSU, CCTV, MVDS, etc.)	5%	TOPS-BC potential impacts literature indicates 15% reduction in fuel use for incident management strategies

Benefits	Default	Source/Notes[1]
Ramp Meters		
Reduction in delay	5%	Ohio TSMO (2019) has 5% reduction.
Reduction in delay (with DMS)	7%	
Reduction in crashes	6%	TOPS-BC. Ohio TSMO (2019) has 20% reduction.
Reduction in crashes (with DMS)	12%	
Area of impact (applies to crashes)	0.50 mile	
Percent time operating	8.6%	TOPS-BC, weekday peak hours (6 hours per day, 250 days per year)
Reduction in vehicle operating costs	2%	TOPS-BC, 10% reduction in fuel use
ATM (System 3-Lane and 4-Lane)		
Reduction in delay (3-Lane)	25%	FHWA Benefits Database: ATM system installed along I-66 reduces travel times by up to 11% and vehicle delay by up to 68%
Reduction in delay (4-Lane)	15%	FHWA Benefits Database: ATM system installed along I-66 reduces travel times by up to 11% and reduces vehicle delay by up to 68%
Reduction in crashes	20%	FHWA Benefits Database: Implementing variable mandatory speed limits on four lanes with the optional use of the hard shoulder as a running lane resulted in a 55.7% decrease in the number of personal injury accidents on a major motorway in England. Florida TSMO 12% for mostly hard shoulder running.
Percent time activated	8.6%	TOPS-BC, weekday peak hours (3 hours per day, 250 days per year)
Reduction in vehicle operating costs	5%	TOPS-BC potential impacts literature indicates 15% reduction in fuel use for incident management strategies
Days per year for annualizing	**365**	
Value of crashes		
Freeway	$83,110.08	Estimated by applying weighted average of the MDOT crashes by type (fatal, injury, and PDO) and the monetary values (U.S. DOT Benefit/Cost Analysis Guidance for Discretionary Grant Programs (Jan 2020)) of those crash types

Benefits	Default	Source/Notes[1]
Arterial	$79,886.27	Estimated by applying weighted average of the MDOT crashes by type (fatal, injury, and PDO) and the monetary values (U.S. DOT Benefit/Cost Analysis Guidance for Discretionary Grant Programs (Jan 2020)) of those crash types
Value of time (per hour)		
Autos	$16.60	U.S. DOT Benefit/Cost Analysis Guidance for Discretionary Grant Programs (Jan 2020)
Commercial vehicles	$29.50	U.S. DOT Benefit/Cost Analysis Guidance for Discretionary Grant Programs (Jan 2020)
Auto occupancy	1.67	U.S. DOT Benefit/Cost Analysis Guidance for Discretionary Grant Programs (Jan 2020)
Commercial vehicle occupancy	1	
Vehicle Operating Costs and Winter Maintenance Costs (per mile)		
Autos	$0.41	U.S. DOT Benefit/Cost Analysis Guidance for Discretionary Grant Programs (Jan 2020)
Commercial vehicles	$0.96	U.S. DOT Benefit/Cost Analysis Guidance for Discretionary Grant Programs (Jan 2020)
Winter maintenance costs	$2,700.00	MIDOT Regional Deployment Plans (2006–2013), based on results from the FHWA's MDSS program. Inflated to current year.
Weather Factors (NOAA Comparative Climatic Data (days per month with >.01 inch precipitation * % of day))		
North	10%	Alpena and Houghton Lake
Metro	6%	Detroit
Bay	6%	Flint
Grand	7%	Grand Rapids and Muskegon
University	6%	Lansing
Southwest	7%	No Cities in Southwest Region—used Grand as substitute

Benefits	Default	Source/Notes[1]
Superior	14%	Sault Ste Marie
Winter Maintenance (days/year) (Currentresults.com/weather/Michigan/—Days with more than 1” of snow		
North	27.3	Houghton Lake and Traverse City
Metro	13.3	Detroit
Bay	14.9	Flint
Grand	23	Grand Rapids
University	16.3	Lansing
Southwest	22.9	Holland
Superior	40	Used 1.5 multiplier over North based on average snowfall

[1] FHWA Tool for Operations Benefit-Cost Analysis (TOPS-BC) is a planning-level decision support tool for the application for benefit-cost analysis of transportation system management and operations (TSMO) strategies and is based on guidance and input from planning and operations practitioners, including real-world evaluation studies were available.

4.4 Costs Calculation and Parameters

Costs for the projects evaluated within the tool are obtained directly from the imported Device Location Form. The following list contains the data inputs for estimating costs:

- Capital cost—Project Total (w/ inflation) from the Device Location Form.
- Operations and maintenance (O&M) cost—Annual Maintenance Costs + Operation Costs from the Device Location Form.
- Useful life—Derived from the FHWA ITS Cost Database.

Costs are estimated as follows:

- Average annual costs = (Capital cost / average of the useful life values for strategies) + O&M cost.

The useful life default parameters are provided in Table 11 below. They were derived from the FHWA ITS Cost Database equipment and strategy components.

Table 11 Default Useful Life Parameters

Strategy/Equipment	Useful Life (years)
General Site	15
Large DMS	15
Small DMS	14
CCTV Freeway	19
CCTV Arterial	16
CCTV Signal	13
MVDS	14
Lane Control System, 1 Panel	17
Lane Control System, 3 Panel	18
Lane Control System, 3 Panel w/ small DMS	16
Lane Control System, 4 Panel	17
Lane Control System, 4 Panel w/ small DMS	15
Dynamic Message Panel, 1 Panel	16
Dynamic Message Panel, 2 Panel	16
Travel Time Signs	16

Strategy/Equipment	Useful Life (years)
Dynamic Message Panel, 3 Panel	15
ESS	20
Ramp Meter	14
RSU—Stand Alone	14
RSU—Traffic Signal	13
3-Lane ATM Corridor	17
4-Lane ATM Corridor	16
Curve Warning	16
Queue Warning	16
OHVDS	18

4.5 ITS Network Gap Score

There have been many studies that quantify the benefits of ITS deployments. These vary is sophistication and scale, ranging from very simplistic assignments of benefit on a per-device basis to complex models that estimate the effect of a device on conditions that create disbenefits and then assess the value given the local travel conditions.

What has not been included in previous approaches is the concept of a deployment in the context of existing networks of ITS devices. A camera installed in an area that already has continuous coverage of the roadway surface is likely to yield less benefit than one installed where no other cameras exist, given comparable local travel conditions.

The ITS Network Gap Score introduces the concepts of deployment context and diminishing marginal returns to benefit/cost analysis and provides a mechanism to adjust the calculated benefit based on the local compliment of devices.

Gap Score Definition

Each roadway in the analysis is divided into one-mile segments (centerline, bi-directional) and each segment has a gap score. To determine the presence of a “gap,” a comparison is made between the existing ITS inventory, and a “reference” ITS inventory that represents an unconstrained theoretical deployment.

When a segment contains more reference devices than existing, it is given a score of -1. Equal numbers give a 0 score and where existing inventory device counts exceed the score is set to 1. By using this simple scoring system on relatively short segments, the overall Gap Score for a project can be obtained by aggregating and averaging the one-mile segments coincident with the project boundaries.

This score can then be incorporated into a gap multiplier, which can increase or decrease the modeled benefit for the project.

Gap Score Process

Calculating and applying gap scores requires several preparatory steps to properly classify the roadway network and develop the reference ITS deployment. This process is described in the section below.

Roadway Classification

The ITS reference deployment is a representative, unconstrained model deployment based on the current deployments in Michigan that are considered to be mature or fully complete. Since an unconstrained deployment will differ based on the roadway location and performance characteristics, a simple taxonomy describing the road network emphasizing how ITS deployments correlate was developed.

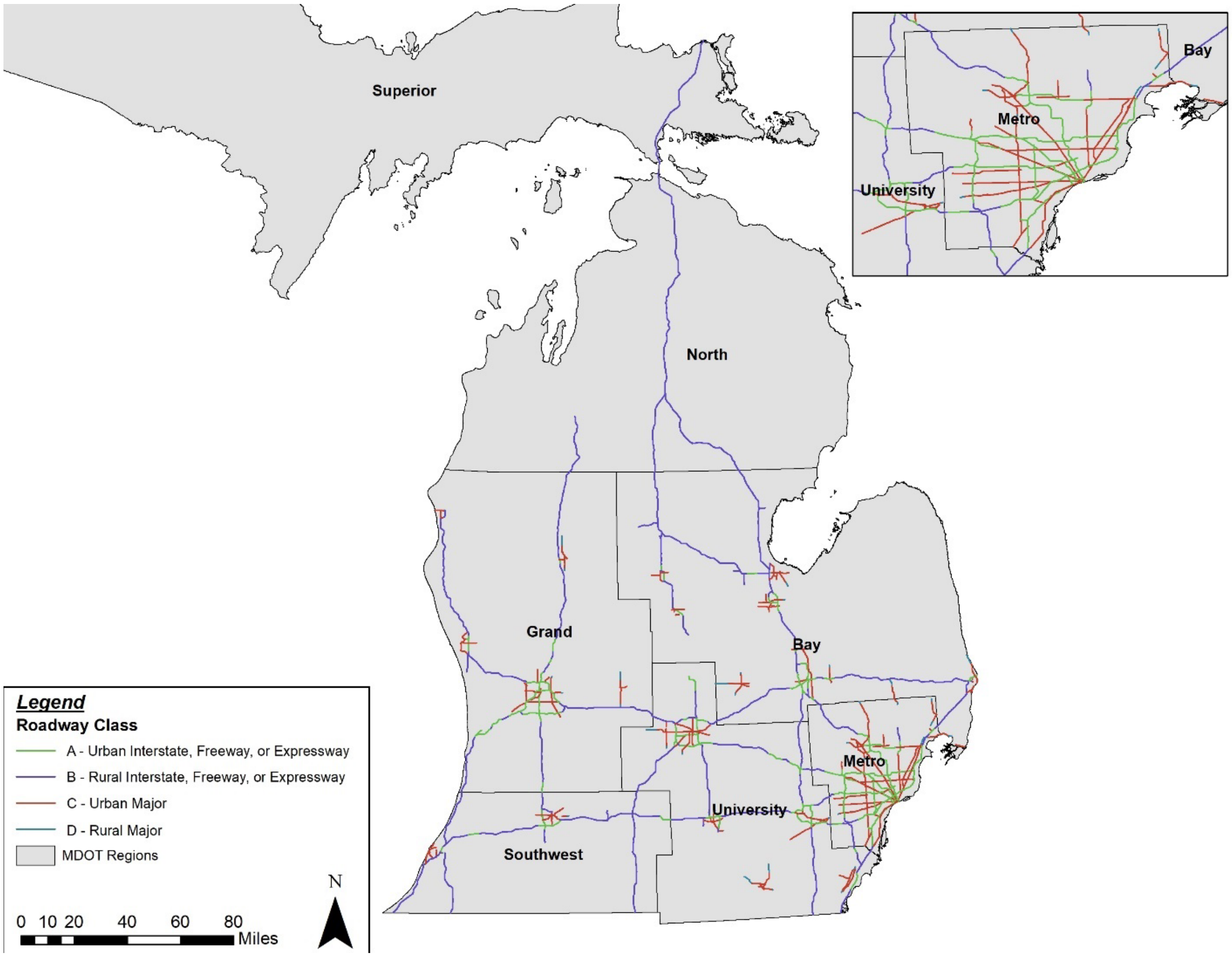
Since formal definitions describing the locations and numbers of ITS devices based on roadway type, daily traffic volumes, crashes, etc., is not available, the process used a trial and error approach to find combinations of characteristics that corresponded to the highest density existing deployments. Using the areas around Detroit, Lansing and Grand Rapids as models, Table 12 shows how the classifications were derived.

Table 12 Roadway Gap Score Classifications

Category	Criteria
A: Urban Interstate, Freeway or Expressway **NFC 1 and 2**	1. Roadway class of Interstate or U.S. Trunk Highway or comparable. 2. Contained within or within one mile of a Minor Civil Division with a population density greater than 1,800 per square mile. 3. AADT >= 12,000
B: Rural Interstate, Freeway or Expressway **NFC 1 and 2 (below AADT)**	1. Roadway class of Interstate or U.S. Trunk Highway or comparable. 2. Greater than one mile from the boundary of a Minor Civil Division with a population density greater than 1,800 per square mile. OR 3. AADT <=3,000
C: Urban Major **NFC 3, 4, 5 and 6**	1. Roadway class NOT Interstate or U.S. Trunk Highway or comparable 2. Contained within or within two miles of a Minor Civil Division with a population density greater than 2,000 per square mile. 3. AADT >=5,000
D: Rural Major **NFC 3, 4, 5 and 6**	1. Roadway class NOT Interstate or U.S. Trunk Highway or comparable 2. NOT Contained within or within two miles of a Minor Civil Division with a population density greater than 2,000 per square mile. 3. AADT <=5,000

Using these criteria resulted in the roadway network shown in Figure 11.

Figure 11 Michigan Roadway Classes A–D



Identify ITS "Reference" Deployment

The basis of the gap score is a difference between an existing and theoretical, idealized ITS deployment that represents an "full" or "mature" array of devices modeled on existing areas assumed to have enough equipment that additional installations are not being considered.

Ideally, individual installations for each device type would be considered for every location on every roadway in Michigan. However, given the large number of possible installations and the need to update the model over time, this was not considered practical.

Instead of attempting to design an installation location for every device on every roadway, the concept of a "deployment density" was used to model the number of devices that would be installed for reference on each roadway class. A similar approach has been used for statewide

ITS sketch planning in Wisconsin as part of the Traffic Operations Infrastructure Plan and have proven to be satisfactory for large-scale planning.

For each device type (CCTV, DMS, MVDS, etc.) the number of devices per centerline mile of roadway was measured in mature deployment areas using the existing ITS inventory. That average device density was than applied to for each device type on each respective roadway class, giving a reference deployment.

For the reference deployment, Class D roadways were excluded from the model. Class D roadways are low-volume, non-freeway roads outside of urban areas. These were excluded for three reasons:

- The low numbers of existing ITS devices made a density (device per mile) calculation impossible.
- Deployments on low volume roadways tend to address a specific safety or traveler information need at a specific location. This made using a generalized model approach impractical.
- The relatively small number of potential deployments would not have a significant impact on the overall Benefit/Cost or Gap analyses.

Several reference deployments were modeled and reviewed by the project team to ensure that the results were both reasonable and resembled the existing deployments in mature area.

Create Analysis Segments

To establish the concept of a gap, a geographic context was needed to compare existing and reference inventories. For this process, each roadway was divided into one-mile segments.

The locations of both the existing and reference inventories were then analyzed to determine which devices fell within each of the analysis segments. Each segment then was assigned a value for total number of devices coincident for both the existing and reference inventories.

Calculate Gap Scores

The gap score for each analysis segment is a value assigned as shown in Table 13.

Table 13 Gap Score Criteria

Score	Criteria
-1	More devices are present in the existing inventory than the reference inventory.
0	Equal number (or no) devices are present in both reference and existing inventories.
1	More devices are present in the reference inventory than the existing inventory.

This approach provided a simple, per-segment score that can then be aggregated as needed based on the boundaries of a project being analyzed for benefits to give an indication of whether the new deployments are filling a “gap” in coverage and should receive an adjustment to their calculated benefits.

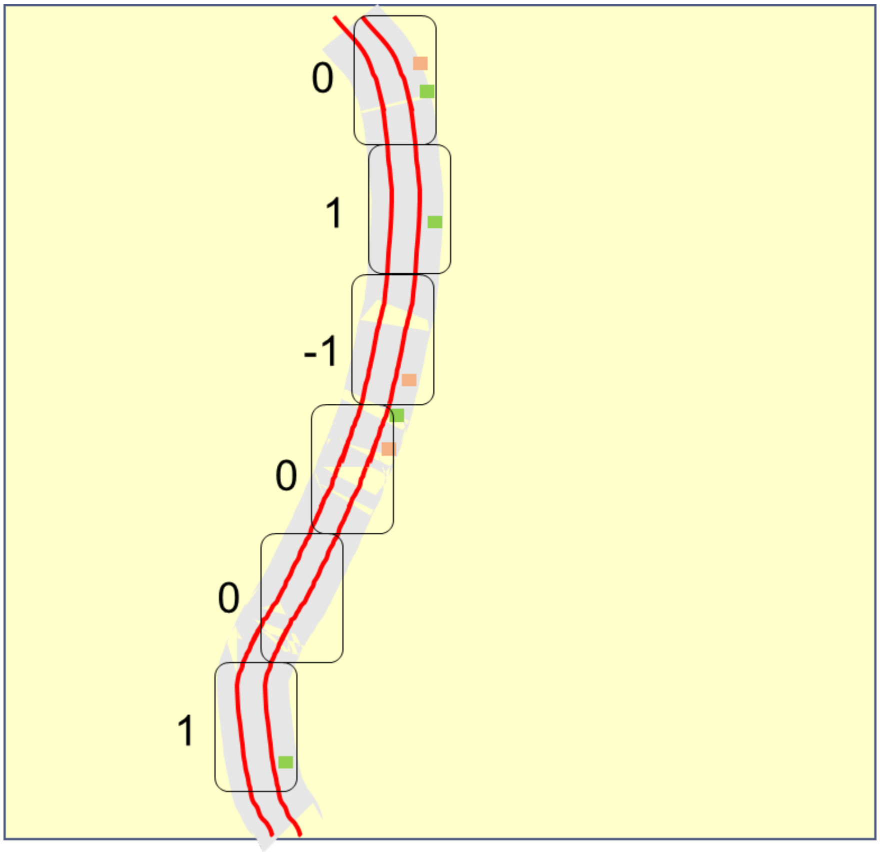
Benefit/Cost Gap Multipliers

The final step in gap analysis is to adjust the calculated benefit for a project based on the gap scores on the analysis segments. The results of this process is unique to each project as the boundaries, devices and intended use will be different for each.

Once a project is defined in the tool, the system compares its boundaries to the segments on the roadway, identifies the gap analysis segments, and computes an average gap score for the project area.

Figure 12 shows a simplified schematic of a project area (shown in grey) with roadways segments (red) and gap analysis segments (boxes) labeled with a gap score (-1,0,1)

Figure 12 Gap Score Sample Segment



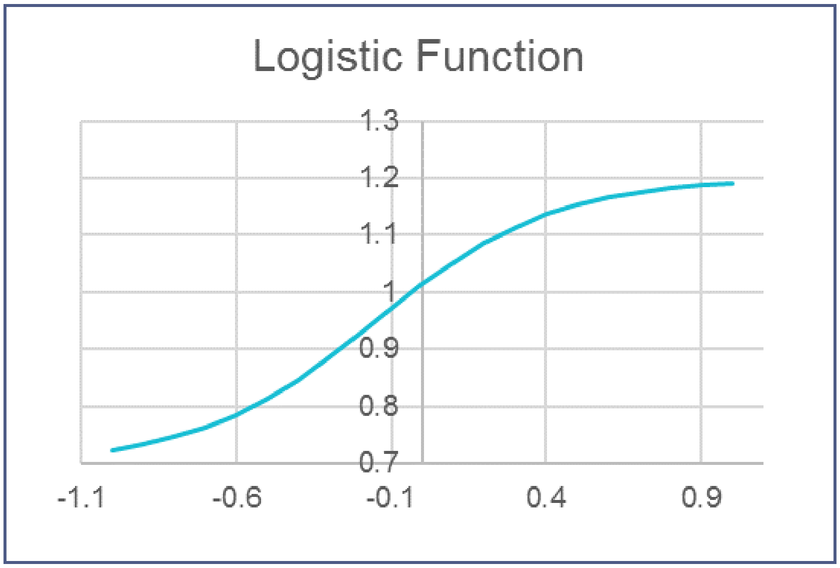
In this example, the project's overall gap score would be 0.167.

To convert the gap score into an adjustment to the project's calculated benefit, a logistic function is used with the raw gap score. The logistic function is important for several reasons:

- It introduces the concept of diminishing marginal returns, which is fundamental to many economic analyses.
- It bounds the effect of the gap analysis, preventing benefits from being unrealistically amplified or diminished.
- It provides a set of parameters that can be adjusted to fine tune the gap analysis methodology as experience generates data on its effect.

The logistic function converts the gap scores into a sigmoid curve, as shown in Figure 13.

Figure 13 Graph of Logistic Function



The curve is described by the function $f(x) = \frac{L}{1+e^{-k(x-x_0)}}$ where x{0} = the x value of the sigmoid's midpoint, L = the curve's maximum value, and k = the logistic growth rate or steepness of the curve. For this example, the gap multiplier is 1.08.

Given the existing ITS deployments in the area (or lack thereof) the project has a gap score of 0.167, which translates to a multiplier of 1.08. Thus the benefits for the project would be increased by 8 percent.

Conversely if the there were substantial deployments already in the area where the new project was proposed, its gap score would be negative and calculated benefits correspondingly reduced.

4.6 Benefit Cost Calculation Summary

The benefit/cost analysis for the evaluation tool involves the use of the following inputs:

- Average annual benefit—as described in the Benefit Calculation and Parameters section (4.3).
- Average annual costs—as described in the Costs Calculation and Parameters section (4.4).
- Gap Score—as described in the ITS Network Gap Score section (4.5).

The benefit/cost ratio is calculated as follows:

- Benefit/cost ratio = (Average annual benefit X gap score) / average annual costs.

5.0 Sample ITS Project Applications

In order to test and validate the evaluation tool and methodology, 12 sample projects were analyzed both manually and within the evaluation tool itself. The sample projects included:

Table 14 Sample ITS Projects

Project Type/Location	Description	Use(s)
#1—Freeway Rural (Beaver Creek)	CCTV (2) and DMS (3) prior to major rural interchange along primary leisure/vacation route	Incident management, weather
#2—Freeway Suburban (East of Lansing)	CCTV (11), DMS (5), and MVDS (11) between Brighton and Lansing in the University area	Incident management, safety, traffic conditions, travel times
#3—Freeway Urban Interchanges (Farmington Hills)	CCTV (29), DMS (11), and MVDS (29) on I-96/I-696/I-275/U.S.-24 interchanges area	Incident management, safety, traffic conditions, route diversion, travel times
#4—Non-Freeway Urban (Grand Rapids)	CCTV (7), DMS (7), and MVDS (7) on 28th Street	Traffic conditions, incident management, route diversion
#5—Non-Freeway Rural (Superior)	CCTV (6) and DMS (2) on U.S.-2	Traffic conditions, incident management, weather, route diversion
#6—ESS Freestanding (North Region)	CCTV (10) and ESS (10) at various locations	Traffic conditions, weather
#7—Travel Time Signs (University)	DMP travel time signs (4) U.S.-23	Travel times, route diversion
#8—Connected Vehicle RSU (Oakland)	RSU-Traffic Signal U.S.-24 (Telegraph Road) from I-696 to Square Lake Rd	Safety, other (connected vehicle application)
#9—Flex Lane Deployment—Comprehensive (University)	3 Lane ATM Corridor on U.S.-23 (Dynamic Shoulder Lane) between M-36 in Livingston County and M-14 in Washtenaw County, comprehensive system	Traffic conditions, incident management, safety, route diversion
#10—Flex Lane Deployment—Individual (University)	3 Lane ATM Corridor U.S.-23 (both directions) between M-36 in Livingston County and M-14 in Washtenaw County, individual components	Traffic conditions, incident management, safety
#11—Freeway Urban (Grand Rapids)	DMS (3), CCTC (4), and MVDS (10) on U.S.-131 just north of Grand Rapids, West River Dr to 10 Mile Rd	Incident management, traffic conditions, travel times
#12—ESS (Grand)	ESS (20) and bridge deck warning system (2) for regional system	Weather

All of the sample projects had at least a benefit/cost ratio between 0.7 and 16.7. Table 15 shows the results of the benefit/cost analysis for the sample projects. Results are shown for both with and without the gap score included in the analysis. Note that the recommendation of the research team is to include the Gap Score in calculations.

Table 15 Benefit/Cost Analysis for Sample Projects

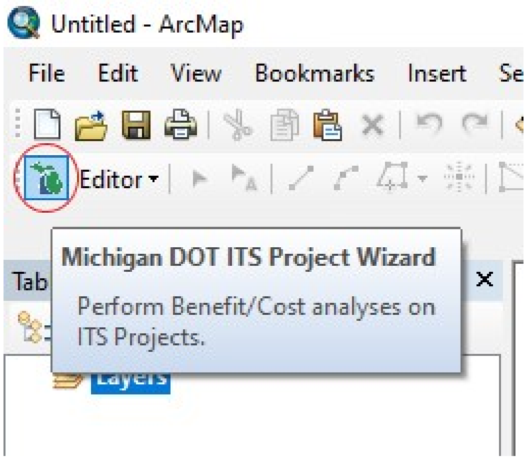
Project	Type	B/C (Without Gap Score)	B/C (With Gap Score)
1	Freeway Rural—CCTV, DMS	7.1	7.5
2	Freeway Suburban—CCTV, DMS, MVDS	14.7	16.7
3	Freeway Urban IC—CCTV, DMS, MVDS	16.4	16.6
4	Non-Freeway Urban Arterial—CCTV, DMS	11.9	9.5
5	Non-Freeway Rural Arterial—CCTV, DMS	3.6	3.7
6	ESS Freestanding	2.1	2.1
7	Travel Time Signs	7.0	6.0
8	Connected Vehicles Urban RSU Signals	0.7	0.7
9	Flex Lanes—Comprehensive (3-Lane ATM)	4.9	3.6
10	Flex Lanes—Individual (3-Lane ATM)	3.0	2.2
11	Urban Freeway—CCTV, DMS, MVDS	9.6	11.2
12	ESS Regional	5.9	6.6

6.0 ITS Evaluation Tool

6.1 Tool Description

The MDOT Network-Level Evaluation Tool for Managing ITS Infrastructure was developed as an ESRI AddIn, meaning it is used as an add-in tool within ArcGIS. The benefits of this format include the ease of distribution and installation for various ArcGIS users within an organization. The image below shows the appearance of the tool in an ArcMap document, after installation.

Figure 14 MDOT ITS Tool ESRI AddIn



Michigan DOT ITS Project Wizard

Perform Benefit/Cost analyses on ITS Projects.

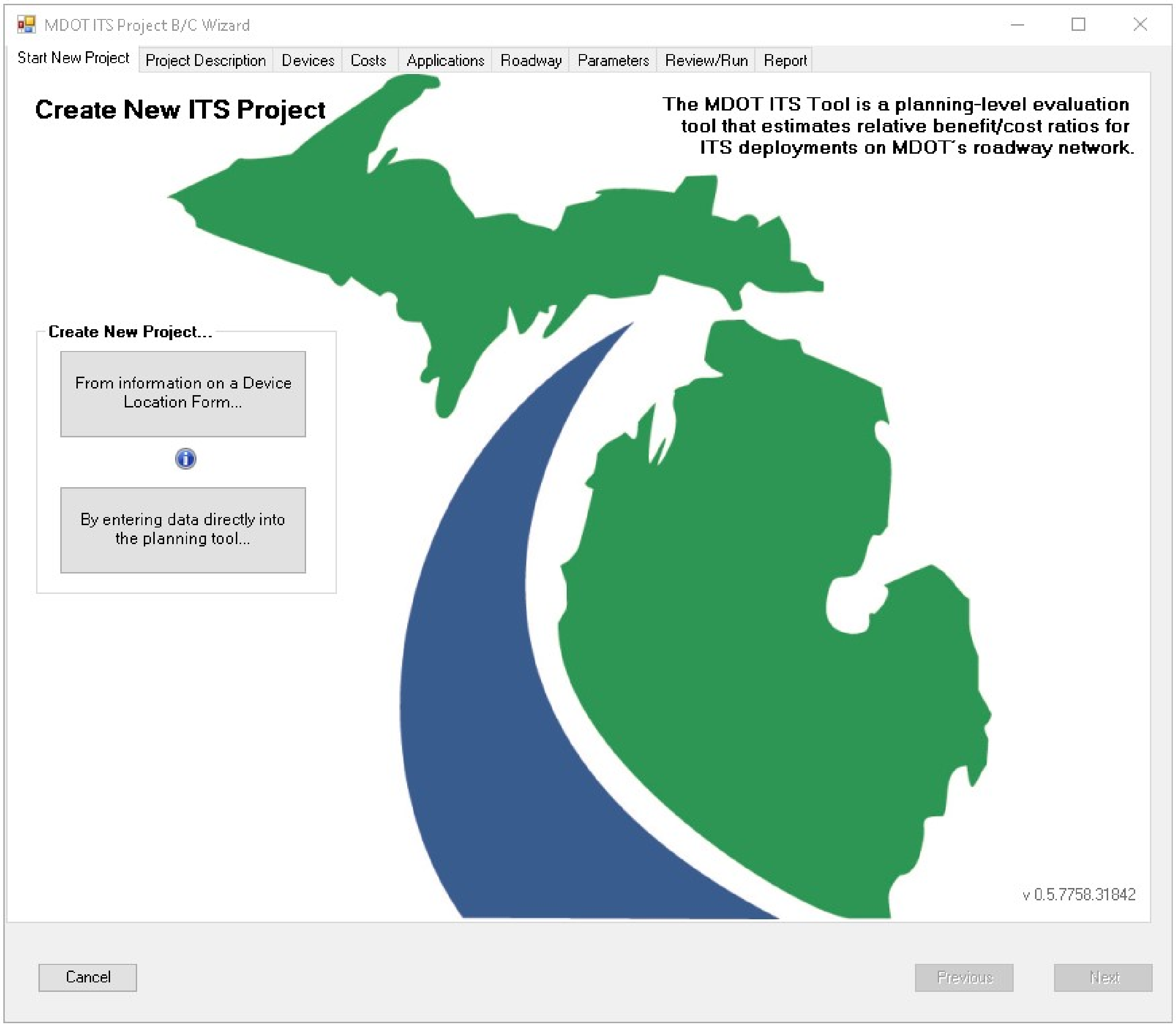
Using the ITS Benefit/Cost Evaluation Methodology, described in Section 3.0, the MI ITS Tool calculates the benefit/cost ratio for ITS deployments on Michigan state trunklines. The tool draws from several inputs, which are found in the geodatabase. These include several feature classes and tables:

- AADT Crash_HPMS_Final: This feature class contains inputs used for the benefit/cost calculations, including AADT, number of crashes and crashes per mile, and other roadway classification fields found in Michigan's HPMS data.
- Delay_2018_Final: The field "Total_De_1" contains total delay per mile (in minutes), which is used in the tool's benefit/cost calculations.
- MDOT_CBAT_Network_Segments_20201112: This feature class contains the gap score for each segment of roadway, which is ultimately used to calculate and apply the project gap score to the benefit/cost calculation.

- Parameter Tables: There are three tables of parameters within the geodatabase, they are General Parameters, Gap Parameters, Region Specific Parameters, and Device Specific Parameters. These tables include the necessary values that are applied to the inputs above, in order to produce a benefit/cost ratio.

Before opening and running the tool, users are expected to **locate their project** and **select from the corresponding AADT and Delay feature classes**, where applicable. With the project selection complete, the tool can be opened and users can follow each of the tabs for project verification and analysis.

Figure 15 MDOT ITS Tool Device Location Form Tab



Create New ITS Project

The MDOT ITS Tool is a planning-level evaluation tool that estimates relative benefit/cost ratios for ITS deployments on MDOT's roadway network.

v 0.5.7758.31842

Below is a description of the tool's tabs:

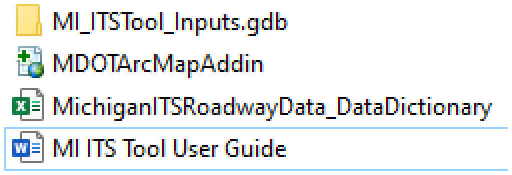
- Device Location Form: The first tab will prompt the user to upload a Device Location Form for their project or enter data manually. Doing so will populate fields in the following tabs, through "Parameters."
- Project Description: Most of the information on this tab are populated from the Device Location Form, if the user uploaded one, including Project Title, Region(s), TSC(s), and Job Number(s), but can be edited by the user.
- Devices: Pulling from the Device Location Form, this tab shows statistics for the Devices, Quantities, and Unit Costs. If not using a Device Location Form, the user must populate these fields manually.
- Costs: This tab displays the costs summary from the Device Location Form. If not using a Device Location Form, the user must populate these fields manually.
- Applications: Based on the devices listed in the Device Location Form, this tab will show the application categories that have been automatically selected. The user can edit the list of selected applications, which is useful if the user is entering data manually.
- Roadway: This tab will prompt the user to select the correct layers for the tool analysis: the Crash/AADT, Delay, and Gap Score layers. Statistics are shown for the selected segments of each layer.
- Parameters: The specific parameters used for the tool analysis are shown in this tab. Users are able to toggle through the Device-Specific, Region-Specific, General, and Gap Parameters and edit them accordingly. It also is important for users to select the project length in this tab, which can be entered manually or selected from either the Delay or Crash layers.
- Review/Run: This tab provides a criteria checklist of the previous tabs necessary to enable the Run Analysis process, ensuring the user did not miss any steps. The project pre-run statistics below this checklist provide the user with additional validation of their selection. At this point, users have the option of exporting the benefit/cost analysis results in either a layer or shapefile output. By exporting as a layer, users can create a new layer or add onto a previously analyzed project layer.

- Report: After running the project analysis, the Report tab provides users with a comprehensive description of the project inputs, calculations, and results. As an HTML link, the report is easily saved for easy access and sharing.

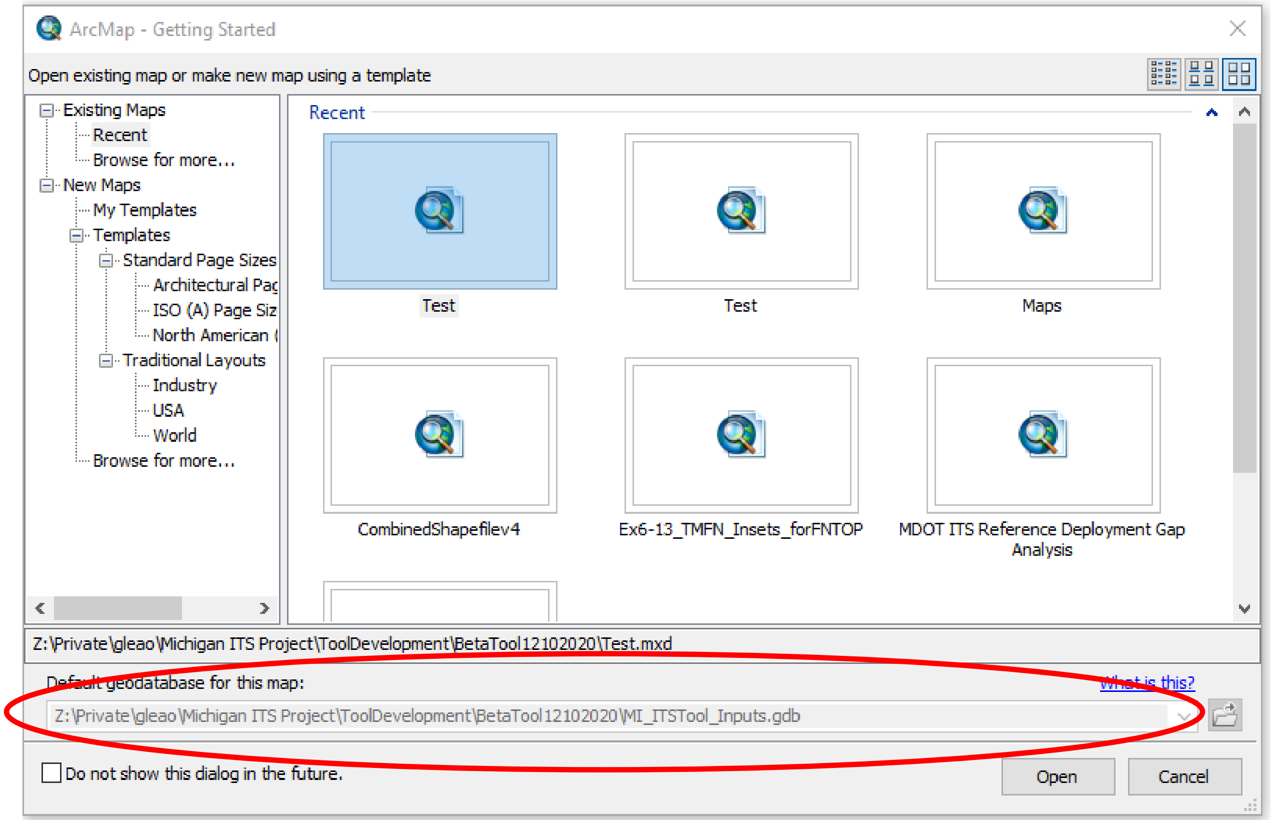
6.2 User Guide

Installation

1. Export the "MI ITS Tool" contents into a folder on your computer. The "MI ITS Tool" zip file contains the following files:
    - Tool Geodatabase
    - User Guide
    - Data Dictionary
    - MDOTArcMapAddin


MI_ITSTool_Inputs.gdb
MDOTArcMapAddin
MichiganITSRoadwayData_DataDictionary
MI ITS Tool User Guide

2. Click the MDOTArcMapAddin and follow instructions to install it.
3. Open a blank ArcMap file. Select the "MI_ITS_Tool_Inputs" geodatabase as the default geodatabase for the map.

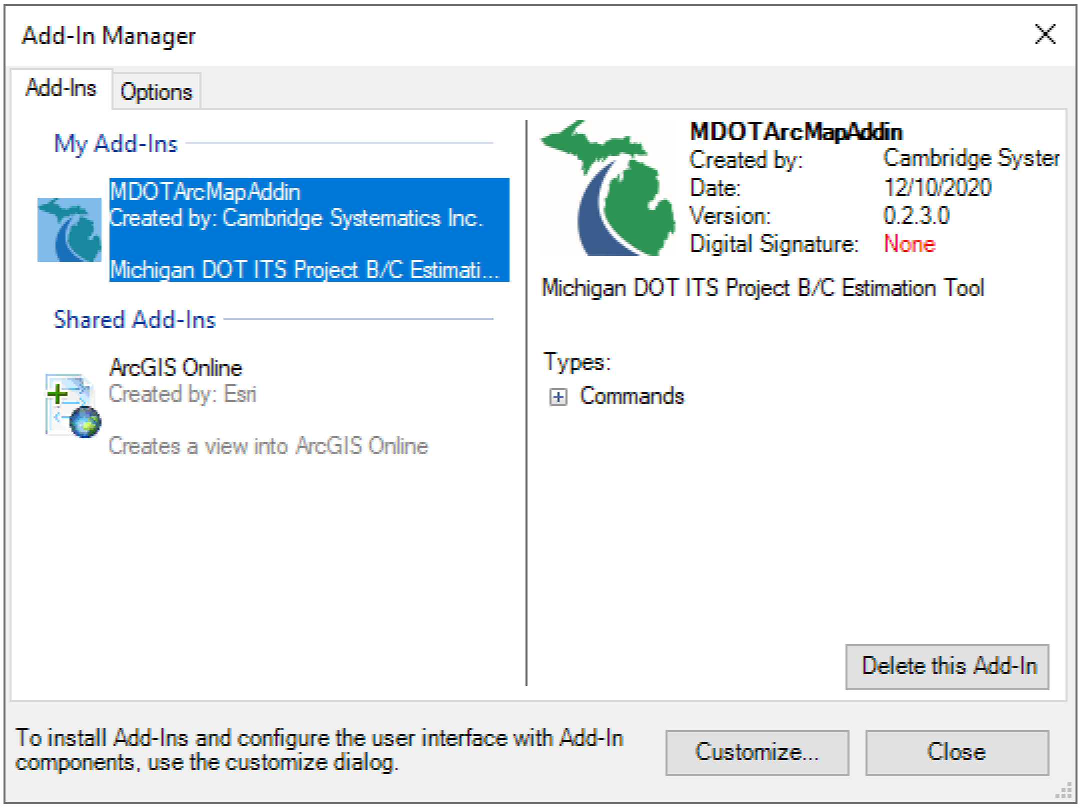


Z:\Private\gleao\Michigan ITS Project\ToolDevelopment\BetaTool12102020\Test.mxd

Default geodatabase for this map:

Z:\Private\gleao\Michigan ITS Project\ToolDevelopment\BetaTool12102020\MI_ITSTool_Inputs.gdb

Select Customize/Add-in Manager:



MDOTArcMapAddin
Created by: Cambridge Systematics Inc.
Michigan DOT ITS Project B/C Estimati...

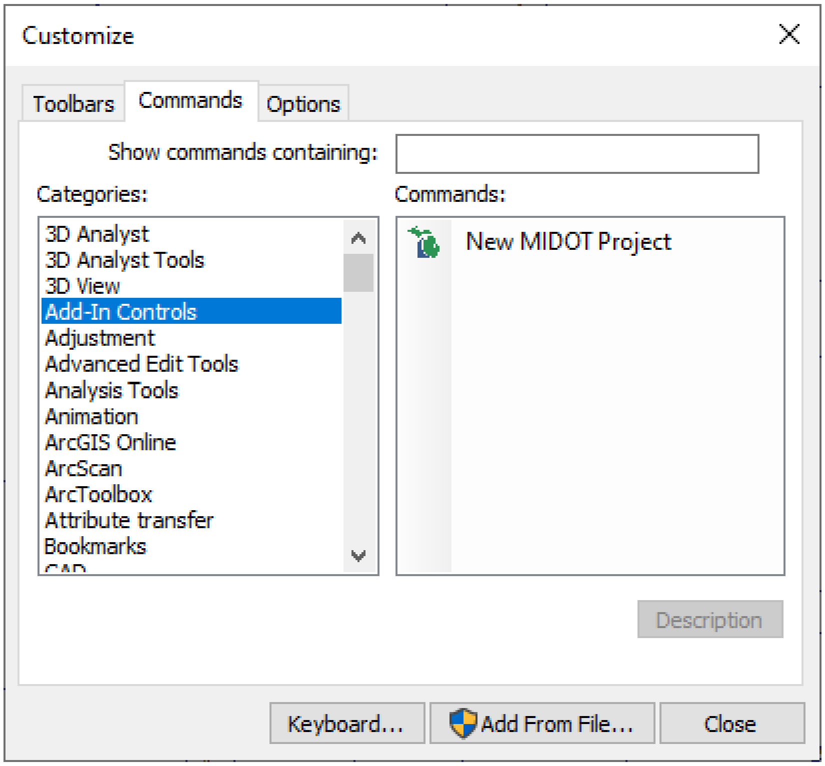
ArcGIS Online
Created by: Esri
Creates a view into ArcGIS Online

MDOTArcMapAddin
Created by: Cambridge Syster
Date: 12/10/2020
Version: 0.2.3.0
Digital Signature: None

Michigan DOT ITS Project B/C Estimation Tool

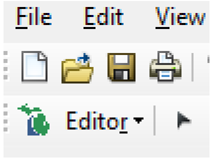
To install Add-Ins and configure the user interface with Add-In components, use the customize dialog.

Then click the Customize… button, and in the Commands tab, the Categories box should refresh and show Add-In Controls.



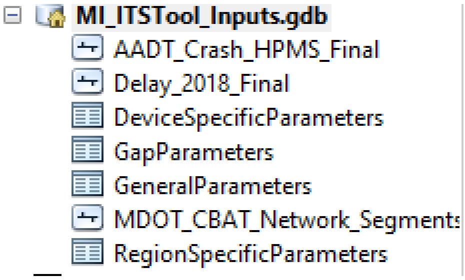
Highlight that category:

Then you can drag the New Project on the right to the desired section of the ArcMap ribbon.



4. In the Catalog, connect to the folder containing the MI ITS Tool files:

5. Expand the geodatabase and drag the three layers "AADT_Crash_HPMS_Final," "Delay_2018_Final," and "MDOT_CBAT_Network_Segments_20201112" into the map:



MI_ITSTool_Inputs.gdb
- AADT_Crash_HPMS_Final
- Delay_2018_Final
- DeviceSpecificParameters
- GapParameters
- GeneralParameters
- MDOT_CBAT_Network_Segments
- RegionSpecificParameters

Following this one-time process, you should have everything in place to use the tool for project analysis.

Project Analysis

In order to analyze the project, you need to know the extent of the project. In the tool, you will select from AADT and Delay files, where applicable, for the project extent. You also may select the project links from the AADT and Delay files before launching the tool. A completed Device Location Form, Version 4.0 can help expedite the data entry process.

6. Open the MI ITS Tool and follow the basic workflow below.

Basic Workflow

1. Either load in a completed Device Location Form in the first tab, or enter all data directly.
   a. Loading in a Device Location Form will fill the project description, Devices, Costs and Applications tabs.
   b. If entering data manually, ensure that the information is complete in the "Device" and "Costs" tab, matching your Device Location Form.
   c. Changes to the Applications will alter the tool output, applying different calculations. Select these manually or use, "Select Applications based on Device Selections."

2. Go to Roadway tab and select layers for project.
    a. Minimize the tool and select from AADT/Crash and Delay layers, where applicable, on the map.
        i. Statistics for your selected roadway segments will be populated.
        ii. Note: Make sure the radio buttons for each layer reflect your desired selection type.
            - AADT/Crash: Selected on map or all.
            - Delay—Selected on map or all or delay layer not needed.
    b. The gap score layer will be automatically selected if it is the only layer with the distinctive Logistic_1 field.
3. On the Parameters tab, in the "Project Length (miles) row, enter a project length. You can select the project length from the AADT or Delay layer and modify as necessary.
    a. Note: Device-specific parameters shown are a subset. The tool uses a set of rules to decide which parameters apply to the specific project as a result of the device mix and the checked applications.
4. In the Review/run tab.
    a. Click the "Create New Project Output Layer" button, under the "Create or Select a Map Layer to Receive Analysis Output" section, and create a name for the layer in which your results will be displayed.
    b. If the tool geodatabase has an output layer that is not appearing on the list, if will be included if it is dragged into the map.
    c. Ensure the criteria checklist, at the top left of the tab, is complete. Click the Run Analysis button.
        i. You should see some progress updates at the bottom of the form—the dissolve step will take the longest so you'll see a pause in updates.
        ii. if all goes well it will eventually flash 'Finished' for about a half-second.
        iii. You will see a layer added to the map that reflects the title from the Device Location Form.

   iv. An additional layer file is saved in the same folder as the geodatabase.
   v. Click the "next" button to continue to the "Report" tab, which contains detailed information on the latest run results.

5. Repeat steps 1-5 as necessary for each project. Results for each individual project run will be in a separate layer.

Potential Error Messages

- Changing certain parameters to 0 may result in divide-by-zero errors.
- If you receive an error message, "Error Writing Output," wait a few seconds and try to run analysis again.
- Tool output layer cannot start with a number.

7.0 Updating the Tool

The MDOT Network-Level Evaluation Tool for Managing ITS Infrastructure is meant to be continuously updated over the years, in order to remain a relevant and accurate evaluation tool. As newer data sources become available and MDOT's project evaluation process changes, it is important for the tool have the ability to incorporate these changes.

7.1 New Data Sources

As outlined in previous sections, the MDOT ITS Tool relies on several roadway input feature classes. These include AADT, crashes, and delay. AADT and delay are from 2018, while crashes are annualized from 2017-2019. In order for the tool to remain accurate in the future, these inputs will need to be updated.

Once a new dataset becomes available, MDOT will need to take a number of steps to integrate it into the tool. Essentially, the new fields will need to be joined to either the AADT/Crash/HPMS or Delay feature classes. For example, if MDOT is planning on using a new 2022 AADT data source, this would require a join with the tool's AADT feature class.

Once the new data is joined to the tool's feature classes, they must be renamed in order for the tool to recognize them as inputs. The tool accesses data by the following field names:

- "Aadt"—total aadt auto and commercial
- "Caadt"—commercial aadt
- "Count_"—number of crashes
- "Total_Dela"—total delay minutes
- "Total_De_2"—total delay per mile in hours
- "Miles_1"—miles (delay file)
- "DistMi"—miles (crash file)

In order to rename a field, use the "Alter Field" tool. First, change the name of the original field to avoid a duplicate with the new data source. For example, "Aadt" can be changed to "Aadt1."

Then change the new data source field name to match the tool's data fields, shown above. This process will be the same for all future data sources.

7.2 Device Location Form

MDOT's Device Location Form is a crucial input of the tool. As the agency's standard method of planning for future ITS devices, this form can help streamline the operation of the tool. It also has been noted that the specific format of the Device Location Form has changed in the past and is subject to change again in the future. Although the tool currently populates fields from the Device Location Form based on the form's current state, an additional capability was included to incorporate future changes.

When the user launches the tool, they are provided the choice to "Upload Devices, Costs, and other Project Information from a Device Location Form." Uploading a complete Version 4.0 Device Location Form will autofill the first three tabs of the tool, "Project Description," "Devices," and "Costs." The other option, "Enter all data directly, do not use a Device Location Form" will prompt the user to fill in the information in these tabs. Benefit/Cost results will be the same regardless of which option is chosen by the user.