Final Report for the TDOT ICM DSS

# ATCMTD Final Report for the TDOT Artificial Intelligence-Based Decision Support System (DSS)

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**for Integrated Corridor Management”**

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| | |
|---|---|
| AASHTOWare | American Association of State Highway and Transportation Officials Software |
| AI | Artificial Intelligence |
| AI-DSS | Artificial Intelligence-based Decision Support System |
| ATCMTD | Advanced Transportation and Congestion Management Technologies Deployment Program |
| ATMS | Advanced Transportation Management System |
| BCA | Benefit-Cost Analysis |
| BCR | Benefit-Cost Ratio |
| BTI | Buffer Time Index |
| CCTV | Closed-Circuit Television |
| CV | Connected Vehicles |
| CEI | Construction Engineering and Inspection |
| DMS | Dynamic Message Sign |
| DRS | Diversion Routing System |
| DSRC | Dedicated Short-Range Communications |
| DSS | Decision Support System |
| FHWA | Federal Highway Administration |
| ICM | Integrated Corridor Management |
| ITS | Intelligent Transportation Systems |
| LCS | Lane Control Sign |
| MM | Mile Marker |
| MOTION | Mobility Technology Interstate Observation Network |
| MPH | Miles per Hour |
| O&M | Operations and Maintenance |
| PTI | Planning Time Index |
| RDS | Radar Detection System |
| RITIS | Regional Integrated Transportation Information System |
| SWCS/SmartWay CS | SmartWay Central Software |
| TDOT | Tennessee Department of Transportation |
| TMC | Transportation Management Center |
| TSMO | Transportation Systems Management and Operations |
| TTI | Travel Time Index |
| USDOT | United States Department of Transportation |
| V2V | Vehicle to Vehicle |
| V2I | Vehicle to Infrastructure |
| VPD | Vehicles per Day |
| VSL | Variable Speed Limit |

# EXECUTIVE SUMMARY

This document serves as the Final Report for the Advanced Transportation and Congestion Management Technologies Deployment Initiative (ATCMTD) grant program. The Tennessee Department of Transportation (TDOT) was awarded an ATCMTD grant in 2021 to deploy an artificial intelligence-based decision support system (AI-DSS) aimed at enhancing the operational performance of the I-24 SMART Corridor between Nashville and Murfreesboro. This Final Report provides a comprehensive overview of the project, detailing the current status of the AI-DSS, its performance in relation to the project goals, any deviations from the original scope, the evaluation approach and results, project challenges, key takeaways and lessons learned, and recommendations for future deployments.

The I-24 corridor between Nashville and Murfreesboro is one of the most congested highways in Tennessee and bears one of the highest crash rates in the state. Initiatives within the corridor over the past 6 years have included I-24 SMART Corridor Phases 1 and 2, which aimed to enhance traffic management and safety through the deployment of advanced technologies, including advanced traveler information systems and transportation management technologies such as dynamic message signs (DMS) including variable speed limits (VSL) and lane control signs (LCS), connected vehicle-based (CV) systems, coordinated and connected traffic signal systems, and radar detection systems (RDS). Furthermore, the I-24 Mobility Technology Interstate Observation Network (MOTION) Test Bed was deployed within this corridor, providing unique insights and parallel research opportunities. The goal of the ATCMTD Grant project was to develop, deploy, and integrate an AI-DSS to enable these technologies to work together in a more automated and cohesive fashion to optimize traffic flow, improve traveler information, and enhance safety along the corridor.

The project evaluation covered four goal areas: Safety, Mobility, Transportation Management Center (TMC) Processes, and User Input. The performance measures identified for this project, including crash frequency and severity, travel time reliability and incident detection rate and response time were used to measure the impacts of the AI-DSS system in line with the defined goals and objectives. The project outcomes are as follows:

- **Favorable Benefit-Cost Analysis (BCA) -** BCA quantified project benefits against costs, identifying a total project cost of approximately $74.5 million. Project benefits were primarily driven by a reduction in user delay costs and crash costs, totaling approximately $30.4 million per year in 2023 dollars. The analysis indicated a break-even point of approximately 2.5 years and a **benefit-cost ratio (BCR) of 4.98**. A typical roadway widening project is generally in the realm of 1.0-2.0.

- **Fewer crashes when VSL is active -** The I-24 MOTION data provided valuable insight into the VSL operations, determining that the **AI-DSS has helped increase the detection rate of crashes along the corridor** and that **fewer crashes occur when the VSL system is active**. It was observed that there was a 14% reduction in crashes when the VSL was active. Conversely, when the VSL was inactive, the crash rate increased by 12%. Additionally, secondary crashes were reduced by 50% when VSL was active.

- **Transportation Management Center (TMC) operation success -** TMC operations and incident management improved post-deployment with **reduced incident clearance times and positive TMC technician feedback** with incidents being detected quicker and making technicians jobs more efficient. Recommended responses are presented in a matter of **seconds** as opposed to the **minutes** it takes for a traditional decision support system (DSS). Additional impacts include event detection rate increasing by 7%, detection time decreasing by 7% and VSL providing correct warnings 88% of the time.

In addition to the before and after analysis, the evaluation was split into three phases: I-24 Integrated Corridor Management (ICM) Go-Live, Initial AI-DSS Go-Live, and Final AI-DSS Go-Live due to the multiple ongoing projects and deployment timeframes along with the continuous development of the AI-DSS itself. Each goal area was evaluated through these phases compared to the respective baseline normality. The detailed results highlight the following:

- Safety metrics Before (1/1/21-6/19/23) versus After (6/20/23-12/31/24) indicated a 7% decrease in primary crashes, 10% decrease in rear-end collisions, and an 11% decrease in fatal collisions.
- Traffic volumes increased 8% from baseline to post-deployment periods with relatively no change in travel times post-deployment indicating increased throughput and improved efficiency along the corridor.
- Incident management metrics indicated a 20% decrease in incident clearance time when comparing Before (1/1/21-6/19/23) versus After (6/20/23-12/31/24) deployment.

In summary, the deployment of the AI-DSS for the I-24 SMART Corridor has demonstrated measurable success in enhancing safety, operational efficiency, and incident management. The project’s significant reductions in crash rates, improvements in traffic management processes, and a favorable BCR underline its effectiveness and potential as a model for future Integrated Corridor Management (ICM) initiatives. While challenges such as delays and data limitations were encountered, the system's demonstrated ability to optimize traffic flow and support real-time decision-making paves the way for broader adoption of artificial intelligence (AI) -driven transportation solutions. The findings and lessons learned from this project will serve as a valuable blueprint for expanding Intelligent Transportation Systems (ITS) across Tennessee and beyond.

# 1.0 PROJECT SUMMARY

This document serves as the Final Report for the Advanced Transportation and Congestion Management Technologies Deployment Initiative (ATCMTD) grant program. The Tennessee Department of Transportation (TDOT) was awarded a $2.6 million ATCMTD grant in 2021 to deploy an artificial intelligence-based decision support system (AI-DSS) to maximize the performance of the I-24 SMART Corridor between Nashville and Murfreesboro. This Final Report provides a complete look at the project and details the following:

- Performance as it relates to the project goals.
- Project deviations.
- Evaluation approach and results.
- Project challenges.
- Key takeaways and lessons learned.
- Recommendations for future deployments.

## 1.1 DESCRIPTION OF THE PROJECT

The I-24 corridor between Nashville and Murfreesboro is the most congested highway in Tennessee and has one of the highest crash rates in the state. Expanding the highway by adding lanes would cost billions and may not effectively reduce congestion and improve safety, as current demand already exceeds capacity. Instead, TDOT and its partner agencies implemented a combination of proven and emerging intelligent transportation systems (ITS) Integrated Corridor Management (ICM) strategies. These strategies aim to provide the equivalent benefits of adding new lanes at a fraction of the cost, thereby improving safety and efficiency throughout the corridor. This approach aligns with TDOT's principles of Transportation Systems Management and Operations (TSMO).

This report presents an evaluation of the new technologies and strategies introduced to TDOT's traffic management operations. The initiative aimed to enhance the separately funded I-24 ICM project by deploying an AI-DSS funded by the ATCMTD grant. As part of the separate ICM project, TDOT and its partners deployed various technologies, including overhead dynamic message signs (DMS) with dynamic lane control signs (LCS), variable speed limit signs (VSL), video detection for emergency pull-offs, upgraded and connected traffic signals, new closed-circuit television (CCTV) cameras, and radar detection systems (RDS). While TDOT primarily manages the ICM corridor using its SmartWay Central Software (SmartWay CS or SWCS) advanced transportation management system (ATMS), the AI-DSS supports critical real-time traffic management. The AI-DSS gathers incident data as well as data from monitoring and control devices[1] deployed in the I-24 SMART Corridor ICM system, analyzes the information in real-time, and incorporates inputs from transportation management center (TMC) technicians to make real-time decisions, including posting VSLs, pushing information to the traveling public, and recommending traffic signal timing plan changes.

The primary stakeholders of the project include TDOT and local municipalities along I-24 and State Route 1 (Murfreesboro Pike), including Nashville, La Vergne, Smyrna, and Murfreesboro. TDOT envisions this

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[1] Monitoring and control devices include RDS, CCTV, DMS, LCS, VSL, and Traffic Signals.

project as a blueprint for implementing similar ICM corridors across Tennessee, allowing for faster implementation and reduced costs.

### 1.1.1 AI-Based DSS Versus Microsimulation-Based DSS

Decision support systems (DSS) for freeway (and transit) corridors have primarily employed some form of online (near real-time) traffic simulation to date. The concept is essentially to use “near real-time” performance data to model potential solutions and “present the right one” (meaning the most beneficial one) to a TMC technician for execution. Although research and development in this area have not yet yielded definitive results that all participants and evaluators can agree upon, one thing is universally accepted: near-real-time microsimulation is a relatively expensive and time-consuming capability to develop, implement, and maintain. As a result of increased costs associated with creating microsimulation-based software solutions tied to a specific corridor and adjusted for changing corridor conditions, the benefit-to-cost ratios that an evaluator might document presumably measure an increase (or decrease) in benefits along with a very substantial increase in cost.

This ATCMTD Grant project developed an AI-DSS (not based on microsimulation) to facilitate a less expensive, quicker-responding, and more transportable solution.

- The AI-based solution can be deployed on a lightweight hardware stack at a fraction of the cost of a standalone high-powered server required for microsimulation-based solutions.
- The AI-based solution processes and responds in a matter of seconds as opposed to minutes required for microsimulation-based solutions.
- The AI-based solution can be easily reconfigured and adapted to different locations and corridors with the required level of existing ITS infrastructure as opposed to microsimulation-based solutions that require highly detailed and calibrated corridor-specific models to be developed and maintained as conditions evolve[2].

The evaluation of this project quantified and reported upon the use of an AI-DSS as opposed to the absence of any form of DSS or what existed in the TMC before the Go-Live of the AI-DSS.

### 1.1.2 AI-DSS Functionalities

This project aimed to leverage the expertise and insights of TMC technicians who monitor roadways daily. These technicians possess valuable knowledge about optimal diversion routes, areas to avoid, and the overall dynamics of traffic flow in their regions. By studying the decision-making processes of TMC technicians and analyzing the data that informs those choices, the system will evolve to generate more effective response plans over time. Furthermore, by evaluating the outcomes of past decisions, the system will gain insights into successful strategies and areas for improvement, enhancing its ability to adapt and respond to traffic conditions.

The following list includes current AI-DSS functionalities:

- AI-DSS deployed for full-time use in the Region 3 TMC
- RDS devices calibrated to provide data to AI-DSS for VSL operations

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[2] AI-DSS deployment in other corridors is dependent on technology and infrastructure available

- AI-DSS receiving lane closure data from a TMC technician for LCS operations
- Capability to provide recommendations for diversion routing subsystem (DRS)

Below is a list of additional functionalities that the AI-DSS could achieve. Although not implemented yet, these functionalities are the ultimate goal TDOT is continuing to build upon:

- Real-time traffic data collection, integration, and monitoring from video analytics on existing cameras
- Real-time roadway weather conditions from environmental sensor systems
- Initiating ramp metering changes
- Locating and activating freeway mobile and ground-mounted changeable message signs
- Selecting and implementing signed traffic detours
- Comparing generated response plans performance indicators
- Integration with transit data to inform routing for express buses

## 1.2 ATCMTD-TARGETED TECHNOLOGIES

This project integrated the following ATCMTD-targeted technologies:

- Advanced traveler information systems
- Advanced transportation management technologies
- Infrastructure maintenance, monitoring, and condition assessment
- Transportation system performance (monitoring) data collection, analysis, and dissemination
- Advanced safety systems, including such as vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, autonomous vehicle deployment or deployment, and associated — technologies that would enable V2V or V2I, including cellular or other technology.

## 1.3 PROJECT TEAM

The project involved a diverse group of stakeholders, including TDOT, the project deployment team, and local municipalities: Nashville, La Vergne, Smyrna, and Murfreesboro. Additionally, the Federal Highway Administration (FHWA) and various end-users played integral roles in the initiative's success.

Stantec led the project's management and evaluation, assisting TDOT with the management of the ATCMTD grant. The development team, comprised of the Southwest Research Institute (SwRI) and Vanderbilt University, with Vanderbilt University taking the lead in developing the artificial intelligence (AI) capabilities of the DSS. Furthermore, Arcadis was responsible for managing the I-24 SMART Corridor Operations in the TMC as the ICM Manager.

# 2.0 PROJECT SCOPE

This project included the implementation of an AI-DSS supported by the ICM enhancements deployed along the I-24 corridor, as detailed in the previous section. As part of the ICM project, TDOT deployed overhead DMS for dynamic LCS and VSL, a key component in AI-DSS implementation. **Figure 1** below shows the AI-DSS project location spanning between the I-440 (MM 52) and I-840 (MM 74) interchanges. TDOT constructed a total of 67 gantries, placed approximately every half mile in each direction. The arrow symbols indicate the eastern and western limits of the overhead LCS gantries. The project primarily progressed and met the original expectations; however, there were a few deviations from the original scope. The project experienced delays due to construction supply chain issues, and the original performance measures were excluded and revised due to concerns over data quality and the feasibility of collecting and analyzing the required data. The following sections outline the changes to the project scope and timeline.

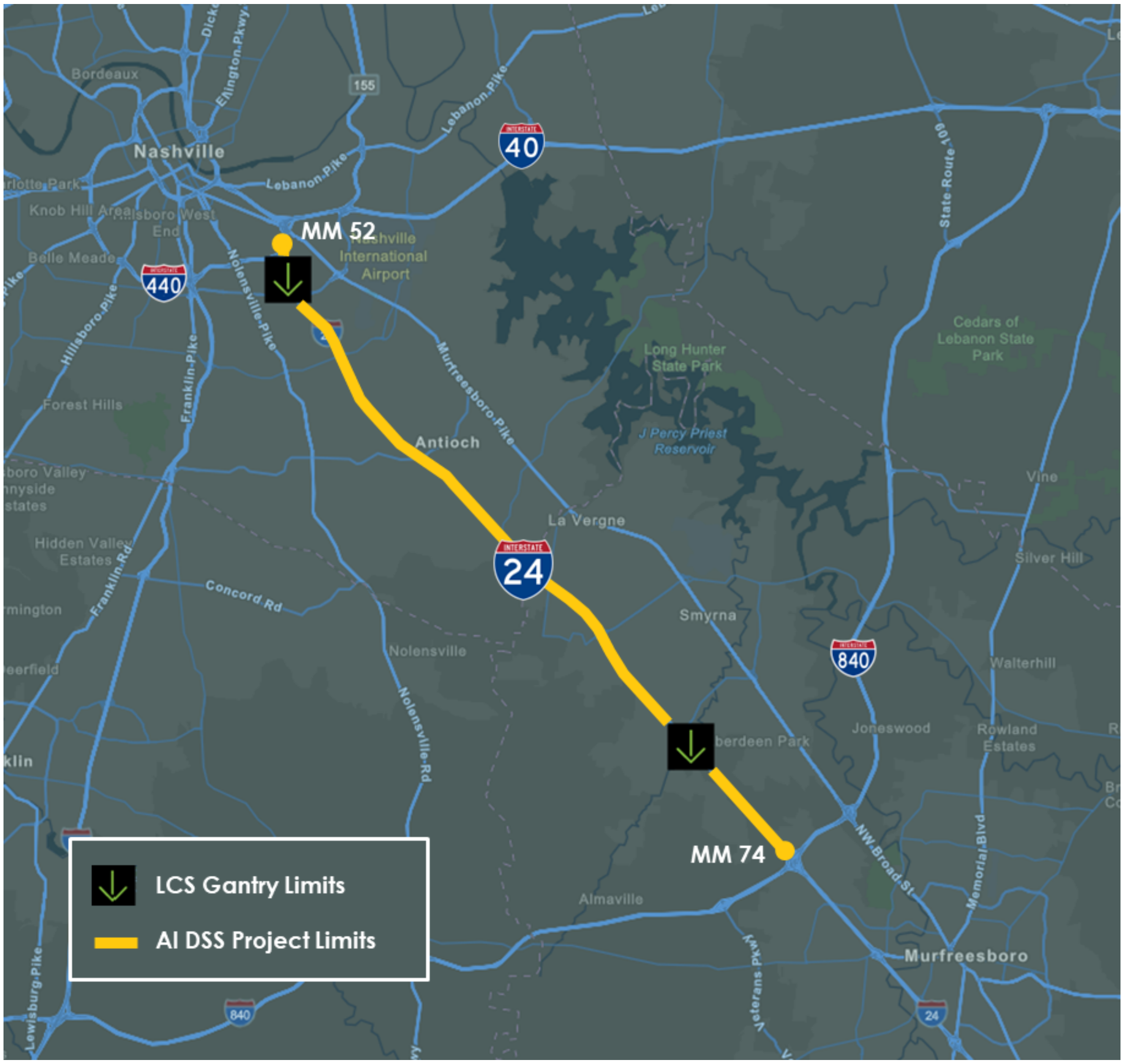

Figure 1: Project Limits

## 2.1 PROJECT DELAYS

Throughout the course of the grant project, several delays occurred which were outside the control of the project team. One deviation was that the implementation and integration of proposed field devices was not completed on schedule and the availability of those devices wasn't achieved until June 2023.The I-24 SMART Corridor Phase 2 construction project, which included RDS and LCS/VSL gantries, continued to encounter delays due to supply chain and other construction issues through early 2023. The initial intent was to use the field devices and related data to develop the dataset for the AI-DSS. Since the field devices and data were unavailable, the team based the initial iteration of the AI algorithms on microsimulation models. This delay caused the initial go-live of the ATCMTD project to be significantly delayed as field testing with the AI-DSS was dependent on the over-lane gantry system being operational. The ATCMTD team capitalized on the delay in the construction of the I-24 SMART Corridor by conducting additional software development for the initial deployment. While simulation models were used to perform the initial training of the AI-DSS, they are no longer needed now that the whole system is operational. The AI-DSS is now learning from real-world scenarios and data inputs, as well as making response suggestions. Additionally, the construction of the arterial portion of the I-24 SMART Corridor Phase 2 project was delayed by over a year, preventing the operational go-live of the DRS before the completion of the software development phase of the grant project. The delays resulted in the functionality not being included in the analysis of the overall AI-DSS deployment.

## 2.2 PERFORMANCE MEASURE DEVIATIONS

Another deviation from the original scope of the ATCMTD grant was the reporting of some of the baseline data. The project evaluator collaborated with TDOT to determine the most effective method for accessing and analyzing the baseline data within the ATMS database. There were issues accessing some baseline data within the ATMS database due to a major update to the ATMS software in September 2022. The project evaluator collaborated with TDOT and the project team to identify suitable solutions and alternatives for collecting and analyzing the additional baseline data.

Due to issues with accessing baseline data and the availability and reliability of data sources, some performance measures were removed from the project evaluation. The excluded performance measures include throughput, speed harmonization, arterial corridor capacity utilization, and time to incident detection, verification, and response.

Although not part of the original scope of the project, data and evaluation methods from TDOT's I-24 Mobility Technology Interstate Observation Network[3] (MOTION) system were also included as a measure of performance specifically for assessing the AI-DSS VSL capabilities. Developed by TDOT and Vanderbilt University, the I-24 MOTION system is a 4.2-mile stretch of roadway within the I-24 SMART Corridor limits, monitored by 276 ultra-high-definition cameras that provide continuous, extremely high-resolution vehicle speed data throughout the stretch of roadway. Vanderbilt University currently monitors and manages this system, allowing for unique insights into the resulting datasets.

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[3] Real-World Deployment and Assessment of a Multi-Agent Reinforcement Learning-Based Variable Speed Limit Control System

## 2.3 PROJECT TIMELINE

The ICM construction project schedule drove the deployment timeline of ITS devices essential for the initial Go-Live of the AI-DSS and data sources required for data collection. Table 1 shows the three phases of the ICM corridor improvement project and the status of improvements in each phase as of January 2025. The ICM project was procured separately from the AI-DSS and ATCMTD Grant project. Additionally, Table 2 summarizes the project timeline to complete the ATCMTD project schedule.

Table 1. ICM Construction Project[4] Phasing

| Phases | Improvements |
|---|---|
| **Phase 1 (Completed Winter 2021)[4]** | Emergency pull-offs, ramp lane extensions, locating communications for arterials, dedicated short-range communications (DSRC)/connected vehicle (CV) with BlueTOAD travel times, arterial signal systems and detection upgrades, provision of new signal timing |
| **Phase 2 (Freeway Elements Completed June 2023, Arterial Elements Completed November 2024)[4]** | Detection of emergency pull-offs, overhead DMS for dynamic lane control and variable speed limits on I-24, incident management coordination, integrated traffic signal control |
| **Phase 3 (Completion by TBD[5])** | Fiber optic cable installation, mobile API, adaptive traffic signal control, dynamic routing and wayfinding, decision support system, tow staging and incentivized clearance, ramp metering, updated TDOT TMC procedures, integrated staffing |

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[4] The I-24 ICM Project Phase 1 and 2 were procured separately from the ATCMTD grant.

[5] Phase 3 will be procured separately from ATCMTD grant. The design process has not started yet, and the construction timeline is to be determined.

Table 2. ATCMTD Grant Project Schedule

| No. | Task Name | Start | Finish |
|---|---|---|---|
| **1** | **Project Management** | **1/21/2021** | **3/31/2025** |
| 1.1 | Kick Off Meeting | 1/21/2021 | 1/21/2021 |
| 1.2 | Quarterly Status Reports | 4/30/2021 | 1/31/2025 |
| 1.3 | Report to Secretary | 11/19/2021 | 12/31/2024 |
| **2** | **Systems Engineering** | **4/1/2021** | **11/30/2021** |
| 2.1 | Concept of Operations | 4/1/2021 | 8/2/2021 |
| 2.2 | System Requirements Specification | 6/7/2021 | 8/27/2021 |
| 2.3 | Architecture and Preliminary Design | 7/26/2021 | 10/29/2021 |
| **3** | **Iterative Development - Design, Development, Deployment, Testing** | **8/30/2021** | **4/5/2024** |
| 3.1 | Iterative Development Year 1 Base Level ICM and AI Algorithms | 8/30/2021 | 3/29/2022 |
| 3.2 | Iterative Development Year 2 - ICM Enhancements, Stakeholder Coordination, AI Training/Enhancements | 4/4/2022 | 4/4/2023 |
| 3.3 | Iterative Development Year 3 - Final ICM Enhancements, AI/ICM Integration | 4/10/2023 | 4/30/2024 |
| **4** | **Data Collection and Evaluation Support** | **1/21/2021** | **12/31/2024** |
| **5** | **Communication and Outreach** | **1/21/2021** | **12/31/2024** |
| **6** | **Final Report and Project Complete** | **12/31/2024** | **3/31/2025** |

# 3.0 PROJECT GOALS

Collectively, the TSMO strategies and ITS deployments are expected to meet four goals identified for the I-24 SMART Corridor and AI-DSS project, which include:

1. Reduce the frequency of crashes in the corridor
2. Improve travel time reliability
3. Increase mobility within the corridor
4. Enhance agency coordination

The system goals identified above have been linked to specific corridor needs[6] that were addressed during the physical upgrades required in the corridor to implement ICM. Although many ITS devices and strategies were deployed as part of the I-24 SMART Corridor Project, the AI-DSS project evaluation will focus primarily on the impact the VSL had on the corridor over the evaluation period.

## 3.1 PERFORMANCE MEASURES

The performance measures identified for this project were used to assess the impact of the AI-DSS system in relation to the defined goals and objectives outlined above.

The stakeholder group for this evaluation selected the performance measures and metrics to assess the pre-implementation and post-implementation impacts of the I-24 SMART Corridor components and, more specifically, the AI-DSS-controlled VSL. It was essential that this project supported TDOT's TSMO goals identified in the TDOT TSMO Program Plan, which includes the following:

> *Safety: reduce the frequency and severity of crashes on the transportation system*
>
> *Efficiency: minimize traffic delays from recurring and non-recurring congestion*

The project team reflected these goals in the development of performance measures to use in the performance evaluation of the AI-DSS. The purpose of the evaluation was to systematically analyze and assess the impacts of the ITS deployments (specifically the AI-DSS-controlled VSL) in the corridor to determine the extent to which the safety and mobility goals have been achieved. The AI-DSS's goals and objectives, along with the associated performance measures, are described throughout this section.

Each evaluation strategy and data method served a specific function in evaluating performance metrics for the I-24 SMART Corridor Project. Quantitative data comparison involves comparing baseline data with post-deployment data to measure changes in key metrics such as the number and severity of crashes. This method is beneficial for assessing safety improvements by analyzing historical data from tools such as the American Association of State Highway and Transportation Officials Software (AASHTOWare Safety). Additionally, field tests (vehicle probe data) gather real-time traffic information from GPS-enabled vehicles or sensors, which helps track changes in speed, travel time, and congestion by analyzing patterns before and after system deployment. Automated data collection or incident detection logs rely on systems like SmartWay CS to automatically detect and log incidents in real time, allowing for seamless tracking of

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[6] Concept of Operations I-24 SMART Corridor

response and clearance times. To evaluate the cost-effectiveness of the project, the BCA calculated metrics such as the net present value and benefit-cost ratios (BCRs) by monetizing the project’s impacts and comparing costs to projected savings. Finally, surveys collected qualitative feedback from TMC technicians to gauge their satisfaction with the system and to track the modification or ignoring of system-generated responses, which provided insight into the system's practical effectiveness in real-world operations. Table 3 summarizes each performance measure used to evaluate the project, including the goal area, expectations, data method, and data source.

Table 3. Performance Measurement Summary

| Key Performance Measures | Goal Area | Expected Impact | Evaluation Strategy/Data Method | Data Source | Data Provider/ Stakeholder |
|---|---|---|---|---|---|
| **Number of primary and secondary crashes** | Safety | Decrease | Quantitative Data Analysis | AASHTOWare Safety, TITAN | TDOT |
| **Number of rear-end collisions** | Safety | Decrease | Quantitative Data Analysis | AASHTOWare Safety, TITAN | TDOT |
| **Severity of crashes** | Safety | Decrease | Quantitative Data Analysis | AASHTOWare Safety, TITAN | TDOT |
| **Cost of crashes** | Safety | Decrease | Quantitative Data Analysis | AASHTOWare Safety, TITAN | All I-24 ICM stakeholders |
| **Travel time on interstate** | Mobility/ Efficiency | Decrease | Quantitative Data Analysis | RITIS | TDOT |
| **Average speed on interstate** | Mobility/ Efficiency | Increase | Quantitative Data Analysis | RITIS | TDOT |
| **Travel time reliability on interstate (PTI, TTI, BTI)** | Mobility/ Efficiency | Increase | Quantitative Data Analysis | RITIS | TDOT |
| **Recurring Congestion (Severity and Duration)** | Mobility/ Efficiency | Decrease | Quantitative Data Analysis | RITIS | TDOT |

| Key Performance Measures | Goal Area | Expected Impact | Evaluation Strategy/Data Method | Data Source | Data Provider/ Stakeholder |
|---|---|---|---|---|---|
| **Incident Detection Rate**[7] | Incident Management/ TMC Processes | Increase | Quantitative Data Analysis | SmartWay CS | TDOT |
| **Incident Response Time** | Incident Management/ TMC Processes | Decrease | Qualitative User Survey/ Interviews | SmartWay CS | TDOT |
| **Incident Clearance Time** | Incident Management/ TMC Processes | Decrease | Quantitative Data Analysis | SmartWay CS | TDOT |
| **Benefit-Cost Ratio** | BCA | Increase | Qualitative Data Analysis | Literature, SmartWay CS, AASHTOWare, RITIS | All I-24 ICM Stakeholders |
| **Perceived quality of responses (per the TMC operators/ shift supervisor)** | User Input | Increase | Qualitative User Survey/ Interviews | Survey/ interview results | All I-24 ICM Stakeholders |
| **Perceived usefulness of information provided to operators for interpretation and decision-making (per the TMC operators/shift supervisor)** | User Input | Increase | Qualitative User Survey/ Interviews | Survey/ interview results | All I-24 ICM Stakeholders |

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[7] Increase the rate at which incidents are detected.

| Key Performance Measures | Goal Area | Expected Impact | Evaluation Strategy/Data Method | Data Source | Data Provider/ Stakeholder |
|---|---|---|---|---|---|
| **Level of operator intervention in altering recommended responses (per the TMC operators/shift supervisor)** | User Input | Decrease | Qualitative User Survey/ Interviews | Survey/ interview results | All I-24 ICM Stakeholders |
| **TMC operator**’s **level of confidence in accepting the AI-DSS recommendations** | User Input | Increase | Qualitative User Survey/ Interviews | Survey/ interview results | All I-24 ICM Stakeholders |
| **TMC operator/shift supervisor satisfaction rate compared to pre-DSS conditions** | User Input | Increase | Qualitative User Survey/ Interviews | Survey/ interview results | All I-24 ICM Stakeholders |

### 3.1.1 Safety

The systems deployed in the corridor are expected to enhance corridor safety by mitigating the potential for both primary and secondary crashes. It is expected that the activation of the VSL should smooth (i.e., harmonize) the flow of traffic, minimizing speed differentials and, therefore, reducing the likelihood of a crash. If a crash or other event occurs in a travel lane, the LCS will help upstream travelers avoid such unexpected obstacles in advance, further contributing to the project's objective to improve corridor safety. The following performance measures were considered to identify and quantify the impacts of deployments on safety:

- *Number of Crashes*
    - *Metric 1: Reduction in primary incidents relative to vehicle miles traveled.*
    - *Metric 2: Reduction in rear-end collisions to indicate a reduction in speed differentials.*
- *Severity of Crashes*
    - *Metric 3: Reduction in severity of crashes*
    - *Metric 4: Reduction in cost of crashes*

### 3.1.2 Mobility and Efficiency

The systems deployed in the corridor were expected to enhance mobility by managing both recurring and non-recurring congestion. The following performance measures were observed to identify if the enhancements are present:

- *Travel Time*
    - *Metric 1: Reduced average travel time in the corridor.*
    - *Metric 2: Increased average speed in the corridor.*
- *Travel Time Reliability*
    - *Metric 3: Improved travel time index in the corridor*
    - *Metric 4: Improved planning time index in the corridor*
    - *Metric 5: Improved buffer time index in the corridor*
- *Recurring Congestion*
    - *Metric 6: Reduction in severity of congestion in the corridor*
    - *Metric 7: Reduction of duration of congestion in the corridor*

Travel time performance focused on the average travel time in minutes to traverse the corridor and the average speed through the corridor.

Travel time reliability is geared toward assessing the temporal variation, consistency, or dependability of travel times within the corridor. The methods used to measure travel time reliability are the 90th or 95th percentile travel times, buffer index, and planning time index[8]. Commuters generally have an idea of how long their commute time is on a typical day (i.e., the average travel time). However, due to incidents (crashes, weather, construction, etc.), there can be an unexpected significant delay in the average travel time, which is undesirable. The 90th or 95th percentiles give an idea of the travel time on the worst days of

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[8] Travel Time Reliability. Making It There on Time All the Time. US. Department of Transportation.

travel in a corridor. A commuter may decide to add extra time (buffer time) to the average travel time to mitigate any unexpected delays or take an alternative mode of transportation to ensure on-time arrival at the destination. The buffer index is a ratio of the buffer time to the average travel time expressed in percentage. The buffer time index is expressed as a percentage, where its value increases as reliability worsens, and is calculated as the difference between the 95th percentile travel time and the average travel time, divided by the average travel time. As an example, a buffer index of 30 percent (or 0.30) means that, for a 20-minute average travel time, a motorist should allow for an additional 6 minutes to ensure on-time arrival (20 minutes x 30 percent = 6 minutes).

The planning time index shows the total time a commuter must allocate to a trip to ensure on-time arrival. The planning time index is calculated by the 95th percentile travel time divided by the free-flow travel time. For example, a planning time index of 1.40 means that for a 20-minute trip in minimal traffic, the total time that should be allotted for the journey is 28 minutes (20 minutes x 1.40 = 28 minutes).

Recurring congestion refers to consistently occurring traffic delays at the same roadway and time. This capacity-related congestion is caused by demand exceeding the roadway's capacity, and is considered a regular, predictable event. Although the goal is to reduce congestion, the AI-DSS was not expected to have a significant impact (positive or negative) on recurring congestion through the corridor primarily due to population growth in the area contributing to increased traffic volumes along the corridor from baseline data collection to post-deployment.

### 3.1.3 TMC Processes

The improvements in the corridor will transform how the TMC manages incidents and congestion. More tools will be available than ever before to identify incidents, respond to them, and provide traveler information on a granular, lane-by-lane basis. With that also comes the need to monitor, manage, and resolve more. The AI-DSS is expected to improve overall incident management, including detection time, response time and clearance time, and will contribute to the safety and efficiency objectives identified as part of the project. The following performance measures were observed to identify if the improvements to the TMC operator and incident response processes are being realized:

- *Incident Management*
    - *Metric 1: Increase in incident detection rate.*
    - *Metric 2: Reduction in mean time to incident clearance.*

### 3.1.4 Operator/User Input

Starting with the Surface Transportation Assistance Act of 1978, the FHWA has invested in developing transportation management systems that are more intelligent and evaluating hypotheses regarding the balanced utilization of multiple roadway facilities for corridor travel capacity. The first major evaluation funded by the 1978 STAA was the Integrated Motorist Information System (IMIS) in New York, a $35M corridor management system for the Long Island Expressway, along with parallel parkways and signalized arterials. That evaluation cost $3.5M and confirmed the effectiveness of the measures deployed. Based on reliance upon the IMIS evaluation, almost 50 years of subsequent "corridor balancing" projects have been accompanied by very few formal evaluations, and certainly not to the size and scale of 10% of the capital investment. The few evaluations that have been conducted have focused more on the simulation software capability than on evaluating the performance of people using the ATMS software.

A unique feature of this ATCMTD grant is the creation of a novel AI-DSS. The AI-DSS provides recommended operator actions based upon algorithmic analyses of combinations of real-time data and subsystem strategies to optimize system performance. There are two AI-DSS functions that are of high interest:

1. *The system must be able to determine the best use of the combination of ITS devices available to the operator at any given time. The system must "know what the operator should do."*
2. *The system must be able to enable, persuade and perhaps convince the human operator to take the recommended course of action. The system must "get the operator to do it."*

In this evaluation of the AI-DSS, the interaction between the software and AI with the operator will be assessed to measure corridor performance resulting from the optimization by the decision support system and its impacts on the TMC technician. The evaluator will conduct interviews with TMC technicians/supervisors to identify if the following goals are being achieved and to begin a baseline measurement for future comparison:

*Metric 1: High-Satisfaction from TMC Technicians*
*Metric 2: Low Percentage of Suggested Responses Modified*
*Metric 3: Low Percentage of Suggested Responses Ignored*

# 4.0 EVALUATION APPROACH

The purpose of this evaluation is to identify and quantify any changes, whether positive or negative, that are attributable to the deployment of the ITS systems in the I-24 SMART Corridor from mile marker (MM) 52 to MM 75 and more specifically the impacts the AI-DSS controlled VSL system has on the corridor. Figure 2 is a flowchart that shows the framework approach to evaluation used in this project. Where feasible, typical before and after evaluations were used to quantify the effect of ITS deployments on mobility and safety. This approach relied on determining baseline information prior to making a change and measuring the post-implementation impacts of new devices. The success of this approach was contingent on having sufficient pre-implementation data available and collecting post-implementation data for analysis.

One of the major challenges to this evaluation was determining which subsystem caused a benefit or change. For example, VSL systems are difficult to evaluate because many factors contribute to ambient speed, with only one of these being the posted speed limit. Additional obstacles, such as construction, seasonal changes, and driver compliance, also present challenges when evaluating VSL systems and the overall AI-DSS. In all cases, approximation and ranges of quantification were used to attempt to attribute the portion of any measurable change associated with the contributing subsystem.

Following the flowchart in Figure 2**,** at the start of the process, the evaluator developed a hypothesis to be tested. A simple example would be “every weekday morning in non-incident conditions, northbound speed drops by about 10 miles per hour (mph) in the vicinity of Harding Place right around 7:15 am. Using the upstream variable speed limit signs, this speed drop could be delayed to about 7:45 am.” The evaluator reviewed the available data to support this hypothesis and designed a test that the evaluation could conduct. In this case, a before-and-after scenario would compare the onset of congestion without the VSL and the onset of congestion after the VSL is used. The evaluator selected the performance measures that were associated with testing this hypothesis and conducted the test. The evaluator then compared the after data with the before data and documented conclusions.

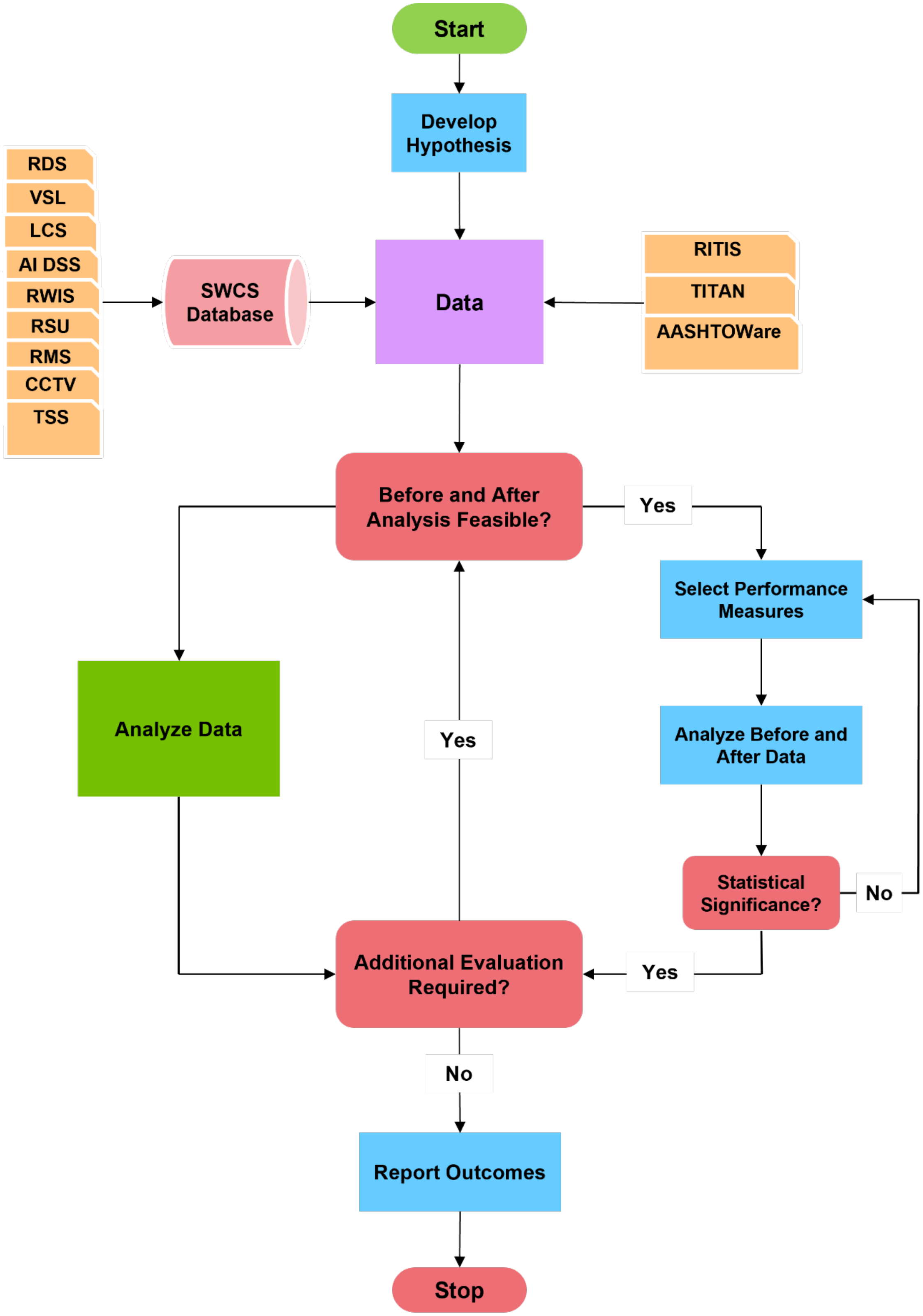

Figure 2: Evaluation Framework

One of the primary challenges in evaluating this corridor was TDOT's preference to avoid depriving the public of the potential benefits of the system once it went live. As a result, turning off the system to collect "before" data or isolating the effects of individual subsystems was not an option.

To support this principle, extensive data was collected before the "go-live" of each subsystem. Deployments were conducted incrementally, with new systems activated as they became operational. Consequently, devices deployed earlier had a limited window for collecting the "after" data needed for analysis and an even shorter period for acclimatization. The analysis primarily evaluated the combined effects of the systems rather than the impact of individual devices. However, the VSL system was specifically highlighted, using targeted techniques to isolate and measure its unique impacts.

While the evaluation framework for the I-24 SMART Corridor focuses on quantifying the impacts of ITS systems, it was essential to integrate the specific functionalities of the AI-DSS to comprehensively assess its performance. This included evaluating the system's data management capabilities, the quality and timeliness of response plans, and how well it leverages real-time information to enhance traffic management. Additionally, incorporating feedback from TMC technicians and conducting user surveys provided valuable qualitative insights that complement the quantitative metrics. Addressing potential safety benefits associated with the AI-DSS and VSL implementation was crucial, as was the challenge of isolating the contributions of individual ITS subsystems. By doing so, the evaluation better captured the holistic impact of the AI-DSS on corridor performance and operational efficiency. The data analysis involved before-and-after comparisons and statistical evaluations using data obtained from the various datasets, as well as I-24 MOTION.

## 4.1 EVALUATION DATA

Evaluation data was primarily obtained from the TDOT SmartWay CS database, AASHTOWare Safety database, and Regional Integrated Transportation Information System (RITIS) Probe Data database. The evaluator (Stantec) utilized periodically downloaded data that was saved on a replica cloud server. RITIS Probe Data was evaluated for weekdays (Monday – Friday), while AASHTOWare Safety and SWCS data were evaluated for 7 days of the week. The data was exported into Stantec’s environment for analysis and evaluation. Additionally, the I-24 MOTION system, developed, monitored, and managed by Vanderbilt University, was leveraged to assess the VSL performance via fine-granular vehicle speed data.

Ideally, the evaluation should utilize at least three years of data prior to initial deployment and three years of data post-deployment (excluding the construction period where appropriate) for the before-and-after analysis. Due to this extended period during which most construction was completed, this evaluation was limited to assessing the joint impact of all ITS systems deployed in the corridor. Furthermore, the data collected in 2020 is not statistically relevant due to the COVID-19 pandemic, so a reduced baseline was used as well. Data was generally collected for 2.5-years pre-deployment and 1.5 years post-deployment.

Some data limitations had to be considered during the evaluation process.

- **Data Completeness**: Not all relevant data may be available from the TDOT SmartWay CS database, AASHTOWare crash database, and RITIS, leading to potential gaps in the analysis. For example, if devices were down or incidents were not reported efficiently, this could result in missing data at certain times of the evaluation.

- **Data Quality**: The accuracy and reliability of the data from various sources varied. For instance, crash data is reported on multiple platforms, leading to discrepancies that could affect the evaluation of the AI-DSS's effectiveness, depending on which data source is used for evaluation.

- **Timeliness of Data**: If the data is not updated in real-time or with sufficient frequency, the analysis may not reflect current conditions, limiting the relevance of insights generated by the AI-DSS.

- **Interoperability Issues**: Integrating data from different databases can present challenges, especially when the data formats or structures are inconsistent, which can complicate the analysis process.

- **Analytical Limitations**: The tools used for analysis may have their own constraints in terms of data processing capabilities, visualization options, or user interface limitations that could affect how insights are derived and presented.

- **Historical Data Gaps**: Some key data points may not be available for the entire 2.5-year baseline period, particularly if certain monitoring technologies were not in place before the project began. Data gaps could result in uneven comparison periods, making it difficult to measure changes accurately.

## 4.2 VSL OPERATIONS AND I-24 MOTION SYSTEM

The I-24 MOTION system[9] is a 4.2-mile stretch of roadway within the I-24 SMART Corridor limits, monitored by 276 high-resolution cameras that provide continuous, extremely high-resolution vehicle speed data throughout the stretch. This system was developed by Vanderbilt University and TDOT and is currently monitored and managed by Vanderbilt University.

The I-24 MOTION system served as a valuable data source to evaluate the AI-DSS, specifically regarding VSL operations and functionality. Video data obtained from the system's cameras is processed by object detection and tracking algorithms to generate the trajectory of data for individual vehicles on I-24. Assessing the safety impact of VSL through I-24 MOTION proved challenging due to the sparsity of vehicle-vehicle collisions and the complexity of variables such as weather and shifting traffic demand over time, which complicated before and after analyses. To assess the performance of the VSL system, Vanderbilt introduced two performance measures: Successful Warning Rate and False Warning Rate. Evaluation data was collected from VSL log files from the I-24 SMART Corridor System and the fine-granular speed field data from the I-24 MOTION system.

## 4.3 BEFORE AND AFTER ANALYSIS

The before and-after-analysis relies on data collected prior to and after deployment of the ITS systems, or an ITS subsystem and analyzed to determine a statistically significant change in outcomes. This approach provides a strong case to measure the effect of the deployment after accounting for confounding factors. Some of the confounding factors include changes in travel demand, traffic incidents, construction, weather,

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[9] Additional information on the I-24 MOTION system can be found here: Real-World Deployment and Assessment of a Multi-Agent Reinforcement Learning-Based Variable Speed Limit Control System

staffing, the economy, the pandemic, or legislation. The collection of pre-deployment data is referred to as baselining. The following section details analysis periods utilized in the project evaluation.

### 4.3.1 Detailed Analysis Periods

A detailed before-and-after analysis was conducted to capture the corridor's performance throughout each phase of the AI-DSS implementation. The system was implemented in three phases as detailed below: I-24 ICM Go-Live, Initial AI-DSS Go-Live, and Final AI-DSS Go-Live.

#### *Baseline*

The project team obtained baseline data results for a 2.5-year period from January 1, 2021, through June 19, 2023. This evaluation phase involved collecting data before any ITS deployments that were part of the I-24 ICM project.

#### I-24 ICM Go-Live

The public Go-Live of the I-24 ICM elements occurred on the morning of June 20, 2023. Data was obtained from June 20, 2023, to September 17, 2023, before the Initial AI-DSS Go-Live. During this period, the AI-DSS was learning the real-world scenarios and data inputs from the deployed infrastructure. A baseline average for the I-24 ICM was established by averaging data from the same periods in previous years: June 20 to September 17 in both 2021 and 2022.

#### *Initial AI-DSS Go-Live (Rules-Based)*

The Go-Live of the AI-DSS occurred on the morning of September 17, 2023. Data was obtained from September 18, 2023, to February 28, 2024. During this initial phase, the AI-DSS was "rules-based," meaning the system used a set of pre-defined rules created by the project team to provide suggestions to the TMC. A baseline average for the Initial AI-DSS was established by averaging data from the same periods in previous years: September 18 to February 28 in both 2021/2022 and 2022/2023.

#### *Final AI-DSS Go-Live (Decision-Based)*

The final AI-DSS Go-Live is the second phase of the AI-DSS Go-Live, implemented on March 8, 2024. Data was obtained from March 9, 2024, through December 31, 2024. During this phase, the AI-DSS was "decision-based," meaning the system was fully deployed, and AI utilized data collected from field devices, predefined rules, and other inputs to provide suggestions to the TMC. A baseline average for the Final AI-DSS was established by averaging data from the same periods in previous years: March 9 to December 31 in both 2021 and 2022.

## 4.4 RISKS AND UNCERTAINTIES

During the evaluation, there are risks that can be mitigated to prevent adverse affects on how the evaluation is conducted and the validity of the results and conclusions. These risks are high for the evaluation associated with the AI-DSS software performance. The risks of this evaluation include those that are common to this type of project, as well as a few that will be unique to this project and discussed below.

### 4.4.1 Excessive Complexity

The attribution of benefits or disbenefits to an ITS subsystem can be difficult given random influences from weather, driver behavior, chance occurrences, and hidden impacts of non-measurable factors.

### 4.4.2 Human Biases

The biases and dependencies on positive outcomes for various evaluation factors can influence the results. Human agendas will be present, and evaluators must be diligent in basing decisions and evaluations on factual data.

### 4.4.3 Oscillation

Evaluating corridor management systems has been challenging in the past due to the high tendency for travel oscillations. A system that has regulatory measures, including traffic lights and ramp meters, will be particularly prone to oscillation. Oscillation in this context refers to the movement of traffic on alternate routes through a corridor when system and operator actions seek to use underutilized capacity. However, when this occurs, the free-flowing facility becomes congested, and traffic returns to congest the primary facility. Depending on the temporal dynamics, the period of oscillation can become very small (less than two minutes), and motorist frustration or dissatisfaction can result. Dampening oscillation will need to be built into the AI-DSS as well, so the operator doesn't say, "Wait a second, two minutes ago it told me to do this, and now it is saying to do something different." This result of oscillation was discovered and experienced on the aforementioned IMIS evaluation, where the oscillation was severe and had to be corrected before the evaluation could proceed.

Furthermore, Data Health data will be observed from a number of various devices, user inputs, and probe sources. There was potential for the accuracy of data to deviate from 100% due to the lack of calibration of field devices, errant user inputs, and low-confidence subsets of probe data.

# 5.0 EVALUATION RESULTS

The following sections detail the performance evaluation of the AI-DSS. Important highlights concluded from the evaluation of the AI-DSS are the following:

- **Favorable BCA -** BCA quantified project benefits against costs, identifying a total project cost of approximately $74.5 million. Project benefits were primarily driven by a reduction in user delay costs and crash costs, totaling approximately $30.4 million per year in 2023 dollars. The analysis indicated a break-even point of approximately 2.5 years and a BCR of 4.98. A typical roadway widening project is generally in the realm of 1.0-2.0.

- **Fewer crashes when VSL is active -** The I-24 MOTION data provided valuable insight into the VSL operations, determining that the AI-DSS has helped increase the detection rate of crashes along the corridor and that fewer crashes occur when the VSL system is active. It was observed that there was a 14% reduction in crashes when the VSL was active. Conversely, when the VSL was inactive, the crash rate increased by 12%. Additionally, secondary crashes were reduced by 50% when VSL was active.

- **TMC operation success -** TMC operations and incident management improved post-deployment, with reduced incident clearance times and positive TMC technician feedback. with incidents being detected quicker and making technicians jobs more efficient. Recommended responses are presented in a matter of seconds as opposed to the minutes it takes for a traditional DSS. Additional impacts include event detection rate increasing by 7%, detection time decreasing by 7% and VSL providing correct warnings 88% of the time.

Additionally, each goal area was evaluated through three implementation phases, as detailed in Section 4.3, compared to the respective baseline normality. The project team also conducted an overall before-and-after analysis of the AI-DSS freeway operations. The detailed results highlight the following:

- Relatively no change in travel times post-deployment.
- Traffic volumes increased 8% from baseline to post-deployment periods.
- Safety metrics Before (1/1/21-6/19/23) versus After (6/20/23-12/31/24) indicated a 7% decrease in primary crashes, a 10% decrease in rear-end collisions, and an 11% decrease in fatal collisions.
- Incident management metrics indicated a 20% decrease in incident clearance time when comparing before versus after deployment.

## 5.1 BENEFIT-COST ANALYSIS

The BCA evaluates the economic feasibility of the I-24 SMART Corridor between I-440 (MM 52) and I-840 (MM 75) by comparing its costs and benefits over a specified period. The BCA for the I-24 SMART Corridor Project was systematically conducted to quantify the project's benefits and costs on an annual basis. All benefits and costs were converted to 2023 dollars for this analysis. A detailed summary of assumptions and calculations of the BCA are included in **Appendix A**.

The project cost included planning, project design and engineering, procurement, and construction costs of the I-24 freeway ITS improvements, as detailed below. The total project cost is allocated to I-24 SMART Corridor Phase 1 and Phase 2 ITS improvements,[10] as well as the AI-DSS, with annual operations and maintenance (O&M) expenses estimated at $1,000,000. The O&M cost was estimated based on previous TDOT operations expenses and maintenance contracts and included as a disbenefit in the analysis. The total project costs in 2023 dollars are detailed below.

- **Construction Costs (ITS Improvements): $55,774,983.86**
- **Construction Engineering and Inspection (CEI) Costs (ITS Improvements): $7,181,279.04**
- **Design Costs (ITS Improvements): $5,814,451.32**
- **AI-DSS Cost: $5,772,000.00** (total grant value + funding match)
- **Total Project Cost: $74,542,714.22** (construction + CEI + design + AI-DSS costs)
- **Annual O&M Costs: $1,000,000**

The project benefits include a reduction in user delay costs and a reduction in crashes. User delay costs for the I-24 corridor were derived from RITIS's Probe Data Analytics Suite. Pre-deployment delay costs were averaged to establish an annual delay cost. Post-deployment user delay costs were then subtracted resulting in the annual reduction in user delay cost.

- **Reduction in User Delay Cost: $1,592,554.14** (pre-deployment annual delay cost – post-deployment annual delay cost)

To evaluate the impact of the ITS deployment on crash reduction, a comparative analysis was conducted using data from the I-24 SMART Corridor alongside similar corridors (I-65 S and I-40 E). Annual averages of pre-deployment crash data were established for comparison with post-deployment data. Percent changes in each crash severity classification (KABCO) were calculated for the I-24 SMART Corridor and the I-65 S and I-40 E corridors for periods before and after ITS deployment. To isolate the ITS effect, the percent changes for the adjacent corridors were subtracted from those in the SMART corridor. Crash prevention estimates were derived by applying the difference in percent change to the number of crashes on the SMART corridor. Finally, the crash prevention data was monetized to determine the total financial benefits of the SMART corridor. The crash prevented data was monetized by applying the KABCO Level Monetized Values (in 2023 $) obtained from *USDOT Benefit-Cost Analysis Guidance for Discretionary Grant Projects (2025)* to calculate the Total Safety Benefits in crash prevented per year: $13,200,000 for fatalities (K), $1,254,700 for incapacitating injuries (A), $246,900 for visible but non-disabling injuries (B), $118,000 for possible injuries (C), and $5,300 for no apparent injuries (O). The adjusted crash costs were then applied to calculate the financial benefits from the reduction of crashes.

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[10] The project costs were obtained from the construction bid documents and CEI and design costs summaries provided by TDOT. The project cost calculated for BCA purposes only included cost of ITS improvements in each project phase. Roadway and arterial improvements were not included in the project cost.

- **Reduction in Crash Cost: $29,767,316.70**

User Delay Costs, Safety Benefits, and O&M Costs were discounted over the 15-year lifespan at a 3.1% discount rate.

- **Total Safety Benefits (Discounted): $363,740,445.74**
- **Total User Delay Benefits (Discounted): $19,460,146.79**
- **O&M Costs (Discounted): -$12,219,456.98**
- **Total Benefits: $370,981,135.55** (Discounted Safety Benefits + Discounted User Delay Costs – Discounted O&M Costs)

The BCR was calculated by dividing the Total Project (Discounted) Benefits by the Total Capital Costs in 2023 dollars. The break-even point (in years) was also determined by summing the discounted benefits until the total project capital costs were met.

- **Benefit-Cost Ratio: 4.98**
- **Break-Even Point: 2.5 years**

## 5.2 VSL OPERATIONS

VSL operations have demonstrated a positive impact on the corridor. Leveraging I-24 MOTION[11] data and analytics, the evaluators were able to determine that when VSL is active, crashes are significantly reduced. I-24 MOTION data was extremely valuable to demystifying the corridor performance. MOTION data allowed evaluators the ability to identify unrecorded crashes, when congestion was occurring and why, and incident response time and clearance time.

The VSL system was evaluated for one year prior to the VSL implementation on June 20, 2023, and one year following the implementation. To evaluate the crash reduction performance, it is important to note that the VSL system runs 24 hours a day. During free-flow conditions, the VSL should post the maximum speed limit, and when it does, the system is considered to be in an inactive state. The VSL system is active any time that the posted speed limit is lower than the maximum speed limit. This distinction is important since the VSL system cannot prevent crashes (e.g., through proactive warning) when it is in an inactive state. Through various experiments, Vanderbilt has demonstrated that the VSL system delivers high-quality, proactive warnings with a low rate of false warnings.

As of November 2024, since VSL was deployed in June 2023, volumes have increased by 6.6%, as estimated by the radar sensors. To assess the effectiveness of the VSL system, the evaluation focused on crashes that occurred when the system was active. For the year following the VSL implementation starting on June 20, 2023, VSL logs were utilized at the time and location of each crash to determine whether the nearest VSL controller was active. For the year preceding the VSL implementation, the RDS data was reprocessed through the VSL algorithm to determine whether the VSL would have been active had it been

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[11] Additional information on the I-24 MOTION system can be found here: Real-World Deployment and Assessment of a Multi-Agent Reinforcement Learning-Based Variable Speed Limit Control System

deployed. All non-recurrent congestion from RDS-based time-space diagrams for two years—one year before and one year after VSL went live was labeled. The non-recurrent congestion events that correspond with crashes recorded in the TMC database were identified.

Table 4 presents the preliminary before and after crash analysis results. The project team conducted a preliminary crash analysis for the year prior to the VSL implementation on June 20, 2023, and for the year following the implementation. It was observed that there was a 14% reduction in the crash rate, decreasing from 18.4 crashes per month to 15.8 crashes per month when the VSL was active (or would have been in the before data). Conversely, when the VSL was inactive, the crash rate increased by 12%, from 23.6 crashes per month to 26.5 crashes per month. These findings suggest that without the deployment of VSL, the total crash rate on I-24 would likely have increased. Additionally, the free-flow crash increase (when VSL is inactive) is consistent with the crash increase adjacent corridors are experiencing; I-65 south of Nashville experienced approximately 19% increase in total crashes over the same period, and I-40 east of Nashville experienced approximately 9% increase. Volume growth in these corridors is a possible factor for increased crashes. Similar to the +6.6% average annual daily traffic (AADT) increase on I-24, I-65 AADT grew by around 5% and I-40 by over 3%.

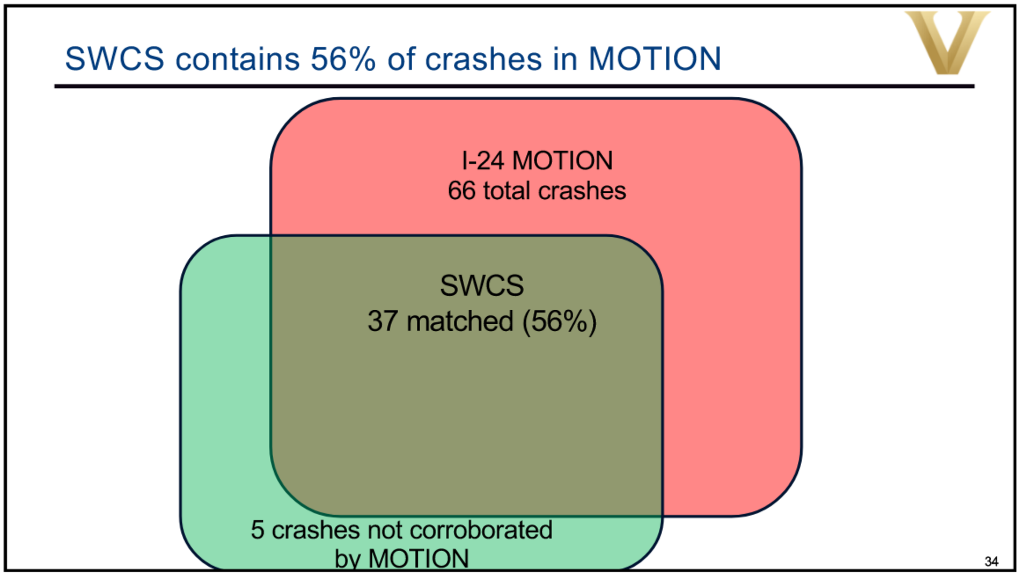
A secondary crash analysis was also conducted, as the VSL system has the potential to prevent such incidents by providing slower speeds to warn upstream traffic. The results showed that the secondary crash rate decreased by 50%, from 7.2 crashes per month to 3.6 crashes per month. It should be emphasized that the preliminary crash statistics are likely to change as more data is collected, but the preliminary results are promising.

Table 4: Before and After Crash Results for VSL Evaluation

| Evaluation Period | Crash Rate with Active VSL (crashes/month) | Crash Rate with Inactive VSL (crashes/month) | Secondary Crash Rate (crashes/month) |
|---|---|---|---|
| **Before (6/20/2022 to 6/19/2023)** | 18.4 | 23.6 | 7.2 |
| **After (6/20/2023 to 6/19/2024)** | 15.8 (↓ 14%) | 26.5 (↑ 12%) | 3.6 (↓ 50%) |

Additionally, the VSL system responds, on average, 9 minutes before the crash is reported within the TMC, indicating a 90% reduction in response time to warn drivers within the VSL area. Compared with the year before AI-DSS operation, the TMC event detection rate – the proportion of event crashes that are logged by the TMC – has increased by 7%, meaning fewer events are missed by the TMC because of the system. Additionally, TMC event detection time has reduced by 7%, indicating that the events are being detected faster by the TMC. These changes are likely due to the increased visibility of congestion and speed limit changes within the VSL system, particularly during non-recurrent congestion. The VSL has demonstrated an 88% accuracy rate in warning of slow traffic ahead, with false warning rate of only 1.6%. These metrics were computed during the first year of AI-DSS operation, June 20, 2023, to June 19, 2024, and compared with the prior year of operation where applicable.

The I-24 MOTION system was also shown to detect more crashes than were reported to SWCS and the AASHTOWare databases. The AASHTOWare database includes crashes reported by law enforcement agencies and leverages the TITAN crash database. SmartWay CS or SWCS includes crashes reported by the regional TMC, which may also include those same crashes reported by law enforcement, but this is not always the case. As shown in the figures below, over an approximately 5-month period, between 5:30 am and 10:00 pm, the SWCS database reported only 56% of the crashes detected by MOTION. Additionally, AASHTOWare reported 45% of crashes detected by MOTION. When observed as a whole, it was determined that 36% of crashes were observed only by MOTION and not reported to SWCS or AASHTOWare databases. MOTION could not corroborate a small number of crashes in SWCS and AASHTOWare due to a mismatch between recorded crash attributes and observations made by the MOTION cameras, such as inaccurate time or geolocation data reported by the TMC or law enforcement.



SWCS contains 56% of crashes in MOTION

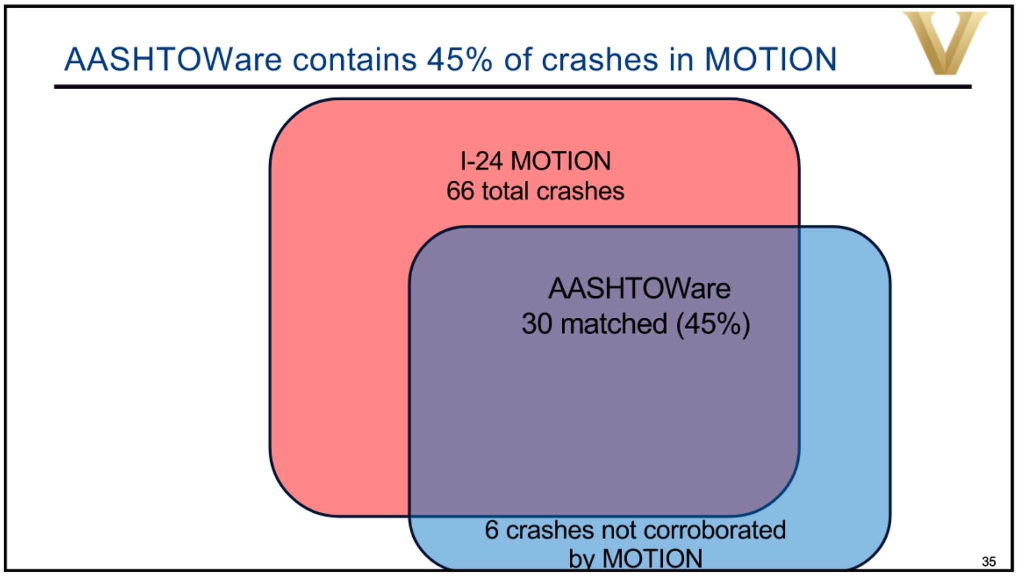
I-24 MOTION
66 total crashes

SWCS
37 matched (56%)

5 crashes not corroborated
by MOTION

34

Figure 3: Comparison of SWCS-Reported Crashes with I-24 MOTION Crashes



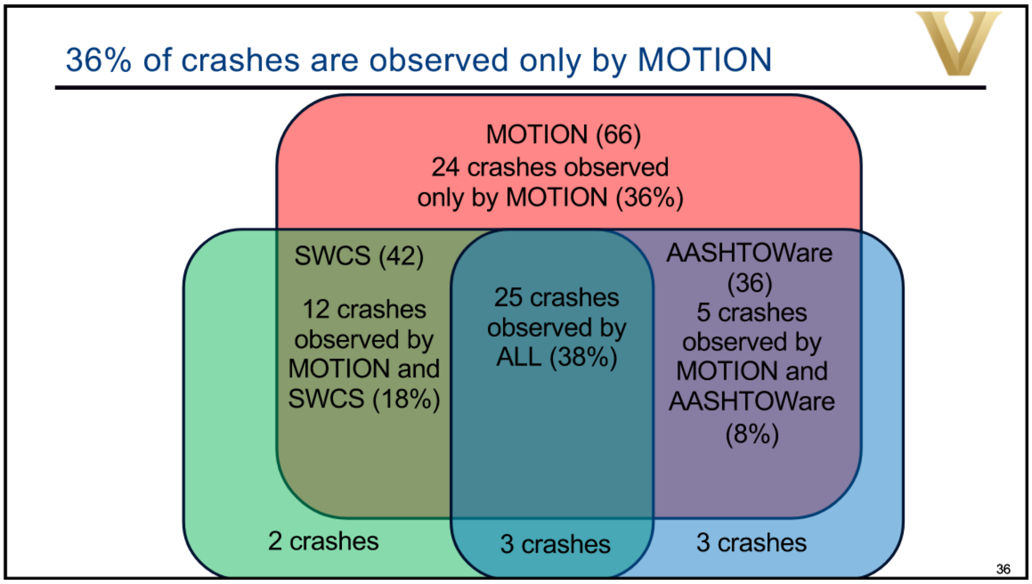
AASHTOWare contains 45% of crashes in MOTION

I-24 MOTION
66 total crashes

AASHTOWare
30 matched (45%)

6 crashes not corroborated by MOTION

Figure 4: Comparison of AASHTOWare Crashes with I-24 MOTION Crashes



36% of crashes are observed only by MOTION

MOTION (66)
24 crashes observed only by MOTION (36%)

SWCS (42)
12 crashes observed by MOTION and SWCS (18%)

25 crashes observed by ALL (38%)

AASHTOWare (36)
5 crashes observed by MOTION and AASHTOWare (8%)

2 crashes

3 crashes

3 crashes

Figure 5: I-24 MOTION Crash Comparison

## 5.3 OPERATOR INPUT

TMC staff were interviewed in late August 2023 to gather data on TMC operations and procedures prior to the deployment of the AI-DSS, and in April 2024, following the Final AI-DSS Go-Live, to gather input on post-deployment operations. Five TMC staff members were invited for an interview, including the TMC Manager, TMC technicians, and the ICM Consultant Manager. Four staff members responded to the user input surveys. The user input survey and responses can be found in Appendix B.

The overarching takeaways from the baseline “Before” period prior to deployment of the AI-DSS on June 20, 2023, are as follows:

- There was consistent congestion throughout the morning and afternoon peak periods along the I-24 corridor, particularly at Old Hickory Boulevard and Sam Ridley Parkway Inbound.
- Tuesdays, Wednesdays, and Thursdays were typically the worst days for traffic congestion. Mondays tend to have the greatest number of incidents.
- Traffic Incidents tended to occur during peak periods and would take 30 to 45 minutes to dissipate.
- Incident clearance would take about 90 minutes to clear during peak periods and about 45 minutes during non-peak periods.
- Limited traveler information tools and limited cooperation from other agencies were the biggest challenges to managing incidents in the corridor.
- Full closures were previously difficult to manage due to a lack of consensus and coordination among agencies, as well as limited tools to manage traffic and discourage drivers from entering the corridor.

The overarching takeaways post AI-DSS deployment, categorized by performance goals, are as follows:

*Metric 1: High-Satisfaction from TMC Technicians*

- All new devices introduced as part of the I-24 Smart Corridor Project have been useful to TMC technicians.
- The information provided by the system has been useful in making the TMC technicians' jobs more efficient and increasing their awareness of what is happening throughout the entire corridor.
- Incidents are being detected more quickly post-deployment, but actual clearance times appear to remain unchanged once the TMC initiates a response. However, response to incidents is smoother, allowing traffic to stay steady.

*Metric 2: Low Percentage of Suggested Responses Modified*

- There has been no issues having to wait for a suggested response. TMC technicians are routinely presented with a response they would expect from the AI-DSS, indicating a low percentage of suggested responses that have been modified.

*Metric 3: Low Percentage of Suggested Responses Ignored*

- TMC technicians are routinely presented with a response they would expect from the AI-DSS, indicating a low percentage of suggested responses ignored.

*Additional Findings:*

- Congestion continued to be consistent throughout the morning and afternoon peak periods along the I-24 corridor, particularly from the Rutherford County Line into Downtown. However, when LCS was utilized, drivers appeared to respond quickly and effectively. Overall, speeds seemed slower, which appeared to smooth traffic flow.
- It is noticeable in the TMC that incidents have decreased in frequency and severity, allowing for quicker incident clearance and reduced congestion.
- Traffic Incidents still tended to occur during peak periods and would take 30 to 45 minutes to dissipate. However, it has been noticeable that when VSL is active, it has attributed to fewer collisions. Secondary collisions have also been reduced tremendously.

- Full closures are now managed by displaying red X's on LCS signs to give motorists pre-warning upstream of the closure. Additionally, providing a red X over the shoulder has had an impact on preventing motorists from driving on the shoulder for a period of time.
- VSL has had the largest positive impact in reducing the number of crashes, and LCS has greatly helped improve the safety of HELP Operators and Emergency Personnel during incidents when lanes are closed, or help is being administered on the shoulder.
- The AI-DSS has enabled the activation threshold to be reduced from 3 minutes to 30 seconds, significantly improving the responsiveness of the VSL.

## 5.4 BEFORE AND AFTER ANALYSIS SUMMARY

Table 5 below summarizes the overall before and after analysis of the AI-DSS freeway operations as a whole. The "before" analysis period included baseline data from January 1, 2021, through June 19, 2023. The "after" period included consecutive post-deployment data from the I-24 ICM, Initial AI-DSS, and Final AI-DSS evaluation phases, as described previously, from June 20, 2023, through December 31, 2024. Safety data and incident detection data were annualized for this evaluation. Mobility data, incident response, and clearance time was averaged for the before and after time periods for comparison.

Overall, the corridor met expectations and objectives as outlined in the report. The AI-DSS did not have significant impact on travel time and travel time reliability, with both performance metrics showing relatively no change. However, with an 8% increase in traffic volumes along the corridor between the before and after evaluation periods, this suggests a positive outcome for the AI-DSS itself. Lastly, incident management improved significantly, showing a 20% decrease in incident clearance time and an increase in incident detection.

Table 5: Overall Before and After Summary

| Goal Area | Performance Metric | | Before (1/1/2021-6/19/2023) | After (6/20/2023-12/31/2024) | Percent Change |
|---|---|---|---|---|---|
| **Mobility** | **Travel Time** | Average Travel Time (minutes) | 22.9 | 23.2 | ↑ 2% |
| | | Average Speed (mph) | 62.2 | 62.0 | 0% |
| | **Travel Time Reliability** | Travel Time Index | 1.08 | 1.13 | ↑ 5% |
| | | Planning Time Index | 1.35 | 1.39 | ↑ 3% |
| | | Buffer Time Index | 0.27 | 0.25 | ↓ 7% |
| **Mobility** | **Travel Time** | Average Travel Time (minutes) | 24.4 | 23.1 | ↓ 5% |
| | | Average Speed (mph) | 63.7 | 61.8 | ↓ 3% |
| | **Travel Time Reliability** | Travel Time Index | 1.06 | 1.13 | ↑ 7% |
| | | Planning Time Index | 1.30 | 1.48 | ↑ 14% |
| | | Buffer Time Index | 0.27 | 0.30 | ↑ 11% |
| **Safety (Annualized)** | **Number of Incidents (Both Directions)** | Primary Crashes | 1811 | 1679 | ↓ 7% |
| | | Rear-End collisions | 770 | 697 | ↓ 10% |
| | **Severity of Incidents (Both Directions)** | Serious Injury | 31 | 33 | ↑ 6% |
| | | Fatality | 9 | 8 | ↓ 11% |
| | | Cost in Crashes | $290,744,009 | $262,564,610 | ↓ 10% |
| **TMC Processes** | **Incident Management** | No. of Incident Detections (per year) | 8200 | 9494 | ↑ 16% |
| | **Time to Incident Clearance** | Incident Clearance (minutes) | 333 | 267 | ↓ 20% |

## 5.5 DETAIL SUMMARY BY IMPLEMENTATION PHASE

The following subsections summarize the before-and-after analysis of the AI-DSS freeway operations, broken down by each phase of implementation, listed below, organized by project goal areas: safety, mobility, and TMC processes (incident management) as detailed in Section 4.3. User input was not evaluated at each implementation phase described below; instead, interviews were conducted on a before-and-after basis, as detailed in Section 5.3. A baseline average for each implementation phase was established by averaging data from the same time periods in previous years.

***I-24 ICM Go-Live:*** *After I-24 ICM ITS Deployment Go-Live and before Initial AI-DSS Go-Live (June 20, 2023, to September 17, 2023) compared to the baseline average from June 20 to September 17, 2021, and 2022.*

***Initial AI-DSS Go-Live (Rules-based):*** *After Initial AI-DSS Go-Live and before Final AI-DSS Go-Live (September 18, 2023, to February 29, 2024) compared to the baseline average from September 18 to February 28, 2021/2022, and 2022/2023.*

***Final AI-DSS Go-Live (Decision-based):*** *After Final AI-DSS Go-Live (March 9, 2024, to December 31, 2024) compared to the baseline average from March 9 to December 31, 2021, and 2022.*

### *5.5.1 Safety*

The safety of the corridor was analyzed using two performance metrics: number of crashes and severity of incidents. Safety data was obtained via AASHTOWare Safety Database. The following subsections provide a summary of post-deployment safety performance compared to the respective baseline averages following the I-24 ICM Go-Live, Initial AI-DSS Go-Live, and the Final AI-DSS Go-Live.

#### *Number of Crashes*

Generally, safety of the corridor improved in each evaluation phase as indicated by the decrease in the number of crashes, including rear-end collisions. After the implementation of the I-24 ICM, primary crashes decreased by 18% (79 crashes), and rear-end collisions decreased by 17% (34 crashes). No significant change was experienced during the Initial AI-DSS phase. After the Final AI-DSS deployment, primary crashes decreased by 16% (245 crashes), and rear-end collisions decreased by 23% (152 crashes). **Table 6** summarizes the number of crashes by each evaluation period.

Table 6: Number of Crashes Evaluation Summary

| Evaluation Phase | Performance Metric | Before (2021/2022/2023) | After (2023/2024) | Percent Change |
|---|---|---|---|---|
| **I-24 ICM Go-Live (6/20 - 9/17)** | Primary Crashes | 448 | 369 | ↓ 18% |
| | Rear-End collisions | 198 | 164 | ↓ 17% |
| **Initial AI-DSS Go-Live (9/18 - 2/29)** | Primary Crashes | 827 | 822 | ↓ 1% |
| | Rear-End collisions | 359 | 359 | 0% |
| **Final AI-DSS Go-Live (3/9 - 12/31)** | Primary Crashes | 1528 | 1283 | ↓ 16% |
| | Rear-End collisions | 662 | 510 | ↓ 23% |

#### *Severity of Crashes*

Crash severity showed improvements after the implementation of ICM, with serious injury crashes decreasing by 33% (2 crashes) and fatal injury crashes decreasing by 50% (1 crash). Following the deployment of the Initial AI-DSS, serious injury crashes increased by 21% (3 crashes), and fatal injury crashes decreased by 40% (2 crashes). After the Final AI-DSS deployment, the evaluator saw an increase in serious injuries and a decrease in fatalities, with serious injury crashes increasing by 11% (3 crashes) and fatal injury crashes decreasing by 11% (1 crash). **Table 7** summarizes the crash severity evaluation by each evaluation period.

Table 7: Crash Severity Evaluation Summary

| Evaluation Phase | Performance Metric | Before (2021/2022/2023) | After (2023/2024) | Percent Change |
|---|---|---|---|---|
| **I-24 ICM Go-Live (6/20 - 9/17)** | Serious Injury | 6 | 4 | ↓ 33% |
| | Fatality | 2 | 1 | ↓ 50% |
| **Initial AI-DSS Go-Live (9/18 - 2/29)** | Serious Injury | 14 | 17 | ↑ 21% |
| | Fatality | 5 | 3 | ↓ 40% |
| **Final AI-DSS Go-Live (3/9 - 12/31)** | Serious Injury | 27 | 30 | ↑ 11% |
| | Fatality | 9 | 8 | ↓ 11% |

### *Cost of Crashes*

The cost in crashes was determined by using monetized values provided in the *USDOT Benefit-Cost Analysis Guidance for Discretionary Grant Projects (2025)* based on the KABCO scale: K for fatalities, A for incapacitating injuries, B for visible but non-disabling injuries, C for possible injuries, and O for no apparent injuries. The unit costs in 2023 dollars are as follows: $13,200,000 for fatalities (K), $1,254,700 for incapacitating injuries (A), $246,000 for visible but non-disabling injuries (B), $118,000 for possible injuries (C), and $5,300 for no apparent injuries (O). These comprehensive unit costs were then applied to each KABCO category for the analysis periods.

Following the first two evaluation phases, I-24 ICM and Initial AI-DSS, the cost of crashes decreased significantly by 30% and 18%, respectively. During the Final AI-DSS phase, the cost of crashes increased by 14%, primarily due to the increase in serious injury crashes. **Table 8** summarizes the cost of crashes through each evaluation period.

Table 8: Crash Cost Summary

| Evaluation Phase | Performance Metric | Before (2021/2022/2023) | After (2023/2024) | Percent Change |
|---|---|---|---|---|
| **I-24 ICM Go-Live (6/20 – 9/17)** | Cost in Crashes | $56,433,350.00 | $39,249,200.00 | ↓ 30% |
| **Initial AI-DSS Go-Live (9/18 – 2/29)** | Cost in Crashes | $131,872,250 | $107,645,100 | ↓ 18% |
| **Final AI-DSS Go-Live (3/9 – 12/31)** | Cost in Crashes | $235,555,800.00 | $268,035,500.00 | ↑ 14% |

## 5.5.2 Mobility

The mobility of the corridor was analyzed using three performance measures: travel time, travel time reliability, and recurring congestion. Mobility data was collected via RITIS archived probe data for weekdays

(Monday through Friday) during each evaluation period. The following subsections summarize the mobility performance results for the post-I-24 ICM, Initial AI-DSS, and Final AI-DSS phases, including the percent change from each baseline average for both eastbound and westbound traffic.

When evaluating the mobility performance of the corridor, external factors that may impact corridor mobility must be considered, including population growth, seasonal changes, driver compliance, construction, and other activities occurring in the corridor. The AADT significantly increased by 8% from pre-deployment (2022) to post-deployment (2023) from 169,048 vehicles per day (vpd) to 182,078 vpd, respectively[12].

### *Travel Time and Corridor Speed*

The average travel time for the eastbound lanes did not show significant variation (<1 minute) from the baseline period for all three evaluation phases. The average travel time in the westbound lanes did not show significant variation, with less than a minute change during the I-24 ICM and Initial AI-DSS phases. The most notable change occurred in the Final AI-DSS phase, where travel time reached 23.6 minutes in the westbound direction, marking a 7% (1.6 minutes) rise. However, these are still minimal changes, especially when considering the 8% increase in traffic volume[8] through the corridor from the baseline period to the post-deployment phases.

The average speed recorded for the eastbound lanes generally reflected a declining trend. During the I-24 ICM phase, the average speed was 64 mph, which represented a 3% (2 mph) increase from the baseline period. The Initial AI-DSS phase recorded relatively no change from the baseline period. The Final AI-DSS phase recorded a slight decrease in average speed, recording 61 mph post-deployment, indicating a 2% (1 mph) decrease. In the westbound direction, the average speed reflected a declining trend. During the ICM the average speed showed relatively no change when compared to the baseline phases. However, during the Initial and Final AI-DSS phases, the average speed recorded a 2% (1 mph) and 5% (3 mph) decrease, respectively, indicating VSL compliance from motorists.

**Table 9 and Table 10** summarize travel time and corridor speed evaluation for the eastbound and westbound directions, respectively.

Table 9: Travel Time and Speed Evaluation Summary (Eastbound)

| Evaluation Phase | Performance Metric | Before (2021/2022/2023) | After (2023/2024) | Percent Change |
|---|---|---|---|---|
| **I-24 ICM Go-Live (6/20 – 9/17)** | Average Travel Time (min) | 23.0 | 22.4 | ↓ 3% |
| | Average Speed (mph) | 62 | 64 | ↑ 3% |
| **Initial AI-DSS Go-Live (9/18 – 2/29)** | Average Travel Time (min) | 22.8 | 22.9 | ↑ <1% |
| | Average Speed (mph) | 63 | 63 | 0% |
| **Final AI-DSS Go-Live (3/9 – 12/31)** | Average Travel Time (min) | 22.9 | 23.6 | ↑ 3% |
| | Average Speed (mph) | 62 | 61 | ↓ 2% |

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[12] AADT counts were obtained at a permanent count location from the TN Times traffic count database.

Table 10: Travel Time and Speed Evaluation Summary (Westbound)

| Evaluation Phase | Performance Metric | Before (2021/2022/2023) | After (2023/2024) | Percent Change |
|---|---|---|---|---|
| **I-24 ICM Go-Live (6/20 – 9/17)** | Average Travel Time (min) | 21.8 | 22.4 | ↑ 3% |
| | Average Speed (mph) | 64 | 64 | 0% |
| **Initial AI-DSS Go-Live (9/18 – 2/29)** | Average Travel Time (min) | 22.2 | 22.7 | ↑ 2% |
| | Average Speed (mph) | 64 | 63 | ↓ 2% |
| **Final AI-DSS Go-Live (3/9 – 12/31)** | Average Travel Time (min) | 21.9 | 23.5 | ↑ 7% |
| | Average Speed (mph) | 64 | 61 | ↓ 5% |

### *Travel Time Reliability*

Travel time reliability was analyzed through performance metrics, of travel time index (TTI), planning time index (PTI), and buffer time index (BTI). The travel time reliability reflected a mixed performance in both the eastbound and westbound directions. **Table 11** and **Table 12** summarize the travel time reliability metrics through each evaluation phase for the eastbound and westbound directions, respectively.

The average TTI increased in each phase when compared to the baseline data. After the implementation of I-24 ICM, the average TTI essentially remained unchanged in the eastbound direction while increasing 5% westbound. Following the deployment of the Initial AI-DSS, the average travel time index increased by 3% eastbound and 4% westbound. After the Final AI-DSS deployment, the travel time index increased by 6% eastbound and 9% westbound.

The PTI fluctuated in the eastbound direction and showed an increase in the westbound direction through each evaluation phase. After the implementation of I-24 ICM, the PTI on I-24 decreased by 11% eastbound; however, a 4% increase was recorded westbound when compared to the baseline. Following the deployment of the Initial AI-DSS, the PTI increased by 4% eastbound and 8% westbound. After the Final AI-DSS deployment, the PTI showed relatively no change eastbound and increased 14% westbound.

The BTI reflected a mixed performance from evaluation phase to evaluation phase. After the implementation of the I-24 ICM, the BTI decreased by 52% eastbound and 29% westbound. Following the deployment of the Initial AI-DSS, the BTI increased in both directions by 8% eastbound and 6% westbound. However, after the Final AI-DSS deployment, the BTI decreased by 17% eastbound and 10% westbound, showing positive results.

Table 11: Travel Time Reliability Summary (Eastbound)

| Evaluation Phase | Performance Metric | Before (2021/2022/2023) | After (2023/2024) | Percent Change |
|---|---|---|---|---|
| **I-24 ICM Go-Live (6/20 – 9/17)** | Average Travel Time Index | 1.09 | 1.08 | <1% |
| | Average Planning Time Index | 1.52 | 1.36 | ↓ 11% |
| | Average Buffer Time Index | 0.44 | 0.21 | ↓ 52% |
| **Initial AI-DSS Go-Live (9/18 – 2/29)** | Average Travel Time Index | 1.08 | 1.11 | ↑ 3% |
| | Average Planning Time Index | 1.34 | 1.40 | ↑ 4% |
| | Average Buffer Time Index | 0.25 | 0.27 | ↑ 8% |
| **Final AI-DSS Go-Live (3/9 – 12/31)** | Average Travel Time Index | 1.09 | 1.15 | ↑ 6% |
| | Average Planning Time Index | 1.42 | 1.44 | ↑ 1% |
| | Average Buffer Time Index | 0.35 | 0.29 | ↓ 17% |

Table 12: Travel Time Reliability Summary (Westbound)

| Evaluation Phase | Performance Metric | Before (2021/2022/2023) | After (2023/2024) | Percent Change |
|---|---|---|---|---|
| **I-24 ICM Go-Live (6/20 – 9/17)** | Average Travel Time Index | 1.05 | 1.10 | ↑ 5% |
| | Average Planning Time Index | 1.36 | 1.41 | ↑ 4% |
| | Average Buffer Time Index | 0.34 | 0.24 | ↓ 29% |
| **Initial AI-DSS Go-Live (9/18 – 2/29)** | Average Travel Time Index | 1.07 | 1.11 | ↑ 4% |
| | Average Planning Time Index | 1.37 | 1.48 | ↑ 8% |
| | Average Buffer Time Index | 0.31 | 0.33 | ↑ 6% |
| **Final AI-DSS Go-Live (3/9 – 12/31)** | Average Travel Time Index | 1.06 | 1.16 | ↑ 9% |
| | Average Planning Time Index | 1.33 | 1.52 | ↑ 14% |
| | Average Buffer Time Index | 0.29 | 0.32 | ↑ 10% |

### *Recurring Congestion*

Recurring congestion was evaluated through RITIS Congestion Scan using corridor speed in miles per hour. The congestion scan did not indicate any significant improvements to congestion along the corridor, however, it did demonstrate how recurring congestion traffic flow smoothed or harmonized over the evaluation phases when compared to the respective baseline, especially in the eastbound direction. **Figure 6** through **Figure 11** below shows the recurring congestion by speed (mph) along the corridor for the I-24 ICM, Initial AI-DSS, and Final AI-DSS evaluation phases.

Additionally, utilizing the RITIS Bottleneck Ranking tool, the evaluator was able to identify the average maximum queue length and average daily duration of congestion along the corridor that originated at each interchange. The corridor saw an increase in the average max queue length and daily duration in both directions during the I-24 ICM evaluation phase. During the Initial AI-DSS phase, there was an increase in both average max queue length and daily duration in the eastbound direction, while the westbound direction experienced a decrease in both metrics. Following the Final AI-DSS implementation, the corridor saw relatively no change to the average max queue length in both directions and an increase in the daily duration.

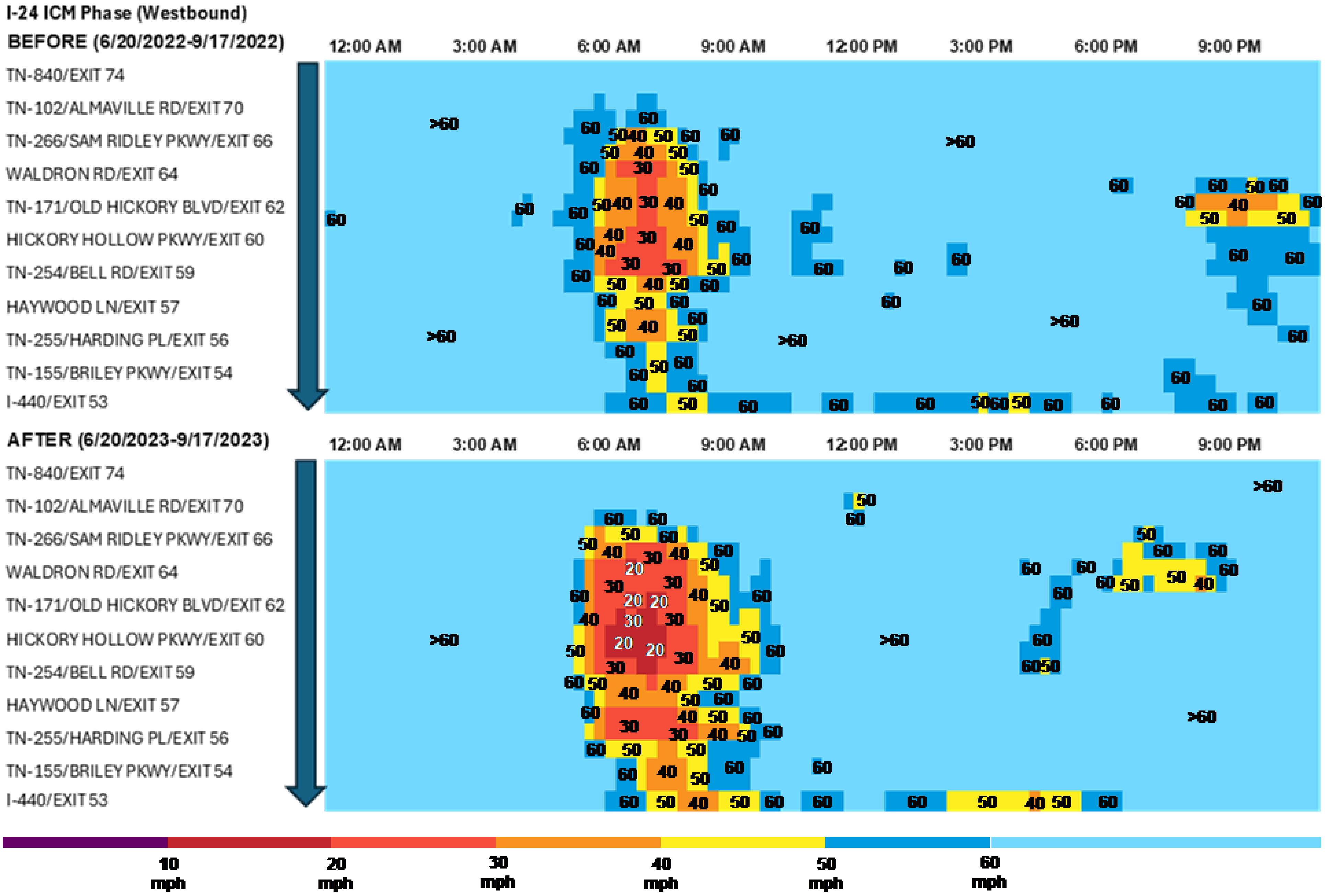

Figure 6: I-24 ICM Phase Congestion Evaluation (Westbound)

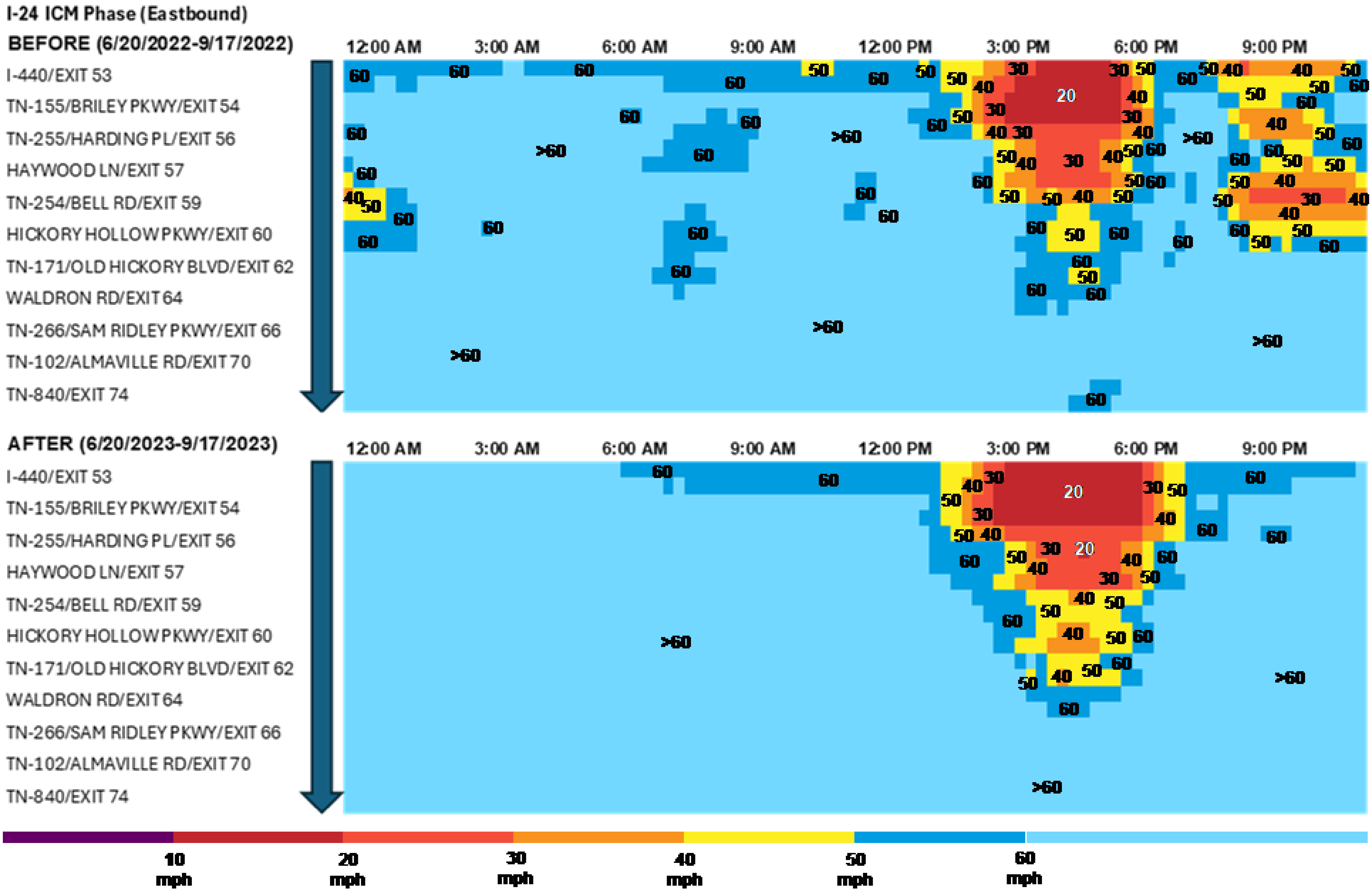

Figure 7: I-24 ICM Phase Congestion Evaluation (Eastbound)

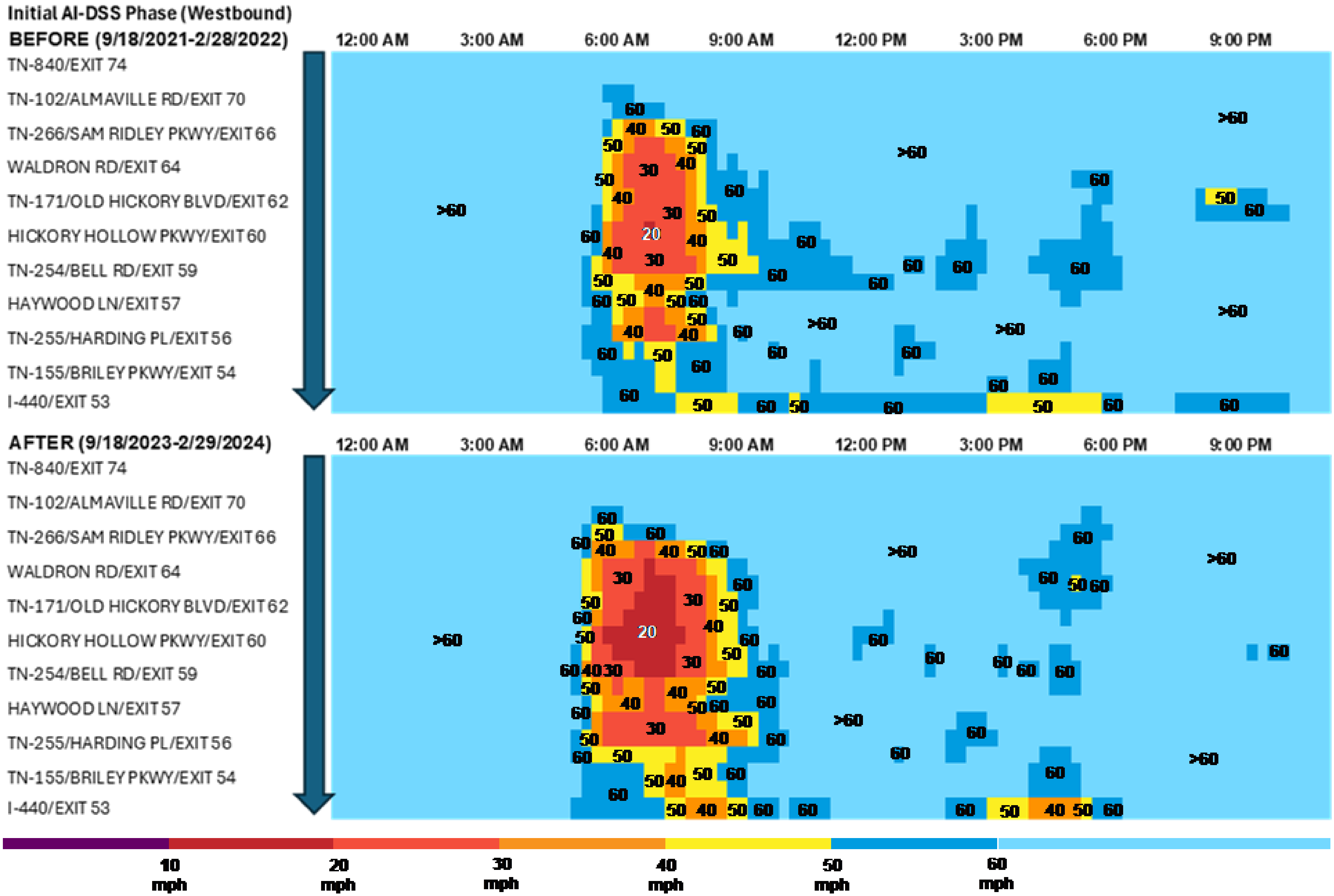

Figure 8: Initial AI-DSS Phase Congestion Evaluation (Westbound)

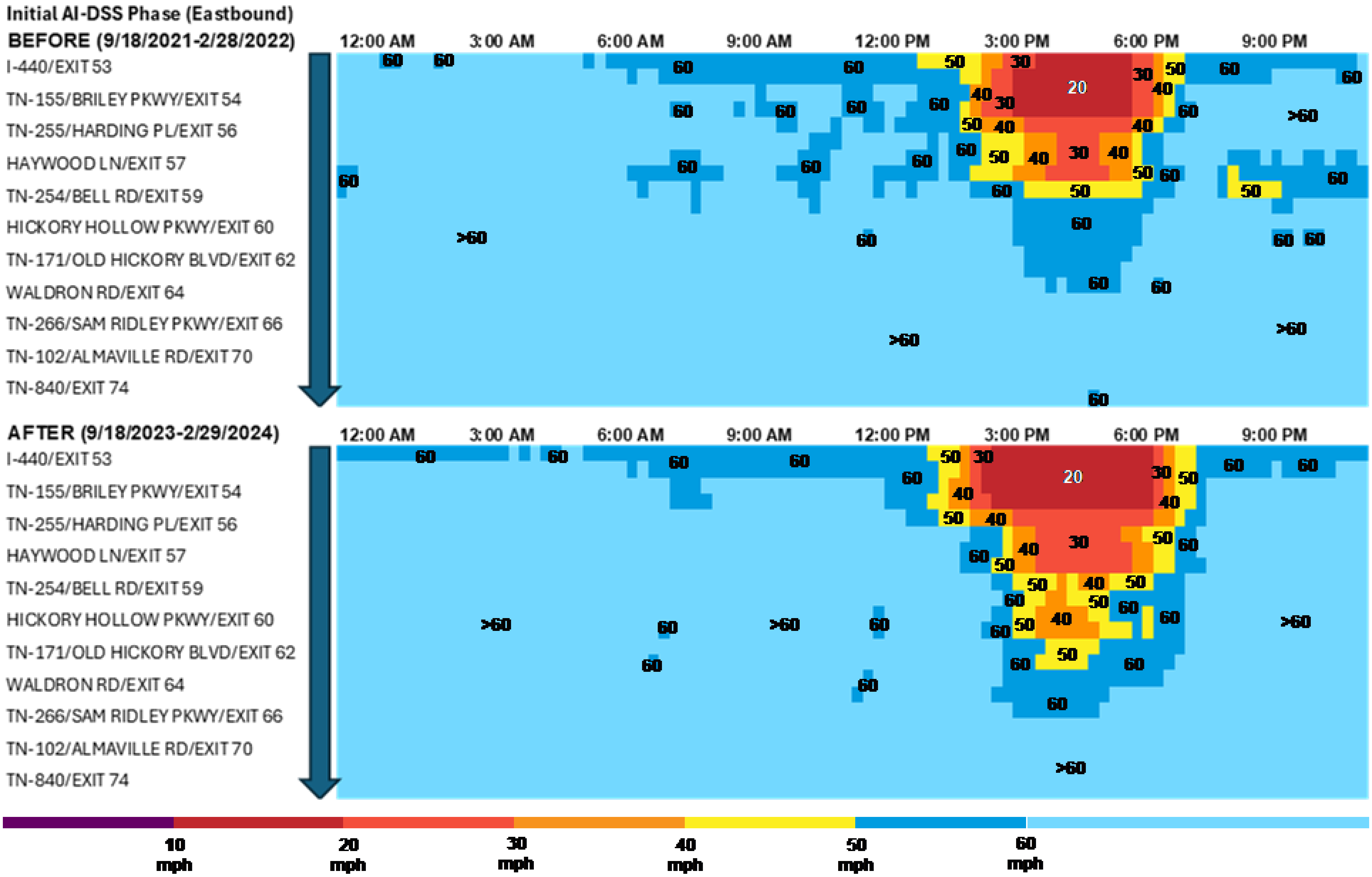

Figure 9: Initial AI-DSS Phase Congestion Evaluation (Eastbound)

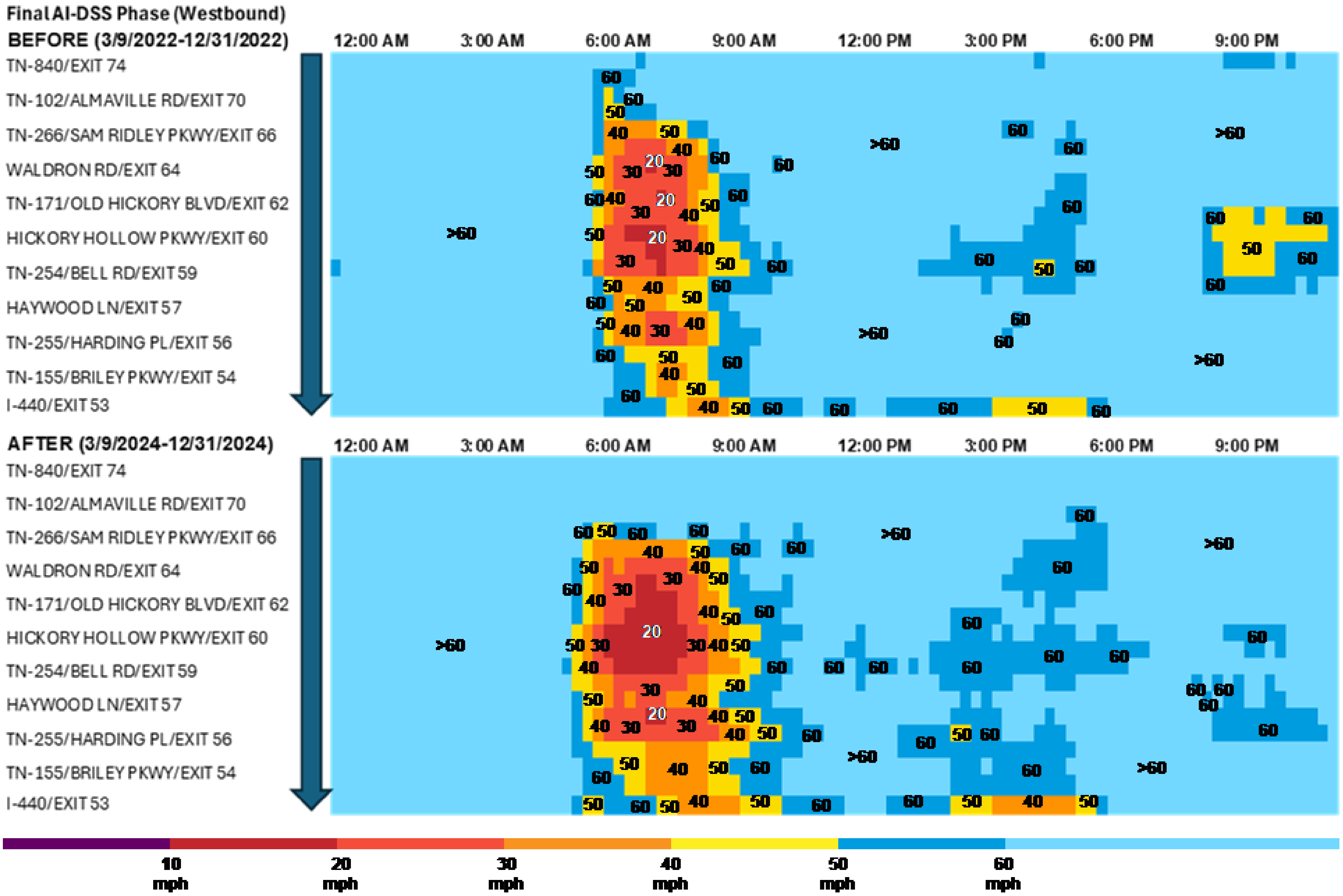

Figure 10: Final AI-DSS Phase Congestion Evaluation (Westbound)

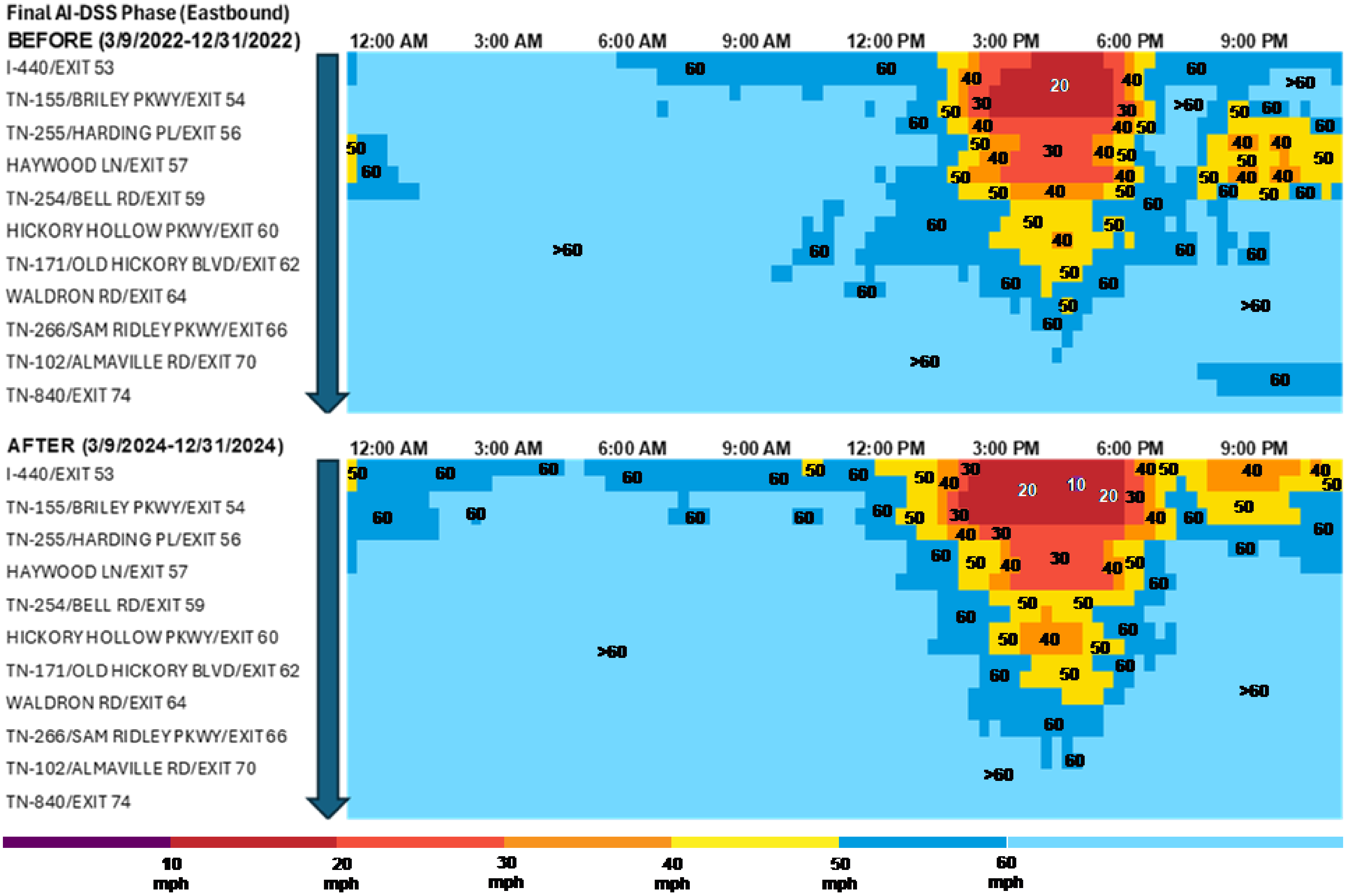

Figure 11: Final AI-DSS Phase Congestion Evaluation (Eastbound)

### 5.5.3 TMC Processes

TMC processes were evaluated using incident management performance metrics, including the number of incident detections and incident clearance time. Incident management data was collected via the SmartWay CS database for each analysis period. **Table 13 and Table 14** below provide a summary of post-I-24 ICM, Initial AI-DSS, and Final AI-DSS incident management performance evaluation results, including the percent change from each baseline average for both eastbound and westbound traffic.

#### *Incident Detections and Incident Clearance*

Generally, incident management showed improvement through each evaluation phase. During the I-24 ICM evaluation phase, incident detections increased by 5% (62 incidents) in the eastbound direction and 9% (85 incidents) westbound. In both the Initial AI-DSS and Final AI-DSS evaluation phases, incident detections decreased. In the Initial AI-DSS phase, incidents detections decreased 15% (296 incidents) in the eastbound direction and 3% (57 incidents) westbound. During the Final AI-DSS evaluation phase, incident detections decreased by 5% (191 incidents) eastbound and 2% (76 incidents) westbound. The decrease in detections could indicate that, while the overall rate at which incidents are being detected has increased, as referenced in Section 5.2, the number of overall incidents occurring has decreased during the short time frame evaluated.

Incident clearance time reduced greatly in each evaluation phase. The I-24 ICM evaluation phase saw a 20% (74-minute) reduction in clearance time for both eastbound and westbound directions. During the Initial AI-DSS evaluation phase, incident clearance time reduced by 22% (81 minutes) eastbound and 17% (54 minutes) westbound. The Final AI-DSS evaluation phase also exhibited drastic reductions in incident clearance time, including a 26% (93 minutes) reduction in clearance time eastbound and a 22% (73 minutes) reduction westbound.

**Table 13: Incident Management Summary (Eastbound)**

| Evaluation Phase | Performance Metric | Before (2021/2022/2023) | After (2023/2024) | Percent Change |
|---|---|---|---|---|
| **I-24 ICM Go-Live (6/20 – 9/17)** | No. of Incident Detections | 1170 | 1232 | ↑ 5% |
| | Time to Incident Clearance (min) | 363 | 289 | ↓ 20% |
| **Initial AI-DSS Go-Live (9/18 – 2/29)** | No. of Incident Detections | 1997 | 1701 | ↓ 15% |
| | Time to Incident Clearance (min) | 365 | 284 | ↓ 22% |
| **Final AI-DSS Go-Live (3/9 – 12/31)** | No. of Incident Detections | 3652 | 3461 | ↓ 5% |
| | Time to Incident Clearance (min) | 361 | 268 | ↓ 26% |

Table 14: Incident Management Summary (Westbound)

| Evaluation Phase | Performance Metric | Before (2021/2022/2023) | After (2023/2024) | Percent Change |
|---|---|---|---|---|
| **I-24 ICM Go-Live (6/20 – 9/17)** | No. of Incident Detections | 992 | 1077 | ↑ 9% |
| | Time to Incident Clearance (min) | 343 | 275 | ↓ 20% |
| **Initial AI-DSS Go-Live (9/18 – 2/29)** | No. of Incident Detections | 1672 | 1615 | ↓ 3% |
| | Time to Incident Clearance (min) | 309 | 255 | ↓ 17% |
| **Final AI-DSS Go-Live (3/9 – 12/31)** | No. of Incident Detections | 3169 | 3093 | ↓ 2% |
| | Time to Incident Clearance (min) | 330 | 257 | ↓ 22% |

# 6.0 LESSONS LEARNED, RECOMMENDATION AND CONCLUSIONS

## 6.1 LESSONS LEARNED

It was a challenge to develop AI learning when the field devices and data were not completely installed and integrated. We would recommend waiting until field devices and data are complete and validated before initiating machine-learning model development in the future. Another option would be to use data from other systems or already deployed devices that can provide the input data to teach the AI-DSS with baseline information. Additionally, data quality is crucial for data-driven modeling and the evaluation of system performance. Not only do field devices need to be operational, but their data streams should also be checked for consistency and reconfigured, if necessary, prior to collecting baseline data.

Dashboard and visualization tools have been helpful throughout the project in developing software and operational strategies, as well as measuring and monitoring performance. Developing these tools early, even in more rudimentary implementations, was helpful to all project partners. We recommend taking this step immediately after the project starts and refining the tools over time.

In addition, alternative delivery methods should be considered for similar future projects, such as integrated project delivery. This is crucial for a complex project like this, as it allows for greater collaboration from all stakeholders from the outset and facilitates an efficient working structure.

## 6.2 FUTURE DEPLOYMENT RECOMMENDATIONS

Additional vehicle detection has been recommended for future deployment to serve as a queue flush function on some of the off-ramps along the corridor. Enhanced data inputs for weather information and real-time arterial traffic conditions are desired to better inform the AI-DSS for VSL and diversion routing.

Furthermore, the opportunity to expand ICM deployments to other locations throughout the state is being explored. Candidate locations are being identified in each of the major metropolitan areas, and this should result in seamless transition from a software perspective, as all TDOT Regions are utilizing the same version of SWCS ATMS software and will have the ability to install the AI-DSS. Extra care has been taken to ensure that everything is configurable for the system to work anywhere in the state and can be scaled down to locations that don’t require overhead gantries for VSL. Future AI-DSS deployments will also be able to leverage the knowledge that the I-24 SMART Corridor AI-DSS will be obtaining over the life of this project.

## 6.3 CONCLUSIONS

The goal of this project was to develop, deploy, and integrate an AI-DSS to enable the various technologies deployed as part of the separately procured I-24 SMART Corridor Phase 1 and Phase 2 projects to work together, optimizing traffic flow, improving traveler information, and enhancing safety along the corridor. The implementation of AI-DSS on the I-24 SMART Corridor provided valuable insights into its capabilities and limitations. The evaluation utilized multiple performance measures, consuming data from various sources, including the RITIS, AASHTOWare Safety Database, TDOT’s SWCS database, and the I-24 MOTION system. The analysis covered key metrics, including the travel time index, recurring congestion, safety performance indicators (such as the number of crashes and their severity), and TMC processes, with a focus on incident management metrics like detection and clearance times.

The BCA quantified project benefits against costs, identifying a total project cost of approximately $74.5 million. Project benefits were primarily driven by a reduction in user delay costs and crash costs, totaling approximately $30.4 million per year in 2023 dollars. The analysis indicated a break-even point of approximately 2.5 years and a BCR of 4.98.

The I-24 MOTION data provided valuable insights into the VSL operations, revealing that the AI-DSS has helped increase the detection rate of crashes along the corridor and that fewer crashes occur when the VSL system is active. It was observed that there was a 14% reduction in crashes when the VSL was active. Conversely, when the VSL was inactive, the crash rate increased by 12%. Additionally, secondary crashes were reduced by 50% when VSL was active.

TMC operations and incident management improved post-deployment, with reduced incident clearance times and positive TMC technician feedback. Recommended responses are presented in a matter of seconds, as opposed to the minutes it takes for a traditional DSS. Additional impacts include event detection rate increasing by 7%, detection time decreasing by 7%, and VSL providing correct warnings 88% of the time.

This project aimed to achieve four specific goals, as detailed in Section 3.0, that were evaluated through four goal areas: safety, mobility, TMC processes, and user input. Each goal area was evaluated through three phases (I-24 ICM, Initial AI-DSS, and Final AI-DSS) compared to the respective baseline normality. An overall before and after analysis of the AI-DSS freeway operations as a whole was also conducted. The project evaluation concluded the following for each project goal identified in Section 3.0.

1. Reducing the frequency of crashes in the corridor.

   Safety metrics exhibited positive results overall. In addition to the insights provided by I-24 MOTION, safety metrics indicated a 7% decrease in primary crashes, a 10% decrease in rear-end collisions, and an 11% decrease in fatal collisions when compared to the period before deployment (1/1/21-6/19/23) to the period after deployment (6/20/23-12/31/24).

2. Improve travel time reliability.

   The AI-DSS had no significant impact on travel time and travel time reliability, with both performance metrics showing relatively no change. However, with an 8% increase in traffic volumes along the corridor between the before and after evaluation periods, this suggests a positive outcome for the AI-DSS itself.

3. Increase mobility within the corridor.

   Recurring congestion showed little improvement; however, traffic flow was harmonized post-deployment during recurring congestion. These results indicate that travel times have essentially remained unchanged despite growing demand.

4. Enhance agency coordination.

   Agency coordination was crucial to the development and integration of the AI-DSS and remains critical as the AI-DSS automates approvals between TDOT and the municipalities. Additionally, this coordination can enhance other capabilities that the AI-DSS could achieve such as disseminating information to transit partners to inform their decisions on services, including route adjustments.

# Appendix A BENEFIT-COST ANALYSIS

# TDOT Artificial Intelligence-Based Decision Support System (AI-DSS) Benefit-Cost Analysis

### Introduction

The purpose of this memorandum is to outline the approach, assumptions, and findings of the Benefit-Cost Analysis (BCA) conducted for the I-24 SMART Corridor Integrated Corridor Management (ICM) Artificial Intelligence-based Decision Support System (AI-DSS) Project. This analysis evaluates the economic feasibility of the I-24 SMART Corridor between I-440 (MM 52) and I-840 (MM 75) by comparing its costs and benefits over a specified period.

### Approach

The BCA for the I-24 SMART Corridor Project was systematically conducted to quantify the project's benefits and costs on an annual basis. All costs and benefits were adjusted to reflect 2023 dollars using the inflation adjustment values provided in the *USDOT Benefit Cost Analysis Guidance for Discretionary Grant Projects (2025)*[13]. The key steps in this approach are detailed in the following sections.

### Capital Costs

The total project costs included construction costs, construction engineering and inspection (CEI) costs, and design costs for the ITS Improvements of I-24 SMART Corridor Phase 1 and Phase 2 projects as well as the cost of the AI-DSS, including grant funds, as detailed in **Table 1** below.

**Table 1: Total Project Costs**

| Project Costs | | | | |
|---|---|---|---|---|
| **Description** | **Year of Cost** | **Cost** | **Inflation Adj** | **2023 Cost** |
| I-24 ITS Improvements Phase 1 | 2018 | $ 10,311,383.05 | 1.20 | $ 12,373,659.66 |
| I-24 ITS Improvements Phase 2 | 2019 | $ 36,780,783.22 | 1.18 | $ 43,401,324.20 |
| AI-DSS (inc. Grant Funds) | 2021 | $ 5,200,000.00 | 1.11 | $ 5,772,000.00 |
| CEI Phase 1 | 2018 | $ 1,572,804.20 | 1.20 | $ 1,887,365.04 |
| CEI Phase 2 | 2019 | $ 4,486,367.80 | 1.18 | $ 5,293,914.00 |
| Design Phase 1 | 2018 | $ 1,384,115.98 | 1.20 | $ 1,660,939.17 |
| Design Phase 2 | 2019 | $ 3,519,925.55 | 1.18 | $ 4,153,512.15 |
| | | | **Total Cost** | **$ 74,542,714.22** |

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[13] Benefit Cost Analysis Guidance 2025 Update (Final).pdf

**Project Benefits**

The total benefits were calculated based on the User Delay Costs and Reduction in Crash Costs. The data was analyzed for the following time periods:

- Pre-ITS Deployment: **January 1, 2021 – June 30, 2023 (2.5 Years)**
- Post-ITS Deployment: **July 1, 2023 – June 30, 2024 (1 Year)**

### *User Delay Benefits*

User delay costs were derived from RITIS's Probe Data Analytics Suite utilizing Inrix volume and speed data. **Table 2** details the Hourly Costs for passenger and commercial vehicle obtained from the *Texas Transportation Institute Urban Mobility Report*[14] and Vehicle Occupancy Rate obtained from *USDOT BCA Guidance for Discretionary Grant Programs (2025)*.

**Table 2: User Delay Benefits Values**

| Travel Time Savings (2023 $) | | |
|---|---|---|
| **Vehicle** | **2021 $** | **2022 $** |
| Passenger All Purpose* | $ 22.00 | $ 23.12 |
| Commercial Vehicle (inc. Operator and Freight)* | $ 62.43 | $ 64.68 |
| **Vehicle Occupancy Rate (Passengers per vehicle)** | | |
| Passenger Vehicles (All Travel)** | 1.7 | |

* Source: Texas Transportation Institute

** Source: RITIS via FHWA

- Delay was calculated against the free-flow speed for segments whose speeds fall 20 mph or more below the free-flow speed.
- Percent vehicle distribution is based on data provided by the Department of Transportation (DOT) on an annual basis. If no value was provided the default was 90% passenger, 10% commercial.

Pre-ITS Deployment delay costs were collected over a 2.5-year period from January 1, 2021, through June 30, 2023, and Post-ITS Deployment delay costs were collected for the 1-year period from July 1, 2023, through June 30, 2024. Delay costs were averaged over the evaluation time period to establish an annual delay cost as shown in **Table 3**, below. Hours of Delay per time period is shown in **Table 4**.

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[14] Texas Transportation Institute Urban Mobility Report: 2025 Urban Mobility Report

## Table 3: User Delay Costs

| I-24 User Delay Costs Pre-ITS Deployment | | | |
|---|---|---|---|
| **Year** | **Total Delay Cost** | **Inflation Adj.** | **Total Delay Costs (2023$)** |
| Jan 1, 2021 - Dec 31, 2021 (2021$) | $ 21,278,331.24 | 1.11 | $ 23,618,947.68 |
| Jan 1, 2022 - Dec 31, 2022 (2022$) | $ 47,173,088.58 | 1.04 | $ 49,060,012.12 |
| Jan 1, 2023 - June 30, 2023 (2022$) | $ 25,657,180.65 | 1.04 | $ 26,683,467.88 |
| | | **Pre-ITS (Annual)** | **$ 39,744,971.07** |

| I-24 User Delay Costs Post-ITS Deployment | | | |
|---|---|---|---|
| **Year** | **Total Delay Cost** | **Inflation Adj.** | **Total Delay Costs (2023$)** |
| July 1, 2023 - June 30, 2024 (2022 $) | $ 36,685,016.28 | 1.04 | $ 38,152,416.93 |
| | | **Post-ITS (Annual)** | **$ 38,152,416.93** |

## Table 4: Hours of Delay per Time Period

| Hours of Delay per period (Total) | | |
|---|---|---|
| **Year** | **Person-Hours** | **Vehicle-Hours** |
| Jan 1, 2021 - Dec 31, 2021 | 869,199.80 | 533,251.40 |
| Jan 1, 2022 - Dec 31, 2022 | 1,837,854.00 | 1,127,517.80 |
| Jan 1, 2023 - June 30, 2023 | 999,598.60 | 613,250.60 |
| July 1, 2023 - June 30, 2024 | 1,429,240.80 | 876,834.80 |

Post-ITS Deployment User Delay Costs were then subtracted from Pre-ITS Deployment User Delay Costs, shown in **Table 5**. The results show a User Delay Cost Benefit of $1,592,554.14.

## Table 5: User Delay Benefit

| Annual I-24 User Delay Benefits | |
|---|---|
| **Year** | **Total Delay Costs (2023$)** |
| Pre-ITS (Annual) | $ 39,744,971.07 |
| Post-ITS (Annual) | $ 38,152,416.93 |
| **User Delay Benefits** | **$ 1,592,554.14** |

### *Safety Benefits*

Crash data was obtained from TDOT AASHTOWare Safety database. A comparative analysis was conducted using data from the I-24 SMART Corridor alongside similar corridors near the I-24 corridor (I-65 S and I-40 E) to evaluate the impact of ITS deployment on crash reduction. Pre-ITS Deployment crash data was averaged on an annual basis for comparison with the Post-ITS Deployment data during the time periods detailed previously. Percent changes in each crash severity classification (KABCO) were calculated for the I-24 SMART Corridor and the I-65 S and I-40 E corridors. To isolate the ITS effect, the percent changes for the adjacent corridors were subtracted from those in the I-24 SMART Corridor. Crash prevention estimates were derived by applying the difference in percent changed to the number of crashes on the I-24 SMART Corridor. The crash prevented data was monetized by applying the KABCO Level Monetized Values (in 2023 $) obtained from *USDOT Benefit Cost Analysis Guidance* *for Discretionary Grant Projects (2025)* to calculate the Total Safety Benefits in crash prevented per year. The following section details the safety benefit calculations.

### *Safety Benefit Calculations*

| **I-65 S** | | |
|---|---|---|
| **Crash Severity** | **Pre (Total)** | **Post (Total)** |
| (O) Property-Damage Only | 1411 | 697 |
| (C) Possible Injury | 131 | 54 |
| (B) Suspected Minor Injury | 274 | 123 |
| (A) Suspected Serious Injury | 31 | 11 |
| (K) Fatal Injury | 8 | 3 |
| **Total** | 1855 | 888 |

| **I-40 E** | | |
|---|---|---|
| **Crash Severity** | **Pre (Total)** | **Post (Total)** |
| (O) Property-Damage Only | 1698 | 716 |
| (C) Possible Injury | 226 | 103 |
| (B) Suspected Minor Injury | 458 | 221 |
| (A) Suspected Serious Injury | 50 | 16 |
| (K) Fatal Injury | 10 | 4 |
| **Total** | 2442 | 1060 |

| **I-65 and I-40 Combined** | | |
|---|---|---|
| **Crash Severity** | **I-65 S/I-40 E Pre (Total)** | **I-65 S/I-40 E Post (Total)** |
| (O) Property-Damage Only | 3109 | 1413 |
| (C) Possible Injury | 357 | 157 |
| (B) Suspected Minor Injury | 732 | 344 |
| (A) Suspected Serious Injury | 81 | 27 |
| (K) Fatal Injury | 18 | 7 |
| **Total** | 4297 | 1948 |
| **Fatal/Serious/Minor Injury Total** | 831 | 378 |

| **I-65 and I-40 Combined (Annual)** | | |
|---|---|---|
| **Crash Severity** | **I-65 S/I-40 E (Pre-ITS) (Total)** | **I-65 S/I-40 E (Post-ITS) (Total)** |
| (O) Property-Damage Only | 1244 | 1413 |
| (C) Possible Injury | 143 | 157 |
| (B) Suspected Minor Injury | 293 | 344 |
| (A) Suspected Serious Injury | 32 | 27 |
| (K) Fatal Injury | 7 | 7 |
| **Total** | 1719 | 1948 |
| **Fatal/Serious/Minor Injury Total** | 332 | 378 |

| I-65 and I-40 Combined Annual | |
|---|---|
| **Crash Severity** | **Yearly Pre vs Post Percent Change** |
| (O) Property-Damage Only | 14% |
| (C) Possible Injury | 10% |
| (B) Suspected Minor Injury | 17% |
| (A) Suspected Serious Injury | -16% |
| (K) Fatal Injury | 0% |
| **Total** | 13% |
| **Fatal/Serious/Minor Injury Total** | 14% |

| I-24 | | |
|---|---|---|
| **Crash Severity** | **Pre (Total)** | **Post (Total)** |
| (O) Property-Damage Only | 3182 | 1292 |
| (C) Possible Injury | 431 | 143 |
| (B) Suspected Minor Injury | 803 | 301 |
| (A) Suspected Serious Injury | 76 | 32 |
| (K) Fatal Injury | 22 | 8 |
| **Total** | 4514 | 1776 |
| **Fatal/Serious/Minor Injury Total** | 901 | 341 |

| I-24 SMART Corridor (Annual) | | |
|---|---|---|
| **Crash Severity** | **Pre-ITS (Total)** | **Post-ITS (Total)** |
| (O) Property-Damage Only | 1273 | 1292 |
| (C) Possible Injury | 172 | 143 |
| (B) Suspected Minor Injury | 321 | 301 |
| (A) Suspected Serious Injury | 30 | 32 |
| (K) Fatal Injury | 9 | 8 |
| **Total** | 1805 | 1776 |
| **Fatal/Serious/Minor Injury Total** | 360 | 341 |

| I-24 SMART Corridor (Annual) | |
|---|---|
| **Crash Severity** | **Yearly Pre vs. Post Percent Change** |
| (O) Property-Damage Only | 1% |
| (C) Possible Injury | -17% |
| (B) Suspected Minor Injury | -6% |
| (A) Suspected Serious Injury | 7% |
| (K) Fatal Injury | -11% |
| **Total** | -2% |
| **Fatal/Serious/Minor Injury Total** | -5% |

**Crashes Prevented (I-65 S/I-40 E) - (I-24)**

| Crash Severity | Yearly Pre vs. Post Percent Change/Crashes Prevented | Monetized Values (2023 $) |
|---|---|---|
| (O) Property-Damage Only | 12% | |
| (C) Possible Injury | 27% | |
| (B) Suspected Minor Injury | 24% | |
| (A) Suspected Serious Injury | -22% | |
| (K) Fatal Injury | 11% | |
| **Total** | 15% | |
| **Fatal/Serious/Minor Injury Total** | 19% | |
| (O) Property-Damage Only | 154 | $ 5,300.00 |
| (C) Possible Injury | 46 | $ 118,000.00 |
| (B) Suspected Minor Injury | 76 | $ 246,900.00 |
| (A) Suspected Serious Injury | -7 | $ 1,254,700.00 |
| (K) Fatal Injury | 1 | $ 13,200,000.00 |
| **Total** | **270** | |
| **Fatal/Serious/Minor Injury Total** | **69** | |

**Dollar Amount Saved Per Year (2023$)**

| Crash Severity | Amount Saved |
|---|---|
| (O) Property-Damage Only | $ 815,880.47 |
| (C) Possible Injury | $ 5,409,020.98 |
| (B) Suspected Minor Injury | $ 18,733,221.50 |
| (A) Suspected Serious Injury | $ (8,390,806.25) |
| (K) Fatal Injury | $ 13,200,000.00 |
| **Total** | **$ 29,767,316.70** |
| **Fatal/Serious/Minor Injury Total** | **$ 23,542,415.25** |

**Discounted Benefits**

User Delay and Safety Benefits were discounted over the 15-year lifespan at a 3.1% discount rate as recommended in the USDOT Benefit Cost Analysis Guidance for Discretionary Grants and OMB Circular A-94[15]. **Table 6** and **Table 7** below detail the discounted benefit calculations.

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[15] OMB Circular A-94

## Table 6: Discounted User Delay Costs

| Discounted User Delay Costs | | | | |
|---|---|---|---|---|
| Calendar Year | Project Year | Discount Factor for 3.1% | User Delay | User Delay (Discounted 3.1%) |
| **2023** | 1 | 1 | $ 1,592,554.14 | $ 1,592,554.14 |
| 2024 | 2 | 0.9699 | $ 1,592,554.14 | $ 1,544,669.39 |
| 2025 | 3 | 0.9408 | $ 1,592,554.14 | $ 1,498,224.43 |
| 2026 | 4 | 0.9125 | $ 1,592,554.14 | $ 1,453,175.98 |
| 2027 | 5 | 0.8850 | $ 1,592,554.14 | $ 1,409,482.03 |
| 2028 | 6 | 0.8584 | $ 1,592,554.14 | $ 1,367,101.87 |
| 2029 | 7 | 0.8326 | $ 1,592,554.14 | $ 1,325,996.00 |
| 2030 | 8 | 0.8076 | $ 1,592,554.14 | $ 1,286,126.09 |
| 2031 | 9 | 0.7833 | $ 1,592,554.14 | $ 1,247,454.99 |
| 2032 | 10 | 0.7598 | $ 1,592,554.14 | $ 1,209,946.64 |
| 2033 | 11 | 0.7369 | $ 1,592,554.14 | $ 1,173,566.09 |
| 2034 | 12 | 0.7148 | $ 1,592,554.14 | $ 1,138,279.43 |
| 2035 | 13 | 0.6933 | $ 1,592,554.14 | $ 1,104,053.76 |
| 2036 | 14 | 0.6724 | $ 1,592,554.14 | $ 1,070,857.19 |
| 2037 | 15 | 0.6522 | $ 1,592,554.14 | $ 1,038,658.77 |
| | | | **Total User Delay Benefit** | **$ 19,460,146.79** |

## Table 7: Discounted Crash Savings Costs

| Discounted Crash Savings | | | | |
|---|---|---|---|---|
| Calendar Year | Project Year | Discount Factor for 3.1% | Crash Savings | Crash Savings (Discounted 3.1%) |
| **2023** | 1 | 1 | $ 1,592,554.14 | $ 1,592,554.14 |
| 2024 | 2 | 0.9699 | $ 1,592,554.14 | $ 1,544,669.39 |
| 2025 | 3 | 0.9408 | $ 1,592,554.14 | $ 1,498,224.43 |
| 2026 | 4 | 0.9125 | $ 1,592,554.14 | $ 1,453,175.98 |
| 2027 | 5 | 0.8850 | $ 1,592,554.14 | $ 1,409,482.03 |
| 2028 | 6 | 0.8584 | $ 1,592,554.14 | $ 1,367,101.87 |
| 2029 | 7 | 0.8326 | $ 1,592,554.14 | $ 1,325,996.00 |
| 2030 | 8 | 0.8076 | $ 1,592,554.14 | $ 1,286,126.09 |
| 2031 | 9 | 0.7833 | $ 1,592,554.14 | $ 1,247,454.99 |
| 2032 | 10 | 0.7598 | $ 1,592,554.14 | $ 1,209,946.64 |
| 2033 | 11 | 0.7369 | $ 1,592,554.14 | $ 1,173,566.09 |
| 2034 | 12 | 0.7148 | $ 1,592,554.14 | $ 1,138,279.43 |
| 2035 | 13 | 0.6933 | $ 1,592,554.14 | $ 1,104,053.76 |
| 2036 | 14 | 0.6724 | $ 1,592,554.14 | $ 1,070,857.19 |
| 2037 | 15 | 0.6522 | $ 1,592,554.14 | $ 1,038,658.77 |
| | | | **Total Crash Savings Benefit** | **$ 363,740,445.74** |

**Operations and Maintenance Costs**

Annual operations and maintenance (O&M) costs were estimated at $1,000,000 based on previous TDOT operations expenses and maintenance contracts. O&M costs were discounted over the 15-year lifespan and included as a disbenefit. **Table 8** shows the O&M discounting calculations.

### Table 8: Discounted O&M Costs

| Discounted O&M Costs | | | | |
|---|---|---|---|---|
| **Calendar Year** | **Project Year** | **Discount Factor for 3.1%** | **O$M** | **O&M (Discounted 3.1%)** |
| **2023** | 1 | 1 | $ (1,000,000.00) | $ (1,000,000.00) |
| 2024 | 2 | 0.9699 | $ (1,000,000.00) | $ (969,932.10) |
| 2025 | 3 | 0.9408 | $ (1,000,000.00) | $ (940,768.29) |
| 2026 | 4 | 0.9125 | $ (1,000,000.00) | $ (912,481.37) |
| 2027 | 5 | 0.8850 | $ (1,000,000.00) | $ (885,044.97) |
| 2028 | 6 | 0.8584 | $ (1,000,000.00) | $ (858,433.53) |
| 2029 | 7 | 0.8326 | $ (1,000,000.00) | $ (832,622.24) |
| 2030 | 8 | 0.8076 | $ (1,000,000.00) | $ (807,587.04) |
| 2031 | 9 | 0.7833 | $ (1,000,000.00) | $ (783,304.60) |
| 2032 | 10 | 0.7598 | $ (1,000,000.00) | $ (759,752.28) |
| 2033 | 11 | 0.7369 | $ (1,000,000.00) | $ (736,908.13) |
| 2034 | 12 | 0.7148 | $ (1,000,000.00) | $ (714,750.85) |
| 2035 | 13 | 0.6933 | $ (1,000,000.00) | $ (693,259.80) |
| 2036 | 14 | 0.6724 | $ (1,000,000.00) | $ (672,414.94) |
| 2037 | 15 | 0.6522 | $ (1,000,000.00) | $ (652,196.83) |
| | | | **Total O&M** | **$ (12,219,456.98)** |

**Benefit-Cost Analysis**

Total project benefits included the Total Discounted User Delay Costs, Total Discounted Crash Savings Cost, and Discounted O&M Disbenefits. The Benefit-Cost Ratio (BCR) was calculated by dividing the Total Project (Discounted) Benefits by the Total Capital Costs in 2023 dollars. The following section details the BCR calculations.

### *Benefit-Cost Ratio Calculations*

| Total Benefits | Annual Costs (2023 $) | Discounted at 3.1% over 15-years |
|---|---|---|
| **Crash Benefits** | $ 29,767,316.70 | $ 363,740,445.74 |
| **User Delay Benefits** | $ 1,592,554.14 | $ 19,460,146.79 |
| **O&M Costs** | $ (1,000,000.00) | $ (12,219,456.98) |
| **Total Benefits** | $ 30,359,870.84 | **$ 370,981,135.55** |

| Total Costs | |
|---|---|
| **Total Capital Costs** | **$ 74,542,714.22** |

| Benefit-Cost Analysis | |
|---|---|
| **Total (Discounted) Benefits** | $ 370,981,135.55 |
| **Total Costs** | $ 74,542,714.22 |
| **BCR** | **4.98** |

# **Appendix B** OPERATOR SURVEYS

# TMC Operators’ Survey
# ATCMTD AI-DSS Project

**Please complete this user survey for the ATCMTD Artificial Intelligence-Based Decision Support System to provide input on your perceived functionality and ease-of-use of the system.**

**Interviewee:** Alexx Dennis (AM Shift Operator)
**Interviewer:** Matt Davis

**Before Freeway ICM ITS Deployment Go-Live (Prior to June 20, 2023)**

1. How many bottlenecks would you say I-24 had prior to the Freeway ICM ITS Deployment Go-Live?
    a. The full corridor from MM 60 into downtown seemed to be congested during the morning peak period.
2. How often did you typically see traffic breakdown on I-24 everyday?
    a. Typically, it would build up around 8 AM. Taper off around midday. Usually there are no events during midday. Thursdays are typically the worst. Mondays tended to have a lot of crashes, but lower traffic volumes.
3. How long did it typically take for the traffic breakdown to dissipate?
    a. Crashes typically occur during peak periods. Getting back to “normal” operations would typically take about 30 minutes to dissipate. A good rule of thumb has been that it takes as long to dissipate as the duration of the lane blockage.
4. How long did it typically take for an incident to be cleared (from the time it occurs to the time it is completely cleared)?
    a. The average wreck that blocks 2 out of 4 lanes would take about 20 minutes to move everything to the right shoulder and another 20 minutes for the queue to clear in non-rush. In rush hour, it would take about 90 minutes to fully clear the queue.
5. What was the biggest challenge to managing incidents on I-24 prior to the Freeway ICM ITS Deployment Go-Live?
    a. We only had the DMS to pre-warn drivers and they rarely looked at them. With the new devices, drivers respond better to the LCS to move into the appropriate, open lanes.
6. How were full-closures of I-24 handled from an incident management perspective prior to the Freeway ICM ITS Deployment Go-Live?
    a. There was no focus on diversion routing. HELP Trucks would close off the interstate at an exit ramp and it was up to drivers to figure out how to get to their destination. Drivers would be warned up to 15 miles back that the interstate is closed ahead and all applicable departments in TDOT would be alerted. Maintenance queue trucks would also be dispatched to help out.

**After Freeway ICM ITS Deployment Go-Live and before Initial AI-DSS Go-Live (June 20, 2023, to September 16, 2023)**

1. How many bottlenecks does I-24 have after the Freeway ICM ITS Deployments? The same as before?
    a. It seems the same. When LCS is utilized, drivers respond quickly and effectively, though. Overall, drivers seem to be driving a bit slower across the board, which seems to have helped smooth out the overall traffic flow a bit.
2. How often do you now typically see traffic breakdown on I-24 everyday?
    a. There definitely seems to be fewer incidents. There have only been 3 crazy days during the morning peak period over a 2-month period.
3. How long does it now typically take for the traffic breakdown to dissipate?
    a. There are fewer incidents to compare to, but it seems about the same as before.

4. Do you think the Freeway ICM ITS Deployment has shortened the window of traffic breakdown (i.e. duration of congestion due to breakdown)?
    a. Yes. There are definitely fewer wrecks. VSL has attributed to fewer collisions.
5. How long does it now take for an incident to be cleared (from the time it occurs to the time it is completely cleared)?
    a. Incidents are being identified quicker, but actual clearance times seem to be about the same once the TMC initiates response.
6. How are full-closures of I-24 now handled from an incident management perspective after the Freeway ICM ITS Deployment Go-Live?
    a. When one does happen, we put up all red Xs and give more pre-warning upstream.
7. Have you been able to reasonably manage all of the new devices introduced as part of the Freeway ICM ITS Deployment Go-Live?
    a. Yes
8. Have you found the new traffic management tools of VSL and LCS to be useful?
    a. Yes
9. What aspect of the Freeway ICM ITS Deployment has been the most beneficial to you in performing your job or meeting your group's goals?
    a. VSL seems to be making the larges impact in reducing the number of crashes. LCS definitely helps protect the HELP Operators and Emergency Personnel.

**After Initial AI-DSS Go-Live (September 17, 2023, to March 8, 2024)**

1. How often do you now typically see traffic breakdown on I-24 everyday?
    a. There are still traffic breakdowns from 6:30-9:30 from Rutherford County Line into Downtown.
2. How long does it now typically take for the traffic breakdown to dissipate?
    a. It seems like there are fewer crashes, which helps resolve congestion quicker.
3. Do you think the Freeway ICM ITS Deployment has shortened the window of traffic breakdown (i.e. duration of congestion due to breakdown)?
    a. Yes. The congestion period is resolved faster with the VSL enabled and good compliance. Also, the reduction in number of crashes supports this.
4. How long does it now take for an incident to be cleared (from the time it occurs to the time it is completely cleared)?
    a. Incident clearance isn't necessarily quicker, but the safety of the responders has been improved due to LCS and there is better advanced warning for motorists upstream to prevent secondary collisions due to VSL.
5. How are full-closures of I-24 now handled from an incident management perspective after the Freeway ICM ITS Deployment Go-Live?
    a. All red Xs where the diversion starts.
6. Does the system quickly provide a suggested response?
    a. Yes, there have been no issues with having to wait for a suggested response. For diversion routing, the emails are near instantaneous with emails going out to the municipalities for confirmation to enable timing plan changes.
7. Are you routinely presented with the suggested plan you would expect from the AI-DSS?
    a. Yes, I'm routinely presented with the response I would expect from the AI-DSS. There may be some improvements the AI-DSS could provide around LCS with full-closures being implemented at the upstream off-ramp.
8. How good are the suggestions? (Rate form 1-5)[16]
    a. 5
9. Do you feel that information provided by the system is useful to make appropriate decisions?

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[16] 1: Very bad, 2: bad, 3: ok, 4: good, 5: very good

    a. Definitely. Being able to spot crashes from the VSL status screen is very doable by spotting lower speeds at an abnormal time at an abnormal location. We're spotting things before Metro Police get a call in many times.
10. Does the AI-DSS make your job faster or easier?
    a. Both. More efficient. More aware of what's happening on the entire corridor.
11. Do you see improvement in the corridor after implementing an AI-DSS recommendation?
    a. Yes. The VSL gives motorists a heads up in advance and the suggested speed limits do a good job of slowing traffic down at a safe rate.
12. Do incidents get cleared faster if you apply the AI-DSS response plan compared to the standard response plan suggestion prior to AI-DSS Go-Live?
    a. Yes, it's improved. The responses seem smoother in keeping traffic as steady as possible. It does not necessarily seem faster…just better.
13. Has your workload been reduced after the AI-DSS implementation?
    a. Probably yes. It seems like it has reduced the number of crashes along the corridor, which has reduced the workload.
14. What aspect of the AI-DSS has been the most beneficial to you in performing your job or meeting your group's goals?
    a. The quickness of it identifying a lower variable speed limits. It has also helped reduce the number of collisions, reducing the workload. Going from a 3-minute activation threshold to 30 seconds has greatly improved the responsiveness of VSL.

**Any additional feedback?**

1. For full-closures, future development of the AI-DSS could aid in automatically pushing LCS red Xs across the board to the LCS gantry in advance of the nearest upstream exit.
2. Having a red X over the shoulder for a full closure seems to have made an impact on preventing people from driving on the shoulder for a period of time.

# TMC Operators' Survey
# ATCMTD AI-DSS Project

**Please complete this user survey for the ATCMTD Artificial Intelligence-Based Decision Support System to provide input on your perceived functionality and ease-of-use of the system.**

**Interviewee:** Matt Richardi (ICM Coordinator)
**Interviewer:** Matt Davis

**Before Freeway ICM ITS Deployment Go-Live (Prior to June 20, 2023)**

1. How many bottlenecks would you say I-24 had prior to the Freeway ICM ITS Deployment Go-Live?
   a. In the afternoon, between 2 and 3 congestions would begin from downtown and progressively jam up moving away from town.
2. How often did you typically see traffic breakdown on I-24 everyday?
   a. Mondays are hit or miss and tend to have more crashes. The traffic still moves fairly well on Mondays. Tuesday through Thursday are typically the worst. Friday is fairly smooth sailing.
3. How long did it typically take for the traffic breakdown to dissipate?
   a. If the incident is near the start of the peak period or further out from the LCS, it could sometimes take 45 minutes or so to clear.
4. How long did it typically take for an incident to be cleared (from the time it occurs to the time it is completely cleared)?
   a. Average wreck that blocks 2 out of 4 lanes would take about 20 minutes to move everything to the right shoulder and another 20 minutes for the queue to clear in non-rush. In rush, it would take about 90 minutes to fully clear the queue.
5. What was the biggest challenge to managing incidents on I-24 prior to the Freeway ICM ITS Deployment Go-Live?
   a. There was less to monitor and manage from an ITS equipment standpoint for the TMC Operators before the Freeway ICM went live.
6. How were full-closures of I-24 handled from an incident management perspective prior to the Freeway ICM ITS Deployment Go-Live?
   a. Poorly. There are definitely more benefits with the new system in place, which includes much better coordination with the local municipalities.

**After Freeway ICM ITS Deployment Go-Live and before Initial AI-DSS Go-Live (June 20, 2023, to September 17, 2023)**

1. How many bottlenecks does I-24 have after the Freeway ICM ITS Deployments? The same as before?
   a. It seems like there is much less hard braking occurring. The VSL is helping to smooth out the slowdowns. This is particularly noticeable where there are less-than-ideal geometrics with horizontal and/or vertical curves.
2. How often do you now typically see traffic breakdown on I-24 everyday?
   a. There seems to be less traffic breakdown due to fewer incidents throughout the day.
3. How long does it now typically take for the traffic breakdown to dissipate?
   a. If it's inbound in the morning, there hasn't been much of a difference. If it's outbound afternoon rush or outside of peaks, then it definitely seems to dissipate quicker. If an EB incident occurs in the morning, it will mess up traffic in the WB direction because of rubbernecking.
4. Do you think the Freeway ICM ITS Deployment has shortened the window of traffic breakdown (i.e. duration of congestion due to breakdown)?

    a. LCS provides a lot of benefits for incident response, but VSL has made a night and day difference on how traffic is responding on the interstate. VSL has definitely been a big contributing to improving the corridor. The VSL also helps the TMC Operators identify potential issues and slowdowns based on the triggering of the module, which helps with incident identification and response times.

5. How long does it now take for an incident to be cleared (from the time it occurs to the time it is completely cleared)?
    a. Incidents do seem to clear a bit faster with LCS because there is more room to spread out once the lanes clear.
6. How are full-closures of I-24 now handled from an incident management perspective after the Freeway ICM ITS Deployment Go-Live?
    a. There has only been 1 full closure since go-live and it was slightly outside of the corridor at the I-440 split. I-440 was still open so all traffic was sent onto I-440 and didn't need to utilize arterials.
7. Have you been able to reasonably manage all of the new devices introduced as part of the Freeway ICM ITS Deployment Go-Live?
    a. Yes, for all of the devices that are currently on-line. We are awaiting the arterial devices and BlueTOADs to come online.
8. Have you found the new traffic management tools of VSL and LCS to be useful?
    a. Yes
9. What aspect of the Freeway ICM ITS Deployment has been the most beneficial to you in performing your job or meeting your group's goals?
    a. VSL has done the most to help alert drivers that something is happening ahead and reducing the number of incidents. LCS also seems to help Emergency Responders be able to get to incidents more easily with cleared-out lanes as well as protect them more from traffic exposure.

# TMC Operators' Survey
# ATCMTD AI-DSS Project

**Please complete this user survey for the ATCMTD Artificial Intelligence-Based Decision Support System to provide input on your perceived functionality and ease-of-use of the system.**

**Interviewee:** Victoria Warren (PM Shift Operator)
**Interviewer:** Matt Davis

**Before Freeway ICM ITS Deployment Go-Live (Prior to June 20, 2023)**

1. How many bottlenecks would you say I-24 had prior to the Freeway ICM ITS Deployment Go-Live?
    a. During morning and evening rushes it was quite congested from end to end. Around Old Hickory Boulevard, there seems to be slowdowns at other periods throughout the day.
2. How often did you typically see traffic breakdown on I-24 everyday?
    a. It was either really bad or just OK. If there was an incident, it would spawn other incidents. There wasn't really a rhyme or reason. Changes in weather would tend to spur incidents.
3. How long did it typically take for the traffic breakdown to dissipate?
    a. It depends on if it was rush hour or not. It would never recover during rush hour and just made things worse. If it was not during rush hour, it would take about 10 to 15 minutes to clear.
4. How long did it typically take for an incident to be cleared (from the time it occurs to the time it is completely cleared)?
    a. Minimum 45 minutes to an hour.
5. What was the biggest challenge to managing incidents on I-24 prior to the Freeway ICM ITS Deployment Go-Live?
    a. Cooperating with other agencies was a big challenge. Coordination has been greatly improved since Freeway ICM Go-Live.
6. How were full-closures of I-24 handled from an incident management perspective prior to the Freeway ICM ITS Deployment Go-Live?
    a. It was a nightmare. It was difficult to figure out what exit to detour on and there was not a set standard procedure on how to handle the event. There wasn't as much cooperation with THP. Incident clearance time wasn't considered as much before.

**After Freeway ICM ITS Deployment Go-Live and before Initial AI-DSS Go-Live (June 20, 2023, to September 16, 2023)**

1. How many bottlenecks does I-24 have after the Freeway ICM ITS Deployments? The same as before?
    a. The bottlenecks seem to be reduced and clear up a bit quicker.
2. How often do you now typically see traffic breakdown on I-24 everyday?
    a. It has changed since Go-Live, but unsure if it is due to the corridor changes since school has been out over the summer. There have been way fewer incidents since the Freeway ICM Go-Live.
3. How long does it now typically take for the traffic breakdown to dissipate?
    a. If it's not rush hour, it now takes about 5-10 minutes to clear.
4. Do you think the Freeway ICM ITS Deployment has shortened the window of traffic breakdown (i.e. duration of congestion due to breakdown)?
    a. Yes, definitely improved.
5. How long does it now take for an incident to be cleared (from the time it occurs to the time it is completely cleared)?

    a. Now this is closer to 30 to 45 minutes.
6. How are full-closures of I-24 now handled from an incident management perspective after the Freeway ICM ITS Deployment Go-Live?
    a. There’s a lot more signage to support closure direction to drivers. There’s much better understanding by all parties involved as to who is in charge of what decisions.
7. Have you been able to reasonably manage all of the new devices introduced as part of the Freeway ICM ITS Deployment Go-Live?
    a. Yes. The ATMS software does have some lag at times with the number of devices and windows open to manage all of them.
8. Have you found the new traffic management tools of VSL and LCS to be useful?
    a. With VSL, I have it set to only show what’s triggered, so I can quickly see where slowdowns may be located. This makes it easy to spot potential incidents, debris, and other causes of slowdowns. There was some resistance with LCS compliance, but drivers seem to be responding well to them now. Drivers are realizing that the reduced speed limits mean there is something going on up ahead.
9. What aspect of the Freeway ICM ITS Deployment has been the most beneficial to you in performing your job or meeting your group’s goals?
    a. Incidents are being identified MUCH faster. VSL has been a great tool in watching traffic activity and patterns to spot incidents. The pull off cameras have also been very helpful in spotting.

**Any additional feedback?**

1. Software speed isn’t always as fast as operator speed.

# TMC Operators’ Survey
# ATCMTD AI-DSS Project

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**Interviewee:** Adam Perez
**Interviewer:** Matt Davis

**Before Freeway ICM ITS Deployment Go-Live (Prior to June 20, 2023)**

1. How many bottlenecks would you say I-24 had prior to the Freeway ICM ITS Deployment Go-Live?
    a. Around Sam Ridley inbound traffic there always seemed to be slowdowns even outside of peak periods.
2. How often did you typically see traffic breakdown on I-24 everyday?
    a. This is a bit tough to answer.
3. How long did it typically take for the traffic breakdown to dissipate?
    a.
4. How long did it typically take for an incident to be cleared (from the time it occurs to the time it is completely cleared)?
    a.
5. What was the biggest challenge to managing incidents on I-24 prior to the Freeway ICM ITS Deployment Go-Live?
    a.
6. How were full-closures of I-24 handled from an incident management perspective prior to the Freeway ICM ITS Deployment Go-Live?
    a. There was a detour plan in place but there wasn’t as much discussion by all of the entities before. This is greatly increased so everyone is aware of the plan and who is in charge of making the routing decisions.

**After Freeway ICM ITS Deployment Go-Live and before Initial AI-DSS Go-Live (June 20, 2023, to September 16, 2023)**

1. How many bottlenecks does I-24 have after the Freeway ICM ITS Deployments? The same as before?
    a. The congestion is the same but there isn’t as much stop and go. It’s a bit smoother overall.
2. How often do you now typically see traffic breakdown on I-24 everyday?
    a. There has been a large reduction in number of incidents.
3. How long does it now typically take for the traffic breakdown to dissipate?
    a.
4. Do you think the Freeway ICM ITS Deployment has shortened the window of traffic breakdown (i.e. duration of congestion due to breakdown)?
    a.
5. How long does it now take for an incident to be cleared (from the time it occurs to the time it is completely cleared)?
    a.
6. How are full-closures of I-24 now handled from an incident management perspective after the Freeway ICM ITS Deployment Go-Live?
    a. Incident Management Plan is now in place for better coordination when a closure does happen. Rutherford County meets monthly on a safety task force to coordinate this.
7. Have you been able to reasonably manage all of the new devices introduced as part of the Freeway ICM ITS Deployment Go-Live?

    a. Yes.
8. Have you found the new traffic management tools of VSL and LCS to be useful?
    a. Compliance seems to be pretty strong with regard to VSL and LCS.
9. What aspect of the Freeway ICM ITS Deployment has been the most beneficial to you in performing your job or meeting your group’s goals?
    a. The pull off cameras have been very useful to spot stopped vehicles.

**Any additional feedback?**

1. Still early on in the process but should have better feedback in the future.