Applying Predictive Analytics (PA) to the Real-Time Management and Operation of Traffic Management Systems (TMSs)

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Presentation Outline

What Are TMSs?

- Complex operational systems that combine field equipment, advanced communications and information technology, and software.
- Software that collects and synthesizes traffic data, integrates external systems, and enables command and control of intelligent transportation system field devices.

Prediction and Connection to TMSs

What is PA?

- Using data and models to predict what may happen in the future.
- Integrating PA tools and methods into active management and operation of TMSs to improve the safety and efficiency of surface transportation.
- Delivering prediction in the context of TMSs through decision support tools (DSTs).
- Recognizing the need to understand:
  - Issues to consider.
  - Requirements for integration.
  - Opportunities to use PA in the context of real-time management and operation of TMSs.

What Is Decision Support?

Decision support is a concept that involves:

- Improving the timeliness and effectiveness of decisionmaking.

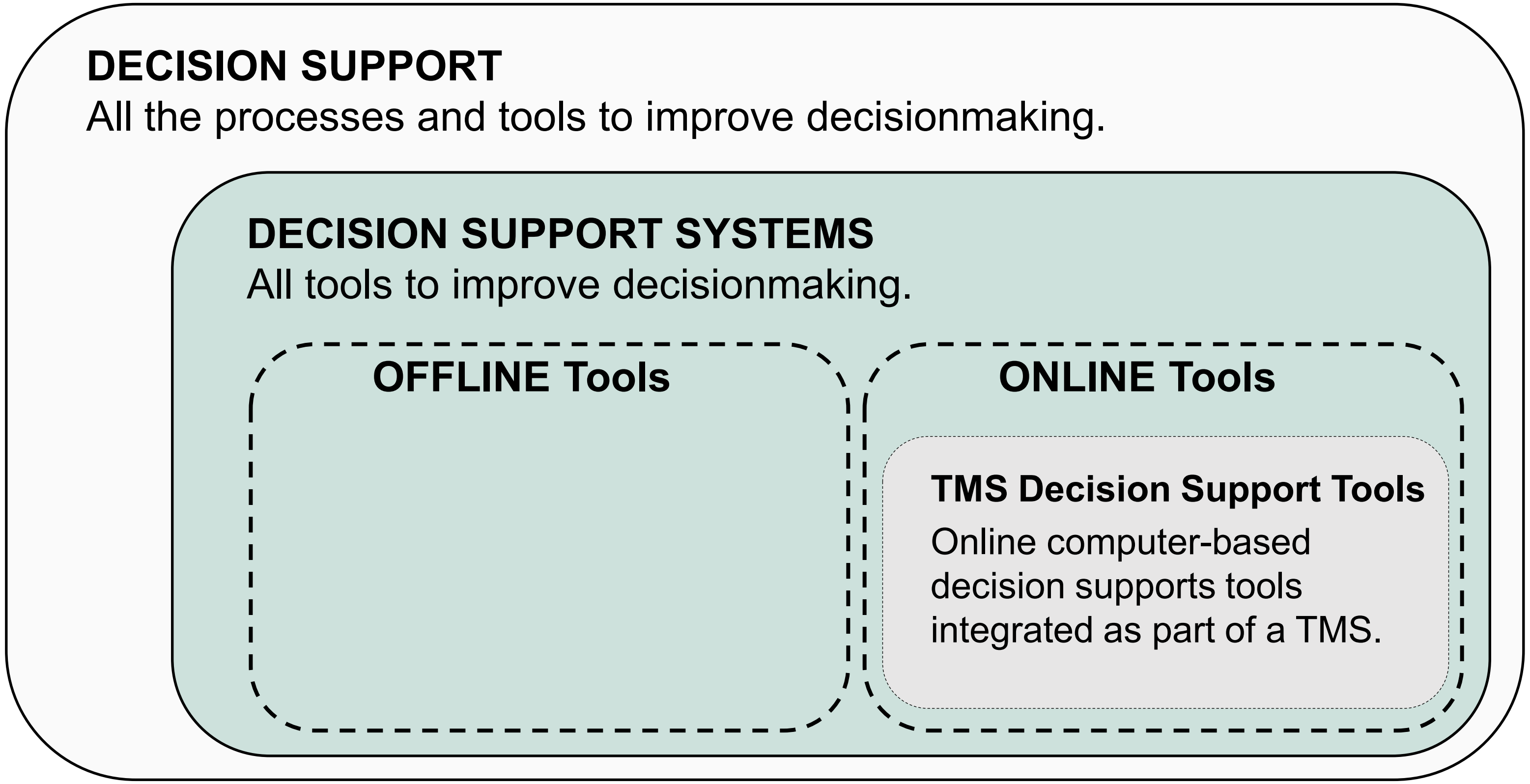
- Using all the processes and tools that enable better, faster, and more consistent decisionmaking.

What Are DSTs?

- DSTs are offline or online tools that support a range of decisions.
- Offline DSTs are typically used to support planning:
  - Incident response plans.
  - Paper-based decision trees.
- Online DSTs are computer-based tools that support real-time traffic management and operational decisionmaking:
  - Real-time traffic analysis tools.
  - Lookup tables integrated into a TMS.

How Are Offline and Online DSTs Used?

Offline and online DSTs are used to improve decisionmaking.



Source: FHWA.[1]

How Can DSTs Enhance TMSs?

DSTs enhance TMSs through the following means:

- Providing strong knowledge of the transportation system.
- Understanding agency policies and operational procedures.
- Applying policies and procedures in realtime based on changing conditions and different events.
- Processing a wide range of data and information.
- Anticipating effects of different operational strategies or plans.

What Are the Benefits of TMSs Using DSTs?

- Improve decisionmaking (e.g., faster, fewer, more consistent decisions).
- Improve performance (e.g., reduce traffic disruptions).
- Evaluate and prioritize alternative responses.
- Monitor transportation network performance.
- Operate and manage TMS and a portion of a surface transportation network proactively.
- Automate selecting event response plans.

What Are Common Types of DSTs?

Three common types include the following:

- Knowledge driven.
- Data driven.
- Model driven.

What Are the Primary Characteristics of Knowledge-Driven DSTs?

- Provide specialized problem-solving by processing stored facts, rules, procedures, or knowledge.
- Emulate reasoning and expert decisionmaking behavior.
- Process facts and business rules instead of data—commonly known as rules-based systems or expert systems.

Example: Florida Department of Transportation's (FDOT) regional integrated corridor management system uses an expert rule engine to: (2)

- *Make decisions based on predefined rules.*
- *Monitor conditions to decide when a response plan must be implemented, modified, or deactivated.*

What Are the Primary Characteristics of Data-Driven DSTs?

- Process and analyze data to develop insights that support decisionmaking.
- Enable processing, manipulation, and visualization of large amounts of data.
- Depend on the quality of the data.
- Offer flexible analytical and reporting capabilities.
- Assist decisionmaker's interpretation of data patterns for predictions.

Example: PA and machine-learning algorithms that learn from historical data to identify patterns and make predictions based on multiple variables, such as time of day, weather, congestion, and average speeds.

What Are the Primary Characteristics of Model-Driven DSTs?

- Simulate the behavior of a transportation network using mathematical models and simulation tools.
- Provide what-if analyses.
- Derive insights and provide forecasting and prediction capabilities.
- Use online or offline to support managing and operating TMS.

Example: Simulate the behavior of a transportation system using mathematical models and predict possible outcomes of actions to assess impact on travel time, environment and throughput.

DSTs Mapped to Decision Support Classifications

Table 1. DSTs mapped to decision support classifications.

Approach	Incident Response Plans	Decision Trees	Performance Measurement Tools	Real-Time Traffic Analysis Tools	Look-Up Tables
Knowledge driven	Yes	Yes	No	Yes	Yes
Data driven	No	Yes	Yes	Yes	Yes
Model driven	No	No	Yes	Yes	No

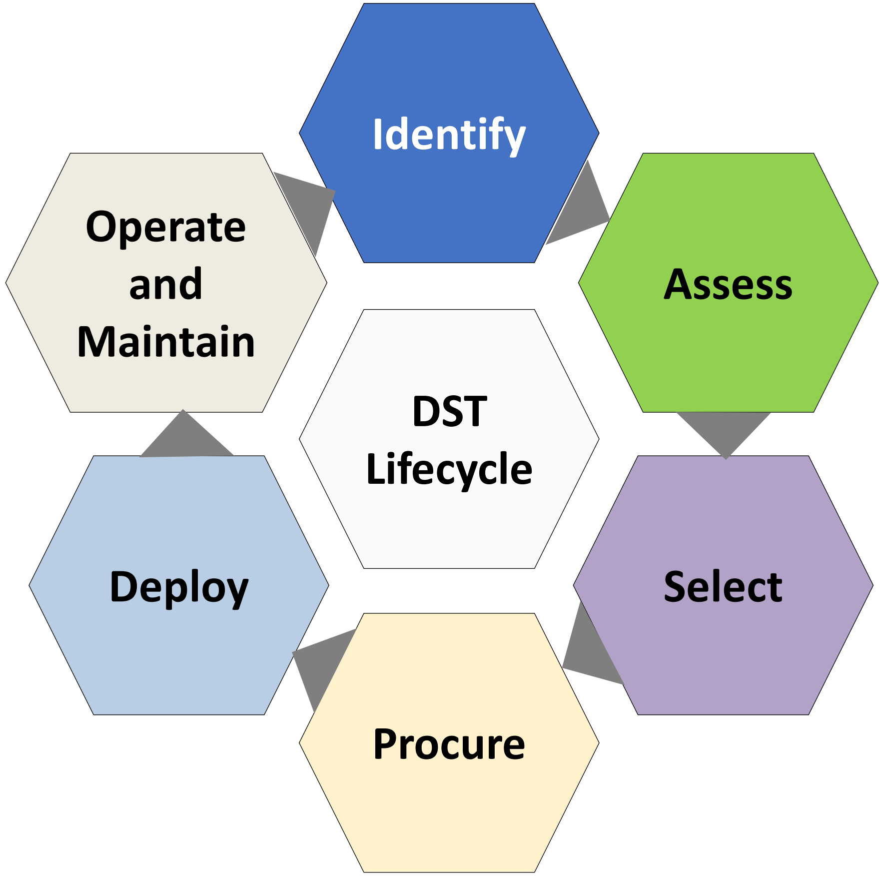
Analytics Maturity Path for Supporting Decisionmaking in TMS Management and Operation

Source: FHWA.[(3)]

What Is a DST Lifecycle Framework?

The DST lifecycle includes:

- Identifying needs and requirements.
- Assessing needs.
- Selecting a DST.
- Procuring a DST.
- Deploying a DST.
- Operating and maintaining a DST.



Source: FHWA.[3]

What Issues Might an Agency Consider When Selecting and Procuring a DST?

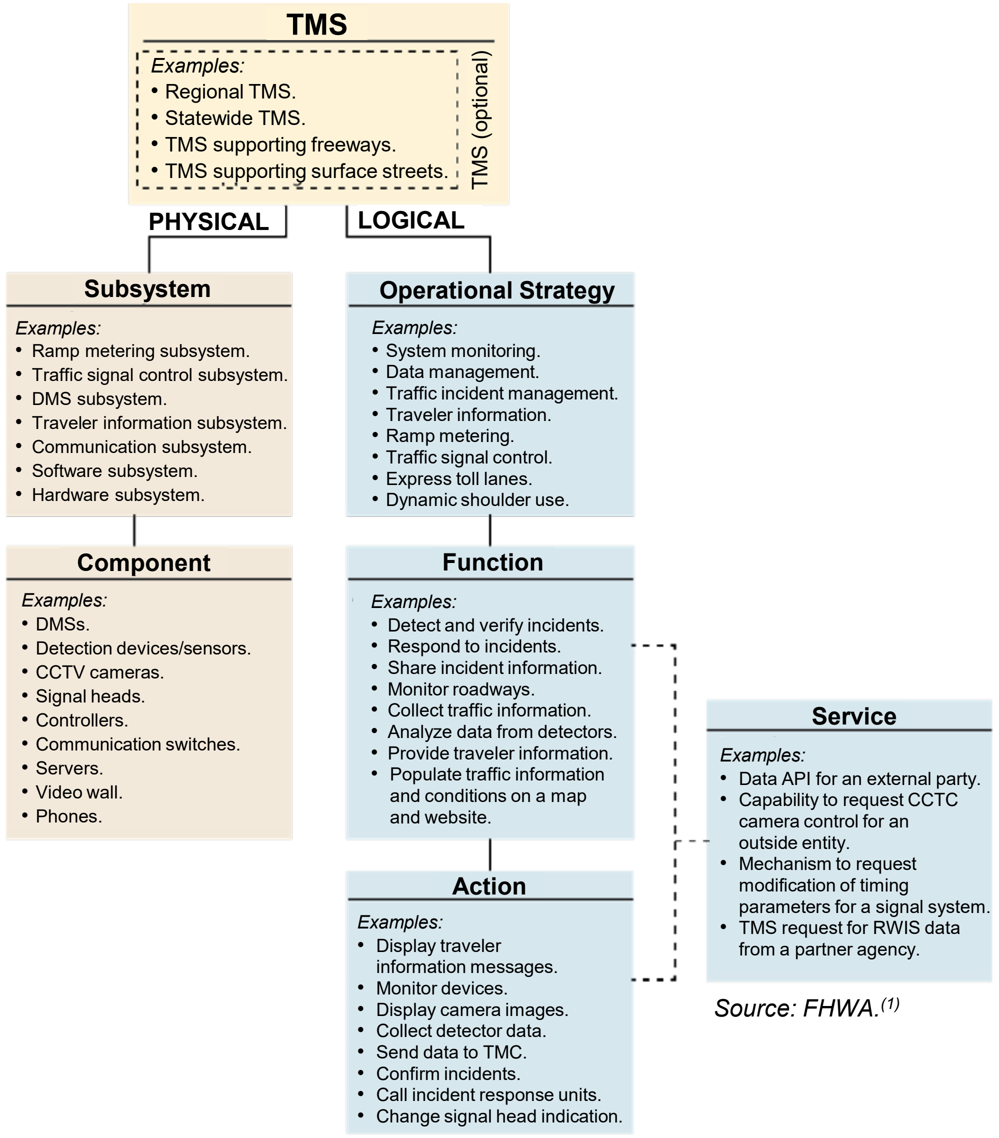
- Has the agency analyzed tradeoffs between build, buy, and reuse?
- What are the agency’s options for developing a custom DST?
- What are the agency’s procurement processes and can the agency use existing contracts, or does the agency have staff who could develop a DST?
- How does the agency value reliability of an off-the-shelf product versus the flexibility of a custom product?
- Does the agency need a current practice or trade study to better understand available DST products?
- How closely do agency requirements match existing off-the-shelf products?
- What is the plan for developing procurement documents (e.g., request for proposal, direct purchase)?
- How will the agency select solutions or vendors to implement DST?

Context for Integrating PA into TMS Management and Operations

- Effective traffic management requires both active traffic management and management of TMS, including subsystems and processes.
- Active traffic management provides dynamic and adaptive adjustments to current changes and future conditions.
- Active management of response levels may include static, reactive, responsive, and proactive.
- PA has the potential to improve responsiveness from static and reactive to responsive and proactive.

How PA Could Support TMS

- PA can take place within TMS:
  - Closed-circuit television camera (CCTV) component.
  - Ramp metering subsystem.
- PA can support TMS logical elements such as the detect incident function.
- PA can inform offline and online DST.

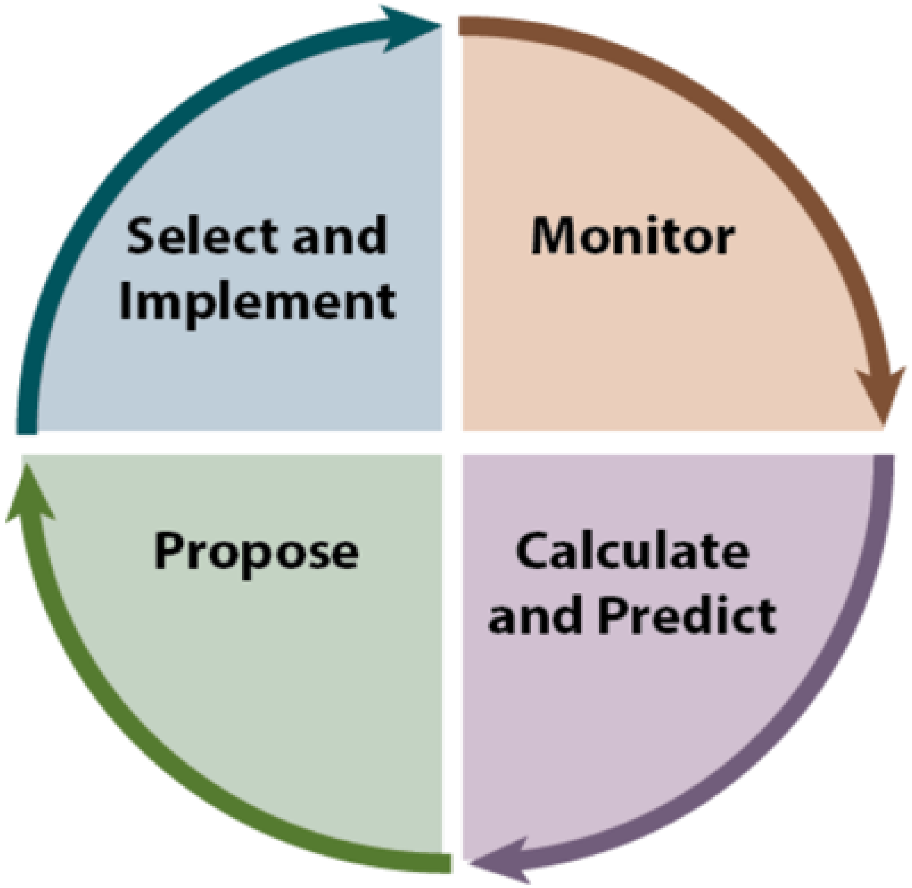


Source: FHWA.[1]

API = application programming interface; DMS = dynamic messages sign; RWIS = Roadway Weather Information System.

PA in the Context of TMS Decisionmaking

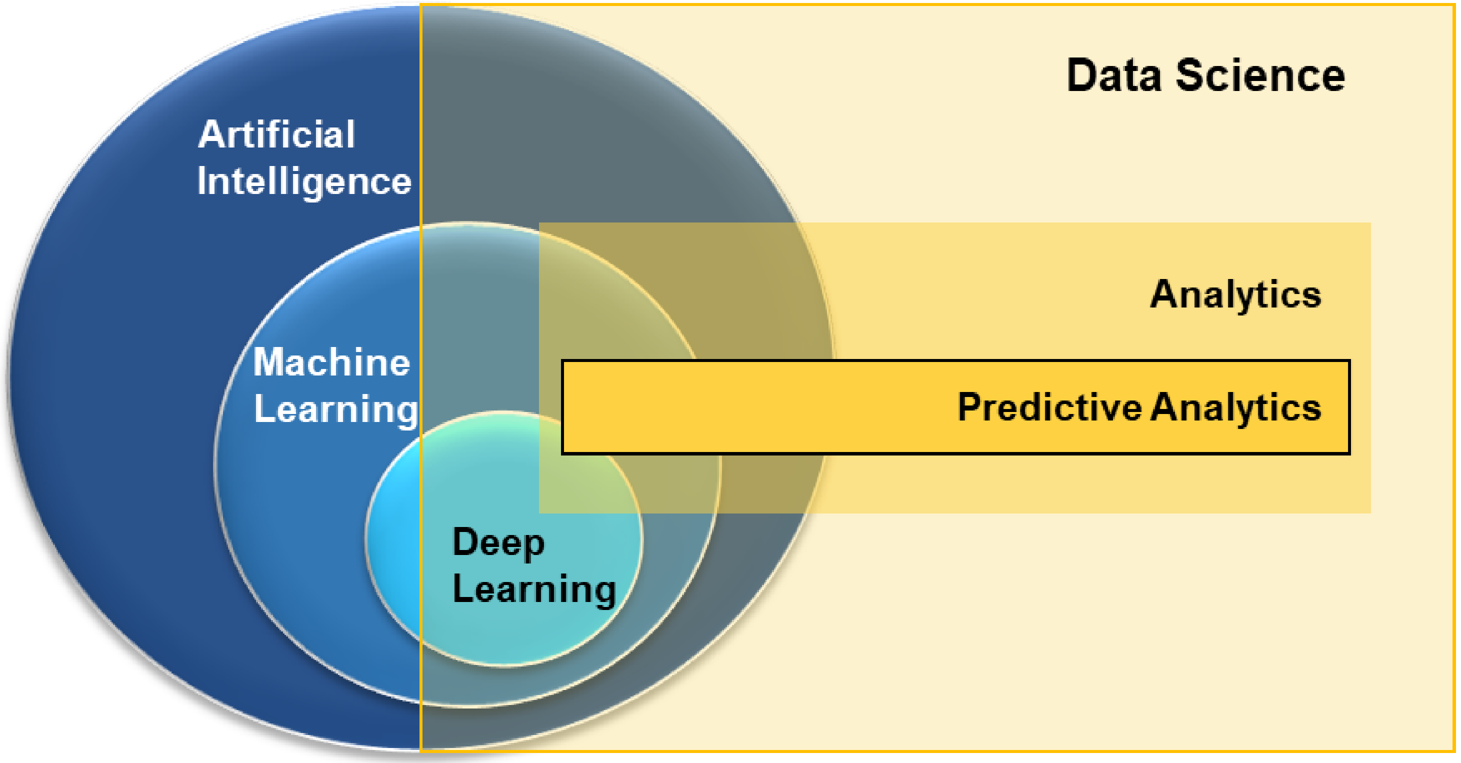
- Descriptive and diagnostic analytics assist with monitoring the current condition of the transportation network.
- PA offer earlier insights regarding future outcomes to help operators formulate a response strategy.
- Prescriptive analytics will propose a response and, potentially, even offer insights as to the outcome of action or inaction.



Source: FHWA.[1]

PA in the Context of Future TMS Capabilities

- Identify needs and requirements for integrating PA into TMS management.
- Select DST to enable PA integration:
  - Knowledge driven.
  - Data driven.
  - Model driven.



Source: FHWA.[3]

AI and Machine Learning Techniques for Supporting Prediction in TMSs

- Classification—Good Fit:
  - Image detection.
  - Object recognition.
  - Text recognition.
  - Language translation.
  - Sound recognition.
- Generate new data—Good Fit:
  - Text generation.
  - Image generation.
  - Video generation.
- Regression—Fair Fit:
  - The compositional nature of the world.
  - The pattern of patterns (spatial and temporal).
  - The many techniques in images and speech.
  - The limited techniques for categorical variables, e.g., predict the income of an individual based on their sex, age, nationality, academic degree, family size, etc.

Issues To Be Considered in Assessing the Options to Add Prediction into Decisions Made to Support TMSs

- Data and data-management issues.
- Human resources and institutional issues.
- Implementation and maintenance issues.

Considerations: Data and Data Management

- Understand what data are available, their quality—completeness, timeliness, accuracy, consistency, validity, integrity.
- Use sufficient data labeling for PA model development using machine learning or deep learning.
- Employ modern data management principles when using big data PA, such as:
  - Use of cloud services for scalability, flexibility, and cost-effectiveness.
  - Distributed computing to support efficient and timely real-time analytics.
  - Decentralized data governance.
  - Decoupled hardware and software.

Considerations: Human Resource and Institutional

- TMC operators and TMS managers' focus is on systems management and operations:
  - Tradeoffs in building agency-internal PA capacity and using external expertise (vendor, university, consultant, and others).
  - Significant turnover in agency staff and staff knowledgebase may challenge the agency's ability to understand PA, develop PA models, and maintain them.
- Institutional data or intelligent technology practices and policies.
- Institutional culture to embrace new tools and practices.
- Interactions between the PA information; the delivery interface; and human knowledge, reasoning, and decisionmaking will determine whether the PA will be adopted.

Considerations: Implementation and Maintenance

Table 2. Comparison of PA implementation approaches.

Implementation Features for PA	On-premise or Cloud with Traditional Devices	On-premise or Cloud with Predictive Devices	Cloud Native with Predictive Devices	Cloud Vendor Software-as-a-Service
Cost	L	H	M	M*
Real-time functionality (e.g., ability to conduct analytics)	L	M	H	H
Expertise for managing system that supports real-time prediction	L	L	L	M
Resiliency (e.g., cyber, natural disaster, staff change)	H/L	H/L	M/H	M/H
Flexibility (e.g., peak demand, data growth, new models)	L	L	H	H
Institutional fit with traditional TMS culture	H	M	L	L
Ownership and analytics transparency	H	M	L	L
Delivery speed and up-time (e.g., data access by vendors and users)	L	L	H	H

Key: H= High, M= Medium, L= Low. *Cost depends on scale; it can be low, but cost can increase exponentially as data and models grow.

Readiness Assessment To Integrate PA in TMSs

Areas that require readiness assessment include:

- Policy.
- System.
- Data.
- Acquisition.
- Maintenance.

Policy Readiness

- Does your agency have a policy for the cloud and cloud services? If it has one, what does it entail?
- Does your agency have an open data policy? If so, what does it entail? Might it limit what data can be used by predictive models?
- Does your agency have policies regarding how analytics will be used to inform decisions and specific types of actions? If so, what types of decisions and actions are explained?
- How are data and analytics actively managed in the TMS?
- What policy or cultural barriers may limit governing and managing data and analytics in your agency?

System Readiness

- Do you have a place to store large amounts of data?
- Do you have computing power or a graphics processing unit (GPU) to read and process large amounts of data quickly?
- Is there power or communications bandwidth (roadside fiber) or both available for traditional and edge sensors, and will smart edge sensor communications be supported?
- Is the advanced transportation management system (ATMS) able to support data volumes for building, training, and iterating models? If no, consider cloud service analytics and PA in the loop.

Data Readiness

- Are there issues with storing specific types of data?
- Does your agency have sufficiently high resolution, disaggregated data?
- Does your agency have multiple years of data?
- What percentage of data are labeled, and what is the quality of the labeling?
- Is there ground truth data?
- Does your agency have ancillary data to create labels?
- Does your agency store raw, unprocessed or unaltered data?
- Are data representative of the entire area of interest, e.g., are data more reliable in one area versus another?

Acquisition Readiness

- Is your agency able to purchase cloud services?
- Have you defined the capabilities, rather than processes, for acquisition?
- Has your agency considered what data is “owned,” and how the data it can be shared?
- Do the agencies’ procurement methods support monthly service charges (e.g., Cloud) which may vary?
- Will the current or evolving PA requirements exceed the capabilities of the TMSs computing hardware (servers)?
- Is your agency able to outsource data analytics (e.g., consultant support)?

Maintenance Readiness

- Is there a replacement strategy for TMS devices which may need to be replaced to meet requirements for using PA?
- Is there a plan, resources, or both in place for continuous data preparation and maintenance?
- Will protocols or automation be put in place to detect when your prediction models need to be retrained?
- Will the agency have the resources to monitor, evaluate, and manage the use of predictive models?

Potential PA Use Cases Within the TMS

- Traffic incident management (TIM).
- Road weather management.
- Ramp metering.
- Variable speed limit (VSL).

PA Maturity: TIM

- Most real-time PA for TIM in the research or proof-of-concept stage:
  - Models have yet to estimate real-time, network-wide impact, severity, or duration of incidents that match expert judgment.
  - Models can predict the incident hotspots, but these predictions generally do not exceed expert judgment.
  - Vendor products detect slow downs, incidents, stalled vehicles, and other events by processing camera sensor images.
  - Some products are integrated with ATMS using an API.
- Tremendous value in TIM from descriptive and diagnostic analytics.

PA Maturity: Road Weather Management

- Real-time PA for road weather management are at the research or proof of concept stage:
  - Potential for improved pavement status over a 1-h, 4-h, 1-d, and 1-w horizon by roads with more detailed segments.
  - Potential to support route, materials/treatment use, or staffing optimization.
  - The Integrated Modeling for Road Condition Prediction (IMRCP) system offers an example of PA research.(4)
- IMRCP provides tremendous value from available descriptive and diagnostic analytics:
  - Maintenance decision support systems use heuristics based on traditional PA.
  - Real-time detection of weather-affected roadways.

PA Maturity: Ramp Metering and VSL Speed Limit

- Real-time PA for ramp metering and VSL in research stage:
  - PA will require improved lane-specific volume and speed data, potentially from connected vehicles.
  - PA will require focused simulation, field, and human factors testing.
  - While VSL in practice is rule based, researchers explored other methods: fuzzy-logic, analysis, and control-theory-based strategies.
- Fuzzy logic and predictive models (e.g., simulation) are used to develop ramp metering algorithms.

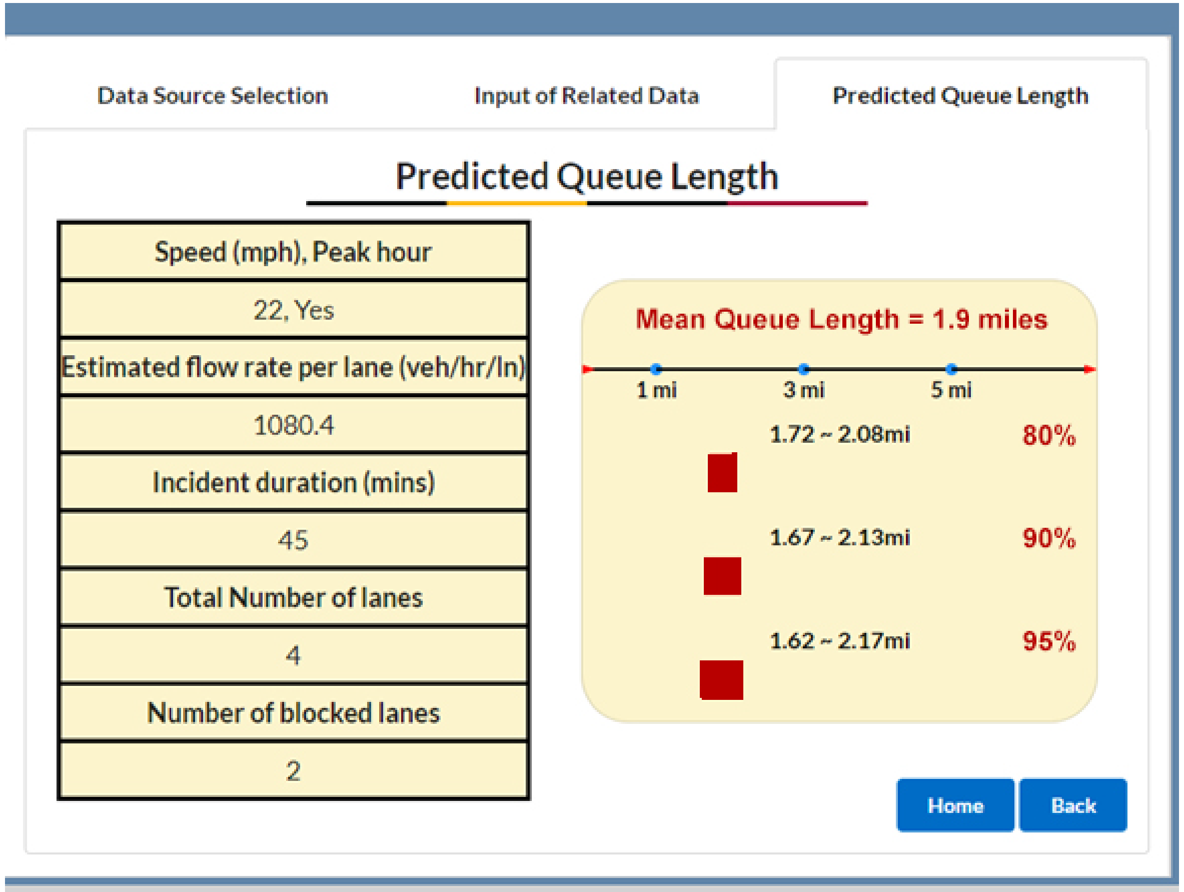
Examples of Using Prediction in TMS

- Predicting incident duration.
- Predicting queue length.
- Predicting traffic flow.
- Predicting weather.

Predicting Incident Duration and Queue Length

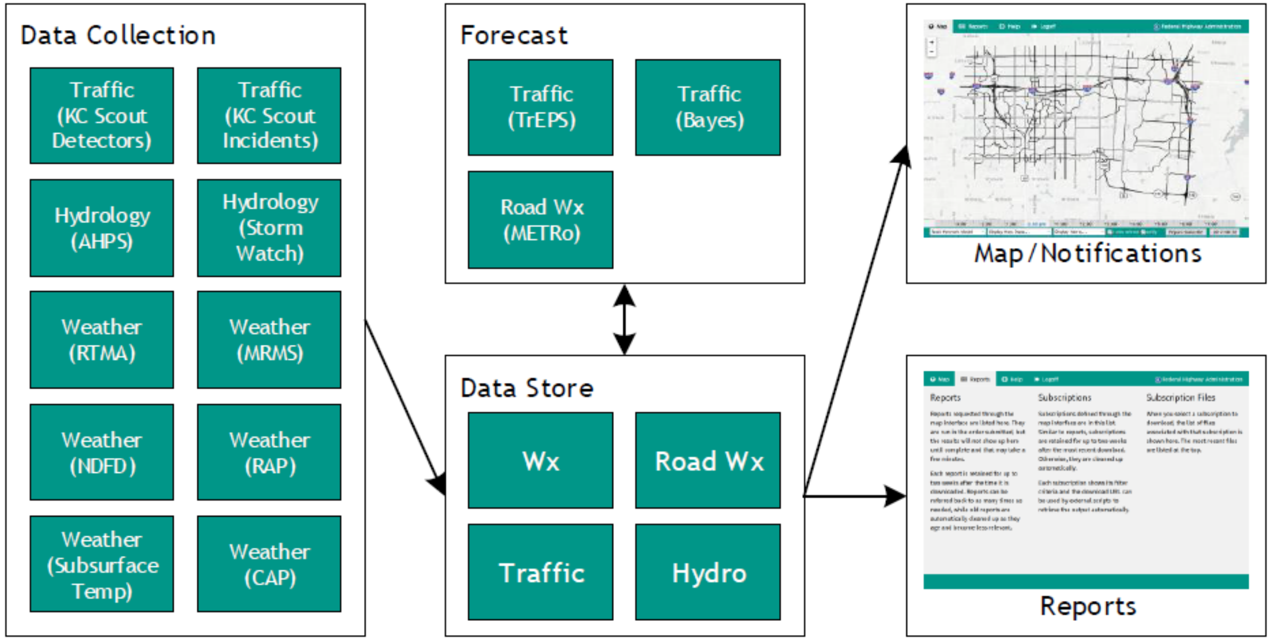
Maryland Department of Transportation, Coordinated Highways Action Response Team program:(5)

- Applies traditional PA (regression modeling).
- Predicts incident duration in 30-min bins.
- Predicts likely queue length.
- Shows significantly greater value once it is integrated within the TMS.



Predicting Traffic Flow and Weather

- IMRCP model applies traditional PA (regression modeling), machine learning, and simulation.(4)
- The model is not integrated within the TMS.
- The model is based on two winters of data.
- The speed prediction model showed great deviations from ground truth.
- Data sources and services require consistent monitoring to assure a high quality of service, due to the distributed nature of the system.



Source: FHWA.(5)

AHPS = Advanced Hydrologic Prediction Service; CAP = common alerting protocol; MRMS = multiradar/multisensor System; NDFD = National Digital Forecast Database; RAP = rapid refresh; RTMA = real-time mesoscale analysis; Wx = weather.

Trends and Implications for PA in TMS

- Trends that will make predictive analytics more accessible and usable:
  - TMSs are being rearchitected to become more modular.
  - Big data vendors are beginning to offer predictive analytics as a service.
  - Cloud service providers are developing tools that simplify model development and use.
  - Big data are becoming more accessible and improving in quality.
- Agencies may get ready for predictive analytics by considering the following:
  - Supporting a process and policy shift to proactive strategies.
  - Exploring traditional PA.
  - Shifting toward modern data management.
  - Exploring big data first through descriptive and diagnostic analytics.
  - Considering multiagency or multistate data sharing.
  - Considering open-source tools and code.
  - Focusing on human-centered decision needs.

Resources and Additional Information on Other TMS Practices

- TMS portal.[6]
- TMC PFS website.[7]
- "Traffic Analysis Tools" website.[8]
- *Predictive Analytics for Traffic Management Systems*.[3]
- *Decision Support Methods and Tools for TMSs*.[9]

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