Integrated Modeling for Road Condition Prediction (IMRCP)

System Design Description

www.its.dot.gov/index.htm

June 1, 2019

FHWA-JPO-18-727

U.S. Department of Transportation

Produced under contract DTFH61-16-D-00053, Operations IV
U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology, Intelligent Transportation Systems Joint Program Office
and
Federal Highway Administration, Office of Operations

Notice

Technical Report Documentation Page

1. Report No. FHWA-JPO-18-727	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Integrated Modeling for Road Condition Prediction (IMRCP) – Phase 3 System Design Description		5. Report Date 6. Performing Organization Code
7. Author(s) J. Kyle Garrett, Bryan Krueger, and Aaron Cherney, Synesis Partners LLC; Jiaqi Ma, University of Cincinnati; Hani Mahmassani, Northwestern University; Michelle Neuner, Leidos		8. Performing Organization Report No.
9. Performing Organization Name and Address Leidos, Inc. 11951 Freedom Drive Reston, VA 20190		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61-16-D-00053L, Task 693JJ318F000084
12. Sponsoring Agency Name and Address Federal Highway Administration U.S. Department of Transportation 1200 New Jersey Avenue, SE Washington D.C., 20590		13. Type of Report and Period Covered Systems Design Description 14. Sponsoring Agency Code ITS-JPO
15. Supplementary Notes The Government's Task Managers: Gabriel Guevara, Jawad Paracha		

16. Abstract

Transportation system management and operations (TSMO) is on the cusp of dramatic changes due to increased availability of data and sophistication of models and systems supporting those operations. Intelligent transportation systems (ITS) are widely deployed and gather data about weather and traffic conditions across road networks. The imminent deployment of connected vehicles (CV) will bring an orders-of-magnitude increase in data availability. These data power traffic and road condition predictions; as data availability increases, the accuracy and reliability of the models improve. This convergence of opportunities presents enough potential for operational improvements in safety and mobility that the Federal Highway Administration's (FHWA) Road Weather Management Program (RWMP) is initiating research into an integrated model for road condition prediction (IMRCP) to investigate and capture that potential.

This System Design Description (SDD) documents a common understanding among stakeholder groups of system features and components, and serves as a basis for system design and development activities. The SDD consists of an introduction describing the objectives of both the IMRCP system and the SDD itself; a general description of the IMRCP distilled from the Concept of Operations (ConOps); and a design description of the system components and their interactions.

17. Key Words System Design; Prediction; Road Weather Management Program (RWMP); Transportation system management and operations (TSMO)		18. Distribution Statement No restrictions.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 120	22. Price N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

Table of Contents

Executive Summary **1**

Chapter 1. Introduction **2**

Background 2

Purpose 2

Scope 3

Document Overview 3

Chapter 2. General Description **4**

System Perspective 4

Chapter 3. Design Description **6**

Traffic Estimation and Prediction System 9

Origin-Destination Estimation 10

Network State Estimation 11

Origin-Destination Prediction 11

Short-Term Consistency Checking 12

Long-Term Consistency Checking 12

TrEPS Adapter 13

TrEPS Collect 13

TrEPS Input 13

TrEPS Output 14

Machine Learning-based Prediction 14

Machine Learning-based Prediction Scenario Identifier 18

Machine Learning-based Prediction Traffic Predictor 19

Machine Learning-based Prediction Update Manager 20

Prediction for Links without Real-time Detector Data 20

Maintenance Decision Support System 21

Road Weather Forecast 23

Road Temperature and Snow Depth Module (METRo) 24

Road Condition Treatment Model 24

Storm Characterization Module 25

Chemical Concentration Module 26

Rules of Practice Module 28

Net Mobility Module 29

Ensemble 30

Collect 31

Advanced Hydrologic Prediction Service [AHPS]........32
StormWatch [StormWatch]........32
KC Scout Detectors [KCScoutDetectors]........33
KC Scout Incidents [KCScoutIncidents]........33
Subsurface Temperature [SubSurfaceTemp]........34
National Digital Forecast Database [NDFD]........34
Rapid Refresh [RAP]........35
Real-Time Mesoscale Analysis [RTMA]........36
Multiple Radar/Multiple Sensor [MRMS]........36
Common Alerting Protocol [CAP]........36
Traffic Controls [Traffic Cntrls]........37
Maintenance Rules [Maint Rules]........37
Special Events [Special Events]........37
DMS [DMS]........37
Store........37
StormWatch [StormWatchStore]........38
NDFD [NDFDStore]........38
RAP [RAPStore]........39
RTMA [RTMAStore]........39
MRMS [MRMSStore]........39
AHPS [AHPSStore]........40
METRo [METRoStore]........40
TrEPS [TrEPSStore]........40
MLP [MLPStore]........41
KC Scout Detector [KCScoutDetectorStore]........41
KC Scout Incidents [KCScoutIncidentsStore]........41
Alerts [AlertsStore]........42
Notifications [NotificationsStore]........42
Observation View [ObsView]........42
CAP [CAPStore]........43
Maintenance Operations [Maint Ops]........43
Traffic Control Operations [Control Ops]........43
Special Events [Spcl Evnts]........43
DMS [DMS]........43
Archive........43
Archive Data........44
Performance Measures [Perf Msrs]........44
System........45
Directory........45
Configuration........45
Scheduling........46
IMRCP Block........46
Monitor........48

System Monitor [SysMon] 48
Route....48
Routes....49
Computation 50
Alert [Alerts] 50
Notification [Notifications] 50
Speed Stats [SpeedStats] 51
Geo Services 51
Segment Definitions [SegmentShps]....52
NED [NED] 52
Polygons [Polygons] 52
Sensor Locations [SensorLocations]....53
Subscription 53
Subscription [Subscriptions] 53
Export....53
Common Alerting Protocol (CAP) 53
Web 54
Alerts Layer 54
Area Layer 55
Web Pages 55
Index 56
Primary Menu Bar 56
Dashboard 58
Apps 58
System Computing Infrastructure 58
Chapter 4. References....60
Appendix A. Glossary 61
Appendix B. Kansas City Study Area....63
Appendix C. Input Data Availability....67
Appendix D. TrEPS Module Inputs and Outputs 68
Appendix E. Kansas City Scout Real-Time Detector XML File Example 70
Appendix F. Kansas City Scout Real-Time Incident Feed XML File Example 71
Appendix G. StormWatch File Example....73
Appendix H. TrEPS Input Files Description....74
Appendix I. TrEPS Output File List....79
Appendix J. TrEPS Link Statistics Output Files 81
Appendix K. MLP Input Files Description....88
Appendix L. MLP Output File Description 91

Appendix M. Alert Definitions **93**
Appendix N. Layer Definitions **95**
Appendix O. Observation Type Definitions **100**
Appendix P. Alert Definitions **106**

List of Figures

Figure 1. Integrated Modeling for Road Condition Prediction Composition. 7
Figure 2. Integrated Modeling for Road Condition Prediction Process. 8
Figure 3. Traffic Estimation and Prediction System-based Decision Support Framework for Weather-responsive Traffic Signal Operations. 9
Figure 4. System Structure of DYNASMART-X Modules and Data Flow.. 10
Figure 5. Proposed Machine Learning-based Prediction Network Model Algorithm.......................... 15
Figure 6. Graphical Representation of the Integrated Model for Road Condition Prediction Machine Learning-based Prediction Process. 16
Figure 7. Machine Learning-based Prediction Estimator Output Example. 18
Figure 8. Machine Learning-based Prediction Predictor Output Example. 19
Figure 9. Overview of National Center for Atmospheric Research Maintenance Decision Support System. 21
Figure 10. The Integrated Model for Road Condition Prediction Maintenance Decision Support System Package.. 22
Figure 11. Maintenance Decision Support System Process.. 23
Figure 12. National Center for Atmospheric Research Road Condition Treatment Model. 25
Figure 13. Storm Characterization Process. 26
Figure 14. Rules of Practice Evaluation Process. 29
Figure 15. Collect Package Diagram.. 32
Figure 16. Configured Route Process Diagram. 49
Figure 17. User-Generated Route Process Diagram... 49
Figure 18. Alert Process Diagram. 50
Figure 19. Notification Process.. 51
Figure 20. Integrated Model for Road Condition Prediction Deployment. 59
Figure 21. Road Network Configuration for Study Area... 63
Figure 22. Traffic Detectors in Study Area... 64
Figure 23. Traffic Signals Modeled in Study Area. 64
Figure 24. Stormwatch Hydrology Stations in Study Area. 65
Figure 25. AHPS Hydrology Stations in Study Area 66

List of Tables

Table 1. Origin-Destination Estimation Module Input Categories. 10
Table 2. Network State Estimation Module Input Categories. 11
Table 3. Variables and State Definitions for Machine Learning-based Prediction. 16
Table 4. Machine Learning-based Prediction Scenario Identifier Input Categories............................ 18
Table 5. The National Center for Atmospheric Research Maintenance Decision Support System Mobility Index. 30
Table 6. Weather Elements Collected by the National Digital Forecast Database............................. 35
Table 7. The Directory Component.. 45

Table 8. The Configuration Component. 46
Table 9. The Scheduling Component. 46
Table 10. The Integrated Model for Road Condition Prediction Block Component. 47
Table 11. Example Class Diagram of Obs. 48
Table 12. Input Data Available Frequency and Computation Frequency. 67
Table 13. TrEPS Module Inputs and Outputs 68
Table 14. TrEPS Input Files Description for Weather.dat 74
Table 15. TrEPS Input Files Description for Incident.dat 75
Table 16. TrEPS Input Files Description for WorkZone.dat 76
Table 17. TrEPS Input Files Description for vms.dat 76
Table 18. TrEPS Input Files Description for Referencetable.txt 77
Table 19. TrEPS Input Files Description for detector_mapping_to_link.txt 78
Table 20. TrEPS Real-time Detector Data Example File. 78
Table 21. TrEPS Output File List 79
Table 22. LinkVolume.dat file format. 81
Table 23. OutLinkGen.dat file format. 81
Table 24. OutLinkVeh.dat file format. 82
Table 25. OutLinkQue.dat file format. 83
Table 26. OutLinkSpeedAll.dat file format. 83
Table 27. OutLinkDent.dat file format. 84
Table 28. OutLinkSpeedFree.dat file format. 84
Table 29. OutLinkDentFree.dat file format. 85
Table 30. OutLeftFlow.dat file format. 85
Table 31. OutGreen.dat file format. 86
Table 32. OutFlow.dat file format. 87
Table 33. OutAccuVol.dat file format. 87
Table 34. MLP Archive Input File Description. 88
Table 35. MLP Real-Time Input File Description. 89
Table 31. MLP Output File Description. 91
Table 32. Weather-related Alert Definitions. 93
Table 33. Traffic-related Alert Definitions. 94
Table 34. Layer Definitions. 95
Table 35. Observation Type Definitions. 100
Table 36.Traffic Alert Definitions 106
Table 37. Weather Alert Definitions. 106
Table 38. Road Condition Alert Definitions. 107

Executive Summary

Transportation system management and operations (TSMO) is on the cusp of dramatic changes due to the increased availability of data and the increasing sophistication of models and systems supporting those operations. Intelligent transportation systems (ITS) are widely deployed and gather data about weather and traffic conditions across road networks. The imminent deployment of connected vehicles (CV) will bring an orders-of-magnitude increase in data availability. This array of data powers traffic and road condition predictions, and as data availability increases, the accuracy and reliability of the models improve. This convergence of opportunities presents enough potential for operational improvements in safety and mobility that the Federal Highway Administration's (FHWA) Road Weather Management Program (RWMP) is initiating research into an integrated model for road condition prediction (IMRCP) to investigate and capture that potential. This system design description (SDD) documents a common understanding among stakeholder groups of system features and components, and serves as a basis for system development activities. Follow-on efforts will mplement the design and deploy the system with an operating transportation agency to evaluate its effectiveness.

The SDD consists of an introduction describing the objectives of both the IMRCP system and the SDD itself, a general description of the IMRCP distilled from the concept of operations (ConOps), and a design description of the system components.

Chapter 1. Introduction

Background

Transportation systems management and operations (TSMO) is at the cusp of a revolution, spurred by the explosion in data from different sources and the increasing sophistication of models using this data. New approaches in road weather management are bringing together meteorology, traffic management, law enforcement, maintenance, and traveler information to support agency decision making and influence travel behavior. Through these operational efforts and private sector innovations, travelers today have higher expectations for their travel experience. Travelers now participate in generating and validating information as well as consuming it. This trend will accelerate with deployment of connected vehicle (CV) systems. Within this context, the role of prediction and forecasting will become more important to the travel and activity choices made by travelers, as well as to agency decisions in transportation operations. Freight carriers and logistics providers will also benefit in planning routes, times and delivery schedules.

Development and adoption of traffic prediction approaches by operating agencies have been limited even with a growing body of research. While this is partly attributable to limited data, available predictive tools have been narrowly focused and have not taken full advantage of developments in related disciplines and domains. As a result, the use of predictive strategies in support of operational decisions continues to be limited.

Recent efforts to incorporate forecast weather conditions in traffic predictions in the United States Department of Transportation (USDOT) Traffic Estimation and Prediction System (TrEPS) project have shown considerable promise. The utility of traffic predictions can, however, be further enhanced by augmenting the forecast weather conditions with known and likely capacity constraints, such as work zones and incidents. Factoring in reported conditions from environmental sensor stations, vehicle fleets, and citizen-reported conditions will further enhance predictions. Current and planned road treatment approaches, snowplow routing, parking restrictions, and maintenance decisions could be included as well.

Based on these opportunities, the Federal Highway Administration (FHWA) has initiated an investigation into and development of an Integrated Model for Road Condition Prediction (IMRCP). This effort includes an initial survey of available and imminent weather, hydrological, traffic, and related transportation management models; development of a concept of operations (ConOps); and development of fundamental system requirements. Follow-on efforts will develop a system architecture and system design, implement a foundational system, and deploy the system with an operating transportation agency to evaluate its effectiveness.

Purpose

As described in the IMRCP ConOps, the purpose of the IMRCP is to integrate weather and traffic data sources and predictive methods to effectively predict road and travel conditions. The first step in the study surveyed the existing field of predictive models in road weather, traffic and related disciplines. The ConOps then developed the case for and a description of an integrated model for predicting road conditions that incorporates transportation and non-transportation data, deterministic and probabilistic data, and measured and reported data. The model could ultimately become a practical tool for transportation agencies to support traveler advisories, maintenance plans, and operational decisions at both strategic and tactical levels.

The purpose of this System Design Description (SDD) is to document a common understanding among stakeholder groups of system features and components and to serve as a basis for system design and development activities. The descriptions of the system views and models provide a starting point for further elucidation and elaboration of the system design, but are themselves subject to revision as system implementation proceeds and new interactions are discovered. The System Architecture Description (SAD) is therefore preliminary and seminal to later system design documentation.

Scope

The IMRCP will provide a framework for the integration of road condition monitoring and forecast data to support tactical and strategic decisions by travelers, transportation operators and maintenance providers. The system will collect and integrate environmental observations and transportation operations data; collect forecast environmental and operations data when available; initiate road weather and traffic forecasts based on the collected data; generate travel and operational advisories and warnings from the collected real-time and forecast data; and provide the road condition data, forecasts, advisories and warnings to other applications and systems. Road condition and operations data and forecasts to be integrated into the prediction may include atmospheric weather; road (surface) weather; small stream, river, and coastal water levels; road network capacity; road network demand; traffic conditions and forecasts; traffic control states; work zones; maintenance activities and plans; and emergency preparedness and operations.

Document Overview

The structure of this document is generally consistent with the outline of a System or Software Design Description defined in ISO/IEC/IEEE Standard 42010-2011.[1] Some sections herein have been enhanced to accommodate more detailed content than described in the standard. Titles of some sections have been edited to specifically capture that enhancement.

Section 2 provides a general description of the system perspective and stakeholder concerns. It is largely a summary of material described in more detail in the ConOps.

Section 3 documents the system design. The relevant architectural viewpoints are identified, and views and models are described for each viewpoint. Rationales for and correspondence among elements of the views are included in the view and model descriptions. Four viewpoints are described: composition, process, deployment, and related designs.

[1] ISO/IEC/IEEE. *Systems and software engineering – Architecture description*. ISO/IEC/IEEE 42010:2011

Chapter 2. General Description

System Perspective[2]

Describing and predicting roadway conditions and events that may impact travel across road networks requires an understanding of and tools for interacting with the system and its operations across all of the road network's stakeholder groups. For example, travelers have an immediate need for information about conditions along their planned route, and they contribute to the aggregate travel conditions along their route by their choices and behaviors. Winter maintenance crews plan ahead for reducing the impact of storms on roadway conditions based on weather forecasts and perhaps on a sophisticated maintenance decision support system (MDSS), but also adapt to conditions on the roadway as they execute those plans. Operators in a transportation management center (TMC) monitor roadway conditions across a network with cameras and sensors accessed through an Advanced Transportation Management System (ATMS), and respond to conditions and events by generating alerts to be published on dynamic message signs (DMS) on the roadside and pushed out to web pages and mobile apps through traveler information systems. In all of these examples, stakeholders are making and executing plans, monitoring and adjusting to current conditions, and potentially changing their plans based on their analyses of potential future conditions.

A complete context for prediction of road conditions would have to consider a broad range of stakeholders, their activities, and interactions with the roadway, their decision processes, and the underlying models of the roadway and environmental conditions. Descriptions of the current state of stakeholders and their activities in the IMRCP ConOps therefore focused on identifying the processes and decisions that are affected by currently available roadway condition information and predictions. An analysis of current and imminent road and weather condition models was performed in a previous task and documented in the *Integrated Modeling for Road Condition Prediction Model Analysis.*[3] The aggregate of these analyses of modeling capabilities and stakeholder interests formed the basis for the architectural views of the functional and system packages for a potential IMRCP system in the ConOps.

Architectural views of a system provide sketches of what an implemented system might look like from various conceptual frameworks. For the IMRCP, the functional view of the system describes the system's purpose: to provide integrated predictions of road weather and traffic conditions. To fulfill this purpose, the system will have to have models for the roadways and phenomena of interest, prediction capabilities and forecasts from other models, and current observations in order to set initial conditions for the predictions.

The system package view describes the system as a set of software packages (components) to be implemented and deployed for operations. The IMRCP system package view divides the system packages into package types, which include data collection, models, forecasting, forecasts, decision support, and interface. The view also illustrates the relationships between these packages and

[2] This section was previously published in the *Integrated Modeling for Road Condition Prediction System Requirements Specification.*
[3] Leidos, Inc. *Integrated Modeling for Road Condition Prediction Model Analysis*. May 10, 2015.

external sources. The functional view and the system package view provide a context for the development and structuring of the system requirements. Specific requirements for the IMRCP can be found in the *Integrated Modeling for Road Condition Prediction System Requirements Specifications.*[4]

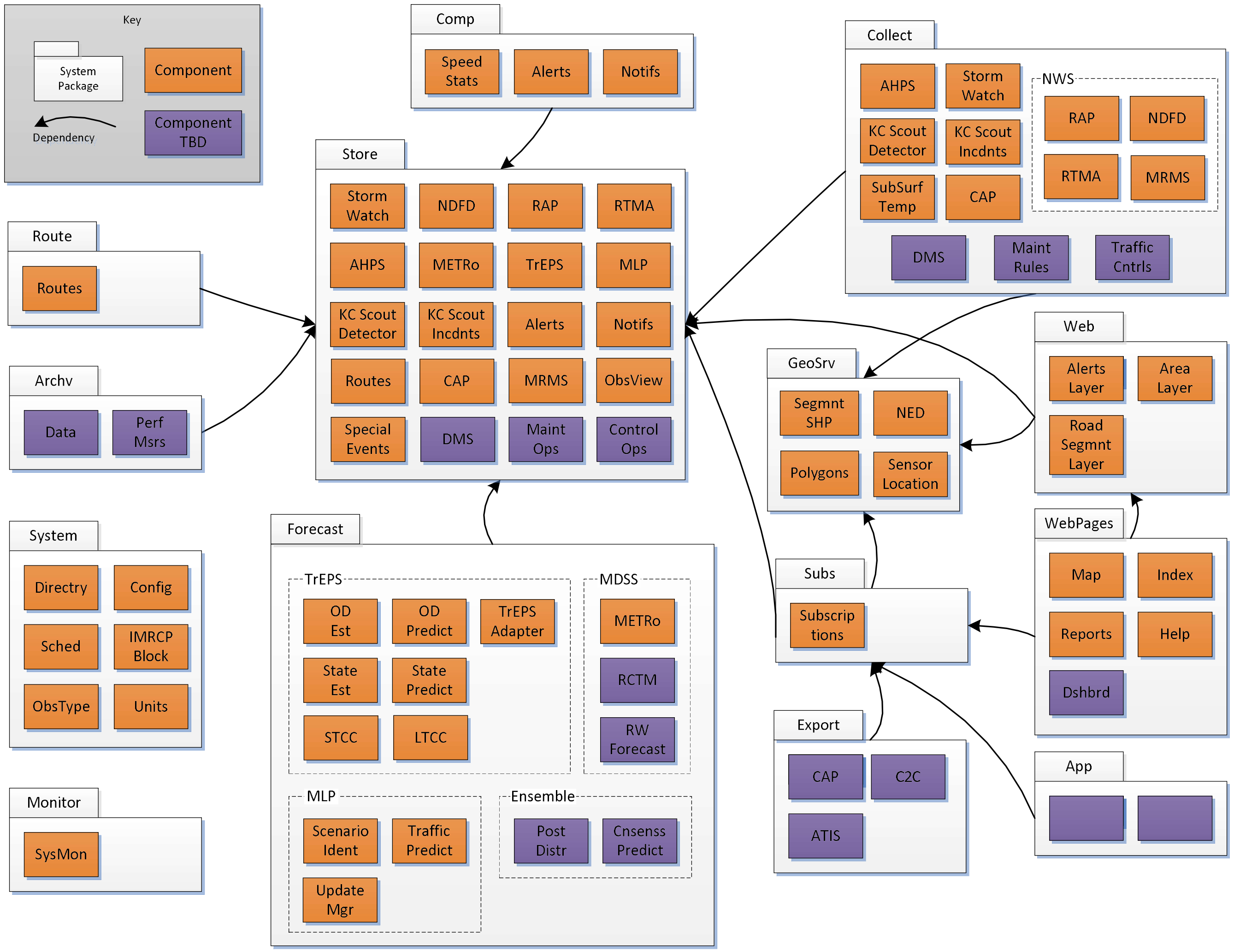
Based on the requirements determined in the System Requirements Specifications document, the system architecture is created using a set of architectural views in the *Integrated Modeling for Road Condition Prediction System Architecture Description.*[5] The composition view describes the system in terms of sets of software components and their relationships. The process view describes the system in terms of data processing functions and flows. The deployment view describes the system in terms of the deployment of components to computing devices or nodes. Finally, the architectural view relates the system to other established architectural depictions of the functional domain.

[4] FHWA. 2016. *Integrated Modeling for Road Condition Prediction System Requirements Specification.* Washington, DC.
[5] FHWA. 2016. *Integrated Modeling for Road Condition Prediction System Architecture Description.* Washington, DC.

Chapter 3. Design Description

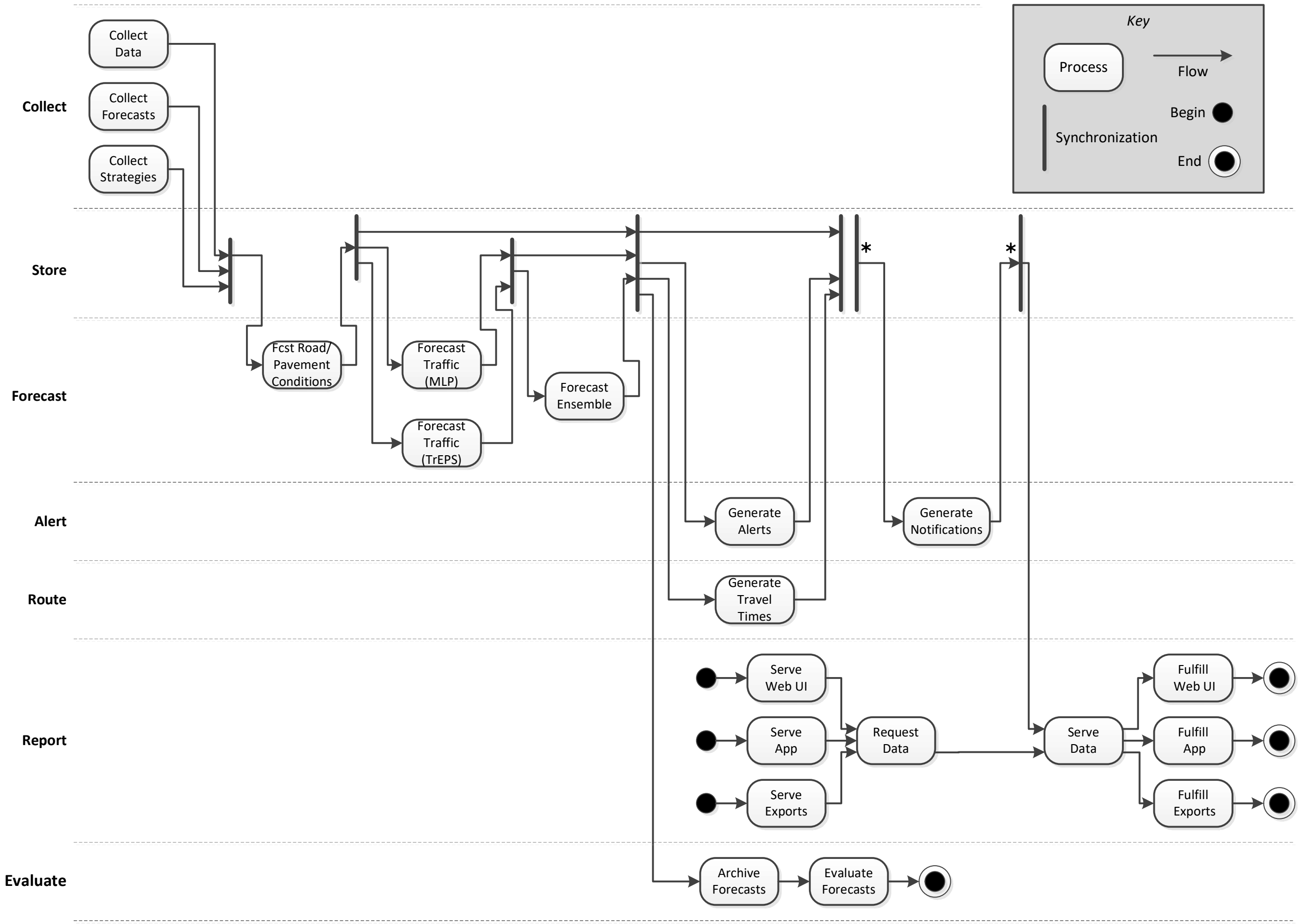
The IMRCP system design is described here as a set of subsystem packages, each of which has its own sets of architectural views. These subsystem packages were previously identified and described in the system architecture description (SAD) composition view, and are used in this design description as organizing entities for the details of the system design. The Unified Modeling Language (UML)[6] package and activity diagrams are used freely within each subsystem package description to illustrate the technical concepts and maintain continuity with the SAD. The integrated high-level composition view of the system is shown as a package diagram in Figure 1, and the overall processing is illustrated with the activity diagram in , 2019
Figure 2. The deployment view from the SAD is filled out with more detail in allocating subsystem packages to particular computing devices on UML deployment diagrams. The requirements from which the design is derived are documented in the *Integrated Modeling for Road Condition Prediction System Requirements Specification*.[7]

[6] Object Management Group. *OMG Unified Modeling Language*™, Version 2.5. OMG Document Number: formal/2015-03-01. Normative Reference: http://www.omg.org/spec/UML/2.5. Available at: https://www.omg.org/spec/UML/2.5/PDF, last referenced March 27, 2019.
[7] Leidos, Integrated Modeling for Road Condition Prediction System Requirements. 2016. Unpublished working paper developed under FHWA Contract DTFH61-12-D-00050, Task Order 5022, Integrated Modeling for Road Condition Prediction.



Source: FHWA, 2019

Figure 1. Integrated Modeling for Road Condition Prediction Composition.



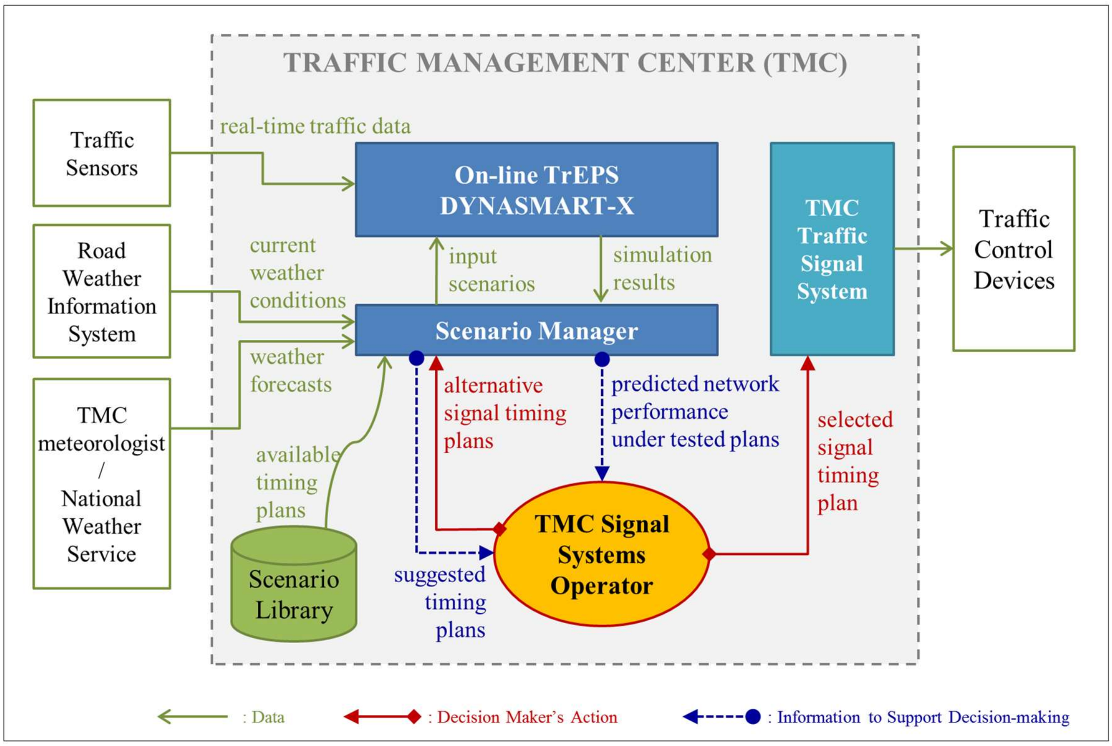
Source: FHWA, 2019

Figure 2. Integrated Modeling for Road Condition Prediction Process.

Traffic Estimation and Prediction System

The Traffic Estimation and Prediction System (TrEPS) package estimates and predicts traffic network states as well as the traffic demand in the zone-to-zone (origin-destination) level. The package includes an essential methodology that enables implementation and evaluation of on-line traffic management by incorporating field observations and traffic measures into estimating and predicting network states.

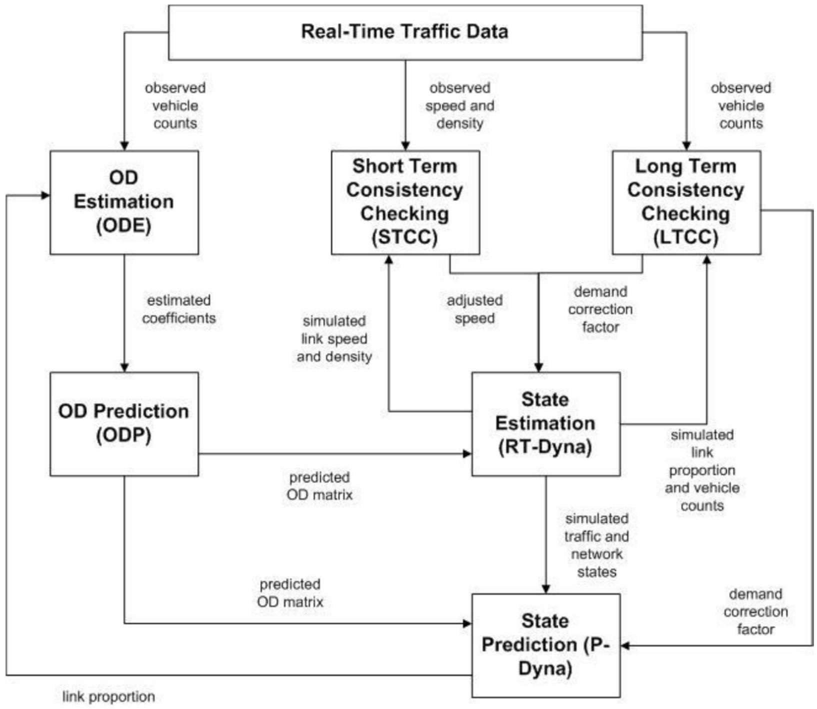
The TrEPS package implements the models for estimating and predicting the traffic state and interacts continuously with multiple sources of current/real-time traffic data, such as from loop detectors, roadside sensors, and vehicle probes, which it integrates with its own model-based representation of the network traffic state. Furthermore, the TrEPS package is able to integrate current road weather conditions, the road weather forecast and incidents to estimate and predict the traffic state and demand. Figure 3 below illustrates the framework of TrEPS-based decision support.



© Mahmassani et al., 2014

Figure 3. Traffic Estimation and Prediction System-based Decision Support Framework for Weather-responsive Traffic Signal Operations.

Within the TrEPS framework, a comprehensive DYNASMART-X simulation is triggered by six modules: Origin-Destination (OD) Estimation, OD Predictions, Short Term Consistency Checking (STCC), Long Term Consistency Checking (LTCC), State Estimation (RT-Dyna), and State Prediction (P-Dyna). Figure 4 depicts the structure and data flow of these output files.



Source: Mahmassani, 2001.

Figure 4. System Structure of DYNASMART-X Modules and Data Flow.

Origin-Destination Estimation

Background: The OD Estimation module within the TrEPS package uses a Kalman filtering approach to estimate the coefficients of a time-varying polynomial function that describes the structural deviation of OD demand in addition to a historical regular pattern (i.e., the base OD input). This procedure is considered an OD update process.

Inputs: This module requires the data from the data Store; i.e., the real-time observed link volume and the estimated and predicted link proportion from the Network State Estimation module and Network State Prediction module.

Table 1. Origin-Destination Estimation Module Input Categories.

Simulation	Real-time Observation
• Estimated link volume (link proportion) • Predicted link volume (link proportion) • Initial Traffic Demand	• Link Volume

Source: FHWA.

Outputs: The coefficients of a time-varying polynomial function are generated from this module, which are used to describe the structural deviation of OD demand in addition to a historical regular pattern (i.e., the base OD input).

Process: The OD Estimation module estimates demand for the current estimation stage and calculates the coefficients. First, the link proportion is estimated from the estimated traffic condition. With the current OD demand and estimated link proportion, the estimated link volume is obtained and compared with the real-time observed link volume. The module conducts an optimization process by minimizing the difference between estimated link volume and observed link volume and the difference between current demand and estimated demand to generate the adjustment coefficients.

Dependencies: The OD Estimation module depends on the data Store and the Network State Estimation module and Network State Prediction module modules in the TrEPS package.

Network State Estimation

Background: The Network State Estimation module provides up-to-date estimates of the current state of the network. It has the full simulation functionality of a (meso-) simulation-based intelligent transportation network planning tool, namely, DYNASMART-P, and its execution could be synchronized to the real-world clock.

Inputs: This module needs the network file, the initial traffic OD demand, the estimated/predicted OD demand, and the real-time observed link speed. It may also require any external event, including weather event, incident event and/or some special event. The special event will influence the demand pattern. The weather.dat input file used for a weather event can be found in Appendix H. If the effect of the special event is to be simulated and evaluated, a special initial OD pattern will be sent from the data Store to the TrEPS package. To obtain this special OD pattern, *a priori* demand calibration is expected as part of mining historical traffic data. If such data is missing, the system will adjust the OD pattern based on observations. However, prediction quality may suffer in the initial transition until the system has adapted. A detailed list of input files is presented in Table 2.

Table 2. Network State Estimation Module Input Categories.

Network file	Demand file	Event	Real-time observation
• Roadway Network Link • Network Links Conditions • Network Nodes • Node Conditions • Traffic Control Operations (signal control, etc.)	• OD Pairs	• Weather Event • Incident Event • Special Event • Road Construction Event (work zone)	• Link Speed

Source: FHWA.

Outputs: This module generates and updates the current state of the network and traffic assignment in the network.

Process: The Network State Estimation module simulates the dynamic traffic assignment with the initial traffic OD demand and the estimated/predicted OD demand. The estimated speed can be adjusted for a better match with the real-time observed link speed and contribute to a better estimation result.

Dependencies: The Network State Estimation module depends on the data Store, the OD Estimation module and OD Prediction module modules in the TrEPS package.

Origin-Destination Prediction

Background: The OD Prediction module uses the predicted OD coefficients provided by OD Estimation module to calculate the demand that is generated from each origin to each destination at each departure time interval.

Inputs: This module requires the estimated time-dependent OD matrices (and the adjustment coefficients) and the estimated and predicted traffic state in the network.

Outputs: This module generates the predicted traffic demand at each departure-time interval.

Process: The process uses the historical demand or estimated traffic demand, the adjusted demand coefficient, and the observed link volume to compute forecasts of future travel demand. The OD Prediction module adopts the estimated coefficients from the OD Estimation module, which is prepared after the demand estimation procedure finishes estimating for the current stage. The predicted demand is to be used in the Network State Prediction module.

Dependencies: The OD Prediction module is dependent on the data from the OD Estimation module.

Network State Prediction

Background: The Network State Prediction module provides future network traffic states for a pre-defined horizon as an extension from the current network state estimated by the Network State Estimation module.

Inputs: This module needs the snapshot of the network traffic states from the Network State Estimation module, and the Traffic Operations package from the operational control lists in the data Store.

Outputs: This module provides the future network traffic states for a pre-defined prediction horizon.

Process: In a mesoscopic simulation environment, the predicted traffic states are obtained through the detailed vehicle assignment in the network, including vehicle location and speed. The process uses the estimated or prevailing traffic assignment, the predicted travel demand and the observed link speed to compute and adjust forecasts of future traffic condition. The Network State Prediction module is capable of predicting the traffic state with and without parallel traffic control. The potential interventions are selected according to the Decision Making module. Interventions, if appropriate, are updated within a prediction horizon after any prediction interval is finished.

Dependencies: The Network State Prediction module depends on the OD Prediction module and Network State Estimation modules in the TrEPS package. It is also partially dependent on the Decision Making module from the Traffic Operations package.

Short-Term Consistency Checking

Background: The Short-Term Consistency Checking (STCC) module compares the link densities and speeds of the simulator with the real-world observations to evaluate the consistency of the flow propagation and correct the simulated speeds.

Inputs: This module takes as input the observed link speeds and densities fed from the field detectors for all instrumented links as well as the corresponding simulated link speeds and densities from RT-DYNA.

Outputs: This module produces adjusted speeds in the RT-DYNA simulator and P-DYNA predictions.

Process: The process operates continuously with RT-DYNA and consists of a modified PID (proportional-integral-derivative) controller that adjusts estimated speed values in response to deviations between simulator-estimated values and actual field detector data.

Dependencies: The STCC module depends on data from the sensors (via the IMRCP) and estimated values from RT-DYNA.

Long-Term Consistency Checking

Background: The Long-Term Consistency Checking (LTCC) module compares the simulated and observed link counts to calculate scaling factors that are used to adjust the O-D demand levels in both RT-DYNA and P-

DYNA. The LTCC component also periodically performs pattern matching to identify best-matching scenario selection from off-line libraries.

Inputs: This module takes as input the observed link volumes (counts) fed from the field detectors for all instrumented links, the corresponding simulated link volumes from RT-DYNA, as the time-dependent link proportions (which relate link flows to time-varying OD demands) from RT-DYNA.

Outputs: This module produces OD demand corrections for use as input in estimation (RT-DYNA) and prediction (P-DYNA).

Process: The process is intended to provide corrections to the estimated and predicted OD demands between cycles of execution of the main OD Estimation and OD Prediction modules. It operates consistently with the modified Kalman Filter process underlying those two modules. It is driven by the difference between observed and estimated (simulated) link volumes; higher observed values translate into reduced OD values for those OD pairs that generate the link flows in question (consistently with the simulated time-dependent link proportionality matrix).

Dependencies: The LTCC module depends on data from the sensors (via the IMRCP) and estimated values from RT-DYNA, as well as OD predictions from the OD Prediction module.

TrEPS Adapter

The TrEPS Adapter system package contains modules for collecting TrEPS files and adapting TrEPS input and output files to the proper structure for use in the TrEPS and data Store packages.

TrEPS Collect

Background: TrEPS is run on a remote server, and its output files are received through FTP. The TrEPS Collect module contains the methods used to download the output files using FTP.

Inputs: Inputs for TrEPS Collect reside in the configuration file and include the FTP credentials, the output files to download, the location to which to save the data, and the parameters passed to the Scheduling module that are used to create a task that regularly downloads the data.

Outputs: Output for TrEPS Collect are the output files downloaded using FTP. They are stored in memory until they are processed and stored on disk by the TrEPS Output module.

Process: TrEPS Collect connects to the remote FTP server and continually polls the directory, checking whether new files have been updated. The connection will stay open for up to 1 minute or until an error occurs and then reconnect. Once it has detected that a new set of files have been uploaded, it will download the files, store them in memory, and notify the TrEPS Output module that the files are ready to be processed.

Dependencies: TrEPS Collect is dependent on the remote FTP site that contains the TrEPS output files.

TrEPS Input

Background: TrEPS expects input data in specific formats in multiple .dat files. The Real Time TrEPS Input module converts the data received from the data Store into the files accepted by the TrEPS package.

Inputs: Inputs for the Real Time TrEPS Input module include weather and traffic data from the data Store.

Outputs: Outputs of the Real Time TrEPS Input module are .dat input files in the accepted format for the TrEPS package.

Process: The Real Time TrEPS Input module receives data from the data Store and coverts the data into a file acceptable by the TrEPS package. The input files accepted by TrEPS can be found in Appendix H.

The Real Time TrEPS Input module converts data from NDFDStore, RAPStore, RTMAStore, KCScoutDetectorsStore, KCScoutIncidentsStore, and Geo Services into weather.dat, detector.dat, incident.dat, and workzone.dat file formats.

Dependencies: The Real Time TrEPS Input module is dependent on the data Store.

TrEPS Output

Background: The TrEPS package produces multiple .dat output files. The OutputManager module reads all of these files to produce one output file containing all of the TrEPS output data that is sent to the TrEPSStore.

Inputs: Inputs for TrEPS Output include notifications from the TrEPS Collect module that files are ready to be processed and entries in the configuration file that include the TrEPS network.dat file location, the location to save the files, a list of files to process, and a mapping of observation type to output file

Outputs: Outputs of the TrEPS Output module is a single file that contains all of the TrEPS output data for a specific timestamp. This file is saved to disk and the TrEPSStore is notified that it is ready to be used.

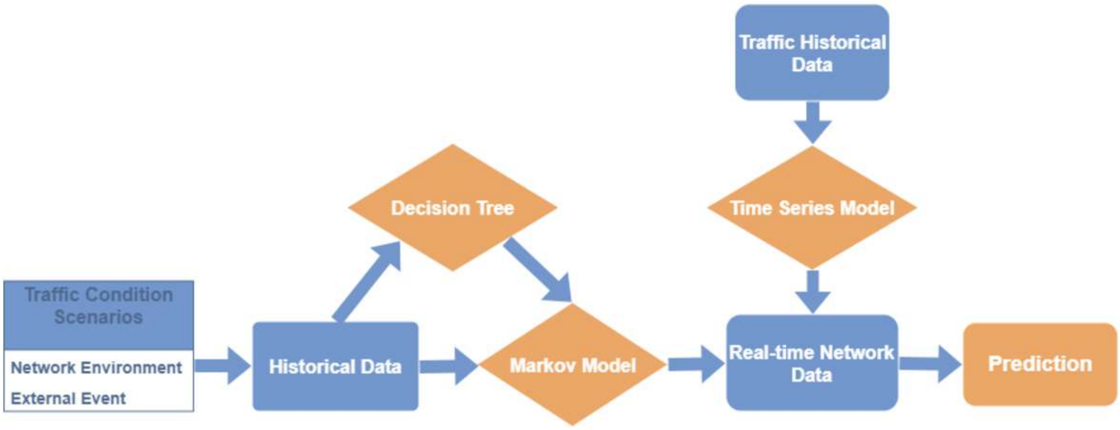
Process: The TrEPS Output module is notified by the TrEPS Collect module that there are new files in memory to be processed. Each file is processed, and a new file is created that contains all of the observations from the individual files. Appendix J describes the link statistics output files generated by the RT-DYNA and P-DYNA modules in the TrEPS package.

Dependencies: The TrEPS Output module is dependent on the TrEPS package in the Forecast package.

Machine Learning-based Prediction

The Machine Learning-based Prediction (MLP) package predicts traffic network conditions given a set of system variables that include weather, work zones, incidents, and special events. MLP is a comprehensive, data-driven prediction module that uses a Markov process to explicitly characterize the probabilistic transition between traffic states under different external conditions (e.g., weather, incidents). The MLP package contains three classes: MLP Scenario Identifier, MLP Traffic Predictor and MLP Update Manager. For links without detectors, a Neural Network model is used for predictions if a detector can be matched within 5 miles downstream, and historical INRIX data is used when no detector can be found downstream.

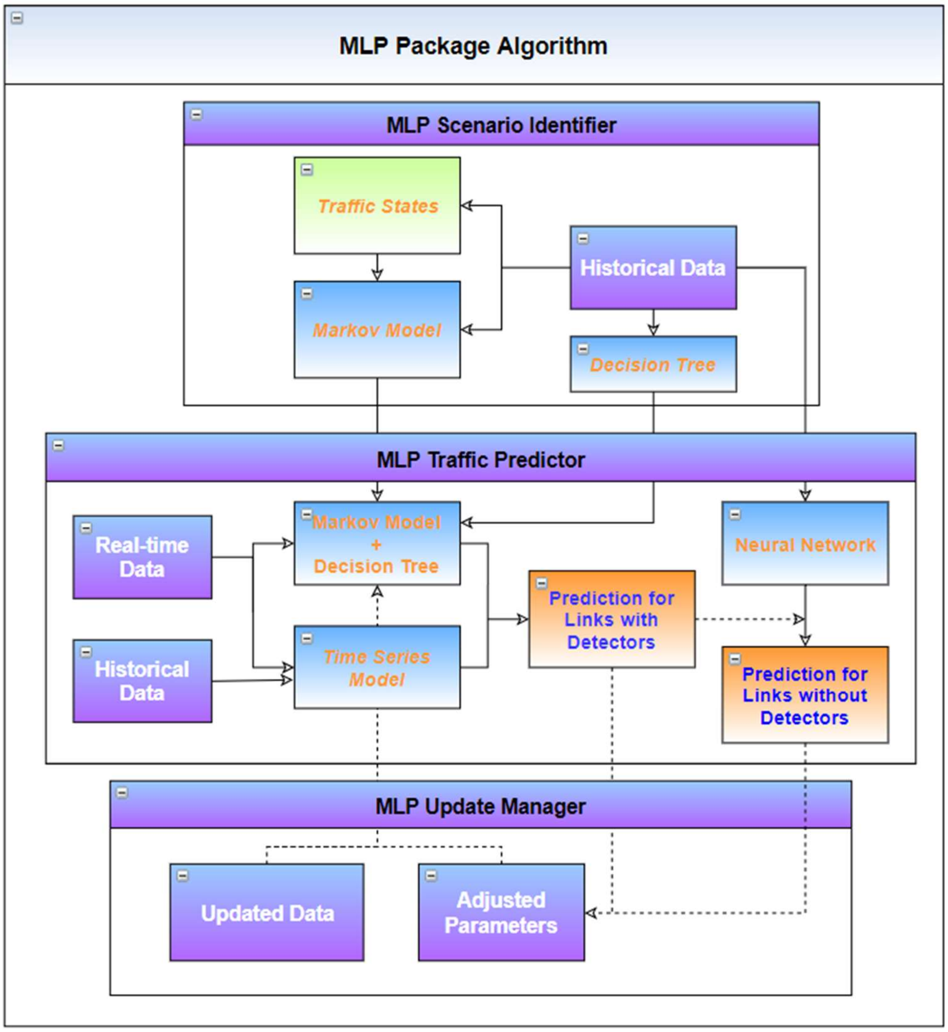
A Markov stochastic process is used to model the randomly evolving system with the assumption that future states depend only on the current state. A Markov transition matrix consists of a set of probabilities that are used to represent the transition probabilities between different traffic states. It is built based on archived data and can be applied online using real-time feeds to generate precise prediction models and results. With a calibrated Markov model, the probability of transition between traffic states under different external conditions can be computed. To be specific, Figure 5 illustrates the main components of the MLP models. The algorithm considers that the environment variables (e.g., weather) and the external event variables (e.g., incidents) affect the transition probability matrices between different traffic states. A decision tree model constructed based on the historical data is used to determine whether the external events will affect the traffic states and whether the Markov model will be applied. The time series model takes online data as input to reflect the most current traffic conditions observed in the field. This makes the prediction model robust, particularly during special conditions that have traffic patterns that are different from regular scenarios.



Source: FHWA, 2019

Figure 5. Proposed Machine Learning-based Prediction Network Model Algorithm.

Figure 6 shows a graphical representation of the IMRCP MLP algorithmic flow. The module first understands which facility groups (e.g., functional type) the link belongs to and then extracts data about the network environment and external event scenarios (e.g., system variables, such as weather and incidents). The module then pulls most relevant historical data and calculates inputs for the Markov and time series models. New online data feeds are also used as inputs for the prediction to ensure the predicted traffic conditions can best reflect real-time conditions.



Source: FHWA, 2019

Figure 6. Graphical Representation of the Integrated Model for Road Condition Prediction Machine Learning-based Prediction Process.

Variables used in the IMRCP MLP model are presented in Table 3. A total of 14 variables are categorized into three groups, including network environment, external event and traffic condition.

Table 3. Variables and State Definitions for Machine Learning-based Prediction.

Node Group	Variable	States	State Definitions
Group 1: Network Environment	Direction	-Eastbound -Southbound -Westbound -Northbound	

Table 3. Variables and State Definitions for Machine Learning-based Prediction. (continued)

Node Group	Variable	States	State Definitions
Group 1: Network Environment (cont'd)	Weather	-Clear -Light rain, clear visibility -Light rain, reduced visibility -Light rain, low visibility -Moderate rain, clear visibility -Moderate rain, reduced visibility -Moderate rain, low visibility -Heavy rain, reduced visibility -Heavy rain, low visibility -Light snow, clear visibility -Moderate snow, reduced visibility -Heavy snow, reduced visibility -Heavy snow, low visibility	00mm/h; visibility >3300ft < 2.5mm/h; > 3300ft < 2.5mm/h; 330 - 3300ft < 2.5mm/h; < 330ft 2.5 - 7.6mm/h; > 3300ft 2.5 - 7.6mm/h; 330 - 3300ft 2.5 - 7.6mm/h; < 330ft ≥ 7.6mm/h; 330 - 3300ft ≥ 7.6mm/h; < 330ft ; >3300ft* ; 1650 - 3300ft* ; 330 - 1650ft* ; < 330 ft*
	DayOfWeek	-Weekend -Weekday	Saturday, Sunday Monday - Friday
	TimeOfDay	-Morning -AM peak -Off-peak -PM peak -Night	1AM - 6AM (5 hrs) 6AM - 10 AM (4hrs) 10AM - 4PM (6hrs) 4PM - 8PM (4hrs) 8PM - 1AM (5 hrs)
Group 2: External Event	IncidentDownstream	-No incident -Incident	
	IncidentOnLink	-No incident -Incident	
	IncidentUpstream	-No incident -Incident	
	Workzone	-No work zone -Workzone	
	RampMetering	-No ramp metering -Ramp metering	
	SpecialEvents**	-Special event Type 1 -Special event Type 2 -Special event Type 3 -No special event	Local special events as defined by the agency, such as football games
Group 3: Traffic Condition	Flow (veh/h/ln)	-Very low -Low -High -Very high	< 0.25*** 0.25 - 0.5 0.5 - 0.75 ≥ 0.75
	Speed (mph)	-Very low -Low -High -Very high	< 0.25*** 0.25 - 0.5 0.5 - 0.75 ≥ 0.75
	Occupancy (%)	-Very low -Low -High -Very high	< 0.25*** 0.25 - 0.5 0.5 - 0.75 ≥ 0.75

* Snowfall's intensity is determined by visibility.

Input to the MLP package includes data from the data Store such as traffic condition, weather, work zones, incidents, and traffic control states. A complete list and description of the inputs and outputs for the MLP package can be found in Appendix K and Appendix L.

Machine Learning-based Prediction Scenario Identifier

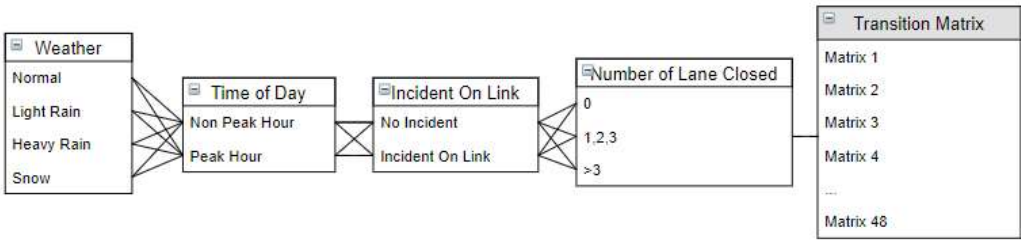
Background: The MLP Scenario Identifier module within the MLP package contains two parts: a Scenario Identifier and a Markov Model Generator, the latter of which is computed from the archived data. The Scenario Identifier is a submodule within the MLP Estimator that identifies the specific scenario the current traffic condition belongs to and then selects or generates corresponding models for traffic state prediction. The Markov Model is developed based on historical traffic state transitions and is used to explain the stochastic evolutions of traffic states for each link.

Inputs: Inputs to the MLP Scenario Identifier module include weather, roadwork, incidents, traffic control strategies, special events and traffic state data. These datasets are obtained from the data Store. They are categorized into the three groups shown in Table 4: Network Environment, External Events and Traffic Condition.

Table 4. Machine Learning-based Prediction Scenario Identifier Input Categories.

Group 1: Network Environment	Group 2: External Events	Group 3: Traffic Condition
• Direction • Weather • Time of day • Day of week	• Incident downstream • Incident on this link • Incident upstream • Workzone • Ramp metering • Special events	• Flow • Speed • Occupancy • Congestion (indicator)

Outputs: The MLP Scenario Identifier module generates clustered groups of links and different traffic states based on historical traffic data. The Markov Model computes a transition probability matrix between different states for each scenario of system variables. Figure 7 provides an example of the output from the MLP Scenario Identifier.



Source: FHWA, 2019.

Figure 7. Machine Learning-based Prediction Estimator Output Example.

Process: This module uses an approach based on the K-means clustering algorithm and pattern recognition for scenario identification. The K-means clustering method is used to define and categorize the traffic states into different levels of congestion, from free flow to heavily congested. Each of the traffic states is assigned with a distribution of traffic speeds and volumes based on the archived data. Then roadway links are clustered into different groups based on factors such as the link volume pattern and functional type. For each detector and traffic condition scenario (based on the weather, roadwork, traffic and other data inputs), the module computes and estimates the transition matrix that includes the transition probabilities between the traffic states.

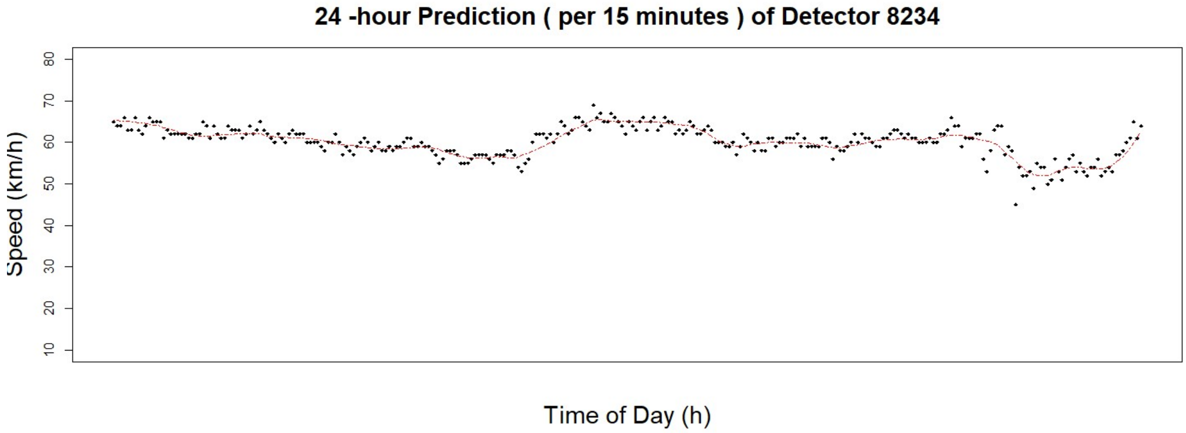
Dependencies: The MLP Scenario Identifier module depends on the weather, roadwork, incidents, traffic control strategies and traffic state data from data Store.

Machine Learning-based Prediction Traffic Predictor

Background: The MLP Traffic Predictor is a module within the MLP package that predicts likely future network traffic states for a specified prediction horizon (such as 15 min, 30 min, 1 hour or 2 hours) under specific network environment and external event conditions. The MLP Traffic Predictor uses information on current network link traffic states and other system variables, such as work zones and incidents, as model inputs to predict future network states. The Predictor considers different transition probabilities between traffic states under different external conditions (e.g., weather, incident) and uses the time series model to account for the latest trends and observations from the field. Therefore, it is able to accurately predict traffic state evolution under different external conditions and adjust the prediction based on real-time field observations.

Inputs: The MLP Traffic Predictor inputs contain three groups of data. The first group is Network Environment (e.g., weather, time, date). The second is External Events, such as incidents, work zones, and special events. The third group is real-time and archived data of traffic data as clustered into different traffic states. These inputs are similar to the inputs in Table 3. All these data inputs are current information on current network link provided by the data Store. The outputs from the MLP Scenario Identifier also serve as input to this module.

Outputs: The MLP Traffic Predictor provides future network traffic conditions (flow, speed, occupancy and congestion status) for the next specified prediction horizon (15 mins, 30 mins, 1 hour or 2 hours). An example of the MLP Predictor can be seen in Figure 8. Each point represents a 5-min interval traffic speed value. The black points are the real speeds collected by a detector and the red points represent a 2-hour prediction starting from time index 5480.



Source: FHWA, 2019

Figure 8. Machine Learning-based Prediction Predictor Output Example.

Process: A time series model is applied to predict traffic speeds under normal traffic conditions. When the network environment changes or an external event occurs, the Markov model is used to predict the traffic state for the next 5-min interval. Then the speed estimate is calculated using the means of speed distributions for different traffic states (extracted from the archived data), the time series prediction, and transition matrix probabilities. For each 5-minute time interval prediction, the data from one week before the current time are taken as inputs for the time series model.

Dependencies: The MLP Predictor depends on current weather, roadwork, incidents and traffic control strategies from the data Store and the outputs from the MLP Scenario Identifier. Particularly, both archived data and real-time feeds are used.

Machine Learning-based Prediction Update Manager

Background: The MLP Update Manager is a module within the MLP package that maintains and updates the latest MLP package parameters. The purpose of the online update module is to use both the empirical and real-time distribution of travel speed/time for different traffic conditions to enhance prediction accuracy and robustness.

Inputs: Inputs to the MLP Estimator include real-time data from the following three groups: Network Environment, External Events and Traffic Condition. These inputs are similar to the inputs in Table 4. The outputs from the MLP Traffic Predictor module also serve as input to this module.

Outputs: The Update Manager provides up-to-date distribution of system variables. It also provides new MLP Predictor variables such as new transition matrices and new time series models.

Process: The Update Manager has two tasks. First, it updates the distribution of key traffic variables (e.g., traffic speed, volume) and prepares them for use by the MLP Traffic Predictor. Second, the Update Manager schedules periodic updates to the Traffic Predictor through a re-calibration process using new data collected from the previous period. At a minimum, the manager also identifies when the Predictor should be updated based on recent model prediction accuracy through an automatic evaluation process.

Dependencies: The MLP Update Manager depends on the data Store as well as the outputs of the MLP Scenario Identifier, the MLP Traffic Predictor, and itself.

Prediction for Links without Real-time Detector Data

Background: There are 1,003 detectors installed on the modeled road links in the greater Kansas City area. There are more than 7,000 links without any detectors, but for which predictions are also needed. This module implements a prediction approach to cover those traffic network links without detectors. For links without real-time detector data feeds, data from the closest downstream detectors is used to predict the future speed values. Due to the highly non-linear relationship between the target link traffic states and downstream detector data, if it can be matched with a traffic detector within 5 miles downstream, a neural network model is built to predict the link traffic speed under normal cases based on the downstream detector data.

Inputs: Inputs include weather conditions, external events (e.g., work zones, incidents), the speeds from the closest downstream detectors, and the distance between the detector and the link.

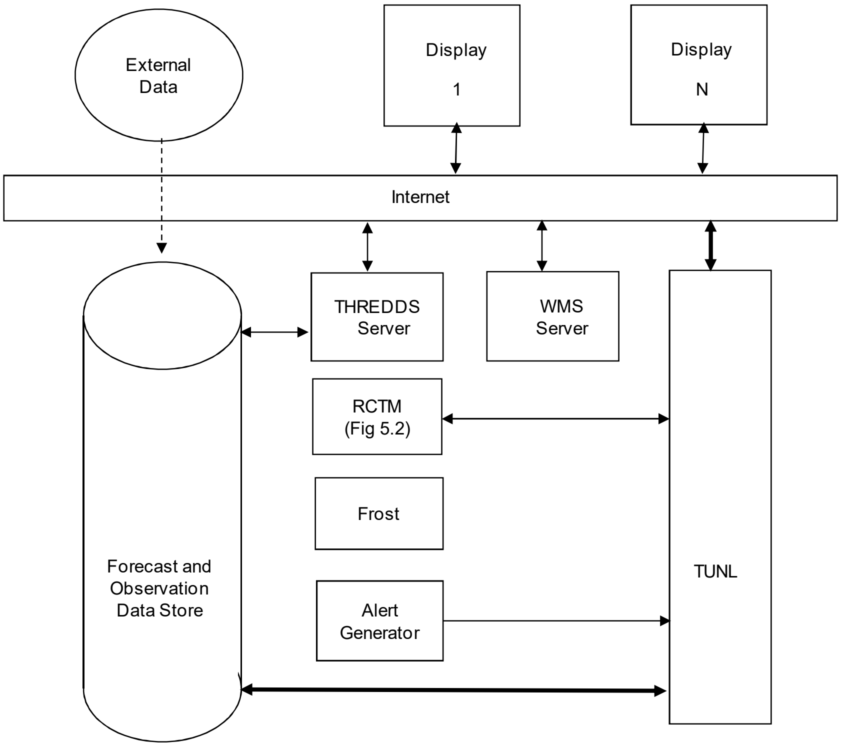
Outputs: The output includes future network traffic conditions (flow, speed, occupancy, and congestion status) on the target link for the next specified prediction horizon (15 mins, 30 mins, 1 hour or 2 hours).

Process: The neural network model is based on the relationships between all the detectors during the past 6-months of data collection. The neural network model takes in all systematic variables, including weather conditions, external events, the speeds from the closest detectors downstream, and the distance between the detector and the link. The output is the predicted real-time speed of the link in the middle. For the areas without real-time detector data and no nearby detector downstream, the historical INRIX data is used to build the long-term time series model, similar to the model above. If external conditions exist, the same transition matrices are applied.

Dependencies: This module depends on current weather, roadwork, incidents, and traffic control strategies from the data Store and the outputs from the closest link with a downstream detector.

Maintenance Decision Support System

The Maintenance Decision Support System (MDSS) package predicts road weather and pavement conditions based on designated treatment plans. The models and techniques are based on those developed by the National Center for Atmospheric Research (NCAR) for FHWA in the Pikalert® Vehicle Data Translator (VDT) and Enhanced Maintenance Decision Support System (EMDSS) modules,[8] and originally used in the Maintenance Decision Support system developed by NCAR for FHWA.[9] That system uses real-time data, such as road weather forecasts, weather and road observations, Global Positioning Service/Automated Vehicle Location (GPS/AVL) data, and gridded data sets such as radar and satellite data to derive the current network condition and initialize the forecasts. The data comes from many sources, including DOT maintenance trucks and Road Weather Information Systems (RWIS) data from Meteorological Assimilation Data Ingest System (MADIS). As shown in Figure 9, the NCAR MDSS provides user interfaces as well as models of roadway treatments and conditions. Since the IMRCP will have unified interfaces for traffic and weather condition information, it will use only the road weather condition models in the Road Conditions Treatment Module (RCTM) from NCAR's MDSS.



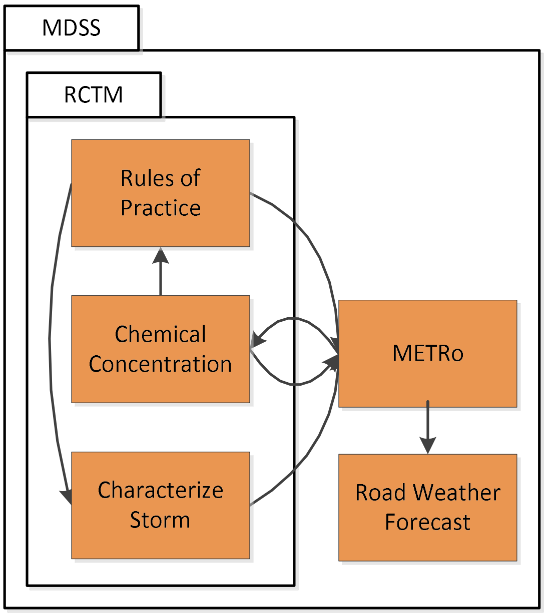
Source: National Center for Atmospheric Research, 2018

Figure 9. Overview of National Center for Atmospheric Research Maintenance Decision Support System.

The MDSS package implements models for associating atmospheric and road weather forecasts, predicting pavement conditions, characterizing storms and implementing pavement treatment plans. The pavement

[8] National Center for Atmospheric Research. 2015. *Pikalert® Vehicle Data Translator 4.0, Enhanced Maintenance Decision Support System, Motorist Advisory and Warning Application Installation Guides*; Version 1.0.
[9] National Center for Atmospheric Research. 2009. *MDSS Prototype Release-6 Technical Description*; Version 1.2.

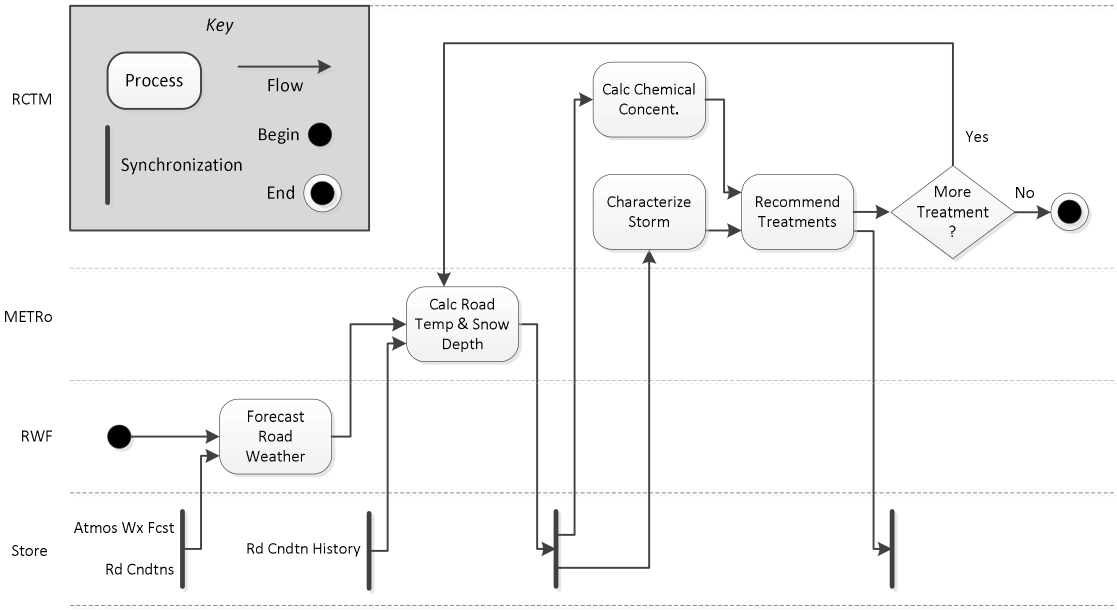
condition prediction models include surface temperature, precipitation burden (liquid, snow, and ice) and treatment chemical concentration. Inputs to these models include atmospheric weather predictions and rules of practice for road surface treatments, such as chemical pre-wetting and plowing. As shown in Figure 10, the IMRCP MDSS package contains five modules: Road Weather Forecast (RWF), Model of the Environment and Temperature of Roads (METRo), Characterize Storm, Chemical Concentration, and Rules of Practice, the last three of which are contained within a Road Conditions Treatment Module (RCTM). The NCAR MDSS also includes two modules, the Net Mobility Module and Pavement Frost Module, which are not needed in the IMRCP for integration between weather and traffic models, but may nonetheless be of interest to readers.



Source: FHWA, 2019

Figure 10. The Integrated Model for Road Condition Prediction Maintenance Decision Support System Package.

The analytical process, illustrated in Figure 11, starts with current atmospheric and road weather conditions and atmospheric forecasts being pulled from the data Store. Road weather forecasts are generated for segments in the road network. Forecasts of pavement conditions are computed from the road weather forecast without road treatments to generate base conditions. Key characteristics of the storm are derived from the forecasts and are input to aid in the assessment of the treatment rules of practice. Treatment chemical concentrations are calculated for the pavement surface, and rules of practice are evaluated to determine if and when additional treatments need to be made based on forecasted conditions. Subsequent iterations then apply the recommended treatments, and the pavement and subsurface condition forecasts are reanalyzed. Pavement conditions and treatment plans are then sent to the data Store for use by other IMRCP modules.



Source: FHWA, 2019

Figure 11. Maintenance Decision Support System Process.

The MDSS package depends on the data Store for current and forecast atmospheric weather conditions, current road weather conditions as measured at Environmental Sensor Station (ESS) and by mobile sensors, and treatment plan rules of practice.

Road Weather Forecast

Background: The Road Weather Forecast (RWF) module within the MDSS package forecasts road weather conditions from associated atmospheric weather forecasts and road segment definitions. The RWF module is not implemented in the IMRCP v2.0.

Inputs: Atmospheric weather forecasts are generated and distributed as gridded data. As described in the *Integrated Modeling for Road Condition Prediction Model Analysis,*[10] these forecasts can be obtained from a variety of weather models, such as the Global Forecast System (GFS) or the North American Model (NAM) from the National Weather Service (NWS). The focus of the initial implementation of the IMRCP will be on the accuracy of near-term forecasts, since traffic models lose their efficacy for simulations that project longer than a few hours into the future. As such, the Rapid Refresh (RAP) and the National Digital Forecast Database (NDFD), which provide more frequent updates and smaller grids than other forecast products, will be used for the initial IMRCP implementation.

Outputs: The RWF provides road weather conditions associated with roadway segments as input to the METRo model.

Process: The RWF module allocates forecast conditions such as visibility, precipitation type, and precipitation rate from the atmospheric forecast models to specific road segments. The forecast model products are gridded

[10] Leidos. 2015. *Integrated Modeling for Road Condition Prediction Model Analysis*. 2015. Unpublished working paper developed under FHWA Contract DTFH61-12-D-00050, Task Order 5022, Integrated Modeling for Road Condition Prediction.

in keeping with the underlying model's physics, e.g., a 13-kilometer grid for the RAP. Surface atmospheric conditions forecast for a given grid cell are allocated to all surface roadway segments within that cell.

Dependencies: The RWF module depends on forecast weather data from the data Store.

Road Temperature and Snow Depth Module (METRo)

Background: The METRo model is used as the Road Temperature and Snow Depth Module in both NCAR's MDSS and in the IMRCP. As described in the *Integrated Modeling for Road Condition Prediction Model Analysis*, METRo is a standard pavement thermal modeling tool developed by the Canadian Meteorological Center of Environment Canada as part of its road weather forecasting suite.[11] It is widely used and adapted in many winter maintenance decision support systems, including NCAR's Pikalert suite. In the IMRCP design, METRo is implemented as part of its MDSS package to support RCTM treatment recommendation analyses.

Inputs: METRo needs three input files: one containing the recent history of the observations, one describing the station configurations, and one containing weather forecast data. The recent history data set is generated by the MDSS module from information contained in the data Store and the Subsurface Temperature collector module. The station configuration data is built from the ESS and roadway segment definitions data. The surface weather forecast data is provided by the RWF module.

Outputs: METRo computes pavement and subsurface thermal characteristics based on road weather conditions and pavement geometries and materials. The outputs are associated with pavement segments and added to the data Store.

Process: The system uses the METRo model to perform a one-dimensional time-dependent computation of pavement surface and sub-surface conditions for each road segment. The MDSS module generates METRo input files from the data Store and METRo is executed at each segment/site. Initial pavement conditions for segments without direct observations from ESS/RWIS are inferred from nearby observations. The METRo output is parsed by the MDSS module and the relevant pavement condition data (temperature profile and precipitation overburden) are saved in the data Store. METRo may be called more than once per site if treatments are called for.

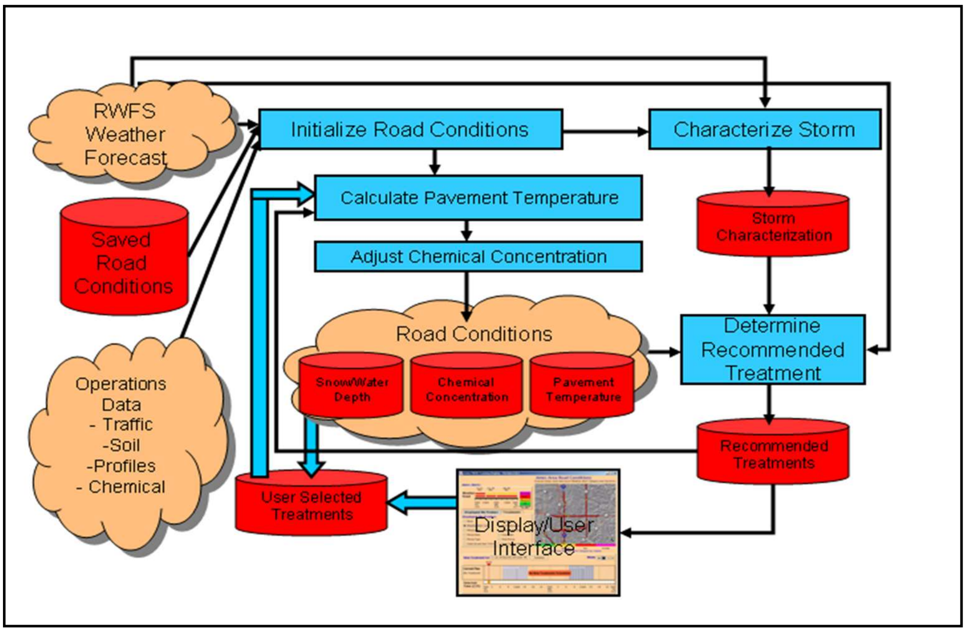
Dependencies: METRo depends on the RWF for forecast surface weather condition data and on the data Store for pavement condition history.

Road Condition Treatment Model

The Road Condition Treatment Model (RCTM) is a subpackage-level module within the MDSS package that makes road treatment and plowing recommendations for road segments based on road weather forecasts.[12] As shown in Figure 12, The NCAR RCTM model includes the storm characterization module, the chemical concentration module, the rules of practice module, the net mobility module, and the pavement frost product. This modularization is retained in the IMRCP implementation, as shown in Figure 10, in order to preserve continuity with the independent MDSS implementations.

---

[11] Crevier, L.-P., and Y. Delage. 2001. "METRo: A New Model for Road-Condition Forecasting in Canada." *Journal of Applied Meteorology* 40: 2026-2037. Available at: http://journals.ametsoc.org/doi/pdf/10.1175/1520-0450%282001%29040%3C2026%3AMANMFR%3E2.0.CO%3B2, last accessed March 27, 2019.
[12] NCAR. 2009. *MDSS Prototype Release-6 Technical Description,* Version 1.2, p. 22.



Source: National Center for Atmospheric Research, 2018

Figure 12. National Center for Atmospheric Research Road Condition Treatment Model.

Results from the METRo pavement condition forecasts are used by the RCTM as input to treatment assessment algorithms based on winter maintenance strategies and associated rules maintained in the data Store. Pavement conditions are then re-evaluated by METRo with the recommended treatments to forecast the treated road segment conditions, which are returned to the data Store for use by other modules.

The RCTM depends on the data Store for winter maintenance decision rules and on METRo for current and forecast pavement conditions. The RCTM module is not implemented in the IMRCP v2.0.

Storm Characterization Module

Background: The Storm Characterization module within the RCTM assesses weather and road characteristics before, during, and after a storm in order to provide input to the winter maintenance Rules of Practice.[13]

Input:

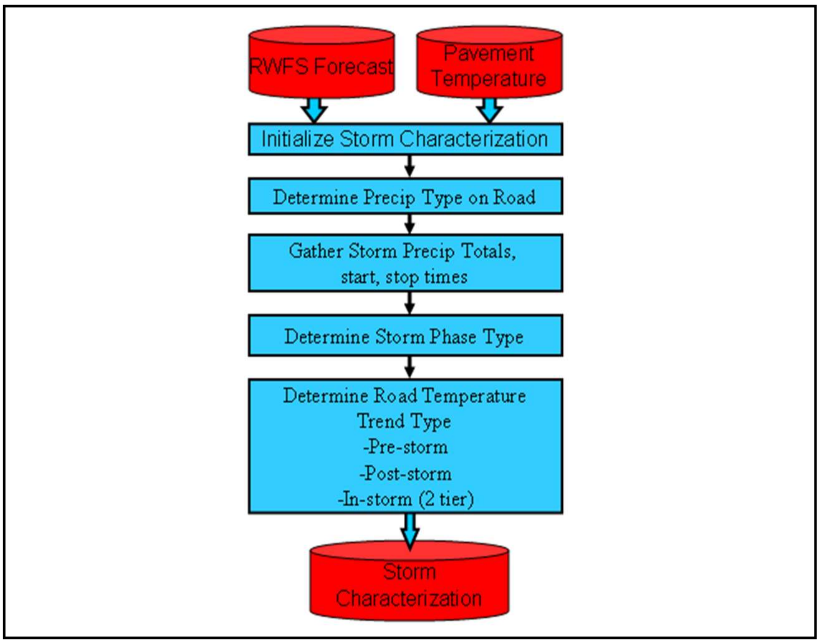
1. Forecasts of precipitation rate and type (expressed as a liquid water equivalent) from the Data Store, sourced from the atmospheric weather forecasts.
2. Wind speed values, also from the Data Store, sourced from the atmospheric weather forecasts.
3. Pavement temperatures as forecasted by METRo.

Output: The Storm Characterization module creates a consolidated storm characteristics state mapping of the pre-, in-, and post-storm environment, used only in the Rules of Practice module for determining treatment plans.

Process: Processing for the Storm Characterization algorithm is described in detail in Appendix E of the MDSS Technical Description. The module is initiated by the RCTM when a new road weather forecast

[13] NCAR. 2009. *MDSS Prototype Release-6 Technical Description*, Version 1.2, pp. Page 166-169.

becomes available from METRo. The module uses current weather forecasts, recent road condition data, and operational characteristics of the road segment to create the variables for the pre-, in-, and post-storm environment, as illustrated in Figure 13.



National Center for Atmospheric Research, 2018

Figure 13. Storm Characterization Process.

Chemical Concentration Module

Background: The Chemical Concentration module computes the amount of treatment chemical on a roadway segment based on the treatment plan and road conditions.

Inputs:

1. Precipitation Rate (expressed as a liquid water equivalent) - Weather Observations from the Data Store.
2. Relative humidity - Weather Observations from the Data Store.
3. Wind speed values - Weather Observations from the Data Store.
4. Pavement temperature – forecasted in METRo.
5. The type, rate and application time of chemical used in treatment – determined in RulesOfPractice Module.
6. Prediction of traffic intensity over the forecast period.

Output: The Chemical Concentration Module outputs an estimate of the chemical concentration of anti-icing and de-icing chemicals on the road over the forecast interval based on the type of treatment material and accumulated water on the road.

Process: The Chemical Concertation Module within NCAR's MDSS can be triggered by the RCTM or the user recommending a new treatment. The IMRCP system will not have an interface for user-specified treatment plans and will depend on pre-configured rules of practice to be executed by the RCTM. In either case, the

Chemical Concentration module would begin processing at the time the treatment plan specified the treatment should initialize and calculate the net rate of chemical delivery during treatment hours; it then tracks the available chemical and water over time based on dilution, traffic, runoff, and evaporation.

The chemical concentration model sums the amount of water on road from the previous hours with the water from precipitation that fell in the current hour to find the water currently on the road. The model then calculates the concentration of chemicals still on the road. This algorithm needs to be modified for the IMRCP to reflect its integration with the traffic models.

> *The amount of chemicals available for anti-icing operations is defined as:*
>
> *AvailableChemical =*
> *(1-tfactor)*(ChemRate+ResidualChemical+ChemInSolution)*
>
> *where tfactor represents the fraction of chemicals lost from the road surface due to transport from automobiles and trucks on the road (as calculated in the routine* ***CalcTrafficFactor****).*[14]

The NCAR MDSS/RCTM uses the following scale to estimate traffic:

1 = Low (less than 250 vehicles per hour per lane).
2 = Medium (between 250 and 2,000 vehicles per hour per lane).
3 = High (more than 2,000 vehicles per hour per lane).

The higher estimated traffic volumes dissipate chemicals more quickly. Within IMRCP, traffic levels calculated by TrEPS will be used as input to the CalcTrafficFactor Module.

> *The next series of steps is used to calculate the final concentration level of the solution remaining on the road surface. The nominal chemical concentration is determined by simply dividing the available chemicals by the sum of the available water and chemicals. However, chemicals can only dissolve into water up to their saturation level. Therefore, the nominal concentration is clipped to the chemical saturation point (as calculated in CalcCriticalChemSaturationPoint) and used as the final chemical concentration value. Once precipitation has ceased, the available water is allowed to evaporate from the road surface, eventually the road surface will be considered dry and, therefore safe from re-freezing.*
>
> *Any surface water remaining on the road is reduced by evaporation if the water is in liquid form (when chemicals are effective or no chemicals are needed). The routine CalcEvaporationRate estimates a simplified evaporation rate from relative humidity and wind speed factors only.*
>
> *One last step is to determine at what time step the chemical concentration will become ineffective. The algorithm currently determines this by finding the first time step where the final chemical concentration is at or below the chemical solution point (as calculated in CalcCriticalChemSolutionPoint). The forecasted chemical concentration levels and failure time step are then passed back to the RCTM.*[15]

[14] NCAR. 2009. pp. 145-147.
[15] Ibid.

Rules of Practice Module

Background: The Rules of Practice module recommends appropriate road treatment actions for winter storm maintenance crews during winter storms based on the FHWA "*Manual of Practice for an Effective Anti-icing program: A guide for Highway Maintenance Personnel.*"[16]

Inputs:

1. Precipitation Rate – Weather Observations from the Data Store.
2. Precipitation Type – Weather Observations from the Data Store.
3. Pavement Temperature – forecasted in METRo.
4. Snow Depth – forecasted in METRo.
5. Storm Characterization – from the Storm Characterization Module.
6. Chemical Used – from User.

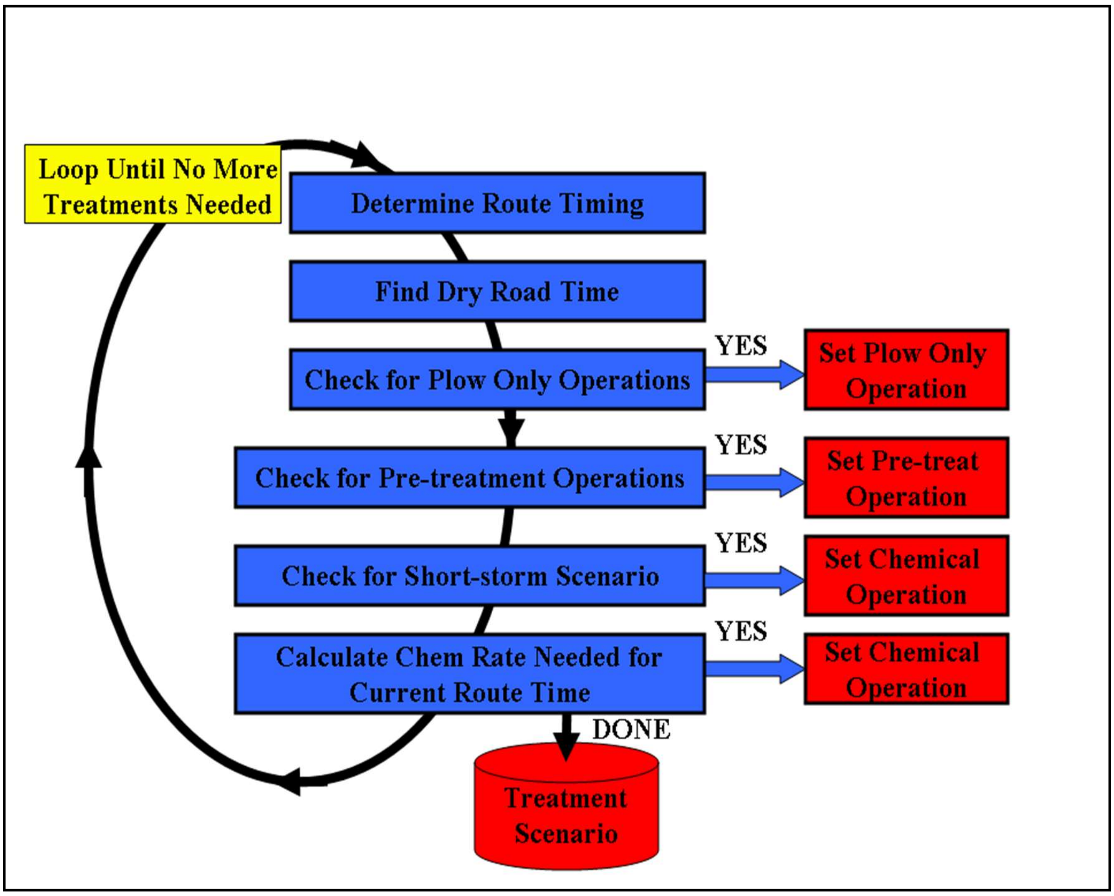
Output: The Rules of Practice module determines if treatment is needed, and, if so, what type(s) of treatment to implement and when.

Process: The algorithm as implemented in NCAR's MDSS is initiated by a user looking for options for a specific route, chemical type, and form. For the IMRCP, the Rules of Practice will be evaluated for all road segments in the study area road network. The algorithm loops over all the forecast hours looking for a treatment trigger. If treatment is needed, the Rules of Practice module determines the treatment type and time.

The Rules of Practice module starts by determining if the storm conditions can be managed by only plowing the roads. If anti-icing chemicals are warranted, it determines whether pre-treatment is necessary. If pre-treatment is not needed, or has already been applied, the Rules of Practice module calculates the amount of anti-icing chemicals needed to protect the road surface.

The process has access to prior known pavement conditions in the data Store, including prior treatments. The ChemConc and Pavement Temperature modules update the road conditions according to the atmospheric forecast, and the Rules of Practice module then iterates to find the next treatment (if necessary) until the entire storm-impacted area has been treated.[17] The process is shown in Figure 14, below.

[16] NCAR. 2009. pp. 155-165
[17] NCAR. 2009. pp. 155-160



Source: National Center for Atmospheric Research, 2009.

Figure 14. Rules of Practice Evaluation Process.[18]

Net Mobility Module

Background: The net mobility module is used by NCAR's MDSS to create a mobility index. Since the TrEPS within the IMRCP estimates traffic, a mobility index is not needed, and this module is not included. It is included here for comparison to the IMRCP methods.

Input: Inputs are pavement conditions forecast by METRo. The module does not take into account some of the more subtle factors (e.g., wet snow, dry snow, snow on ice, etc.) that may impact mobility.

Output: The Net Mobility Module estimates an index of the mobility for a vehicle on a road. It ranges from 0 (no mobility) to 1 (optimal road conditions).

Process: The Net Mobility Module uses a decision tree to synthesize a mobility index from meteorological and road surface conditions.[19]

[18] NCAR. 2009. p. 157
[19] NCAR. 2009. p. 154.

Table 5. The National Center for Atmospheric Research Maintenance Decision Support System Mobility Index.

Pavement Condition	Mobility Index
Dry	1.0
Wet	0.7
Snow < 4 inches	0.6
Snow 4-6 inches	0.4
Snow > 6 inches	0.3
Ice	0.2

Source: National Center for Atmospheric Research. 2009. MDSS_Tech_Description Version 6. p. 154.

Pavement Frost Product

Background: NCAR's MDSS uses a frost potential algorithm to estimate a frost state based on environmental conditions. The algorithm must run several times in a row to compensate for the minute changes that alter frost disposition. The output is termed "frost potential" rather than "frost probability" due to the inability to completely remove uncertainty due to the nature of frost. The frost potential index is not used by any other module.

Input: The algorithm requires forecasts and use estimates of the variances in air temperature, dew point temperature, and wind speed.

Output: The Frost Potential Index is a single value between zero (no frost) and one (heavy frost on the pavement).

Process: The module uses a pseudo-Monte Carlo algorithm ("pseudo" because it is not a statistically random variation) to evaluate the sensitivity of the frost calculation to its inputs. Each variation of the inputs is weighted based on how far they are from the original forecast. The frost forecasts are indexed as a weighted average to generate an hourly frost potential. Each hourly frost potential forecast is categorized into one of four groups reflecting the severity of the expected frost.

Ensemble

The Ensemble package produces final traffic state predictions by combining results from the TrEPS Package with those of the MLP Package.

The uncertainties in the initial conditions of models, model parameters and model structures all influence traffic state predictions. An ensemble model can improve prediction accuracy by combining prediction results from different models or even the same models with different parameters. This is because none of the existing models (e.g., traffic flow model-based models, statistical learning approaches) can by themselves adequately address complex traffic characteristics.

In the IMRCP framework, the Ensemble package aggregates prediction results from two single models with a weighted average approach. The weights can be updated off-line at certain intervals based on comparisons of previous predicted and observed traffic conditions. For example, the weights can be updated each day. Alternatively, in real-time, a rolling horizon approach can be used to update weighting coefficients. At the beginning of each horizon, the weights are updated based on empirical measurements and simulated results of each model from the last horizon. This process uses a least-square estimation method,[20] which aims to find

[20] Li, L., Chen, X., & Zhang, L. 2014. "Multimodel ensemble for freeway traffic state estimations." *IEEE Transactions on Intelligent Transportation Systems* 15(3): 1323-1336.

optimal weights that can minimize the square of the sum of the differences between the measurement and ensemble prediction result at each location of interest. When more single-model prediction packages are available in the future, the same Ensemble framework can be used. The Ensemble package is not implemented in the IMRCP 2.0.

Background: The Ensemble package predicts traffic network states by comparing results of the forecasting TrEPS and MLP packages.

Inputs: The Ensemble package takes previous observed and predicted traffic conditions as inputs to generate the weights for the results of the TrEPS package and MLP Package and update the weights of Ensemble model at certain intervals. The model also needs current predicted traffic states data to predict final traffic condition.

Outputs: The model will decide the weights for the predicted traffic states of the TrEPS package and MLP Package. Based on the weights and the predicted traffic states data from the TrEPS package and MLP Package, the Ensemble package will provide the final traffic states (e.g., traffic speed, occupancy, congestion condition).

Process: First, the Ensemble model estimates the weights for the predicted traffic states generated from the TrEPS package and MLP Package. The estimation is based on the comparisons of previous observed data and previous predicted data. The weights will be updated frequently at a certain interval with new predicted and observed traffic states data. After estimating the weights, the model combines current predicted traffic states predicted by the TrEPS package and MLP Package using weights and generates final predicted traffic conditions for future roadway segments and links for next specified prediction horizon (15 mins, 30 mins, and 1 hour).

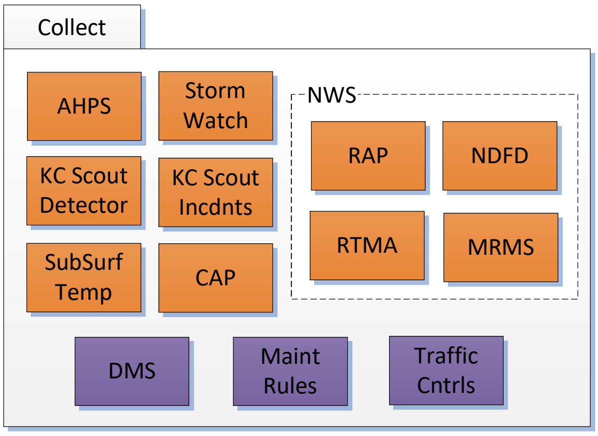
Dependencies: The Ensemble package depends on the data Store, particularly requiring collected traffic measurements and prediction results from the TrEPS and MLP packages.

Collect

The data collection (Collect) package collects data needed for IMRCP computations. Collect modules depend on external systems for making the data available for collection and on corresponding modules in the data Store to provide a destination for the collected data. Collection interfaces, formats, and intervals are determined by the external data sources. Appendix B lists the data availability for the systems accessed by the Collect modules. Figure 15 shows all of the Collect modules within the Collect package. The package is designed to be extensible and will accommodate new collection modules as new sources are identified and made accessible to the IMRCP modules initially included within the Collect package include:

- Advanced Hydrologic Prediction Service [AHPS], for hydrological conditions and forecasts
- StormWatch [StormWatch], for hydrological conditions and forecasts
- KC Scout Detectors [KCScoutDetectors], for current traffic conditions on the network of interest
- KC Scout Incidents [KCScoutIncidents], for the current state of incidents
- Subsurface Temperature [SubSurfaceTemp], for the current subsurface temperature
- National Digital Forecast Database [NDFD], for atmospheric weather forecasts
- Rapid Refresh [RAP], for forecasted surface pressure, precipitation amount, and precipitation type
- Real-Time Mesoscale Analysis [RTMA], for current air temperature, wind speed, surface pressure, and humidity
- Multiple Radar/Multiple Sensor [MRMS], for radar and precipitation rate and type
- Common Alerting Protocol [CAP], for alerts, watches, and warning
- Traffic Controls [TrafficCntrls], for the current state of and plans for traffic controls

- Maintenance Rules [MaintRules], for roadway maintenance rules (e.g., winter maintenance operations)
- Special Events [SpecialEvents], for the current state of and plans for special events



Source: FHWA

Figure 15. Collect Package Diagram.

Advanced Hydrologic Prediction Service [AHPS]

Background: The Advanced Hydrologic Prediction Service (AHPS) collector module collects hydrological data from the National Weather Service's AHPS.[21] AHPS forecasts are provided in SHP-formatted (Shapefile) files. The data included in the shape-file include names and location of detectors, latest observation value and time, and flood stages for that location.

Inputs: Inputs for AHPS reside in the configuration file and include the URL from which to download the data, the location to which to save the data, and the parameters passed to the Scheduling module used to create a task that regularly downloads the data.

Outputs: The Shapefile obtained by the collector is passed to the data Store.

Process: Shapefiles are generated on the AHPS website whenever new forecasts are available. The AHPS collector module polls the website continuously, and once a new file has been generated, the file is downloaded. After the download is complete, the AHPS Store is notified that the new file is available for use

Dependencies: The AHPS depends on the National Weather Service, National Hydrologic Assessment. Current year data available at: http://water.weather.gov/ahps/download.php

StormWatch [StormWatch]

Background: The StormWatch collector module collects data from StormWatch, a flood warning system created and used by Overland Park, KS to monitor weather stations throughout the Kansas City area.[22] Most sensors report real-time rainfall and some report stream levels, temperature, relative humidity, wind, pavement

---

[21] National Weather Service. 2019. National Hydrologic Assessment. Available at: http://water.weather.gov/ahps/index.php, last accessed March 27, 2019

[22] Johnson County, Kansas. 2019. StormWatch ALERT Flood Warning System. Available at: https://www.stormwatch.com/home.php, last Accessed March 29, 2019.

temperature, pavement state, and other weather data. Data is available for some stations back to the 1980s. An example of the .csv files collected can be found in Appendix G.

Inputs: The observation type, Site Id, Site UUID, Device Id, and Device UUID are needed to generate the URL to download the latest value for the desired observation and location. Inputs for StormWatch reside in the configuration file and include the URL from which to download the data, the location to which to save the data, the location of the station metadata file, and parameters passed to the Scheduling module used to create a task that regularly downloads the data.

Outputs: The files obtained by the StormWatch module are parsed and new information is passed through to the data Store.

Process: The StormWatch collector module polls the StormWatch website at a regular interval and only downloads the latest observations if they have been updated since the last polling interval. After the download is complete, the new observations are written to a file, and the StormWatch Store is notified that there is new data ready for use.

Dependencies: The StormWatch collector module depends on the Johnson County, Kansas, StormWatch ALERT Flood Warning System available at: https://stormwatch.com/home.php

KC Scout Detectors [KCScoutDetectors]

Background: The KC Scout Detectors collector module collects current traffic condition data from the Kansas City Scout real-time detector feed, which includes traffic speed, volume, and occupancy collected in XML format. An example of these files can be found in Appendix E. The data are compliant with the Traffic Management Data Dictionary (TMDD) Center-to-Center (C2C) standard.

Inputs: Inputs and metadata for KC Scout Detectors reside in the configuration file and include the location to which to save the data and parameters passed to the Scheduling module used to create a task that regularly downloads the data.

Outputs: The KC Scout Detectors collector submits traffic speed, volume, and occupancy data to the data Store.

Process: The KC Scout Detectors collector module collects traffic conditions from the Kansas City Scout real-time detector every minute and submits the data to KC Scout Detectors module in the data Store for system retention.

Dependencies: KC Scout Detectors collector module depends on the Kansas City Scout TransSuite Data Portal available at http://www.kcscout.net/KcDataPortal/

KC Scout Incidents [KCScoutIncidents]

Background: The KC Scout Incidents collector module gets data describing the current incidents and work zones and their expected resolutions from the Kansas City Scout Real-Time Events feed within the IMRCP geographical domain of interest. The files collected from Kansas City Scout are in XML format. An example of these files can be found in Appendix F. The format and structure of the data should generally comply with the TMDD C2C standard data element models.

Inputs: Inputs and metadata for KC Scout Incidents reside in the configuration file and include the location to which to save the data and parameters passed to the Scheduling module used to create a task that regularly downloads the data.

Outputs: Data describing the current incidents and work zones and their expected resolutions, including incident type, incident time, approximate resolution time, and number of lanes affected, are submitted to the data Store. The specific data formats and structures will be determined by those used by the initial prototype deployment partner.

Process: The Incidents collector module collects Incidents from the Kansas City Scout real-time events data feed on a scheduled interval and submits the data to the KC Scout Incident module in the data Store for system retention. The organization is dependent on the geographical domain of interest.

Dependencies: KC Scout Incidents collector module depends on the Kansas City Scout TransSuite Data Portal http://www.kcscout.com/TransSuite.DataPortal/

Subsurface Temperature [SubSurfaceTemp]

Background: The Subsurface Temperature collector module is used for collecting the subsurface temperature observation from an ASOS station to initialize the METRo forecast module.

Inputs: Inputs for Subsurface Temperature reside in the configuration file and include the URL from which to download the data, the location to which to save the data, and the parameters passed to the Scheduling module used to create a task that regularly downloads the data.

Outputs: The Subsurface Temperature collect module provides the subsurface temperature observation it gets from an ASOS station to other modules in the IMRCP system.

Process: The Subsurface Temperature collect module collects the subsurface temperature observation from the NOAA ASOS website on a scheduled interval.

Dependencies: Subsurface Temperature collector module relies on various external sources, depending on the station.

National Digital Forecast Database [NDFD]

Background: The National Digital Forecast Database (NDFD) contains a compilation of gridded digital forecasts from NWS field offices. The NDFD collector module collects atmospheric weather forecasts from the NDFD system, which currently "contains data representing the following weather elements. More elements will be added as development of the NDFD progresses. NDFD data are available for projections (as described in Table 6 below) at the following Coordinated Universal Times (UTC): 0000, 0300, 0600, 0900, 1200, 1500, 1800, 2100."[23]

Inputs: Inputs and metadata for NDFD reside in the configuration file and include the URL from which to download the data, the location to which to save the data, the files to download, and the parameters passed to the Scheduling module that are used to create a task that regularly downloads the data.

[23] NOAA National Centers for Environmental Information. National Digital Forecast Database (NDFD) available at http://www.nws.noaa.gov/ndfd/technical.htm, last accessed March 29, 2019.

Table 6. Weather Elements Collected by the National Digital Forecast Database.

Elements	No. of Grids	Projections
12-hour Probability of Precipitation (PoP12)	13-15	Every 12 hours, out to 168 hours
Apparent Temperature	33-41	Every 3 hours out to 72 hours; every 6 hours out to 168 hours
Dew Point	33-41	Every 3 hours out to 72 hours; every 6 hours out to 168 hours
Hazards	59-82	Every hour, out to 72 hours; every 6 hours out to 120 hours
Maximum Temperature	7-8	Every 24 hours, out to 168 hours
Minimum Temperature	6-7	Every 24 hours, out to 168 hours
Quantitative Precipitation Amount	9-13	Every 6 hours out to 72 hours
Relative Humidity	33-41	Every 3 hours out to 72 hours; every 6 hours out to 168 hours
Significant Wave Height	17-21	Every 6 hours out to 120 hours
Sky Cover	33-41	Every 3 hours out to 72 hours; every 6 hours out to 168 hours
Snow Amount	5-9	Every 6 hours out to 48 hours
Temperature	33-41	Every 3 hours out to 72 hours; every 6 hours out to 168 hours
Weather	33-41	Every 3 hours out to 72 hours; every 6 hours out to 168 hours
Wind Direction	33-41	Every 3 hours out to 72 hours; every 6 hours out to 168 hours
Wind Gust	17-25	Every 3 hours out to 72 hours
Wind Speed	33-41	Every 3 hours out to 72 hours; every 6 hours out to 168 hours

Outputs: The weather elements are passed to the data Store in GRIB2-formatted (GRIdded Binary) files.

Process: The NDFD module collects data from the NDFD website on a scheduled interval and notifies the NDFD Store there are new files available for use and system retention.

Dependencies: The NDFD module depends on the National Weather Service NDFD home page located at: https://www.weather.gov/mdl/ndfd_home

Rapid Refresh [RAP]

Background: The Rapid Refresh (RAP) collector module collects data from the RAP system. The RAP system is an assimilation/modeling system that initializes a numerical forecast model that covers North America.

Inputs: Inputs and metadata for RAP reside in the configuration file and include the URL from which to download the data, the location to save the data, the number forecast hours to download, and parameters passed to the Scheduling module used to create a task that regularly downloads the data.

Outputs: The RAP collector module sends forecasted surface pressure, precipitation amount, and precipitation type to the data Store.

Process: The RAP collector module downloads files from the RAP website on a scheduled interval and notifies the RAP Store there are new files available for use and system retention.

Dependencies: The RAP module depends on the National Weather Service RAP home page located at: http://rapidrefresh.noaa.gov/

Real-Time Mesoscale Analysis [RTMA]

Background: The Real-Time Mesoscale Analysis (RTMA) collector module collects data from the RTMA system, "a NOAA/NCEP high-spatial and temporal resolution analysis/assimilation system for near-surf ace weather conditions."[24]

Inputs: Inputs and metadata for RTMA reside in the configuration file and include the URL from which to download the data, the location to which to save the data, and the parameters passed to the Scheduling module used to create a task that regularly downloads the data.

Outputs: The RTMA collector module sends air temperature, dewpoint temperature, surface pressure, surface visibility, wind direction, wind speed, wind gust speed and cloud coverage to the data Store.

Process: The RTMA collector module downloads files from the RTMA website on a scheduled interval and notifies the RTMA Store there are new files available for use and system retention.

Dependencies: The RTMA module depends on the National Weather Service RTMA products page located at: http://www.nco.ncep.noaa.gov/pmb/products/rtma/

Multiple Radar/Multiple Sensor [MRMS]

Background: The Multiple Radar/Multiple Sensor (MRMS) collector module collects data from Multiple Radar/Multiple Sensor system created by National Severe Storms Laboratory (NSSL) and activated by NWS. The collector module collects radar and precipitation rate and type data

Inputs: Inputs and metadata for MRMS reside in the configuration file and include the URL from which to download the data, the location to which to save the data, and the parameters passed to the Scheduling module used to create a task that regularly downloads the data.

Outputs: The MRMS collector module sends radar, precipitation rate, and precipitation type to the data Store.

Process: The MRMS collector module downloads files from the MRMS website on a scheduled interval and notifies the MRMS Store there are new files available for use and system retention.

Dependencies: The MRMS module depends on the National Severe Storms Laboratory MRMS products page located at: http://www.nssl.noaa.gov/projects/mrms/

Common Alerting Protocol [CAP]

Background: The Common Alerting Protocol (CAP) collector module is able to collect and process alert messages published in the CAP format from the NWS.[25]

Inputs: Inputs and metadata for CAP reside in the configuration file and include the URL and states from which to download the data, the location to which to save the data, and the parameters passed to the Scheduling module used to create a task that regularly downloads the data.

Outputs: The CAP collector processes the information received from the CAP message and outputs the alert title, information, resource, and area.

[24] National Weather Service NCEP Central Operations. RTMA Documentation available at http://nomads.ncep.noaa.gov/txt_descriptions/RTMA_doc.shtml last accessed 2019.03.29
[25] OASIS, Common Alerting Protocol Version 1.2. available at http://docs.oasis-open.org/emergency/cap/v1.2/CAP-v1.2-os.html, last accessed 2019.03.29.

Process: The CAP collector module collects data from the NWS on a scheduled interval and notifies the CAP Store there are new files available for use and system retention.

Dependencies: The CAP collector module can be configured to receive CAP messages from a variety of sources. IMRCP 2.0 collects alerts from the NWS.

Traffic Controls [Traffic Cntrls]

Background: The Traffic Controls collector module gets data describing the current and planned traffic controls status from the City of Overland Park, Operation Green Light, and other sources within the IMRCP geographical domain of interest. The data are likely to be compliant with the TMDD Center-to-Center (C2C) standard.

Inputs: The Traffic Control collector module collects data describing the current and planned traffic controls status, including type of control device, status of control device, and timing plans for signals. The format and structure of the data varies somewhat across potential source systems, and the particular traffic controls data sources will be those belonging to the initial prototype deployment partner.

Outputs: The Traffic Control collector sends information describing the current and planned traffic controls status, including type of control device and timing plans for signals to the data Store. The format and structure of the data varies somewhat across potential source systems, and the particular traffic controls data sources will be those belonging to the initial prototype deployment partner.

Process: The Traffic Controls collector module collects Traffic Conditions from specified systems and submits the data to Control Ops in the data Store for system retention. The collection interval is dependent on the organization from which the traffic condition information is obtained. The organization is dependent on the geographical domain of interest.

Dependencies: The Traffic Controls collector module is dependent on the City of Overland Park, Operation Green Light and other sources within the IMRCP geographical domain of interest.

Maintenance Rules [Maint Rules]

Background: The Maintenance Rules collector module gets data describing the current and planned roadway maintenance status from sources within the IMRCP geographical domain of interest. There are no data sources available for the IMRCP to collect maintenance rules data, so this module is not implemented.

Special Events [Special Events]

Background: The Events collector module gets data describing the current and planned events. There are no data sources available for the IMRCP to collect special event data, so this module is not implemented.

DMS [DMS]

Background: The DMS collector module gets data pertaining to dynamic message signs in the study area for use on the web interface map and for routing purposes. There are no data sources available for the IMRCP to collect DMS data, so this module is not implemented.

Store

The data Store package includes modules for containing and providing interfaces to all of the persistent data object classes in the system. Maintaining persistent data objects assures that computational modules and user interfaces throughout the system are interacting with a consistent model. Data object classes in the data Store include:

- StormWatch [StormWatchStore]
- NDFD [NDFDStore]
- RAP [RAPStore]
- RTMA [RTMAStore]
- MRMS [MRMSStore]
- AHPS [AHPSStore]
- METRo [METRoStore]
- TrEPS [TrEPSStore]
- MLP [MLPStore]
- KC Scout Detector [KCScoutDetectorsStore]
- KC Scout Incidents [KCScoutIncidentsStore]
- Alerts [AlertsStore]
- Notifications [NotificationsStore]
- Observation View [ObsView]
- CAP [CAPStore]
- Maintenance Operations [Maint Ops]
- Control Operations [Control Ops]
- Special Events [Special Events]
- DMS [DMS]

It is critical to the overall objectives of the IMRCP that its functional modules and user interfaces use and present consistent data sets across all views of the system. A shared data Store fulfills this intent. Any data reused in multiple modules, including system evaluation, is preferentially maintained in the Store. Data in the Store are generally associated with a geodetic location, road segments that may be aggregated into links in a traffic network, or with control points (nodes) within the traffic network. Weather data, for example, is associated with a geodetic location and time. Road weather data, however, is associated with a road segment. Traffic signal states are associated with a node representing the intersection.

The data Store does not depend on any other functional packages within the IMRCP system, but virtually all other packages depend on the Store for access to the persistent data objects. These dependencies are described in each of the other packages.

StormWatch [StormWatchStore]

Background: The StormWatch Store module provides an interface for collecting weather and hydrological observations from the StormWatch collector module.

Inputs: Inputs to the StormWatch Store module include notifications of available data from the StormWatch collector module.

Outputs: The StormWatch Store module provides pavement temperature and flood stage observations from StormWatch to modules requesting data.

Process: The StormWatch Store module subscribes to the StormWatch collector module in the collect system package and is notified when data is available. The Store module then requests and is provided data from the collector module. The StormWatch Store module returns the data to any module that requests the data.

Dependencies: The StormWatch Store module does not have any dependencies.

NDFD [NDFDStore]

Background: The NDFD Store module provides an interface for gathering current and forecasted weather data from the NDFD Collector.

Inputs: The NDFD Store module receives notification from the NDFD collector module of available data.

Outputs: The NDFD Store module provides an interface for cloud coverage, wind speed, air temperature, and dew point temperature observations from the NDFD collector module.

Process: The NDFD Store module subscribes to the NDFD collector module in the Collect system package and is notified when data is available. The Store module then requests the data from the collector module and receives the requested data from the NDFD collector module. The NDFD Store module returns the data to any module that requests data from it.

Dependencies: The NDFD Store module does not have any dependencies.

RAP [RAPStore]

Background: The RAP Store module provides an interface for obtaining current and forecasted weather data from the RAP collector module.

Inputs: The RAP Store module is notified of available data in the RAP collector module.

Outputs: The RAP Store module provides an interface for surface pressure, precipitation rate and type, and surface visibility data from the RAP Collector.

Process: The RAP Store module subscribes to the RAP collector module in the collect system package and is notified when data is available. The Store module then requests the data from the collector module and receives the requested data from the RAP collector module. The RAP Store module returns the data to any module that requests data from it.

Dependencies: The RAP Store module does not have any dependencies.

RTMA [RTMAStore]

Background: The RTMA Store module provides an interface for collecting current and forecasted weather data from the RTMA collector module.

Inputs: The RTMA Store is notified of available data in the RTMA collector module.

Outputs: The RTMA Store module provides an interface for dew point temperature, surface pressure, air temperature, surface visibility, wind direction, wind speed, wind gust speed, and cloud coverage data from the RTMA Collector.

Process: The RTMA Store module subscribes to the RTMA collector module in the Collect system package and is notified when data is available. The Store module then requests the data from the collector module and receives the data from the collector module. The RTMA Store module returns the data to any module that requests data from it.

Dependencies: The RTMA Store module does not have any dependencies.

MRMS [MRMSStore]

Background: The MRMS Store module provides an interface for gathering radar and precipitation rate and type data from the MRMS collector module.

Inputs: The MRMS Store is notified of available data in the MRMS collector module.

Outputs: The MRMS Store module provides an interface for radar, precipitation rate, and precipitation type data from the MRMS collector.

Process: The MRMS Store module subscribes to the MRMS collector module in the Collect system package and is notified when data is available. The Store module then requests the data from the collector module and receives the data from the collector module. The MRMS Store module returns the data to any module that requests data from it.

Dependencies: The MRMS Store module does not have any dependencies.

AHPS [AHPSStore]

Background: The AHPS Store module provides an interface for obtaining flood stage data from the AHPS collector.

Inputs: The AHPS Store module is notified by the AHPS collector module of available data.

Outputs: The AHPS Store module provides an interface for flood stage data from the AHPS collector.

Process: The AHPS Store module subscribes to the AHPS collector module in the Collect system package and is notified when data is available. The Store module then requests the data from the collector module and receives the data from the collector module. The Store module returns the AHPS data to modules that request it.

Dependencies: The AHPS Store module does not have any dependencies.

METRo [METRoStore]

Background: The METRo Store module provides an interface for collecting pavement and subsurface thermal characteristics from the METRo module in the MDSS forecast package.

Inputs: The METRo Store module is notified of available data by the METRo module in the MDSS forecast package.

Outputs: The METRo Store module provides an interface for pavement and subsurface thermal characteristics from the METRo module in the MDSS forecast package.

Process: The METRo Store module subscribes to the METRo collector module in the Collect system package and is notified when data is available. The Store module then requests the data from the collector module and receives the data by the collector module. The Store module returns METRo results to modules that request the data.

Dependencies: The METRO Store module does not have any dependencies.

TrEPS [TrEPSStore]

Background: The TrEPS Store module provides an interface for gathering output data from the TrEPS forecast package.

Inputs: The TrEPS Store module is notified of available data by the TrEPS Output Adapter module in the TrEPS Adapter system package.

Outputs: The TrEPS Store module provides an interface for getting the TrEPS output data. This data includes link volume, vehicle generation, vehicles on each link, queued vehicles, average speed, average density, left-turning vehicles, average green-time, and flow.

Process: The TrEPS Store module subscribes to the TrEPS Output adapter module in the TrEPS adapter system package and is notified when data is available. The Store module then requests the data from the adapter module, and the adapter module provides the output data to the Store module. The TrEPS Store module then provides the output data to the modules that request it.

Dependencies: The TrEPS Store module does not have any dependencies.

MLP [MLPStore]

Background: The MLP Store module provides an interface for obtaining predictions from the MLP package.

Inputs: The MLP Store module is notified by the MLP forecast package of any available data.

Outputs: The MLP Store module provides an interface for getting speed, volume, and occupancy predictions from the MLP package.

Process: The MLP Store module subscribes to the MLP forecast package in the Forecast system package and is notified when data is available. The Store module then requests the data from the forecast module, and the forecast module provides the Store module with the requested data. The MLP Store module then provides MLP prediction data to the modules that request the data.

Dependencies: The MLP Store module does not have any dependencies.

KC Scout Detector [KCScoutDetectorStore]

Background: The KC Scout Detector Store module provides an interface for collecting real-time speed, volume, and occupancy data from the KC Scout Detector collector module.

Inputs: The KC Scout Detector Store module is notified by the KC Scout Detector collector module of any available data.

Outputs: The KC Scout Detector Store module provides an interface for getting real-time speed, volume, and occupancy data from the KC Scout Detector collector module.

Process: The KC Scout Detector Store module subscribes to the KC Scout Detector collector module in the Collector system package and is notified when data is available. The Store module then requests the data from the collector module and is provided the detector data by the collector module. The KC Scout Detector module provides the detector data to other modules in the system that request it.

Dependencies: The KC Scout Detector Store module does not have any dependencies.

KC Scout Incidents [KCScoutIncidentsStore]

Background: The KC Scout Incidents Store module provides an interface for gathering current incidents and current and planned work zones. Incident data includes incident type, time stamp, approximate resolution time, and number of affected lanes. Work zone data includes location, start time, end time, estimated duration, description, and number of affected lanes.

Inputs: Inputs to the KC Scout Incident Store module is notified by the KC Scout Incidents collector module of any new available data.

Outputs: The KC Scout Incident Store module provides an interface for obtaining incident and work zone data from KC Scout.

Process: The KC Scout Incident Store module subscribes to the KC Scout Incident collector module in the Collector system package and is notified when data is available. The Store module then requests the data from the collector module and the collector module provides the data to the Store module. The KC Scout Incident Store module provides the incident and work zone data to other system modules that request it.

Dependencies: The KC Scout Incident Store module does not have any dependencies.

Alerts [AlertsStore]

Background: The Alerts Store module contains the attributes of alerts generated by the system. Alerts may be associated with a geographic extent to which the alert applies and a temporal extent in which it is active.

Inputs: The Alerts Store module is notified by the Alert module of any new available alert data.

Outputs: The attributes available from the Alerts module in the data Store are the same as those taken from the Alert module in the Computation system package. The attributes include the event type (watch or warning); its geographical extent, described by a polyline enclosure; a temporal extent characterized by a start time and an end time; and its rationale or basis.

Process: The Alerts module in the Computation system package notifies the Alerts Store module when new alert information is available. Once notified, the Alerts Store receives the data and stores it to be used by other system components.

Dependencies: The Alerts Store module does not have any dependencies.

Notifications [NotificationsStore]

Background: The Notifications Store is very similar to the Alerts Store. Notifications are generated from specific Alerts that meet configured criteria.

Inputs: The Notifications Store module is notified by the Notifications module of any new available notification data.

Outputs: The Notifications Store module provides an interface for obtaining current Notifications for weather and traffic conditions.

Process: The Notifications module in the Computation system package notifies the Notifications Store module when new notification information is available. Once notified the Notifications Store receives the data and stores it to be used by other system components.

Dependencies: The Notifications Store module does not have any dependencies.

Observation View [ObsView]

Background: The Observation View module allows other modules within the system to request specific observation types from the data Store. The Observation View module returns the results of the requested data to the requesting module.

Inputs: Inputs to the Observation View Store module include requests from other modules within the system for specific observation types within specific geographic and temporal domains.

Outputs: The data requested by other modules within the system are the outputs of the Observation View module.

Process: Modules within the IMRCP system request specific observation type data within a specific geographic and temporal domain from the Observation View module. The Observation View module then requests the specified data from the modules containing those data. The modules containing the specified data return the data to the Observation View module and the Observation View module returns the data to the module that requested it.

Dependencies: The Observation View module is dependent on the other modules in the data Store.

CAP [CAPStore]

Background: The CAP Store module contains the alerts collected by the CAP collector module.

Inputs: The CAP Store module is notified of available data from the CAP collector module.

Outputs: The CAP Store module provides watches, warnings, and advisories data to the Area Layer module in the Web system package.

Process: The CAP Store module subscribes to the CAP collector module in the Collector system package and is notified when data is available. The Store module then requests the data from the collector module, which provides the data to the Store module. The CAP Store module provides CAP data to other system modules that request it.

Dependencies: The CAP module in the data Store does not have any dependencies.

Maintenance Operations [Maint Ops]

Background: The Maintenance Operations (Maint Ops) module contains the record of maintenance operations on roadways and is associated directly with roadway segments. IMRCP v2.0 is not collecting any maintenance operations data so this module has not been implemented.

Traffic Control Operations [Control Ops]

Background: The Traffic Control Operations (Control Ops) module contains the time-varying status of roadway traffic controls in the system. Roadway control states are mapped to specific roadway nodes. IMRCP v2.0 is not collecting any traffic control data so this module has not been implemented.

Special Events [Spcl Evnts]

Background: The Special Events module contains information on the planned special events in the area that may cause a change in traffic flow due to an increase in traffic demand or reduction in roadway capacity. Events may include but are not limited to sporting events, concerts, and conventions. The special events are likely to affect the general public, transit and service providers such as law enforcement, medical or fire responders. IMRCP v2.0 is not collecting any special event data, so this module has not been implemented.

DMS [DMS]

Background: Dynamic messaging signs provide information for travelers along highways in Metro areas. DMS in the Kansas City area alert drivers of incidents and provide travel times for traveler destinations. IMRCP v2.0 is not collecting any DMS data, so this module has not been implemented.

Archive

The Archive package manages the data needed for IMRCP evaluation. It is responsible for retaining records of system input, processing and output, and for providing measures of system performance. Data to be archived are identified in a manner similar to establishing a subscription to IMRCP data. The Archive package contains two modules: Archive Data and Performance Measures (PerfMsrs). The Archive package is not implemented in IMRCP v2.0. All of the data collected by the system is available for system use.

The Archive package depends on the data Store for access to system data.

Archive Data

Background: Forecasts are volatile representations of potential future states. As time advances, the earliest parts of past forecast are replaced by observations of real-world conditions. Forecasts of still-future conditions are replaced by newer forecasts. Nonetheless, the previous forecasts are needed to evaluate the forecasting process and methods. The Archive Data module provides long-term storage and retrieval of data from the IMRCP data Store.

Inputs: Parameters for identifying what data are to be accessed, retrieved and archived are similar to those found in other system subscription components: data types, geographical areas, and time domains of interest. The term of data storage as an archive is indeterminate, as retention is based expressly on support of system evaluation.

Outputs: The Archive Data module offers the data it gathers to other modules such as the modules in the WebPages system package. The data components may include data types, geographical areas, and time domains of interest. The term of data storage as an archive is indeterminate, as retention is based expressly on support of system evaluation.

Process: The Archive Data module creates a schedule to run daily through the Schedule module in the System package. When the schedule is executed, the Archive Data module will be configured to remove all of the data from the data Store that is older than a specific date and time and then place the data in the Archives Data module.

Dependencies: The Archive Data module is dependent on the modules in the data Store.

Performance Measures [Perf Msrs]

Background: The Performance Measures module synthesizes and retains measures of IMRCP system performance from archived data. This assessment is based on a set of measures of effectiveness (MOEs) for the forecasting processes. Generation of MOEs uses a set of rules and computations comparing the forecast data to observed system conditions. For example, an MOE on the percentage of road condition predictions that are within a margin of error relative to actual measured conditions could be applied to pavement temperature or traffic speed. MOE evaluations are retained and aggregated over time to serve as the basis for refining and improving the forecasts.

Inputs: The inputs of the Performance Measures may include any data from the data Store that is useful in creating performance measures.

Outputs: Performance measures are configured through the Performance Measures module using data sets from the data Store.

Process: Performance measures, or MOEs, are configurable with respect to the specific algorithms being applied to particular data sets and to the intervals and spatial domains to which they are applied. For example, a measure could be configured to compare a forecast traffic speed to a measured speed on a specific set of segments over a specific time domain. It might be further configured to do so one time or on a recurring basis.

Dependencies: The Performance Measures module is dependent on the modules in the data Store and the Archive Data module.

System

The System package provides the base system operating modules and utilities. These components are the first to be instantiated on system startup and provide services that enable other components to interact within the system. The System package contains three components: Directory, Configuration and Scheduling. Although not shown in Figure 1, all other components in the system depend on the System package.

Directory

Background: The Directory component identifies the components and services available within the system. Use of a Directory component enhances system extensibility and maintainability relative to a closed system.

Inputs: The inputs to the Directory register method are the IMRCPBlock that is being registered and the instances (the classes and interfaces that Block is interested in) given as a string array. The input to the Directory unregister method is the IMRCPBlock that is being unregistered and its registration ID.

Outputs: The output of the Directory register method is the registration ID. The output of the Directory unregister method is a Boolean value labeling the registration ID as unregistered.

Process: The Directory keeps track of all of the IMRCPBlocks in the system. Each IMRCPBlock is registered with the Directory upon system startup. It registers by referencing the IMRCPBlock with the supported and desired interface and returns the registration ID. Once an IMRCPBlock is registered, the Directoy can be used to look up that IMRCPBlock to be used by other components in the system. The Directory also acts as a monitor for the registered IMRCPBlock by tracking the state changes of all the IMRCPBlocks. The Directory unregisters by referencing the IMRCPBlock block with the registrationId; this returns a Boolean value stating the registration ID is unregistered.

Dependencies: The directory is dependent on IMRCPBlocks and their desired instances.

Table 7. The Directory Component.

Directory
+ init() : void + stop() : void + getInstance() : Directory + register(IMRCPBlock block, string[ ] instances) : int + unregister(IMRCPBlock block, int registrationId) : bool + lookup(String blockname) : IMRCPBlock + registerStateChange(int id, int state, long timestamp) : void

Configuration

Background: The Configuration component contains the configuration parameters for other system components and complements the Directory. Use of a Configuration component provides developmental and operational flexibility, theoretically enabling some system operating characteristics to be modified without stopping and restarting the system.

Inputs: The Configuration component input is the name of the requesting class, the instance name, the key, and the default value which are used to look up configured values from a configuration file.

Outputs: Outputs the int, string, or string array value from the instance of the class requested.

Process: The Configuration component takes in the name and instance of a class and returns the int or string from the instance requested. If error, it can return the default value.

Dependencies: The Configuration component is dependent on the requested class and the configuration file.

Table 8. The Configuration Component.

Config
+ getInstance() : Config + getInt(string class, string instanceName, string key, int default) : int + getString(string class, string intstanceName, string key, string default) : string + getStringArray(string class, string instanceName, string key string default) : string[]

Scheduling

Background: The Scheduling component provides scheduling services to other components in the IMRCP services-based architecture, much like a “Cron job” in a UNIX/Linux environment. The Scheduling and Configuration components work together to orchestrate the process-related operations of the system.

Inputs: The input to the Scheduling createSched method are the IMRCPBlock to be scheduled, midnightOffset, and repeatInterval. The input to the Scheduling cancelSched method is the IMRCPBlock to be canceled and its schedID.

Outputs: The output of createSched is the schedule ID. The output of cancelSched is a Boolean value labeling the schedule ID as unregistered.

Process: The Scheduling component creates and cancels schedules. It creates schedules by referencing the IMRCPBlock with the midnightOffset and repeatInterval and returns the schedID. The Scheduling component cancels schedules by referencing the IMRCPBlock block with the registration ID; this returns Boolean value stating the registration Id is unregistered.

Dependencies: The Scheduling component is dependent on IMRCPBlock.

Table 9. The Scheduling Component.

Sched
+ getInstance() : Scheduling + getNextPeriod(int midnightOffset, long repeatInterval) : Calendar + createSched(IMRCPBlock block, long midnightOffset, int repeatInterval) : int + createSched(IMRCPBlock block, Date timeToStart, int repeatInterval) : int + scheduleOnce(IMRCPBlock block, int delay) : void + cancelSched(IMRCPBlock block, int schedId) : bool

IMRCP Block

Background: The IMRCPBlock processes the data to allow the system to send status, subscribe, notify and unsubscribe to data, get observations, and attach and detach an instance.

Inputs: The IMRCP Block inputs are dependent on class. The subscribe and getObs receive startTime, endTime, startLat, endLat, startLon, and endLon. (The notify, unsubscribe, and getObs take in subscriptionId.)

Outputs: The start and stop methods return a bool representing if the function is stopped or started. The status method can return STOPPED, STARTING RUNNING, IDLE, ERROR, STOPPING. The statusMsg method returns a string dependent on the status, with more information on the status (for example, reason for error). The getObs method returns the observation requested.

Dependencies: The IMRCPBlock component is dependent on IMRCPBlock.

Process: The Directory and Scheduling components call on the IMRCPBlock for information. The information is processed within the IMRCP block and requested information is sent back to the requesting party.

Table 10. The Integrated Model for Road Condition Prediction Block Component.

IMRCPBlock
+ start() : bool + status() : string + statusMsg() : string + stop() : bool + subscribe(int[ ] type, long startTime, long endTime, int startLat, int endLat, int startLon, int endLon, IMRCPBlock subscribe) : int + notify(IMRCPBlock provider, int subscriptionId) : void + unsubscribe(IMRCPBlock subscriber, int subscriptionId) : void + getData(int type, long startTime, long endTime, int startLat, int endLat, int startLon, int endLon, long refTime) : ResultSet + getData(ImrcpResultSet resultSet, int type, long startTime, long endTime, int startLat, int endLat, int startLon, int endLon, long refTime): void + attach(IMRCPBlock blockAttachTo, string instanceName) : void + detach(IMRCPBlock blockDetachFrom) : void + execute() : void + setStatus(int status, int checkStatus) : bool

Table 11. Example Class Diagram of Obs.

Obs
+ type : int + contribId : int + objId : int + startTime : long + endTime : long + timeRecv : long + startLat : int + endLat : int + startLon : int + endLon : int + altitude : int + value : double + detail : String + clearedTime :long

Monitor

The Monitor package provides automated observation of system operations and notifies operators of off-normal conditions. The Monitor is initiated independently of the system itself, but depends on interfaces built into all other components for information on their states. It can be configured to write its observations of system operations to a log file and send email notifications to administrators when IMRCP system attention is needed. The package contains only the SysMon module.

System Monitor [SysMon]

Background: The System Monitor module is used to observe the IMRCP system and notify administrators of off-normal conditions.

Inputs: Each of the modules in the IMRCP system feeds into the System Monitor module so the module is able to monitor the conditions of the entire system.

Outputs: The System Monitor module provides a log file and email notification of the system observations gathered from the other modules to the system administrator.

Process: The System Monitor module subscribes to all other modules within the system and is notified when new data is available in the modules. The module then observes and evaluates the data to ensure normal conditions. The module sends a log file and email notification of the observed data to the system administrator.

Dependencies: The System Monitor module is dependent on all other modules.

Route

The Route package generates routes based on current and predicted transportation system conditions for use by other IMRCP system components and eventual users. The package contains a single implementing Routes module.

Routes

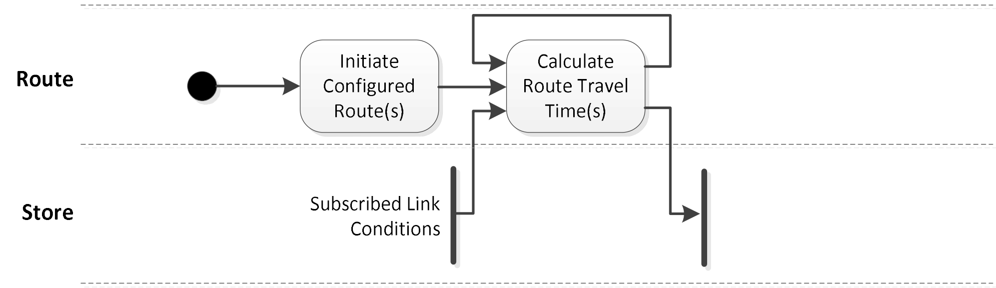
Background: The Routes module generates and stores routes based on current and predicted transportation system conditions for use by other IMRCP system components and eventual users.

Inputs: The Routes module loads predefined routes from a file. The travel times associated with the routes are calculated using the link statistics output files from the TrEPS module in the data Store.

Outputs: Routes will be generated based on expected travel time with forecasted traffic.

Process: Routes are generated from sets of links between an origin and a destination and characterized by distance, travel time, and (potentially) travel time reliability. Route characteristics are generated automatically for certain (subscribed) routes. Routes could also be generated on demand for specific OD pairs and would be stored as if they were otherwise subscribed. Particular route recommendations can then be provided based on shortest distance, fastest travel time, or most reliable travel time. The generated routes are stored, so other system components can access them.

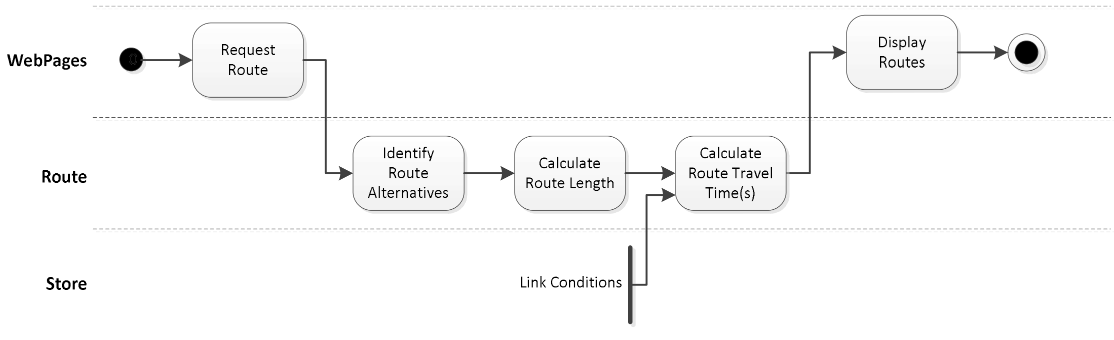
Figure 16 displays the Route process diagram for Routes configured in the system. After the Routes have been initiated, the Route travel times are calculated based on data from the TrEPS data Store module. The travel times are then stored and the process is repeated.



Source: FHWA, 2018.

Figure 16. Configured Route Process Diagram.

The process diagram for the Route Package for user-generated Routes can be seen in Figure 17, below. User-generated Routes are not implemented in the current system. In the user-generated process, users request a set of links or a start and end point through the WebPages. The Route package then identifies Route alternatives. Route lengths are calculated and then, based on the Link Conditions in the Store, Route travel times are calculated. After calculations, the Route travel time is displayed on the WebPages.



Source: FHWA, 2018.

Figure 17. User-Generated Route Process Diagram.

Dependencies: The route module is dependent on the Store for both the originating system condition data and for storage of the resulting route information.

Computation

The Computation package contains modules that use algorithms to compute new observations based on other system observations and conditions. For example, alert generation is based on a set of rules in the form of logical statements about transportation system conditions. A “slick pavement” alert could be based on a measurement of ice on a roadway segment, or on an assessment of pavement surface temperature less than a configured threshold temperature with precipitation present along a roadway segment. The level of alert (i.e., advisory, watch, or warning) depends on the confidence and likelihood of the conditions. An observation or measurement of a condition would merit a warning, whereas an assessment based on future regional conditions might only warrant an advisory.

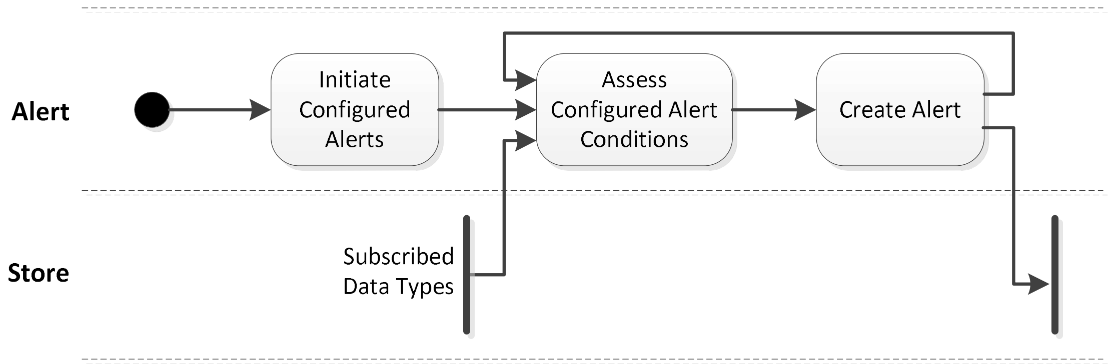
Alert [Alerts]

Background: The Alert module generates alerts of the current and predicted system conditions for use by other IMRCP system components and eventual users.

Inputs: The Alert module generates alerts based on the data found in the data Store in modules such as the TrEPS, MLP, AHPS, and KC Scout Detectors modules. A list of the alerts that can be generated and their algorithms can be found in Appendix M. Other inputs to the Alerts module reside in the configuration file and include the set of rules used to generate alerts and the location to save the alerts on disk.

Outputs: The Alert module generates alerts with time, location, and type conditions.

Process: The Alert module subscribes to modules in the data Store such as TrEPS, MLP, AHPS, and KC Scout Detectors. When these modules receive new data from the Collect system package, the Alert module is notified, and then it gathers the new data. The data is compared with a set of rules in the form of logical statements about transportation system conditions (Appendix M). If the data meets the requirements for generating an alert, an alert is generated. The alert is sent to the data Store for storage. The process can be seen below in a process diagram represented by Figure 18.



Source: FHWA, 2018.

Figure 18. Alert Process Diagram.

Dependencies: The Alert module is dependent on the data Store.

Notification [Notifications]

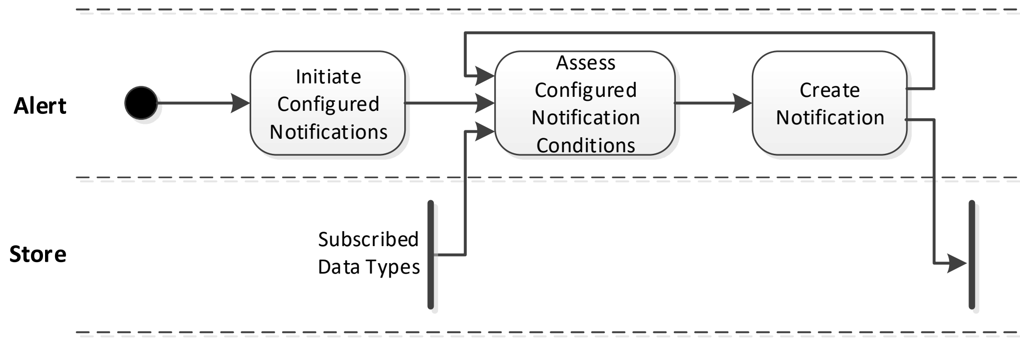
Background: The Notification module in the Alert system package generates notifications based on specific alerts from the Alert Store module. These notifications are presented in the user interface to notify users of off-normal conditions.

Inputs: Inputs to the Notification module include alert data from the Alerts Store module. Other inputs to the Notifications module reside in the configuration file and include the set of alerts used to generate notifications and the location to save the notifications on disk.

Outputs: The Notification module generates notifications as output.

Process: The Notification module subscribes to the AlertsStore module and generates notifications for the configured alerts. Alerts configured to generate notifications are listed in Appendix M.

Dependencies: The Notification module is dependent on the AlertStores module.



Source: FHWA, 2018.

Figure 19. Notification Process.

Speed Stats [SpeedStats]

Background: The Speed Stats module in the Computation system package calculates statistics based on historical data for use in calculating off-normal conditions. The off-normal conditions are used for creating notifications for the user.

Inputs: Inputs to the Speed Stats module include data from the RAP, KC Scout Incidents, and KC Scout Detector Store modules.

Outputs: Outputs of the Speed Stats module include the statistics generated based on the historical data.

Process: On system start-up, the Speed Stats module gets the past two years of speed, weather, incident and work zone data from the RAP, KC Scout Incidents, and KC Scout Detector Store modules for the links with detectors on them. The module then generates the mode values for each link for each 30-minute window of the year. After system start-up, the module runs once a week.

Dependencies: The Speed Stats module is dependent on the RAP, KC Scout Incidents, and KC Scout Detector Store modules.

Geo Services

The Geo Services (GeoSrv) package maintains the fundamental geographical description of the roadway system and its components.

Segment Definitions [SegmentShps]

Background: The Segment Definitions module defines and describes all of the roadway segments in the network of interest. Network links and routes are then assembled from the underlying segment definitions. Maintaining the three-dimensional latitude/longitude/elevation definitions of the segments outside the main data Store simplifies indexing of other properties and conditions across the network and enables the reporting and presentation of data to be abstracted from any particular set of mapping tools. To accommodate changes in road networks due to construction, each segment has a time range associated with it that describes when the segment's geometry is valid.

Inputs: The Segment Definitions module reads SHP or CSV files from an external source that include information on the segments, links, and nodes of the roads.

Outputs: Segments, links, and nodes are distributed from the Segment Definitions module.

Process: The Segment Definitions module is initiated manually by the administrator. The SHP files are collected and processed, and the segment, link, and node information is extracted from the files and stored in a processed CSV file or the database.

Dependencies: The Segment Definitions module is dependent on external sources for the SHP files.

NED [NED]

Background: The NED module in the Geo Services package contains the elevations of the roads in the IMRCP study area from the National Elevation Dataset. The data is used for calculating forecasts and hydrological conditions.

Inputs: The NED module gets elevation data from the National Elevation Dataset.

Outputs: The NED module provides elevation data to other modules in the IMRCP system.

Process: The NED module collects elevation from the National Elevation Dataset and provides the data to other modules in the IMRCP system.

Dependencies: The NED module depends on the United Stares Geological Survey (USGS) national map elevation products page located at:
https://viewer.nationalmap.gov/basic/?basemap=b1&category=ned,nedsrc&title=3DEP%20View

Polygons [Polygons]

Background: The Polygons module defines and describes all of the polygons in the network of interest. Maintaining the three-dimensional latitude/longitude/elevation definitions of the polygons outside the main data Store simplifies indexing of other properties and conditions across the network and enables the reporting and presentation of data to be abstracted from any particular set of mapping tools.

Inputs: The Polygons module gets inputs from external sources and from the CAP Store module.

Outputs: Polygon definitions are the output of the Polygons module.

Process: On system start-up, the Polygons module loads the county polygon definitions for the study area. The module also saves into memory new polygons generated from CAP alerts

Dependencies: The Polygons module is dependent on the CAP Store module and external sources for polygon definitions.

Sensor Locations [SensorLocations]

Background: The Sensor Locations module defines and describes all of the sensor locations in the network of interest. A sensor can be any type of device that detects data at a single point like traffic detectors, environmental sensor stations (ESS), or StormWatch stations.

Inputs: The Sensor Locations module gets inputs from configuration files containing the sensor locations that have been provided by external sources such as KC Scout.

Outputs: Sensor Location definitions are the output of the Sensor Locations module.

Process: On system start-up, the Sensor Locations module loads the metadata of the sensors and stores them in memory so that other system components can access them.

Dependencies: The Sensor Locations module is dependent on external data sources for sensor metadata.

Subscription

The Subscription (Subs) package provides an interface to the data Store for system components that provide data to user interfaces and other systems. It contains a single subscription (Subscriptions) module.

Subscription [Subscriptions]

Background: The Subscription package enables the IMRCP to provide data reports and subscriptions to external systems and end users.

Inputs: The inputs to the Subscription package are the information necessary to create a report or subscription, including the requested observation types, geographic context (which can be an area), group of segments or group of stations, output format, reference time, offset time, and duration.

Outputs: The outputs of the Subscription package are the data requested for a report or subscription. The Reports webpage displays when a report is fulfilled and all available files created for a subscription.

Process: The Subscription module runs every 5 minutes, checking if there are any reports or subscriptions to fulfill. Each report/subscription is processed serially. Parameters defining the filters and context for the report are set by the user through the Web Pages interface. Once a report/subscription is created, the data can be accessed using the provided URL or the Reports webpage.

Dependencies: The Subscription package depends on the Store, GeoSrv, and WebPages packages. The Store provides the data used to fulfill the subscriptions, GeoSrv provides roadway and station definitions, and WebPages provide an interface to create and view subscriptions.

Export

The Export package provides interfaces to the IMRCP system outputs for other systems. Export enables but does not implement any particular integration with other systems. The package contains three classes: CAP (Common Alerting Protocol), C2C (Center-to-Center) and ATIS (Advanced Traveler Information System).

The Export package depends on the DataSrv package for access to system data from the data Store. The Export package is not implemented in the IMRCP v2.0.

Common Alerting Protocol (CAP)

Background: The CAP module provides IMRCP system alerts formatted as Common Alerting Protocol messages.[26] The types of alerts to be published on system CAP interface are configurable.

Inputs: The CAP module inputs alerts in CAP format from the Data Services package.

Outputs: The CAP module outputs alerts in CAP format to outside systems subscribed to the CAP alerts.

Process: The CAP module takes in CAP alerts from the Data Services packages and exports the messages to subscribed parties.

Dependencies: The CAP module is dependent on the Data Services package.

Center to Center

Background: The Export C2C module provides IMRCP outputs bundled into TMDD C2C messages.[27] The data to be published by the C2C interface are configurable.

Inputs: The C2C module inputs alerts in C2C format from the Data Services package.

Outputs: The C2C module outputs alerts in C2C format to outside systems subscribed to the C2C alerts.

Process: The C2C module takes in C2C alerts from the Data Services packages and exports the messages to subscribed parties.

Dependencies: The C2C module is dependent on the Data Services package.

Advanced Traveler Information System

Background: The ATIS module provides IMRCP system alerts in the ATIS format.[28]

Inputs: The ATIS module inputs alerts in ATIS format from the Data Services package.

Outputs: The ATIS module outputs alerts in ATIS format to outside systems subscribed to the ATIS alerts.

Process: The ATIS module takes in ATIS alerts from the Data Services packages and exports the messages to subscribed parties.

Dependencies: The ATIS module is dependent on the Data Services package.

Web

The Web package defines the layers for the map webpage.

Alerts Layer

Background: The Alerts Layer module in the Web package is used to define the alerts layers on the web interface.

Inputs: Inputs to the Alerts Layer module include alert data from the Alerts module in the data Store. The alert data includes a data type, location, description, and start and end time. The Alerts Layer module also obtains

[26] https://www.fema.gov/common-alerting-protocol
[27] https://www.standards.its.dot.gov/Factsheets/Factsheet/17
[28] https://www.standards.its.dot.gov/factsheets/factsheet/54

data from the KC Scout Incidents module in the data Store. The Alerts Layer module also gets definition data from the GeoServices system package.

Outputs: The definition of the alerts layer for the web interface is the output of the Alerts Layer module.

Process: The Alerts Layer module gets alert data from the Alerts module and KC Scout Incidents module in the data Store and the GeoServices package. Using this data, the Alerts Layer module defines the alert layers for the web interface map. The alert layer definitions are then provided to the WebPages package to be used on the web interface.

Dependencies: The Alerts Layer module is dependent on the Alerts module and KC Scout Incidents module in the data Store and the GeoServices package.

Area Layer

Background: The Area Layer module in the Web package is used to define the area layers on the web interface.

Inputs: Inputs to the Area Layer module include area data from the NDFD, RAP, RTMA, and CAP modules in the data Store. The Area Layer also obtains polygon definitions from the Polygons module in the GeoServices package.

Outputs: The definition of the area layers for the web interface are the output of the Area Layer module.

Process: The Alerts Layer gets alert data from the Alerts module in the data Store and defines the alert layer for the web interface map. The alert layer definitions are then provided to the WebPages package to be used on the web interface.

Dependencies: The Alerts Layer module is dependent on the Alerts module in the data Store.

Road Segment Layer

Background: The Road Segment Layer module in the Web package is used to define the road segment layers on the web interface.

Inputs: Inputs to the Road Segment Layer module include road weather and traffic data from the data Store. The module uses data from the StormWatch, NDFD, RAP, RTMA, AHPS, METRo, TrEPS, MLP, KC Scout Detector, and Routes modules in the data Store. The Road Segment Layer also get road segment definitions from the Segment Definitions module in the GeoServices system package.

Outputs: The road segment layer definitions are the output of the Road Segment Layer module.

Process: The Road Segment Layer module in the Web package requests and receives segment definitions data from the Segment Definitions module in the GeoServices package. The module also requests and receives road weather and traffic data from the data Store. The module then gives the definitions to the Web package to be used on the web interface.

Dependencies: The Road Segment Layer module is dependent on modules in the data Store and GeoServices package.

Web Pages

The WebPages package provides user interfaces to the IMRCP system outputs. The system web pages enable users to browse the system-provided forecasts; to request and subscribe to specific segment condition, alert, and route outputs; and to provide feedback. The package the following web pages:

- Index – the main login user interface.
- Map – providing a map user interface for browsing system output.
- Reports – lists user defined report and subscription output.
- Help – system user documentation.
- Dashboard – overall system view of key data and performance metrics

The WebPages package depends on the Web package for access to system data from the data Store.

Index

The Index provides the user login interface and text describing the system purpose and high-level view of the system interfaces. Users are required to enter a username and corresponding password to log into the system.

Primary Menu Bar

The menu bar navigates users to the Map, Reports, Help, and Logoff interfaces.

Map

The Map provides a selectable, layered presentation of archived, current, and forecast traffic and weather conditions across the roadway network. A time control enables the user to change the time perspective being viewed on the map.

The map provides several sets of controls for setting the view context. Typical map interactions (e.g., pan, zoom) set the spatial context for the view. Time controls set the temporal context for the view. Layer controls set the map overlays, icons, and display options. A reports and subscriptions control invokes an interface for generating reports and subscriptions based on map selections.

Base map interactions enable users to set the spatial context for viewing data in the system. The map can be zoomed to set the scope of the view and panned to move across the map. The maximum view level (greatest geographical scope) may be limited to reduce the amount of data and corresponding level of visual clutter needed to fill that viewport.

Time controls enable setting the reference date/time from which forecasts and recent experience is viewed. The default reference date and time is “now,” based on the local client date and time. The reference date or time is changed through a control that enables the user to select a different date or time on a calendar. (Selecting any particular date and time does not assure that data will be available for that temporal context.) A relative time selector enables the user to select a particular time view relative to the reference time. Going back in time from the reference enables viewing observations and model results as they were current at that time. Going forward in time from the reference point enables forecast data to be viewed as it was available at that reference date and time.

Map layer controls set the data that are to be presented on the map interface. Selection categories are based on map graphical constructs. Layers available for each category correspond to particular data elements available from the Store as defined in Appendix N. “Point” constructs are used to locate and identify observations from sensors (e.g., traffic sensors) and alerts to localized events (e.g., incidents on roadways). Available “point” layers include:

- None
- Traffic Detectors
- Stormwatch Stations
- AHPS Stations
- All Alerts

- Traffic Alerts
- Road ZCondition Alerts
- Weather Alerts

"Road" constructs are used to locate and describe attributes of roadway segments including traffic and pavement conditions. Available "road" layers include:

- None
- Road Network Model
- Pavement State
- Pavement Temperature (F)
- Pavement Snow Depth (in)
- Pavement Flood Depth (in)
- Traffic (%)
- Traffic Speed (mph)
- Traffic Density
- Traffic Flow (veh/min)
- Routes (min)

"Area" constructs are used to represent areal attributes such as atmospheric conditions and weather alert areas. Available "area" layers include:

- None
- Air Temp (F)
- Surface Visibility (mi)
- Wind Gust Speed (mph)
- Wind Speed (mph)
- Radar (dBZ)
- Precip Rate and Type
- NWS Alerts

Map "Settings" enable the user to select overall map attributes. These include the road types that are to be included in the map display ("highways" and/or "arterials"), whether the map refreshes itself to maintain the reference date and time at "now," whether to enable alert notifications as they are created within the system, and which attributes to save to a default view associated with the user's account profile.

The report and subscription control enables users to generate reports of and subscriptions to data from the Store. The report and subscription process first requires a user to select a type of report; e.g., "stations," "segments," or "area." The user is then returned to the map to select the particular stations, segments, or area for which data is to be reported or subscribed. One or more of each type can be selected. Tool tips in each context provide instructions as to how to select the objects for reporting.

Selecting "stations" displays detector stations on the map; selecting "segments" displays roadway segments; selecting "area" enables drawing a rectangle to select an ad hoc area. Making the selection leads to a dialog for defining the particular report filters and attributes. The user can manually modify the selection coordinates, provide a name for the report, select up to five observation types (as identified in Appendix O), select the report format, and choose whether to run the report or create a subscription using these parameters. Running a report requires specifying a reference time and time window around that time. Creating a subscription requires setting the subscription interval (how often the system will run the subscribed report) and time window. Submitting the report and subscription request starts the data query process. Results of the report or subscription are accessed through the Reports menu item.

Reports

The Reports web interface lists user-defined, on-demand report output as well as recurring subscriptions and their output files. Report and subscription creation, filter criteria, and execution status are shown for each report or subscription. Selecting a subscription displays the available results files for that subscription. Selecting a report or subscription file brings up an open/save dialog for that particular report or file. Reports and files are retained by the system for up to 2 weeks after they are last accessed.

Help

The Help interface links to a downloadable set of instructions for the user interface.

Logoff

The Logoff menu item ends the current IMRCP session and returns to the Index page.

Dashboard

The Dashboard component presents key road network and weather performance metrics to system users through the IMRCP web interface. The particular parameters to be displayed are configurable within the system, but the data on which they are based must be available from the data Store. The Dashboard is not implemented in IMRCP v2.0.

Apps

The Apps package provides a container for future mobile applications accessing IMRCP outputs. No public user interface or applications are planned for this initial research and prototype development effort, but the system will be developed to enable such applications in future versions.

The Apps package will depend on the DataSrv package for access to system data from the data Store.

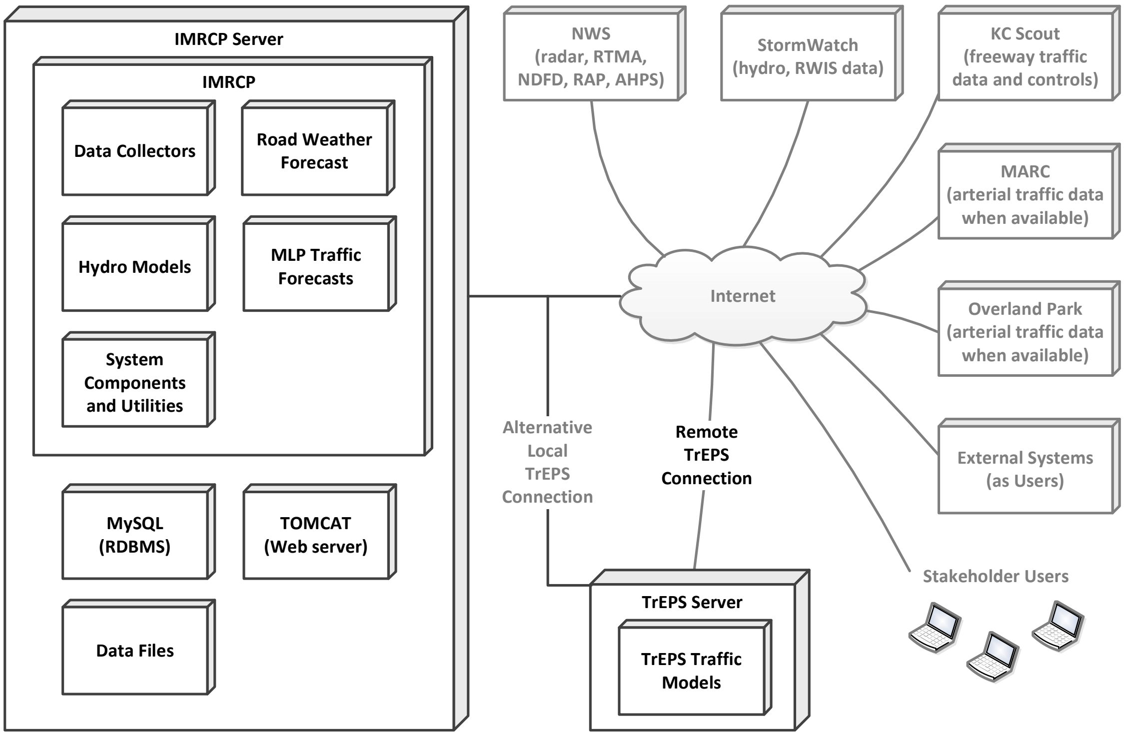
System Computing Infrastructure

This deployment of the IMRCP is a system demonstration prototype. As such, the focus is on the development, and it is desirable to simplify the deployment in order to minimize system management overhead. To that end, the prototype is being deployed to a core IMRCP environment and a remote TrEPS environment. It provides distributed user access for the development team, the review team, and the partner prototype agency. The following factors contribute todetermining this configuration:

- IMRCP data services and computational services are closely linked to and benefit from co-location to reduce latencies and remote network calls.
- TrEPS functions as an independent computing environment that exchanges data through files with the core IMRCP modules.
- Other data sources, (for example, atmospheric weather and hydrology) are provided by external web services that do not drive any particular deployment solution.
- Potential future phase operational deployments would be linked to transportation management centers (TMCs) and integrated management solutions. The bulk of the real-time operational and traffic data comes from transportation management systems, and the majority of the end users are either agency personnel or travelers for whom data is already sourced from TMCs and their

associated systems. It makes sense within that context to anticipate and demonstrate a deployment as a forecast “appliance” rather than a distributed system with the potential limitations of traffic predictions as external services.

The demonstration system deployment is shown in Figure 20. The IMRCP system software and the TOMCAT Web server will be deployed on a common server. The server will use a high-bandwidth connection to the Internet to access data contributors and to provide access to IMRCP forecast products for stakeholders and systems. This configuration will be subject to review and re-evaluation during the development process to assure the project and system needs are being met.



Source: FHWA, 2018.

Figure 20. Integrated Model for Road Condition Prediction Deployment.

Chapter 4. References

ISO/IEC/IEEE. *Systems and Software Engineering – Life Cycle Processes – Requirements Engineering*. ISO/IEC/IEEE 29148:2011.

ISO/IEC/IEEE. *Systems and software engineering – Architecture description*. ISO/IEC/IEEE 42010:2011.

Leidos. 2015. *Integrated Modeling for Road Condition Prediction Model Analysis*. 2015. Unpublished working paper developed under FHWA Contract DTFH61-12-D-00050, Task Order 5022, Integrated Modeling for Road Condition Prediction.

Leidos. 2015. *Integrated Modeling for Road Condition Prediction Concept of Operations*. Unpublished working paper developed under FHWA Contract DTFH61-12-D-00050, Task Order 5022, Integrated Modeling for Road Condition Prediction.

Leidos. 2016. *Integrated Modeling for Road Condition Prediction System Requirements.* Unpublished working paper developed under FHWA Contract DTFH61-12-D-00050, Task Order 5022, Integrated Modeling for Road Condition Prediction.

Lukasik, et al. 2011. *Assessment of Emerging Opportunities for Real-time, Multimodal Decision Support Systems in Transportation Operations*. Report Number FHWA-JPO-10-058. Washington, DC: FHWA.

Mahmassani, H. S., 2001. "Dynamic network traffic assignment and simulation methodology for advanced system management applications." *Networks and Spatial Economics*, 1(3-4): 267-292.

Mahmassani, H. S., Dong, J., Kim, J., Chen, R., & Park, B. 2009. *Incorporating Weather Impacts in Traffic Estimation and Prediction Systems.* Report Number FHWA-JPO-09-065. Washington, DC: FHWA.

Mahmassani, H. S., Hou, T., Kim, J., Chen, Y., Hong, Z., Halat, H., & Haas, R. 2014. *Implementation of a Weather Responsive Traffic Estimation and Prediction System (TrEPS) for Signal Timing at Utah DOT.* Report Number FHWA-JPO-14-140. Washington, DC: FHWA.

Appendix A. Glossary

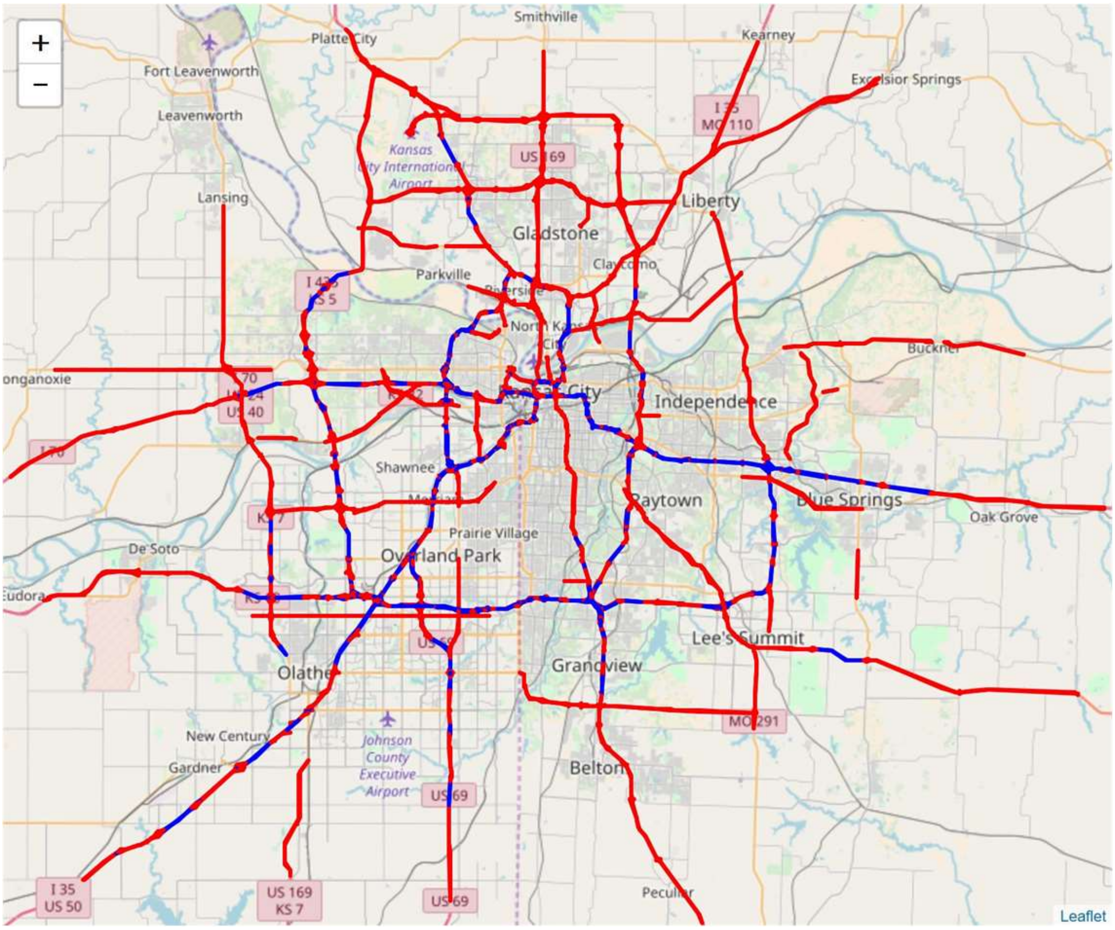
AHPS	Advanced Hydrologic Prediction Service
AMS	Analysis, Modeling and Simulation
ATDM	Active Transportation and Demand Management
ATMS	Advanced Transportation Management System
AVL	Automatic Vehicle Location
C2C	Center-to-Center
CAP	Common Alerting Protocol
ConOps	Concept of Operations
CV	Connected Vehicle
DAG	Directed Acyclic Graph
DMA	Dynamic Mobility Applications
DMS	Dynamic Message Signs
DOT	Department of Transportation
DYNASMART	Dynamic Network Assignment-Simulation Model for Advanced Roadway Telematics
EMDSS	Enhanced Maintenance Decision Support
EnableATIS	Enable Advanced Traveler Information Systems
ESS	Environmental Sensor Station
FHWA	Federal Highway Administration
GPS	Global Positioning Service
IMRCP	Integrated Model for Road Condition Prediction
INFLO	Integrated Network Flow Optimization
ITS	Intelligent Transportation Systems
MAW	Motorist Advisories and Warnings
MDSS	Maintenance Decision Support System
MOE	Measures of Effectiveness
NCAR	National Center for Atmospheric Research
NDFD	National Digital Forecast Database
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OD	Origin-Destination
PGM	Probabilistic Graphical Model
Q-WARN	Queue Warning
RAP	Rapid Refresh
RCTM	Road Conditions Treatment Module
RTMA	Real-Time Model Assessment
RWF	Road Weather Forecast

RWIS	Road Weather Information System
SAD	System Architecture Description
SDD	System Design Description
SHRP2	Strategic Highway Research Program 2
SPD-HARM	Speed Harmonization
TMC	Transportation Management Center
TMDD	Traffic Management Data Dictionary
TrEPS	Traffic Estimation and Prediction System
TSMO	Transportation Systems Management and Operations
URL	Uniform Resource Locator
USDOT	United States Department of Transportation
USGS	United States Geological Survey
VDT	Vehicle Data Translator
WAF	Weather Adjustment Factor
WxDE	Weather Data Environment

Appendix B. Kansas City Study Area

The study city for the IMRCP was selected out of several candidate cities in the U.S. based on several criteria. Kansas City was chosen because of the working relationship between the local agencies and the data availability. The Kansas City Metro area is subject to highly variable weather conditions and local recurring congestion.

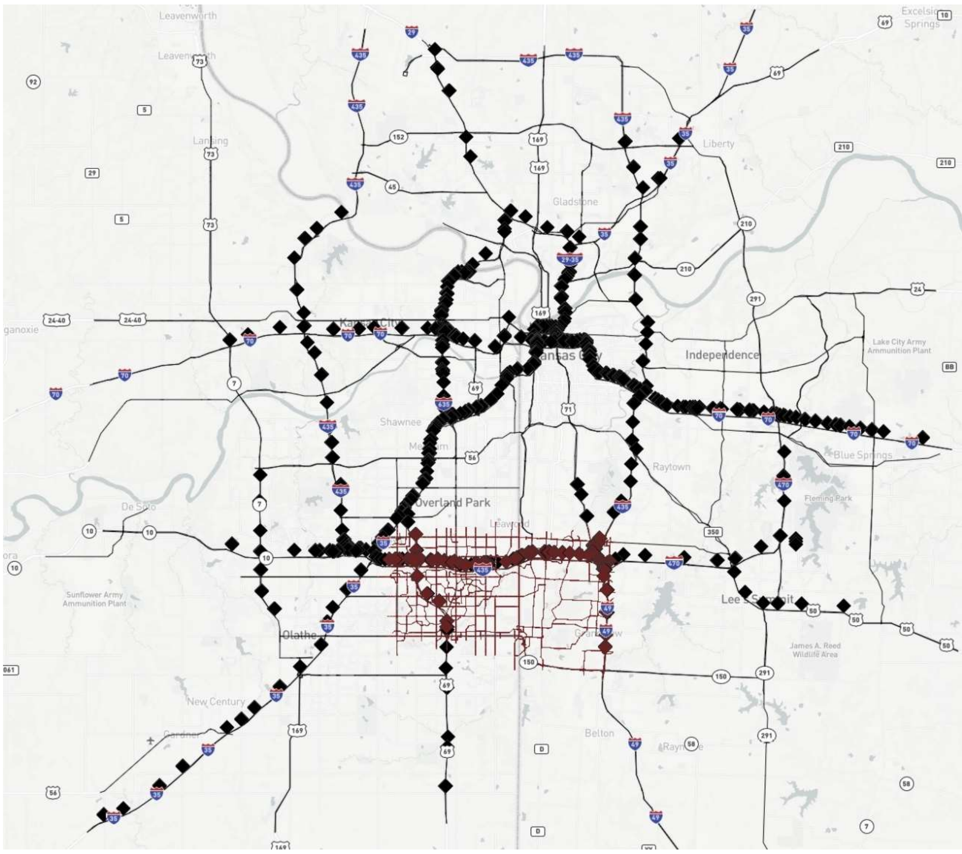
The road network model (Figure 21) includes links both with and without traffic detectors.



Source: FHWA, 2019

Figure 21. Road Network Configuration for Study Area.

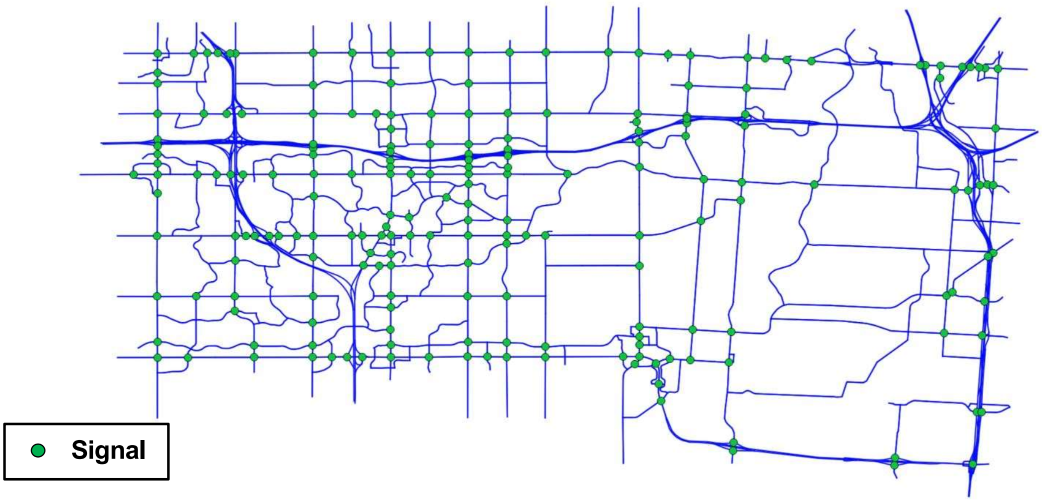
Traffic detectors are spread widely but unevenly across the metro area, as shown in Figure 22.



Source: FHWA, 2019

Figure 22. Traffic Detectors in Study Area.

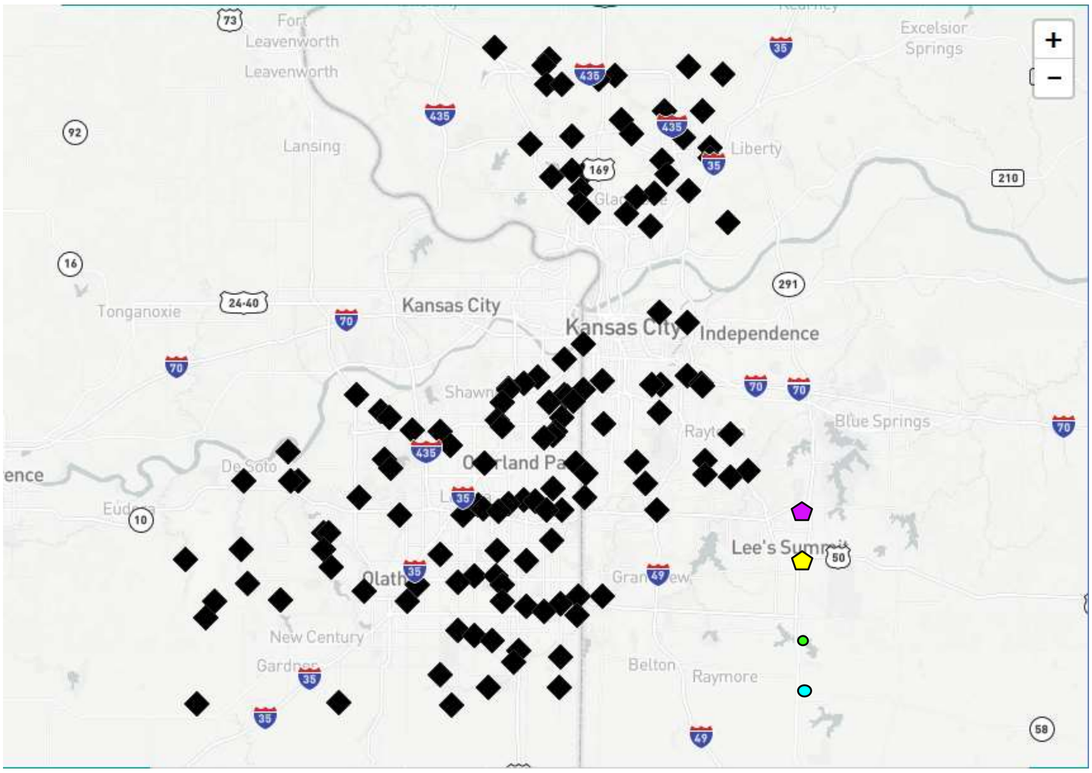
There are 215 traffic signals being modeled, all in the IMRCP Phase 2 study area as shown in Figure 23.



Source: FHWA, 2019

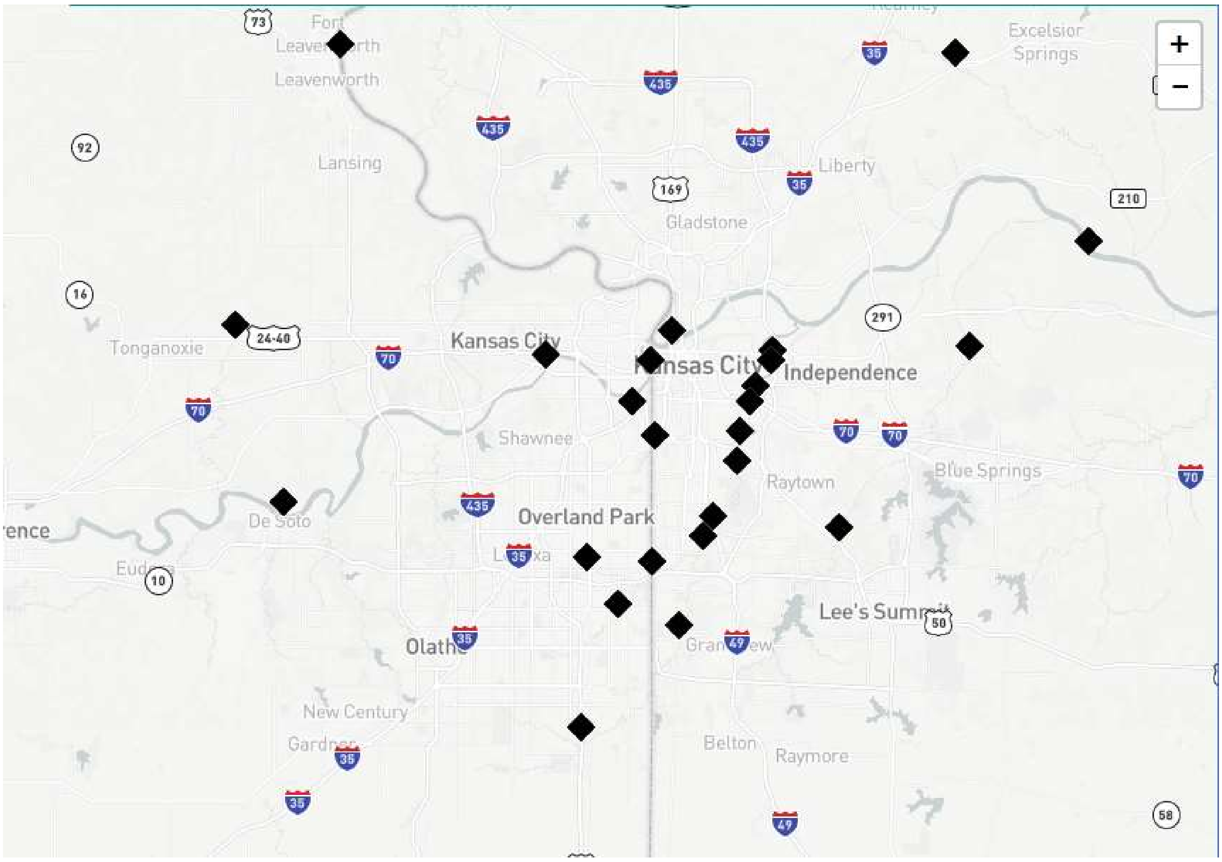
Figure 23. Traffic Signals Modeled in Study Area.

Weather data in the study area is collected from weather stations including StormWatch stations, AHPS stations, and an ASOS station.



Source: FHWA, 2019

Figure 24. Stormwatch Hydrology Stations in Study Area.



Source: FHWA, 2019

Figure 25. AHPS Hydrology Stations in Study Area

Work Zone data is also collected from the following agency websites:

- The MissouriDOT work zones information page located at: http://traveler.modot.org/report/modottext.aspx, last accessed 2019.03.29.
- The Overland Park, Kansas Future Projects information page located at https://www.opkansas.org/resident-resources/traffic-and-transportation/road-constructionpublic-improvement-projects/future-road-constructionpublic-improvement-projects/, last accessed 2019.03.29
- The Kansas DOT Kansas City Metro Projects page located at https://www.ksdot.org/kcMetro/laneclose.asp, last accessed 2019.03.29
- The City of Leawood (Kansas) Engineering projects page located at https://www.leawood.org/public%20works/constructionprojects.aspx, last accessed 2019.03.29
- The City of Kansas City, MO Project Tracker located at http://maps.kcmo.org/apps/cip/, last accessed 2019.03.29

Appendix C. Input Data Availability

Table 12. Input Data Available Frequency and Computation Frequency.

Source	Available Frequency	Computation Frequency
KC Scout Events Real-Time Data Feed	1 min.	not applicable
KC Scout Detector Real-Time Data Feed	1 min.	not applicable
AHPS	15 min.	not available
NDFD	1 hr.	1 hr.
RAP	1 hr.	1 hr.
RTMA	1 hr.	1 hr.
WxDE	5 min.	not applicable
StormWatch	15 min.	Rainfall-12 hr. Stage-12 hr. Air Temp- 15 min. Rel Humid- 15 min. Wind Direction- 15 min. Wind Velocity- 15 min. Pavement Conduct- 12 hr. Road State- 12 hr. Road Temp- varies, approx.10 min.
RADAR	Available 2 min. collect 4 min.	not applicable
CAP	2 min.	not applicable

Source: FHWA, 2019

Appendix D. TrEPS Module Inputs and Outputs

Table 13. TrEPS Module Inputs and Outputs

TrEPS Output File	Input	Output
Network State Estimation (RT-DYNA)	**Network topology:** Network.dat, movement.dat, leftcap.dat **Network Control:** signal.dat, ramp.dat, vms.dat **Transit data:** bus.dat **Scenario data:** system-rt.dat, scenario.dat **Incident data:** incident.dat **Pricing data:** pricing.dat **Output_option:** output_option.dat	**Link Information:** links speed, links densities, link volumes, queue lengths. **Vehicle information:** vehicle trajectory, travel time, travel distance, stop time. **Network overall statistics:** average travel time, average travel distance, average stop time.
Network State Prediction (P-DYNA)	**Network topology:** network.dat, movement.dat, leftcap.dat **Network control:** signal.dat, ramp.dat, vms.dat **Transit data:** bus.dat **Scenario data:** system-rt.dat, scenario.dat **Incident data:** incident.dat **Pricing data:** pricing.dat **Output_option:** output_option.dat	**Link information:** links speed, links densities, link volumes, queue length. **Vehicle information:** vehicle trajectory, travel time, travel distance, stop time. **Network overall statistics:** average travel time, average travel distance, average stop time.
OD Estimation (ODE)	**Static input:** Network topology, stage length, and observation length. **Dynamic input:** Link proportions, real-world link densities.	Estimated OD coefficients. Initial guess for the next stage.
OD Prediction (ODP)	**Static input:** Network topology, stage length. **Dynamic input:** OD estimated coefficients.	OD demand for the next stage.

Source: FHWA, 2019

Table 13. TrEPS Module Inputs and Outputs. (continued)

TrEPS Output File	Input	Output
Long Term Consistency Check (LTCC)	**Static input:** Network topology, departure time interval, observation interval. **Dynamic input:** Estimated OD values for the current departure time interval. Link proportion data for the current departure time interval. Real world observations (in terms of link densities).	Adjusted OD Demand for the next departure time interval.
Short Term Consistency Check (STCC)	**Static input:** Network topology, observation interval. **Dynamic Input:** Network state variables of the current observation interval, Observed link densities of the current observation interval.	Adjusted network state variables for the next simulation interval.

Source: FHWA, 2019

Appendix E. Kansas City Scout Real-Time Detector XML File Example


```
<s:Envelope xmlns:s="http://schemas.xmlsoap.org/soap/envelope/">
<s:Body>
<GetDetectorDataResponse xmlns="http://tempuri.org/">
<GetDetectorDataResult>
<?xml version="1.0"?>
<detectors xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="DetectorRealtimeData.xml">
        <date>20161228</date>
        <time>095750000</time>
        <agency>KCATMS</agency>
        <detector>
                <detector-Id>283</detector-Id>
                <lane>
                <lane-Number>1</lane-Number>
                <lane-Status>OK</lane-Status>
                <lane-Volume>2</lane-Volume>
                <lane-Occupancy>1.4114</lane-Occupancy>
                <lane-Speed>41.256</lane-Speed></lane>
        </detector>
        <detector>
                <detector-Id>291</detector-Id>
                <lane>
                <lane-Number>1</lane-Number>
                <lane-Status>OK/OK</lane-Status>
                <lane-Volume>0</lane-Volume>
                <lane-Occupancy>1.0849</lane-Occupancy>
                <lane-Speed>37.5822</lane-Speed></lane>
                <lane>
                <lane-Number>2</lane-Number>
                <lane-Status>OK/OK</lane-Status>
                <lane-Volume>2</lane-Volume>
                <lane-Occupancy>5.6616</lane-Occupancy>
                <lane-Speed>30.8906</lane-Speed></lane>
        </detector>
</detectors><
/GetDetectorDataResult>
</GetDetectorDataResponse>
</s:Body>
</s:Envelope
```

Appendix F. Kansas City Scout Real-Time Incident Feed XML File Example


```
<s:Envelope xmlns:s="http://schemas.xmlsoap.org/soap/envelope/">
<s:Body>
<GetIncidentDataResponse xmlns="http://tempuri.org/">
<GetIncidentDataResult>
<?xml version="1.0"?>
<events xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xsi:noNamespaceSchemaLocation="eventInformation.xml">
<datetime>Wed Dec 28 09:57:33 CST 2016</datetime>
<agency>KCATMS</agency>
<event>
        <eventId>332170</eventId>
        <eventType>Scheduled</eventType>
        <eventStatus>Active</eventStatus>
        <eventLocation>
        <crossStreets>
        <onStreetName>I-70 WB</onStreetName>
        <atCrossStreet>AT 110TH ST</atCrossStreet>
        <longitude>-94.831264</longitude>
        <latitude>39.106216</latitude></crossStreets></eventLocation>
        <event-Description>ROADWORK
                I-70 WB AT 110TH ST
                LEFT LANE CLOSED
                EST. CLEARANCE TIME: 5/1/2017 9:00 AM</event-Description>
        <event-LanesBlockedOrClosedCount>1</event-LanesBlockedOrClosedCount>
        <laneClosedList>1</laneClosedList>
        <laneConfigurationList>1,2,3</laneConfigurationList>
        <eventStartTime>Tue Nov 29 09:18:15 CST 2016</eventStartTime>
        <event-TimeLineEstimatedDuration>220303</event-TimeLineEstimatedDuration>
</event>
<event>
        <eventId>335637</eventId>
        <eventType>Incident</eventType>
        <eventStatus>Active</eventStatus>
        <eventLocation>
        <crossStreets>
        <onStreetName>I-470 SB</onStreetName>
        <atCrossStreet>AT WOODS CHAPEL RD</atCrossStreet>
        <longitude>-94.3564</longitude>
        <latitude>38.983288</latitude></crossStreets></eventLocation>
        <event-Description>STALLED VEHICLE
```

I-470 SB AT WOODS CHAPEL RD
RIGHT SHOULDER
EST. CLEARANCE TIME: 10:15 AM</event-Description>
<event-LanesBlockedOrClosedCount>0</event-LanesBlockedOrClosedCount>
<laneClosedList></laneClosedList>
<laneConfigurationList>1,2</laneConfigurationList>
<eventStartTime>Wed Dec 28 09:50:03 CST 2016</eventStartTime>
<event-TimeLineEstimatedDuration>25</event-TimeLineEstimatedDuration>
</event>
</events>
</GetIncidentDataResult>
</GetIncidentDataResponse>
</s:Body>
</s:Envelope

Appendix G. StormWatch File Example

TH09 – Roe @ Tomahawk Creek Bridge Deck Temperature

Reading	Receive	Value	Unit	Quality
01/08/2017 05:03:18 PM	01/08/2017 05:06:20 PM	31.1	F	A
01/08/2017 04:26:18 PM	01/08/2017 04:29:20 PM	33	F	A
01/08/2017 04:00:18 PM	01/08/2017 04:03:20 PM	35	F	A
01/08/2017 03:44:18 PM	01/08/2017 03:47:20 PM	36.8	F	A
01/08/2017 03:18:18 PM	01/08/2017 03:21:21 PM	38.7	F	A
01/08/2017 01:37:18 PM	01/08/2017 01:40:20 PM	40.1	F	A
01/08/2017 01:08:18 PM	01/08/2017 01:11:20 PM	38.1	F	A
01/08/2017 01:05:18 PM	01/08/2017 01:08:20 PM	36	F	A
01/08/2017 12:47:18 PM	01/08/2017 12:50:20 PM	34.1	F	A
01/08/2017 12:30:18 PM	01/08/2017 12:33:20 PM	32.3	F	A
01/08/2017 12:21:18 PM	01/08/2017 12:24:20 PM	30.2	F	A
01/08/2017 12:08:18 PM	01/08/2017 12:11:20 PM	28.1	F	A
01/08/2017 11:29:18 AM	01/08/2017 11:32:20 AM	26.1	F	A

Appendix H. TrEPS Input Files Description

Table 14. TrEPS Input Files Description for Weather.dat

Record Type	Field	Format	Width	Description
Network-wide Weather count	1	Integer	Free	≥1: Number of time periods with network-wide weather; 0: if no network-wide weather is specified[1]
Network Weather Information	1 2 3 4 5	Float Float Float Float Float	Free Free Free Free Free	Visibility (mile). Rain intensity (inch per hour) Snow intensity (inch per hour) Start time for the 1st network-wide weather condition (minutes) End time for the 1st network-wide weather condition weather condition (minutes)
…..	…..	…..	…..	…..
Network Weather Information	1 2 3 4 5	Float Float Float Float Float	Free Free Free Free Free	Visibility (mile). Rain intensity (inch per hour) Snow intensity (inch per hour) Start time for the last network-wide weather condition (minutes)[2] End time for the last network-wide weather condition weather condition (minutes)[2]
Number of links with link-specific weather	1	Integer	Free	≥ 1: Number of links with link-specific weather condition; 0: if no link-specific weather is specified[1]
Link Information	1 2 3 4	Integer Integer Integer Integer	Free Free Free Free	Link counter (1st link with inclement weather condition) From node To node Number of time periods
Weather Information	1 2 3 4 5	Float Float Float Float Float	Free Free Free Free Free	Start time for the 1st weather condition (minutes) End time for the 1st weather condition (minutes) Visibility (mile) Rain intensity (inch per hour) Snow intensity (inch per hour)
…..	…..	…..	…..	…..
Weather Information	1 2 3 4 5	Float Float Float Float Float	Free Free Free Free Free	Start time for the Nth weather condition (minutes)[2] End time for the Nth weather condition (minutes)[2] Visibility (mile) Rain intensity (inch per hour) Snow intensity (inch per hour)
…..	…..	…..	…..	…..

Source: FHWA, 2019

Table 14. TrEPS Input Files Description for Weather.dat. (continued)

Record Type	Field	Format	Width	Description
Link Information	1 2 3 4	Integer Integer Integer Integer	Free Free Free Free	Link counter (last link with inclement weather condition) From node To node Number of time periods
Weather Information	1 2 3 4 5	Float Float Float Float Float	Free Free Free Free Free	Start time for the 1st weather condition (minutes) End time for the 1st weather condition (minutes) Visibility (mile) Rain intensity (inch per hour) Snow intensity (inch per hour)
…..	…..	…..	…..	…..
Weather Information	1 2 3 4 5	Float Float Float Float Float	Free Free Free Free Free	Start time for the Nth weather condition (minutes) End time for the Nth weather condition (minutes) Visibility (mile) Rain intensity (inch per hour) Snow intensity (inch per hour)

[1]*Note that "0" must be specified in this field if there is no network-wide / link-specific weather. If there is no weather condition to specify, set this field for both network-wide and link-specific weathers to be "0" or simply remove weather.dat from the working directory*

[2]*Each weather condition will start at the minute specified for its start time and end at the time immediately before the minute specified for the end time (i.e., start time ≤ time period with weather < end time).*

Source: FHWA, 2019

Table 15. TrEPS Input Files Description for Incident.dat

Record Type	Field	Format	Width	Description
General	1	Integer	Free	Total number of incidents in network
Incident description	1 2 3 4 5	Integer Integer Float Float Float	Free Free Free Free Free	Upstream node of the 1st incident link Downstream node of the 1st incident link Start time of the 1st incident (minutes) End time of the 1st incident (minutes) Severity[1] of the 1st incident
…..	…..	…..	…..	…..
Incident description	1 2 3 4 5	Integer Integer Float Float Float	Free Free Free Free Free	Upstream node of the last incident link Downstream node of the last incident link Start time of the last incident (minutes) End time of the last incident (minutes) Severity[1] of the last incident

[1]*The fraction of link capacity lost due to the incident (remaining capacity becomes one minus the severity)*

Source: FHWA, 2019

Table 16. TrEPS Input Files Description for WorkZone.dat

Record Type	Field	Format	Width	Description
General	1	Integer	Free	Total number of work zones in network
Work zone description	1 2 3 4 5 6 7	Integer Integer Float Float Float Integer Integer	Free Free Free Free Free Free Free	Upstream node of the 1st work zone link Downstream node of the 1st work zone link Start time of the 1st work zone (minutes) End time of the 1st work zone (minutes) Capacity reduction rate[1] for the 1st work zone Posted speed limit for the 1st work zone Queue discharge rate for the 1st work zone (vphpl)
…..	.....	.....	.....	.....
Work zone description	1 2 3 4 5 6 7	Integer Integer Float Float Float Integer Integer	Free Free Free Free Free Free Free	Upstream node of the last work zone link Downstream node of the last work zone link Start time of the last work zone (minutes) End time of the last work zone (minutes) Capacity reduction rate[1] for the last work zone Posted speed limit for the last work zone Queue discharge rate for the last work zone (vphpl)

[1]*The fraction of physical link capacity (lane closure) lost due to the work zone*

Source: FHWA, 2019

Table 17. TrEPS Input Files Description for vms.dat

Record Type	Field	Format	Width	Description
Number of tables	1	Integer	Free	Number of look-up tables for VSL
Description of the 1st look-up table	1 2	Integer Integer	Free Free	Look-up table counter Number of lines in the 1st table
The 1st line of the 1st look-up table	1 2 3 4 5 6 7	Float Float Float Float Float Float Float	Free Free Free Free Free Free Free	Visibility upper bound (miles) Visibility lower bound (miles) Rain intensity lower bound (inch/hour) Rain intensity upper bound (inch/hour) Snow intensity lower bound (inch/hour) Snow intensity upper bound (inch/hour) Speed limit reduction (mph)
…..	.....	.....	.....	.....
The last line of the 1st look-up table	1 2 3 4 5 6 7	Float Float Float Float Float Float Float	Free Free Free Free Free Free Free	Visibility upper bound (miles) Visibility lower bound (miles) Rain intensity lower bound (inch/hour) Rain intensity upper bound (inch/hour) Snow intensity lower bound (inch/hour) Snow intensity upper bound (inch/hour) Speed limit reduction (mph)
…..	.....	.....	.....	.....
Description of the last look-up table	1 2	Integer Integer	Free Free	Look-up table counter Number of lines in the last table

Source: FHWA, 2019

Table 17. TrEPS Input Files Description for vms.dat. (continued_

Record Type	Field	Format	Width	Description
The 1st line of the last look-up table	1	Float	Free	Visibility upper bound (miles)
	2	Float	Free	Visibility lower bound (miles)
	3	Float	Free	Rain intensity lower bound (inch/hour)
	4	Float	Free	Rain intensity upper bound (inch/hour)
	5	Float	Free	Snow intensity lower bound (inch/hour)
	6	Float	Free	Snow intensity upper bound (inch/hour)
	7	Float	Free	Speed limit reduction (mph)
…..	…..	…..	…..	…..
The last line of the last look-up table	1	Float	Free	Visibility upper bound (miles)
	2	Float	Free	Visibility lower bound (miles)
	3	Float	Free	Rain intensity lower bound (inch/hour)
	4	Float	Free	Rain intensity upper bound (inch/hour)
	5	Float	Free	Snow intensity lower bound (inch/hour)
	6	Float	Free	Snow intensity upper bound (inch/hour)
	7	Float	Free	Speed limit reduction (mph)

Source: FHWA, 2019

Table 18. TrEPS Input Files Description for Referencetable.txt

Record Type	Field	Format	Width	Description
General	1	Integer	Free	Total number of links in network
	2	Integer	Free	Total number of links with observations in network
Link with observation	1	Integer	Free	Link id of the 1st link
	2	Integer	Free	Upstream node of 1st link
	3	Integer	Free	Downstream node of 1st link
	4	Integer	Free	observation index[1] of 1st link
	5	Integer	Free	number of lanes of 1st link
	6	Integer	Free	link length of 1st link
…..	…..	…..	…..	…..
Link with observation	1	Integer	Free	Link id of the last link
	2	Integer	Free	Upstream node of last link
	3	Integer	Free	Downstream node of last link
	4	Integer	Free	observation index[1] of last link
	5	Integer	Free	number of lanes of last link
	6	Integer	Free	link length of last link

[1]*Observation index of each link is defined as 0 if this link does not have any observations from detector data, or i if this link has observation data, where i means that this link is the ith link with observations. i should be no larger than total number of links with observations in the network*

Source: FHWA, 2019

Table 19. TrEPS Input Files Description for detector_mapping_to_link.txt

Record Type	Field	Format	Width	Description
Detector description	1	Integer	Free	Detector id of 1st available detector in the network
	2	Integer	Free	Geo location x[1] of 1st available detector
	3	Integer	Free	Geo location y[1] of 1st available detector
	4	Integer	Free	Link id of the 1st available detector
	5	Integer	Free	Upstream node of this link
	6	Integer	Free	Downstream node of this link
…..	.....	.....	.....	.....
Detector description	1	Integer	Free	Detector id of last available detector in the network
	2	Integer	Free	Geo location x[1] of last available detector
	3	Integer	Free	Geo location y[1] of last available detector
	4	Integer	Free	Link id of the last available detector
	5	Integer	Free	Upstream node of this link
	6	Integer	Free	Downstream node of this link

[1]The geo location x, y of detector could be in longitude and latitude. However, they but be mapping in to the same geo reference system as the xy.dat in DYNASMART.
Source: FHWA, 2019

Table 20. TrEPS Real-time Detector Data Example File.

Detector ID	TimeStamp	Volume	Speed (MPH)	Occupancy	Link ID
500218	01:40	8	42.0056	11.0213	1149
500220	01:40	7	22.91	22.6933	648
…….					

Source: FHWA, 2019

Appendix I. TrEPS Output File List

Table 21. TrEPS Output File List

Folder Name	Output File
/DTAX/run	• debug.log • dataman.log • man.log • times.log
/DTAX/run/estimate	• rtdyna.log • ErrorLog.dat • Warning.dat • Summary Stat.dat • VehTrajectory.dat • Link Statistics Output Files -LinkVolume.dat -OutLinkGen.dat -OutLinkVeh.dat -OutLinkQue.dat -OutLinkSpeedAll.dat -OutLinkDent.dat -OutLinkSpeedFree.dat -OutLinkDentFree.dat -OutLeftFlow.dat -OutGreen.dat -OutFlow.dat -OutAccuVol.dat • Fort.600 • Fort.700 • Fort.800 • Fort.900

Source: FHWA, 2019

Table 21. TrEPS Output File List. (continued)

Folder Name	Output File
/DTAX/run/predict	• pdyna.log • ErrorLog.dat • Warning.dat • SummaryStat.dat • VehTrajectory.dat • Link Statistics Output Files -LinkVolume.dat -OutLinkGen.dat -OutLinkVeh.dat -OutLinkQue.dat -OutLinkSpeedAll.dat -OutLinkDent.dat -OutLinkSpeedFree.dat -OutLinkDentFree.dat -OutLeftFlow.dat -OutGreen.dat -OutFlow.dat -OutAccuVol.dat • Fort.600 • Fort.700 • Fort.800 • Fort.900
/DTAX/run/odestimate	• Ode.log • Fort.1133 • Fort.112 • Fort.113
/DTAX/run/odpredict	• Odp.log
/DTAX/run/stcc	• Stcc.log • Fort.119 • Fort.19
/DTAX/run/ltcc	• Ltcc.log • Fort.19

Source: FHWA, 2019

Appendix J. TrEPS Link Statistics Output Files

LinkVolume.dat – number of vehicles on each link

This file reports the number of vehicles on pre-specified interval (10 intervals). As each simulation interval is 6 seconds (0.1 minute), 10 intervals will be 1 minute. The general format of this file can be seen below:

Table 22. LinkVolume.dat file format.

1.0									
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	1.00
2.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00

Source: FHWA, 2019

The first line of the table indicates the time interval in minutes (minute 1 in this example). The next record provides link information. In this example, it shows that zero vehicles were on links 1 (field 1), 2 vehicles were on links 19 (field 9 on the next line), and so on. The process is repeated for all time intervals.

OutLinkGen.dat – vehicles generated on each generation link (optional)

This file reports the number of vehicles generated on each link per simulation interval, averaged over the number of simulation intervals specified in output_option.dat. The averaging period is also the reporting period. The general format of this file is can be seen below:

Table 23. OutLinkGen.dat file format.

1.0									
0.00	0.00	0.10	0.00	0.00	0.00	0.20	0.20	0.00	0.00
0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.10
0.10	0.00	0.10	0.10	0.20	0.00	0.00	0.00	0.10	0.00
0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.20	1.00	0.00	0.00	0.00	1.00	0.00	0.10	0.00	0.00

Source: FHWA, 2019

The first record indicates the time interval in minutes (minute 1 in this example). The next record provides link information. In this example, it shows that zero vehicles were generated on links 1 (field 1), 0.1 vehicle was generated on links 3 (field 3), and so on. The process is repeated for all averaging time intervals.

OutLinkVeh.dat – number of vehicles on each link (optional)

This file contains the number of vehicles present on each link per simulation interval, averaged over the number of simulation intervals specified in output_option.dat. The general format of this file is presented below:

Table 24. OutLinkVeh.dat file format.

1.0									
0.00	0.00	0.30	0.00	0.00	0.20	0.60	0.60	0.00	0.00
0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.20	0.90	0.80
1.10	0.00	0.60	0.30	0.40	0.30	0.00	0.00	0.30	0.00
0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.20	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.40	0.10	0.00	0.00	0.20	0.30	0.00	0.40	0.00
0.40	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00

Source: FHWA, 2019

The first record of the table indicates the time interval in minutes (minute 1 in this example). The next record provides link information. In this example, its shows that zero vehicles (field 1) are currently present on link 1, 0.3 vehicles (field 3) are present on link 3, and so on. The process is repeated for all averaging time intervals.

- ***OutLinkQue.dat* - number of queued vehicles on each link (optional)**

This file contains the number of vehicles in the queue on each link per simulation interval, averaged over the number of simulation intervals specified in output_option.dat. The reporting period is again identical to the averaging interval. The general format of this file is presented below.

Table 25. OutLinkQue.dat file format.

1.0									
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00
0.10	0.00	0.20	0.40	0.00	0.50	0.10	0.00	0.00	0.00

Source: FHWA, 2019

In this figure, the first record indicates the time interval in minutes (minute 1 in this example). The next record provides link information. In this example, it shows that 0 vehicles (field 1) are queued on link 1, 0 vehicles (field 2) are queued on link 2, 0.1 vehicles (field 91, line 17 first field) are queued on link 91, and so on. The process is repeated for all averaging time intervals.

OutLinkSpeedAll.dat – average speed of vehicles on each link (optional)

This file contains the speed (miles/hr) prevailing on each link per simulation interval, averaged over the number of simulation intervals specified in output_option.dat. The general format of this file is presented below.

Table 26. OutLinkSpeedAll.dat file format.

1.0									
45.00	45.00	44.81	45.00	45.00	44.90	44.61	44.64	45.00	45.00
45.00	45.00	45.00	45.00	44.80	45.00	45.00	44.76	44.22	44.53
44.02	45.00	44.74	44.94	44.64	44.69	45.00	45.00	44.83	45.00
45.00	45.00	45.00	45.00	45.00	44.82	45.00	45.00	45.00	45.00
45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00
45.00	44.85	45.00	44.88	45.00	45.00	45.00	57.00	45.00	45.00
45.00	44.59	44.83	45.00	45.00	44.65	44.80	45.00	44.79	45.00
44.58	45.00	45.00	45.00	45.00	44.77	45.00	45.00	45.00	45.00

Source: FHWA, 2019

The first record indicates the time interval in minutes (minute 1 is this example). The next record provides link information. In this example, it shows that link 1 has an average speed of 45.00 mph (field 1), link 2 has an average speed of 45.00 mph (field 2), link 3 has an average speed of 44.81 mph (field 3), and so on. The process is repeated for all averaging time intervals.

OutLinkDent.dat – average density of vehicles on each link (optional)

This file contains the density (pc/mile/lane) prevailing on each link per simulation interval, averaged over the number of simulation intervals specified in output_option.dat. The general format of this file is presented below.

Table 27. OutLinkDent.dat file format.

1.0									
0.00	0.00	0.59	0.00	0.00	0.31	1.24	1.14	0.00	0.00
0.00	0.00	0.00	0.00	0.63	0.00	0.00	0.78	2.49	1.50
3.13	0.00	0.81	0.20	1.14	1.00	0.00	0.00	0.54	0.00
0.00	0.00	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.48	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.31	0.53	0.00	0.00	1.13	0.64	0.00	0.68	0.00
1.34	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00

Source: FHWA, 2019

The first record indicates the time interval in minutes (minute 1 in this example). The next record provides link information. In this example, it shows that link 1 has an average density of 0.0 pc/mile/lane (field 1), link 3 has an average density of 0.59 pc/mile/lane (field 3), link 6 has an average density of 0.31 pc/mile/lane (field 6), and so on. The process is repeated for all averaging time intervals.

OutLinkSpeedFree.dat – average speed of moving vehicles on each link (optional)

This file contains the average speed (mph) for the moving vehicles on each link per simulation interval, averaged over the number of simulation intervals specified in output_option.dat. The general format of this file is presented in

Table 28. OutLinkSpeedFree.dat file format.

1.0									
45.00	45.00	44.81	45.00	45.00	44.90	44.61	44.64	45.00	45.00
45.00	45.00	45.00	45.00	44.80	45.00	45.00	44.76	44.22	44.53
44.02	45.00	44.74	44.94	44.64	44.69	45.00	45.00	44.83	45.00
45.00	45.00	45.00	45.00	45.00	44.82	45.00	45.00	45.00	45.00
45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00	45.00
45.00	44.85	45.00	44.88	45.00	45.00	45.00	57.00	45.00	45.00
45.00	44.59	44.83	45.00	45.00	44.65	44.80	45.00	44.79	45.00

Source: FHWA, 2019

The first record indicates the time interval in minutes (minute 1 in this example). The next record provides link information. This example shows that moving vehicles on link 1 have an average speed of 45.00 mph (field 1), moving vehicles on link 2 have an average speed of 45.00 mph (field 2), moving vehicles on link 3 have an average speed of 44.81 mph (field 3), and so on. The process is repeated for all link averaging time intervals. Note that this file is similar to OutLinkSpeedAll.dat, except it excludes stopped vehicles.

OutLinkDentFree.dat – average density of moving vehicles on each link (optional)

This file contains the prevailing density (pc/mile/lane) for moving vehicles on each link per simulation interval, averaged over the number of simulation intervals specified in output_option.dat. The general format of this file is presented below.

Table 29. OutLinkDentFree.dat file format.

1.0									
0.00	0.00	0.59	0.00	0.00	0.31	1.24	1.14	0.00	0.00
0.00	0.00	0.00	0.00	0.63	0.00	0.00	0.78	2.49	1.50
3.13	0.00	0.81	0.20	1.14	1.00	0.00	0.00	0.54	0.00
0.00	0.00	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.48	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.31	0.53	0.00	0.00	1.13	0.64	0.00	0.68	0.00

Source: FHWA, 2019

The first record indicates the time interval in minutes (minute 1 in this example). The next record provides link information. In this example, it shows that moving vehicles on link 1 have an average density of 0.0 pc/mile/lane (field 1), moving vehicles on link 3 have an average density of 0.59 pc/mile/lane (field 3), moving vehicles on link 6 have an average density of 0.31 pc/mile/lane (field 6), and so on. The process is repeated for all averaging time intervals. Note that this file is similar to OutLinkDen.dat, except it excludes stopped vehicles.

OutLeftFlow.dat – number of left-turning vehicles on each link (optional)

This file contains the number of left-turning vehicles on the link per simulation interval, averaged over the number of simulation intervals specified in output_option.dat. The general format of this file is presented below.

Table 30. OutLeftFlow.dat file format.

1.0									
0.00	0.00	0.10	0.00	0.00	0.31	0.10	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: FHWA, 2019

The first record indicates the time interval in minutes (minute 1 in this example). The next record provides link information. In this example, it shows that link 1 has an average of 0.000 turning vehicles (field 1), link 3 has an average of 0.100 turning vehicles (field 3) and so on. The process is repeated for all averaging time intervals.

OutGreen.dat – average green time for each approach (optional)

This file contains the green time (seconds) for each approach per simulation interval, averaged over the number of simulation intervals specified in output_option.dat. The general format of this file is presented in the table below.

Table 31. OutGreen.dat file format.

1.0									
60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
60.00	60.00	24.00	60.00	24.00	24.00	24.00	60.00	60.00	60.00
60.00	60.00	60.00	60.00	0.00	60.00	60.00	60.00	24.00	60.00
60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00	24.00

Source: FHWA, 2019

The first record indicates the time interval in minutes (minute 1 in this example). The next record provides link information. In this example, link 1 has an average green time of 60 seconds (field 1), link 43 has an average green time of 24 seconds (field 43, line 12 field 3), and so on. The process is repeated for all link averaging time intervals.

OutFlow.dat – number of vehicles that pass through the link (optional)

This file contains the number of vehicles that pass through the link per simulation interval, averaged over the number of simulation intervals specified in output_option.dat. It includes through, left-turning, and right-turning vehicles. The general format of this file is presented in the table below.

Table 32. OutFlow.dat file format.

1.0									
0.00	0.00	0.10	0.00	0.00	0.00	0.10	0.10	0.00	0.00
0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.10	0.00
0.20	0.00	0.10	0.00	0.20	0.00	0.00	0.00	0.10	0.00
0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.10	0.10	0.00	0.00	0.10	0.00	0.00	0.10	0.00
0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00

Source: FHWA, 2019

The first record indicates the time interval in minutes (minute 1 in this example). The next record provides link information. In this example, it shows that an average of 0.00 vehicles (field 1) pass through link 1, an average of 0.10 vehicles (field 3) pass through link 3, and so on. The process is repeated for all averaging time intervals.

OutAccuVol.dat – cumulative number of vehicles that pass the midpoint of links (every min – always generated)

This file contains the cumulative number of vehicles that pass through the midpoint of the link, reported every minute. The general format of this file is presented in the table below.

Table 33. OutAccuVol.dat file format.

1.0									
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	1.00
2.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: FHWA, 2019

The first record indicates the time interval in minutes (minute 1 in this example). The next record provides link information. In this example, it shows that at min 1.0, 2 vehicles (field 19) pass through link 19, 1 vehicles (field 20) pass through link 20, and so on. The process is repeated for all averaging time intervals.

Appendix K. MLP Input Files Description

Table 34. MLP Archive Input File Description.

Input variable	Variable name	Input data format	Format definitions
Link Direction	Direction	1-Eastbound 2-Southbound 3-Westbound 4-Northbound	
Weather	Weather	1-Clear 2-Light rain, clear visibility 3-Light rain, reduced visibility 4-Light rain, low visibility 5-Moderate rain, clear visibility 6-Moderate rain, reduced visibility 7-Moderate rain, low visibility 8-Heavy rain, reduced visibility 9-Heavy rain, low visibility 10-Light snow, clear visibility 11-Moderate snow, reduced visibility 12-Heavy snow, reduced visibility 13-Heavy snow, low visibility	00mm/h; visibility >3300ft < 2.5mm/h; > 3300ft < 2.5mm/h; 330 - 3300ft < 2.5mm/h; < 330ft 2.5 - 7.6mm/h; > 3300ft 2.5 - 7.6mm/h; 330 - 3300ft 2.5 - 7.6mm/h; < 330ft ≥ 7.6mm/h; 330 - 3300ft ≥ 7.6mm/h; < 330ft ; >3300ft* ; 1650 - 3300ft* ; 330 - 1650ft* ; < 330 ft*
Time	DayOfWeek	1-Weekend 2-Weekday	Saturday, Sunday Monday - Friday
Time	TimeOfDay	1-Morning 2-AM peak 3-Off-peak 4-PM peak 5-Night	1AM - 6AM (5 hrs) 6AM - 10 AM (4hrs) 10AM - 4PM (6hrs) 4PM - 8PM (4hrs) 8PM - 1AM (5 hrs)
Incident	IncidentDownstream	0 1	-No incident -Incident
Incident	IncidentOnLink	0 1	-No incident -Incident
Incident	IncidentUpstream	0 1	-No incident -Incident
Workzone	Workzone	0 1	-No work zone - Workzone
Ramp Metering	RampMetering	0 1	-No ramp metering -Ramp metering

Source: FHWA, 2019

Table 34. MLP Archive Input File Description. (continued)

Input variable	Variable name	Input data format	Format definitions
Flow	Flow (normalized)	1-Very low 2-Low 3-High 4-Very high	< 0.25 0.25 - 0.5 0.5 - 0.75 ≥ 0.75
Speed	Speed (normalized)	1-Very low 2-Low 3-High 4-Very high	< 0.25 0.25 - 0.5 0.5 - 0.75 ≥ 0.75
Occupancy	Occupancy (normalized)	1-Very low 2-Low 3-High 4-Very high	< 0.25 0.25 - 0.5 0.5 - 0.75 ≥ 0.75

Source: FHWA, 2019

Table 35. MLP Real-Time Input File Description.

Input variable	Variable name	Input data format	Format definitions
Link Direction	Direction	1-Eastbound 2-Southbound 3-Westbound 4-Northbound	
Weather	Weather	1-Clear 2-Light rain, clear visibility 3-Light rain, reduced visibility 4-Light rain, low visibility 5-Moderate rain, clear visibility 6-Moderate rain, reduced visibility 7-Moderate rain, low visibility 8-Heavy rain, reduced visibility 9-Heavy rain, low visibility 10-Light snow, clear visibility 11-Moderate snow, reduced visibility 12-Heavy snow, reduced visibility 13-Heavy snow, low visibility	00mm/h; visibility >3300ft < 2.5mm/h; > 3300ft < 2.5mm/h; 330 - 3300ft < 2.5mm/h; < 330ft 2.5 - 7.6mm/h; > 3300ft 2.5 - 7.6mm/h; 330 - 3300ft 2.5 - 7.6mm/h; < 330ft ≥ 7.6mm/h; 330 - 3300ft ≥ 7.6mm/h; < 330ft ; >3300ft* ; 1650 - 3300ft* ; 330 - 1650ft* ; < 330 ft*
Time	DayOfWeek	1-Weekend 2-Weekday	Saturday, Sunday Monday - Friday
Time	TimeOfDay	1-Morning 2-AM peak 3-Off-peak 4-PM peak 5-Night	1AM - 6AM (5 hrs) 6AM - 10 AM (4hrs) 10AM - 4PM (6hrs) 4PM - 8PM (4hrs) 8PM - 1AM (5 hrs)
Incident	IncidentDownstream	0 1	-No incident -Incident

Source: FHWA, 2019

Table 35. MLP Real-Time Input File Description. (continued)

Input variable	Variable name	Input data format	Format definitions
Incident	IncidentOnLink	0 1	-No incident -Incident
Incident	IncidentUpstream	0 1	-No incident -Incident
Workzone	Workzone	0 1	-No work zone - Workzone
Ramp Metering	RampMetering	0 1	-No ramp metering -Ramp metering
Min Flow	MinFlow (veh/h/ln)	(minimum value in Archived Flow data)	(Raw data)
Max Flow	MaxFlow (veh/h/ln)	(maximum value)	(Raw data)
Min Speed	MinSpeed (mph)	(minimum value in Archived Speed data)	(Raw data)
Max Speed	MaxSpeed (mph)	(maximum value)	(Raw data)
Min Occupancy	MinOccupancy (%)	(minimum value in Archived Occupancy data)	(Raw data)
Max Occupancy	MaxOccupancy (%)	(maximum value)	(Raw data)

Source: FHWA, 2019

Data Processing

Step 1: Normalization

The variables Flow, Speed and Occupancy need to be normalized before we input values to the MLP Network model.

The equation of normalization is: $(X_i - Min\ X)/(Max\ X - Min\ X)$. X_i represents a number that we want to normalize. *X* represent a set of data. For example, when we normalize the values in the variable Flow, X means all Flow data. *Min X* represents the minimum value in the dataset *X*. *Max X* represents the maximum value the dataset *X.*

Step 2: Categorization

After normalization, all data from Flow, Speed and Occupancy need to be categorized. If a value is less than 0.25, then it belongs to category 1. If it is >= 0.25 but < 0.5, it belongs to category 2. If it is >= 0.5 but < 0.75, it belongs to category 3. If it is >= 0.75, it belongs to category 4. Then we store the category data to the input data table.

Appendix L. MLP Output File Description

Table 36. MLP Output File Description.

Input variable	Variable name	Input data format	Format definitions
Link Direction	Direction	1-Eastbound 2-Southbound 3-Westbound 4-Northbound	
Weather	Weather	1-Clear 2-Light rain, clear visibility 3-Light rain, reduced visibility 4-Light rain, low visibility 5-Moderate rain, clear visibility 6-Moderate rain, reduced visibility 7-Moderate rain, low visibility 8-Heavy rain, reduced visibility 9-Heavy rain, low visibility 10-Light snow, clear visibility 11-Moderate snow, reduced visibility 12-Heavy snow, reduced visibility 13-Heavy snow, low visibility	00mm/h; visibility >3300ft < 2.5mm/h; > 3300ft < 2.5mm/h; 330 - 3300ft < 2.5mm/h; < 330ft 2.5 - 7.6mm/h; > 3300ft 2.5 - 7.6mm/h; 330 - 3300ft 2.5 - 7.6mm/h; < 330ft ≥ 7.6mm/h; 330 - 3300ft ≥ 7.6mm/h; < 330ft ; >3300ft* ; 1650 - 3300ft* ; 330 - 1650ft* ; < 330 ft*
Time	DayOfWeek	1-Weekend 2-Weekday	Saturday, Sunday Monday - Friday
Time	TimeOfDay	1-Morning 2-AM peak 3-Off-peak 4-PM peak 5-Night	1AM - 6AM (5 hrs) 6AM - 10 AM (4hrs) 10AM - 4PM (6hrs) 4PM - 8PM (4hrs) 8PM - 1AM (5 hrs)
Incident	IncidentDownstream	0 1	-No incident -Incident
Incident	IncidentOnLink	0 1	-No incident -Incident
Incident	IncidentUpstream	0 1	-No incident -Incident
Workzone	Workzone	0 1	-No work zone - Workzone
Ramp Metering	RampMetering	0 1	-No ramp metering -Ramp metering
Predicted Flow Category	FlowCate		Normalized data

Source: FHWA, 2019

Table 36. MLP Output File Description. (continued)

Input variable	Variable name	Input data format	Format definitions
Predicted Flow Percentage	FlowProb		%
Predicted Speed Category	SpeedCate		Normalized data
Predicted Speed Percentage	SpeedProb		%
Predicted Occupancy Category	OccupancyCate		Normalized data
Predicted Flow Percentage	OccupancyProb		%

Source: FHWA, 2019

Appendix M. Alert Definitions

Weather-related Alerts

Weather-related alerts were previously defined as part of the Pikalert system implementation and became part of the WxDE implementation. Those definitions will be carried forward into the IMRCP to the extent that they are supported by data availability and forecast models.

Table 37. Weather-related Alert Definitions.

Type	Algorithm	geoExtent	Reference	Notify
Light Winter Precip	RTEPC <= 7.056×10^{-5} kg/m^2-s and TYPPC = [snow, ice pellets, freezing rain]	area	Pikalert	N
Medium Winter Precip	7.056×10^{-5} < RTEPC <= 7.056×10^{-4} kg/m^2-s and TYPPC = [snow, ice pellets, freezing rain]	area	Pikalert	Y
Heavy Winter Precip	7.056×10^{-4} < RTEPC kg/m^2-s and TYPPC = [snow, ice pellets, freezing rain]	area	Pikalert	Y
Light Precip	RTEPC <= 7.056×10^{-4} kg/m^2-s and TYPPC = [rain]	area	Pikalert	N
Medium Precip	7.056×10^{-4} < RTEPC <= 2.117×10^{-3} kg/m^2-s and TYPPC = [rain]	area	Pikalert	N
Heavy Precip	2.117×10^{-3} < RTEPC kg/m^2 and TYPPC = [rain]	area	Pikalert	Y
Dew on Roadway	STPVT= [dew]	segment	METRo	N
Frost on Roadway	STPVT = [frost]	segment	METRo	N
Blowing Snow	10 < SPDWND m/s and 1 < DPHSN cm within last 24 hours	segment	RAP/METRo, ? NEW	Y
Low Visibility	VIS < 0.2 mi	area	RAP	Y

Source: FHWA, 2019

Traffic-related Alerts

Traffic-related alerts include both traditional event-type alerts (e.g., crashes, debris on roadway) and alerts to potentially difficult traffic conditions.

Table 38. Traffic-related Alert Definitions.

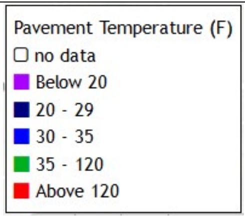
Type	Algorithm	Extent	Reference	Notify
Incident	EVT=Incident	point	KC Scout	Y
Work Zone	EVT=Workzone	link	KC Scout	N
Slow Traffic	20<TRFLNK<40%	link	KC Scout, TrEPS, MLP	N
Very Slow Traffic	0<TRFLNK<20%	link	KC Scout, TrEPS, MLP	N
Flooded Road	0<DPHLNK	segment	AHPS	Y
Lengthy Queue	QPRLNK > 0.3	link	TrEPS (fort.600)	N
Unusual Congestion	0<TRFLNK<0.5*MODE[TRFLNK]	link	TrEPS, Scout	Y

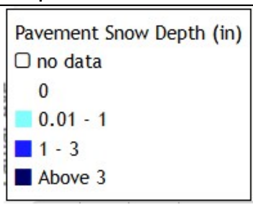
Source: FHWA, 2019

Appendix N. Layer Definitions

Table 39. Layer Definitions.

<table>
<tr><th>Layer</th><th>Observation Type</th><th>Definition</th></tr>
<tr><td>Pavement State</td><td>STPVT</td><td>

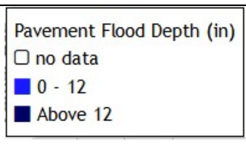
The Pavement State layer is divided into categories for the map based on METRo’s output for pavement state. STPVT categories are described in 0.</td></tr>
<tr><td>Pavement Temperature</td><td>TPVT</td><td>

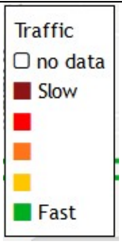
The Pavement Temperature layer is divided into levels for the map based on pavement behaviors at temperature intervals. Pavement temperatures above 120°F may cause the pavement to be at risk of high temperature degradation. Pavement temperatures between 35°F and 120°F are considered normal. Pavement temperatures between 32°F and 35°F are likely to cause the pavement to meet the freezing point. Pavement treatment may be effective on pavement at temperatures between 20°F and 29°F where as pavement at tempertures below 20°F may remain frozen in response to treatment.</td></tr>
<tr><td>Pavement Snow Depth</td><td>DPHSN</td><td>

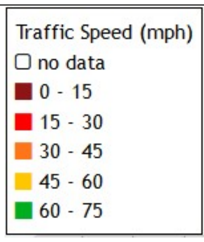
The Pavement Snow Depth layer consists of four levels ranging from 0 in. to above 3 in.</td></tr>
</table>

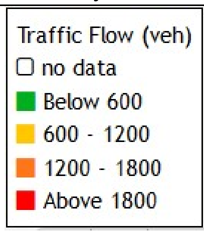
Source: FHWA, 2019

Table 39. Layer Definitions. (continued)

<table>
<tr><th>Layer</th><th>Observation Type</th><th>Definition</th></tr>
<tr><td>Pavement Flood Depth</td><td>DPHLNK</td><td>

On the Pavement Flood Depth layer, links will appear transparent until flooding occurs on the pavement. When the flooding on the pavement reaches 12 in. (or 1 ft.), the link coding reaches a new level because flooding above 12 in. can carry away a car.</td></tr>
<tr><td>Traffic</td><td>TRFLNK</td><td>

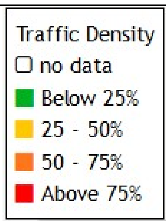
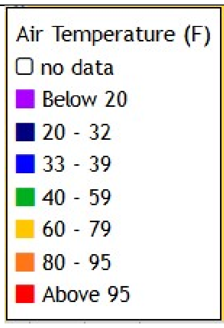
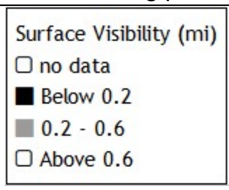
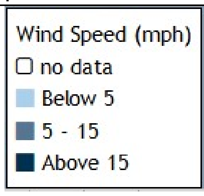
The Traffic layer is divided into five equal levels ranging from standstill traffic to traffic moving at full speed relative to the speed limit.</td></tr>
<tr><td>Traffic Speed</td><td>SPDLNK</td><td>

The Traffic Speed layer is divided into five equal levels ranging from 0 to 75 mph, a reasonable upper bound for the speed of travelers in the study area.</td></tr>
<tr><td>Traffic Flow</td><td>VOLLNK</td><td>

The Traffic Flow layer is divided into four equal levels ranging from below 600 to above 1800 vehicles per hour. A traffic flow above 1800 vehicles per hour on any link in the study area can cause major congestion.</td></tr>
</table>

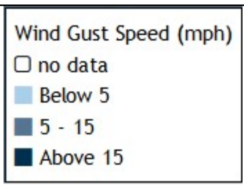
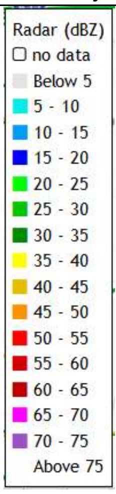
Source: FHWA, 2019

Table 39. Layer Definitions. (continued)

Layer	Observation Type	Definition
Traffic Density	DNTLNK	 The Traffic Density layer is divided into four equal levels ranging from below 25% to above 75%. Traffic density above 75% indicates major congestion and density below 25% indicates free flow.
Routes	TIMERT	The Routes layer displays routes on the map when they have an available route travel time.
Air Temperature	TAIR	 The Air Temperature Layer is divided into layers based on typical temperature behaviors. There is a breakpoint at 32°F because this is the freezing point.
Surface Visibility	VIS	 The Surface Visibility layer remains white until the visibility is below 0.6 mi. Travelers can be siginificantly effected by visibility below this point.
Wind Speed	SPDWND	 The Wind Speed layer is divided into levels that are typical of the study area.

Source: FHWA, 2019

Table 39. Layer Definitions. (continued)

Layer	Observation Type	Definition
Wind Gust Speed	GSTWND	 The Wind Gust Speed layer is divided into levels that are typical of the study area.
Radar	RDR0	 The Radar layer is divided into levels based on those used by the NWS.
Precipitation Rate & Type	PCCAT	 The Precipitation Rate & Type layer is divided into categories based on the observation returned by PCCAT. PCCAT categories are described in 0.

Source: FHWA, 2019

Table 39. Layer Definitions. (continued)

Layer	Observation Type	Definition
NWS Alerts	EVT	 The NWS Alerts Layer is divided into categories based on the type of alert issued.

Source: FHWA, 2019

Appendix O. Observation Type Definitions

Table 40. Observation Type Definitions.

NAME	DESCRIPTION	SOURCE – OBSERVATIONS	SOURCE – PREDICTIONS
COVCLD	total cloud cover	Total cloud coverage observation values are collected from Real-Time Mesoscale Analysis (RTMA) in 3 km x 3 km grids.	Total cloud coverage predicted values are collected from National Digital Forecast Database (NDFD) in 3 km x 3 km grids.
CTLEFT	number of left-turning vehicles on each link	The estimated number of left-turning vehicles on each link are collected from TrEPS.	The predicted number of left-turning vehicles on each link are collected from TrEPS.
CTMID	cumulative number of vehicles on each link	The estimated cumulative number of vehicles on each link are collected from TrEPS.	The predicted cumulative number of vehicles on each link are collected from TrEPS.
CTTHRU	number of vehicles that pass through the link	The estimated number of vehicles that pass through the link are collected from TrEPS.	The predicted number of vehicles that pass through the link are collected from TrEPS.
DIRWND	wind direction	Wind direction observation values are collected from RTMA in 3 km x 3 km grids.	Wind direction predicted values are collected from NDFD in 3 km x 3 km grids.
DNFLNK	average density of moving vehicles on each link	The estimated average density of moving vehicles on each link are collected from TrEPS.	The predicted average density of moving vehicles on each link are collected from TrEPS.
DNTLNK	average density of vehicles on each link	The estimated density values for each link are collected from TrEPS.	The predicted density values for each link are collected from TrEPS.
DPHLIQ	liquid inundation depth	Model of the Environment and Temperature of Roads (METRo) is run for each link in the study area to determine liquid inundation depth estimations.	METRo is run for each link in the study area to determine liquid inundation depth predictions.
DPHLNK	link depth	AHPS stage observations at three locations in the study area are collected when new values are available. These values are used to determine the flood depth on links based on inundation mapping provided by NOAA.	AHPS stage predictions at three locations in the study area are collected when new values are available. These values are used to determine the flood depth on links based on inundation mapping provided by NOAA.

Table 40. Observation Type Definitions. (continued)

NAME	DESCRIPTION	SOURCE – OBSERVATIONS	SOURCE – PREDICTIONS
DPHSN	snow inundation depth	METRo is run for each link in the study area to determine pavement snow depth estimations.	METRo is run for each link in the study area to determine pavement snow depth predictions.
DURGRN	average green time for each link	The estimated average green time for each link are collected from TrEPS.	The predicted average green time for each link are collected from TrEPS.
EVT	event	Workzone and Incident event details are collected from KC Scout. National Weather Service (NWS) Common Alerting Protocol (CAP) alert events are collected from NWS. CAP alerts affecting counties use previously stored county defintions to display on the map. CAP alerts affecting areas other than counties use the area definition provided in the CAP alert to display on the map.	Workzone and Incident event details are collected from KC Scout. NWS CAP alert events are collected from NWS. CAP alerts affecting counties use previously stored county defintions to display on the map. CAP alerts affecting areas other than counties use the area definition provided in the CAP alert to display on the map.
FLWCAT	precited flow category	All of the possible outcomes of the MLP model are stored in a table in the database. The system performs a lookup in the table based on the inputs of each of the links in the model for each time period to determine the predicted flow category.	All of the possible outcomes of the MLP model are stored in a table in the database. The system performs a lookup in the table based on the inputs of each of the links in the model for each time period to determine the predicted flow category.
GENLNK	vehicles generated on each link	The estimated vehicles generated on each link are collected from TrEPS.	The predicted vehicles generated on each link are collected from TrEPS.
GSTWND	wind speed gust height above ground	Wind gust speed observation values are collected from RTMA in 3 km x 3 km grids.	
OCCCAT	predicted occupancy category	All of the possible outcomes of the MLP model are stored in a table in the database. The system performs a lookup in the table based on the inputs of each of the links in the model for each time period to determine the predicted occupancy category.	All of the possible outcomes of the MLP model are stored in a table in the database. The system performs a lookup in the table based on the inputs of each of the links in the model for each time period to determine the predicted occupancy category.

Table 40. Observation Type Definitions. (continued)

NAME	DESCRIPTION	SOURCE – OBSERVATIONS	SOURCE – PREDICTIONS
PCCAT	precipitation category	The precipitation category is determined based on observation TYPPC and RTEPC. • Light Freezing Rain: RTEPC <= 7.056x10-5 kg/m2-s and TYPPC = [freezing rain] • Medium Freezing Rain: 7.056x10-5 < RTEPC <= 7.056x10-4 kg/m2-s and TYPPC = [freezing rain] • Heavy Freezing Rain: 7.056x10-4 < RTEPC kg/m2-s and TYPPC = [freezing rain] • Light Snow: RTEPC <= 7.056x10-5 kg/m2-s and TYPPC = [snow] • Medium Snow: 7.056x10-5 < RTEPC <= 7.056x10-4 kg/m2-s and TYPPC = [snow] • Heavy Snow: 7.056x10-4 < RTEPC kg/m2-s and TYPPC = [snow] • Light Ice Pellets: RTEPC <= 7.056x10-5 kg/m2-s and TYPPC = [ice pellets,] • Medium Ice Pellets: 7.056x10-5 < RTEPC <= 7.056x10-4 kg/m2-s and TYPPC = [ice pellets,] • Heavy Ice Pellets: 7.056x10-4 < RTEPC kg/m2-s and TYPPC = [ice pellets] • Light Rain: RTEPC <= 7.056x10-4 kg/m2-s and TYPPC = [rain]	The precipitation category is determined based on predicted TYPPC and RTEPC. • Light Freezing Rain: RTEPC <= 7.056x10-5 kg/m2-s and TYPPC = [freezing rain] • Medium Freezing Rain: 7.056x10-5 < RTEPC <= 7.056x10-4 kg/m2-s and TYPPC = [freezing rain] • Heavy Freezing Rain: 7.056x10-4 < RTEPC kg/m2-s and TYPPC = [freezing rain] • Light Snow: RTEPC <= 7.056x10-5 kg/m2-s and TYPPC = [snow] • Medium Snow: 7.056x10-5 < RTEPC <= 7.056x10-4 kg/m2-s and TYPPC = [snow] • Heavy Snow: 7.056x10-4 < RTEPC kg/m2-s and TYPPC = [snow] • Light Ice Pellets: RTEPC <= 7.056x10-5 kg/m2-s and TYPPC = [ice pellets,] • Medium Ice Pellets: 7.056x10-5 < RTEPC <= 7.056x10-4 kg/m2-s and TYPPC = [ice pellets,] • Heavy Ice Pellets: 7.056x10-4 < RTEPC kg/m2-s and TYPPC = [ice pellets] • Light Rain: RTEPC <= 7.056x10-4 kg/m2-s and TYPPC = [rain]

Table 40. Observation Type Definitions. (continued)

NAME	DESCRIPTION	SOURCE – OBSERVATIONS	SOURCE – PREDICTIONS
		• Medium Rain: $7.056x10^{-4}$ < RTEPC <= $2.117x10^{-3}$ kg/m^2-s and TYPPC = [rain] • Heavy Rain: $2.117x10^{-3}$ < RTEPC kg/m^2 andTYPPC = [rain]	• Medium Rain: $7.056x10^{-4}$ < RTEPC <= $2.117x10^{-3}$ kg/m^2-s and TYPPC = [rain] • Heavy Rain: $2.117x10^{-3}$ < RTEPC kg/m^2 andTYPPC = [rain]
PRSUR	surface pressure	Surface pressure observation values are collected from RTMA in 3 km x 3 km grids.	Surface pressure predicted values are collected from Rapid Refresh (RAP) in 13 km x 13 km grids.
QPRLNK	queue percentage on link	The estimated queue percentage on each link are collected from TrEPS.	The predicted queue percentage on each link are collected from TrEPS.
QUELNK	number of queued vehicles on each link	The estimated number of queued vehicles on each link are collected from TrEPS.	The predicted number of queued vehicles on each link are collected from TrEPS.
RDR0	merged base reflectivity	Radar observation values are collected from MRMS in 1 km x 1 km grids	
RH	relative humidity	Relative humidity observation values are collected from RTMA in 3 km x 3 km grids.	Relative humidity predicted values are collected from NDFD in 3 km x 3 km grids.
RTEPC	precipitation rate surface	Precipitation rate observation values are collected from MRMS in 1 km x 1 km grids.	Precipitation rate predicted values are collected from RAP in 13 km x 13 km grids.
SPDCAT	predicted speed category	All of the possible outcomes of the MLP model are stored in a table in the database. The system performs a lookup in the table based on the inputs of each of the links in the model for each time period to determine the predicted speed category.	All of the possible outcomes of the MLP model are stored in a table in the database. The system performs a lookup in the table based on the inputs of each of the links in the model for each time period to determine the predicted speed category.
SPDLNK	average speed of vehicles on each link	The estimated speed values for each link are collected from TrEPS.	The predicted speed values for each link are collected from TrEPS.
SPDWND	wind speed height above ground	Wind speed observation values are collected from RTMA in 3 km x 3 km grids.	Wind speed forecast values are collected from NDFD in 3 km x 3 km grids.
SPFLNK	average speed of moving vehicles on each link	The estimated average speed of moving vehicles on each link are collected from TrEPS.	The predicted average speed of moving vehicles on each link are collected from TrEPS.

Table 40. Observation Type Definitions. (continued)

NAME	DESCRIPTION	SOURCE – OBSERVATIONS	SOURCE – PREDICTIONS
STPVT	pavement state	METRo is run for each link in the study area to determine pavement state estimations. • Dry Road: The water reservoir contains less than 0.01 mm and the ice/snow reservoir contains less than .2 mm of water equivalent. • Wet road: The water reservoir contains more than 0.01 mm of water. • Ice/Snow: The ice/snow reservoir contains more than 0.2 mm of water equivalent. • Water/Snow: Both of the reservoirs (water and ice/snow) contains more than 0.2 mm of water equivalent. • Dew: Condensation on the road when the temperature of the surface of the road is above the freezing point. • Frost: Condensation on the road when the temperature of the surface of the road is under the freezing point or water already present on the road turning into ice.	METRo is run for each link in the study area to determine pavement state predictions. • Dry Road: Each reservoirs (water and ice/snow) contains less than 0.01 mm of liquid water equivalent. • Wet road: The water reservoir contains more than 0.01 mm of water. • Ice/Snow: The ice/snow reservoir contains more than 0.2 mm of water equivalent. • Water/Snow: Both of the reservoirs (water and ice/snow) contains more than 0.2 mm of water equivalent. • Dew: Condensation on the road when the temperature of the surface of the road is above the freezing point. • Frost: Condensation on the road when the temperature of the surface of the road is under the freezing point or water already present on the road turning into ice.
TAIR	air temperature	Air temperature observation values are collected from RTMA in 3 km x 3 km grids.	Air temperature predicted values are collected from NDFD in 3 km x 3 km grids.
TDEW	dew point temperature	Dew point temperature observation values are collected from RTMA in 3 km x 3 km grids.	Dew point temperature predicted values are collected from NDFD in 3 km x 3 km grids.
TDNLNK	traffic density	The traffic density is the normalized density from MLP to historical data.	The traffic density is the normalized density from MLP to historical data.

Table 40. Observation Type Definitions. (continued)

NAME	DESCRIPTION	SOURCE – OBSERVATIONS	SOURCE – PREDICTIONS
TIMERT	route time	Routes are preconfigured. The estimated travel times for each link are collected from TrEPS. The travel times of the links that make up a preconfigured route are added together to determine the estimated total travel time of the route.	Routes are preconfigured. The predicted travel times for each link are collected from TrEPS. The travel times of the links that make up a preconfigured route are added together to determine the predicted total travel time of the route.
TPVT	pavement temperature	METRo is run for each link in the study area to determine pavement temperature estimations.	METRo is run for each link in the study area to determine pavement temperature predictions.
TRFLNK	traffic	The estimated speed value for each link collected from TrEPS is divided by the speed limit for that link.	The predicted speed value for each link collected from TrEPS is divided by the speed limit for that link.
TSSRF	subsurface temperature	The subsurface temperture observation is collected from an ASOS station.	
TYPPC	precipitation type	Precipitation type observation values are collected from MRMS in 1 km x 1 km grids.	Precipitation type predicted values are collected from RAP in 13 km x 13 km grids.
VEHLNK	number of vehicles on each link	The estimated number of vehicles each link is collected from TrEPS.	The predicted number of vehicles each link is collected from TrEPS.
VIS	surface visibility	Surface visibility observation values are collected from RTMA in 3 km x 3 km grids.	Surface visibility forecast values are collected from RAP in 13 km x 13 km grids.
VOLLNK	link volume	The estimated flow values for each link are collected from TrEPS.	The predicted flow values for each link are collected from TrEPS.

Source: FHWA, 2019

Appendix P. Alert Definitions

Table 41.Traffic Alert Definitions

Type	Algorithm	Extent	Reference	Notify	Icon
Incident	EVT=Incident	point	KC Scout	Y	
Work Zone	EVT=Workzone	link	KC Scout	N	
Slow Traffic	20<TRFLNK<40%	link	KC Scout, TrEPS, MLP	N	
Very Slow Traffic	0<TRFLNK<20%	link	KC Scout, TrEPS, MLP	Y	
Lengthy Queue	QPRLNK > 0.3	link	TrEPS (fort.600)	N	
Unusual Congestion	0<TRFLNK<0.5*MODE[TRFLNK]	link	TrEPS, Scout	Y	

Source: FHWA, 2019

Table 42. Weather Alert Definitions.

Type	Algorithm	geoExtent	Reference	Notify	Icon
Light Winter Precip	PCCAT= [Light Freezing Rain, Light Snow, Light Ice Pellets]	area	Pikalert	N	
Medium Winter Precip	PCCAT= [Medium Freezing Rain, Medium Snow, Medium Ice Pellets]	area	Pikalert	Y	
Heavy Winter Precip	PCCAT= [Heavy Freezing Rain, Heavy Snow, Heavy Ice Pellets]	area	Pikalert	Y	
Light Precip	PCCAT= [Light Rain]	area	Pikalert	N	
Medium Precip	PCCAT= [Medium Rain]	area	Pikalert	N	
Heavy Precip	PCCAT= [Heavy Rain]	area	Pikalert	Y	
Blowing Snow	10 < SPDWND m/s and 1 < DPHSN cm within last 24 hours 31 > TAIR F within the last 24 hours	segment	RAP/METRo	Y	
Low Visibility	VIS < 0.2 mi	area	RAP	Y	

Source: FHWA, 2019

Table 43. Road Condition Alert Definitions.

Type	Algorithm	geoExtent	Reference	Notify	Icon
Dew on Roadway	STPVT= [dew]	segment	METRo	N	
Frost on Roadway	STPVT= [frost]	segment	METRo	N	
Ice on Bridge	STPVT= [ice]	segment	METRo	Y	
Flooded Road	DPHLNK > 0 in.	segment	AHPS	Y	

Source: FHWA, 2019

U.S. Department of Transportation
ITS Joint Program Office – HOIT
1200 New Jersey Avenue, SE
Washington, DC 20590

Toll-Free “Help Line” 866-367-7487

www.its.dot.gov

FHWA-JPO-18-727

U.S. Department of Transportation