Integrated Modeling for Road Condition Prediction (IMRCP)

System Design Description

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### 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.

### Key Words

System Design; Prediction; Road Weather Management Program (RWMP); Transportation system management and operations (TSMO)
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Executive Summary

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.
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 sophistication of models utilizing the 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 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. 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 between elements of the views are included in the view and model descriptions. Four viewpoints are described: composition, process, deployment, and related designs.
Chapter 2 General Description

System Perspective

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 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 Model for Road Condition Prediction Model Analysis. The aggregate of these analyses of modeling capabilities and stakeholder interests formed the basis for the functional and system package architectural views of 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/or forecasts from other models, and current observations 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, decision support, and interface. The view also illustrates the relationships between these packages and external sources. The functional view and the system package view provide a context for the development and

1 This section was previously published in the Integrated Modeling for Road Condition Prediction System Requirements Specification.
structuring of the system requirements. Specific requirements for the IMRCP can be found in the Integrated Model for Road Condition Prediction System Requirements Specifications\(^3\).

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\(^4\). 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 sets of software components and their relationships. 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.


\(^4\) Leidos, Inc. Integrated Modeling for Road Condition Prediction System Architecture Description. May 17, 2016
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. Unified Modeling Language (UML)\(^5\) 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 as shown as a package diagram in Figure 1, and the overall processing is illustrated with the activity diagram in 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.\(^6\)

\(^5\) [http://www.omg.org/spec/UML/2.5/PDF](http://www.omg.org/spec/UML/2.5/PDF)

Figure 1 – IMRCP Composition
Figure 2 – IMRCP Process
Traffic Estimation and Prediction System

The TrEPS package estimates and predicts the 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, as well as estimating and predicting network states. The TrEPS package contains four classes: a Demand Estimator, a Traffic Estimator, a Demand Predictor and a Traffic Predictor.

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.

![Figure 3 –TrEPS-based Decision Support Framework for Weather-responsive Traffic Signal Operations](Source: Mahmassani et al., 2014)
The inputs for the TrEPS package include the data from the data Store (such as demand, traffic, and weather) and the decision made from the Traffic Operations package. The output of the TrEPS package is the estimation and prediction of the traffic state, which is then sent to the Traffic Operations package for system evaluation and decision making. The TrEPS and Traffic Operations packages form a loop in a rolling horizon framework.

**Demand Estimator**

**Background:** The Demand Estimator is a module within the TrEPS package that uses a Kalman filtering approach to estimate the coefficients of a time-varying polynomial function that describes the structural deviation of origin-destination (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 Traffic Estimator and Traffic Predictor.

**Table 1 – Demand Estimator Input Categories**

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Real-time Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated link volume (link proportion)</td>
<td>Link Volume</td>
</tr>
<tr>
<td>Predicted link volume (link proportion)</td>
<td></td>
</tr>
<tr>
<td>Initial Traffic Demand</td>
<td></td>
</tr>
</tbody>
</table>

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

**Process:** The Demand Estimator conducts the demand estimation for the current estimation stage and calculates the coefficients. First, the link proportion is estimated from the estimated traffic condition. With the current origin-destination (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 Demand Estimator depends on the data Store and the Traffic Estimator and Traffic Predictor modules in the TrEPS package.

**Traffic Estimator**

**Background:** The Traffic Estimator is a module within the TrEPS package that 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. 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 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 – Traffic Estimator Input Categories**

<table>
<thead>
<tr>
<th>Network file</th>
<th>Demand file</th>
<th>Event</th>
<th>Real-time observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roadway Network Link</td>
<td>OD Pairs</td>
<td>Weather Event</td>
<td>Link Speed</td>
</tr>
<tr>
<td>Network Links Conditions</td>
<td></td>
<td>Incident Event</td>
<td></td>
</tr>
<tr>
<td>Network Nodes</td>
<td></td>
<td>Special Event</td>
<td></td>
</tr>
<tr>
<td>Node Conditions</td>
<td></td>
<td>Road Construction Event (workzone)</td>
<td></td>
</tr>
<tr>
<td>Traffic Control Operations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(signal control, etc)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

**Process:** It 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 Traffic Estimator depends on the data Store and the Demand Estimator and Demand Predictor modules in the TrEPS package.

**Demand Predictor**
Background: The Demand Predictor is a module within the TrEPS package that uses the predicted OD coefficients provided by Demand Estimator 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 Demand Predictor adopts the estimated coefficients from the Demand Estimator, which is prepared after the demand estimation procedure finishes estimating for the current stage. The predicted demand is to be used in the Traffic Predictor.

Dependencies: The Demand Predictor is dependent on the data from the Demand Estimator.

Traffic Predictor

Background: The Traffic Predictor is a module within the TrEPS package that provides future network traffic states for a pre-defined horizon, as an extension from the current network state estimated by the Traffic Estimator.

Inputs: This module needs the snapshot of the network traffic states from the Traffic Estimator, 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 Traffic Predictor 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 Traffic Predictor depends on the Demand Predictor and Traffic Estimator modules in the TrEPS package. It is also partially dependent on the Decision Making module from the Traffic Operations package.

Traffic Operations

The Traffic Operations package evaluates traffic system states and selects appropriate interventions to return operations to the desired performance levels. The system evaluation considers potential interventions at link, corridor and network-wide levels to address particular performance measures. The Traffic Operations package contains two classes: a System Evaluator and a Decision Making module.

The Traffic Operations package may iterate with the TrEPS models considering alternative interventions until an optimal solution addressing the balance of performance measures is achieved. It depends on the data Store for the operational control state, environment conditions/forecast and library of potential interventions.
The input for the Traffic Operations package consists of the operational control data, environmental/road conditions and the estimated and predicted traffic state data as computed by the TrEPS package. The output of the Traffic Operations package is the selected operational control interventions to be modeled by the TrEPS package.

**Decision Making**

**Background:** The Decision Making module within the Traffic Operations package selects from among alternative interventions from the operational control list in the data Store based on a side-by-side comparison and the expected benefit from the System Evaluator.

**Inputs:** Operational control list in the data Store, the system evaluation from the System Evaluator module, and the predicted traffic state from TrEPS package are needed.

**Outputs:** The selected interventions and strategies to be evaluated are generated.

**Process:** The Decision Making module gets access to the data Store for a list of potential alternative interventions to improve traffic conditions. The interventions include short term interventions (active traffic management strategies, active demand management, and weather-related strategies), and medium-long term interventions (trip mode change and departure time shift behaviors).

**Dependencies:** The Decision Making module depends on the System Evaluator module in the TrEPS package and the data Store.

**System Evaluator**

**Background:** The System Evaluator is a module within the Traffic Operations package that provides multi-level evaluation of the traffic system state based on the estimated and predicted traffic state from the TrEPS package.

**Inputs:** It requires the outputs from Traffic Estimator and Traffic Predictor module in the TrEPS package, i.e. the estimated and predicted traffic state in the network.

**Outputs:** The expected benefits and effectiveness of each evaluated intervention is to be analyzed.

**Process:** The System Evaluator is able to extract various performance measures from the simulation output once the TrEPS package completes the Traffic Predictor for the next prediction interval. It presents a side-by-side comparison of network states with and without intervention suggested in the previous interval from the Decision Making module.

**Dependencies:** The System Evaluator depends on the Traffic Estimator and Traffic Predictor module in the TrEPS package and requires the selected interventions from the Decision Making module.

**Capacity Prediction**

The Capacity Prediction package provides the predicted link capacity given a set of variables, including traffic state, traffic network conditions, road conditions and management strategies. It is an integrated tool for predicting link capacity and capable of handling a combination of conditions that could induce link capacity change. This package contains two classes: a Capacity Estimator and a Capacity Predictor.
The Capacity Prediction package may iterate with TrEPS, MDSS, Incident and Bayes packages to update the estimated and predicted capacity for each simulation interval whenever there is new real-time information or scenarios. The scenarios that may reduce capacity include any weather event from the MDSS package, any incident from the Incident Package, the probability of each event from the Bayes package, and any inducing or potential breakdowns estimated given the traffic state and external events. However, there are some strategies from the Decision Making Module in the Traffic Operations package that may help increase or recover capacity. Those strategies include some Active Transportation and Demand Management (ATDM) strategies and weather-related strategies. The updated capacity feeds back to the TrEPS package for future simulation and may also be used to update the probability for each event in the Bayes Package.

The input for the Capacity Prediction package consists of traffic state and strategies from TrEPS and the probabilistic events from the MDSS and Bayes packages. The output of this package is the predicted capacity to be used in the TrEPS and Bayes packages.

**Capacity Estimator**

**Background:** Adverse weather conditions and incidents can lead to an obvious capacity drop in the network locally and network widely. The Capacity Estimator is a module within the Capacity Prediction package that estimates the capacity with the predicted probabilistic weather and incident events.

**Inputs:** This module requires the default link capacity, which is the link capacity under clear day scenario without any other influence, such as incidents or work zones, and the probabilistic weather conditions and incidents. The decreased capacity under the weather conditions is dependent on the calibrated weather adjustment factor.

**Impact from Weather Condition**

The capacity affected by inclement weather is captured by the weather adjustment factor integrated into the TrEPS model. The adjustment factor for capacity is obtained based on the inclement weather parameters (visibility, rain intensity, and snow intensity) and the calibrated weather-traffic flow relation. The parameters that are relevant to inclement weather impacts on the supply side of the TrEPS model are listed in Table 3. The parameter values may be affected by weather, and may be affected differently by the characteristics of different weather instances.

In TrEPS, supply-side parameters that are expected to be affected by the weather condition are identified as presented in Table 3. The inclement weather impact on each of these parameters is represented by a corresponding weather adjustment factor (WAF) such that
\[ f_i^{\text{Weather Event}} = f_i^{\text{Normal}} \]

Where \( f_i^{\text{Weather Event}} \) denotes the value of parameter \( i \) under a certain weather event, \( f_i^{\text{Normal}} \) denotes the value of parameter \( i \) under the normal condition and \( F_i \) is the WAF for parameter \( i \).

The WAF is assumed to be a linear function of weather conditions, and is expressed in the following form

\[ F_i = \beta_{i0} + \beta_{i1} \cdot v + \beta_{i2} \cdot r + \beta_{i3} \cdot s + \beta_{i4} \cdot v \cdot r + \beta_{i5} \cdot v \cdot s \]

Where \( F_i \) is the weather adjustment factor for parameter \( i \), \( v \) is visibility (mile), \( r \) is precipitation intensity of rain (inch/hr), \( s \) precipitation intensity of snow (inch/hr), and \( \beta_{i0}, \beta_{i1}, \beta_{i2}, \beta_{i3}, \beta_{i4} \) and \( \beta_{i5} \) are coefficients to be estimated.

Thus, once the speed-density functions for different weather conditions (i.e., normal, light rain, moderate rain, etc.) are obtained for each network, a linear regression analysis is performed to obtain the WAF for each parameter based on observed rain intensities, snow intensities and visibility levels. A detailed description of the calibration procedure is provided below.

**Table 3 – Supply side properties related with weather impact in TrEPS**

<table>
<thead>
<tr>
<th>Input data</th>
<th>Traffic properties</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic flow model</td>
<td>1. Speed-intercept, (mph)</td>
<td>The italic styled properties are only available in dual-regime model</td>
</tr>
<tr>
<td></td>
<td>2. Minimal speed, (mph)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. Density break point, (pcp mpl)</td>
<td></td>
</tr>
<tr>
<td>Link</td>
<td>4. Jam density, (pcp mpl)</td>
<td></td>
</tr>
<tr>
<td>Link</td>
<td>5. Shape term alpha</td>
<td></td>
</tr>
<tr>
<td>Link</td>
<td>6. Maximum service flow rate, (pcphpl or vphpl)</td>
<td></td>
</tr>
<tr>
<td>Link</td>
<td>7. Saturation flow rate, (vphpl)</td>
<td></td>
</tr>
<tr>
<td>Link</td>
<td>8. Posted speed limit adjustment margin, (mph)</td>
<td></td>
</tr>
<tr>
<td>Signal control</td>
<td>Cycle length, offset, green, amber, max green, min green</td>
<td>All same units, (seconds)</td>
</tr>
<tr>
<td>Left-turn capacity</td>
<td>9. g/c ratio</td>
<td></td>
</tr>
<tr>
<td>2-way stop sign capacity</td>
<td>10. Saturation flow rate for left-turn vehicles</td>
<td>All same units, (vphpl)</td>
</tr>
<tr>
<td></td>
<td>11. Saturation flow rate for through vehicles</td>
<td></td>
</tr>
<tr>
<td>2-way stop sign capacity</td>
<td>12. Saturation flow rate for right-turn vehicles</td>
<td></td>
</tr>
<tr>
<td>4-way stop sign capacity</td>
<td>13. Discharge rate for left-turn vehicles</td>
<td>All same units, (vphpl)</td>
</tr>
<tr>
<td>4-way stop sign capacity</td>
<td>14. Discharge rate for through vehicles</td>
<td></td>
</tr>
<tr>
<td>4-way stop sign capacity</td>
<td>15. Discharge rate for right-turn vehicles</td>
<td></td>
</tr>
<tr>
<td>Yield sign capacity</td>
<td>16. Saturation flow rate for left-turn vehicles</td>
<td>All same units, (vphpl)</td>
</tr>
<tr>
<td>Yield sign capacity</td>
<td>17. Saturation flow rate for through vehicles</td>
<td></td>
</tr>
</tbody>
</table>
Impact from Road Closure

The impact from road closure could come from incidents or road construction (work zones). The incident data needs to specify the number of incidents to be simulated, their starting and ending times (duration), location and severity. The workzone data should contain the number of work zones to be simulated, their start and end times, location, lane closure, reduced speed limits and queue discharge rate (i.e., maximum flow rate on the specified link, which also acts as an upper bound to the effective rate at which upstream queued vehicles may discharge into a work zone link).

The capacity reduction refers to the reduction in the physical storage capacity (lane miles). The queue discharge rate refers to the maximum flow rate vehicles are able to maintain when flowing out of the work zone link. TrEPS uses the capacity reduction to compute available link storage capacity and determine whether an upstream vehicle can physically move into the work zone link. The queue discharge rate is used by TrEPS to determine the rate at which vehicles can flow out of the work zone link.

Outputs: This module generates the estimated capacity based on the predicted probabilistic weather and incident events, which is the expected capacity with the effect of weather and incident events.

Process: The Capacity Estimator estimates the capacity with the predicted probabilistic weather and incident events. In this module, any secondary change from inducing breakdowns and potential strategies are not considered.

Dependencies: The Capacity Estimator depends on the MDSS package.

Capacity Predictor

Background: The Capacity Predictor is a module within the Capacity Prediction package that predicts the link capacity with the estimated capacity, inducing events and potential strategies. Similar to the Capacity Estimator, the Capacity Predictor calculates the expected capacity from the current stage for a pre-defined prediction horizon. Due to the potential or selected strategies from the Decision Making module and from the Traffic Operations module, some other changes in capacity may occur. Changes due to predicted breakdown and strategies can be regarded as secondary capacity changes, with the primary change due to the probabilistic events estimated in the Capacity Estimator.

Inputs: This module requires the inducing events from the TrEPS package and potential strategies from the Decision Making module and from the Traffic Operations module. The inducing events primarily refer to the probabilistic breakdown events. Once a breakdown occurs, the capacity may be reduced further from the estimated capacity of the Capacity Estimator.

Impact from Traffic Breakdown

Many studies have documented the occurrence of flow breakdown events, in conjunction with recurrent and non-recurrent congestion, the associated capacity drop, and the time it may
take to recover from such breakdown. Historical records and real-time traffic data can help calibrate traffic flow-density relations (fundamental diagrams) before and after the traffic breakdown to capture the capacity drop. With the calibrated traffic flow-density diagram and the probability of breakdown event from the Traffic Predictor, it is possible to predict the road capacity drop.

Table 4 – Capacity Predictor Input Categories

<table>
<thead>
<tr>
<th>Traffic State</th>
<th>Event</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated Traffic State</td>
<td>Weather Event</td>
<td>Historical Link Density and Speed</td>
</tr>
<tr>
<td>Predicted Traffic State</td>
<td>Incident Event</td>
<td>Real-Time Link Density and Speed</td>
</tr>
<tr>
<td>Probability of Breakdown</td>
<td>Road Construction Event</td>
<td>(workzone)</td>
</tr>
</tbody>
</table>

Outputs: This module generates the link capacity for the pre-defined prediction horizon.

Process: The Capacity Predictor predicts the link capacity with the estimated capacity, inducing events and potential strategies. From historical data, the probabilistic capacity curve and the weather adjustment factor to describe the weather effect on capacity can be calibrated. The Capacity Predictor adopts the calibrated curves and factors to generate predicted link capacity.

Dependencies: The Capacity Predictor depends on the Capacity Estimator and TrEPS.
Bayes

The Bayes package predicts traffic network conditions given a set of system variables, including weather, roadwork, incidents, traffic control strategies and special events. It is a powerful tool for diagnosing and predicting traffic states under uncertainty. The Bayes package contains two classes: a Bayesian Estimator and a Bayesian Predictor.

A Bayesian Network (BN) is a probabilistic graphical model (PGM) that represents probabilistic relationships among a set of variables via a directed acyclic graph (DAG). A BN consists of a set of nodes and arcs with nodes representing random variables and arcs representing causal relationships (direct dependencies) between variables. It can combine elicitation from experts and learning using archived and real-time data to generate precise prediction models. With a calibrated BN model, the probability of each state of a traffic state variable can be computed, conditioned on other sets of event or control variables.

Kim and Wang (2016)\(^7\) developed a Bayesian Network and determined the BN configuration by using Brisbane, Australia data. Their paper recommends use of the configuration in Figure 6 for the BN model. The configuration assumes that the Environment variables affect the External event variables and the Traffic condition variables directly; the External event variables also have a direct influence on the Traffic condition variables. This model has been validated as the best among the tested seven configurations by measuring a network-level scoring function and a variable-specific classification error. Therefore, we use this configuration as our basic BN model structure.

![Figure 6 – Proposed Bayesian Network Model Configuration](image)

---

Variables used in the IMRCP Bayesian Network model are presented in Table 5. A total of 14 variables are categorized into three groups. In each group, each variable does not have a relationship with other variables in the same group, which means each variable does not affect other variables in the same group. The relationships of the three groups are listed below:

- Variables in Group 1 (Network Environment) can directly affect variables in Group 2 (External Event) and Group 3 (Traffic Condition), but not the other way around (e.g., weather, such as snow, can cause an incident, but an incident cannot cause a weather event).
- Variables in Group 2 (External Event) can directly affect variables in Group 3 (Traffic Condition).
- Variables in Group 3 are different measures of the same link traffic condition. They are independent from each other.

Table 5 – Variables and State Definitions for IMRCP Bayesian Network

<table>
<thead>
<tr>
<th>Node Group</th>
<th>Variable</th>
<th>States</th>
<th>State Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1: Network Environment</td>
<td>Direction</td>
<td>-Eastbound</td>
<td>00mm/h; visibility &gt;3300ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Southbound</td>
<td>&lt;2.5mm/h; &gt;3300ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Westbound</td>
<td>&lt;2.5mm/h; &lt;3300ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Northbound</td>
<td>2.5 - 7.6mm/h; &gt;3300ft</td>
</tr>
<tr>
<td></td>
<td>Weather</td>
<td>-Clear</td>
<td>2.5 - 7.6mm/h; 330 - 3300ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Light rain, clear visibility</td>
<td>≥ 7.6mm/h; &lt;330ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Light rain, reduced visibility</td>
<td>≥ 7.6mm/h; &lt;330ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Light rain, low visibility</td>
<td>≥ 7.6mm/h; &lt;330ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Moderate rain, clear visibility</td>
<td>≥ 7.6mm/h; &lt;330ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Moderate rain, reduced visibility</td>
<td>≥ 7.6mm/h; &lt;330ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Moderate rain, low visibility</td>
<td>≥ 7.6mm/h; &lt;330ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Heavy rain, clear visibility</td>
<td>≥ 7.6mm/h; &lt;330ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Heavy rain, low visibility</td>
<td>≥ 7.6mm/h; &lt;330ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Light snow, clear visibility</td>
<td>≥ 7.6mm/h; &lt;330ft</td>
</tr>
</tbody>
</table>

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Intelligent Transportation System Joint Program Office
<table>
<thead>
<tr>
<th>Group 2: External Event</th>
<th>IncidentDownstream</th>
<th>-No incident</th>
<th>-Incident</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IncidentOnLink</td>
<td>-No incident</td>
<td>-Incident</td>
</tr>
<tr>
<td></td>
<td>IncidentUpstream</td>
<td>-No incident</td>
<td>-Incident</td>
</tr>
<tr>
<td></td>
<td>Workzone</td>
<td>-No workzone</td>
<td>-Workzone</td>
</tr>
<tr>
<td></td>
<td>RampMetering</td>
<td>-No ramp metering</td>
<td>-Ramp metering</td>
</tr>
<tr>
<td></td>
<td>SpecialEvents**</td>
<td>-Special event</td>
<td>-No special event</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group 3: Traffic Condition</th>
<th>Flow (veh/h/ln)</th>
<th>-Very low</th>
<th>-Low</th>
<th>-High</th>
<th>-Very high</th>
<th>&lt; 0.25***</th>
<th>0.25 - 0.5</th>
<th>0.5 - 0.75</th>
<th>≥ 0.75</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (mph)</td>
<td>-Very low</td>
<td>-Low</td>
<td>-High</td>
<td>-Very high</td>
<td>&lt; 0.25***</td>
<td>0.25 - 0.5</td>
<td>0.5 - 0.75</td>
<td>≥ 0.75</td>
<td></td>
</tr>
<tr>
<td>Occupancy (%)</td>
<td>-Very low</td>
<td>-Low</td>
<td>-High</td>
<td>-Very high</td>
<td>&lt; 0.25***</td>
<td>0.25 - 0.5</td>
<td>0.5 - 0.75</td>
<td>≥ 0.75</td>
<td></td>
</tr>
<tr>
<td>Congestion</td>
<td>-Uncongested</td>
<td>-Congested</td>
<td></td>
<td></td>
<td>Occupancy &lt; Occ_{crit}****</td>
<td>Occupancy ≥ Occ_{crit}</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** This is one potential way to accommodate "special events" in the Bayesian Network model. The "special event" here is nominal. It can represent any special event, such as football or hockey games. The special event will be defined when real world data are used to train the BN model. Any special event in Bayesian model should be considered on a case-by-case basis.
*** Based on normalized parameter values, which range between 0 and 1
**** Occ_{crit} represents the critical occupancy at which the link flow becomes maximum

Input to the Bayes package includes data from the data Store such as traffic, weather, work zones, incidents, and traffic control states. The outputs of the Bayes package are predicted traffic states.
Bayesian Estimator

**Background:** The Bayesian Estimator within the Bayes package maintains up-to-date model estimation using the subject matter expertise inherent in the BN applied to the aggregated operational data archive and real-time data stream.

**Inputs:** Inputs to the Bayesian Estimator include historical weather, roadwork, incidents, traffic control strategies, special events and traffic state data which are obtained from the data Store. These data are categorized into three groups: Network Environment, External Events and Traffic Condition. The groups can be seen below in . Network Environment directly affects both External Events and Traffic Condition, and there is also a direct influence of External Events on Traffic Condition.

**Table 6 – Bayesian Estimator Input Categories**

<table>
<thead>
<tr>
<th>Group 1: Network Environment</th>
<th>Group 2: External Events</th>
<th>Group 3: Traffic Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction</td>
<td>Incident downstream</td>
<td>Flow</td>
</tr>
<tr>
<td>Weather</td>
<td>Incident on this link</td>
<td>Speed</td>
</tr>
<tr>
<td>Time of day</td>
<td>Incident upstream</td>
<td>Occupancy</td>
</tr>
<tr>
<td>Day of week</td>
<td>Workzone</td>
<td>Congestion (indicator)</td>
</tr>
<tr>
<td></td>
<td>Ramp metering</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Special events</td>
<td></td>
</tr>
</tbody>
</table>

**Outputs:** The model estimator computes a conditional probability distribution for each node and posterior probabilities based on the prior and latest observations.

**Process:** The Bayesian Estimator model starts with the BN network structure. Then based on the weather, roadwork, traffic and other data inputs, the estimator computes and estimates the
distributions of all variables (nodes). After a certain time period, the Bayesian Estimator will recompute the distributions and determines posterior probabilities based on the prior and latest observations. The estimation or learning process is continuous and keeps the BN model updated as new observations are obtained.

**Dependencies:** The Bayesian Estimator depends on previous weather, roadwork, incidents, traffic control strategies and traffic state data from data Store and the output of itself in the previous estimation.

**Bayesian Predictor**

**Background:** The Bayesian Predictor within the Bayes package predicts likely future network traffic states for a specified prediction horizon (such as 30 min, 1 hour) or for a specific time of day.

**Inputs:** The Bayesian Predictor inputs contain two groups of data. One is Network Environment (e.g., weather, time, date) and the other is External Events, such as incidents, workzones and special events. All data inputs are current information on current network link provided by the data Store.

**Table 7 – Bayesian Predictor Input Categories**

<table>
<thead>
<tr>
<th>Group 1: Network Environment</th>
<th>Group 2: External Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction</td>
<td>Incident downstream</td>
</tr>
<tr>
<td>Weather</td>
<td>Incident on this link</td>
</tr>
<tr>
<td>Time of day</td>
<td>Incident upstream</td>
</tr>
<tr>
<td>Day of week</td>
<td>Workzone</td>
</tr>
<tr>
<td></td>
<td>Ramp metering</td>
</tr>
<tr>
<td></td>
<td>Special events</td>
</tr>
</tbody>
</table>

**Outputs:** The Bayesian Predictor provides future network traffic states (flow, speed, occupancy and congestion status) for the next specified prediction horizon (15 mins, 30 mins and 1 hour) of the same day.

**Process:** Based on the updated BN model from the Bayesian Estimator, the Bayesian Predictor uses data on current link traffic states (e.g., direction, current weather, current time) and other system variables, such as work zones and incidents, from the data Store as model inputs. Using the estimated distributions of system variables, the Bayesian Predictor predicts the future network states, such as traffic flow, speed, occupancy and congestion status.

**Dependencies:** The Bayesian Predictor depends on current weather, roadwork, incidents and traffic control strategies from the data Store and the Bayes Estimator in the Bayes package. The activation of intervention related nodes in the Bayesian network (e.g., Ramp Metering), if used, is dependent on the Decision Making module from the Traffic Operations package.
Incident

The Incident package predicts the likelihood of an incident occurrence using a BN model given a set of variables including traffic, weather, types of roadway facility, types of incidents (fatal/injury or property damage only), number of closed lanes and other variables. With a calibrated BN model, the likelihood of incident occurrence can be computed, conditioned on the variables mentioned above. The Incident package contains two classes: an Incident Estimator and an Incident Predictor. Note that the prediction in the Incident Package is optional. Alternatively, the Incident package can also be simplified, only for information purpose, using pure descriptive statistics based on archived incident data from the data Store. In the meantime, if no incident prediction is involved, the incident input for traffic prediction models are detected incidents in real time.

Figure 9 - Graphical Representation of the Bayesian Network for Incident Occurrence Prediction

Variables used in IMRCP Bayesian Network model are presented in Table 8. A total of 11 variables are categorized into three groups. In each group, each variable does not have a relationship with the other variables in the same group, which means each variable does not affect other variables in the same group. The relationships of three groups are below:

- Variables in Group 1 (Network Environment) can directly affect variables in Group 2 (External Event) and Group 3 (Traffic Condition), but not the other way around (e.g., weather, such as snow, can cause an incident, but an incident cannot cause a weather event).
- Variables in Group 2 (External Event) can directly affect variables in Group 3 (Traffic Condition).
- Variables in Group 3 are different measures of the same link traffic condition. They are independent from each other.
Table 8 – Variables and State Definitions for IMRCP Bayesian Network

<table>
<thead>
<tr>
<th>Node Group</th>
<th>Variable</th>
<th>States</th>
<th>State Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group 1: Network Environment</strong></td>
<td></td>
<td><strong>Direction</strong></td>
<td>-Eastbound&lt;br&gt;-Southbound&lt;br&gt;-Westbound&lt;br&gt;-Northbound</td>
</tr>
<tr>
<td></td>
<td><strong>Weather</strong></td>
<td>-Clear&lt;br&gt;-Light rain, clear visibility&lt;br&gt;-Light rain, reduced visibility&lt;br&gt;-Light rain, low visibility&lt;br&gt;-Moderate rain, clear visibility&lt;br&gt;-Moderate rain, reduced visibility&lt;br&gt;-Moderate rain, low visibility&lt;br&gt;-Heavy rain, reduced visibility&lt;br&gt;-Heavy rain, low visibility&lt;br&gt;-Light snow, clear visibility&lt;br&gt;-Moderate snow, reduced visibility&lt;br&gt;-Heavy snow, reduced visibility&lt;br&gt;-Heavy snow, low visibility</td>
<td>00mm/h; visibility &gt;3300ft&lt;br&gt;&lt; 2.5mm/h; &gt; 3300ft&lt;br&gt;&lt; 2.5mm/h; 330 - 3300ft&lt;br&gt;&lt; 2.5mm/h; &lt; 330ft&lt;br&gt;2.5 - 7.6mm/h; &gt; 3300ft&lt;br&gt;2.5 - 7.6mm/h; 330 - 3300ft&lt;br&gt;2.5 - 7.6mm/h; &lt; 330ft&lt;br&gt;2.5 - 7.6mm/h; &lt; 3300ft&lt;br&gt;&gt; 7.6mm/h; 330 - 3300ft&lt;br&gt;&gt; 7.6mm/h; &lt; 330ft&lt;br&gt;; &gt;3300ft*&lt;br&gt;; 1650 - 3300ft*&lt;br&gt;; 330 - 1650ft*&lt;br&gt;; &lt; 330 ft*</td>
</tr>
<tr>
<td></td>
<td><strong>DayOfWeek</strong></td>
<td>-Weekend&lt;br&gt;-Weekday</td>
<td>Saturday, Sunday&lt;br&gt;Monday - Friday</td>
</tr>
<tr>
<td></td>
<td><strong>TimeOfDay</strong></td>
<td>-Morning&lt;br&gt;-AM peak&lt;br&gt;-Off-peak&lt;br&gt;-PM peak&lt;br&gt;-Night</td>
<td>1AM - 6AM (5 hrs)&lt;br&gt;6AM - 10 AM (4hrs)&lt;br&gt;10AM - 4PM (6hrs)&lt;br&gt;4PM - 8PM (4hrs)&lt;br&gt;8PM - 1AM (5 hrs)</td>
</tr>
<tr>
<td><strong>Group 2: External Event</strong></td>
<td><strong>IncidentDownstream</strong></td>
<td>-No incident&lt;br&gt;-Incident</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>HistoricalIncident</strong></td>
<td>-No incident&lt;br&gt;-Incident</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>IncidentUpstream</strong></td>
<td>-No incident&lt;br&gt;-Incident</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Workzone</strong></td>
<td>-No workzone&lt;br&gt;-Workzone</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>RampMetering</strong></td>
<td>-No ramp metering&lt;br&gt;-Workzone</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>SpecialEvents</strong></td>
<td>-Special event&lt;br&gt;-Ramp metering</td>
<td></td>
</tr>
<tr>
<td><strong>Group 3: Incident</strong></td>
<td><strong>IncidentThisLink</strong></td>
<td>-No incident&lt;br&gt;-Incident</td>
<td></td>
</tr>
</tbody>
</table>

** This is one potential way to accommodate "special events" in the Bayesian Network model. The "special event" here is nominal. It can represent any special event, such as football games, hockey games or others. The special event will be defined when real world data are used to train the BN model. Any special event in Bayesian model should be considered on a case-by-case basis.
The input to the Incident package includes data from the data Store such as traffic, weather, and road segment conditions. All these required data elements are built into the incident BN network.

![Figure 10 – Incident Bayesian Network Process](image)

**Incident Estimator**

**Background:** The Incident Estimator within the Incident package maintains up-to-date model estimation using incident and operational data archives and real-time data streams.

**Inputs:** Similar to the Bayesian Estimator, there are three groups of historical data inputs for the Incident Estimator. One is Network Environment, such as weather, date and time. Another is External Events, for example, incidents downstream and upstream. The third one is the Incident Occurrence which contains the incident that occurred on this link. These data are prior data stored in the data Store collected by TMCs and other resources.

<table>
<thead>
<tr>
<th>Group 1: Network Environment</th>
<th>Group 2: External Events</th>
<th>Group 3: Incident Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction</td>
<td>Incident downstream</td>
<td>Incident on this link</td>
</tr>
<tr>
<td>Weather</td>
<td>Historical Incident</td>
<td></td>
</tr>
<tr>
<td>Time of day</td>
<td>Incident upstream</td>
<td></td>
</tr>
<tr>
<td>Day of week</td>
<td>Workzone</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ramp metering</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Special events</td>
<td></td>
</tr>
</tbody>
</table>

**Outputs:** The Incident Estimator computes a conditional probability distribution for each node and posterior probabilities based on the prior and latest observations.

**Process:** The Incident Estimator module starts with the BN network structure. Then based on the weather, roadwork, traffic and other data inputs, the estimator computes and estimates the distributions of all variables (nodes). After a certain specified time period, the Incident Estimator will recompute the distributions and determines posterior probabilities based on the prior and latest observations.
latest observations. The estimation or learning process is continuous and keeps this BN model updated as new observations are obtained.

**Dependencies:** The Incident Estimator depends on the data Store and the output of itself in the previous estimation.

**Incident Predictor**

**Background:** The Incident Predictor within the Incident package predicts the likelihood of potential incidents.

**Inputs:** The Incident Predictor inputs contain two groups of data. One is Network Environment (e.g., weather, time, date) and the other is External Events, such as incidents downstream and upstream and work zones. All data inputs are current information on current link provided by the data Store.

**Table 10 – Incident Predictor Input Groups**

<table>
<thead>
<tr>
<th>Group 1: Network Environment</th>
<th>Group 2: External Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction</td>
<td>Incident downstream</td>
</tr>
<tr>
<td>Weather</td>
<td>Historical Incident</td>
</tr>
<tr>
<td>Time of day</td>
<td>Incident upstream</td>
</tr>
<tr>
<td>Day of week</td>
<td>Workzone</td>
</tr>
<tr>
<td></td>
<td>Ramp metering</td>
</tr>
<tr>
<td></td>
<td>Special events</td>
</tr>
</tbody>
</table>

**Outputs:** The Incident Predictor provides the prediction of likelihood of potential incidents for the next specified prediction horizon (15 mins, 30 mins and 1 hour) of the same day.

**Process:** Based on the updated BN model for Incident Occurrence Prediction, the Incident Predictor uses information on current network link traffic states and other system variables, such as work zones and incidents, and historical incident data as model inputs. Using the estimated distributions of system variables, the Incident Predictor outputs the likelihood of potential incidents.

**Dependencies:** The Incident Predictor depends on the data Store and the Incident Estimator in the Incident package.
Ensemble

The Ensemble package produces final traffic state predictions by combining results of the TrEPS Package and Bayes 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 adequately by themselves 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 using a least-square estimation method \(^8\) aimed at finding 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.

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Figure 11 – Ensemble Package Process

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Intelligent Transportation System Joint Program Office
Background: The Ensemble package predicts final traffic network state predictions by ensembling results of the TrEPS package and Bayes Package.

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 Bayes 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 Bayes Package. Based on the weights and the predicted traffic states data from the TrEPS package and Bayes 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 Bayes 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 Bayes 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 Bayes packages.
MDSS

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, and originally in the Maintenance Decision Support System (MDSS). 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, 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.

Figure 12 – Overview of NCAR MDSS
(Source: NCAR)

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9 National Center for Atmospheric Research; Pikalert® Vehicle Data Translator 4.0, Enhanced Maintenance Decision Support System, Motorist Advisory and Warning Application Installation Guides; Version 1.0, February 2015.

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

The analytical process, illustrated in , 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 sent to the data Store for use by other IMRCP modules.
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.

**Inputs:** Atmospheric weather forecasts are generated and distributed as gridded data. As described in the *IMRCP Model Analysis*\(^{11}\), 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 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 longer than a few hours. 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 in keeping with the underlying model's physics, e.g., a 13-

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\(^{11}\) Leidos, Inc. *Integrated Modeling for Road Condition Prediction Model Analysis; Version 1*, May 10, 2015.
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 IMRCP 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. 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. 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.

RCTM

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. As shown in , 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 , in order to preserve continuity with the independent MDSS implementations.

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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.

**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.14

**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

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**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:** The Storm Characterization algorithm processing 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 becomes available from METRo. The module uses current weather forecasts, recent road condition data, and operation characteristics of the road segment to create the variables for the pre-, in-, and post-storm environment. Illustrates the 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. The NCAR MDSS/RCTM module is used in IMRCP in its entirety, with an exception for

**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

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**Figure 16 – Storm Characterization Process**

(Source: NCAR)
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 Concentration 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:

$$\text{AvailableChemical} = (1-t\text{factor})(\text{ChemRate}+\text{ResidualChemical}+\text{ChemInSolution})$$

where \(t\text{factor}\) 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 \(\text{CalcTrafficFactor}\))."^^15"

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 2000 vehicles per hour per lane)
3 = High (more than 2000 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 \(\text{CalcCriticalChemSaturationPoint}\)) 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

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"^^15 MDSS_Tech_Description_v6 page 145-147"
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. 16

Rules of Practice Module


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 RulesOfPractice 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 Treatment 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 modules determines the treatment type and time.

The RulesOfPractice Module starts by determining if the storm conditions can be managed by only plowing the roads. If anti-icing chemicals are warranted, it determines if pre-treatment is necessary. If pre-treatment is not needed, or has already been applied, the RulesOfPractice 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 RulesOfPractice module then iterates to find the next treatment (if necessary) until the entire storm has been treated. 18

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16 MDSS_Tech_Description_v6 page 145-147
17 MDSS_Tech_Description_v6 page 155-165
18 MDSS_Tech_Description_v6 page 155-160
Figure 17 – Rules of Practice Evaluation Process
(Source: NCAR, Source: MDSS_Tech_Description Version 6 Page 157)

**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 within IMRCP 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 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

<table>
<thead>
<tr>
<th>Pavement Condition</th>
<th>Mobility Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>1.0</td>
</tr>
<tr>
<td>Wet</td>
<td>0.7</td>
</tr>
<tr>
<td>Snow &lt; 4 inches</td>
<td>0.6</td>
</tr>
<tr>
<td>Snow 4-6 inches</td>
<td>0.4</td>
</tr>
<tr>
<td>Snow &gt; 6 inches</td>
<td>0.3</td>
</tr>
<tr>
<td>Ice</td>
<td>0.2</td>
</tr>
</tbody>
</table>

19 MDSS_Tech_Description_v6 page 154

U.S. Department of Transportation, Research and Innovative Technology Administration
Intelligent Transportation System Joint Program Office
**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 of and uses 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 expected.
Hydro

The hydrological forecast (Hydro) package translates forecasts of stream water levels into predictions of road segment inundation. The models and techniques are based on available hydrological data products from the National Weather Service, but could be extended to other data sources and locations. For the NWS case, water level predictions from the Advanced Hydrological Prediction Service (AHPS) are acquired for the system by a corresponding collector component. These data are forecasted stream levels based on the local gauge for particular sensor locations. These gauge levels are then indexed to areas of inundation based on topological maps from the National Geospatial Program of the U.S. Geological Survey (USGS). The Hydro forecast package consists of a single Inundation (Inndtn) component that provides this translation.

**Inundation [Inndtn]**

**Background**: The Inundation component translates stream levels into road segment inundation. The inundation data can then be factored into computations of link capacity.

**Inputs**: The Inundation component needs stream levels and associated segment IDs from the Hydro component in the data Store.

**Outputs**: Outputs from the Inundation component are segment inundation states to be associated with the Segment Conditions.

**Process**: The Inundation component subscribes to the Hydro component in the data Store. When Hydro receives new stream level data, Inundation determines what road segments would be inundated at that stream level. The resulting segment inundation state is then provided to the Segment Conditions component in the Store.

**Dependencies**: Inundation depends on the data Store for its inputs and outputs.
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:

- Weather Conditions [Wx]
- Hydrological Conditions [Hydro]
- Environmental Sensor Station [ESS]
- Roadway Segment [Seg]
- Segment Conditions [Seg Cndtns]
- Maintenance Operations [Maint Ops]
- Roadway Network Link [Link]
- Network Links Conditions [Link Cndtns]
- Network Nodes [Node]
- Node Conditions [Node Cndtns]
- Traffic Control Operations [Control Ops]
- Work Zones [WZ Ops]
- Incidents [Incdnt]
- Alerts
- Routes
- Special Events [Special Events]

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.

Weather Conditions [Wx]

**Background:** The Weather Conditions (Wx) module contains the time-varying predictions of atmospheric weather conditions for the current forecast interval.

**Inputs:** The forecast weather conditions will include elements such as air temperature, relative humidity, dew point temperature, wind speed, wind direction, insolation (or sky cover), visibility, precipitation rate, precipitation type and precipitation probability that have been collected by WxDE, NDFD, RAP, RTMA, and Radar. These data generally consist of a time, location, and value detail.

**Outputs:** The Weather Conditions module provides the same elements it receives from the Collect system package. Those elements include air temperature, relative humidity, dew point temperature, wind speed, wind direction, insolation (or sky cover), visibility, precipitation rate,
precipitation type and precipitation probability. These data can be used by other modules to create forecasts and display information to the final user.

**Process:** The Weather Conditions module subscribes to the WxDE, Wx Forecast and Radar modules in the Collect system package and is notified when data is collected by those modules. The Weather Condition module then gets the new information from the modules in the Collect system package. Forecast data structures conform to the spatiotemporal grids used by the forecast provider(s). Old forecast data are overwritten when new forecast data are acquired.

**Dependencies:** The Weather Conditions module does not have any dependencies.

**Hydrological Conditions [Hydro]**

**Background:** The Hydrological Conditions (Hydro) module contains the time-varying predictions of local hydrological conditions for the current forecast interval.

**Inputs:** The forecast hydrological conditions include elements such as location, submersion depth, and submersion rate from the Hydro and Hydro Forecast modules in the data Collect. This data generally consists of a time, location, and value detail. The Hydro module in the data Store also contains the inundations forecasted in the Hydro module in the Forecast system package.

**Outputs:** The Hydrological Conditions module provides elements such as location, submersion, depth, and submersion rate.

**Process:** The Hydrological Conditions module subscribes to the Hydro and Hydro Forecast modules in the Collect system package and is notified when hydrological condition information is collected by the Hydro module. The Hydrological Conditions module then gets the new information from the Hydro collector module. Forecast data structures conform to the spatiotemporal grids used by the forecast provider(s). Old forecast data are overwritten when new forecast data are acquired.

**Dependencies:** The Hydrological Conditions module does not have any dependencies.

**Environmental Sensor Station [ESS]**

**Background:** The Environmental Sensor Station (ESS) observations object contains the time-varying observations of road weather conditions at ESS within the geographical domain of the system. ESS observations are used to initialize the road weather forecasts to measured conditions on roadways within the network.

**Inputs:** Observation types included in the ESS module may consist of the air temperature, barometric pressure, pavement temperature, subsurface temperature, precipitation rate, precipitation thickness, wind speed, wind direction, wind gust, visibility, dew point, relative humidity, road condition and conductivity (a measure of chemical treatment concentration), when those data are available from the ESS

**Outputs:** The ESS module provides local measured conditions on road network segments.

**Process:** The ESS module subscribes to data provided by the WxDE collector module and is notified when new data are available.

**Dependencies:** The ESS module does not have any dependencies.
**Roadway Segment [Seg]**

**Background:** The Roadway Segment (Seg) module contains the static attributes of roadway segments to be modeled within the system.

**Inputs:** The Roadway Segment module includes physical attributes of the roadway such as a polyline defining the travel path in three-dimensional space, the number of lanes, its pavement material layers and their thicknesses and its (untreated) surface coefficient of friction.

**Outputs:** The Roadway Segment module provides the information it gets from an external transportation model which includes the physical attributes of the roadway such as a polyline defining the travel path in three-dimensional space, the number of lanes, its pavement material layers and their thicknesses and its (untreated) surface coefficient of friction.

**Process:** The roadway segment information is stored in the module using an administrative process in which an administrator of the system inputs the data directly into the Roadway Segment module using an external transportation model.

**Dependencies:** The Roadway Segment module is dependent on the GeoServices package.

**Segment Conditions [Seg Cndtns]**

**Background:** The Segment Conditions (Seg Cndtns) module contains the time-varying attributes of roadway segments modeled in the system. Roadway segment conditions are mapped to a specific roadway segment.

**Inputs:** The time-varying roadway segment conditions in the Segment Conditions module are described by attributes including the one-dimensional distribution of pavement temperatures from the surface through its substructure to the bottom of the base layer; precipitation layer material, density, and thickness; pavement treatment material and linear density (mass per unit of roadway path length). These attributes are gathered from the TrEPS and TffcOps modules in the forecast system package.

**Outputs:** The same time-varying roadway segment conditions stored in the Segment Conditions module are considered outputs for use in other packages such as the forecast package. These attributes, as described above, may include the one-dimensional distribution of pavement temperatures from the surface through its substructure to the bottom of the base layer; precipitation layer material, density, and thickness; pavement treatment material and linear density (mass per unit of roadway path length).

**Process:** The Segment Conditions module subscribes to the TrEPS and Traffic Operations packages in the Forecast package and is notified when segment condition information is available. The segment condition module then gets the information from the TrEPS and Traffic Operations packages. Old data are overwritten when new data are acquired.

**Dependencies:** The Segment Conditions module does not have any dependencies.

**Roadway Network Link [Link]**

**Background:** The Roadway Network Link (Link) module contains the static attributes of roadway links to be modeled within the system. A link is associated with one or more segments and with exactly two nodes.

**Inputs:** The roadway link is described by the logical attributes of the roadway and its traffic: its constituent physical segments, association of its starting and ending nodes and direction of travel between the nodes. These attributes are included in the Roadway Network Link module.
**Outputs:** The Roadway Link module provides the information it gets from an external transportation model which includes the static attributes of the roadway links such as its constituent physical segments, association of its starting and ending nodes and direction of travel between the nodes.

**Process:** The roadway link information is stored in the module using an administrative process in which an administrator of the system inputs the data directly into the Roadway Link module using an external transportation model.

**Dependencies:** The Roadway Link module is dependent on the GeoServices package

**Link Conditions [Link Cndtns]**

**Background:** The Link Conditions (Link Cndtns) module contains the time-varying attributes of roadway links used to describe the traffic on the roadway. Roadway link conditions are mapped to a specific roadway link.

**Inputs:** Time-varying roadway link conditions are described by attributes including but not limited to speed, volume, occupancy and speed limit. These attributes are gathered from the TrEPS and TffcOps modules in the forecast system package and the roadway segment conditions module in the data Store.

**Outputs:** The same time-varying roadway link conditions stored in the Link Conditions module are considered outputs for use in other packages such as the forecast package. These attributes, as described above, may include but are not limited to speed, volume, occupancy and speed limit.

**Process:** The Link Conditions module subscribes to the TrEPS and Traffic Operations packages in the Forecast package and is notified when link condition information is available. The Link Condition module then gets the information from the TrEPS and Traffic Operations packages. Old data are overwritten when new data are acquired.

**Dependencies:** The Link Conditions module does not have any dependencies.

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**Figure 18 – Relationship Between Segments, Links, Nodes and Routes**

**Roadway Network Node [Node]**

**Background:** The Roadway Network Node (Node) module contains the static attributes of roadway nodes to be modeled within the system. Nodes correspond to decision or control points on the roadway network and are the endpoints of two or more links.
**Inputs:** The roadway node is described by physical and logical control attributes of the roadway such as the presence and configuration of traffic signals, ramp meters, speed limit zones, and gates. These attributes are included in the Roadway Network Node module.

**Outputs:** The Roadway Network Node module provides the information it gets from an external transportation model which includes the static attributes of the roadway nodes such as the presence and configuration of traffic signals, ramp meters, speed limit zones, and gates. These attributes are included in the roadway network node module.

**Process:** The roadway node information is stored in the module using an administrative process in which an administrator of the system inputs the data directly into the Roadway Networks Node module using an external transportation model.

**Dependencies:** The Roadway Network Node module is dependent on the GeoServices package.

### Node Conditions [Node Cndtns]

**Background:** The Node Conditions (Node Cndtns) module contains the time-varying attributes of roadway nodes modeled in the system. Roadway node conditions are mapped to a specific roadway node.

**Inputs:** Time-varying node conditions consist primarily of flow volume fractions from link to link. These attributes are gathered from the TrEPS and TffcOps modules in the forecast system package.

**Outputs:** The same time-varying roadway node conditions stored in the node conditions module are considered outputs for use in other packages such as the forecast package. These attributes, as described above, consist primarily of flow volume fractions from link to link.

**Process:** The Node Conditions module subscribes to the TrEPS and Traffic Operations packages in the Forecast package and is notified when node condition information is available. The Node Condition module then gets the information from the TrEPS and Traffic Operations packages. Old data are overwritten when new data are acquired.

**Dependencies:** The Node Conditions module 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.

**Inputs:** Time-varying maintenance operation attributes are generally consistent with the Traffic Management Data Dictionary (TMDD) “Events” module data elements and include the location, start time, end time, and number of affected lanes. Consequence of maintenance operations on snow and ice removal are modeled directly in the segment conditions.

**Outputs:** The time-varying maintenance operation attributes stored in the Maintenance Operations module, which include the location, start time, end time, and number of affected lanes, are also the outputs for the module. These attributes may be used in the Forecast system as well as other systems in the model.

**Process:** The Maintenance Operations module subscribes to the Maintenance Rules module in the Collect system package and is notified when maintenance operation information is collected by the Maintenance Operations module. The operations module then gets the new information from the Collect system package. Forecast data structures conform to the...
spatiotemporal grids used by the forecast provider(s). Old forecast data are overwritten when new forecast data are acquired.

**Dependencies:** The maintenance operations module does not have any dependencies.

**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.

**Inputs:** Time-varying traffic control operations are described by attributes such as the traffic signal plans, ramp metering plans, variable speed limits, and gate status.

**Outputs:** The time-varying traffic control operation attributes stored in the traffic control operations module, which include the location, start time, end time, and number of affected lanes, are also the outputs for the module. These attributes may be used in the Forecast system as well as other systems in the model.

**Process:** The Traffic Controls Operations module subscribes to the Traffic Controls module in the Collect system package and is notified when traffic control operation information is collected by the Traffic Controls module. The operations module in the data Store then gets the new information from the Collect system package. Forecast data structures conform to the spatiotemporal grids used by the forecast provider(s). Old forecast data are overwritten when new forecast data are acquired.

**Dependencies:** The Traffic Control Operations module does not have any dependencies.

**Work Zone [WZ Ops]**

**Background:** The Work Zone Operations (WZ Ops) module contains the time-varying attributes of work zones modeled in the system. Work zones are mapped to one or more road segments.

**Inputs:** Time-varying work zone attributes are generally consistent with the TMDD “Events” module data elements and include the location, start time, end time, and number of affected lanes.

**Outputs:** The time-varying work zone operation attributes stored in the Work Zone Operations module, which include the location, start time, end time, and number of affected lanes, are also the outputs for the module. These attributes may be used in the Forecast system as well as other systems in the model.

**Process:** The Work Zone Operations module subscribes to the Work Zone module in the Collect system package and is notified when maintenance operation information is collected by the Work Zone module. The operations module then gets the new information from the Collect systems. Forecast data structures conform to the spatiotemporal grids used by the forecast provider(s). Old forecast data are overwritten when new forecast data are acquired.

**Dependencies:** The Traffic Control Operations module does not have any dependencies.

**Incident [Incdnt]**

**Background:** The Incident module contains the time-varying attributes of incidents modeled in the system. Incidents are mapped to one or more road segments.
**Inputs:** Attributes of incidents are consistent with the TMDD Standard for Center to Center Communications and the IEEE 1512 standard for incident data. These attributes are taken from the incidents module in the Collect system and include the time, location, and type of incident.

**Outputs:** The outputs of the Incident module are the same attributes that are taken from the Collect system and include the time, location, and type of incident. These attributes may be used in some modules within the Forecast system package.

**Process:** The Incident module in the data Store subscribes to the Incidents module in the Collect system package and is notified when incident information is collected by the Collect system package. The data Store Incidents module then gets the new information from the Collect systems. Forecast data structures conform to the spatiotemporal grids used by the forecast provider(s). Old forecast data are overwritten when new forecast data are acquired.

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

**Alerts**

**Background:** The Alert 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:** Attributes of alerts 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, which are taken from the alert module in the Alert system package.

**Outputs:** The attributes available from the Alerts module in the data Store are the same as those taken from the Alert module in the Alert 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 data Store subscribes to the Alert module in the Alert system package and is notified when alert information is available in the Alert system package. The data Store alerts module then gets the new information from the Alert system package.

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

**Routes**

**Background:** The Route module contains the attributes of routes generated by the system. Routes consist of a set of links between a start point and end destination. Multiple routes are possible between any start point and end destination.

**Inputs:** Attributes of routes include the start node, the end node, the set of links, the time at the start node to which the route attributes apply, the route distance traveled and the travel time. Other attributes can be associated with the route through its association with its component link conditions, and through those links with their component segments. These attributes of the routes generated in the Route module of the Route system package are kept in the data Store Route module.

**Outputs:** The attributes available from the Routes module in the data Store are the same as those taken from the route module in the Route system package. The attributes include the start node, the end node, the set of links, the time at the start node to which the route attributes apply, the route distance traveled and the travel time.
**Process:** The Routes module in the data Store subscribes to the Route module in the Route system package and is notified when route information is available in the Route system package. The data Store Routes module then gets the new information from the Route system package.

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

**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.

**Inputs:** The attributes of special events gathered from the Collect Events module include the time, location, type, and attendance of the special event.

**Outputs:** The attributes collected from the Collect Events module also act as outputs for the Special Events module in the data Store for use in other modules such as those in the Forecast system package.

**Process:** The Special Events module in the data Store subscribes to the Events module in the Collect system package and is notified when event information is available in the Collect system package. The data Store Special Events module then gets the new information from the Collect system package.

**Dependencies:** The Special Events module in the data Store does not have any dependencies.
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. 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:

- WxDE [WxDE], for surface weather observations
- Hydrological Conditions [Hydro], for hydrological conditions and forecasts
- Hydrological Forecast [Hydro Forecast], for Overland Park hydrological conditions and forecasts
- CAP [CAP], for alerts, watches, and warning
- Traffic Conditions [Traffic Cndtns], for current traffic conditions on the network of interest
- Traffic Controls [Traffic Cntrls], for the current state of and plans for traffic controls
- Maint Rules [Maint Rules], for roadway maintenance rules (e.g., winter maintenance operations)
- Intervention Rules [Intrvntn Rules], for operational intervention strategies not otherwise associated with traffic controls
- Work Zones [WZ], for the current state of and plans for work (construction) zones
- Incidents [Incdnts], for the current state of incidents
- Events [Events], for the current state of and plans for events
- DemandTrips [Demand Trips], for inferring demand trip information from probe data
- RADAR [RADAR], for radar reflectivity
- Weather Forecast [Wx Forecast], for atmospheric weather forecasts
- NDFD [NDFD], for atmospheric weather forecasts
- RAP [RAP], for forecasted surface pressure, precipitation amount, and precipitation type
- RTMA [RTMA], for current air temperature, wind speed, surface pressure, and humidity

![Collect Package Diagram](image-url)

**Figure 19 – Collect Package Diagram**
**WxDE [WxDE]**

**Background:** The WxDE collector module collects information from the Weather Data Environment, part of the United States Department of Transportation's (USDOT’s) Data Capture and Management Program and associated with the Research Data Exchange.

**Inputs:** The WxDE collector module collects data on weather observations from fixed Environmental Sensor Stations (i.e., fixed stations), called nonmobile data; weather observations from vehicles (i.e., mobile stations) specially-equipped to collect weather data and provide that data in near real-time; quality control metrics computed for weather observations from both fixed and mobile stations; road segment data, including statistical averages of weather observations along specific road segments and estimates of weather conditions along these roads; and metadata that describes the data contained in the Weather Data Environment.

**Outputs:** The WxDE collector module sends weather observations from fixed Environmental Sensor Stations (i.e., fixed stations), called nonmobile data; weather observations from vehicles (i.e., mobile stations) specially-equipped to collect weather data and provide that data in near real-time; quality control metrics computed for weather observations from both fixed and mobile stations; road segment data, including statistical averages of weather observations along specific road segments and estimates of weather conditions along these roads; and metadata that describes the data contained in the Weather Data Environment to the data Store.

**Process:** The WxDE collector module collects data from the WxDE system every 5 minutes then submits the data to Wx Module in the data Store for system retention.

**Dependencies:** The WxDE Module is dependent on a WxDE subscription.

**Hydrological Conditions [Hydro]**

**Background:** The Hydro collector module collects from the National Weather Service’s AHPS.

**Inputs:** The module collects hydrological conditions and forecast data. 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.

**Outputs:** Data obtained by the collector are passed to the data Store. The data passed includes names and location of detectors, latest observation value and time, and flood stages for that location.

**Process:** Shapefiles are generated on the AHPS site every 15 minutes. After generation, the AHPS collector module calls the AHPS site to gather the information and passes the information to Hydro in the data store.

**Dependencies:** [http://water.weather.gov/ahps/download.php](http://water.weather.gov/ahps/download.php)

**Hydro Forecast [Hydro Forecast]**

**Background:** The Hydro Forecast 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.

---

**Inputs:** The Hydro Forecast collector module collects information from StormWatch’s sensors. Most sensors report real-time rainfall and some report stream levels, temperature, relative humidity, wind, pavement temperature, pavement state, and other weather data. Data is available for some stations back to the 1980s.

**Outputs:** Information obtained by the Hydro Forecast module is passed through to the data Store.

**Process:** The StormWatch system collects data at different time intervals depending on station and datatype. The Hydro Forecast collector module obtains data from the StormWatch collector. Water level is submitted to the Hydro module in the data Store while all other data are sent to the Wx module in the data Store.

**Dependencies:** [https://stormwatch.com/home.php](https://stormwatch.com/home.php)

---

**CAP [CAP]**

**Background:** The CAP (Common Alerting Protocol) collector module is able to collect and process alert messages published in the CAP format<sup>21</sup>.

**Inputs:** The CAP collector collects alerts in CAP format from the NWS.

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

**Process:** The CAP collector module collects data from the NWS every 2 minutes. The CAP collector module processes the data and submits the data to Alerts in the data Store for system retention.

**Dependencies:** The CAP collector module can be configured to receive CAP messages from a variety of sources. Currently, it collects alerts from the NWS.

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**Traffic Conditions [Traffic Cndtns]**

**Background:** The Traffic Conditions collector module collects current traffic condition data from 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 Conditions collector module collects current traffic condition data, including traffic speed, volume and occupancy. The format and structure of the data varies somewhat across potential source systems, and the particular traffic data sources will be those belonging to the initial prototype deployment partner.

**Outputs:** The Traffic Conditions collector submits traffic speed, volume and occupancy to the data Store. The format and structure of the data varies somewhat across potential source systems, and the particular traffic data sources will be those belonging to the initial prototype deployment partner.

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

<sup>21</sup> [http://docs.oasis-open.org/emergency/cap/v1.2/CAP-v1.2-os.html](http://docs.oasis-open.org/emergency/cap/v1.2/CAP-v1.2-os.html), Accessed 2016.05.03.
** Dependencies: ** The organization the Traffic Conditions collection module obtains information from is dependent on the geographical domain of interest.

**Traffic Controls [Traffic Cntrls] **

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

This module is distinguished from the Traffic Conditions module, since the traffic data are associated with roadway network segments, whereas the traffic controls are associated with roadway network nodes, and by the need to obtain future plans for traffic controls as opposed to only the current state of conditions.

** 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 the traffic condition information is obtained from. The organization is dependent on the geographical domain of interest.

** Dependencies: ** The organization the Traffic Controls collection module obtains information is dependent on the 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.

** Inputs: ** The Maintenance Rules collector module gets data describing the current and planned roadway maintenance status, including location, start and end data, and number of lanes affected, from sources within the IMRCP geographical domain of interest. The format and structure of the data is unconstrained across potential source systems, and the particular maintenance data sources will be those belonging to the initial prototype deployment partner.

** Outputs: ** Information obtained by the Maintenance Rules collector module, including location, start and end data, and number of lanes affected, are submitted to the data Store. The format and structure of the data is unconstrained across potential source systems, and the particular maintenance data sources will be those belonging to the initial prototype deployment partner.

** Process: ** Two processes are likely. In the optimal case, the rules would be provided by a winter-weather MDSS that would otherwise make its own treatment recommendations and condition forecasts. In the more likely case, the data will consist of treatment and plowing rules...
from less structured planning methodologies. The Maintenance Rules collector module passes available options to Maint Ops in the data Store for system retention.

**Dependencies:** The Maintenance Rules collector module is dependent on the MDSS to make treatment recommendations or local maintenance plans.

**Intervention Rules [Intrvntn Rules]**

**Background:** The Intervention Rules collector module gets data describing the current and planned operational interventions from sources within the IMRCP geographical domain of interest.

**Inputs:** The Intervention Rules collector module gets data describing the current and planned operational interventions from sources within the IMRCP geographical domain of interest. The format and structure of the rules is yet to be determined, and the particular intervention rule sources will be those belonging to the initial prototype deployment partner.

**Outputs:** Intervention rules obtained by the collector module are submitted to the data Store.

**Process:** The Intervention Rules collector module collects Intervention Rules from specified systems and submits the data to the data Store for system retention. The collection interval is dependent on the organization the intervention rules information is obtained from. The organization is dependent on the geographical domain of interest.

**Dependencies:** The organization the Intervention Rules collection module obtains information from is dependent on the geographical domain of interest.

**Events [Events]**

**Background:** The Events collector module gets data describing the current and planned events from sources within the IMRCP geographical domain of interest. The format and structure of the data should generally comply with the TMDD C2C standard data element models.

**Inputs:** The Events collector module gets data describing the current and planned events, including event location, start time, end time, and guest approximation, from sources within the IMRCP geographical domain of interest. The specific data formats and structures will be determined by those used by the initial prototype deployment partner.

**Outputs:** Data describing the current and planned events, including event location, start time, end time, and guest approximation, 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 Events collector module collects Events from specified systems and submits the data to Special Events in the data Store for system retention. The collection interval is dependent on the organization the event information is obtained from. The organization is dependent on the geographical domain of interest.

**Dependencies:** The organization the Events collection module obtains information from is dependent on the geographical domain of interest.

**Work Zones [WZ]**

**Background:** The Work Zones (WZ) collector module gets data describing the current and planned roadway work zones from sources within the IMRCP geographical domain of interest.
**Inputs:** The Work Zones (WZ) collector module gets data describing the current and planned roadway work zones, including location, start time, end time, and number of affected lanes, from sources within the IMRCP geographical domain of interest. The format and structure of the data are unconstrained across potential source systems, although the TMDD C2C standard data element models for events may be used.

**Outputs:** Data describing the current and planned roadway work zones, including location, start time, end time, and number of affected lanes, are submitted to the data Store. The format and structure of the data are unconstrained across potential source systems, although the TMDD C2C standard data element models for events may be used.

**Process:** The Work Zones collector module collects Events from specified systems and submits the data to WZ Ops in the data Store for system retention. The collection interval is dependent on the organization the work zone information is obtained from. The organization is dependent on the geographical domain of interest.

**Dependencies:** The organization the Work Zones collection module obtains information is dependent on the geographical domain of interest.

**Incidents [Incidents]**

**Background:** The Incidents collector module gets data describing the current incidents and their expected resolutions from sources within the IMRCP geographical domain of interest. The format and structure of the data should generally comply with the TMDD C2C standard data element models.

**Inputs:** The Incidents collector module gets data describing the current incidents and their expected resolutions, including incident type, incident time, approximate resolution time, and number of lanes affected, from sources within the IMRCP geographical domain of interest. The specific data formats and structures will be determined by those used by the initial prototype deployment partner.

**Outputs:** Data describing the current incidents 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 specified systems and submits the data to Incndnt in the data Store for system retention. The collection interval is dependent on the organization the incident information is obtained from. The organization is dependent on the geographical domain of interest.

**Dependencies:** The organization the Incidents collection module obtains information is dependent on the geographical domain of interest.

**Demand Trips [Demand Trips]**

**Background:** The Demand Trips module deals with the traffic demand in the Collection package.

Unlike the OD Pairs module in the GeoSrv package that describes the traffic demand as an Origin-Destination table, the Demand Trips module provides link-specific information.

**Inputs:** The Demand Trip collector module collects vehicle and driver-level probe data to formulate traffic assignment information in near real-time rather than from the base OD input.
**Outputs:** The Demand Trip collector module outputs the traffic assignment information in near real-time. The traffic assignment information from the demand trips data is then simulated or reproduced in the TrEPS package.

In addition to the traffic assignment information, which only deals with the vehicles and trips, driver behavior (i.e., user choices in response to varying interventions) associated with the vehicles and trips are also represented by the data collected in this module. Feedback from traffic management strategies and reactions to external events (incident and weather) are captured in these data.

**Process:** The Demand Trips collector module collects traffic demand from specified vehicle and driver-level probe data, then formulas the data into near real-time. The collection interval is dependent on the organization the incident information is obtained from. The organization is dependent on the geographical domain of interest. The module then passes the detailed trip data to Link Conditions in the data Store. The detailed trip data is later used by the TrEPS package.

**Dependencies:** The organization the Demand Trips collection module obtains information is dependent on the geographical domain of interest.

**Radar [Radar]**

**Background:** The Radar collector module collects data from the Radar system, a NOAA tool used to gather reflectivity data to track weather conditions.

**Inputs:** The Radar collector module receives current radar reflectivity from the Radar tool.

**Outputs:** The Radar collector module sends current radar reflectivity to the data Store.

**Process:** The Radar collector module receives data from the Radar tool, formats the data to be received, and sends the information to Wx in the data Store for system retention.

**Dependencies:** [http://www.nws.noaa.gov/radar_tab.php](http://www.nws.noaa.gov/radar_tab.php)

**Weather Forecast [Wx Forecast]**

The Weather Forecast collector module contains the National Digital Forecast Database (NDFD), the RAP system, and the RTMA system collector modules.

**NDFD [NDFD]**

**Background:** The NDFD contains a compilation of gridded digital forecasts from NWS field offices.

**Inputs:** 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 the table below) at the following Coordinated Universal Times (UTC): 0000, 0300, 0600, 0900, 1200, 1500, 1800, 2100.”

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22 [http://www.nws.noaa.gov/ndfd/technical.htm](http://www.nws.noaa.gov/ndfd/technical.htm), Accessed 2016.08.05.
Table 11 – Weather Elements Collected by NDFD

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

**Outputs:** The weather elements are passed to the data Store. The Wx Forecast module collects data provided in GRIB2-formatted (GRIdded Binary) files.
Process: The NDFD module collects data from the NDFD system hourly and then submits the data to the Wx module in the data Store for system retention.

Dependencies: http://www.nws.noaa.gov/ndfd/index.htm

Rapid Refresh [RAP]

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

Inputs: The RAP collector module receives forecasted surface pressure, precipitation amount, and precipitation type from the RAP system.

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

Process: The RAP collector module receives data from the RAP system, formats the data to be received, and sends the information to Wx in the data Store for system retention.

Dependencies: 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-surface weather conditions.”

Inputs: The RTMA collector module receives current air temperature, wind speed, surface pressure, and humidity from the RTMA system.

Outputs: The RTMA collector module sends current air temperature, wind speed, surface pressure, and humidity to the data Store.

Process: The RTMA collector module receives data from the RTMA system, formats the data to be received, and sends the information to Wx in the data Store for system retention.

Dependencies: http://www.nco.ncep.noaa.gov/pmb/products/rtma/

23 http://nomads.ncep.noaa.gov/txt_descriptions/RTMA_doc.shtml Accessed 2016.08.09
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 depends on the data Store for access to system data.

Archive Data

Background: Forecasts are volatile representations of potential future states. As real 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 for evaluations of 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 through the Schedule module in the System package to run daily. 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 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, a MOE on the percent of road condition predictions that are within a margin of error to actual measured conditions could be applied to pavement temperature or traffic speed. Evaluations of MOEs 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 measures of effectiveness, 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 labeling the registration ID as unregistered.

**Process:** The Directory component registers and unregisters. It registers by referencing the IMRCPBlock block with the supported and desired interface and returns the registrationId. The Directory unregisters by referencing the IMRCPBlock block with the registrationId; this returns a Boolean value stating the registrationId is unregistered.

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

<table>
<thead>
<tr>
<th>Directory</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ init() : void</td>
</tr>
<tr>
<td>+ stop() : void</td>
</tr>
<tr>
<td>+ getInstance() : Directory</td>
</tr>
<tr>
<td>+ register(IMRCPBlock block, string[ ] instances) : int</td>
</tr>
<tr>
<td>+ unregister(IMRCPBlock block, int registrationId) : bool</td>
</tr>
</tbody>
</table>

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.
### 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 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.

### 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 IMRCP block and requested information is sent back to the requesting party.
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.
Alert

The Alert package generates alerts of the current and predicted system conditions for use by other IMRCP system components and eventual users. The package contains a single implementing Alert module.

Alert generation is based on a set of rules in the form of logical statements about transportation system conditions. For example, 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**

**Background:** The Alert module in the Alert system package 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 Weather, Hydrological, and Link Conditions modules.

**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 Weather, Hydrological, and Link Conditions. When these modules receive new data from the Collect system package, the Alert module is notified and then gathers the new data. The data is compared with a set of rules in the form of logical statements about transportation system conditions. 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 20.

**Dependencies:** The Alert module is dependent on the data Store for the storage of the resulting alerts.

![Figure 20 – Alert Process Diagram](image_url)
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 Route module.

**Route**

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

**Inputs:** The Route module generates routes based on the data found in the data Store in modules such as the Weather, Hydrological, and Link Conditions modules. The Route module chooses which routes to generate based on the Route module in the data Store which contains the routes requested by the user and the OD Pairs module.

**Outputs:** Routes will generate based on expected travel time with forecasted traffic at the point on your route.

**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 based on high-volume OD pairs. Routes will 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 route is stored back in the data Store for use from other modules.

The process diagram for the Route Package for user-generated Routes can be seen in Figure 21, below. 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.

![Figure 21 – User-Generated Route Process Diagram](image)

Figure 22 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 the Link Conditions.
from the data Store. The travel times are then stored in the data Store and the process is repeated.

**Figure 22 – Configured 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.
Geo Services

The Geo Services (GeoSrv) package maintains the fundamental geographical description of the roadway system and its components. It contains two modules: the roadway segment definitions (SegSHPs) and the base origin-destination pairs (OD Pairs).

**Segment Definitions [Segment SHPs]**

**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.

**Inputs:** The Segment Definitions module gets SHP 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 to the Segment, Link, and Node modules in the data Store.

**Process:** The Segment Definitions module is initiated manually by the administrator. The SHP files are collected and the segment, link, and node information is extracted from the files and given to modules in the data Store.

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

**OD Pairs**

**Background:** The OD Pairs module represents the historical OD pairs and enables calibration to current traffic observations.

**Inputs:** The OD Pairs module gains input administratively based on historical data of traffic flow.

**Outputs:** This module becomes the base OD input for the scenarios of interest. The base OD input is available through the data Store for TrEPS and other modules. In the Demand Estimator module of TrEPS, the base OD input gets updates or adjustments according to online traffic volume observations.

**Process:** The OD Pairs module is developed administratively. The module is used to prepare the base demand data for the data Store. The historical OD pairs may be collected from survey data or archives of planning agencies. To obtain more reliable and representative OD pairs for the scenarios of interest, OD pair data are calibrated based on actual traffic volume observations from the representative operational condition scenarios, typically determined through a cluster analysis of long-term historical data.

**Dependencies:** The OD Pairs module is dependent on external sources for input.
Data Services

The Data Services (DataSrv) 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 (Subscrpt) module.

Subscription [Subscrpt]

**Background:** The Subscription package allows the IMRCP to provide data to external systems and end users as well as other IMRCP-internal components. These represent two significantly different constituencies. Internal components require low-latency high-availability interactions with the Store to maintain the computational efficiency of the forecast modules. User interactions are intermittent and variable in their data needs. As such, subscriptions implemented by the Subscrpt module are used to configure and provide access to the data Store for user interfaces and reports.

**Inputs:** The inputs to the Subscription package would be information necessary to create a subscription, including information needed, place(s) in the data Store the information is coming from, time interval requested for subscription, and output format.

**Outputs:** The output of the Subscription package is the data requested from a subscription and a notification when data is available. The notification lets the user interface - the Export, WebPages, and/or Apps package – know that the subscription data has become available.

**Process:** The Export, WebPages, or Apps package can call the Data Services package to create a subscription. The requesting package sends the Data Services package which information it needs, the time interval it wants it, and the output format it would like it in. The subscription module processes the information, finds the place in the data Store the information is located, formats the data how the requesting package wants it, and submits a notification to the requesting package that the data is ready.

**Dependencies:** The Subscription package depends on the data Store to fulfill the subscriptions. It also depends on the GeoSrv package for definitions of roadway segments relative to selection of geographical context in user interfaces.

Credentials [Cred]

**Background:** The Credentials module verifies credentials of users accessing the WebPages.

**Inputs:** The inputs of the Credentials module are the username and password of the user. The Credentials module can also input the admin status of a registered user from a system administrator.

**Outputs:** The output of the Credentials module is a Boolean to verify that the new user has been created or a Boolean to verify that the registered user does have access to the system. The Credentials module would also need to output the admin status. The outputs are sent to WebPages.

**Process:** The User page in the WebPages class sends information regarding a new or registered user to the Credentials module. If the user is new, the Credentials module adds the user, and the Credentials module sends a verification that the new user has been added. For a registered user, the Credentials module verifies the username and password pair match a
pair within the system and sends back a notification that the user is in the system along with the user’s admin status to WebPages.

**Dependencies:** The Credentials module is dependent on the User module in the WebPages package.
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.

**CAP**

**Background:** The CAP module provides IMRCP system alerts formatted as Common Alerting Protocol messages\(^{24}\). 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.

**C2C**

**Background:** The Export C2C module provides IMRCP outputs bundled into TMDD C2C messages\(^{25}\). 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.

**ATIS**

**Background:** The ATIS module provides IMRCP system alerts in the Advanced Traveler Information System format\(^{26}\).

**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.

\(^{24}\) [https://www.fema.gov/common-alerting-protocol](https://www.fema.gov/common-alerting-protocol)

\(^{25}\) [https://www.standards.its.dot.gov/Factsheets/Factsheet/17](https://www.standards.its.dot.gov/Factsheets/Factsheet/17)

\(^{26}\) [https://www.standards.its.dot.gov/factsheets/factsheet/54](https://www.standards.its.dot.gov/factsheets/factsheet/54)
Dependencies: The ATIS module is dependent on the Data Services 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 contains eight classes:

- Map, providing a map user interface for browsing system output
- Sgmnt, for accessing segment-level output reports
- Alert, for creating custom alert subscriptions
- Route, for requesting and building custom route information
- Subscript, for creating custom report subscriptions
- Fdbk, for receiving system user feedback
- User, for creating and maintaining user accounts
- Dshbrd, providing an index of WebPages

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

Map

**Background:** The Map provides a selectable layered presentation of 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.

**Inputs:** The inputs to the Map module include information from Seg, Link and Node to display position of each. Also, current and forecasted weather and road conditions to display weather conditions. The map would pull hydrology information, maintenance operations, control operations, work zone operations, incident data, alerts and routes to display if necessary. The map would also take in user inputs to decide what is displayed.

**Outputs:** The outputs of the Map module are information displayed on the map. This includes all inputs if need to be displayed. For example, forecasted weather and road conditions would be displayed if the temporal domain is in the future. The user can select which layers of information appears.

**Process:** The users request information from the Map module, and the Map module requests information from Data Services. The Map modules has the ability to allow users to display information from each party of the data Store and receiving information from Data Services when information is requested.

**Dependencies:** The Map package depends on the DataSrv package for access to system data from the data Store.

Sgmnt

**Background:** The Sgmnt page enables users to request segment and link condition data for specific geographies and segments.

**Inputs:** The inputs to the Sgmnt module include information from Seg Cndtns, Link Cndtns, Node Cndtns and Routes

**Outputs:** The output of the Sgmnt module is the data requested reformatted for WebPages.

**Process:** The users request information from the Sgmnt module, and the Sgmnt module requests information from Data Services. The Sgmnt modules has the ability to allow users to
display information from each party of the data Store and receiving information from Data Services when information is requested.

**Dependencies**: The Sgmnt package depends on the DataSrv package for access to system data from the data Store.

**Alert**

**Background**: The Alert page enables users to create custom alert functions based on segment and link conditions, and to associate those alerts with subscriptions.

**Inputs**: The input to the Alert module is an alert subscription from Data Services.

**Outputs**: The output to the Alert module is an alert subscription reformatted for WebPages.

**Process**: The Alert module within WebPages requests alert data from Data Services. Data services sends a notification to the Alert module when the data is available. The Alert module obtains the information from Data Services and presents the data for viewing.

**Dependencies**: The Alert package depends on the DataSrv package for access to system data from the data Store.

**Route**

**Background**: The Route page enables users to request and view common route conditions, to create custom routes, and to subscribe to route reports.

**Inputs**: The input to the Route module is a route subscription from Data Services.

**Outputs**: The output to the Route module is a route subscription reformatted for WebPages.

**Process**: The Route module within WebPages requests route data from Data Services. Data Services sends a notification to the Route module when the data is available. The Route module obtains the information from Data Services and presents the data for viewing.

**Dependencies**: The Subscrpt package depends on the DataSrv package for access to system data from the data Store.

**Subscrpt**

**Background**: The Subscription page enables users to subscribe to system output data.

**Inputs**: The inputs to the Subscription module within Web Pages are the data necessary to create a subscription, including information requested, time interval requested for subscription, and output format.

**Outputs**: The output of the Subscription module is the data requested reformatted for WebPages.

**Process**: The Subscription module within WebPages requests a subscription for data requested from Data Services. Data Services sends a notification to the Subscription module when the data is available. The Subscription module obtains the information from Data Services and presents the data for viewing. The Subscription module allows the user to see all subscriptions requested by that user.
Dependencies: The Subscrpt package depends on the DataSrv package for access to system data from the data Store.

Fdbk

Background: The Feedback page enables users to provide feedback on the system web pages and data to system administrators.

Inputs: The input to Feedback page is feedback provided by the user to the system administrator. Other potential inputs can include name of user, email of user, and section of WebPages reporting feedback on.

Outputs: The output of the Feedback page is an email sent to a system administrator or system administrators.

Process: Users fill out feedback information on the Feedback page. The information is sent to designated system administrators for review.

Dependencies: The Fdbk page has no dependencies.

User

Background: The User page enables users to establish and maintain accounts on the system. A user account is necessary for creating alerts and subscriptions.

Inputs: The User page allows a user to register for or log into an account on the system. To register a new account or edit information on an account, the User page inputs must include a username and password, and could include email, name, and information about the user’s organization. To log into an existing account, only username and password are inputs. After submitting information to Data Services, the User page also inputs a Boolean to verify if the user is in the system and the admin status of the user.

Outputs: The User page outputs information necessary to register for or login to the system to Data Services. The User page also outputs a verification to the user if they can enter the system.

Process: A user registers for access to the system on the User page. The information entered is sent to Data Services for storage, and Data Services sends back a verification that the user is added to the system. The User page displays to the user that their info has been added.

A user logs into the system on the User page. The login information is sent to Data Services to verify that the username and password pair match a pair in the system. If it does, the Data Services module looks up the admin status and returns the verification and admin status to WebPages. The User page verifies that the user was able to log in.

Dependencies: The User package depends on the DataSrv package for access to system data from the data Store.

Dashboard [DshBrd]

Background: 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.

Inputs: The Dashboard subscribes to reports of the needed system performance parameters through the Data Services module.
Outputs: Outputs are displayed on the Dashboard web interface.

Process: The Dashboard component subscribes to a report of the desired system performance parameters through the Data Services package. Parameters to be included are configurable by the system administrator, but must be supported by and available from the data Store for results to be available on the Dashboard.

Dependencies: The Dashboard depends on Data Services to obtain the configured set of performance parameters from the data Store. It further depends on the same Web service platform and libraries as do the other Web Pages.
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 development 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 will be deployed to a single computing environment and provide distributed user access for the development team, the review team, and the partner prototype agency. Factors contributing to this configuration determination include:

- IMRCP data services and computational services are closely linked and benefit from co-location to reduce latencies and remote network calls.
- 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 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.

The presumed system deployment is shown in Figure 23. 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.

![Figure 23 – IMRCP Deployment](image-url)
References


# APPENDIX A. Glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>AHPS</td>
<td>Advanced Hydrologic Prediction Service</td>
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<td>AMS</td>
<td>Analysis, Modeling and Simulation</td>
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<tr>
<td>ATDM</td>
<td>Active Transportation and Demand Management</td>
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<tr>
<td>ATMS</td>
<td>Advanced Transportation Management System</td>
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<tr>
<td>AVL</td>
<td>Automatic Vehicle Location</td>
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<td>BN</td>
<td>Bayesian Network</td>
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<td>C2C</td>
<td>Center-to-Center</td>
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<tr>
<td>CAP</td>
<td>Common Alerting Protocol</td>
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<td>ConOps</td>
<td>Concept of Operations</td>
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<td>CV</td>
<td>Connected Vehicle</td>
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<tr>
<td>DAG</td>
<td>Directed Acyclic Graph</td>
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<td>DMA</td>
<td>Dynamic Mobility Applications</td>
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<td>DMS</td>
<td>Dynamic Message Signs</td>
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<tr>
<td>DOT</td>
<td>Department of Transportation</td>
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<tr>
<td>DYNASMArt</td>
<td>Dynamic Network Assignment-Simulation Model for Advanced Roadway Telematics</td>
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<tr>
<td>EMDSS</td>
<td>Enhanced Maintenance Decision Support</td>
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<td>EnableATIS</td>
<td>Enable Advanced Traveler Information Systems</td>
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<tr>
<td>ESS</td>
<td>Environmental Sensor Station</td>
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<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
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<tr>
<td>GPS</td>
<td>Global Positioning Service</td>
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<tr>
<td>IMRCP</td>
<td>Integrated Model for Road Condition Prediction</td>
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<td>INFLO</td>
<td>Integrated Network Flow Optimization</td>
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<td>ITS</td>
<td>Intelligent Transportation Systems</td>
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<tr>
<td>MAW</td>
<td>Motorist Advisories and Warnings</td>
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<tr>
<td>MDSS</td>
<td>Maintenance Decision Support System</td>
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<tr>
<td>MOE</td>
<td>Measures of Effectiveness</td>
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<td>NCAR</td>
<td>National Center for Atmospheric Research</td>
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<tr>
<td>NDFD</td>
<td>National Digital Forecast Database</td>
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<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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<td>NWS</td>
<td>National Weather Service</td>
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<tr>
<td>OD</td>
<td>Origin-Destination</td>
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<tr>
<td>PGM</td>
<td>Probabilistic Graphical Model</td>
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<tr>
<td>Q-WARN</td>
<td>Queue Warning</td>
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<tr>
<td>RAP</td>
<td>Rapid Refresh</td>
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<tr>
<td>RCTM</td>
<td>Road Conditions Treatment Module</td>
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<tr>
<td>RTMA</td>
<td>Real-Time Mesoscale Analysis</td>
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<tr>
<td>RWF</td>
<td>Road Weather Forecast</td>
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<tr>
<td>RWIS</td>
<td>Road Weather Information System</td>
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<tr>
<td>SAD</td>
<td>System Architecture Description</td>
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<tr>
<td>SDD</td>
<td>System Design Description</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>SHRP2</td>
<td>Strategic Highway Research Program 2</td>
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<tr>
<td>SPD-HARM</td>
<td>Speed Harmonization</td>
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<tr>
<td>TMC</td>
<td>Transportation Management Center</td>
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<tr>
<td>TMDD</td>
<td>Traffic Management Data Dictionary</td>
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<tr>
<td>TrEPS</td>
<td>Traffic Estimation and Prediction System</td>
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<tr>
<td>TSMO</td>
<td>Transportation Systems Management and Operations</td>
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<tr>
<td>URL</td>
<td>Uniform Resource Locator</td>
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<tr>
<td>USDOT</td>
<td>United States Department of Transportation</td>
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<tr>
<td>USGS</td>
<td>United States Geological Survey</td>
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<tr>
<td>VDT</td>
<td>Vehicle Data Translator</td>
</tr>
<tr>
<td>WAF</td>
<td>Weather Adjustment Factor</td>
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<tr>
<td>WxDE</td>
<td>Weather Data Environment</td>
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