A real-time simulation-based decision support system for traffic management: the San Diego I-15 ICM model

IPAM Workshop IV: Decision Support for Traffic

Matthew Juckes

November 1

Presentation Overview

- Program Background
- System Overview
- Network Prediction System (NPS)
- Response Plans & Corridor Scoring
- Maintenance & Real Time Targets
- Related Projects

FHWA ICM Program

7-Year Federally-sponsored program supporting development of improved mobility, safety, and other transportation objectives for people and goods through integrated management of transportation networks and cross-network connections in major transportation corridors in metropolitan areas.

FHWA ICM Program

- **Phase 1:** Conducted research into the current state of corridor management
- **Phase 2:** Develops analytic tools and methods that enable the implementation and evaluation of ICM strategies.
- ***Phase 3: Corridor Site Development, Analysis and Demonstration - San Diego and Dallas***
- **Phase 4:** ICM Outreach and Knowledge and Technology Transfer

Project Partners/Stakeholders

SANDAG

Caltrans

Department of Transportation – United States of America

Kimley-Horn and Associates, Inc.

Delcan – Transportation • Information Technology • Water

TSS Transport Simulation Systems

The City of San Diego

City of Poway – The City in the Country

Escondido – City of Choice

MTS

NCTD

California PATH

National ICM Evaluator
Battelle – The Business of Innovation

National AMS Contractor
Cambridge Systematics

Phase 3 – ICM Demonstration

- Five primary ICM goals:
  1. The corridor's multi-modal and smart-growth approach shall improve accessibility to travel options and attain an enhanced level of mobility for corridor travelers.
  2. The corridor's safety record shall be enhanced through an integrated multimodal approach.
  3. The corridor's travelers shall have the informational tools to make smart travel choices within the corridor.
  4. The corridor's institutional partners shall employ an integrated approach through a corridor-wide perspective to resolve problems.
  5. The corridor's networks shall be managed holistically under both normal operating and incident/event conditions in a collaborative and coordinated way.

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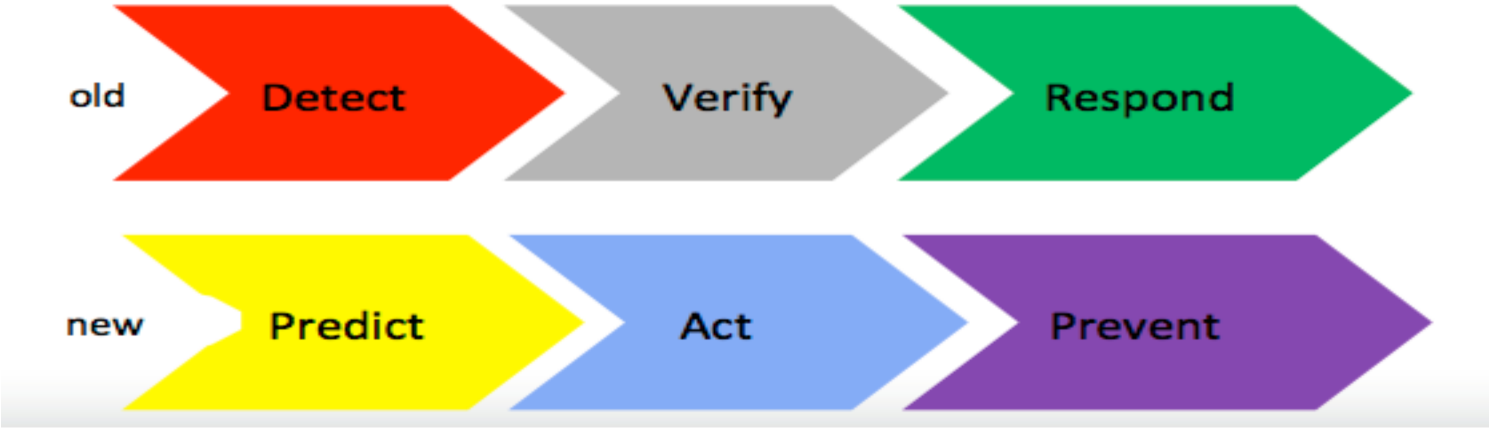
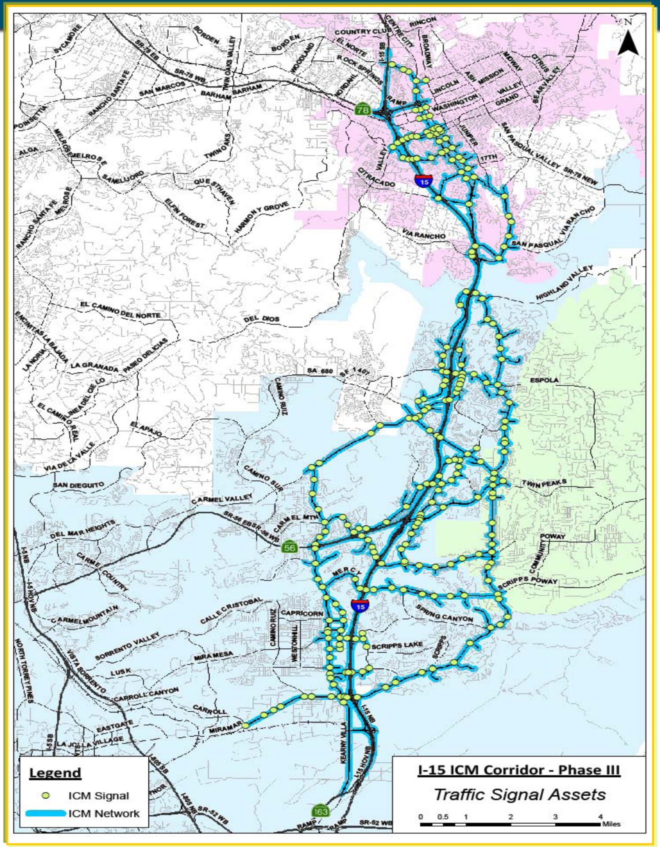
ICMS Innovation

Paradigm shift to more pro-active traffic management method, making use of prediction tools, on-line micro simulation and improved decision support

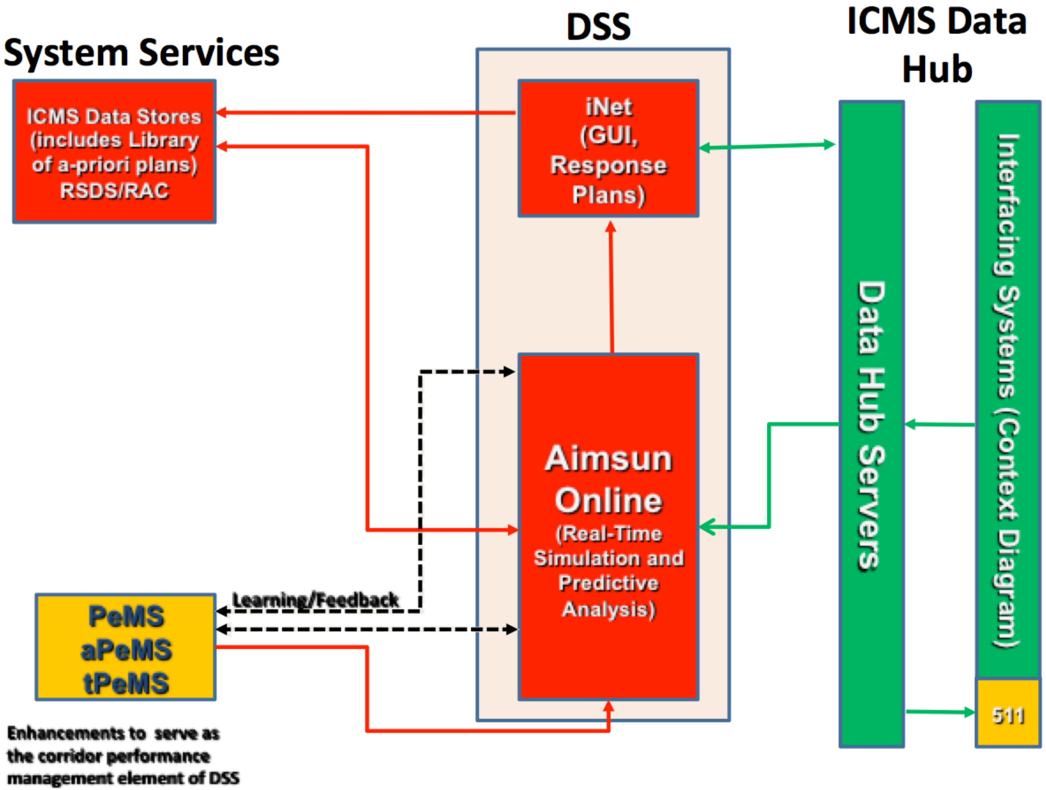


Location Description

- 21 mile North-South Stretch of I-15 between SR-78 and SR-163
- I-15 is a 6-10 lane freeway with a 4 lane managed HOV/SOV toll road in the center
- Multiple parallel arterials including: Black Mountain Road, Pomerado Rd and Center City Parkway
- Encompasses three cities: Escondido, Poway, San Diego
- A microsimulation network coded in Aimsun software
- 60 minute prediction engine coded in Aimsun Online

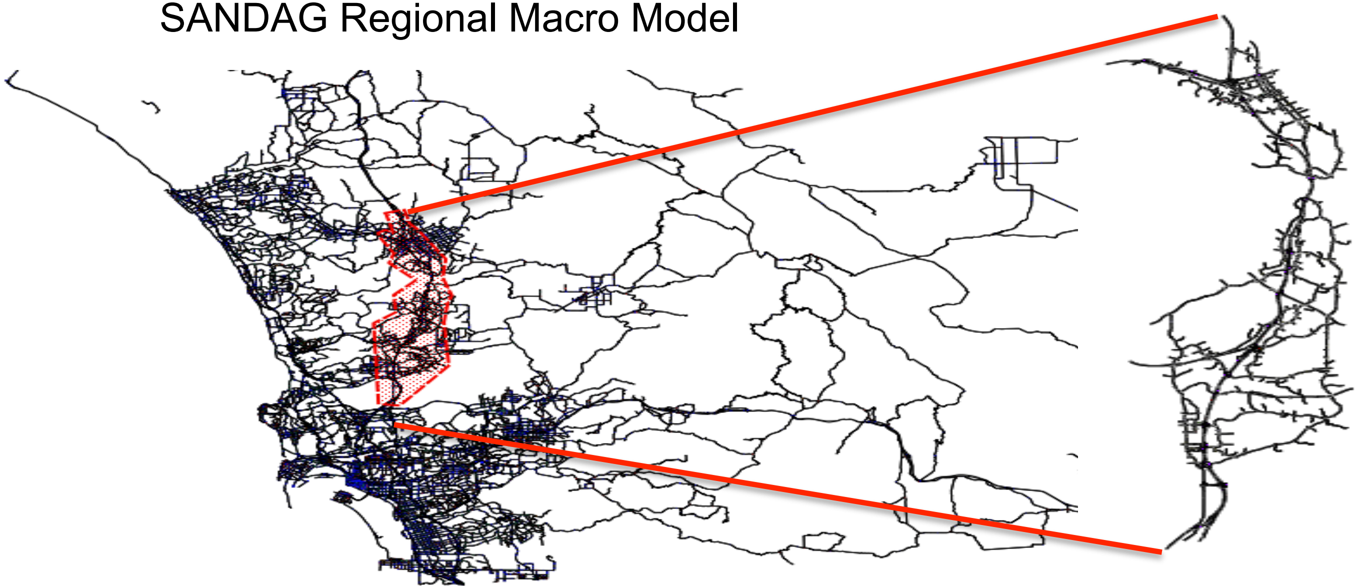


ICM System

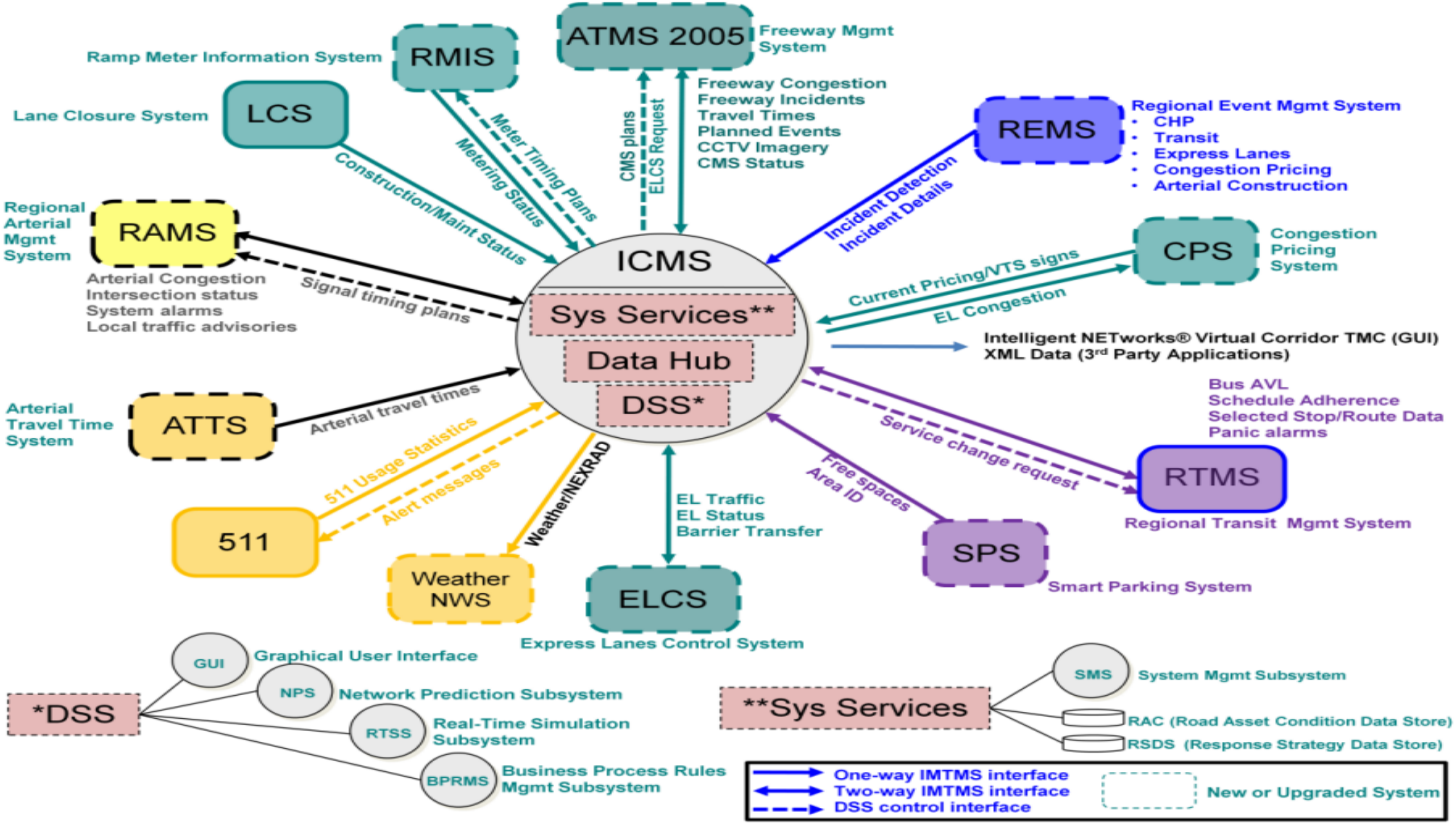

System Services
DSS
ICMS Data Hub
ICMS Data Stores (includes Library of a-priori plans) RSDS/RAC
iNet (GUI, Response Plans)
Aimsun Online
(Real-Time Simulation and Predictive Analysis)
Data Hub Servers
Interfacing Systems (Context Diagram)
511
Learning/Feedback
PeMS
aPeMS
tPeMS
Enhancements to serve as the corridor performance management element of DSS

Model Description

- I-15 ICM Model generated from the SANDAG Regional Macro Model



Data Inputs and Outputs



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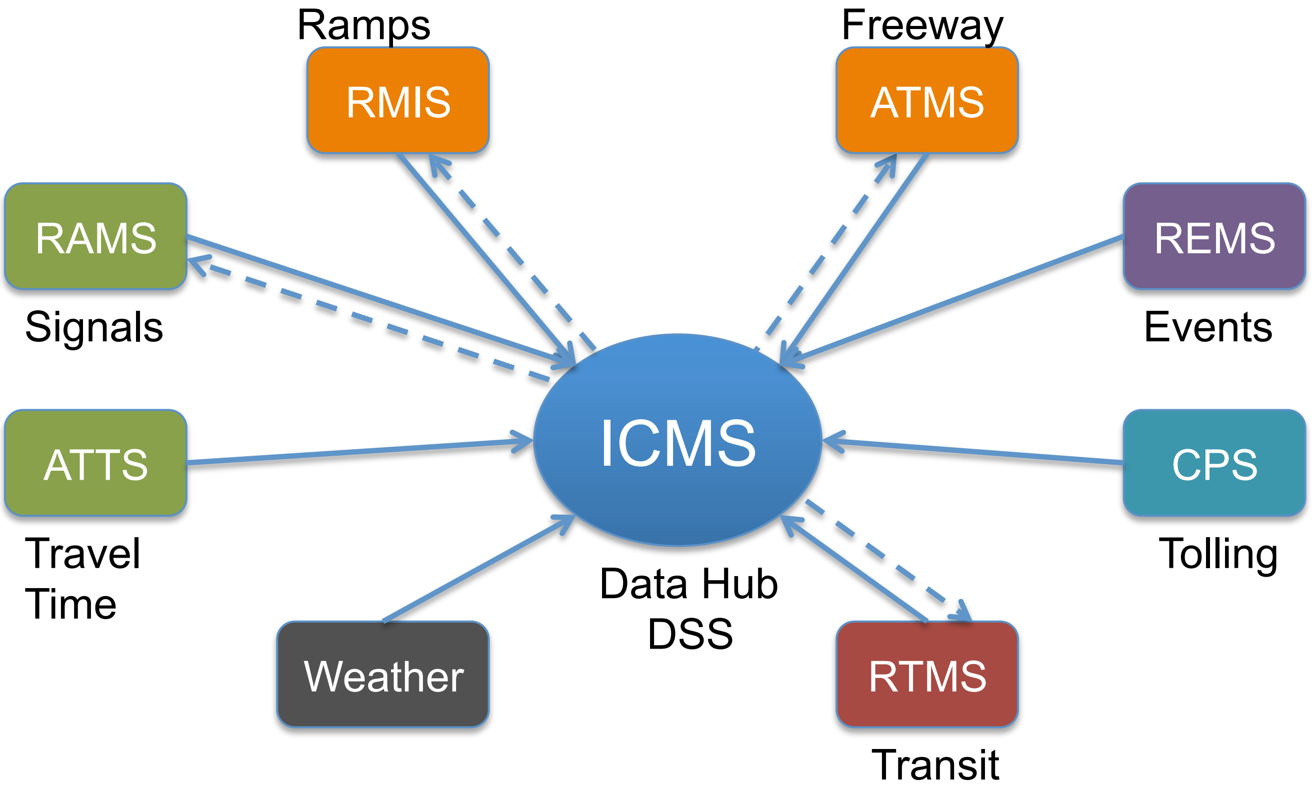
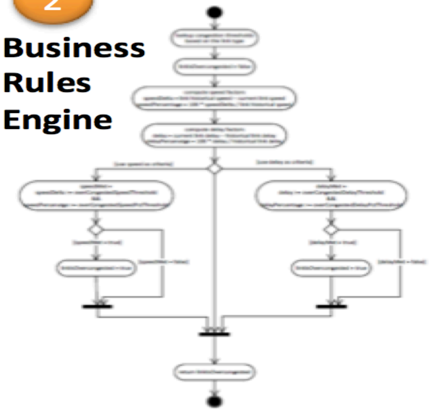


System Evolution

Response Plan Evaluation

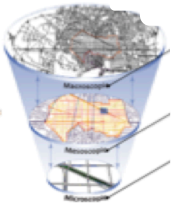
Inventory + Prediction 1

2 **Business Rules Engine**



Event Response Suite 3

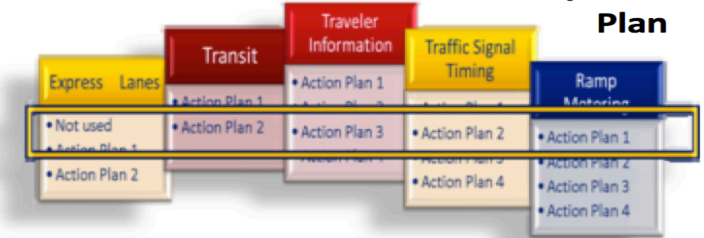
Multi Layer Analysis 4



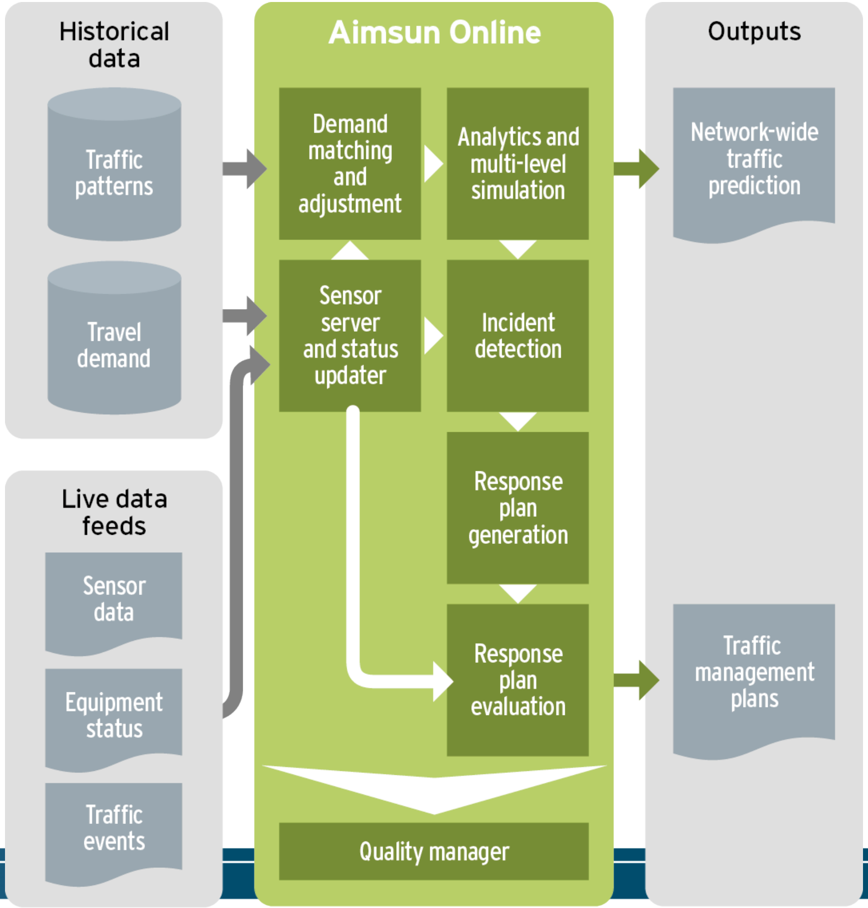
Corridor MOE 5

{0.00, -13.28, 11.14, 1.19, 7.81, 2.2}

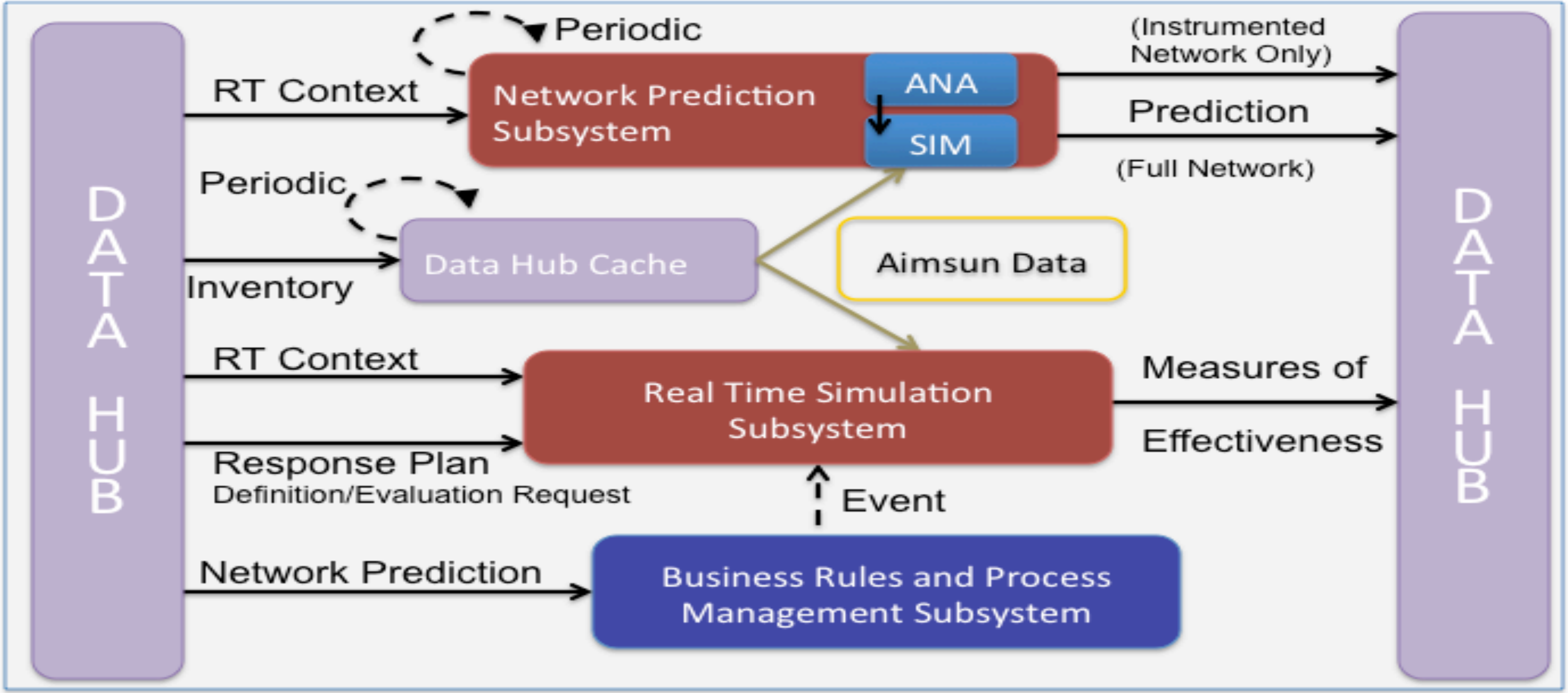
6 **Recommended Response Plan**



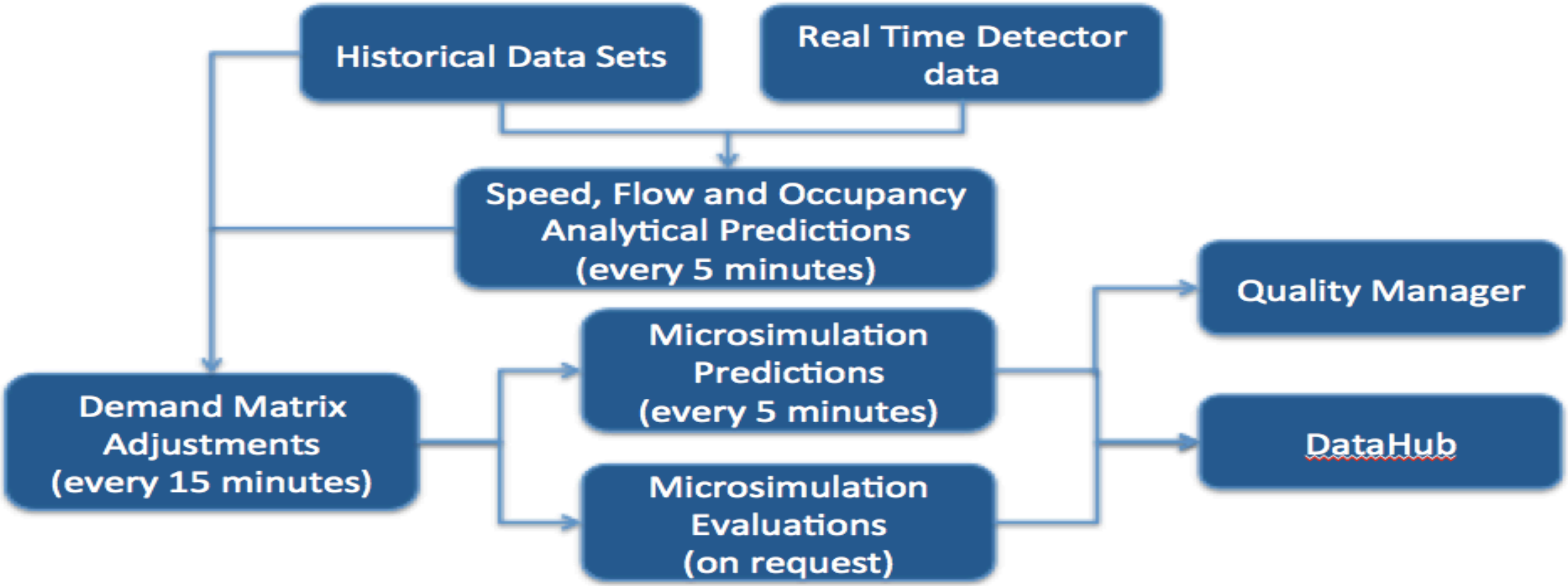
Aimsun Online Architecture



DSS Model Flow



Network Prediction System



Network Prediction System

- The Network Prediction System (NPS), summarizing, consists in an analytical model for each detector such that:

$$Y_D^{k,t} = f(X^t),$$

  where

  - $Y_D^{k,t}$, represents the k predicted variable for detector D at time t.
  - f, represents the analytical model.
  - X^t, represents the real detector measures available at time t.

NPS – Problem Description

- "Given a time point t and a detector D, a prediction of the flow (or other provided measure) of that detector at time t+h is wanted, using all the information available at the moment t". Mathematically expressed:

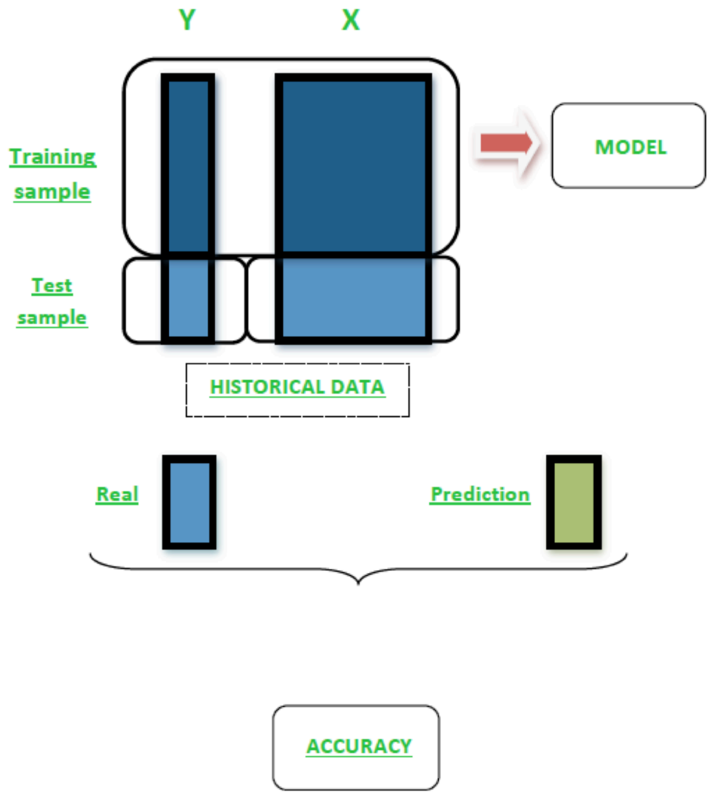
$$Y = f(X)$$

where

- Y is the objective variable (flow, occupancy or speed at time $t + h$),
- X is the matrix containing all the necessary input information at time t,
- f is the model representing the relationship between X and Y.

- The matrix X is built with the explicative variables of the model, that is those variables considered as necessary to explain the behavior of Y, including:
  - Previous values of the selected detector D at time points t, t-1, t-2 …
  - Previous values of the upstream and downstream of D at time points t, t-1, t-2 …
  - Or even other quantities such as occupancies or speeds. The rows of X determine the observed day.
- The model f has to be trained with historical data and has to be estimated by means of statistical techniques. The set of upstream and downstream have also to be specified.

NPS – Problem Description



NPS – Technical Issues

- Linearity
- Multicollinearity
- Variable selection/Dimensionality Reduction
- Missing Data

NPS - Methodology

- **LASSO** (least absolute shrinkage and selection operator) is an alternative regularized version of least squares which uses the constraint that $\|\cdot\|_1$, the L_1-norm of the parameter vector, is no greater than a given value.
- Regularization methods are used for model selection, in particular to prevent overfitting by penalizing models with extreme parameter values. One of the most common variants in machine learning is L_1-norm (being the other the squared L_2-norm) regularization, which can be added to learning algorithms that minimize a loss function $E(X,Y)$ by instead minimizing

$$E(X,Y) + \alpha\|w\|,$$

where
- w is the model's parameter vector,
- $\|\cdot\|$ is the L_1-norm,
- α is a free hyperparameter that needs to be tuned empirically (in ours case using the described k-fold cross-validation).

NPS - Methodology

- L_1-norm regularization is often preferred because it produces sparse models and thus performs feature selection within the learning algorithm (increasing the penalty cause more and more of the parameters to be driven to zero and this deselects the features from the regression, thus Lasso automatically selects more relevant features and discards the others).
- But since the L_1-norm is not differentiable, it may require changes to learning algorithms, in particular gradient-based learners. For that reason the optimization problem may be solved using quadratic programming or more general convex optimization methods, as well as by specific algorithms such as the least angle regression algorithm.

NPS – Accuracy and Validation

- When training a model, the deviations of the predictions from the data set used for training (such as the R^2 coefficient in linear regression) can be calculated. However, these errors are not representative of the error within the model when another set of new data is used. Thus, another way to measure the error is needed.

- In order to select the model with higher accuracy, a ***k*-fold cross-validation** scheme is used. This is the most standard way to ensure that the errors estimated in the training stage will be consistent with future predictions. In the k-fold cross-validation, the set of historical days is split into k groups.
  For each group the procedure is:
  1. Remove the group of days (called the test sample) from the historical data. The remaining set is called the training sample.
  2. Train the model with the training sample.
  3. Evaluate predictions with the test sample
  4. Then the mean of the errors achieved by these k test samples is calculated.

- In our problem, $k = 10$.

NPS – Accuracy and Validation

- Two performance evaluation measurements have been used.
  - Mean absolute percentage error (MAPE) is defined:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{y_t - \hat{y}_t}{y_t}\right|$$

where

- y_t is the actual value,
- $\hat{y}_t$ is the forecast value.

  - Quality measurement criteria:
    - If flow > 750 veh/h: check if relative error (MAPE) is below 15% to satisfy the quality criteria
    - Else: check if absolute difference between actual and forecast is below 150 veh/h.

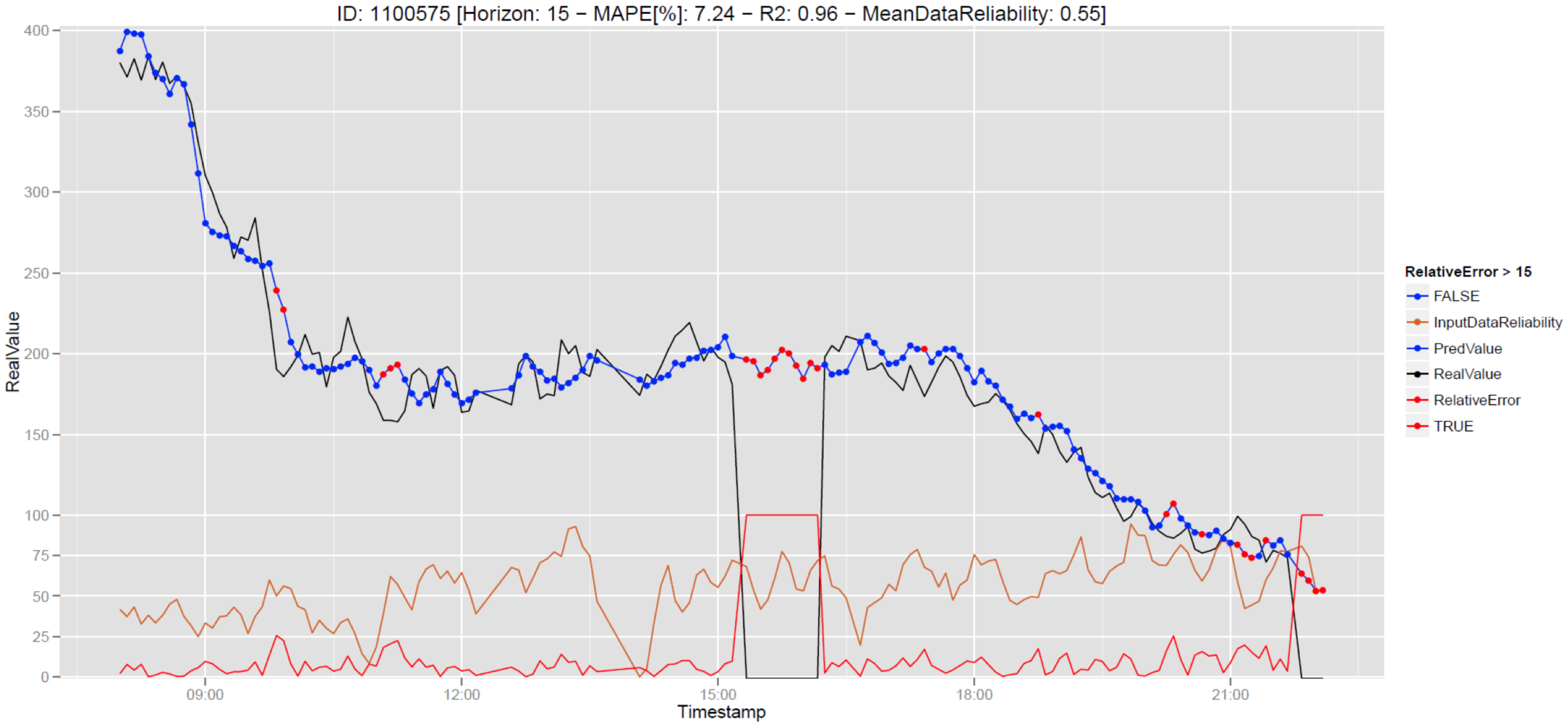
NPS – Tests with Training Data

(aggregated results)

Forecast horizon [min]	Minimum error [%]	Maximum error [%]	Mean error [%]	Standard deviation [%]
15	2.43	23.75	7.87	4.49
30	2.8	24.7	8.43	4.49
45	3.06	24.67	8.72	4.51
60	3.23	25.78	8.99	4.56
75	3.37	26.47	9.24	4.61

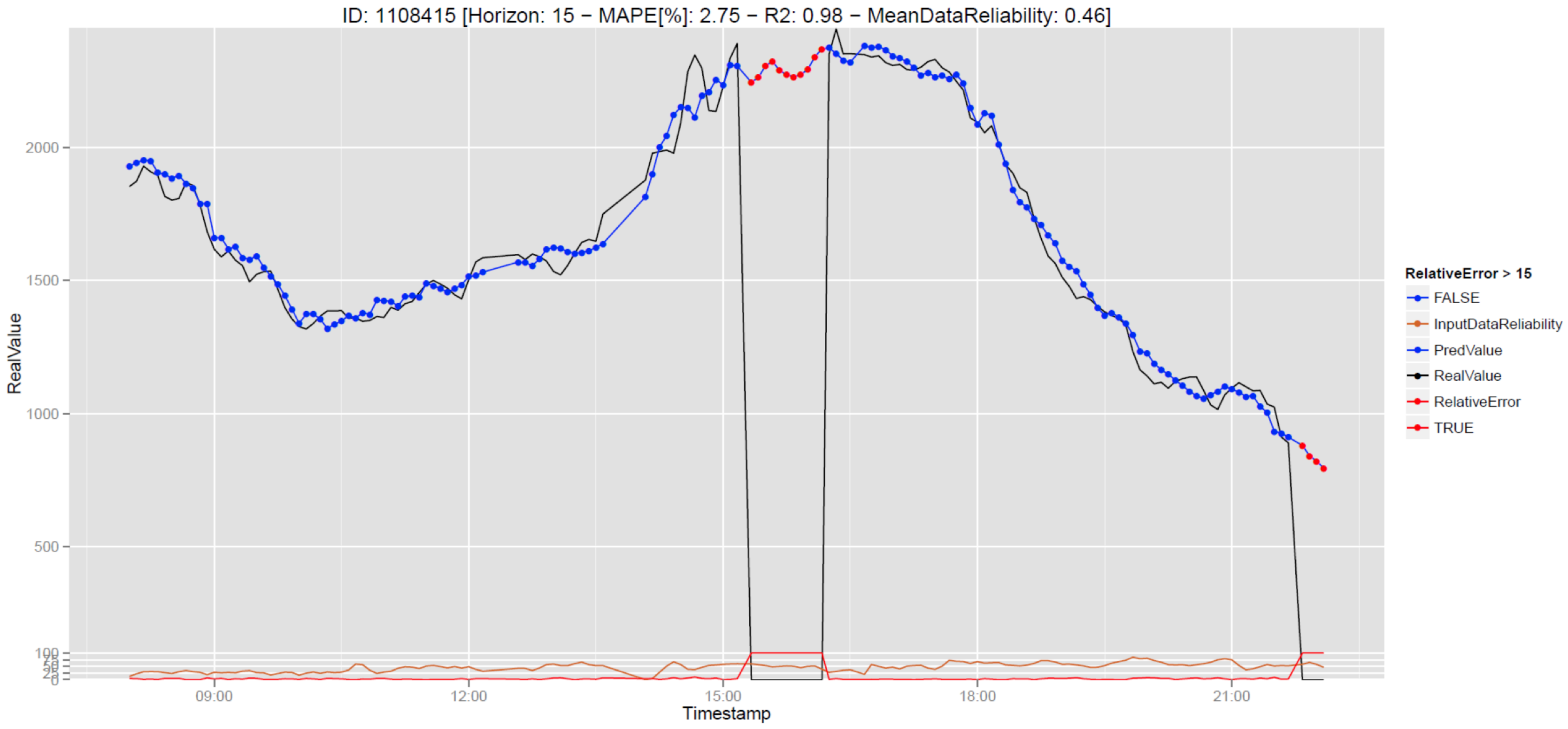
Forecast horizon [min]	Minimum Quality ratio [0, 1]	Maximum Quality ratio [0, 1]	Mean Quality ratio [0, 1]	Standard deviation [0, 1]
15	0.93	1	1	0.01
30	0.89	1	1	0.01
45	0.85	1	0.99	0.01
60	0.83	1	0.99	0.01
75	0.81	1	0.99	0.02

NPS – Tests with Real Data



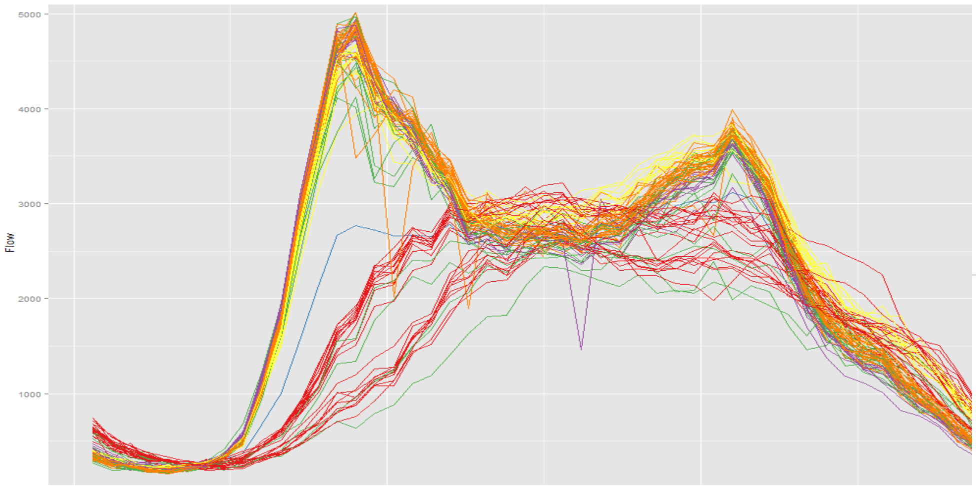
TSS TRANSPORT SIMULATION SYSTEMS

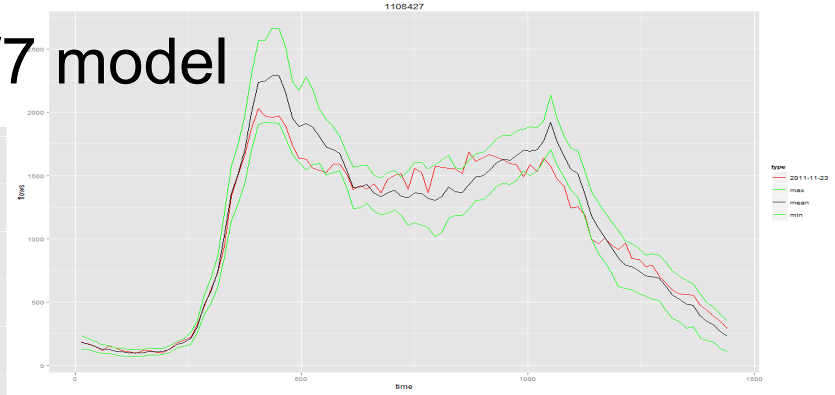
NPS – Tests with Real Data

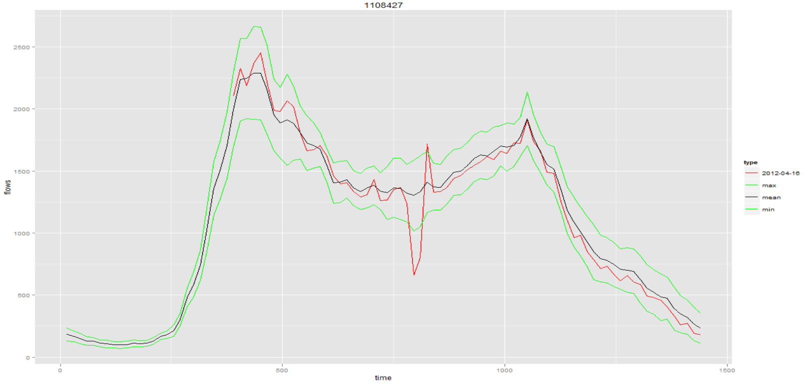


Pattern Calibration

Pattern and historical data for 24/7 model

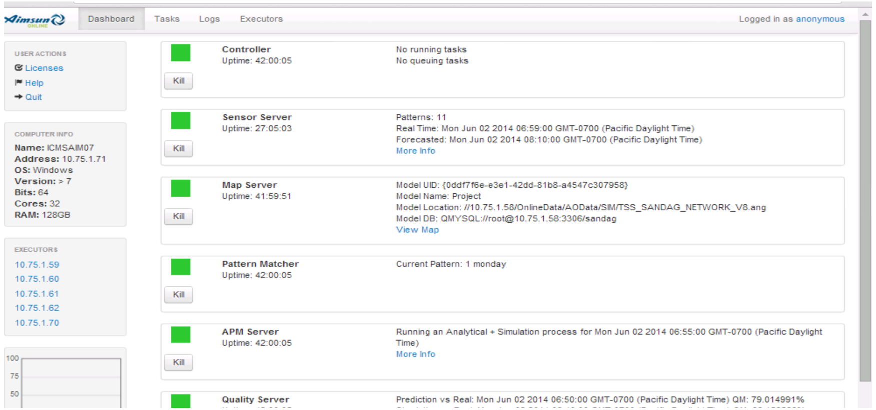






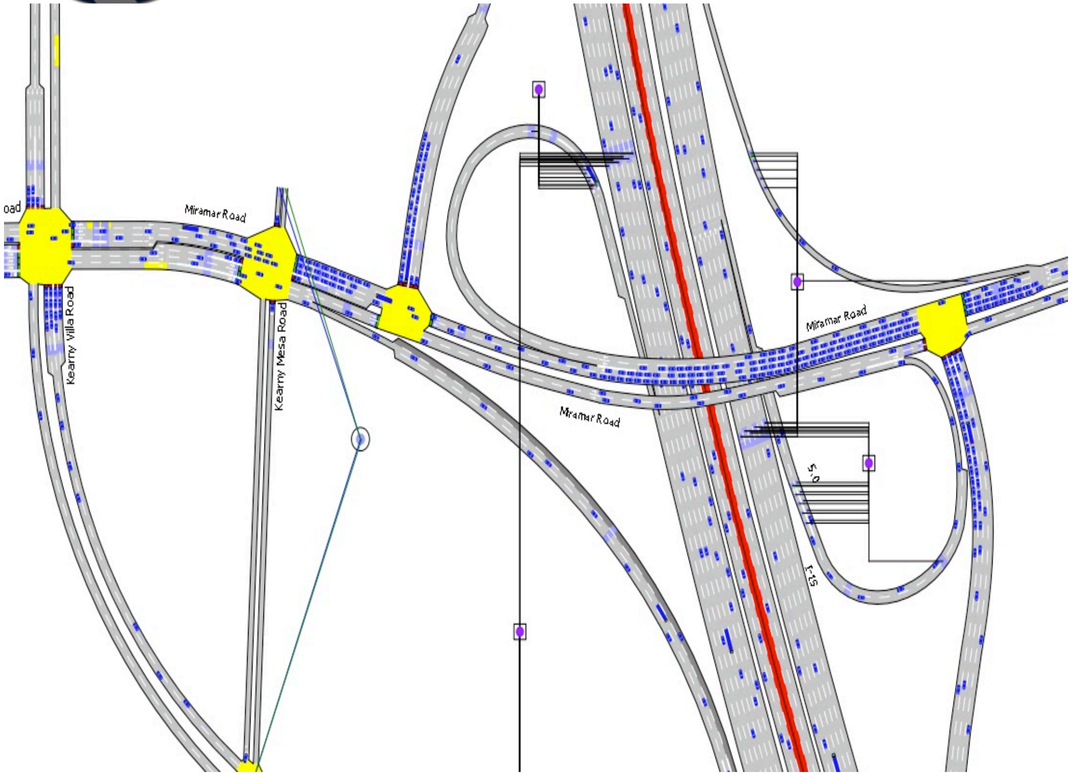
24/7 Model

- 11 Day Patterns
  - Weekdays
  - Holidays
  - Rainy Days
  - Special events
- 15 – Minute data sets
- Runs every 5 minutes



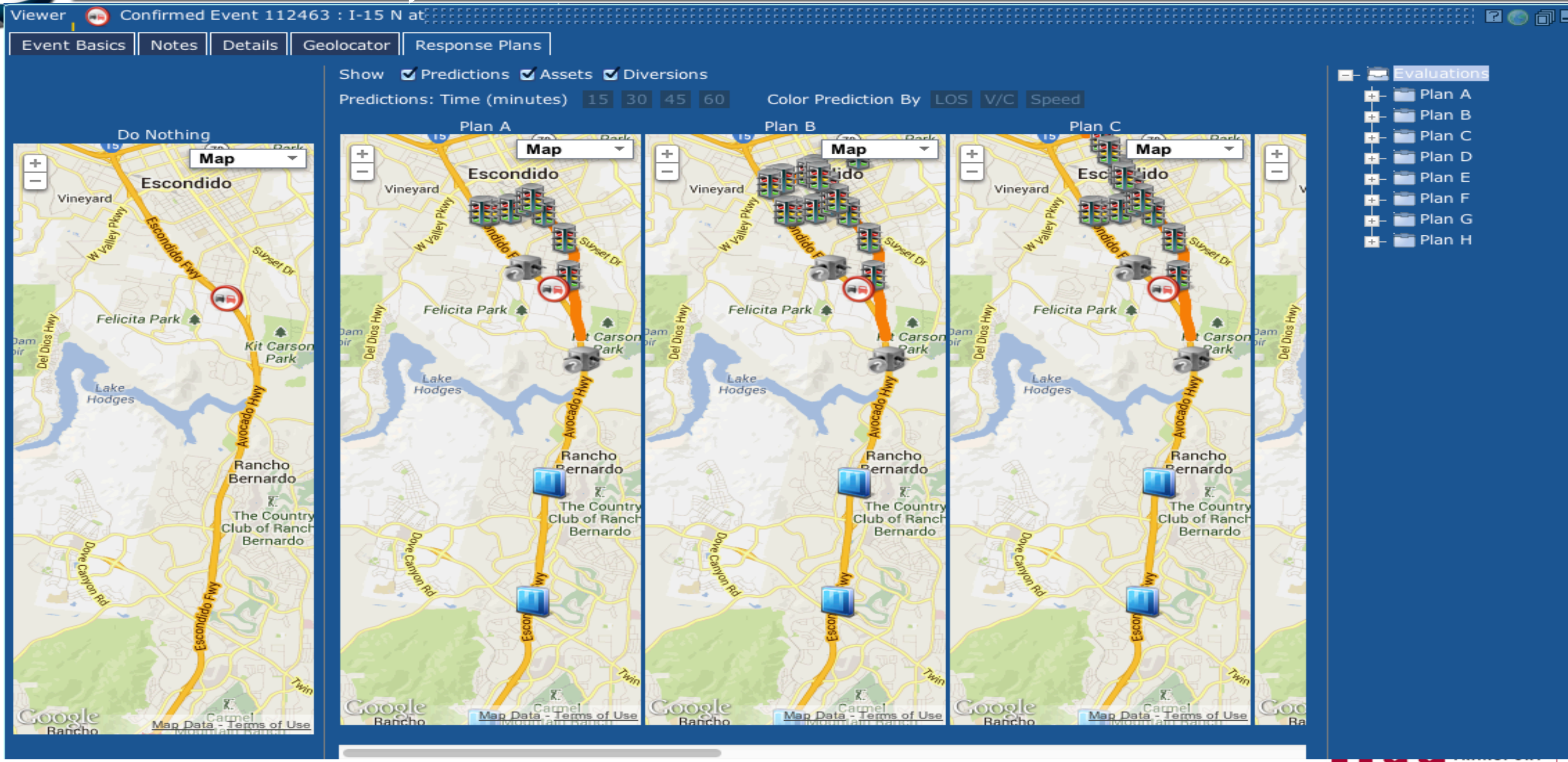
Aimsun Online Dashboard

Corridor Performance Needs



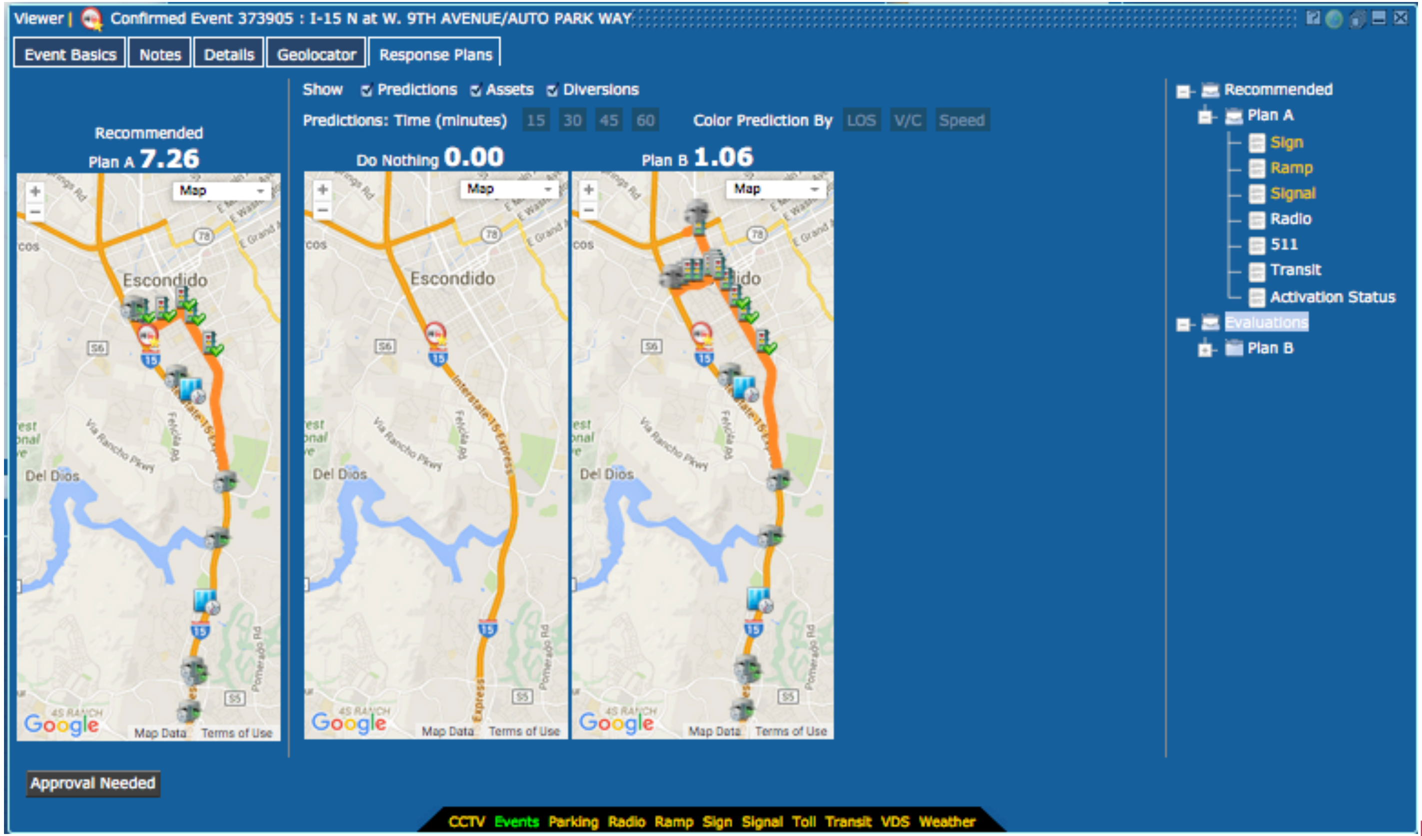
- **Measures**
  - Intersection
  - Ramp Meter
  - Express Lanes
  - Sections
  - Transit
  - Routes
- **Targets (within 15%)**
  - 0-15 minutes 92%
  - 15-30 minutes 80%
  - 30-60 minutes 40%

Response Plan Generation



SIMULATION SYSTEMS

Response Plan Scoring



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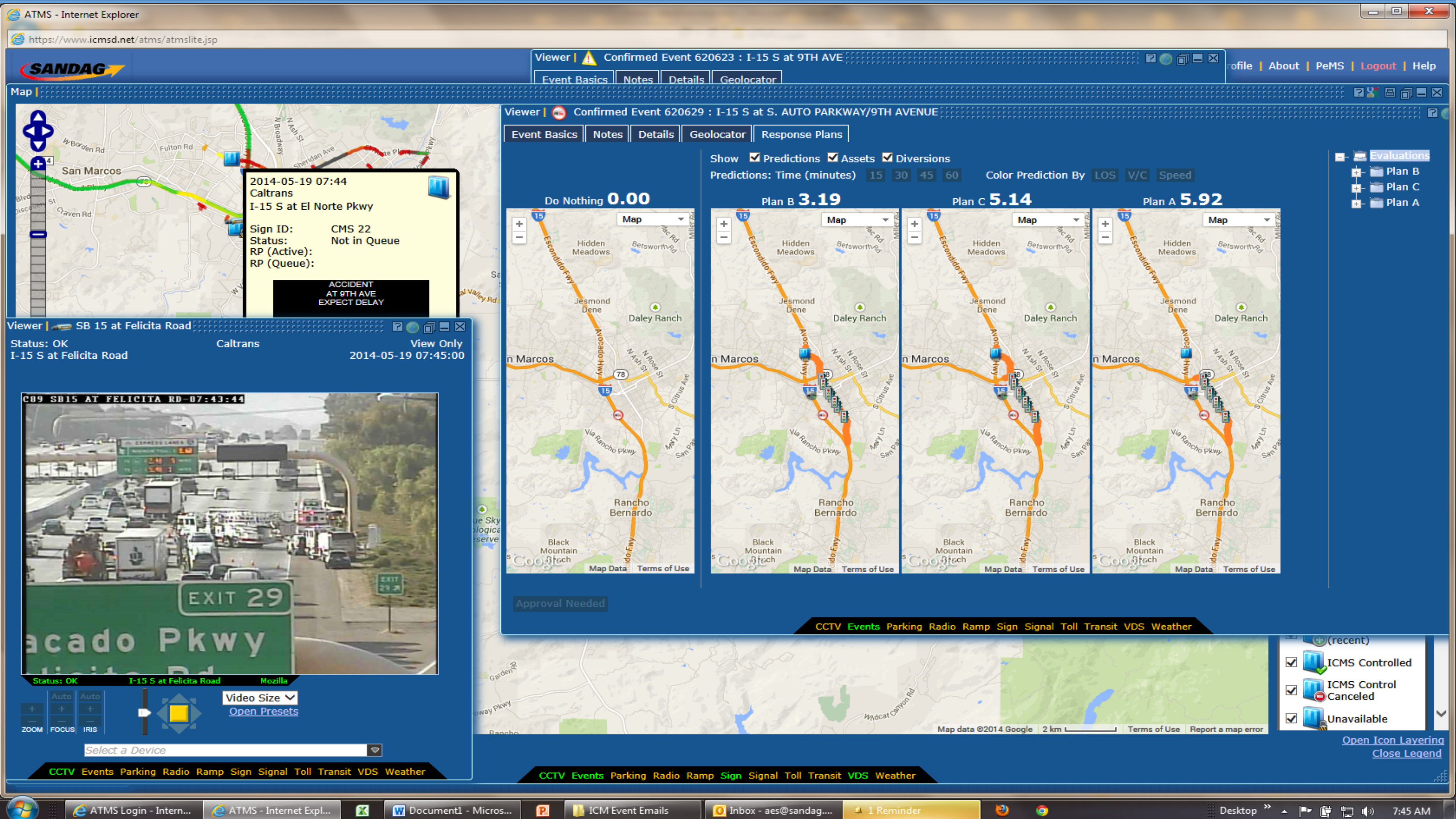
ATMS - Internet Explorer
https://www.icmsd.net/atms/atmslite.jsp
SANDAG
Viewer | Confirmed Event 620623 : I-15 S at 9TH AVE
Event Basics
Notes
Details
Geolocator
rofile | About | PeMS | Logout | Help
Map
2014-05-19 07:44
Caltrans
I-15 S at El Norte Pkwy
Sign ID: CMS 22
Status: Not in Queue
RP (Active):
RP (Queue):
ACCIDENT
AT 9TH AVE
EXPECT DELAY
Viewer | Confirmed Event 620629 : I-15 S at S. AUTO PARKWAY/9TH AVENUE
Event Basics
Notes
Details
Geolocator
Response Plans
Show Predictions Assets Diversions
Predictions: Time (minutes) 15 30 45 60
Color Prediction By LOS V/C Speed
Evaluations
Plan B
Plan C
Plan A
Do Nothing 0.00
Plan B 3.19
Plan C 5.14
Plan A 5.92
Approval Needed
CCTV Events Parking Radio Ramp Sign Signal Toll Transit VDS Weather
Viewer | SB 15 at Felicita Road
Status: OK
I-15 S at Felicita Road
Caltrans
View Only
2014-05-19 07:45:00
C89 SB15 AT FELICITA RD-07:43:44
EXIT 29
Status: OK
I-15 S at Felicita Road
Mozilla
ZOOM FOCUS IRIS
Video Size
Open Presets
Select a Device
CCTV Events Parking Radio Ramp Sign Signal Toll Transit VDS Weather
ICMS Controlled
ICMS Control Canceled
Unavailable
Open Icon Layering
Close Legend
Map data ©2014 Google 2 km Terms of Use Report a map error
CCTV Events Parking Radio Ramp Sign Signal Toll Transit VDS Weather
ATMS Login - Intern...
ATMS - Internet Expl...
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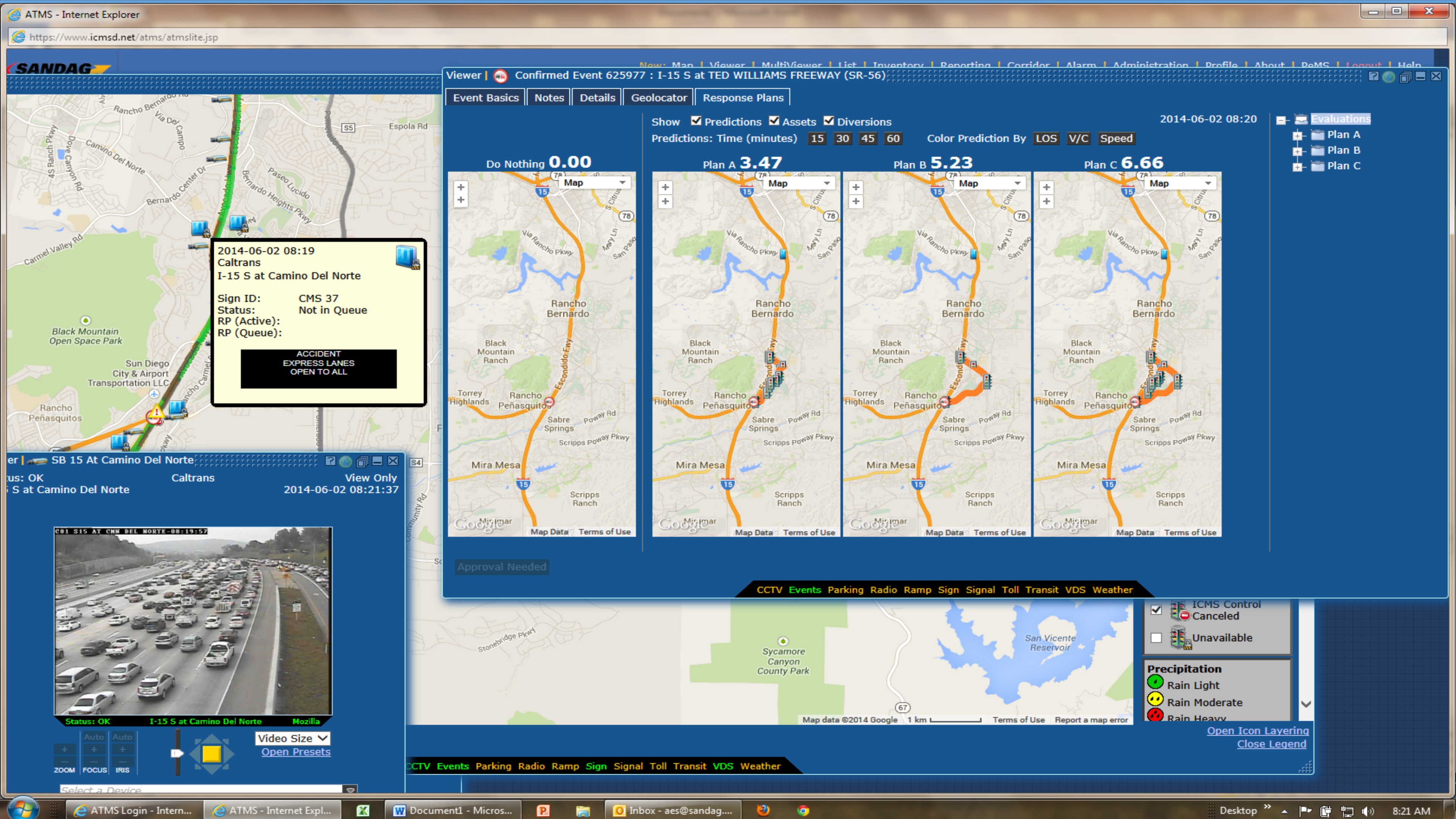
Inbox - aes@sandag....
1 Reminder
Desktop
7:45 AM


ATMS - Internet Explorer
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SANDAG
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Event Basics
Notes
Details
Geolocator
Response Plans
Show Predictions Assets Diversions
2014-06-02 08:20
Predictions: Time (minutes) 15 30 45 60
Color Prediction By LOS V/C Speed
Evaluations
Plan A
Plan B
Plan C
Do Nothing 0.00
Plan A 3.47
Plan B 5.23
Plan C 6.66
Approval Needed
CCTV Events Parking Radio Ramp Sign Signal Toll Transit VDS Weather
2014-06-02 08:19
Caltrans
I-15 S at Camino Del Norte
Sign ID: CMS 37
Status: Not in Queue
RP (Active):
RP (Queue):
ACCIDENT
EXPRESS LANES
OPEN TO ALL
SB 15 At Camino Del Norte
Caltrans
View Only
S at Camino Del Norte
2014-06-02 08:21:37
Status: OK
I-15 S at Camino Del Norte
Video Size
Open Presets
ZOOM
FOCUS
IRIS
ICMS Control Canceled
Unavailable
Precipitation
Rain Light
Rain Moderate
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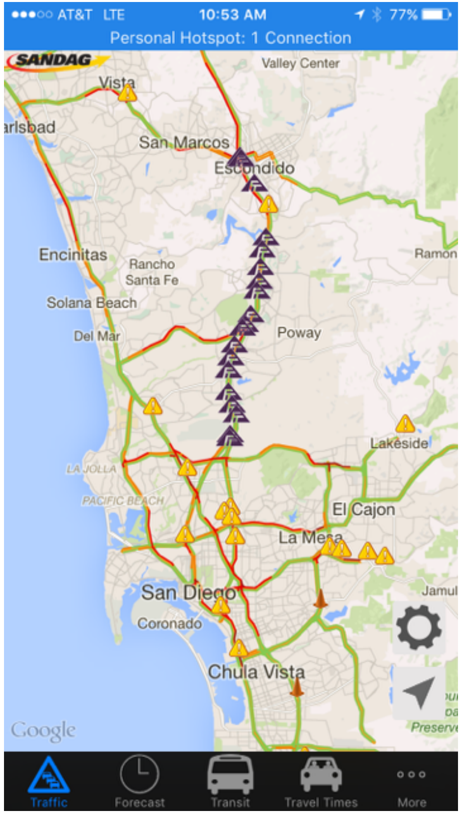
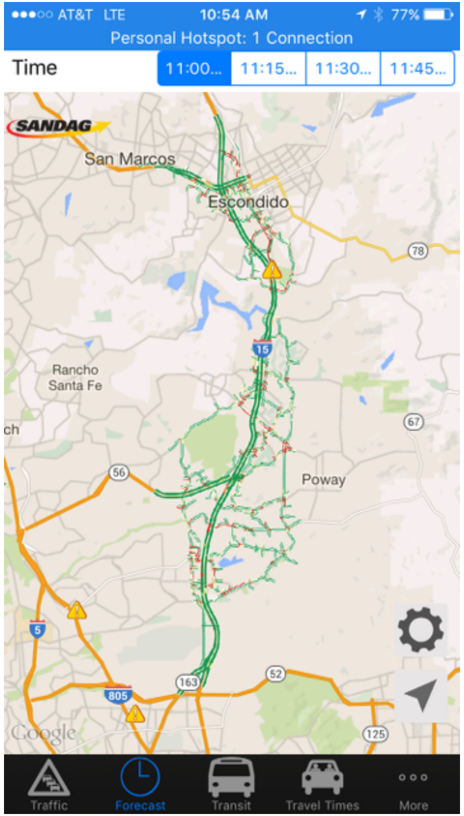
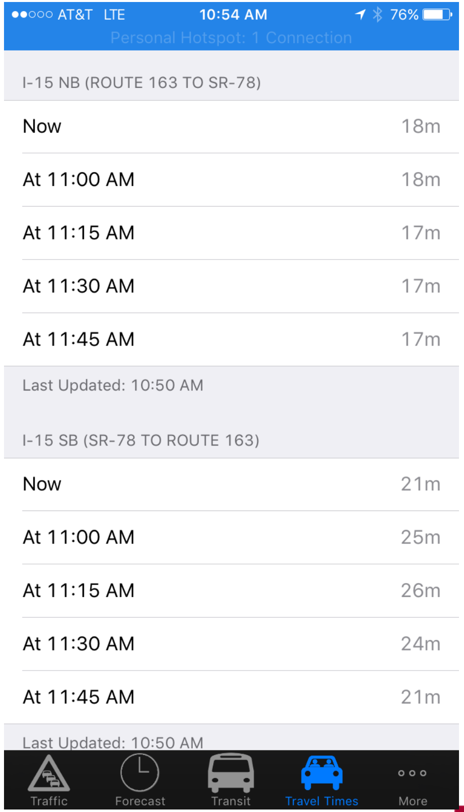
ATMS Login - Intern...
ATMS - Internet Expl...
Document1 - Micros...
Inbox - aes@sandag....
Desktop
8:21 AM

San Diego 511 - APP

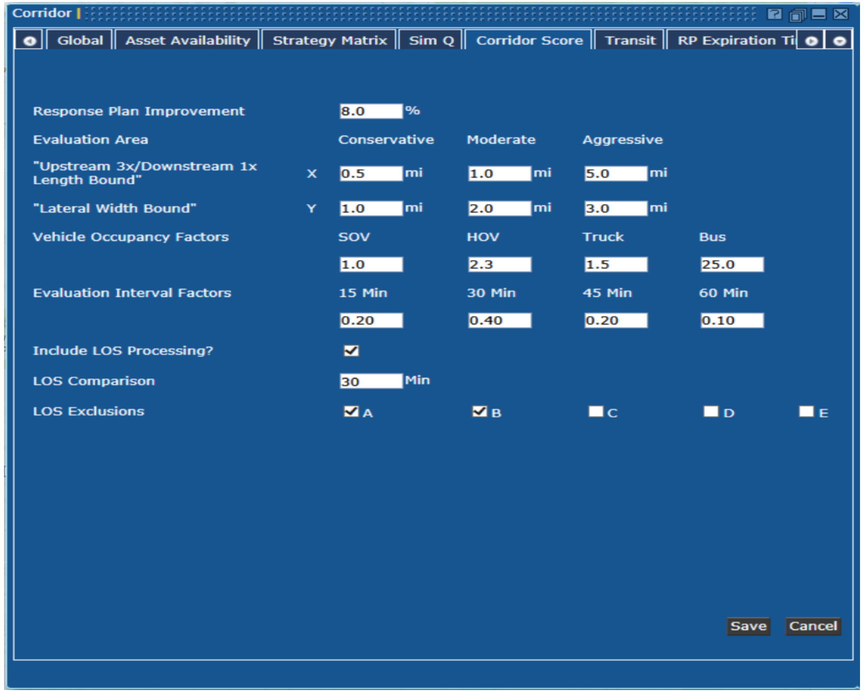


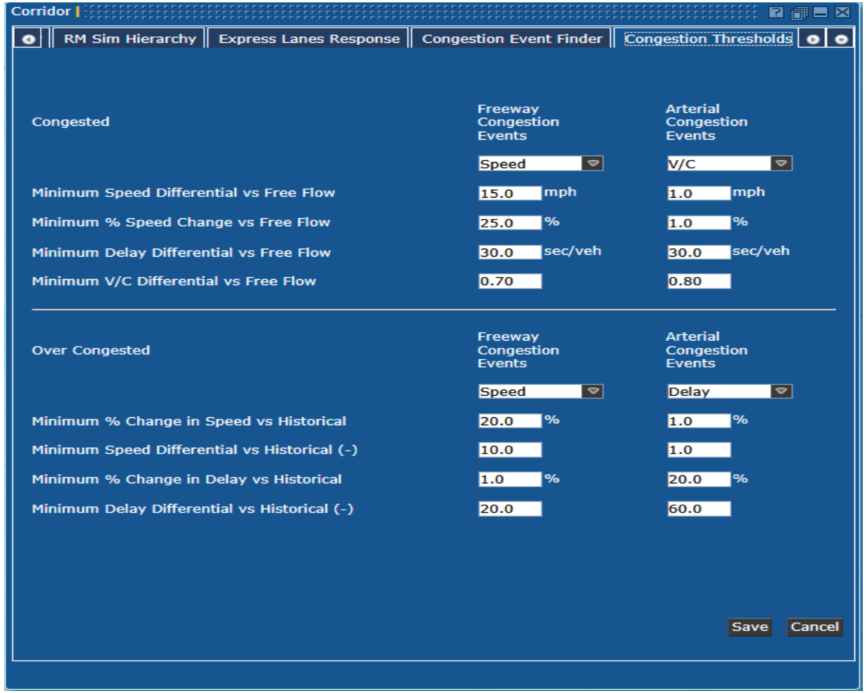




TSS TRANSPORT SIMULATION SYSTEMS

System Configuration



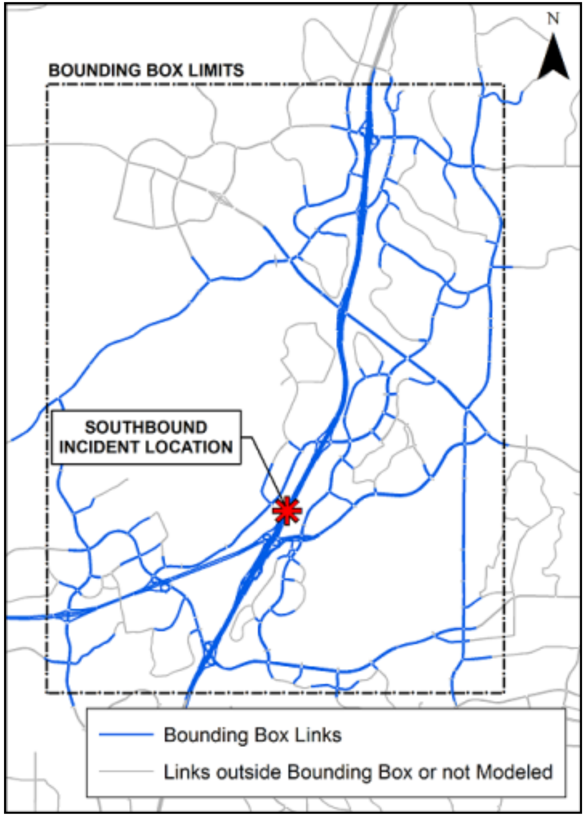


TSS TRANSPORT SIMULATION SYSTEMS

Corridor Score

1. Bounding Box – size defined by response posture to identify minimum selection set

2. LOS Comparison – to identify additional links where response plan implementation has changed operations within the network



Corridor Score

LOS Comparison

Link	Do Nothing	Response Plan A	Response Plan B	Response Plan C	Included in Evaluation?
1	C	D	E	C	Yes
2	B	A	B	B	No*
3	C	C	C	D	Yes
4	C	C	C	C	No
5	F	F	F	F	No
6	D	E	D	C	Yes
7	C	C	C	B	Yes

* This link is not included with LOS A and LOS B exclusion options turned on.

Corridor Score

Determined by comparing each Response Plan against 'Do Nothing'

$$\text{Corridor Score} = \frac{D_0 - D_z}{D_0} * 100$$

- D_0 = Person-delay under Do Nothing Case
- z corresponds to the response plan evaluation
  - D_1 = Person-delay under Response Plan A
  - D_2 = Person-delay under Response Plan B
  - D_3 = Person-delay under Response Plan C

Corridor Score

Person Delay per link = $(SV_{SOV} + HV_{HOV} + TV_{Truck} + BV_{Bus}) * D_{Avg}$

- D_{Avg} = Average Link Delay
- Configurable Static Occupancy Factors:
  - » S – Single Occupancy Vehicle
  - » H – High Occupancy Vehicle
  - » T – Truck
  - » B – Bus
- V_{SOV} = Link Volume of SOVs
- V_{HOV} = Link Volume of HOVs
- V_{Truck} = Link Volume of Trucks
- V_{Bus} = Link Volume of Buses

Corridor Score

- Person delay is totaled for all of the Evaluation Area links, for each Response Plan and the Do Nothing case. Resulting in four corridor delay values for each 15 minute time period.

  D_{15} = 0-15 minute

  D_{30} = 15-30 minute

  D_{45} = 30-45 minute

  D_{60} = 45-60 minute

Corridor Score

The Corridor Person Delay value utilized for comparison of response plans is determined by factoring each of the 15 minute evaluation period by configurable weighting factors:

$$D_y = (W_{15} * D_{15}) + (W_{30} * D_{30}) + (W_{45} * D_{45}) + (W_{60} * D_{60})$$

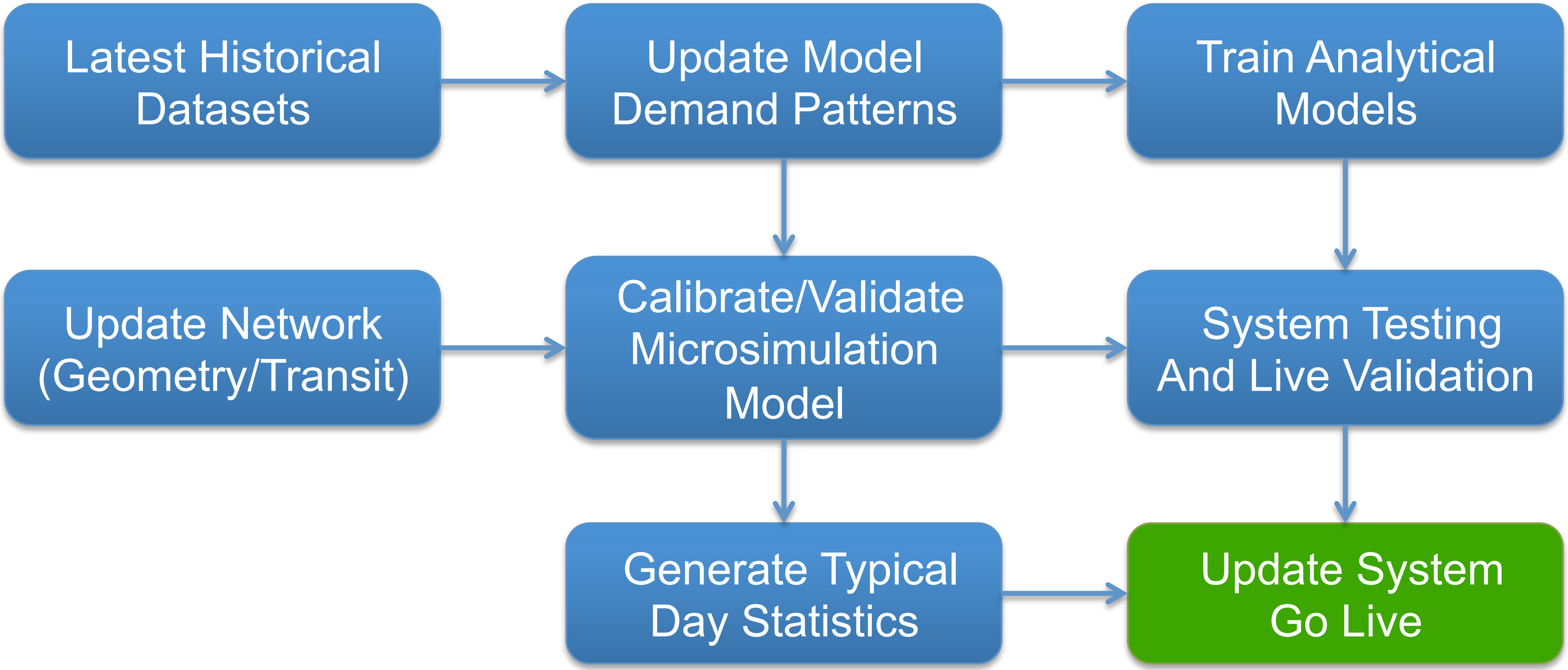
- W_{15} = 0-15 minute weighting factor
- W_{30} = 15-30 minute weighting factor
- W_{45} = 30-45 minute weighting factor
- W_{60} = 45-60 minute weighting factor
- $W_{15} + W_{30} + W_{45} + W_{60} = 1$

- y corresponds to the Response Plan Evaluation
  - 0 = Do Nothing
  - 1 = Response Plan A
  - 2 = Response Plan B
  - Etc.

New Methodology Being Explored

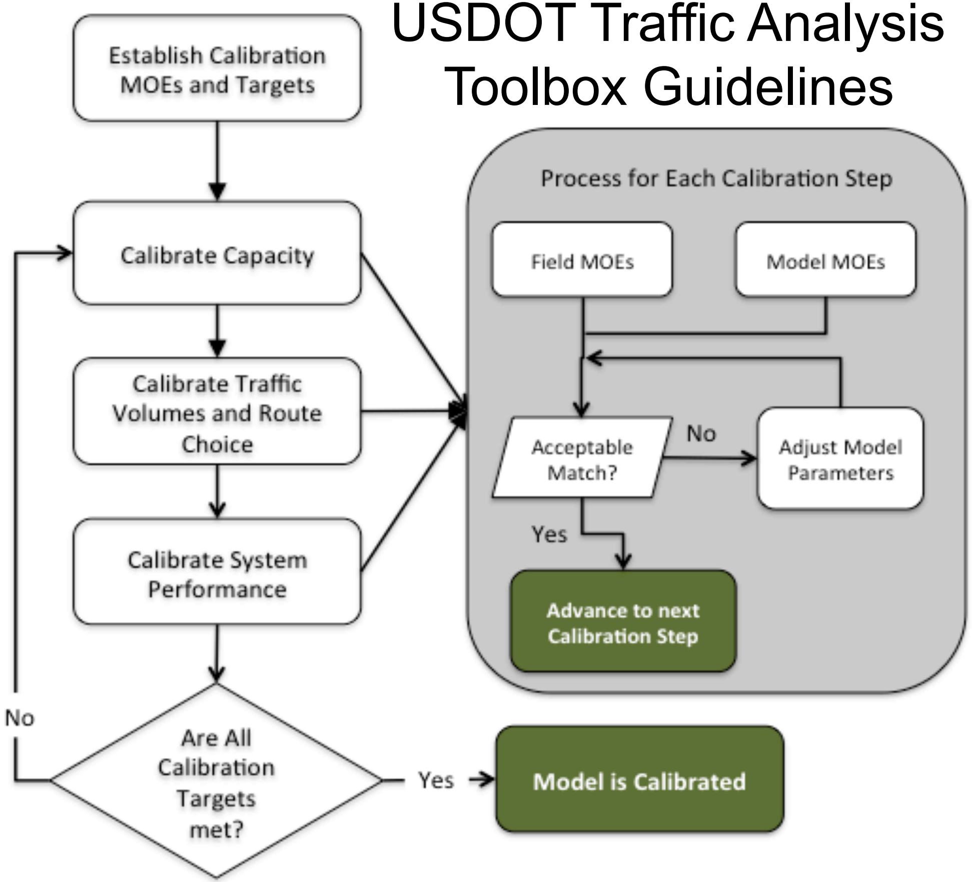
- Travel Time Index & Travel Time Reliability
  - Percentage of trips below Travel Time threshold
  - Freeway Threshold example - 1.33 * Free Flow Travel Time;
  - Arterial Threshold example 2.50 * Free Flow Travel Time;

Model Maintenance Flow



Offline Model Calibration

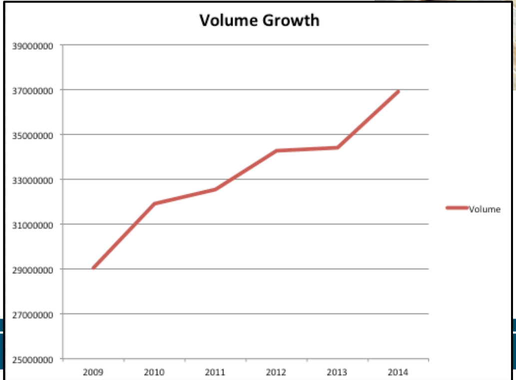
USDOT Traffic Analysis Toolbox Guidelines



Maintaining the Model

Reasons for Model Updates

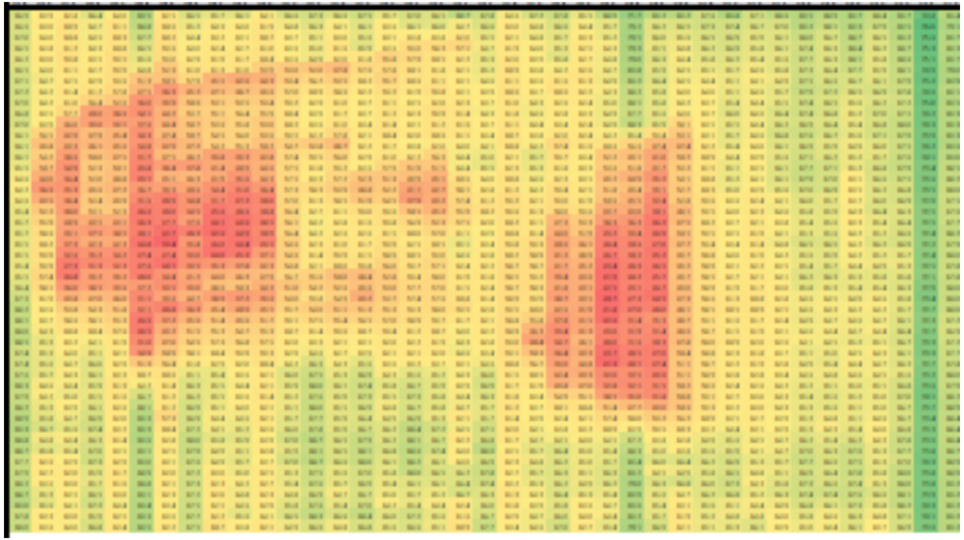
- Change in travel patterns and demands;
- New Infrastructure;
- New ITS systems;
- New Public Transit;
- New Developments;

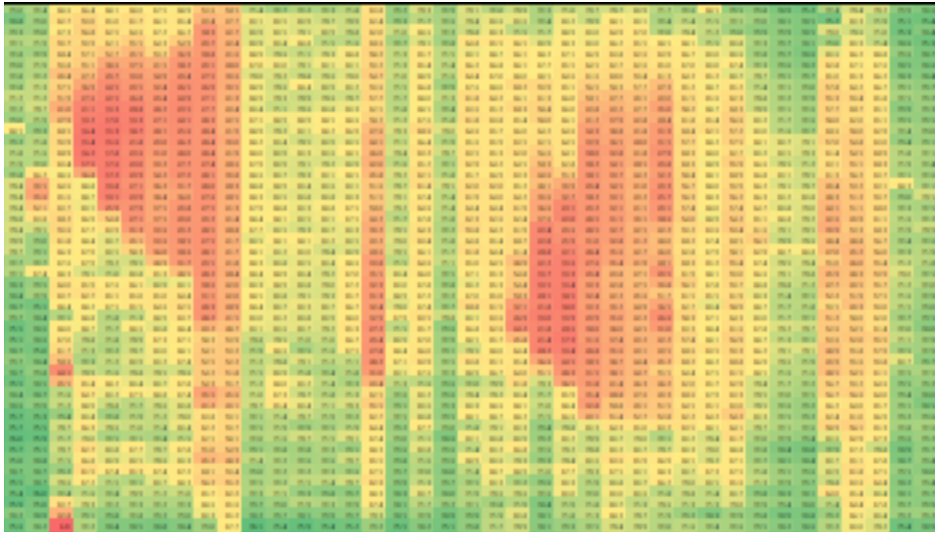


Real Time Validation Data

- Speed
- Count (with 15%; R^2; Slope)
  - 15 minute periods
  - Targets:
    - 80% counts within 15%
    - R^2 & slope between 0.92 & 1.08

Speed Contours





Real Data VS Predicted Data

Related Projects

- SANDAG DTA-ABM Integration
- USDOT ATDM-DMA Testbed
- Post Deployment AMS Evaluation
- MIT Optimization Project
- Future ICM Corridors (13 USDOT Grants)

Why DTA-ABM Integration

- ABM Temporal Integration
  - Choice models
- Congestion Duration
- Dynamic Tolling
- Travel Time Reliability
- Refined Speeds for Air Quality Analysis
- Launching Point for New ICM Corridors

What DTA Brings to RTP

- Operational Analysis
  - ITS/System management applications
  - Signal timing
  - Transit improvements/projects
  - Connected Vehicles

USDOT AMS ATDM-DMA

- ATDM Strategies
  - Network Prediction Sensitivity
  - Dynamic routing
  - Dynamic Pricing
  - Dynamic Lane Use Control
  - Dynamic Managed Use Lanes

USDOT AMS ATDM-DMA

- DMA Strategies
  - INFLO
    - Queue Warning (Q-Warn)
    - Dynamic Speed Harmonization (SPD-HARM)
    - Cooperative Adaptive Cruise Control (CACC)
  - MMITSS
    - Intelligent Traffic Signal System (ISIG)
    - Transit Signal Priority (TSP)

Questions

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