Analysis, Modeling, and Simulation (AMS) Testbed Development and Evaluation to Support Dynamic Mobility Applications (DMA) and Active Transportation and Demand Management (ATDM) Programs

Pasadena Testbed Analysis Plan

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Final Report — June 30, 2016

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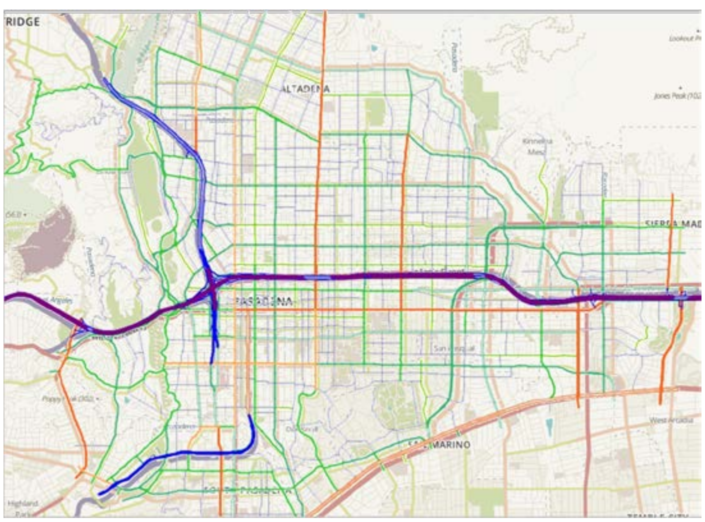

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16. Abstract

The primary objective of this project is to develop multiple simulation Testbeds/transportation models to evaluate the impacts of DMA connected vehicle applications and the active and dynamic transportation management (ATDM) strategies. The outputs (modeling results) from this project will help USDOT prioritize their investment decisions for DMA and ATDM programs.

The primary purpose of this report is to document the Analysis Plan for AMS Pasadena Testbed. The report expands on detailed testbed description including the geographic location, modes, operational conditions and cluster analysis details. In addition, the plan also provides details on the analysis scenarios, DMA/ATDM applications and strategies that are evaluated using the Testbed and the plan to answer DMA/ATDM-specific research questions. The analysis plan provides details on the evaluation approach used to answer specific research questions.

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Chapter 1. Introduction

The United States Department of Transportation (USDOT) initiated the Active Transportation and Demand Management (ATDM) and the Dynamic Mobility Applications (DMA) programs to achieve transformative mobility, safety, and environmental benefits through enhanced, performance-driven operational practices in surface transportation systems management. In order to explore a potential transformation in the transportation system's performance, both programs require an Analysis, Modeling, and Simulation (AMS) capability. Capable, reliable AMS Testbeds provide valuable mechanisms to address this shared need by providing a laboratory to refine and integrate research concepts in virtual computer-based simulation environments prior to field deployments.

The foundational work conducted for the DMA and ATDM programs revealed a number of technical risks associated with developing an AMS Testbed which can facilitate detailed evaluation of the DMA and ATDM concepts. Therefore, instead of selecting a single Testbed, it is desirable to identify a portfolio of AMS Testbeds and mitigate the risks posed by a single Testbed approach by conducting the analysis using more than an "optimal" number of Testbeds, reduces the resources available to enhance or improve the Testbeds to address the gaps. At the conclusion of the AMS Testbed selection process, four (4) AMS Testbeds were initially selected to form a diversified portfolio to achieve rigorous DMA bundle and ATDM strategy evaluation: San Mateo (US 101), Pasadena, ICM Dallas and Phoenix Testbeds. In addition, the AMS Testbed Team plans to add the ICM San Diego Testbed and the Chicago Testbed to the selected Testbeds. The analysis plan describes the overall approach for modeling and evaluating the impacts of DMA bundles and ATDM strategies. In addition, the analysis plan helps to test the hypotheses of the DMA and ATDM Programs and evaluate the implementation's costs of their applications.

The primary purpose of this report is to document the analysis plan approach for the **Pasadena** Testbed. The Pasadena testbed is located in Los Angeles County, California, covering a dense urban road network of 44.36 square miles with both freeways and surface streets. This testbed will be used to test ATDM strategies including Dynamic Shoulder Lanes, Dynamic Speed Limits, Queue Warning and Adaptive Ramp Metering and Dynamic Merge Control, as well as DMA application bundles including: INFLO (queue warning, speed harmonization) and MMITSS (I-SIG). The Testbed will integrate third party software implementing these strategies and applications, with a general data bus to link all systems as well as Vissim serving the virtual reality.

This report is organized into ten chapters as follows:

- Chapter 1 – Introduction: This chapter presents the report overview and objectives
- Chapter 2 – Testbed Description: This chapter presents the regional characteristics of the Testbed (e.g., geographic characteristic) and the proposed operational conditions.
- Chapter 3 – Analysis Hypotheses: This chapter identifies the DMA/ATDM hypotheses that will be tested by the Testbed. The hypotheses to be tested will, in many cases, determine the analysis approach and the operational scenarios to be considered for the specific Testbed.
- Chapter 4 – Analysis Scenarios: This chapter describes the analysis scenarios (combination of operational conditions and alternatives) to be evaluated. The description will include demand considerations, vehicle type mix and characteristics, weather conditions, presence and severity of incidents, traveler characteristics, user acceptance rates (key consideration), and others.

- Chapter 5 – Data Needs and Availability: This chapter illustrates the data needs and gaps for the Testbed. In addition, this chapter will provide a detailed plan for data collection and data mining to fill the identified gaps.
- Chapter 6 – Key Assumptions and Limitations: This chapter identifies assumptions, including market penetration of devices (e.g., nomadic device), behavioral responses of drivers, travelers, and system managers, communication technology, latency and errors associated with different communication types, and others.
- Chapter 7 – Modeling Approach: This chapter details the modeling approach to test the hypothesis and generate performance measure statistics to compare alternatives and thus evaluate them.
- Chapter 8 – Model Calibration: This chapter outlines the calibration approach and criteria. It is especially important to establish a consistent calibration approach and criteria across multiple Testbeds in order to effectively compare and combine the results.
- Chapter 9 – Evaluation Approach: This chapter presents the system evaluation plan to answer the DMA/ATDM research questions based on the analysis conducted and the sensitivity analysis.
- Chapter 10 – Execution Plan: This chapter presents the proposed schedule, budget and resources required to complete the analysis, and key roles and responsibilities of team members.

Chapter 2. Testbed Description

2.1 Regional Conditions

This section details the geography, the demographic characteristics, the transportation system elements, and existing supply and demand characteristics of Pasadena

2.1.1 Geography and Demographics

The Pasadena Testbed takes the roadway network of the City of Pasadena in Los Angeles County, California. This testbed network was derived from the regional travel model that had been developed under US DOT contract DTFH6111C00038, which can be publically accessed through the Research Data Exchange portal (https://www.its-rde.net/). Primarily covering the City of Pasadena, the network also includes unincorporated area of Altadena to the north, part of the Cities of Arcadia to the east, Alhambra to the south and Glendale and Northeast Los Angles to the west. The total area is 44.36 square miles.

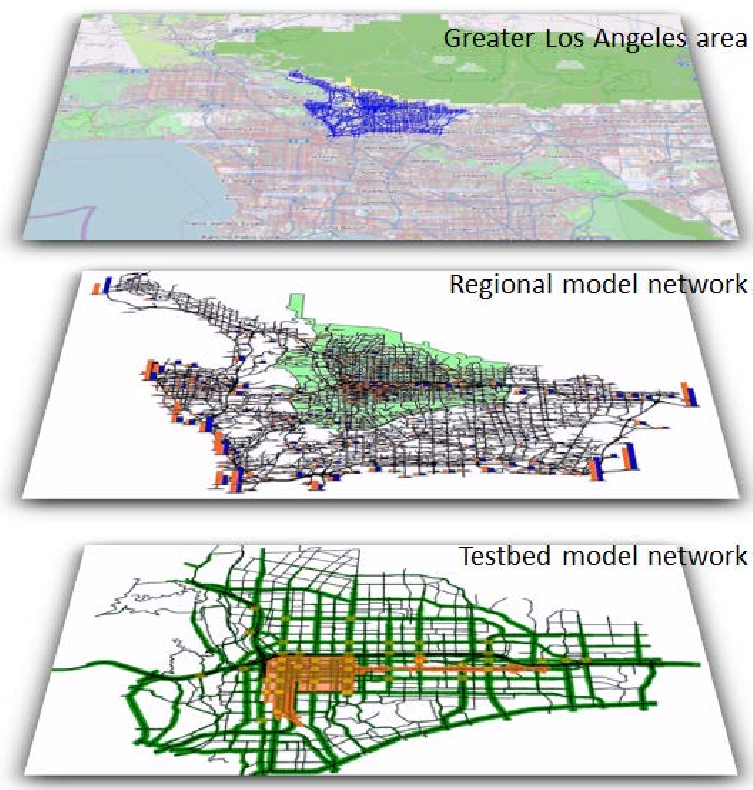

Figure 2-1: Pasadena Testbed Network Derived from past USDOT Project in the Greater Los Angeles Area [Source: HBA]

2.1.2 Transportation System

2.1.2.1 Roadways

The Pasadena Testbed network in its current state was the result of a recent dynamic traffic assignment (DTA) model update efforts for the City of Pasadena, which corresponds to the City's travel demand forecast model. This model network includes four major freeway segments: I-210, I-710, CA-134 and CA-110, totaling to 17.7 centerline miles. The freeways also included about 10.5 miles of HOV lanes on I-210 and CA-134 for both directions, as illustrated in the following figure. The HOV lanes are effective all time.

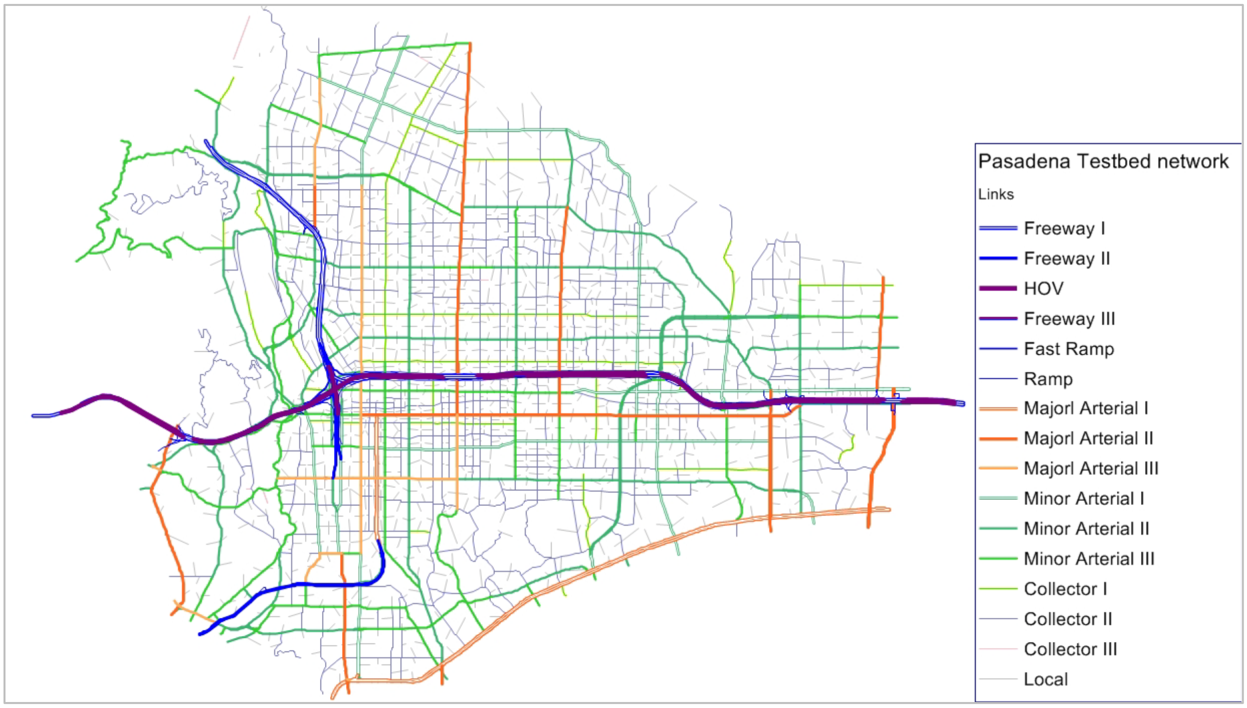

Figure 2-2: Pasadena Testbed Network by Facility Types [Source: HBA]

The network also covers a wide range of arterials and collectors that comprises a balanced roadway system.

The network base map was from NAVTEQ navigation map (Year 2011, Quarter 1 release) that has accurate and detailed geometric representations of the roadway network.

2.1.2.2 Travel Modes

The existing DTA model includes the segments for both single occupancy vehicle (SOV) and high occupancy vehicles (HOV). The Southern California Association of Governments (SCAG) travel demand model also includes truck segments, which could also be imported into the model network. However, only single occupancy vehicle (SOV) and high occupancy vehicles (HOV) will be modeled in the Pasadena Testbed.

2.1.2.3 Types of Vehicles Included in the Testbed

Vehicle classes in the Pasadena Testbed are cars (SOV and HOV) and trucks (light, medium and heavy).

2.1.2.4 ITS and Infrastructure Condition

Field ITS infrastructure includes:

- Traffic detection: extensive freeway vehicle detection stations (VDS) known as Freeway Performance Measurement System (PeMS),
- Freeway on-ramp and freeway to freeway connector meters,
- Variable message signs (VMS) and
- CCTV cameras.

Metered ramp locations are illustrated in the following figure; in total there are 31 metered locations in the field in the testbed network.

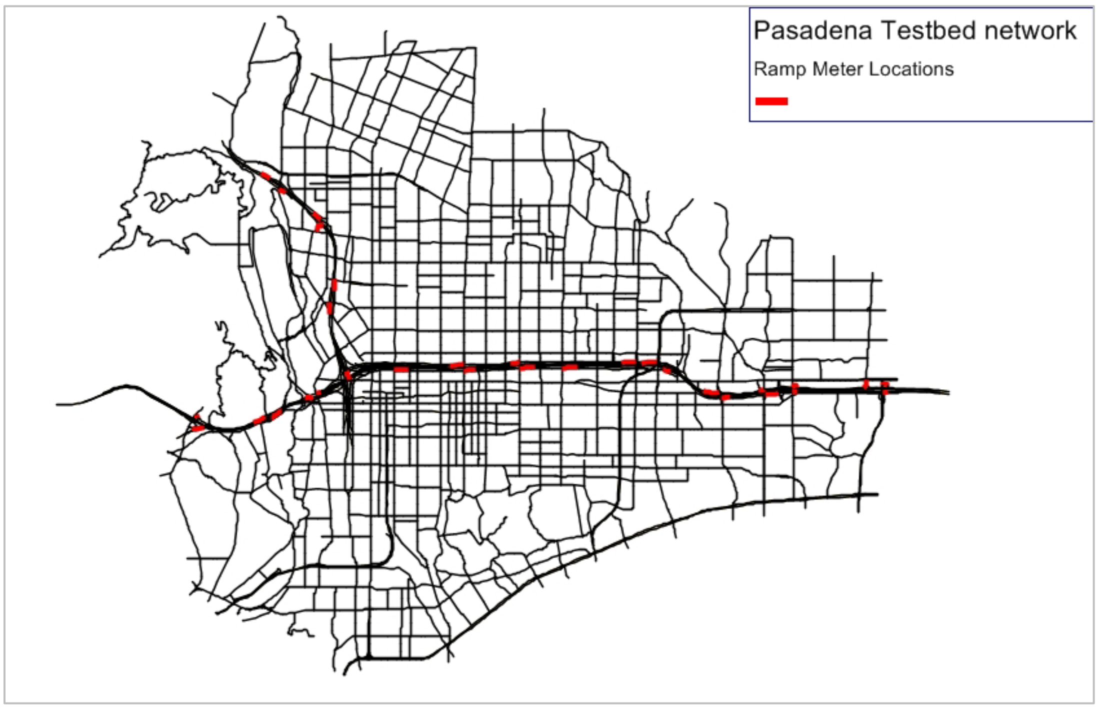

Figure 2-3: Pasadena Testbed Ramp Meter Locations [Source: HBA]

The following figure shows the location of VMS and CCTV cameras in the study area. It is understood that even though AMS testbed scenarios will be based on field ITS infrastructure, the analysis may not necessarily be confined by existing conditions; as such more virtual ITS infrastructure could be added as the detailed analysis plan is laid out next. In total, there are 122 PeMS VDS that include on/off ramps, mainline, HOV lanes, and freeway to freeway connectors, and 17 arterial ATMS system detectors, as seen from the following figure.

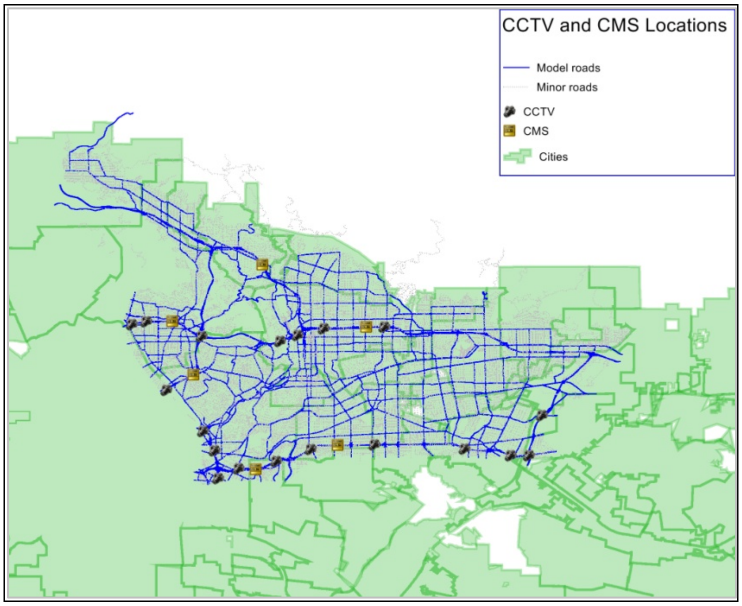

Figure 2-4: Pasadena Ramp Meter Locations [Source: DTFH6111C00038 Final Report]

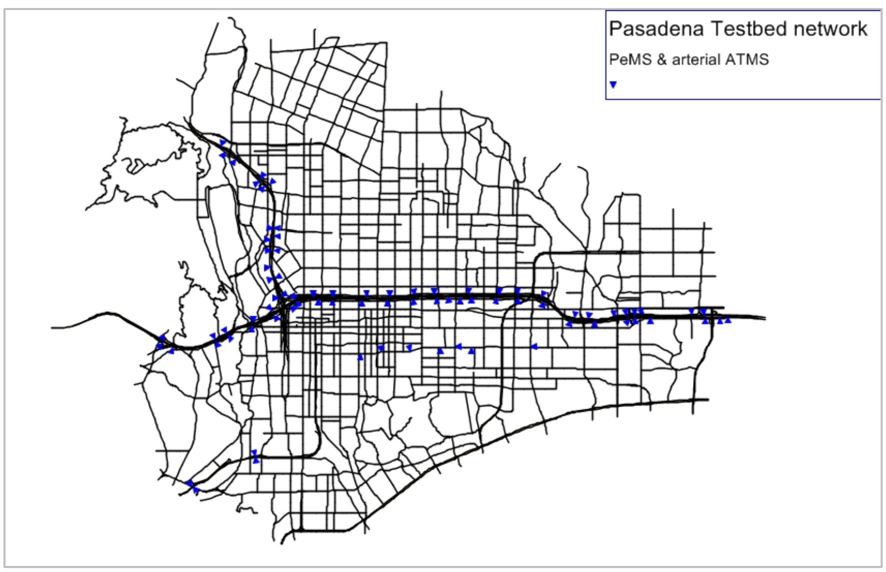

Figure 2-5: Testbed Vehicle Detection Stations and Arterial System Detector Locations [Source: HBA]

2.1.3 Existing Traffic Conditions

The Pasadena Testbed road network carries a mixed traffic including major freeway through volumes, local circulation from mixed land use in the City downtown area, and all external related traffic. The major freeways of I-210 and CA-134 both see Average Annual Daily Traffic (AADT) between 210,000 and 294,000, of which 8-15% are HOV 2+ vehicles. Major east-west arterials including Colorado St, Walnut St and Orange Grove carry daily traffic between 8,000 and 13,000.

Adverse weather conditions are comparatively infrequent and mild compared to other parts of the country. In June 2013 to May 2014, there were 5 rain days out of 365 (1.4%) when there were more than trace amounts of rain. High winds, snow and ice did not occur in the study period.

No major new construction occurred on the freeway during the study year, June 2013 to May 2014. Maintenance work zones on weekdays are timed to run between 9 AM and 2 PM, with all lanes reopened to traffic by 2 PM.

Demand does not vary greatly over the course of the year. The 5th percentile and the 95th percentile highest non-holiday weekday PM peak period demands span a range of plus or minus 9.5% of the median demand. For the non-holiday weekday AM peak period, demand spans a range of plus or minus 9.6% of the median demand.

2.2 Operational Conditions

2.2.1 Data Needs for Cluster Analysis

In general, there are three types of data needed for conducting the cluster analysis and identifying the prevalent operational conditions:

1. Type 1 data represents the underlying phenomena, i.e., data which are used as input to simulation models (e.g., traffic flows).
2. Type 2 data considers the non-recurring measurements (e.g., incident and weather data).
3. Type 3 data characterizes the system outcomes in terms of specific measures (e.g., travel time) in order to perform the cluster analysis.

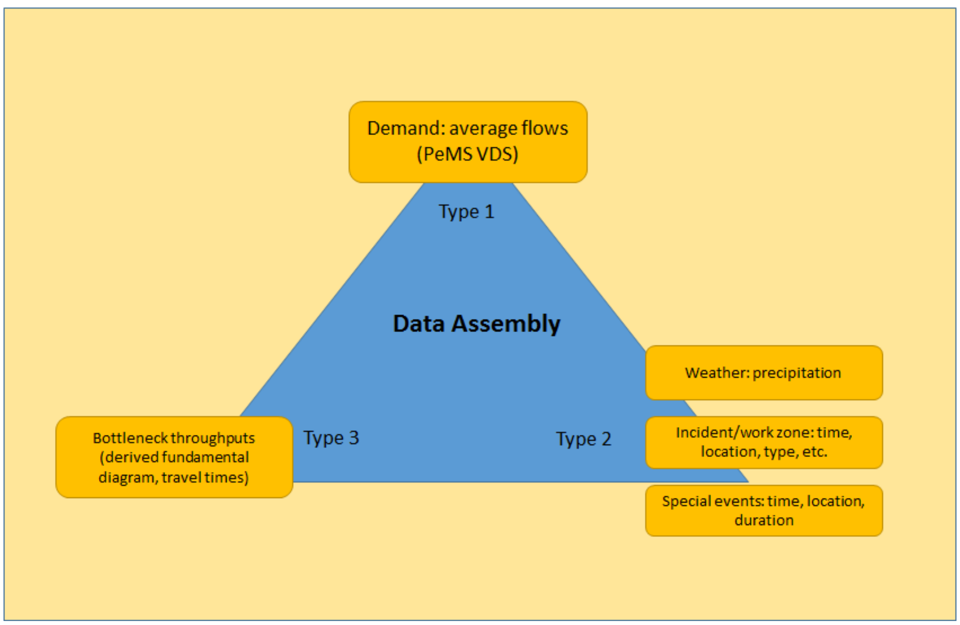

Figure 2-6: Data Assembly Components, Adapted from [1]

2.2.1.1 Type 1: Data to Represent Underlying Phenomena

Demand: Traffic flow rate data is available for the I-210, I-710, and CA-134 freeways at 5-minute, one hour or daily total resolution. Caltrans maintains the Freeway Performance Measurement System (or PeMS) that are publically available for visualization and download; the data for June 1, 2013 through May

[1] Vasudevan, M. Analysis, Modeling, and Simulation (AMS) Testbed Development and Evaluation to Support Dynamic Mobility Applications (DMA) and Active Transportation and Demand Management (ATDM) Programs: Cluster Analysis for Existing Operation Conditions. Noblis, 2014.

31, 2014 are obtained from the PeMS web portal. Two days of data (April 24 and April 28) had problems with their data and were excluded from the analysis; the analysis dataset thus included 363 days of data. These dates, excluding the two days with missing data, were selected primarily for they are most recent when the analysis was initiated, and other model support data were also collected around similar time from the City of Pasadena. The traffic volume is used in this analysis to provide information on the demand level in the corridor.

2.2.1.2 Type 2: Data to Represent Non-Recurrent Conditions

Weather: Weather data was extracted from the weather underground website www.wunderground.com for the El Monte Airport, CA, which is the closest airport to the Pasadena Testbed. Weather data include precipitations by hour in general. Out of the 363 days (June 1 2013 through May 31, 2014, excluding April 24 and 28), 2 days of rainy weather were observed for the AM peak and 4 days of rainy weather were observed for the PM peak. There were no snow or ice conditions during the analyzed horizon.

Incident: Incident logs were also obtained for the one-year analysis horizon from the PeMS web portal. Incident data includes starting time, duration, location information, and description. About 1,350 incidents were recorded throughout the Testbed. Data was not available for June, July, August, October, or December, which accounts for 154 days of the year. The majority of accidents were due to either traffic collisions with no injuries (43.0%) or traffic collisions with unknown injuries (41.2%). The third most likely incident was a hit and run with no injuries (10.0%). The overall rate of accidents on I-210 or CA-134 within the testbed area for the available months was 5 accidents per day.

2.2.1.3 Type 3: Data to Represent System Outcomes

Bottleneck Throughput: Bottleneck locations are automatically identified and classified along the I-210, I-710, and CA-134 corridors in the PeMS database by their spatial spreading scope and days of congestion. The nearest detectors upstream and downstream of the locations of these bottlenecks are identified, and their time-dependent flow rate records are used to provide an estimate of the traffic throughput at these bottleneck locations. Characterized by the so-called fundamental diagram (FD), these throughputs include characteristics values such as capacity, free flow speeds, and shockwave speeds for a simplified triangular FD. One method from a TRB paper was used to derive these values [2].

However, because VDSs were not experiencing congestion on every single day in the analysis horizon, not enough data could be obtained for the congestion branch in the fundamental diagram. As such FDs could not be established for those days.

Travel Time: While travel time (TT) is not directly available in the PeMS database, the average speed of traffic and the freeway mainline segment length that each vehicle detection station (VDS) spans are available and can be used to approximate TT. TT was calculated by summing the average of each VDSs' TT by direction for I-210.

2.2.2 Cluster Analysis Approach

The general cluster analysis methodology suggested in [1] was implemented by the Pasadena Testbed team in a statistics package **R**. With this tool in place, a cluster analysis was performed aiming to examine and identify typical operational conditions that will be characterized by the above three types of data.

[2] Dervisoglu, Gunes, G. Gomes, J. Kwon, A. Muralidharan, P. Varaiya, R. Horowitz (2008). Automatic calibration of the fundamental diagram and empirical observations on capacity. 88th TRB Annual Meeting, Washington DC.

2.2.2.1 Preparation of Data Vector Inputs to Cluster Analysis

The approach started with reorganizing the data into different forms of data vectors as input to the developed cluster analysis program in **R**. After initial rounds of data vector selection and preliminary analysis, the following data vectors were chosen for the final cluster analysis. These data vectors were targeted to reveal various aspects of the operational conditions throughout the corridor network. They are organized by direction of travel, by peak periods, and by day.

Vehicle Miles Traveled. This is type 1 data aiming to classify the demand variations across different days. Vehicle Miles Traveled (VMT) were calculated by summing the product of the volumes at each vehicle detection station (VDS) and the freeway mainline segment that the same VDS covers with no bifurcations or merges. VMT is divided into eastbound (EB) and westbound (WB) values separately, aiming to capture peaking directions.

Travel Time. This is type 3 data aiming to classify system conditions across different days. Travel times are also separated for EB and WB directions.

Incident Data. The total number of incidents and the total duration of incidents were both collected for each peak period for each day. This is type 2 data aiming to classify the frequency and severity of incidents through the testbed.

Precipitation. This is type 2 data aiming to classify the effect of rain on operational conditions within the testbed area.

2.2.2.2 Cluster Analysis Procedure

The Pasadena Testbed developed the cluster analysis procedure with two objectives: 1) to identify most representative operational conditions from the collected one-year data; 2) to ensure adequate remaining project resources for sufficient testbed evaluation of specific ATDM and DMA applications. After all three types of data were collected and processed, the following steps were taken to carry out the analysis procedure.

1. Examine the real world conditions at the testbed corridor, and also gather local knowledge from the City of Pasadena for qualitative assessment of congestion patterns;
2. Compare the cluster characteristics such as cluster size, physical meaning correspondence like incident severities, and decide on whether the cluster is only the collection of outliers or a group representing a typical combination of operational conditions including demand, congestion patterns and non-recurring events. Appropriate clusters of larger sample sizes with distinctive traffic operation patterns are selected as representative baseline conditions.

2.2.2.3 Cluster Analysis Results

Cluster analysis running on all data vectors as in Section 2.2.2.1 brought out different findings on various data types and combinations. The following tables and figures illustrate the results of cluster analysis for both AM and PM peak periods.

The cluster analysis results for the AM peak period are shown in Table 2-1.

Table 2-1: AM Peak Period (6-9AM) Cluster Analysis Results

Cluster	1	2	3	4	5	6	7	8	9
No. Records	47 (13%)	82 (23%)	31 (9%)	9 (2%)	7 (2%)	57 (16%)	8 (2%)	46 (13%)	76 (21%)
VMT EB (mi)	177863	171566	164733	92133	124032	65961	144639	109565	181184

Cluster	1	2	3	4	5	6	7	8	9
VMT WB (mi)	192502	200069	191652	91819	145631	57488	167292	108892	204035
TT EB (min)	8.49	9.22	9.40	8.18	9.42	8.06	7.73	8.49	8.46
TT WB (min)	10.90	11.65	10.85	8.58	9.92	8.62	8.79	8.96	10.82
Total No. Incidents	124	70	38	8	1	33	31	28	131
Total Incident Duration (min)	4298	1366	1169	671	10	670	808	789	3631
Incident Frequency (Incidents/day)	2.64	0.85	1.23	0.89	0.14	0.58	3.88	0.61	1.72
Incident Severity (Avg. Incident Duration)	34.66	19.51	30.76	83.88	10.00	20.30	26.06	28.18	27.72
Precipitation (in)	0.000	0.000	0.000	0.000	0.003	0.000	0.038	0.000	0.000

(low values have green text, average values have black text, and high values have red text)

Descriptions for each cluster were developed from the values found in Table 2-1 and are shown in Table 2-2.

Table 2-2: AM Peak Period Cluster Descriptions

Cluster	Percentage of Year in Cluster	Description
1	13%	High Demand, High Incident Frequency, High Incident Severity, Weekdays
2	23%	High Demand, Low Incident Frequency, Low Frequency Severity, Weekdays
3	9%	Medium to High Demand, Weekdays
4	2%	Low Demand, Low Incident Frequency, High Incident Severity
5	2%	Medium Demand, Low Incident Frequency, Low Incident Severity
6	16%	Low Demand, Low Incident Frequency, Low Incident Severity, Sundays
7	2%	Medium to High Demand, High Incident Frequency, Rain (1 day, 0.30 inches total)
8	13%	Medium Demand, Low Incident Frequency, Saturdays
9	21%	High Demand, Weekdays, medium incident frequency and duration

A calendar was created that shows which days were assigned to which clusters for the AM peak period. The AM peak period calendar heat map is showing in Figure 2-7.

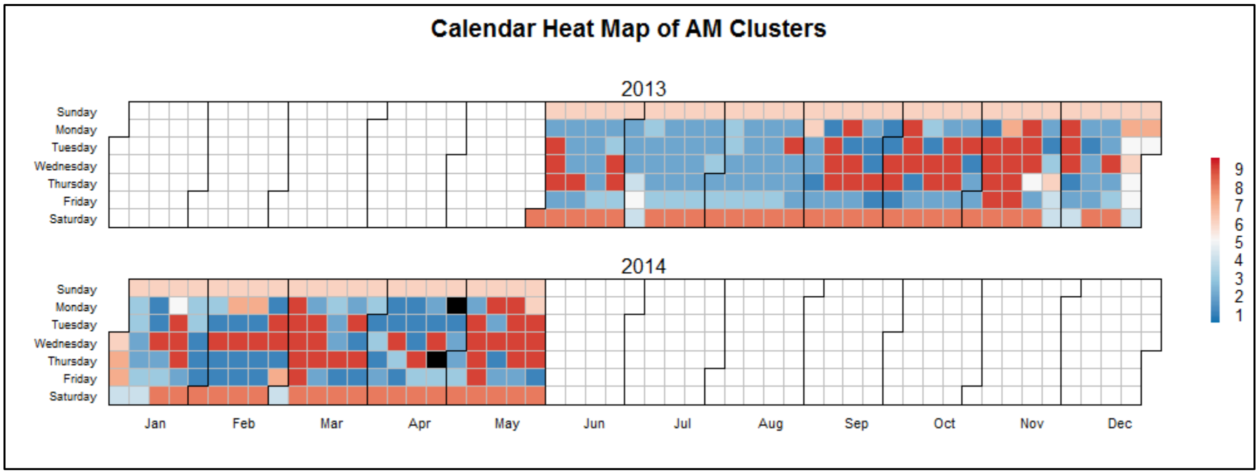

Figure 2-7: AM Peak Period Calendar Heat Map (days in black had no data) [Source: HBA]

The cluster analysis results for the PM peak period are shown in **Table** 2-3.

Table 2-3. PM Peak Period (3-7PM) Cluster Analysis Results

Cluster	1	2	3	4	5	6
No. Records	49 (13%)	16 (4%)	115 (32%)	51 (14%)	76 (21%)	56 (15%)
VMT EB (mi)	215240	192914	258823	235390	243383	224525
VMT WB (mi)	233468	204825	262669	242130	265283	258573
TT EB (min)	11.17	8.90	11.97	11.92	16.14	19.20
TT WB (min)	9.89	9.05	9.95	9.79	10.71	11.21
Total No. Incidents	116	30	260	143	192	145
Total Incident Duration (min)	3207	560	7862	4453	5942	4289
Incident Frequency (Incidents/day)	2.37	1.88	2.26	2.80	2.53	2.59
Incident Severity (Avg. Incident Duration)	27.65	18.67	30.24	31.14	30.95	29.58
Precipitation (in)	0.015	0.024	0.000	0.000	0.000	0.000

(low values have green text, average values have black text, and high values have red text).

Descriptions for each cluster was developed from the values found in **Table** 2-3 and are shown in Table 2-4.

Table 2-4. PM Peak Period Cluster Descriptions

Cluster	Percentage of Year in Cluster	Description
1	13%	Low Demand, Rain (2 days, 0.73 inches total), Sundays
2	4%	Low Demand, Low TT, Low Incident Severity, Rain (1 day, 0.39 inches total)
3	32%	High Demand, Weekdays

Cluster	Percentage of Year in Cluster	Description
4	14%	Medium Demand, Saturdays
5	21%	High Demand, High EB TT, Weekdays
6	15%	Medium Demand, High EB TT, Fridays

A calendar was created that shows which days were assigned to which clusters for the PM peak period. The PM peak period calendar heat map is showing in Figure 2-8.

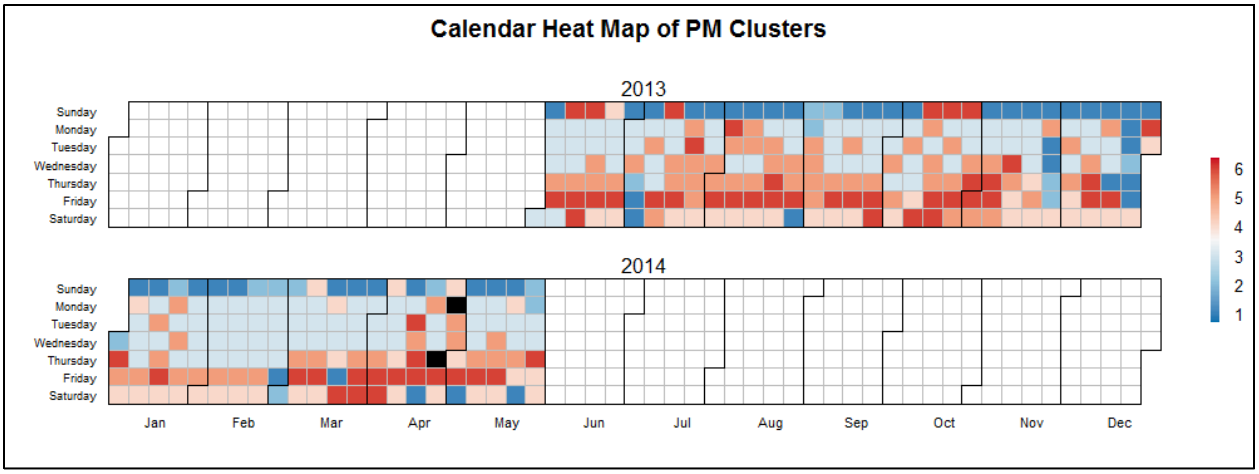

Figure 2-8. PM Peak Period Calendar Heat Map (days in black had no data)

Demand variations (type 1 data) reveal that for Pasadena Testbed area, at least for freeway segments, morning and afternoon peak periods see different patterns. While AM cluster analysis clearly identified high, medium or low demand levels, PM analysis presented much less demand variations across different clusters. The calendar heat maps plotted days in clusters of various demand levels; weekend days and holidays are mostly in clusters separate from weekdays. For weekdays, AM had three large clusters all with high demand (cluster 1, 2 & 9) that are much higher than other clusters (VMT more than double of the low demand clusters 4 or 6), but PM had only two clusters (3 & 5) with relatively higher demand but less contrast (30% higher than cluster 2).

Non-recurring events, particularly incidents, demonstrated a role in dividing data into separate clusters. For example, AM cluster 1 & 2 are different mainly from their incident occurrence frequency and severity. For medium level demand clusters (3, 5 & 7), a clear difference is also noticed for incident frequency and severity. Because the detailed precipitation data indicated only a few rainy days, these days were separated into different clusters.

System throughput by corridor travel times by directions also played a role in defining distinctive groups, for PM peak in particular. Note that for cluster 5 & 6, EB travel times are high even though their demand levels and incident frequency and severities are comparable.

2.2.2.1 Recommended Existing Operational Conditions

Based on the cluster analysis results, the team can recommend the following operational conditions for subsequent testbed analysis, all representing normal weekday traffic peaking:

#1 High demand, low to medium incident frequency/severity, medium corridor travel times. Normal traffic peaking operational condition corresponds to typical recurring traffic congestion in the testbed area.

These are supported by the typical AM and PM weekday clusters. The AM weekday clusters include #2 and #9, account for 158 days or 46% of the analysis horizon, while the PM weekday clusters include #3, account for 115 days or 32% of the analysis horizon.

#2 Medium to high demand, high incident frequency/severity, medium or low corridor travel times. This baseline condition is mainly featured by high incident frequency and/or severities. For AM peak clusters, this refers to cluster #1 and #3, accounting for 78 days or 22% of the analysis horizon.

#3 High demand, medium incident frequency/severity, high corridor travel times. This baseline represents a situation where the traffic suffered from high corridor travel times. For PM period, this condition refers to cluster #5 and #6, accounting for 132 days or 46% of the horizon.

2.2.3 Hypothetical Operational Conditions

In addition to the three operational conditions mentioned above, the Pasadena Testbed could also be used to model hypothetical conditions such as work zones or special events. The testbed lends itself uniquely for a special events scenario give the location of the Rose Bowl football stadium within the testbed boundaries. While the analysis plan currently does not include any hypothetical operational conditions, any such scenario could be added at a later time in consultation with the US DOT.

2.3 Existing Testbed Modeling Infrastructure

There are three levels of traffic modeling tools in use for the City of Pasadena area, macroscopic, mesoscopic/DTA and microscopic. These tools and their corresponding model data sets have been developed over several projects and are linked with each other through a number of interfaces. Figure 2-9 below illustrates the existing model architecture.

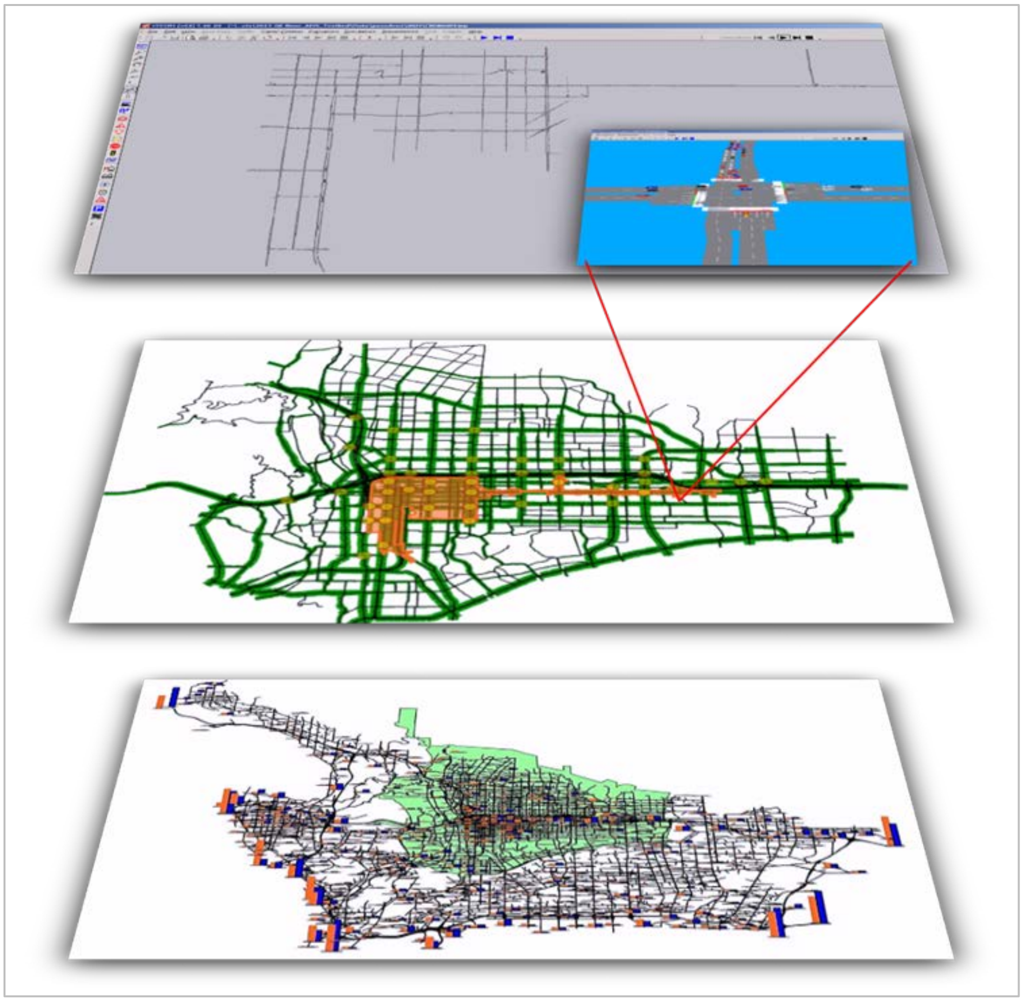

Figure 2-9: Traffic Model Architecture Linking the Three Levels of Analysis Tools [Source: HBA]

2.3.1 Macroscopic Traffic Model Tool: TransCAD

The City of Pasadena maintains a citywide travel demand forecast model which is implemented in TransCAD. It has been updated recently to Year 2013 land use and traffic conditions. It features 581 traffic assignment zones covering the City of Pasadena and surrounding areas.

2.3.2 Dynamic Traffic Assignment Model Tool: Visum DUE

The City of Pasadena also maintains a dynamic traffic assignment model which is implemented in Visum DUE. The DTA model has been updated to the same traffic conditions as the underlying travel demand model. However, the travel demand model and the DTA model have different assumptions and network coding conventions as they are implemented in different software platforms. Therefore, special care was taken to ensure model consistency with zoning and connector structures matching each other for potential demand data transfer. The following figure shows the model coding consistency.

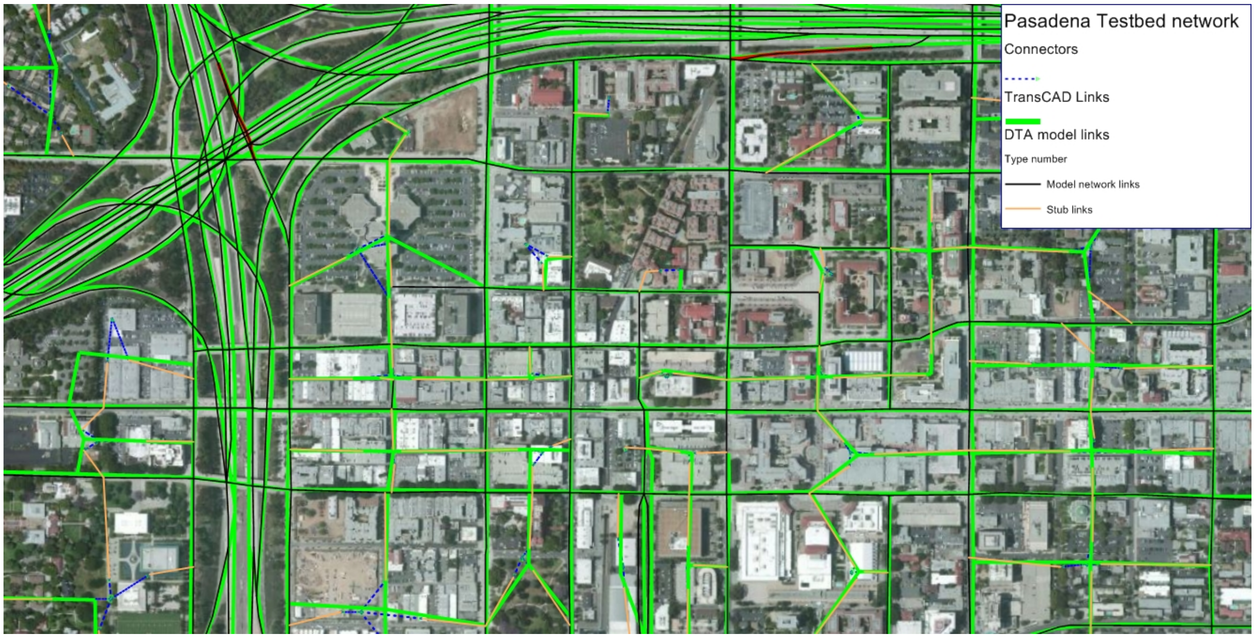

Figure 2-10: Traffic Analysis Zoning and Connector Consistency between Travel Demand Model and DTA Model Network [Source: HBA]

2.3.3 Microscopic Traffic Modeling Tool: Vissim

Vissim will be the testbed's microscopic traffic modeling tool. The DTA model is transferred to micro simulation in Vissim with all traffic demand and routing, network elements and traffic control. In the travel demand model and DTA model update in 2013, a considerable number of intersections were further updated to Year 2013 conditions. These updates were also included in the Pasadena Testbed network.

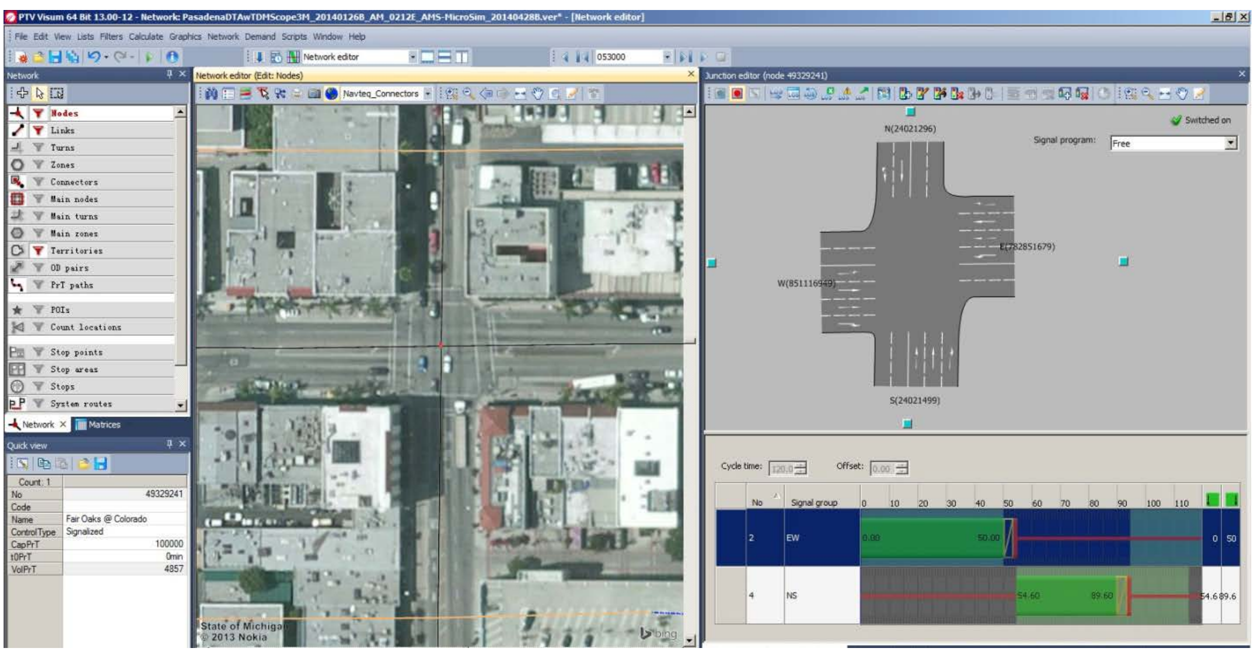

Figure 2-11: Example Detailed Junction Data Maintained in Pasadena Testbed Network (Fair Oaks Avenue and Colorado St) [Source: HBA]

In the testbed, the Vissim microscopic traffic model will serve as the *virtual reality* base for both testing ATDM/DMA strategies and application bundles and measuring their effectiveness. As such the microscopic simulation model must be capable of capturing a realistic picture of traffic operations with a sufficiently large geographic scope. The factors that were considered in the scoping of the geographic coverage include the following:

- Roadway facilities: as many ATDM and DMA strategies and bundles are targeted at specific facilities, the sub-network must include both freeway facilities and arterials.
- ITS infrastructure: the sub-network will need to include a substantial amount of ITS measures as for benchmarking the field operational conditions.
- Event modeling. The sub-network will cover traffic analysis zones for Rose Bowl Stadium and surrounding area for modeling the sports event;
- Data support: traffic count and traffic control data were collected and updated for a good number of intersections in the City for Year 2013 conditions. The sub-network will include as many such intersections as possible for both calibration and validation purposes.
- Corridor size – a number of sizeable corridors must be included for modeling both ATDM strategies and DMA bundles;

In consideration of the above, the geographic scope is determined as in the following figure. The sub-network covers an area of 11 square miles, around 190 signalized intersections and most of the freeway facilities in the testbed network.

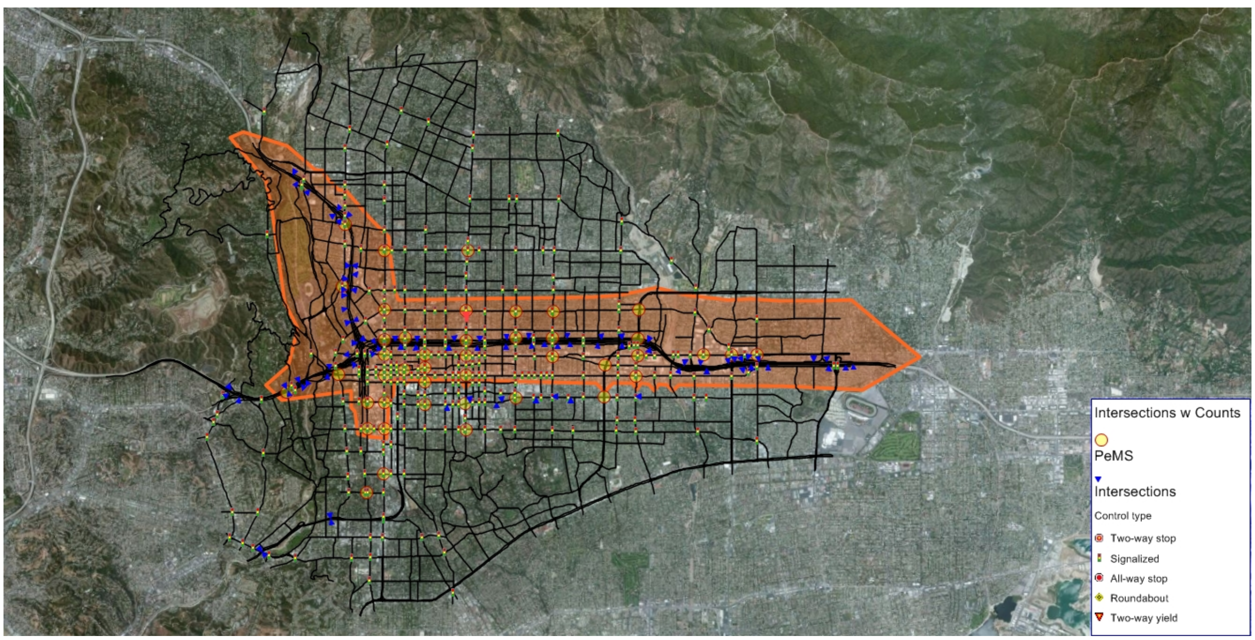

Figure 2-12: Geographic Scope for Microscopic Simulation Modeling [Source: HBA]

Chapter 3. Analysis Hypotheses

This section details the analysis hypotheses to address the different DMA and ATDM research questions by the Pasadena Testbed as shown in Table 3-1 and Table 3-2, respectively.

Table 3-1: DMA Research Questions and Corresponding Hypotheses.

ID	DMA Research Question	Preliminary Hypothesis
I	**Connected Vehicle Technology vs. Legacy Systems**	
1	Will DMA applications yield higher cost-effective gains in system efficiency and individual mobility, while reducing negative environmental impacts and safety risks, with wirelessly-connected vehicles, infrastructure, and travelers' mobile devices than with legacy systems? What is the marginal benefit if data from connected vehicle technology are augmented with data from legacy systems? What is the marginal benefit if data from legacy systems are augmented with data from connected vehicle technology?	Compared to legacy systems, INFLO DMA applications that make use of new forms of wirelessly-connected vehicle, infrastructure, and mobile device data will yield cost-effective gains in system efficiency and individual mobility, while reducing negative environmental impacts and safety risks.
II	**Synergies and Conflicts**	
2	Are the DMA applications and bundles more beneficial when implemented in isolation or in combination?	Not addressed.
3	What DMA applications, bundles, or combinations of bundles complement or conflict with each other?	Not addressed.
4	Where can shared costs or cost-effective combinations be identified?	Not addressed.
5	What are the tradeoffs between deployment costs and benefits for specific DMA bundles and combinations of bundles?	Not addressed.
III	**Operational Conditions, Modes, Facility Types with Most Benefit**	
6	What DMA bundles or combinations of bundles yield the most benefits for specific operational conditions?	Not addressed.
7	Under what operational conditions are specific bundles the most beneficial?	Not addressed.
8	Under what operational conditions do particular combinations of DMA bundles conflict with each other?	Not addressed.
9	Which DMA bundle or combinations of bundles will be most beneficial for certain modes and under what operational conditions?	Not addressed.

ID	DMA Research Question	Preliminary Hypothesis
10	Which DMA bundle or combinations of bundles will be most beneficial for certain facility types (freeway, transit, arterial) and under what operational conditions?	Not addressed.
11	Which DMA bundle or combinations of bundles will have the most benefits for individual facilities versus system-wide deployment versus region-wide deployment and under what operational conditions?	Not addressed.
12	Are the benefits or negative impacts from these bundles or combinations of bundles disproportionately distributed by facility, mode or other sub-element of the network under specific operational conditions?	Not addressed.
IV	**Messaging Protocols**	
13	Is SAE J2735 BSM Part 1 transmitted via Dedicated Short Range Communications (DSRC) every 10th of a second critical for the effectiveness of the DMA bundles? Will alternate messaging protocols, such as Probe Data Message (PDM), Basic Mobility Messages (BMM), etc., suffice? Given a set of specific messages, what combinations of bundles have the most benefit? Conversely, given a specific combination of bundles, what messages best support this combination?	Not addressed.
14	To what extent are messaging by pedestrians, pre-trip and en-route (e.g., transit riders) travelers critical to the impact of individual bundles or combinations of bundles? Does this criticality vary by operational condition?	Not addressed.
V	**Communications Technology**	
15	Will a nomadic device that is capable of communicating via both DSRC as well as cellular meet the needs of the DMA bundles? When is DSRC needed and when will cellular suffice?	Not addressed.
VI	**Communications Latency and Errors**	
16	What are the impacts of communication latency on benefits?	Not addressed.
17	How effective are the DMA bundles when there are errors or loss in communication?	Not addressed.
VII	**RSE/DSRC Footprint**	
18	What are the benefits of widespread deployment of DSRC-based RSEs compared with ubiquitous cellular coverage?	Not addressed.
19	Which technology or combination of technologies best supports the DMA bundles in terms of benefit-cost analysis?	Not addressed.
VIII	**Prediction and Active Management Investment**	

ID	DMA Research Question	Preliminary Hypothesis
20	Can new applications that yield transformative benefits be deployed without a commensurate investment in prediction and active management (reduced control latency)? How cost-effective are DMA bundles when coupled with prediction and active management?	DMA bundles (Queue Warning and Speed Harmonization) will be most cost-effective only when coupled with prediction and active management.
IX	**Deployment Readiness**	
21	To what extent are connected vehicle data beyond BSM Part 1 instrumental to realizing a near-term implementation of DMA applications? What specific vehicle data are the most critical, and under what operational conditions?	Not addressed.
22	At what levels of market penetration of connected vehicle technology do the DMA bundles (collectively or independently) become effective?	Not addressed.
23	What are the impacts of future deployments of the DMA bundles in the near, mid, and long term (varying market penetration, RSE deployment density, and other connected vehicle assumptions)?	Not addressed.
X	**Policy**	
24	In simulating different policy conditions (such as availability of PII versus no PII), what are the operational implications? For example, what are the incremental values to certain applications of knowing travel itineraries in real-time versus with some delay (i.e., 1-5 minutes)?	Not addressed.
25	To what level are applications dependent upon agency/entity participation to deliver optimal results? What happens to the effectiveness of an application if, for example, local agency participation varies within a regional deployment?	Not addressed.

Table 3-2: ATDM Research Questions and Corresponding Hypothesis

ID	Research Question Category	ATDM Research Question Category	Hypothesis
1	**Synergies and Conflicts**	1. Are ATDM strategies more beneficial when implemented in isolation or in combination (e.g., combinations of ATM, ADM, or APM strategies)?	Adaptive Ramp Metering, Dynamic Shoulder Lanes, Dynamic Speed Limits, Queue Warning and Dynamic Junction Control are more beneficial if deployed together. Dynamic Signal Control works best in combination with Dynamic Routing. The deployment of all strategies together is most beneficial.
		2. Which ATDM strategy or combinations of strategies yield the most benefits for specific operational conditions?	Dynamic Routing and Dynamic Traffic Signal Control yield the most benefits for incident conditions.
		3. What ATDM strategies or combinations of strategies conflict with each other?	There are no strategies that conflict with each other.
2	**Prediction Accuracy**	4. Which ATDM strategy or combination of strategies will benefit the most through increased prediction accuracy and under what operational conditions?	Strategies requiring the longest time to implement will benefit the most from increased prediction accuracy. Thus, Dynamic Traffic Signal Control, Dynamic Routing, and Dynamic Shoulder Lanes benefit the most from increased prediction accuracy, especially under incident conditions.
		5. Are all forms of prediction equally valuable, i.e., which attributes of prediction quality are critical (e.g., length of prediction horizon, prediction accuracy, prediction speed, and geographic area covered by prediction) for each ATDM strategy?	Prediction speed and accuracy are the most important quality attributes.
3	**Active Management or Latency**	6. Are the investments made to enable more active control cost-effective?	ATDM is most effective when time lag (latency) between detection/prediction of queues, shockwaves, bottlenecks, incidents, and breakdown conditions, and strategies

ID	Research Question Category	ATDM Research Question Category	Hypothesis
		7. Which ATDM strategy or combinations of strategies will be most benefited through reduced latency and under what operational conditions?	deployed by System Managers is minimized. Strategies requiring the longest time to implement will benefit the most from reduced prediction latency. Thus, Dynamic Traffic Signal Control, Dynamic Routing, and Dynamic Shoulder Lanes benefit the most from reduced latency, especially under incident conditions.
4	**Operational Conditions, Modes, Facility Types with Most Benefit**	8. Which ATDM strategy or combinations of strategies will be most beneficial for certain modes and under what operational conditions?	Not addressed.
		9. Which ATDM strategy or combinations of strategies will be most beneficial for certain facility types (freeway, transit, arterial) and under what operational conditions?	Most ATDM strategies only apply for freeways (e.g., Dynamic Shoulder Lanes) or arterials (e.g., Dynamic Traffic Signal Control). Dynamic Routing is the exception in that it applies to both facility types. It is assumed that it is equally beneficial to both of them, especially under incident conditions.
		10. Which ATDM strategy or combinations of strategies will have the most benefits for individual facilities versus system-wide deployment versus region-wide deployment and under what operational conditions?	Not addressed.
5	**Prediction, Latency, and Coverage Tradeoffs**	11. What is the tradeoff between improved prediction accuracy and reduced latency with existing communications for maximum benefits?	Increased prediction accuracy typically requires longer computing time and thus increases the latency between detection and active management. An optimum between both extremes exists.

ID	Research Question Category	ATDM Research Question Category	Hypothesis
		12. What is the tradeoff between prediction accuracy and geographic coverage of ATDM deployment for maximum benefits?	Similarly, a larger geographic coverage typically requires longer computing time and thus increases the latency between detection and active management. An optimum between both extremes exists.
		13. What will be the impact of increased prediction accuracy, more active management, and improved robust behavioral predictions on mobility, safety, and environmental benefits?	Increased prediction accuracy, more active management (reduced latency), and improved robust behavioral predictions result in significant mobility, safety, and environmental benefits.
		14. What is the tradeoff between coverage costs and benefits?	Increased prediction accuracy, larger geographic coverage and reduced latency all increase the prediction coverage cost, but also its benefits. An optimum between both extremes exists.
6	**Connected Vehicle Technology and Prediction**	15. Are there forms of prediction that can only be effective when coupled with new forms of data, such as connected vehicle data?	Prediction can be most effective only when coupled with data capture and communications technologies that can systematically capture motion and state of mobile entities, and enable active exchange of data with and between vehicles, travelers, roadside infrastructure, and system operators.
7	**Short-Term and Long-Term Behaviors**	16. Which ATDM strategy or combinations of strategies will have the most impact in influencing short-term behaviors versus long term behaviors and under what operational conditions?	Not addressed.

Chapter 4. Analysis Scenarios

This section describes the analysis scenarios to test the different DMA/ATDM applications. An analysis scenario is defined as "*a combination of operational conditions, applications (or combination of applications) and the alternatives to be used to test hypotheses*".

4.1 DMA and ATDM Applications/Strategies to be addressed by Testbed

Table 4-1 and Table 4-2 summarize the applications to be evaluated by the Pasadena Testbed

Table 4-1: The DMA Applications Evaluated/Addressed by the Pasadena Testbed

DMA Bundle	Application	Addressed?
EnableATIS	Multimodal Real-Time Traveler Information (ATIS)	No
EnableATIS	Smart Park-and-Ride (S-PARK)	No
EnableATIS	Universal Map Application (T-MAP)	No
EnableATIS	Real-Time Route-Specific Weather Information (WX-INFO)	No
INFLO	Queue Warning (Q-WARN)	**Yes**
INFLO	Dynamic Speed Harmonization (SPD-HARM)	**Yes**
INFLO	Cooperative Adaptive Cruise Control (CACC)	No
MMITSS	Intelligent Traffic Signal System (I-SIG)	No
MMITSS	Transit Signal Priority (TSP)	No
MMITSS	Mobile Accessible Pedestrian Signal System (PED-SIG)	No
MMITSS	Emergency Vehicle Preemption (PREEMPT)	No
MMITSS	Freight Signal Priority (FSP)	No
IDTO	Connection Protection (T-CONNECT)	No
IDTO	Dynamic Transit Operations (T-DISP)	No
IDTO	Dynamic Ridesharing (D-RIDE)	No
FRATIS	Freight Real-Time Traveler Information with Performance Monitoring (F-ATIS)	No
FRATIS	Drayage Optimization (DR-OPT)	No
FRATIS	Freight Dynamic Route Guidance (F-DRG)	No
R.E.S.C.U.M.E.	Emergency Communications and Evacuation (EVAC)	No
R.E.S.C.U.M.E.	Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)	No
R.E.S.C.U.M.E.	Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)	No

Table 4-2. ATDM Applications Evaluated/Addressed by the Pasadena Testbed

ATDM Strategy Type	Application	Addressed?
Active Traffic Management Strategies	Dynamic Shoulder Lanes	**Yes**
Active Traffic Management Strategies	Dynamic Lane Use Control	**Yes**
Active Traffic Management Strategies	Dynamic Speed Limits	**Yes**
Active Traffic Management Strategies	Queue Warning	**Yes**
Active Traffic Management Strategies	Adaptive Ramp Metering	**Yes**
Active Traffic Management Strategies	Dynamic Junction Control	**Yes**
Active Traffic Management Strategies	Dynamic Merge Control	No
Active Traffic Management Strategies	Dynamic Traffic Signal Control	**Yes**
Active Traffic Management Strategies	Transit Signal Priority	No
Active Traffic Management Strategies	Dynamic Lane Reversal Or Contraflow Lane Reversal	No
Active Demand Management Strategies	Dynamic Ridesharing	No
Active Demand Management Strategies	Dynamic Transit Capacity Assignment	No
Active Demand Management Strategies	On-demand Transit	No
Active Demand Management Strategies	Predictive Traveler Information	No
Active Demand Management Strategies	Dynamic Pricing	No
Active Demand Management Strategies	Dynamic Fare Reduction	No
Active Demand Management Strategies	Transfer Connection Protection	No
Active Demand Management Strategies	Dynamic HOV / Managed Lanes	No
Active Demand Management Strategies	Dynamic Routing	**Yes**
Active Parking Management Strategies	Dynamically Priced Parking	No
Active Parking Management Strategies	Dynamic Parking Reservation	No
Active Parking Management Strategies	Dynamic Wayfinding	No
Active Parking Management Strategies	Dynamic Overflow Transit Parking	No

4.2 Performance Measures

The performance measures quantify the achievement of DMA/ATDM program objectives in the following categories

- Safety – crash rates, crash probability
- Mobility – travel time and delay;
- Reliability – the relative predictability of the travelers travel time;
- Environmental Impacts – fuel consumption and emissions.

4.3 Analysis Phases

The Pasadena Testbed will focus on the analysis of the following ATM and ADM strategies:

- Dynamic Shoulder Lanes
- Dynamic Lane Use Control
- Dynamic Speed Limits
- Queue Warning
- Adaptive Ramp Metering
- Dynamic Junction Control
- Dynamic Traffic Signal Control
- Dynamic Routing

Furthermore, it will also analyze the following INFLO DMA applications:

- Queue Warning (Q-WARN)
- Dynamic Speed Harmonization (SPD-HARM)

The analysis is structured into the three phases as defined below.

4.3.1 Phase 1 – Operational Condition #1

Analysis phase 1 will address the following ATDM research questions by analyzing different ATDM strategy combinations under Operational Condition #1 and varying levels of prediction quality:

- #1 – Are ATDM strategies more beneficial when implemented in isolation or in combination (e.g., combinations of ATM, ADM, or APM strategies)?
- #3 – What ATDM strategies or combinations of strategies conflict with each other?
- #4 – Which ATDM strategy or combination of strategies will benefit the most through increased prediction accuracy and under what operational conditions?
- #5 – Are all forms of prediction equally valuable, i.e., which attributes of prediction quality are critical (e.g., length of prediction horizon, prediction accuracy, prediction speed, and geographic area covered by prediction) for each ATDM strategy?
- #6 – Are the investments made to enable more active control cost-effective?
- #7 – Which ATDM strategy or combinations of strategies will be most benefited through reduced latency and under what operational conditions?
- #9 – Which ATDM strategy or combinations of strategies will be most beneficial for certain facility types (freeway, transit, arterial) and under what operational conditions?

- #11 – What is the tradeoff between improved prediction accuracy and reduced latency with existing communications for maximum benefits?
- #12 – What is the tradeoff between prediction accuracy and geographic coverage of ATDM deployment for maximum benefits?
- #13 – What will be the impact of increased prediction accuracy, more active management, and improved robust behavioral predictions on mobility, safety, and environmental benefits?
- #14 – What is the tradeoff between coverage costs and benefits?

The project team has defined a total of eight scenarios based on the strategy combinations listed in Table 4-3 below. These combinations include the strategies by themselves (except for strategy pairs that are always deployed together), arterial and freeway focused combinations as well as an all-strategy combination.

Table 4-3. Phase 1 Scenario Definition

Phase 1 Scenarios	1	2	3	4	5	6	7	8
ATM - Adaptive Ramp Metering	X					X		X
ATM - Dynamic Traffic Signal Control		X					X	X
ATM - Dynamic Shoulder Lanes			X			X		X
ATM - Dynamic Speed Limits				X		X		X
ATM - Queue Warning				X		X		X
ATM - Dynamic Junction Control			X			X		X
ADM - Dynamic Routing					X		X	X

Each of the eight scenarios will be analyzed with the following 8 variations of key attributes:

Table 4-4. Phase 1 Prediction Accuracy Attribute Variation

Accuracy Attribute Variation	1	2	3	4	5	6	7	8
Prediction Time Horizon [min]	60	30	60	30	60	30	30	60
Prediction Latency [min]	5	10	10	5	10	5	5	5
Prediction Accuracy [% of actual]	90	50	50	90	90	50	50	50
Traveler Response Compliance [%]	50	20	50	50	50	50	20	20

Modeled driver response will be limited to short-term (e.g., 30-60 minutes) and the choice of in-route re-routing will only be available for scenarios including the strategy of Dynamic Routing. Pre-trip rerouting or trip postponement will be captured for all model scenarios.

4.3.2 Phase 2 – Operational Conditions #2 and #3

Phase 2 will include the analysis of the same eight scenarios (ATDM strategy combinations) used for Phase 1 analysis under Operational Conditions #2 and #3. These scenarios will be evaluated with three attribute combinations of prediction quality that will be selected from Phase 1 evaluations. The analyses of Phase 2 will be performed to answer the following ATDM research questions:

- #2 – Which ATDM strategy or combinations of strategies yield the most benefits for specific operational conditions?
- #4 – Which ATDM strategy or combination of strategies will benefit the most through increased prediction accuracy and under what operational conditions?
- #7 – Which ATDM strategy or combinations of strategies will be most benefited through reduced latency and under what operational conditions?
- #9 – Which ATDM strategy or combinations of strategies will be most beneficial for certain facility types (freeway, transit, arterial) and under what operational conditions?

4.3.3 Phase 3 – ATDM and DMA Combination

Analysis Phase 3 will evaluate the benefits of combining connected vehicle based DMA applications with ATDM strategies. The analysis will address the following ATDM research question:

- #15 – Are there forms of prediction that can only be effective when coupled with new forms of data, such as connected vehicle data?

Furthermore, Phase 3 analyses will also address the following DMA research questions:

- #1 – Will DMA applications yield higher cost-effective gains in system efficiency and individual mobility, while reducing negative environmental impacts and safety risks, with wirelessly-connected vehicles, infrastructure, and travelers' mobile devices than with legacy systems? What is the marginal benefit if data from connected vehicle technology are augmented with data from legacy systems? What is the marginal benefit if data from legacy systems are augmented with data from connected vehicle technology?
- #20 – Can new applications that yield transformative benefits be deployed without a commensurate investment in prediction and active management (reduced control latency)? How cost-effective are DMA bundles when coupled with prediction and active management?

The analyzed scenario will use the best performing ATDM strategy combination identified during the previous analysis phases and add the two INFLO DMA strategies Queue Warning (Q-WARN) and Dynamic Speed Harmonization (SPD-HARM). The analysis will then evaluate this scenario under Operational Condition #1 with the following five variations of key attributes:

Table 4-5. Phase 3 DMA Attribute Variation

DMA Attribute Variation	1	2	3	4	5
Communication Latency [sec]	10	10	10	30	60
Market Penetration [% equipped]	10	20	50	20	50

4.1 Analysis Scenarios

Analysis Phase 1 includes eight scenarios with the focus on the evaluation of each ATDM strategy individually as well as in different combinations. Each scenario is evaluated under Operational Condition #1 and 8 variations of prediction quality attributes. Figure 4-1 below depicts each of the scenarios to be evaluated as part of Phase 1 requiring a total of 640 model runs.

	Scenario Components, Atributes, and Assumptions	Research Question IDs	Phase 1 Scenarios 1.01	1.02	1.03	1.04	1.05	1.06	1.07	1.08
	Overall Research Results Supported by each Scenario									
0	Number of DMA Questions Addressed									
11	Number of ATDM Questions Addressed		11	11	11	11	11	11	11	11
640	Approximant Number of Model Runs		80	80	80	80	80	80	80	80
	Basic Scenario Setting (Combination of Operational Condition and Applications)									
	Operational Conditions (select one per scenario)									
	Operational Condition 1		x	x	x	x	x	x	x	x
	Operational Condition 2									
	Operational Condition 3									
	Active Transportation and Demand Management (ATDM)									
ATM	Adaptive Ramp Metering	ATDM: 1, 3, 4, 5, 6, 7, 9, 11, 12, 13, 14	x					x		x
	Dynamic Traffic Signal Control			x					x	x
	Dynamic Shoulder Lanes				x			x		x
	Dynamic Speed Limits					x		x		x
	Queue Warning					x		x		x
	Dynamic Junction Control				x		x	x		x
ADM	Dynamic Routing								x	x
	Parameters to be varied within a Scenario to answer specific DMA/ATDM research Questions (The Specific Values and Combinations of Parameters will Emerge as the Analysis Proceeds)									
	Estimated Total Number of Attribute Variations		8	8	8	8	8	8	8	8
	Prediction Attributes									
	Time Horizon Sensitivity (e.g., 20, 30, ... minutes)	ATDM: 5	x	x	x	x	x	x	x	x
	Prediction Latency Sensitivity (e.g., 5, 10, ... minutes)	ATDM: 7, 11	x	x	x	x	x	x	x	x
	Prediction Accuracy Sensitivity (e.g., 80% of accuracy)	ATDM: 4, 5, 11, 12, 13	x	x	x	x	x	x	x	x
	Coverage Extent Variation (e.g., corridor only, regional)	ATDM: 9, 12	x	x	x	x	x	x	x	x
	Traveler Response (e.g., 50% comply)		x	x	x	x	x	x	x	x

Figure 4-1: Phase 1 Scenario Combination Chart [Source: HBA]

Phase 2 will further analyze the most promising three attribute combinations for each scenario analyzed in Phase 1. This additional analysis will focus on the scenarios' performance under the two additional operational conditions introduced in Section 2.2. Figure 4-2 below depicts each of the scenarios to be evaluated as part of Phase 2 requiring a total of 480 model runs.

	Scenario Components, Atributes, and Assumptions	Research Question IDs	Phase 2 Scenarios 2.01	2.02	2.03	2.04	2.05	2.06	2.07	2.08	2.09	2.10	2.11	2.12	2.13	2.14	2.15	2.16
	Overall Research Results Supported by each Scenario																	
0	Number of DMA Questions Addressed																	
11	Number of ATDM Questions Addressed		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
640	Approximant Number of Model Runs		30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
	Basic Scenario Setting (Combination of Operational Condition and Applications)																	
	Operational Conditions (select one per scenario)																	
	Operational Condition 1																	
	Operational Condition 2		x	x	x	x	x	x	x	x								
	Operational Condition 3										x	x	x	x	x	x	x	x
	Active Transportation and Demand Management (ATDM)																	
ATM	Adaptive Ramp Metering	ATDM: 2, 4, 7, 9	x					x		x	x					x		x
	Dynamic Traffic Signal Control			x					x	x		x					x	x
	Dynamic Shoulder Lanes				x			x		x			x			x		x
	Dynamic Speed Limits					x		x		x				x		x		x
	Queue Warning					x		x		x				x		x		x
	Dynamic Junction Control				x			x		x			x			x		x
ADM	Dynamic Routing						x		x	x					x		x	x
	Parameters to be varied within a Scenario to answer specific DMA/ATDM research Questions (The Specific Values and Combinations of Parameters will Emerge as the Analysis Proceeds)																	
	Estimated Total Number of Attribute Variations		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	Prediction Attributes																	
	Time Horizon Sensitivity (e.g., 20, 30, ... minutes)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Prediction Latency Sensitivity (e.g., 5, 10, ... minutes)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Prediction Accuracy Sensitivity (e.g., 80% of accuracy)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Coverage Extent Variation (e.g., corridor only, regional)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Traveler Response (e.g., 50% comply)		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Figure 4-2: Phase 2 Scenario Combination Chart [Source: HBA]

Phase 3 of the testbed analysis will focus on the evaluation of the combination of ATDM strategies with DMA applications. The analyzed scenario will add two INFLO DMA applications to the scenario that resulted in the best performance during the previous analysis phases. The resulting scenario will then be analyzed under up to 5 attribute permutations. Figure 4-3 below depicts each of the scenarios to be evaluated as part of Phase 3 requiring a total of 50 model runs.

	Scenario Components, Atributes, and Assumptions	Research Question IDs	Phase 3 Scenarios 3.01
Overall Research Results Supported by each Scenario			
0	Number of DMA Questions Addressed		2
11	Number of ATDM Questions Addressed		1
640	Approximant Number of Model Runs		50
Basic Scenario Setting (Combination of Operational Condition and Applications)			
Operational Conditions (select one per scenario)			
	Operational Condition 1		X
	Operational Condition 2		
	Operational Condition 3		
Dynamic Mobility Applications (DMA)			
EnableATIS	Multimodal Real-Time Traveler Information (ATIS)	DMA: 1, 20	
INFLO	Queue Warning (Q-WARN)		X
	Dynamic Speed Harmonization (SPD-HARM)		X
Active Transportation and Demand Management (ATDM)			
ATM	Adaptive Ramp Metering	ATDM: 15	X
	Dynamic Traffic Signal Control		X
	Dynamic Shoulder Lanes		X
	Dynamic Speed Limits		X
	Queue Warning		X
	Dynamic Junction Control		X
ADM	Dynamic Routing		X
Parameters to be varied within a Scenario to answer specific DMA/ATDM research Questions (The Specific Values and Combinations of Parameters will Emerge as the Analysis Proceeds)			
Estimated Total Number of Attribute Variations			5
Communications Attribute		DMA: 1, 20 ATDM: 15	
	Time Horizon Sensitivity (e.g., 20, 30, ... minutes)		X
	Prediction Latency Sensitivity (e.g., 5, 10, ... minutes)		X
Communications Technology and Policies			
	DSRC		X
Active Management with and without Connected Vehicles			
	Connected Vehicles (with/without)		X
	Prediction Latency Sensitivity (e.g., 5, 10, ... minutes)		X

Figure 4-3: Phase 3 Scenario Combination Chart [Source: HBA]

Chapter 5. Data Needs and Availability

This section illustrates the data needs for the Pasadena Testbed as well as data availability and gaps. In addition, this section will provide a detailed plan for data collection and data mining to fill the identified gaps. If some of the gaps cannot be filled, the team will develop a plan to overcome issues pertaining to lack of data in order to ensure that the testbed can be successfully built.

5.1 Data Needs

For the Pasadena testbed, two major categories of data are needed to support analysis, modeling, and simulation of ATDM/DMA strategies and application bundles.

The first data category is basic traffic modeling input data. Input data include both sides of transportation system supply and travel demand, as well as traveler behavior and model calibration and validation data. Transportation system supply data are the following:

- Network topology and junction geometric layout;
- Traffic control and management, including lane restrictions, junction control types (e.g., yield signs, all-way or two-way stops and intersection signals and ramp meters), control plans, and speed limits;

Travel demand input data include:

- User classes such as SOV, HOV, or trucks.
- Traffic demand usually in the form of time-varying origin-destination matrices, or trip chain lists;

Travel behavior data:

- Driving behavior such as car following, lane changing and lateral movement behavior, different to various modeling tools;
- Travel cost differentiation and perception (e.g., value of time)
- Route choice and departure time choice resulting from above travel cost differentiations as well as provisions of traveler information

Calibration and validation data are usually aggregated traffic operational performance data. For example, traffic counts, corridor or link travel times in 5-min/15-min/hourly increments and queue lengths will be used as calibration and validation target data.

The second data category is relevant to build baseline models for all scenarios of different operational conditions. Except for network and control data, all other basic model input data will need a separate dataset for each additional operational conditions (planned events, major accident, and work zones). To properly model different operational conditions, the following data will be needed:

Work zone and incident data:

- Traffic impact information, including start/end date/time, impacted road segments, lane closures

Planned event data:

- Event time and dates.

Weather data:

- Weather station and weather data relevant to traffic operations, including precipitation level, temperature, wind speed and sky conditions.

In the AMS testbed development plan, clustering analysis has been proposed to develop typical operational conditions. Needed data for cluster analysis will include all relevant traffic data for a longer observation, for example, at least two months. These data will include calibration and validation data, work zone and incidents, and weather data.

5.2 Available Data

The Pasadena Testbed is primarily focused on ATDM and DMA strategies and applications. As such, the need for operational traffic data will be extensive. The following Table 5-1 lists relevant data in the development context of both, baseline and operational scenarios.

Table 5-1: Relevant Data for Pasadena Testbed

Data category	Relevance to scenario development	Relevance to ATDM/DMA	Current availability
Demographic data, land use data, travel behavior data	Already applied in one baseline development; not relevant to other baseline refinement	Not relevant	Available; existing in City and regional (LA) travel demand model dataset
Traffic count – synthetic key intersection turn counts and link counts	Used as calibration target for one baseline (normal day) condition development	Validation of baseline performance (signalized junctions)	Available, included in current Testbed DTA model dataset
Traffic count – PeMS archive	• Bottleneck location • Traffic flow data in various granularity (e.g., 5-min, 1 hour, daily) • Calibration target data	• Freeway capacity and performance	• Available, included in Pasadena data environment (DTFH6111C00038) and any period since 2000 • Geo-coded in Testbed network
Traffic count – arterial ATMS archive	• Calibration target data • Trend analysis and pattern clustering	• Arterial link capacity and performance	• Available, included in Pasadena data environment (DTFH6111C00038)
Link travel speed by time of day	• NAVTEQ Traffic Pattern data, link speeds in 15-minute increment for 24 hours of a day for each typical day of week, for all major links (freeway or	• Network wide validation of baseline condition performance	• Available, included in Testbed DTA model updates

Data category	Relevance to scenario development	Relevance to ATDM/DMA	Current availability
	arterial) on Testbed network • Used in model validation of (normal day) baseline model development		
Corridor travel time	• Available for 19 major corridors in Testbed network • Calibration and validation target for Testbed DTA model development	• Validation of baseline condition performance for concerned arterial corridors (signalized intersections)	• Available, included in Testbed DTA model updates, and coded in the Testbed network
Traffic control – control types	• Freeway junction control and arterial intersection control types • Used in (normal day) baseline condition DTA model development	• Validation of baseline condition performance for all arterials in Testbed network	• Available, included in Testbed DTA model updates, and coded in the Testbed network
Traffic control – urban signals	• Phasing diagrams and timing plans for (normal day) baseline conditions, and holiday/event day conditions • Applicable to planned event day baseline controls	• Validation of baseline condition performance for all relevant intersections	• Available archive in data environment • Coded in Testbed network
Traffic control – ramp meters	• Time-of-day metering rates used in data environment development	• Validation of baseline conditions at ramps • Baseline benchmarking for adaptive ramp metering	• Available in data environment and Testbed network
Video surveillance data	• Archived in data environment • Applicable for validation of baseline conditions	• Validation of baseline conditions for equipped freeway sections	• Available in data environment for visual checking
Incident data	• Archived in data environment	• Validation of baseline conditions for relevant locations	• Available in data environment for programmatic query

Data category	Relevance to scenario development	Relevance to ATDM/DMA	Current availability
	• Available for query and re-alignment to Testbed network		
Work zone	• Archived in data environment (milepost based reference system) • Available for query and re-alignment to Testbed network	• Validation of baseline conditions for relevant locations	• Available in data environment for programmatic query • Milepost based reference system established in data environment and transferable to Testbed environment
Categorical data	• Planned event calendar available from sports event website • Calibration support data for planned event baseline condition	• Validation for baseline conditions of relevant streets and freeway locations	• Available in online data sources by search
Weather data	• Cluster analysis to develop support data for operational conditions	• Validation for all baseline conditions	• Available in online data sources (e.g., NOAA) and archived testbed data environment

5.3 Preliminary Data Collection Plan to Address Gaps

The available data are sufficient for baseline model development. However, the primary data and information gap lies in the lack of support data for user behavior changes to ATDM strategies and operational conditions. As a critical support data for the evaluation of impacts from ATDM strategies, this support data set is not available for the Pasadena Testbed area as currently no ATDM strategies have been deployed at this time. The primary data collection approach will be through literature research of existing project reports and research papers, to develop reasonable estimate transferrable to the Pasadena Testbed context. These will include:

- Users compliance rate to dynamic routing guidance;
- Speed and capacity changes produced by ATM strategies.

Chapter 6. Key Assumptions and Limitations

The Pasadena Testbed model development for baseline conditions has a number of assumptions related to both data collection and model development. These include:

- Existing dynamic traffic assignment (DTA) models have been calibrated and validated against Year 2013 traffic data. This model and dataset will be the initial set up for modeling normal peaking operational conditions.
- DTA model for departure time choice and time of value will follow the default modeling settings, i.e., early and late arrival time penalties will be counted as half of in-route travel times.

The DMA application bundles will only be evaluated after they have been developed and tested first in other testbeds. These will include:

- Driver behavior under INFLO application bundle such as Queue Warning (Q-WARN) and Speed Harmonization (SPD-HARM)

Assumptions made to model travel behavior under ATDM strategies will include the following:

- All drivers will follow the posted speed limit when encountering dynamic speed limit signs.

Communications system in the Pasadena testbed has both high and low fidelity models that adapt to different ATDM/DMA strategies and application bundles. DMA applications require high fidelity and frequency communications between microsimulator (Vissim) and DMA application emulators; therefore the communication model will have 1/10 second updating frequency. On the other hand, communication between ATDM strategy emulation and micro simulator will be at 1 second frequency.

Chapter 7. Modeling Approach

This section details the modeling approach to test the hypothesis, and generate performance measure statistics to compare alternatives and thus evaluate them. This section describes the analysis framework, application-specific algorithms (existing ones and ones to be built), the tools needed for this analysis, and analysis phases or multi-tier approach to be used to conduct the overall modeling effort.

7.1 Analysis Framework

The Pasadena Testbed will be developed based on the following modularized structure. Note that each block represents one module, and the arrows denote the data and information flow between these modules. The system elements are organized in a modularized structure for easy updates and upgrades.

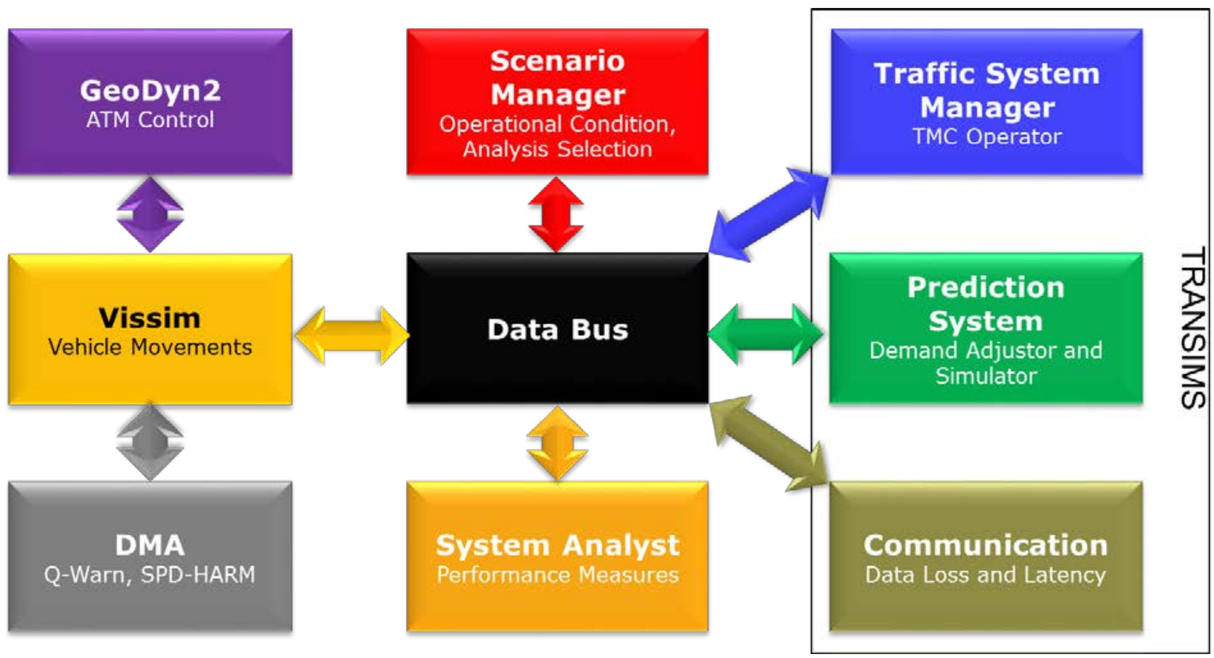

Figure 7-1: Pasadena Testbed Modularized Framework [Source: HBA]

The next section will introduce each module and required analysis, modeling and simulation (AMS) capabilities.

7.2 Application-Specific Algorithm and Needed Tools

7.2.1 Microscopic Traffic Simulator: PTV Vissim

PTV Vissim will be the microscopic traffic simulation tool used to model virtual real world conditions within the Pasadena Testbed. Hand-in-hand with Vissim, the testbed team will also utilize its sister product PTV

Visum for DTA modeling and overall model development and management. This multi-resolution modeling toolset represents the transportation network vehicular flow simulator and the travel demand simulator in the generalized AMS testbed framework.

As briefly introduced in the previous sections, a number of important aspects of Vissim capabilities are of particular use in developing Pasadena Testbed.

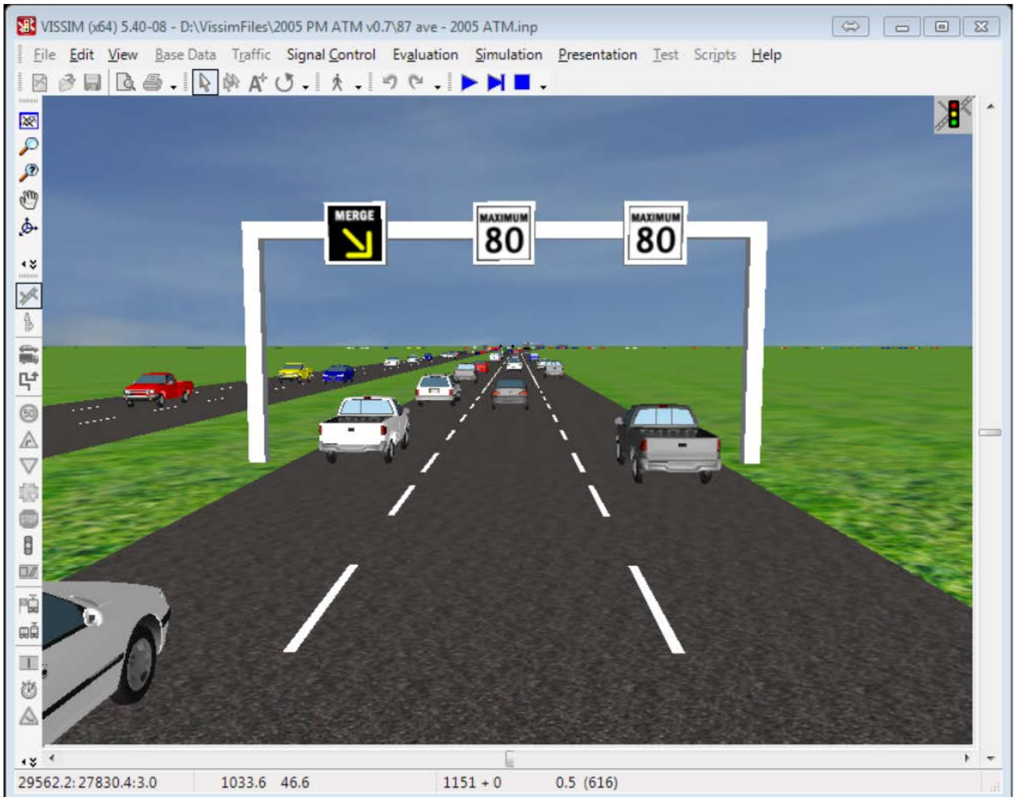

Figure 7-2: Example Vissim 3D Visualization and Animation of ATM Strategies [Source: HBA]

- Multi-resolution modeling and model development. This is accomplished by two modules in Visum/ Vissim interface: 1) the compatibility between the dynamic traffic assignment model (Visum) and corresponding path flow (OD and path) transfer into Vissim; 2) detailed geometric and intersection control data transferrable into corresponding modeling elements in Vissim, for example, speed limits and signal timing plans.
- Traffic demand and routing fixed from the DTA model in Visum for the whole testbed network. As a result of above multi-resolution modeling approach, Vissim baseline models will take the traffic demand and routing directly from Visum DTA model, instead of the lengthy DTA convergence process in Vissim microscopic simulation.
- 3D/2D visualization. Realistic 2D and 3D animation capabilities in Vissim are fully utilized for communication of the strategies and their impacts to a wide range of audiences. This is especially useful for active traffic management (ATM) strategies and other applications where few field deployments could lend to the testbed audience direct experiences of how the target ATM strategies would work in the field.

- Vissim's RBC signal control emulator will be customized to permit the change of pre-computed signal timing patterns. This will allow the testbed to analyze the ATDM strategy of Dynamic Traffic Signal Control where active signal timing patterns are selected by the System Manager based on their predicted performance as determined by the Prediction System.

7.2.2 Active Traffic Management (ATM) Control

ATM control by GeoDyn2 represents the freeway management decision support system (ATDM strategies) in the generalized AMS testbed framework.

The tool and included suite of algorithms for modeling ATM strategies will be GeoDyn2, which are field deployed in over 70 systems in Europe. ATM control strategies for Pasadena Testbed will include dynamic shoulder lanes, dynamic speed limits, queue warning and adaptive ramp metering. GeoDyn2 has been successfully migrated to a testbed environment with Vissim (http://www.hbamerica.com/index.php?id=86). The following figure is a screen capture of GeoDyn2 testbed demo.

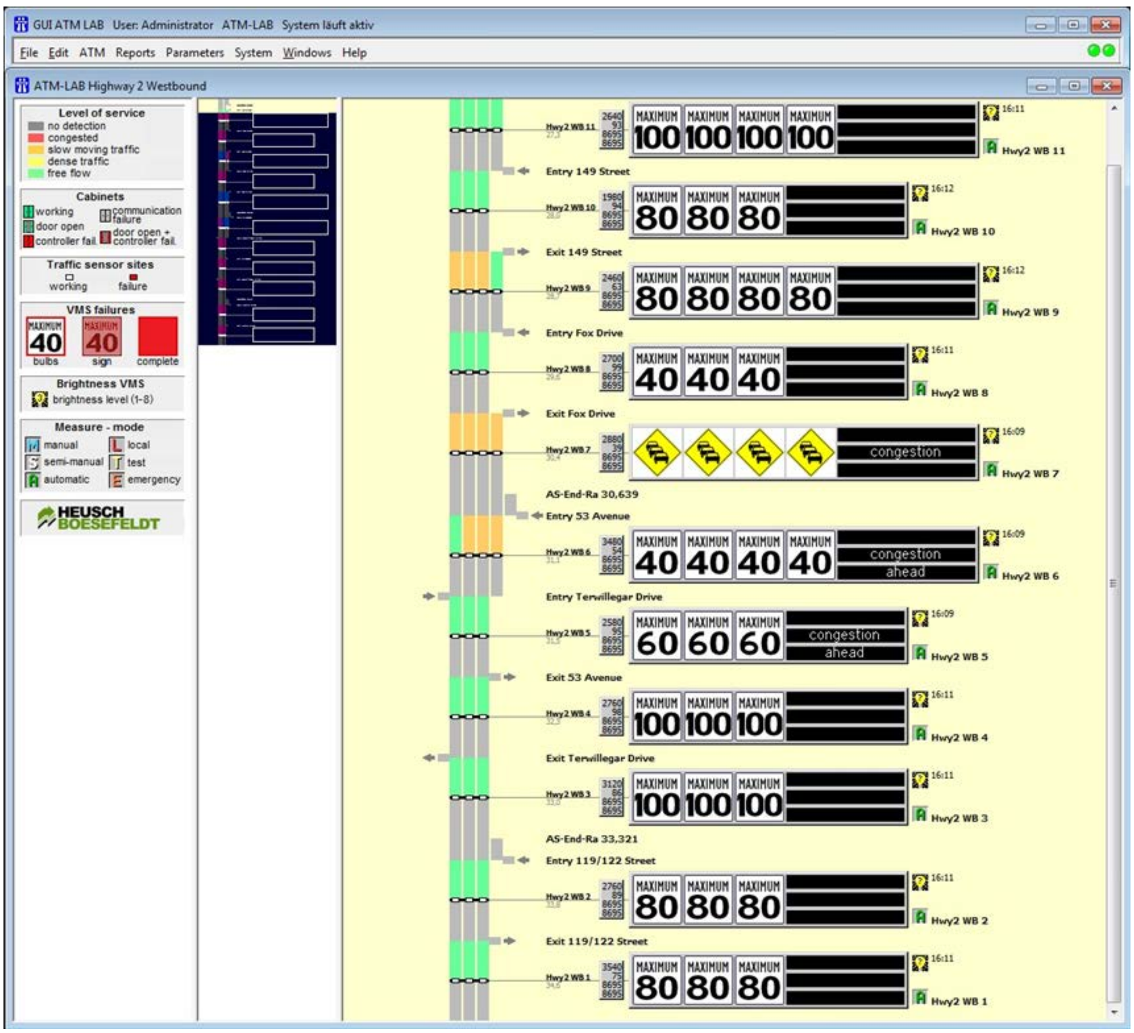

Figure 7-3: Demo GeoDyn2 Application in a Virtual ATM Lab Setup [Source: HBA]

7.2.3 Prediction System

Prediction in the Pasadena Testbed includes two parts, a Demand Adjustor and a Simulator, both implemented in TRANSIMS. The Demand Adjustor will be based on the TRANSIMS router and while the Simulator will use TRANSIMS' mesoscopic simulator. During a testbed run, the router will use the current traffic state combined with assumed prediction scenario to predict OD path flows. These OD path flows, alongside other expected operational condition changes and employed ATDM strategies, will be simulated by the Microsimulator Vissim to provide the predicted network performance metrics.

7.2.4 Traffic System Manager and Communication Simulator

The Traffic System Manager module represents the system manager and their decision emulator while the Communication Simulator in Pasadena Testbed represents the wireless communication emulator in the generalized AMS testbed framework. Both tools will be implemented within TRANSIMS.

The System Manager emulates the decision processes of a typical traffic management center operator. These decisions will include:

- Select the strategic ATDM strategy set to be evaluated by the prediction system.
- Determine and initiate the implementation of the most appropriate ATDM strategy set based on predictive evaluation results.
- Broadcast of incident messages processed by the Communication Simulator.

The Communication Simulator will primarily provide the representation of data loss and latency, two key aspects that would affect the ATDM/DMA strategy and application implementation.

The Prediction System and the Traffic System Manager/Communication Simulator are closely linked with both systems forming one inner data loop, as depicted in blue in Figure 7-4. The featured prediction loop including TRANSIMS router and simulator will evaluate multiple instances in parallel; each instance representing one ATDM strategy set from the System Manager. The goal of this loop is to identify the best ATDM strategy set for implementation in Vissim (virtual real world).

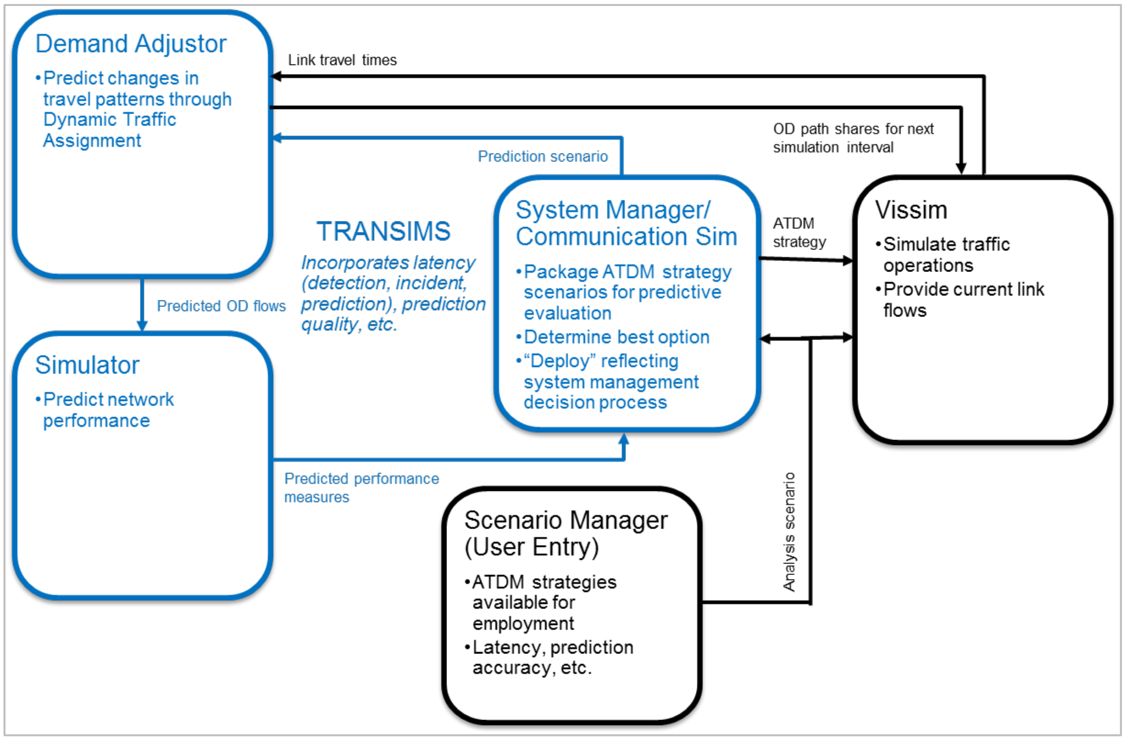

Figure 7-4: Pasadena Testbed Prediction System Architecture [Source: HBA]

7.2.5 Scenario Manager

The Scenario Manager is the Pasadena Testbed run-time control module. The Scenario Manager is provided with a graphical user interface for easy operation control of the testbed. Each testbed run is initiated by the Scenario Manager. The specific evaluation parameters, including tested ATDM strategies, latency, prediction quality, will be broadcasted to all subsystems.

The functions of Scenario Manager include:

- Selection of tactical ATDM
- Selection of available strategic ATDM strategies and DMA applications
- Selection of prediction and communication test parameters
- Start/end testbed sessions

The Scenario Manager will be custom developed for the Pasadena Testbed.

7.2.6 System Analyst

System Analyst represents the report tool for performance measures within the generalized AMS testbed framework. The Pasadena Testbed System Analyst will be responsible for the following aspects of performance measures:

- Definitions
- Aggregation
- Reporting and presentation/visualization

The System Analyst will be custom developed for the Pasadena Testbed.

7.3 Pasadena Testbed Analysis Process

In consideration of the complexity of these systems when deployed in the field, the Pasadena Testbed is designed to emulate the various components in a modularized architecture. Consequently, it relies heavily on data and information flow management. The following architecture workflow chart shows the overall analysis process within Pasadena Testbed.

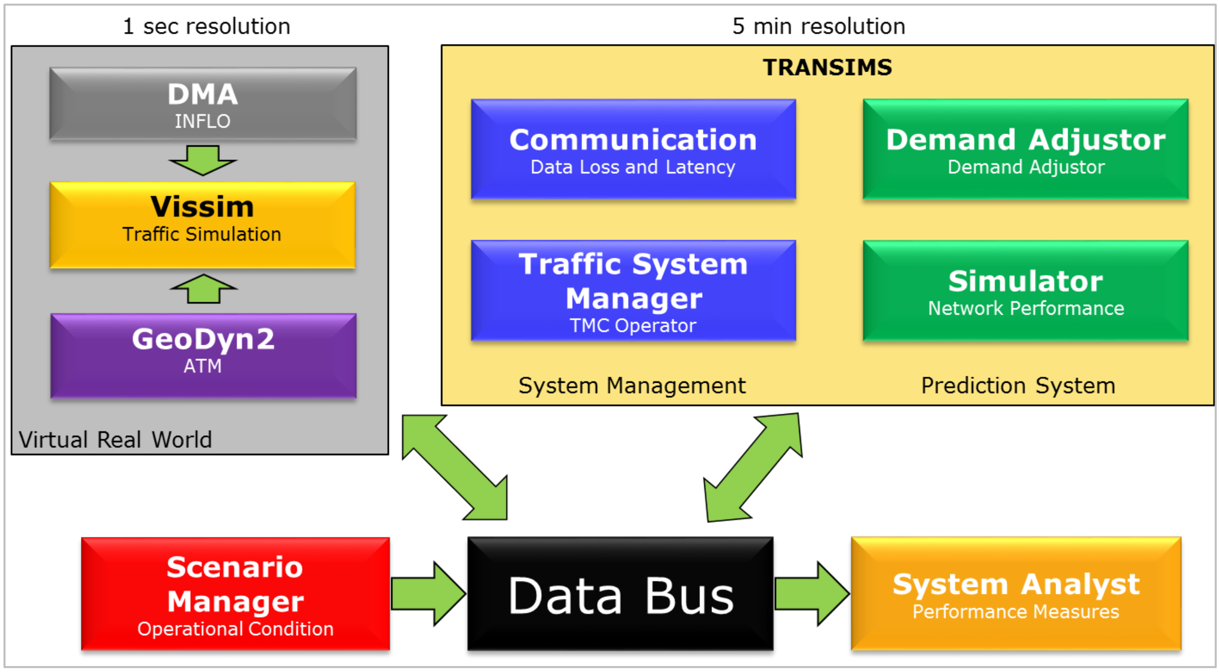

Figure 7-5: Pasadena Testbed Analysis Process and Data/Information Flow [Source: HBA]

The interaction and data/information flow is briefly introduced in the following section. As clearly indicated in the flowchart, the Data Bus serves a central role in linking all components together with proper data flows.

7.3.1 Data Flow – Vissim

The data flow between Vissim and the Data Bus is illustrated in the following chart.

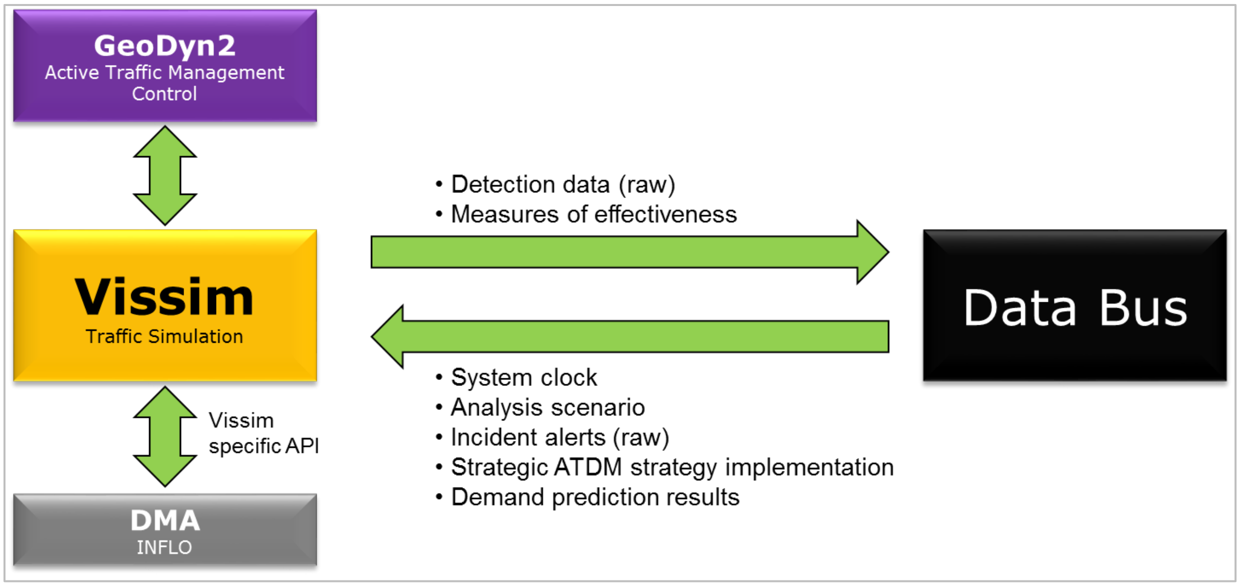

Figure 7-6: Pasadena Testbed Data Flow: Vissim to/from Data Bus [Source: HBA]

7.3.2 Data Flow – TRANSIMS

The data flow between TRANSIMS and the Data Bus is illustrated in the following chart.

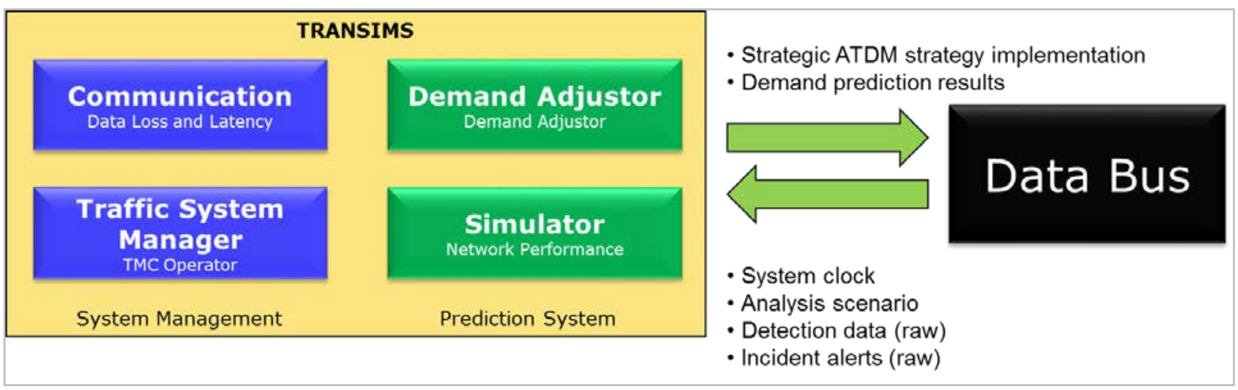

Figure 7-7: Pasadena Testbed Data Flow: TRANSIMS to/from Data Bus [Source: HBA]

7.3.3 Data Flow – Scenario Manager

The data flow between Scenario Manager and the Data Bus is illustrated in the following chart.

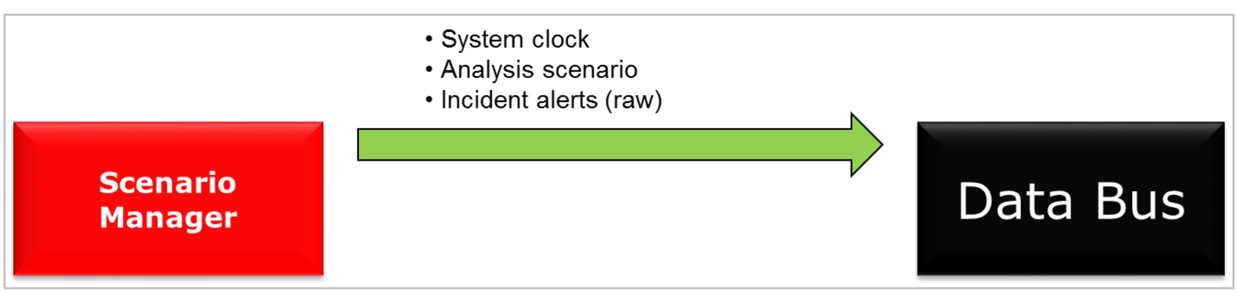

Figure 7-8: Pasadena Testbed Data Flow: Scenario Manager to/from Data Bus [Source: HBA]

7.3.4 Data Flow – System Analyst

The data flow between System Analyst and the Data Bus is illustrated in the following chart.

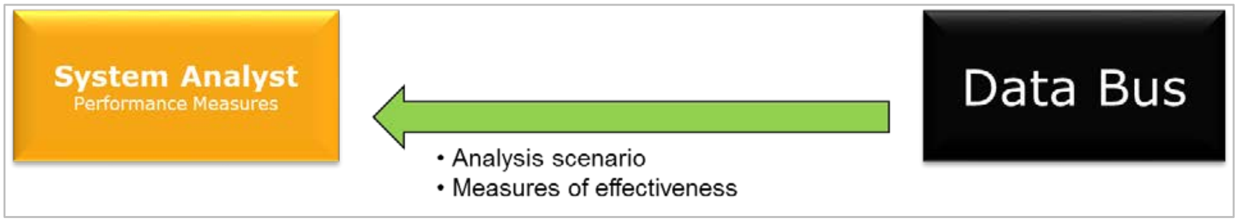

Figure 7-9: Pasadena Testbed data flow: System Analyst to Data Bus [Source: HBA]

The overall data flow is illustrated in the following data flow matrix. Note that the matrix depicts data flow between the individual testbed components (green cells) as well as data flow to and from the Data Bus (magenta cells).

Pasadena Testbed Data Flow Matrix	Data Bus	Vissim - Traffic Simulation and ATM Control	TRANSIMS - System Management and Prediction System	Scenario Manager	System Analyst - Performance Measures
Data Bus		System clock Analysis scenario Incident alerts (raw) Strategic ATDM strategy implementation Demand prediction results	System clock Analysis scenario Detection data (raw) Incident alerts (raw)		Analysis scenario Measures of effectiveness
Vissim - Traffic Simulation and ATM Control	Detection data (raw) Measures of effectiveness		**Detection data (raw)**		**Measures of effectiveness**
TRANSIMS - System Management and Prediction System	Strategic ATDM strategy implementation Demand prediction results	**Strategic ATDM strategy implementation** **Demand prediction results**			
Scenario Manager	System clock Analysis scenario Incident alerts (raw)	**System clock** **Analysis scenario** **Incident alerts (raw)**	**System clock** **Analysis scenario** **Incident alerts (raw)**		**Analysis scenario**
System Analyst - Performance Measures					

Figure 7-10: Pasadena Testbed Overall Data and Information Flow Matrix [Source: HBA]

7.4 Risks

Possible technical difficulties in developing the Pasadena Testbed may include the following:

1. Computation performance of individual system components as well as the testbed as a whole. It is expected that the system management and prediction system can complete their computation within a 5 minute real-time window. Any additional time requirements delay the progress of the overall testbed and thus increase the total computing time required for individual testbed simulation runs.

7.5 AMS Requirements

This section enumerates the AMS requirements which every testbed attempts to satisfy. Table 7-1 shows the list of AMS requirements and the testbed capability when it is fully developed classified into three levels:

1= The AMS requirement is **addressed** by the testbed,

2= The AMS requirement is **partially addressed** by the testbed or

3= The AMS requirement is **not addressed** by the testbed.

Table 7-1: The AMS Requirements and the Capability of the Pasadena Testbed

SNo	ID	Requirement	Pasadena Testbed
1	SU-1	The AMS Testbed shall emulate and track each Traveler's time-referenced geographic location (position) as he/she plans, executes, and completes a trip within the transportation system.	3
2	SU-2	The AMS Testbed shall emulate and track each Travelers' time-referenced state and transition among various potential states (pre-trip, pedestrian, non-motorized traveler, light vehicle driver, light vehicle passenger, and transit rider) as they plan, exec	2
3	SU-3	The AMS Testbed shall emulate each Traveler's time-delimited tour planning, both in the pre-trip as well as en route states, subject to the nature and accuracy of available data on travel cost (parking fee, toll, fuel consumption, and transit fare),.	2
4	SU-4	The AMS Testbed shall emulate decision making by Pedestrians and Travelers in Non-motorized Modes of travel in the absence and presence of mobile devices, subject to the nature and accuracy of data available to support decision making.	3
5	SU-5	The AMS Testbed shall emulate decision making by Light Vehicle Drivers in the absence and presence of mobile devices, carry-in devices, integrated devices, and message signs subject to the nature and accuracy of data available to support decision making.	1
6	SU-6	The AMS Testbed shall emulate decision making by Light Vehicle Passengers in the absence and presence of mobile devices subject to the nature and accuracy of data available to support decision making.	3
7	SU-7	The AMS Testbed shall emulate decision making by Transit Riders in the absence and presence of mobile devices subject to the nature and accuracy of data available to support decision making.	3
8	SU-8	The AMS Testbed shall emulate tactical driving decisions made by Light Vehicle Drivers with respect to lane selection, lane changing, gap acceptance, following headway, speed, acceleration, deceleration, stopping, braking, hard braking, yielding, and merging subject to the nature and accuracy of data available to support decision making.	1
9	SU-9	The AMS Testbed shall emulate and track each Transit Driver and associated transit vehicle's time-referenced geographic location (position) within the transportation system.	1
10	SU-10	The AMS Testbed shall emulate tactical driving decisions made by Transit Drivers with respect to lane selection, lane changing, gap acceptance, following headway, speed, acceleration, deceleration, stopping, braking, hard braking, yielding, and merging su	1
11	SU-11	The AMS Testbed shall emulate fixed route/fixed schedule transit, flexible route bus, rail transit and paratransit.	2
12	SU-12	The AMS Testbed shall emulate a Transit Driver's adherence to dynamic transit dispatch plans (e.g., to counteract bus bunching) when received subject to the nature and accuracy of data available to support decision making.	1
13	SU-13	The AMS Testbed shall emulate decision making by Transit Drivers in the absence and presence of mobile devices, carry-in devices, integrated devices, and message signs subject to the nature and accuracy of data available to support decision making.	1

SNo	ID	Requirement	Pasadena Testbed
14	SU-14	The AMS Testbed shall emulate and track each Truck Driver and associated freight vehicle's time-referenced geographic location (position) within the transportation system.	1
15	SU-15	The AMS Testbed shall emulate tactical driving decisions made by Truck Drivers with respect to lane selection, lane changing, gap acceptance, following headway, speed, acceleration, deceleration, stopping, braking, hard braking, yielding, and merging subject to the nature and accuracy of data available to support decision making.	1
16	SU-16	The AMS Testbed shall emulate a Truck Driver's adherence to plans when received on dynamic routing, tours, and actions at waypoints subject to the nature and accuracy of data available to support decision making.	1
17	SU-17	The AMS Testbed shall emulate decision making by Truck Drivers in the absence and presence of mobile devices, carry-in devices, integrated devices, and message signs subject to the nature and accuracy of data available to support decision making.	1
18	SU-18	The AMS Testbed shall emulate and track each Public Safety Worker and public safety vehicle's time-referenced geographic location (position) within the transportation system, including in an active incident zone.	3
19	SU-19	The AMS Testbed shall emulate tactical driving decisions made by Public Safety Vehicle Drivers with respect to lane selection, lane changing, gap acceptance, following headway, speed, acceleration, deceleration, stopping, braking, hard braking, yielding,	1
20	SU-20	The AMS Testbed shall emulate a Public Safety Vehicle Driver's adherence to plans when received on dynamic routing, and response staging subject to the nature and accuracy of data available to support decision making.	1
21	SU-21	The AMS Testbed shall emulate the time-referenced geographic location of Public Safety Workers acting as emergency response personnel within an active incident zone in the absence and presence of Mobile Devices subject to the nature and accuracy of data available to support decision making	3
22	SU-22	The AMS Testbed shall emulate decision making by Public Safety Vehicle Drivers in the absence and presence of mobile devices, carry-in devices, integrated devices, and message signs subject to the nature and accuracy of data available to support decision	1
23	SU-23	The AMS Testbed shall emulate adherence by Drivers of light, transit, and freight vehicles with directions when received on presence of emergency response personnel subject to the nature and accuracy of data available to support decision making.	1
24	SU-24	The AMS Testbed shall emulate various compliance rates of System Users (drivers, pedestrians, bicyclists, light vehicle passengers, transit riders, transit drivers, truck drivers, and public safety vehicle driver) when presented with advisory and regulations.	1
25	CV-1	The AMS Testbed shall emulate Mobile Devices that are capable of transmitting messages via cellular or DSRC or both.	1
26	CV-2	The AMS Testbed shall emulate the time-referenced geographic location, operational status (ON, OFF, NOT FUNCTIONING), and power status of a Mobile Device, and the state of the device (in use and connected to the vehicle, not in use but within a vehicle, o	1
27	CV-3	The AMS Testbed shall emulate Carry-in Devices that are capable of transmitting messages via cellular or DSRC or both	1
28	CV-4	The AMS Testbed shall emulate the time-referenced geographic location, and operational status (ON, OFF, NOT FUNCTIONING) of Carry-In Devices.	1
29	CV-5	The AMS Testbed shall emulate Integrated Devices that are capable of Transmitting message via cellular or DSRC or both	1
30	CV-6	The AMS Testbed shall emulate the time-referenced geographic location, and operational status (ON, OFF, NOT FUNCTIONING) of Integrated Devices	1
31	CV-7	The AMS Testbed shall emulate coordinated or independent transmission of messages from Mobile Devices, Carry-in Devices and Integrated Devices when co-located in a vehicle (light, transit, freight, public safety) via cellular or DSRC or both.	1

SNo	ID	Requirement	Pasadena Testbed
32	CV-8	The AMS Testbed shall emulate the reception of messages by DSRC-capable Mobile Devices, Carry-in Devices and Integrated Devices from other local DSRC-capable mobile, carry-in, and Integrated Devices	1
33	CV-9	The AMS Testbed shall emulate the reliability of Mobile Devices, Carry-in Devices, and Integrated Devices, specifically the reliability of a device to receive or send messages subject to local interference, device malfunction, or user error.	1
34	CV-10	The AMS Testbed shall track the time-referenced geographic- location and emulate the movement of Connected and Unconnected Vehicles within the transportation system, including time parked between trips made as a part of a multi-trip tour.	2
35	CV-11	The AMS Testbed shall reflect differences in vehicle size and weight among Light Vehicles, Transit Vehicles, Trucks and Public Safety Vehicles and associated differences in vehicle performance.	2
36	CS-1	The AMS Testbed shall emulate the geographic location (position), operational status (FUNCTIONING, NOT FUNCTIONING), and range of individual DSRC-capable Roadside Equipment (RSE) deployed as an element of a DSRC Roadside Device Network.	1
37	CS-2	The AMS Testbed shall emulate latency and reliability of messages passing through a DSRC Roadside Device Network, subject to the location and density of nearby roadside devices, relative position and capability of DSRC-capable devices (Mobile Devices, Carry-in Devices, and Integrated Devices) sending DSRC messages, and communications load local to individual roadside devices.	1
38	CS-3	The AMS Testbed shall emulate latency and reliability of communications using a Wide-Area Wireless Network, subject to the location of capable devices, sources of interference, and overall communications load.	1
39	CS-4	The AMS Testbed shall emulate provision of roadside/local control by Traffic Control Systems through dynamic message signs, lane control signs, ramp meters, and traffic signals.	2
40	CS-5	The AMS Testbed shall emulate provision of advisory information by Traffic Control Systems through dynamic message signs and other forms of advisory information provision.	2
41	CS-6	The AMS Testbed shall emulate the capability of Traffic Control Systems to receive, process, and implement control setting changes from System Managers, including the latency and reliability of response to System Manager direction.	2
42	CS-7	The AMS Testbed shall emulate the provision of Traveler information via Broadcast Media, including television, radio and through the internet, including a differentiation of information delivered to System Users in pre-trip and en route states.	1
43	CS-8	The AMS Testbed shall emulate data capture from Traffic Detection Systems utilizing passive detection to estimate individual vehicle speed, location, and size or to estimate roadway segment occupancy, travel time, and aggregate vehicle flow where deployed	2
44	CS-9	The AMS Testbed shall emulate the accuracy, precision, latency and reliability of data aggregation and pre-processing actions within the Traffic Detection System prior to those data being made available to System Managers within an Operational Data Environment	2
45	OD-1	The AMS Testbed shall emulate Data Quality Control (QC) and Aggregation processes, including the nature and effectiveness of quality checks and data performed for different data types.	3
46	OD-2	The AMS Testbed shall emulate the processing time associated with performing Data Quality Control and Aggregation processes.	3
47	OD-3	The AMS Testbed shall emulate and differentiate between integrated and independent Data Quality Control and Aggregation processes in support of System Managers.	3
48	OD-4	The AMS Testbed shall emulate the capture and aggregation of data from Connected Vehicles, Mobile Devices, and Detection Systems into Private Sector Data Services.	2

SNo	ID	Requirement	Pasadena Testbed
49	OD-5	The AMS Testbed shall account for the processing time associated with performing Data Quality Control and Aggregation processes within Private Sector Data Services.	3
50	OD-6	The AMS Testbed shall emulate the provision of aggregated and quality controlled data products from Private Sector Data Services into Data QC and Aggregation processes supporting System Managers.	3
51	OD-7	The AMS Testbed shall emulate the use of Predictive Tools within an Operational Data Environment, dependent on the flow of data from Data QC and Aggregation processes.	3
52	OD-8	The AMS Testbed shall emulate and differentiate among alternative forms of Predictive Tools, including their prediction horizon, accuracy, scope, and processing time.	2
53	SM-1	The AMS Testbed shall emulate the duration and outcomes of decision-making by Freeway System and Tollway Managers, subject to the latency, accuracy, reliability, and nature of Operational Data Environments available to support this decision-making.	1
54	SM-2	The AMS Testbed shall emulate the duration and outcomes of decision-making by Arterial System Managers, subject to the latency, accuracy, reliability, and nature of Operational Data Environments available to support this decision-making.	2
55	SM-3	The AMS Testbed shall emulate the duration and outcomes of decision-making by Road-Weather System Managers, subject to the latency, accuracy, reliability, and nature of Operational Data Environments available to support this decision-making.	3
56	SM-4	The AMS Testbed shall emulate the duration and outcomes of decision-making by Transit System Managers, subject to the latency, accuracy, reliability, and nature of Operational Data Environments available to support this decision-making.	3
57	SM-5	The AMS Testbed shall emulate the duration and outcomes of decision-making by Parking System Managers, subject to the latency, accuracy, reliability, and nature of Operational Data Environments available to support this decision-making.	3
58	SM-6	The AMS Testbed shall emulate the duration and outcomes of decision-making by Freight System Managers, subject to the latency, accuracy, reliability, and nature of Operational Data Environments available to support this decision-making.	3
59	SM-7	The AMS Testbed shall emulate the duration and outcomes of decision-making by Public Safety Managers, subject to the latency, accuracy, reliability, and nature of Operational Data Environments available to support this decision-making.	3
60	SM-8	The AMS Testbed shall emulate the duration and outcomes of decision-making by Information Service Providers, subject to the latency, accuracy, reliability, and nature of Operational Data Environments available to support this decision-making.	2
61	SM-9	The AMS Testbed shall emulate and differentiate the duration and outcomes of integrated versus independent decision-making among System Managers, including Freeway and Tollway System Managers, Signal System Mangers, Road-Weather System Managers, Parking S	1
62	SM-10	The AMS Testbed shall emulate the forms, scope and limitations of system control exerted by Freeway System and Tollway Managers, including messages passed through Broadcast Media, Traffic Control Systems, the DSRC Roadside Network or Wide-Area Wireless Networks	2
63	SM-11	The AMS Testbed shall emulate the forms, scope, and limitations of system control exerted by Arterial System Managers, including messages passed through Traffic Control Systems, the DSRC Roadside Network, or Wide-Area Wireless Networks to control or influence System User decision-making.	2
64	SM-12	The AMS Testbed shall emulate the forms, scope and limitations of system control exerted by Road-Weather System Managers, including messages passed through Broadcast Media, Traffic Control Systems, the DSRC Roadside Network or Wide-Area Wireless Networks	3

SNo	ID	Requirement	Pasadena Testbed
65	SM-13	The AMS Testbed shall emulate the forms, scope, and limitations of system control exerted by Transit System Managers, including messages passed through Broadcast Media, Traffic Control Systems, the DSRC Roadside Network, or Wide-Area Wireless Networks to control or influence System User decision-making.	3
66	SM-14	The AMS Testbed shall emulate the forms, scope, and limitations of system control exerted by Parking System Managers, including messages passed through Broadcast Media, Traffic Control Systems, the DSRC Roadside Network, or Wide-Area Wireless Networks to control or influence System User decision-making.	3
67	SM-15	The AMS Testbed shall emulate the forms, scope, and limitations of system control exerted by Freight System Managers, including messages passed through Broadcast Media, Traffic Control Systems, the DSRC Roadside Network, or Wide-Area Wireless Networks to control or influence System User decision-making.	3
68	SM-16	The AMS Testbed shall emulate the forms, scope, and limitations of system control exerted by Public Safety Managers, including messages passed through Broadcast Media, Traffic Control Systems, the DSRC Roadside Network, or Wide-Area Wireless Networks to control or influence System User decision-making.	3
69	SM-17	The AMS Testbed shall emulate the forms, scope and limitations of system control exerted by Information Service Providers, including messages passed through Broadcast Media, the DSRC Roadside Network or Wide-Area Wireless Networks to influence System User	2
70	SM-18	The AMS Testbed shall emulate the utilization of Automated Control by one or more System Managers who delegate specific forms of routine decision-making and control message generation.	3
71	DI-1	The AMS Testbed shall emulate the transmission and reception of Information and Data Flows between System Entities over a specific communications system, whether broadcast or point-to-point in nature, the interval at which the data flow occurs, and the co	3
72	DI-2	The AMS Testbed shall emulate the transmission and reception of Basic Safety Messages (BSM) among Connected Vehicles, Mobile Devices, and the DSRC Roadside Network.	2
73	DI-3	The AMS Testbed shall emulate the transmission of Basic Mobility Messages (BMM) from Connected Vehicles and Mobile Devices to the System Entity tasked with managing BMM messaging (either a Private Sector Data Services or a Data QC and Aggregation process)	2
74	DI-4	The AMS Testbed shall emulate the transmission of Signal, Phase and Timing (SPaT) Messages from the DSRC Roadside Device Network to DSRC-capable Connected Vehicles.	3
75	AP-1	The AMS Testbed shall emulate Dynamic Shoulder Lanes.	2
76	AP-2	The AMS Testbed shall emulate driver behaviors in Dynamic Shoulder Lanes that are distinct from behaviors on regular lanes.	2
77	AP-3	The AMS Testbed shall emulate restriction of access to Dynamic Shoulder Lanes by vehicle type (e.g., transit) and vehicle occupancy (e.g., HOV 2+, HOV 3+).	2
78	AP-4	The AMS Testbed shall emulate Dynamic Lane Use Control, including shoulder lanes.	2
79	AP-5	The AMS Testbed shall emulate Dynamic HOV/Managed Lanes.	2
80	AP-6	The AMS Testbed shall emulate detection of position, start time, duration, and length of queues on freeways and arterials in support of a Queue Warning DMA or Queue Warning strategy supporting System Manager decision-making.	2
81	AP-7	The AMS Testbed shall emulate altered driving behavior in response to Queue Warning messages generated by the Q-WARN DMA and delivered to Carry In or Integrated Devices within Connected Vehicles or through local signage within the Traffic Control System.	2
82	AP-8	The AMS Testbed shall emulate the estimation of dynamic target speed recommendations by roadway section and lane made by the SPD-HARM application or the Dynamic Speed Limits strategy deployed in support of System Managers.	2

SNo	ID	Requirement	Pasadena Testbed
83	AP-9	The AMS Testbed shall emulate transmission of SPD-HARM enhanced target speed recommendations via message signs; or directly to Carry-In or Integrated Devices running the SPD-HARM application within a Connected Vehicle.	2
84	AP-10	The AMS Testbed shall emulate driver decision-making in response to target speed recommendations made by the SPD-HARM application running on a Carry-In or Integrated Device within a Connected Vehicle.	2
85	AP-11	The AMS Testbed shall emulate altered driving behavior in response to combined queue warning and target speed recommendations made by a combined Q-WARN/SPD-HARM application.	2
86	AP-12	The AMS Testbed shall emulate the creation, movement, and dispersion of a platoon of Connected Vehicles utilizing Coordinated Adaptive Cruise Control (CACC) application, traveling at the same speed and maintaining the same gap with their respective leader	1
87	AP-13	The AMS Testbed shall emulate the identification and implementation of altered signal control settings enhanced by the M-ISIG DMA bundle or the ATDM Adaptive Traffic Signal Control and Adaptive Ramp Metering strategies.	2
88	AP-14	The AMS Testbed shall emulate the identification and implementation of signal control settings optimized to allow for the rapid and safe movement of Public Safety Vehicles (PREEMPT), Trucks (FSIG), Transit Vehicles (TSP), and Pedestrians (PED-SIG).	2
89	AP-15	The AMS Testbed shall emulate the dynamic creation of high-occupancy vehicles through the DRIDE application running on Mobile Devices or through other Dynamic Ridesharing services supporting informal ridesharing.	1
90	AP-16	The AMS Testbed shall emulate multi-modal forms of Traveler information services that include cost, reliability and parking delivered pre-trip through Broadcast Media or pre-trip and en route through Mobile Devices, Carry-in Devices, and Integrated Device	3
91	AP-17	The AMS Testbed shall emulate Active Parking Management Strategies employed to support decision-making by Parking System Managers, including Dynamic Wayfinding, Dynamic Overflow Transit Parking, Dynamic Parking Reservation, and Dynamic Priced Parking	1
92	AP-18	The AMS Testbed shall emulate Dynamic HOV Lane Conversion, including dynamic alterations to access policy (e.g., HOV-2 to HOV-3) and price.	2
93	AP-19	The AMS Testbed shall emulate Intelligent Dynamic Transit Operations (IDTO), including transit connection protection and dynamic dispatch.	1
94	AP-20	The AMS Testbed shall emulate Incident Management practices, including the management of local incident zones, the staging of emergency response vehicles and personnel, and the closure of lanes and facilities required as a part of the incident response.	1
95	AP-21	The AMS Testbed shall emulate Dynamic Pricing and Dynamic Fare Reduction strategies, including dynamic changes to roadway tolls or transit fares.	3
96	AP-22	The AMS Testbed shall emulate the concurrent deployment of two or more DMAs or ATDM strategies, including synergies or conflicts arising from this interaction.	2
97	AP-23	The AMS Testbed shall emulate Dynamic Junction Control	2
98	AP-24	The AMS Testbed shall emulate Dynamic Merge Control	2
99	AP-25	The AMS Testbed shall emulate Dynamic Lane Reversal or Contraflow lanes, including dynamically adjusting the lane directionality in response to real-time traffic conditions.	1
100	AP-26	The AMS Testbed shall emulate freight operations, including drayage optimization and freight Traveler information	3
101	OC-1	The AMS Testbed shall emulate a range of Operational Conditions, including variations in travel demand, weather, and incident patterns.	2

SNo	ID	Requirement	Pasadena Testbed
102	OC-2	The AMS Testbed shall be capable of calculating a consistent set of Performance Measures describing mobility, safety, and environmental impacts, over all Operational Conditions and subject to multiple alternative systems linking System Users and System Management	2
103	OC-3	The AMS Testbed shall be capable of being calibrated and validated using relevant Performance Measures against real-world conditions, both in terms of the representation of Operational Conditions and Alternative Systems, where such data are available from actual surface transportation systems.	3

Chapter 8. Model Calibration

8.1 Pasadena Testbed Baseline Models and Calibration Guidelines

The Pasadena Testbed baseline models correspond to the baseline operational conditions identified in the cluster analysis: normal traffic peaking, rainy days, and incident/work zones. To prepare these baseline models, the Pasadena Testbed team can leverage a well-built and calibrated traffic model set and a collection of resources to further model calibration. These resources include:

- Pasadena data environment (US DOT contract DTFH6111C00038) contains both calibration target data and validation data. For example, archived freeway counts data at both 5-min and 30-second aggregation levels from PeMS, and arterial ATMS count data at 5-minute level.
- Other archived operational data such as incidents and work zones from the data environment serves for further data mining to analyze traffic operational conditions and patterns in other operational condition baseline model development.
- Travel demand data were derived from large-scale cell phone data, and had been provided as origin-destination matrices for normal weekdays, weekend days, and holidays as well as sports event days.
- Network wide speed profiles for typical day of week for the entire network provide a pervasive validation dataset.
- Recent DTA and travel demand model updates include more up-to-date calibration data such as intersection traffic counts and corridor travel times. In conjunction with both archived data of similar nature, these data will offer necessary insight into the travel reliability and trends in the testbed area.

The above resources and mentioned study approaches were utilized in the DTA model update for operational conditions for which the following model calibration criteria were established:

- Use the static validation criteria (based on 2010 California Regional Transportation Guidelines) for each of the AM and PM peak hour volumes in the peak periods:

Validation Item	Criteria for Acceptance
Volume-to-count ratio	NCHRP 255 standard (hourly counts)
Percent of links with volume-to-count ratios within deviation allowance	At Least 85%
Coefficient of Determination (R squared)	At Least 0.88
Percent Root Mean Squared Error (RMSE)	Below 40%

- Speeds – corridor level travel time (in minutes) comparing model versus measurements also follow RMSE criteria from the above table.

In the normal weekday DTA model calibration for both AM (6-9) and PM (3-7), these criteria were well met. These criteria, together with model calibration guidelines such as FHWA Traffic Analysis Toolbox

Volume III (corridor travel times in particular), will be referenced in the model calibration efforts for all operational conditions.

Table 4. Wisconsin DOT freeway model calibration criteria.

Criteria and Measures	Calibration Acceptance Targets
Hourly Flows, Model Versus Observed	
Individual Link Flows	
Within 15%, for 700 veh/h < Flow < 2700 veh/h	> 85% of cases
Within 100 veh/h, for Flow < 700 veh/h	> 85% of cases
Within 400 veh/h, for Flow > 2700 veh/h	> 85% of cases
Sum of All Link Flows	Within 5% of sum of all link counts
GEH Statistic < 5 for Individual Link Flows*	> 85% of cases
GEH Statistic for Sum of All Link Flows	GEH < 4 for sum of all link counts
Travel Times, Model Versus Observed	
Journey Times, Network	
Within 15% (or 1 min, if higher)	> 85% of cases
Visual Audits	
Individual Link Speeds	
Visually Acceptable Speed-Flow Relationship	To analyst's satisfaction
Bottlenecks	
Visually Acceptable Queuing	To analyst's satisfaction

*The GEH statistic is computed as follows:

$$GEH = \sqrt{\frac{(E-V)^2}{(E+V)/2}} \qquad (4)$$

Figure 8-1: Recommended Micro-Simulation Calibration Standards: Excerpt from FHWA "Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Modeling Software" [Source: FHWA]

Model calibration to baseline scenarios will be based on the existing dynamic traffic assignment (DTA) models that have been recently developed for the City of Pasadena. The DTA model set includes both AM and PM normal weekday traffic. This model set will also serve as the starting point for calibration to operational conditions obtained by cluster analysis. The overall calibration workflow is depicted in the following chart.

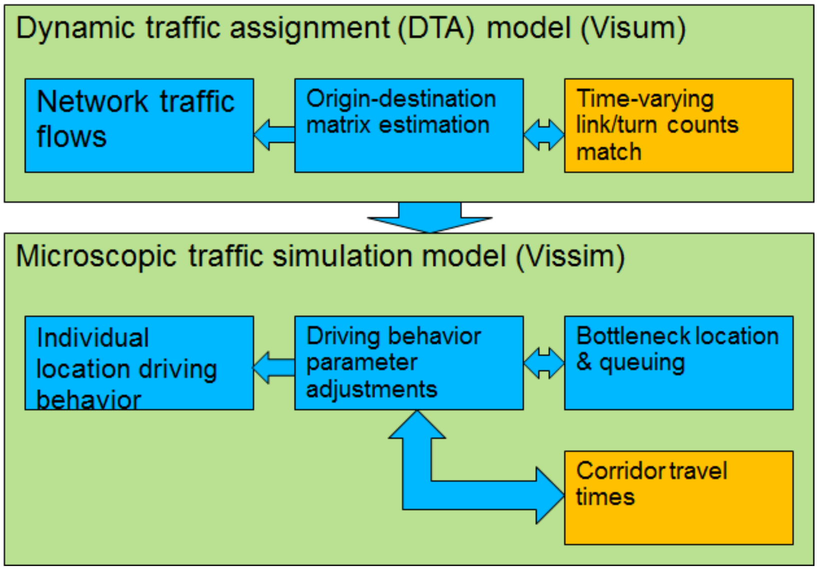

Figure 8-2: Workflow of Model Calibration to Baseline Operational Conditions [Source: HBA]

8.1 Model Calibration to Operational Conditions

The existing DTA model will be validated against data from the cluster analysis. In addition, two other operational conditions will be modeled.

8.1.1 Model Calibration: Operational Condition #1

The macroscopic and dynamic traffic assignment (DTA) model for Operational Condition #1 has been modeled with Visum's DTA module – DUE, initialized from the city wide DTA model for both AM (6-9AM) and PM (3-7PM) traffic conditions. For example, the following charts were the calibration results of the city wide DTA model, indicating a good initial dataset for calibrating Operational Condition #1.

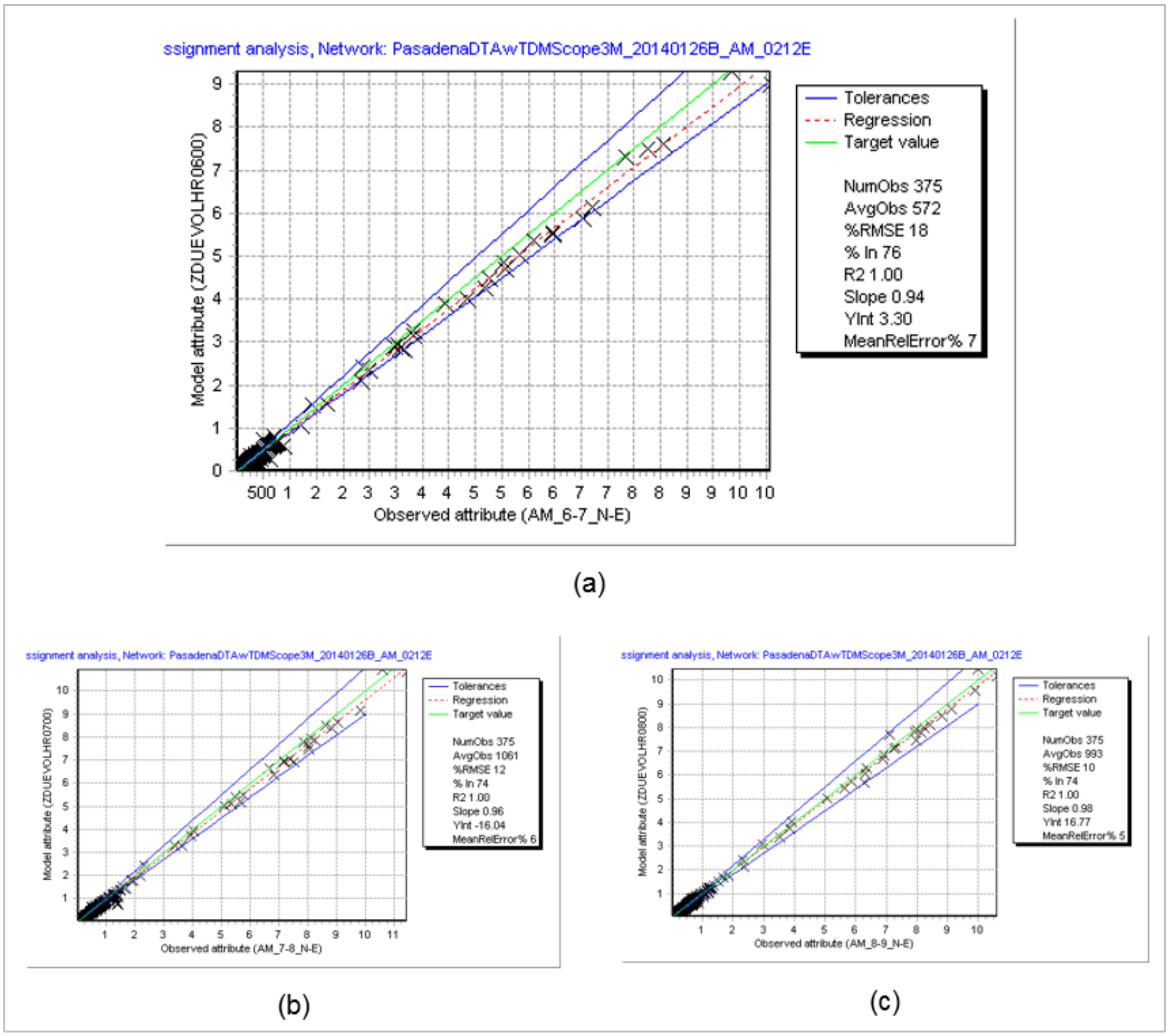

Figure 8-3: Pasadena DTA AM Model Calibration Results: Assignment Analysis for Different Hours (a) 6-7AM (b) 7-8AM (c) 8-9AM [Source: HBA]

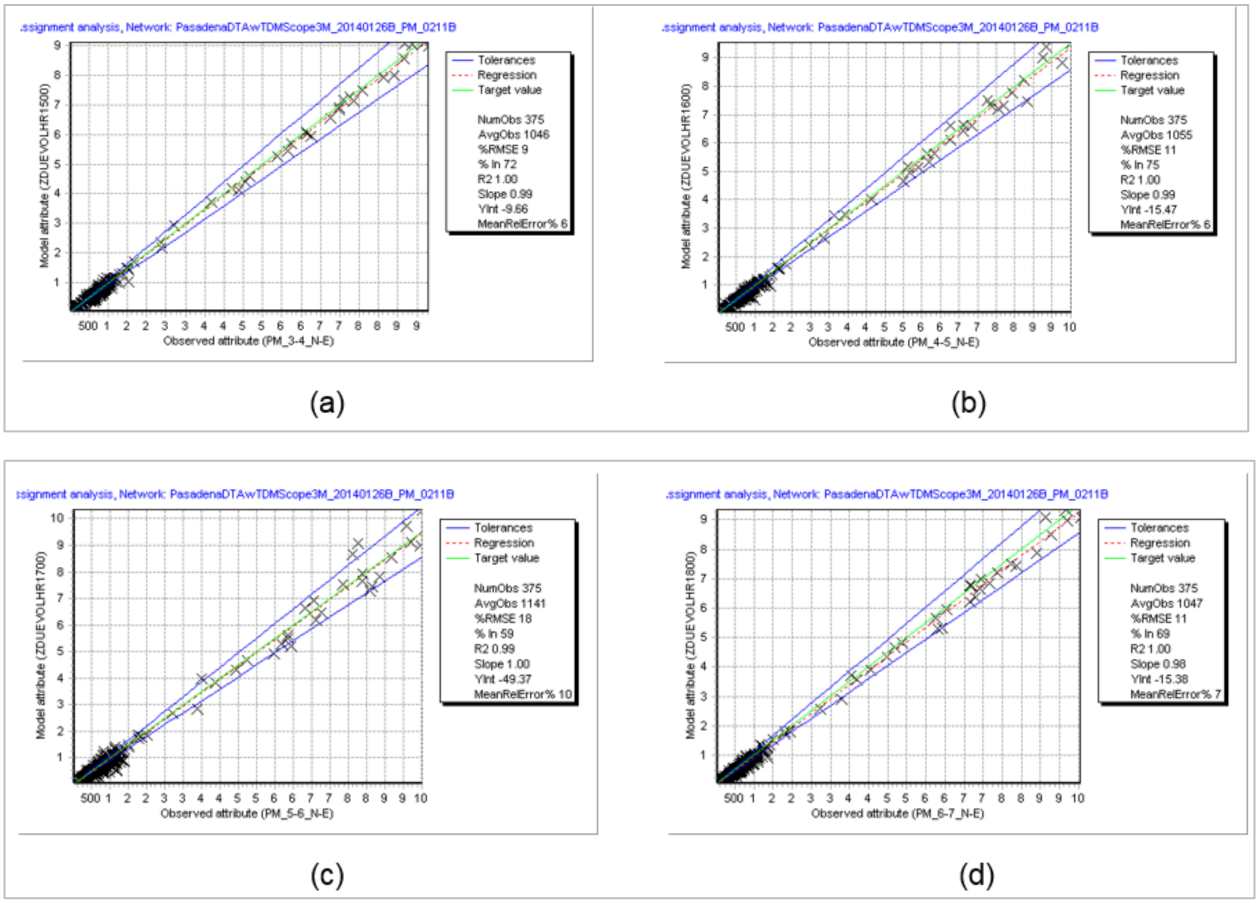

Figure 8-4: Pasadena DTA PM Model Calibration Results: Assignment Analysis for Different Hours (a) 3-4PM (b) 4-5PM (c) 5-6PM (d) 6-7PM [Source: HBA]

In addition to the usual calibration target of traffic counts, one highlight is that the model was also calibrated against corridor travel times. The City of Pasadena has been monitoring 16 travel corridors within the City border, and conducted travel time surveys each year. These corridors are shown in Figure 8-5 below.

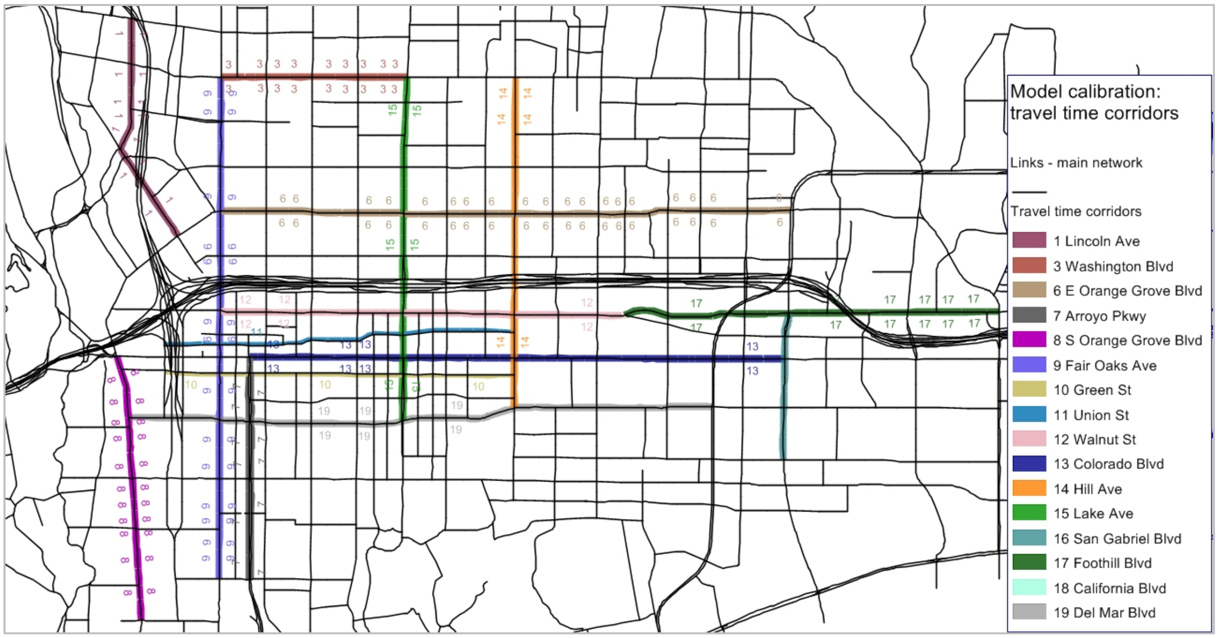

Figure 8-5: Travel Time Data Collection Arterial Corridors in Pasadena [Source: HBA]

The Transportation Report Card[3] reports included travel time survey results for these corridors. In addition, these corridors were presented in an online map archive to show both travel times[4] and average travel speeds[5].

An additional travel time data source has also been included as a reference calibration data. This link travel speed/time data was sourced from NAVTEQ, which has fused multiple raw data sources (e.g., GPS logs from in-vehicle or carry-on navigation devices) to aggregate time-of-day and day-of-week speeds. Dubbed Traffic Pattern, this data are packaged as either 1-hour or 15-minute link speeds and being updated each quarter as typical for NAVTEQ map data. Traffic Pattern data come with a reference to the map links, which was used to reference the data to the NAVTEQ map-based model network in this study. The referenced link data were presented as time-varying attributes in Visum, by 15-minute increments for each day of week (Monday through Sunday). The following Figure 8-6 visualizes these data for time-of-day profiling for Monday, Saturday, and Sunday for one link, illustrating the time-of-day speed profiles.

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[3] 2009 Annual Transportation Report Card, Prepared by City of Pasadena Department of Transportation.

[4] https://maps.google.com/maps/ms?ie=UTF8&hl=en&msa=0&msid=117975475234288021790.00047ce5cb937946a0023&z=13&dg=feature

[5] https://maps.google.com/maps/ms?ie=UTF8&hl=en&msa=0&msid=117975475234288021790.00048037754b9cc1342be&z=13&dg=feature

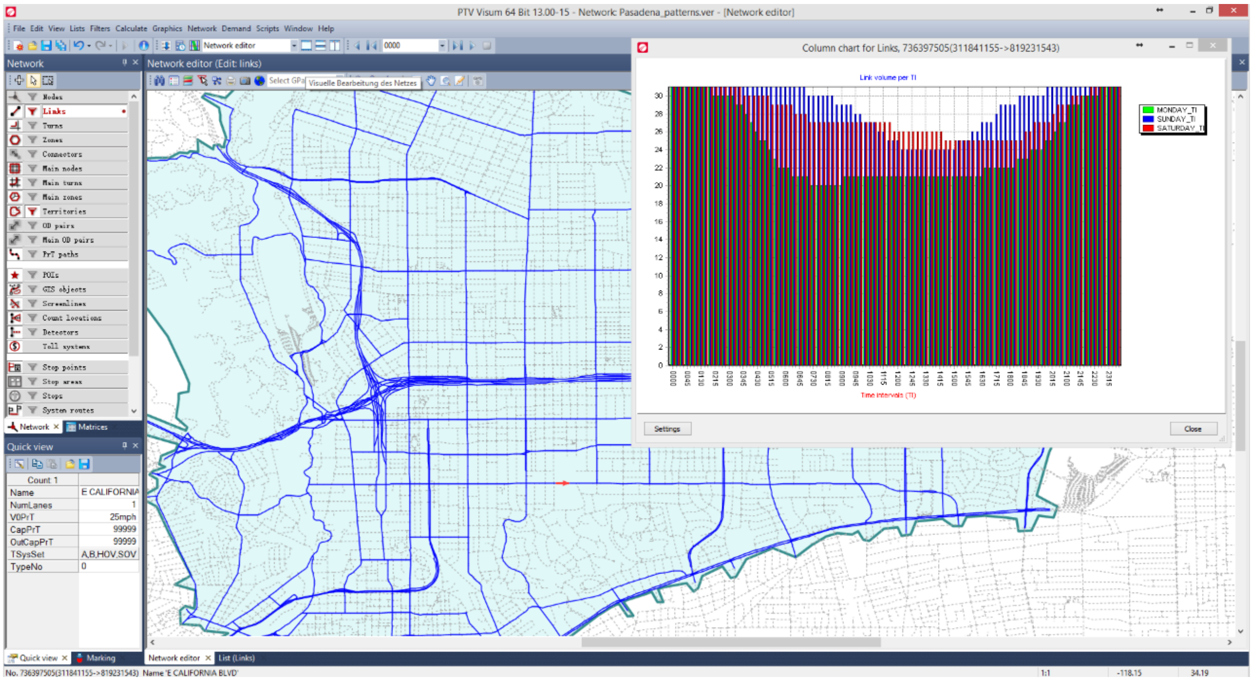

Figure 8-6: NAVTEQ Traffic Patterns Data Coverage in Reference to the Model Network (Links with Data Highlighted in Blue) with One Example of One Link Time-of-Day Speed Profile [Source: HBA]

Corridor travel times from model output are computed by summing up the hourly average for all links that are part of the concerned corridor. The following table summarizes the RMSE statistics for both AM and PM hours in the city wide DTA model. Table 8-1 below shows that corridor travel time calibration targets are well met for all hours of both AM and PM models.

Table 8-1: Corridor Travel Time Calibration Targets for Pasadena Testbed

AM DTA Model Corridor Travel Time RMSE	
Hour	%RMSE
6AM-7AM	15
7AM-8AM	13
8AM-9AM	13
PM DTA Model	Corridor Travel Time RMSE
3PM-4PM	20
4PM-5PM	19
5PM-6PM	18
6PM-7PM	18

Above statistics and charts all indicate that Operational Condition #1 is well represented by the Pasadena DUE model.

8.1.2 Traffic Flow Dynamics Calibration at Bottleneck Locations

The Pasadena Testbed corridor is recognized as having many bottlenecks as evidenced from PeMS website. Traffic flow dynamics parameters at these bottleneck locations will be captured to reflect these changes in operational conditions. For example, the following Figure 8-7 depicts the differences of fundamental diagrams on separate days (dry weather and rainy days), analyzed during cluster analysis process.

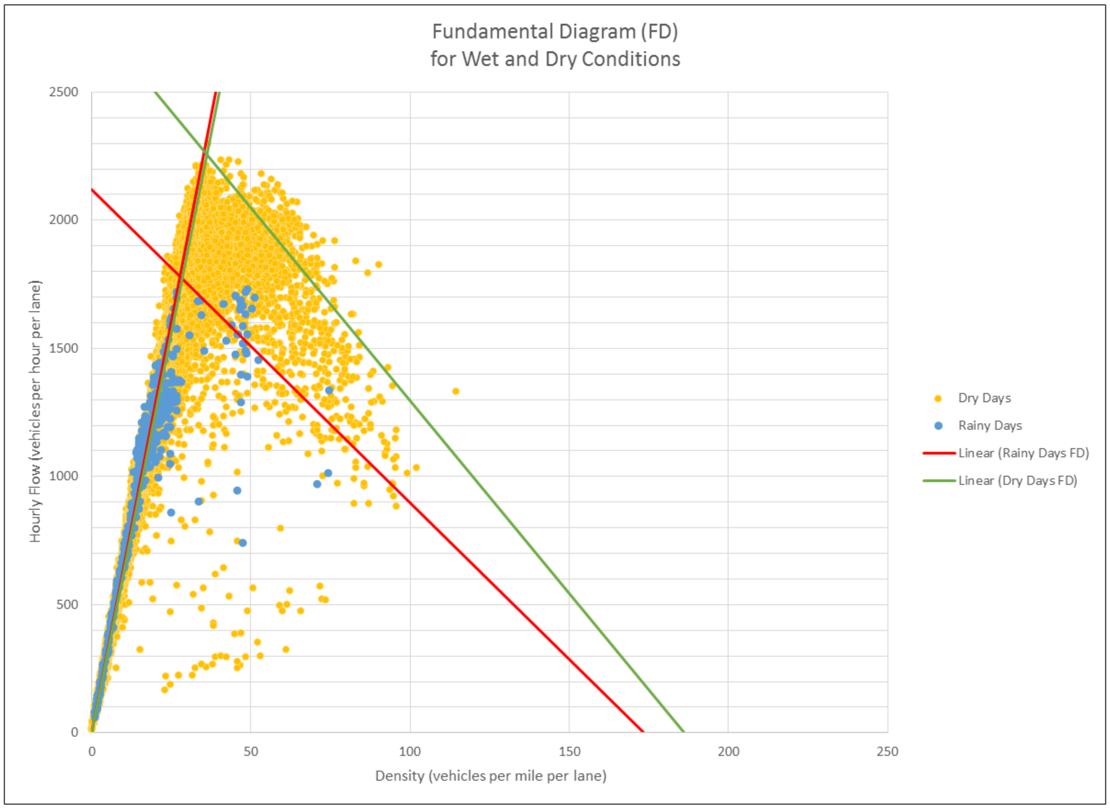

Figure 8-7: Fundamental Diagram Comparison for Rainy and Dry Day Clusters Resulting from Cluster Analysis (PeMS VDS 717599): Rainy Days Cluster Show Capacity of 1,781 vphph and Freeflow Speed of 64.0 mph, while Dry Days Cluster Show Capacity of 2,255 vphpl and ffs [Source: HBA]

Each bottleneck location of the testbed freeway corridors will be characterized by their individual fundamental diagrams

Chapter 9. Evaluation Approach

This section shows the system evaluation plan to answer the DMA and ATDM research questions based on the analysis conducted and the approach to conducting sensitivity analysis.

9.1 Evaluation Plan to Answer DMA and ATDM Questions

The Pasadena Testbed will primarily focus on the analysis of the ATM strategies as well as the specific ADM strategy “Dynamic Routing” and selected INFLO DMA applications. The analysis is structured into three phases with the objective of answering 13 ATDM and 2 DMA research questions.

Phase 1 includes 8 scenarios with the focus on the analysis of each ATDM strategy individually as well as in three different combination bundles. All scenarios are based on the typical weekday PM peak demand as represented by operational condition #1. Each of the 8 scenarios will be analyzed with up to 8 variations of key attributes as described in Section 4.3.1.

Modeled driver response will be limited to short-term (e.g., 30-60 minutes) and the choice of re-routing will only be available for scenarios including the strategy of Dynamic Routing. Each scenario permutation will be simulated 10 times to account for the stochastic behavior of the simulation testbed and thus Phase 1 will include a total of 640 simulation runs.

Phase 2 will further analyze the most promising 3 attribute combinations for each scenario analyzed in Phase 1. This additional analysis will focus on the strategy bundles’ performance under the two additional operational conditions. Using the same 8 scenarios and 10 simulation runs per scenario permutation as before, Phase 2 will include a total of 480 simulation runs (refer to Section 4.3.2 for more detail).

Phase 3 of the simulation analysis will focus on the analysis of the combination of ATDM strategies with DMA applications. The analyzed scenario will add two INFLO DMA applications to the scenario that resulted in the best performance during the previous analysis phases. The resulting scenario will then be analyzed under up to 5 attribute permutations. Using the previously assumed 10 simulation runs per attribute variation, this results in 50 simulation runs (refer to Section 4.3.3 for more detail).

9.2 Sensitivity Analyses

The Pasadena Testbed is centered on the I-210/CA-134 corridor within the city limits of Pasadena, CA. Currently, neither this specific corridor, nor any other corridor in the country is equipped with any true ATDM strategies or DMA applications. Therefore, there is not enough experience with actual deployments of ATDM and DMA to know the response of travelers to these strategies and applications. Consequently, any strategy or strategy combination evaluated as part of this project is subject to assumptions made by the modeling team. To mitigate this liability, sensitivity analyses will be performed to delineate the impacts of these assumptions. The previous section explains the attribute and response variations that will be modeled to account for any insecurity in input data assumptions.

9.3 Anticipated Implementation Cost

The AMS Team will estimate the implementation cost of the DMA/ATDM applications by assessing similar execution efforts and reviewing cost databases (e.g., IDAS Database).

Chapter 10. Execution Plan

10.1 Execution Summary

This section summarizes the process used to conduct the development and analysis for the Pasadena Testbed. The analysis scenarios for this testbed will span three analysis phases to evaluate ATDM strategies and also the combination of ATDM strategies with DMA applications:

- Phase 1
  - Testbed development tasks to be performed
    - Base traffic model calibration (Operational Condition #1)
    - ATDM application module development
    - Prediction system and System Management development
    - Testbed support module (e.g., Scenario Manager, etc.) development
    - Data Bus and interface development
  - Evaluation tasks to be performed
    - 640 testbed runs based on Operational Condition #1
    - Data compilation
    - Documentation
- Phase 2
  - Testbed development tasks to be performed
    - Base traffic model calibration (Operational Condition #2 and #3)
  - Evaluation tasks to be performed
    - 480 testbed runs based on Operational Condition #2 and #3
    - Data compilation
    - Documentation
- Phase 3
  - Testbed development tasks to be performed
    - DMA application implementation
  - Evaluation tasks to be performed
    - 50 testbed runs based on Operational Condition #2 and #3
    - Data compilation
    - Documentation

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