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

San Mateo Testbed Analysis Plan

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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 San Mateo 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. Additional data used for the testbed development and evaluation are provided in the Appendix.

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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 San Mateo (US 101) Testbed. The San Mateo Testbed is an 8.5 mile long stretch of the US 101 freeway and State Route 82 (El Camino Real) in San Mateo County located approximately 10 miles south of the San Francisco International Airport. This Testbed will be used to test DMA including Intelligent Network Flow Optimization (INFLO) (Queue Warning (Q-WARN), Dynamic Speed Harmonization (SPD-HARM), and Cooperative Adaptive Cruise Control (CACC)) and Multi-Modal Intelligent Traffic Signal System (MMITSS).

The Testbed will integrate third party software implementing these applications with the Testbed's native VISSIM implementation using VISSIM's com and other interface capabilities. The Testbed is capable of being integrated with third party software implementing other DMA applications, such as ATIS, IDTO, FRATIS, and R.E.S.C.U.M.E; however, those particular applications will not be tested as part of San Mateo modeling effort.

This report is organized into ten chapters (in addition to the appendix) 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 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 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.
- Appendix – Selection of Scenarios: This chapter documents the process used to identify four baseline scenarios, combining different levels of demand, incident, and weather conditions for testing the performance effects of Dynamic Mobility Applications (DMA) on the San Mateo Testbed.

Chapter 2. Testbed Description

2.1 Regional Conditions

This section presents an overview of the actual region covered by the Testbed, and details the various transportation demand/supply elements for that region and operational conditions.

The San Mateo Testbed is an 8.5 mile long stretch of the US 101 freeway and State Route 82 (El Camino Real) in San Mateo County located approximately 10 miles south of the San Francisco International Airport (SFO) (see Figure 2-1). The coast range bounds the corridor on the west side. The San Francisco Bay bounds the corridor on the east side. State Route 92 (with the San Mateo Bridge) is the only east-west connector in the corridor that extends beyond the physical boundaries of the corridor. SR 92 goes from the Pacific Coastline through the coast range and across the San Francisco Bay to Hayward on the east side of the Bay. All north south traffic on the west side of the Bay is limited to the US 101 freeway, El Camino Real, and Interstate 280 (not included in the Testbed).

San Mateo County (in which the corridor is located) had an estimated population of 740,000 in 2012. The population of the individual cities within the corridor range from 25,000 to 100,000. The greater San Francisco Bay Area, in which San Mateo County is located, has a population of 7 million.

The Testbed includes the US 101 freeway and the El Camino Real (SR 82) from Third Avenue in San Mateo to Woodside Road in Redwood City. The freeway and El Camino Real run parallel to each other ranging from ½ mile to one mile apart within the study corridor. The Testbed includes the following US 101 freeway interchanges and cross-connecting streets between US 101 and El Camino Real:

- East Third Avenue (San Mateo)
- State Route 92 (San Mateo)
- East Hillsdale Blvd. (San Mateo)
- Ralston Ave/Marine Parkway (Belmont)
- Holly Street (San Carlos)
- Brittan Ave. (San Carlos)
- Whipple Ave (Redwood City)
- Woodside Road (SR 84) (Redwood City)

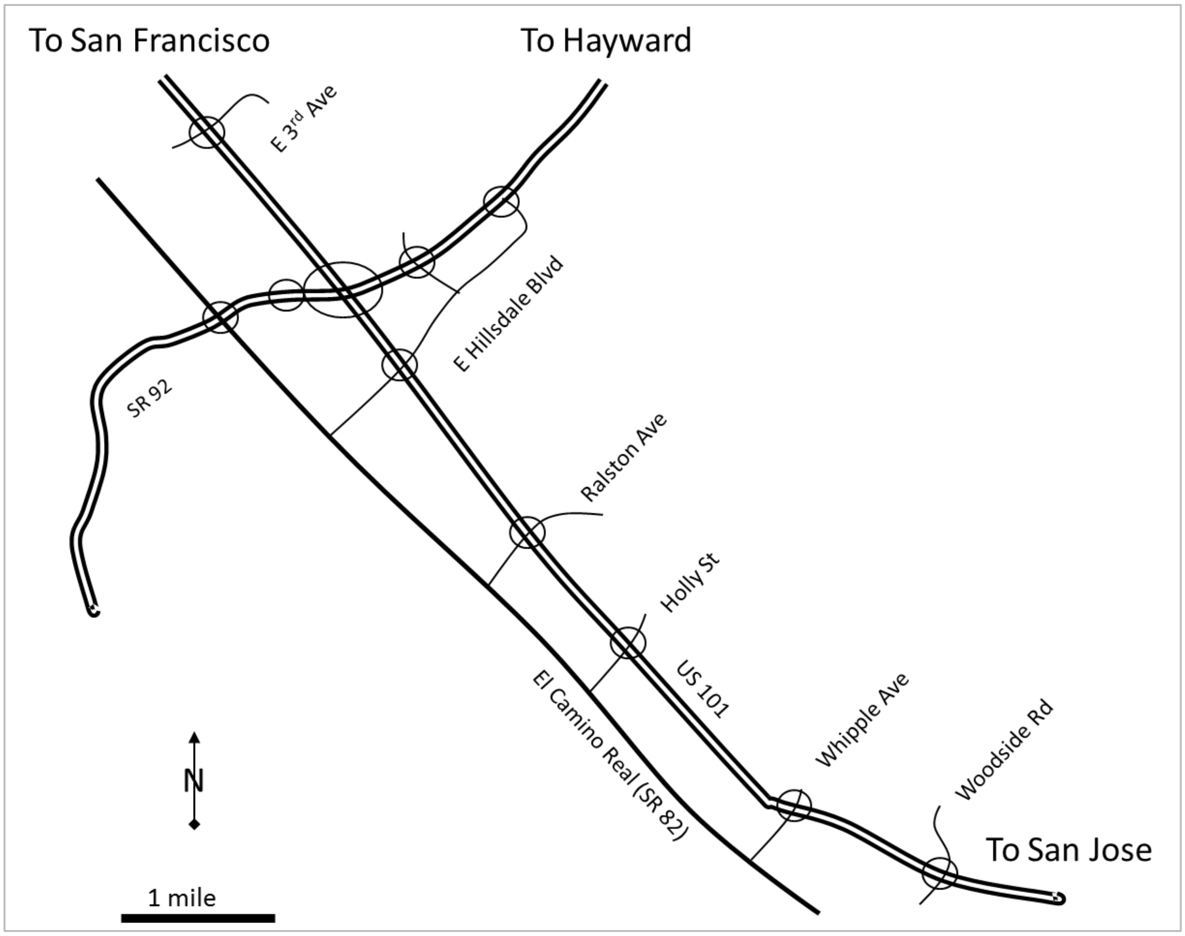

Figure 2-1: San Mateo US 101 and SR 82 Testbed [Source: Kittelson]

2.1.1 Facility Types

The US 101 freeway is an 8 lane freeway, transitioning to 6 mixed flow lanes plus 2 peak period HOV 2+ lanes south of Whipple Avenue (see Figure 2-1). The HOV lanes are continuously accessible from the mixed flow lanes, being limited to 2+ HOVs during the morning and evening peak hours and open to all vehicles outside those hours. For the Northbound direction the HOV lane restriction is in effect from 5 - 10 AM and 3-7 PM weekdays. For the southbound direction the HOV lane restriction is in effect from 5-9 AM and 3-7 PM weekdays. El Camino Real (State Route 82) is a 4 to 6 lane signalized divided arterial with a posted 35 mph speed limit.

2.1.2 Travel Modes

SamTrans currently operates 2 express bus routes on portions of the US 101 freeway during the peak periods (#398, #KX) and two express routes that use El Camino Real (#ECR, #397) (see Table 2-1). Two of the express routes run on portions of both the El Camino Real and the US 101 freeway. There are numerous additional local bus routes serving the corridor. Caltrans runs 3 commuter trains per hour in each direction during the AM and PM peak periods.

Table 2-1: Caltrain and Express Bus Service in Corridor

Route	Runs On	AM/PM Frequency (buses/hr)
ECR	El Camino Real (ECR)	4 buses/hr
397	El Camino Real (ECR)	1 bus/hr
398	US 101 Freeway/ECR	1 bus/hr
KX	US 101 Freeway/ECR	1 bus (in peak direction only)
Caltrain	Commuter Rail	3 trains/hr

Major transit transfer stations in the corridor include:

- BART/Caltrans Millbrae Transit Center
- San Mateo Caltrans Station
- Belmont Caltrans Station
- San Carlos Caltrans Station
- Redwood City Transit Center

Park & Ride Lots are provided at each Caltrans Station and Transit Center. These lots are served by transit. There are also two park and ride lots (not served by transit) located near US 101 freeway at the East Third Avenue interchange and at the SR 92 interchange. SOV's, HOV's, buses, trucks will be modeled. Caltrans, and BART, will not be modeled. Vehicle traffic to and from the stations will be modeled. The major transit transfer stations and the park & ride lots will also NOT be included in the VISSIM model testbed as part of this effort.

2.1.3 Types of Vehicles Included in the Testbed

The Testbed currently includes autos, buses, and trucks. Autos are split between HOV 2+ and SOV's. Two types of Trucks are included in the Testbed: single unit trucks and semi-trailer combination trucks. Motorcycles are not modeled separately. When testing connected vehicles, each vehicle type will be further subdivided into connected and unconnected vehicles. The breakdown of the vehicle fleet is shown in Table 2-2:

Table 2-2: Peak Period Vehicle Fleet Breakdown for San Mateo Testbed

Vehicle Type	Percent of Fleet
Auto and Motorcycles - SOV	73%
Auto/Van – HOV2+	23%
Heavy Vehicles: Single Unit (SU) Trucks (less than or equal 34ft Length), Semi-trailers and Buses	4%
Total	100%

2.1.4 ITS and Infrastructure Condition

The freeway currently has Freeway Service Patrols (FSP), Highway Advisory Radio (HAR), and Variable Message Signs (VMS). The Caltrans TMC monitors freeway operations using loop detectors to monitor lane volumes and speeds at approximately half mile spacing. Local dynamic ramp metering is currently in operation on most on-ramps in both directions during the AM and PM peak periods.

The Metropolitan Transportation Commission provides real time traveler information through 511.org via the internet and cell phones. Within the study section, for the selected analysis year of 2012, changeable message signs were located about every 2 miles on the freeway: South of Hillsdale Blvd., South of Holly Street (near Brittan Ave.), and north of Woodside Drive. The US 101 freeway is covered by 2 FSP beats (#6/7 and #10). Beat #6/7 covers the freeway north of SR 92. Beat #10 covers the freeway south of SR 92. Both beats operate from 6-10 AM and 3-7 PM weekdays. In the month of May 2012 the 4 trucks on beat #6/7 served 620 incidents, the 3 trucks on beat #10 served 450 incidents. (Source: http://www.fsp-bayarea.org/statistics.htm, accessed July 9, 2014).

These specific ATDM strategies already in place will not be explicitly modeled in the VISSIM model used for the testbed. However, they were present during the data collection used to calibrate the VISSIM model to existing performance, and therefore, presumably, had some effect on the calibrated performance.

2.1.5 Existing Traffic Conditions

The US 101 freeway carries between 200,000 and 250,000 Average Annual Daily Traffic (AADT) of which 15-25% are HOV 2+ vehicles. El Camino Real carries between 25,000 and 50,000 AADT.

Special events affecting the corridor occur in Candlestick Park in San Francisco, about 16 miles north of the northern edge of the study Testbed. Candlestick has a seating capacity of slightly over 70,200, which is reached about 10 times a year in the fall season during NFL games at the park. Adverse weather conditions are comparatively infrequent and mild compared to other parts of the country. In 2012 there were 26 rain days out of 251 non-holiday weekday PM peak periods (10%) when there were more than trace amounts of rain. High winds, snow and ice did not occur in 2012. Fog, frequently present during the summer season, rarely descends to and obstructs visibility at the road level. Thus there were no low visibility conditions in 2012.

No major new construction occurred on the freeway during the study year, 2012. Maintenance work zones on weekdays are timed to run between 9 AM and 3 PM, with all lanes reopened to traffic by 3 PM. Thus, work zones are expected to have a negligible effect on PM peak period operations. For the northbound direction of US 101 there were 123 out the 251 non-holiday PM peak periods (49% of the days) when a lane blocking incident occurred at some time during the peak period. Demand does not vary greatly over the course of the year. The 5^{th} percentile and the 95^{th} percentile highest non-holiday weekday PM peak period demands span a range of plus or minus 9% of the median demand for the southbound direction, and plus or minus 10% of the median for the northbound direction.

The US 101 freeway is regularly congested in the northbound direction during weekday PM peak periods. The lane reductions between the SR 92 interchange and the Third Avenue interchange are the bottlenecks. The freeway-to-freeway connector ramps at SR 92 also regularly experience queuing. Traffic is heavy in the southbound direction as well, but it is not usually congested during weekday PM peak hours (see Figure 2-2).

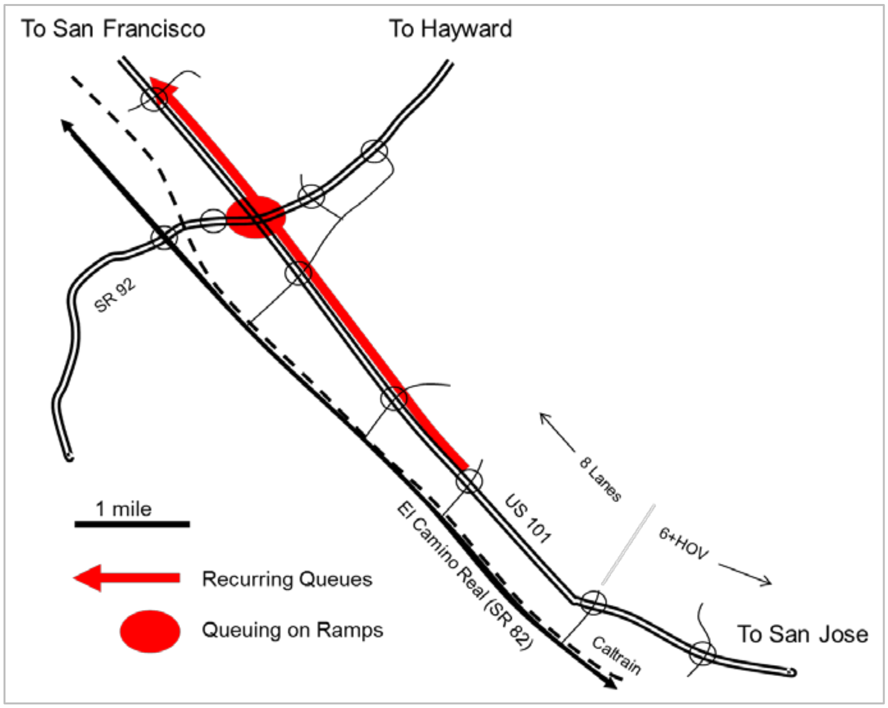

Figure 2-2: Recurring Congestion on US 101SR 82 Testbed [Source: Kittelson]

2.2 Operational Conditions

For the purposes of conducting analysis, the Testbed team identified up to four existing operational conditions or baselines using the Analysis approach defined in the Appendix.

The 5-hour non-holiday, weekday PM peak period extending from 2:30 PM to 7:30 PM will be modeled. The PM peak was selected because the heaviest recurring congestion occurs on the corridor at this time. The peak direction is in the northbound direction. The five hour period from 2:30 to 7:30 PM was selected because recurring congestion normally does not start until after 2:30 PM and normally dissipates before 7:30 PM on the freeway. Of course, one or more incidents can change when the congestion begins or clears.

Review of the freeway travel time distribution data for the corridor determined that the Northbound direction regularly experienced much greater recurring and non-recurring congestion during weekday PM peak periods from 2:30 PM to 7: 30 PM to capture the extent of congestion, i.e. PM peak. So data for this direction was used to select the scenarios.

Review of the daily VMT variability data for the freeway suggested that it could not be effectively used as a proxy for changes in total peak period demand. Consequently, it was decided to model only one overall peak period demand level in the scenarios. The examination of effects by hour within the peak period suggested that a similar hour-by-hour examination of the microsimulation results for each scenario could be used to determine the effects of different demand levels on the performance of DMA. The selected peak period is long enough to span both uncongested and congested conditions, providing a sufficiently robust demand basis for assessing the benefits of DMA under varying demand conditions.

In summary, by dropping the different daily (VMT) demand variation levels from the analysis and dropping the exceptionally low probability scenarios and considering the wet-pavement condition, 4 recommended baseline scenarios were concluded for full microsimulation analysis, as shown in Table 2-3.

Table 2-3: Recommended Set of Operational Conditions

Op. Env. Scenario	*Demand*	*Incident Type*	*Weather Type*
1	50th percentile day, examine hourly variations within peak	None/Other/Short	Dry Pavement
2	Same as above	1 Lane – 30 minutes	Dry Pavement
3	Same as above	1 Lane – 60 minutes	Dry Pavement
4	Same as above	1 Lane – 60 minutes	Wet Pavement*

Notes:

- 1 Lane – 30 minutes = one lane closed NB on freeway for 30 minutes.
- 1 Lane – 60 minutes = one lane closed NB on freeway for 60 minutes.
- Wet pavement is defined as falling rain at 0.1 inches per hour.

2.2.1 Hypothetical Operational Conditions

This section presents for each Testbed up to two "hypothetical" operational conditions which do not exist in the region, but which can be modeled by the Testbed with minimal efforts and adjustment factors (e.g. for snow scenario) can be borrowed from other studies to do the analysis. The proposed hypothetical conditions are:

1. Light snow (0.1 inch per hour) and no incident.
2. Medium snow (0.5 inches per hour) and short incident on freeway (an incident with duration less than 30 minutes).

Light and medium snow is selected to expand the utility of the test results to greater areas of the country. Adding a short incident to snow conditions not only reflects a common snow problem but also is selected to test the benefits of DMA under greater stress.

2.3 Testbed Modeling and Tools Capabilities

This section presents a description of the Testbed tools and models currently used. The Testbed is currently coded in VISSIM Version 5.4, a microsimulation software package. VISSIM has dynamic traffic assignment capabilities, which will be activated when the parallel arterial is added to the network. The model currently works with a fixed set of hourly origin-destination tables for all vehicles. HOV's and trucks are treated as fixed percentages of the all-vehicle OD tables. The model year is 2010 and the simulation time period is from 2:30 PM to 7: 30 PM. The traffic modes modeled in this Testbed consist of the passenger cars, trucks, and buses. The percentage of total heavy vehicles from Table 2-2 is equally divided between buses and trucks.

Two regional travel demand models (one conventional 4-step, the other activity based) and one sub-regional (San Mateo and Santa Clara Counties) are available for estimating mode, route, and time of day shifts. The linkage to these demand models does not currently exist.

The VISSIM software has various features to support modeling of ATDM and DMA applications:

- A driver model dll interface that enables users to replace the innate driver behavior model in VISSIM with their own custom behavior model for all or selected vehicle types.
- COM API that enables users to dynamically modify VISSIM objects (vehicles, links, controls) during the simulation run.
- VAP (vehicle actuated programming) that enables users to write their own traffic actuated signal controls.
- C2X – a pre-written framework for developing a connected vehicle emulator.

The Testbed was originally developed for a project (2009-2013) funded by the Metropolitan Transportation Commission (MTC), the San Mateo County Transportation Authority, and the City and County Association of Governments of San Mateo County (CCAG). This Testbed was calibrated based on observed traffic conditions in the field, such as volumes, travel time, bottleneck location and duration of congestion. A series of operational and traffic management improvements were analyzed using the model; including ramp metering, auxiliary lanes, lane expansions, ramp closures due to short weaving/diverging/merging, and multimodal travel information. The original MTC Testbed will be extended and augmented to include the parallel arterial street, El Camino Real (SR 82), a few key cross-connectors, and existing express bus service on the US 101 freeway.

Chapter 3. Analysis Hypotheses

Table 3-1 presents the mapping of DMA preliminary hypotheses.to the research questions.

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 and MMITSS 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?	DMA bundles that are synergistic such as Q-WARN and SPD-HARM will be more beneficial when implemented in combination than in isolation.
3	What DMA applications, bundles, or combinations of bundles complement or conflict with each other?	Certain combinations of INFLO and MMITSS will complement each other resulting in increased benefits, while others will conflict with each other resulting in no benefits or reduced benefits.
4	Where can shared costs or cost-effective combinations be identified?**	Bundles that are highly synergistic will have shared connected vehicle technology deployment costs
5	What are the tradeoffs between deployment costs and benefits for specific DMA bundles and combinations of bundles?**	Incremental increase in deployment will result in higher benefit-cost ratio up to a certain deployment cost threshold, after which benefit-cost ratio will reduce.
III	**Operational Conditions, Modes, Facility Types with Most Benefit**	

ID	DMA Research Question	Preliminary Hypothesis
6	What DMA bundles or combinations of bundles yield the most benefits for specific operational conditions?	Certain DMA bundles or combinations of bundles will yield the highest benefits under specific operational conditions. For example, a combination of INFLO and MMITSS will have greater impact on days with high-demand.
7	Under what operational conditions are specific bundles the most beneficial?	A DMA bundle will yield the highest benefits only under certain operational conditions. For example, under sever congested conditions, SPD-HARM will have limited impact.
8	Under what operational conditions do particular combinations of DMA bundles conflict with each other?	Certain combinations of bundles will conflict with each other under specific operational conditions, resulting in no benefits or reduced benefits. For example under heavy traffic conditions, the net impact of SPD-HARM and Q-WARN will be minimal.
9	Which DMA bundle or combinations of bundles will be most beneficial for certain modes and under what operational conditions?	Certain DMA bundles or combinations of bundles will yield the highest benefits for specific modes and under certain operational conditions.
10	Which DMA bundle or combinations of bundles will be most beneficial for certain facility types (freeway, transit, arterial) and under what operational conditions?	Certain DMA bundles or combinations of bundles will yield the highest benefits for specific facility types and under certain operational conditions.
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?	(1) Certain synergistic DMA bundles will yield the most benefits when deployed together on individual facilities rather than as system-wide or region-wide deployments and under certain operational conditions. (2) Certain synergistic DMA bundles will yield the most benefits when deployed together on a system rather than as facility-specific or region-wide deployments and under certain operational conditions. (3) Certain synergistic DMA bundles will yield the most benefits when deployed together in a region rather than as facility-specific or system-wide deployments and under certain operational conditions.
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?	Benefits or negative impacts from bundles will be unevenly distributed by facility or other sub-element of the network.
IV	**Messaging Protocols**	

ID	DMA Research Question	Preliminary Hypothesis
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?	(1) BSM Part 1 data transmitted every 10th of a second via DSRC is not critical for the effectiveness of DMA applications, with the exception of CACC. (2) DMA bundles will be more effective with alternate messaging protocols in addition to BSM Part 1
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?	Bundles that most significantly influence or are impacted by travelers' trip making decisions (EnableATIS, IDTO) or pedestrian movements (MMITSS, R.E.S.C.U.M.E.) will have the most critical need for messaging by pedestrians, and pre-trip and en route travelers. This criticality will vary by operational condition.
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?	DMA applications, with the exception of component applications of the INFLO and MMITSS bundles, will not need data to be transmitted via DSRC as higher-latency communications media (e.g., cellular) will suffice.
VI	**Communications Latency and Errors**	
16	What are the impacts of communication latency on benefits?	As communication latency increases, benefits will decrease. Most significant decrease will be observed for MMITSS and INFLO than for the other bundles.
17	How effective are the DMA bundles when there are errors or loss in communication?	Effectiveness of some DMA bundles will be more impacted than others due to errors or loss in communication. MMITSS and INLFO will be most impacted by errors or loss in communication.
VII	**RSE/DSRC Footprint**	
18	What are the benefits of widespread deployment of DSRC-based RSEs compared with ubiquitous cellular coverage?	(1) In comparison to widespread cellular coverage, widespread deployment of DSRC-based RSEs will be excessive for DMA bundles. (2) Concentrated deployment of DSRC-based RSEs will be more cost-beneficial in highly congested urban areas than in non-urban or low to moderate congested urban areas.

ID	DMA Research Question	Preliminary Hypothesis
19	Which technology or combination of technologies best supports the DMA bundles in terms of benefit-cost analysis?**	More cost-effective benefits will be observed when connected vehicles transmit and receive messages using dual mode communications (e.g., both DSRC and cellular).
VIII	**Prediction and Active Management Investment**	
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 (individually and in combination) will be more 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?	BSM Part 1 sent via DSRC is critical only to CACC; however other DMA applications will also need some elements of BSM Part 1 (i.e., position, speed, and acceleration) to be effective even in the near term. This is valid for all operational conditions.
22	At what levels of market penetration of connected vehicle technology do the DMA bundles (collectively or independently) become effective?	Benefits will increase with increase in market penetration of connected vehicle technology; some bundles will yield significant benefits even at lower market penetration levels.
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)? **	Bundles that influence traveler decision-making and leverage widely deployed mobile device technology, such as EnableATIS, FRATIS, and IDTO, will yield measureable but geographically diffused system-level impacts under near-term deployment assumptions.
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)?	Effectiveness of some DMA bundles will be more impacted than others due to availability of PII. Bundles that influence traveler decision-making, such as EnableATIS, FRATIS, and IDTO, will be most impacted with availability of PII versus no PII.
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?	Effectiveness of DMA bundles will be impacted by the lack of participation by local agencies/entities.

Chapter 4. Analysis Scenarios

This section describes the analysis scenarios to test the different DMA 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*".

Scenarios should be developed for the range of operational conditions of greatest interest (to be determined using historical data) to the Testbed site in light of its analysis objectives and based on the current conditions of the Testbed. This section presents a description of the analysis scenarios to be created as part of this analysis in addition to the baseline description.

4.1 DMA Applications to be Addressed by Testbed

This section presents the proposed applications to be evaluated by the Testbed. The San Mateo Testbed will only focus on the DMA applications as summarized in Table 4-1.

Table 4-1 The DMA applications evaluated/addressed by the San Mateo Testbed

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)	Yes
MMITSS	Intelligent Traffic Signal System (I-SIG)	Yes
MMITSS	Transit Signal Priority (TSP)	Yes*
MMITSS	Mobile Accessible Pedestrian Signal System (PED-SIG)	Yes*
MMITSS	Emergency Vehicle Preemption (PREEMPT)	Yes*
MMITSS	Freight Signal Priority (FSP)	Yes*
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

Bundle	Application	Addressed?
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

*to the extent that these MMITSS applications are included in UA MMITSS algorithm

4.2 DMA Application Analysis Scenarios

A total of 24 formal microsimulation analysis scenarios combining one of 6 possible baseline operating condition with the applications of INFLO and the MMITSS bundles will be executed

The proposed analysis scenarios are listed in Table 4-2 by Phase.

In Phase 1 the basic effects of the DMA bundles will be assessed. In Phase 2 additional effects will be assessed for intermediate baseline operating conditions. In Phase 3 the effectiveness of the DMA bundles will be tested against more severe weather conditions.

Each scenario will incorporate the sensitivity analyses described in section 9.4, Sensitivity Analyses, as appropriate

The plan is tentative for Phases 2 and 3. The plan is to evaluate the results at the end of Phase 1, and in in consultation with stakeholders, refine and prioritize the scenarios to be tested in Phases 2 and 3

Table 4-2: DMA Application Analysis Scenarios

Phase	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Scenario #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
OpScn/NINW	X	X	X	X																				
OpScn/SINW									X	X	X	X												
OpScn/LINW													X	X	X	X								
OpScn/LIR					X	X	X	X																
OpScn/NILS																	X	X	X	X				
OpScn/SIMS																					X	X	X	X
INFLO/Q-WARN		X	X	X		X	X	X		X	X	X		X	X	X		X	X	X		X	X	X
INFLO/SPD-HARM		X	X	X		X	X	X		X	X	X		X	X	X		X	X	X		X	X	X
INFLO/CACC			X	X			X	X			X	X			X	X			X	X			X	X
MMITSS/I-SIG				X				X				X				X				X				X

Phase	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
MMITSS/TSP				**X**				**X**				**X**				**X**				**X**				**X**

Notes:

1. OpScn = Operational Scenario
2. NINW = No incident, no adverse weather
3. SINW = short (30 minute) incident on freeway, one lane blocked, no adverse weather
4. LINW = long (60 minute) incident on freeway, one lane blocked, no adverse weather
5. LIR = long (60 minute) incident on freeway, one lane blocked, rain (0.10 inches per hour)
6. NILS = No incident, light snow (0.10 inches per hour).
7. SIMS = Short (30 minute) incident on freeway, medium snow (0.50 inches/hour).
8. PED-SIG, PREEMPT, FSP not explicitly simulated within model, but evaluated by post processing of model outputs.
9. Phase 1 focuses on operations under recurrent congestion and long incident with rainy weather conditions.
10. Phase 2 fills in the results for intermediate non-recurrent conditions.
11. Phase 3 models the snow conditions

Chapter 5. Data Needs and Availability

This section identifies the data needs for the Testbed and details data availability, and gaps (if any). In addition, this section provides a detailed plan for data collection and data mining to fill the data needs.

Since the microsimulation model has already been calibrated and validated for baseline recurring congestion conditions, additional data is needed only where it is desired to validate/calibrate the model for non-recurring conditions, such as, crashes, bad weather, and other incidents. The data needs for this are:

- Mainline and ramp volume 5-minute counts for peak periods on days where one or more incidents are present in one or both directions.
- Sufficient details about the incidents (location, direction, maximum lanes blocked, start and end times) to support their coding in the microsimulation model.
- Mainline travel times every 5-minutes for peak periods on days where one or more incidents are present in one or both directions.

5.1 Available Data

This section describes the data available for model calibration and validation. Generally, the US101/82 Testbed is calibrated, validated, and operational with the data that has previously been collected for it (historical data). At the same time, web-based tools are available to the team to readily collect new data at a moment's notice (Data Readily Accessible). This corridor can also provide real-time data, however; this data currently goes directly to the Caltrans TMC, and would require additional permissions to access it.

5.1.1 Historical Data

The following historical data was acquired for the calibration and validation of the microsimulation model Testbed:

- Mainline lane-by-lane volume counts and spot speeds every half mile
- Point-to-Point travel times for Fastrak equipped vehicles, generally every 3 miles
- Ramp counts for AM and PM peak periods, 15 minute aggregations, acquired a single day only.
- Floating car travel times and trajectories – AM and PM peak periods, single day only.
- Signalized intersection peak hour turn counts and signal controller settings, single day only.
- Freeway to freeway Interchange OD for sample peak hours.

Disaggregate data, such as lane-changing and vehicle trajectories for all vehicles, is not available.

5.1.2 Data Readily Accessible

The following data is currently collected using automated sensors 24 hours/7 days a week and is readily accessible to the team over the web:

- Mainline lane-by-lane volume counts and spot speeds every half mile
- Point-to-Point travel times for Fastrak (toll tag) equipped vehicles, generally every 3 miles
- Incident and weather logs

- Signalized intersection mainline approach detector volumes and occupancies (event based and aggregable to a time period)
- Historic INRIX travel time data is available upon request
- Historic NPMRDS (National Performance Management Research Data Set) travel time data is available upon request of FHWA, Caltrans, or MTC.

5.1.3 Real-time Data

All of the data listed above as readily accessible is also potentially available in real time mode, but would require securing the necessary access permissions from Caltrans TMC.

5.2 Preliminary Data Collection Plan to Address Gaps

No new field data collection is proposed.

The Testbed team will re-examine the 251 weekday PM peak period data it has assembled (described above) to identify days meeting the criteria for bad weather or incidents. Mainline counts and travel times for incident and bad weather conditions can be obtained in this manner.

Ramp count data for incident days will NOT be available, so ramp volumes will be estimated by factoring up or down the original non-incident ramp counts to match the upstream and downstream mainline counts for incident days.

Chapter 6. Key Assumptions and Limitations

This section identifies the assumptions and limitations of the analysis approach for the San Mateo Testbed.

6.1 Market Penetration of Devices

There would be no limitations on the market penetration rates to be evaluated. However, resources will limit the number of different rates that can be tested to two or three representative values from which performance results for the full range of potential market penetration rates will be extrapolated and interpolated.

6.2 Driver/Traveler/System Manager Behavioral Responses (Including Compliance)

The testbed microsimulation model assumes 100% compliance and response for vehicles receiving DMA messages. The effects of lower compliance rates will be estimated from the microsimulation model results. The logic to be used is illustrated by the following example. A microsimulation model run assuming 100% compliance for a 50% market penetration will be assumed to be also representative of a 2/3rds compliance rate on a 75% market penetration.

Regarding route diversion, the San Mateo Testbed will allow drivers to dynamically update their routes based on received information in-vehicle. We will use the default diversion parameters recommended by VISSIM.

6.3 Operating Policies for DMA and ATDM

6.3.1 How Often Will Pricing Be Changed?

The San Mateo Testbed will not be used to test ATDM strategies, like pricing.

6.3.2 How Often Will Target Speeds Be Changed?

For testing Speed Harmonization, the frequency of change for target speeds will be determined by the TTI prototype used in the tests. This is currently once every 15 seconds, rounded to the nearest 5 mph. The limitations of this prototype will apply.

6.4 Adoption of Connected Vehicle Technology, DMA Applications

The SPD-HARM and Q-WARN bundles to be tested will be as defined by the concurrent project investigating the SPD-HARM/Q-WARN prototype. The CACC bundle will be as defined by UC Berkeley PATH in the algorithm they developed. The MMITSS bundle will be as defined by University of Arizona in their algorithm. The limitations of these prototypes will apply.

6.5 Type of Communication Technology and Corresponding Range, Latencies and Errors

Differences in message loss rates and latencies in receipt will be addressed through sensitivity analyses and by direct modeling of communication within the modeling chain. The limitations of the TCA algorithm for testing communications loss will apply.

6.6 Density and Capability of Infrastructure Deployed Over Time

The penetration of connected vehicle technology in to the traveler market is expected to increase with more and more travelers realizing the potential benefits it can give. This increasing penetration rates can cause a trade-off behavior in the overall mobility and communications infrastructure. Several studies have suggested that having a higher penetration rate has greater potential to enhance mobility benefits by DMA applications. However, it can also cause communication over-load on the network. Communication Modeling will use the TCA model to assess communication losses. Since the TCA tool can only assume perfect communication along with some user-defined loss and drop-rates, approximate values of these from similar studies will be used as inputs to the TCA tool. The communication modeling tool will form a basis of development of the actual execution framework and does not closely mimic the actual real-world communication criteria. Apart from penetration rates, infrastructure deployments will be varied to freeways only, freeways and major arterials only as well as freeways, major arterials and major intersections.

6.7 Limitations of Results

The Testbed will suffer from many of the limitations of all microsimulation models.

- Inability to account for geometric and environmental factors not explicitly coded into the model (for example, visual obstructions on the side of the road, etc.)
- Difficulty of accounting for driver inattention or distractions (for example, changing a radio station, cell phones, and roadside distractions like dynamic billboards, a brush fire nearby, etc.).
- Difficulty of accounting for driver non-compliance with driving laws. (Some adjustments can be made, such as driving faster than the speed limit, others, such as crossing over a solid lane line, dangerous lane changing, or exiting past the gore points are more difficult to adequately account for within a microsimulation model.)
- Inability to account for conditions on local and collector roads not coded into the model.
- Inability to directly predict crashes. (Crashes can be modeled, but not predicted).

Other limitations are unique to this Testbed:

- Inability to predict diversion of demand to other modes or times of day due to changes in congestion or in response to traveler alerts (this can be approximated by computing the demand effects off-line and inputting them into the simulation run. However, it is not automated.).
- Inability to predict the effects on communication loss and latency of communication tower overloads, poor siting, tall buildings, and other factors.
- The limitations of the specific DMA prototypes used in the tests: The TTI, PATH, and UA prototype algorithms.

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 Modeling the DMA Applications

The San Mateo test bed will be used to evaluate the INFLO and MMITSS bundles of DMA (see Table 7-1).

EnableATIS, IDTO, FRATIS, and R.E.S.C.U.M.E. will not be evaluated using the San Mateo test bed. This is because these application bundles are designed to affect travel demand and emergency responders, both of which are not currently modeled within the VISSIM San Mateo test bed. Within the INFLO and MMITSS bundles the Q-WARN, SPD-HARM, CACC, I-SIG, and aspects of TSP will be modeled using available software prototypes for each application. The University of Arizona algorithm is designed to give priority to transit vehicles, but the software implementation does not currently have some of the more advanced features of TSP, such as dynamic priority based on status (passenger load, schedule delay). The PED-SIG, PREEMPT, and FSP applications will be evaluated to the extent they are implemented with the UA prototype for MMITSS.

Table 7-1: Modeling of DMA Applications

Bundle	*Application*	*Model*
EnableATIS	Multimodal Real-Time Traveler Information (ATIS)	No
	Smart Park-and-Ride (S-PARK)	No
	Universal Map Application (T-MAP)	No
	Real-Time Route-Specific Weather Information (WX-INFO)	No
INFLO	Queue Warning (Q-WARN)	TTI
	Dynamic Speed Harmonization (SPD-HARM)	TTI
	Cooperative Adaptive Cruise Control (CACC)	PATH
MMITSS	Intelligent Traffic Signal System (I-SIG)	UA
	Transit Signal Priority (TSP)	UA
	Mobile Accessible Pedestrian Signal System (PED-SIG)	UA
	Emergency Vehicle Preemption (PREEMPT)	UA
	Freight Signal Priority (FSP)	UA
IDTO	Connection Protection (T-CONNECT)	No

Bundle	Application	Model
	Dynamic Transit Operations (T-DISP)	No
	Dynamic Ridesharing (D-RIDE)	No
FRATIS	Freight Real-Time Traveler Information with Performance Monitoring (F-ATIS)	No
	Drayage Optimization (DR-OPT)	No
	Freight Dynamic Route Guid. (F-DRG)	No
R.E.S.C.U.M.E.	Emergency Communications and Evacuation (EVAC)	No
	Incident Scene Pre-Arrival Staging Guidance for Emergency Responders (RESP-STG)	No
	Incident Scene Work Zone Alerts for Drivers and Workers (INC-ZONE)	No

EnableATIS, IDTO, FRATIS, R.E.S.C.U.M.E will not be evaluated within the test bed.

7.1.1 Modeling Q-WARN

The Q-WARN application will be modeled using the software prototype developed by TTI for FHWA.[1]

The prototype draws on a combination of road detectors and connected vehicles to spot queues. It then provides a short message to a device in the upstream connected vehicles stating the number of miles ahead to the back of the queue. The prototype does not provide lane specific locations for the queue nor the cause or predicted duration of the queue.

The prototype is designed only for freeway application, so this prototype will be applied only to the US 101 freeway in this test bed.

7.1.2 Modeling SPD-HARM

The SPD-HARM application will be modeled using the software prototype developed by TTI for FHWA.[2]

The prototype draws on a combination of road detectors and connected vehicles to provide a recommended speed once every 15 seconds for each tenth mile length of freeway. Minimum valid sample sizes for a minimum period are required to generate a recommended speed. The recommended speed is rounded to the nearest 5 mph. The recommended speed sent to the vehicle is constrained to match the recommended speed posted by the TMC on the dynamic speed signs (if any) in the subsection. The prototype's recommended speeds are NOT lane specific. The prototype is reactive to observed speeds and queues. It does not predict breakdowns, queuing, or speeds.

The prototype is designed only for freeway application, so this prototype will be applied only to the US 101 freeway for the purposes of this analysis plan.

[1] Battelle/TTI, Report on Dynamic Speed Harmonization and Queue Warning Algorithm Design, Draft Report – January 15, 2014, FHWA-JPO-14-TBD
[2] Battelle/TTI, Report on Dynamic Speed Harmonization and Queue Warning Algorithm Design, Draft Report – January 15, 2014, FHWA-JPO-14-TBD

7.1.3 Modeling CACC

The CACC application will be modeled using the software prototype developed by UC Berkeley PATH. [3] The PATH prototype uses different car following models (speed versus acceptable gap) depending on whether the CACC vehicle is following a similarly equipped vehicle, a vehicle with only a transponder, and an unequipped vehicle. The algorithm seeks to keep the CACC vehicle as close to the speed limit as possible subject to a minimum acceptable gap to the lead vehicle (which varies according to the type of the lead vehicle and the braking characteristics of the following vehicle). Speed control predominates for the CACC vehicle when the gap is greater than 120 meters. Gap control predominates when the gaps is less than 100 meters. These distances are appropriate for freeway operation but are excessive for lower speed operations on surface streets. Thus this particular prototype will only be implemented on the freeway for the purposes of this analysis plan.

7.1.4 Modeling MMITSS Bundle

The MMITSS Bundle will be modeled using the software prototype developed by the University of Arizona (UA). [4] (See also the MMITSS System Design[5]). The UA prototype control strategy considers real-time vehicle actuations for buses, passenger cars and heavy vehicles. Connected pedestrians, emergency vehicles, railway crossings, trucks, and bicycles can be accommodated in the decision framework but specific code has not yet been implemented for those modes in the existing algorithm. The prototype assumes that an optimized signal coordination plan has been prepared offline that can accommodate priority requests. Coordination off-sets between intersections are determined outside of the algorithm using widely available macroscopic signal timing optimization software (e.g. TRANSYT or Synchro). The pedestrian phase duration as implemented in the prototype is assumed to be fixed (although the framework would allow flexible durations).

This application will be implemented only on El Camino Real, which has a coordinated signal system and the necessary coordination plans in place. Note that more advanced features of TSP, such as more advanced communication of vehicle status (passenger load, schedule status) and expected arrival time are not currently incorporated in the current UA software implementation for I-SIG. Similarly the UA prototype framework is designed to accommodate: (a) Mobile Accessible Pedestrian Signal System (PED-SIG), (b) Emergency Vehicle Preemption (PREEMPT), and (c) Freight Signal Priority (FSP) application concepts. However, not all features of these applications are currently implemented in the prototype. Consequently the San Mateo test bed will be used in the rounds of analysis contemplated by the analysis plan to test these additional applications within MMITSS only to the extent they are currently implemented in the UA prototype.

7.2 Modeling Communication Loss

A two pronged approach will be taken to evaluating communication effects on DMA performance.

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[3] Steven E. Shladover, Dongyan Su, and Xiao-Yun Lu, Impacts of Cooperative Adaptive Cruise Control on Freeway Traffic Flow, Transportation Research Record: Journal of the Transportation Research Board, No. 2324, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 63–70.

[4] Qing He, K. Larry Head and Jun Ding, "Multi-Modal Traffic Signal Control with Priority, Signal Actuation and Coordination, Transportation Research Part C: Emerging Technologies, Volume 46, September 2014, Pages 65-82.

[5] Multimodal Intelligent Traffic Signal System, System Design, Version 1.1, May 26, 2014.

- The first prong (Evaluating the contribution of communication error to overall vehicle detection and driver cooperation) will perform sensitivity test microsimulation model runs of different levels of driver response to the DMA guidance. The potential contribution of communications problems to the overall driver response will then be assessed for different levels of market penetration and communication error.
- The second prong (Modeling communication error within the model chain) will select a subset of the microsimulation model runs to repeat with a communications loss model incorporated into the modeling chain. This approach has a significant impact on the number of model repetitions needed to address any individual research question, and will therefore be used sparingly.

7.2.1 Evaluating the Contribution of Communication Errors to Overall Vehicle Detection and Driver Cooperation

The first prong approach to the analysis will use a model post processing method to assess the relative contributions of communication errors and other factors to vehicle detection and driver response with DMA guidance. It is hypothesized that:

- Market penetration, communications delay (or loss),[6] and compliance rate (if the particular DMA application requires a driver's decision to comply) are all tied together into the estimation of the overall vehicle detection and driver response to the DMA application (see Figure 7-1).

Market penetration determines who is eligible to receive the guidance. Communications errors, delays, and loss determine who among the eligible receivers get the message by when. Compliance rate (which will be a function of external conditions and the message received) then determines the actual responses of the drivers. At the same time, we must take into account that drivers may receive the message from multiple non-connected vehicle sources (their direct perception of the problem, changeable message signs, commercial radio, highway advisory radio or a traveler information system). In this case traveler information system (TIS) includes public and proprietary area-wide traffic information systems that the driver may already subscribe to in their vehicle.

Market penetration, communications errors, and compliance rate will be assumed to be independent random variables. Thus the overall response rate can be obtained by multiplying the percent of equipped vehicles by an estimated communication error rate (causing the driver not to receive the message in time), and the percent of drivers receiving the message who agree to comply. We can then construct a table showing what market penetration rates and communication success rates are required to achieve any target overall response rate. Higher penetration rates can tolerate greater communication error rates.

Two or three microsimulation runs (with the requisite repetitions) will be performed for each DMA application evaluation. We will initial start with one run assuming a 10% response rate, and the second run assuming a 25% response rate. Based on the results of those two runs, a third run assuming a different percentage may be performed. Based on the knowledge gained in the first DMA application analysis, different percentages may be used in later DMA applications analyses. Similarly, to assess the effects of communication loss and market penetration on vehicle detection, three microsimulation runs (with the requisite repetitions for each) will be performed for each DMA application with different vehicle detection rates (probably 10% and 25% to start with, with additional percentages tested, if necessary, based on the first few results). In the case of CACC, the assumption is that compliance is automated, so

[6] Note that messages without a confirmation receipt are repeated until the confirmation is obtained. Thus, communication losses may translate into delays in transmission (latency) rather than actual lost messages. Losses occur, if the message does not arrive by a critical time point for action.

the compliance rate would be set at 100%. In the case of MMITSS the issue is vehicle detection, so compliance is set to 100% and the relative contributions of market penetration and communication loss are assessed.

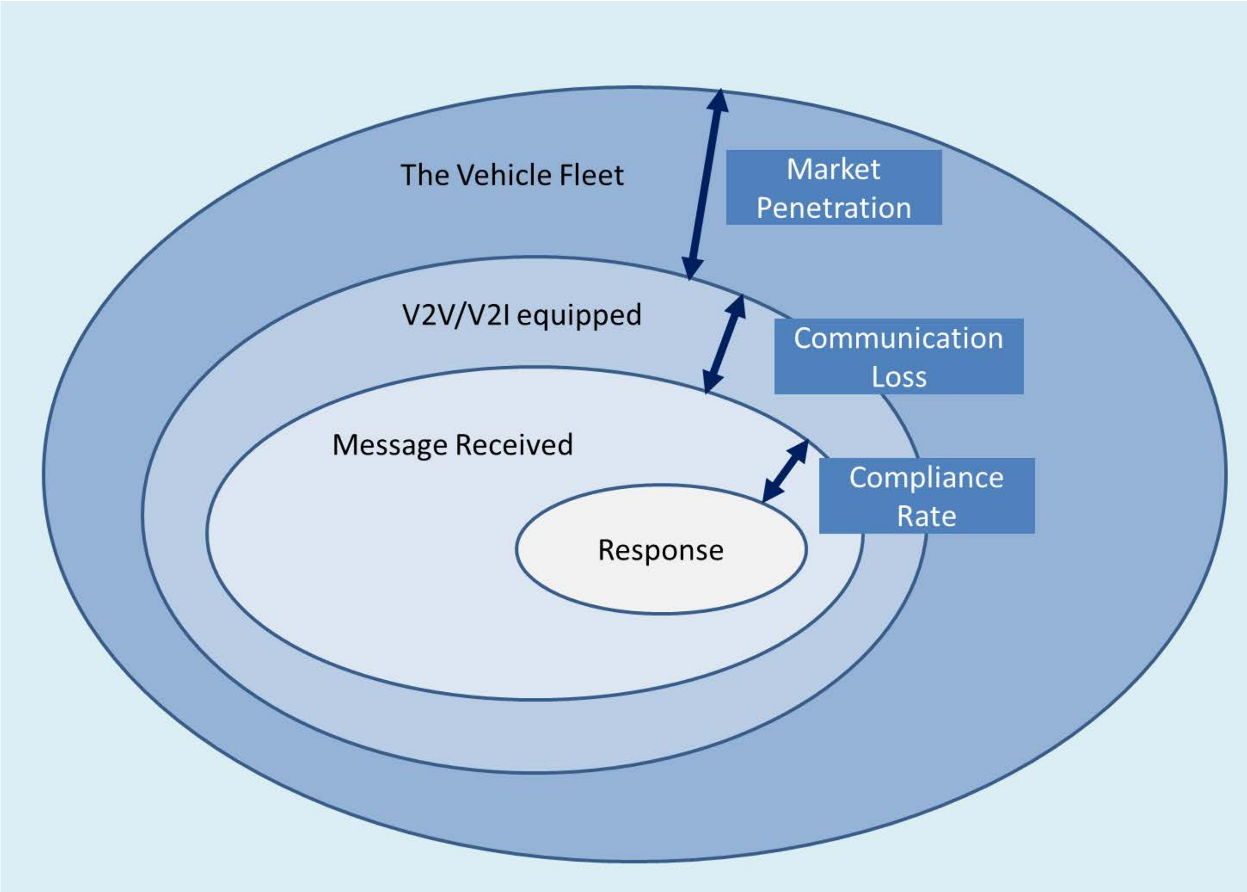

Figure 7-1: Market Penetration, Communication Loss, and Compliance Rate Effect on Response [Source: Booz Allen]

7.2.2 Evaluating Communications Error within the Modeling Chain

This subsection describes how the second prong of communication error analysis will be accomplished. This approach assesses only the communication error component, ignoring driver compliance rates, for a stratified set of given market penetration rates.

Because of the effects of adding the communication dimension to the other dimensions already being evaluated on model run times and the number of required repetitions to obtain a result, it is proposed to apply the communications modeling to a selected subset of scenarios.

In order to analyze the data-flow types associated with each of the DMA applications, a preliminary data-flow matrix has been identified which shows the major data-flow associated with each of these applications. The data-flow elements are defined as follows (Table 7-2):

1. V2V communication is typically DSRC and do not consider intermediate data-flow between V2I and I2V or non-vehicular users.

2. V2I (and I2V) typically represent communication between vehicles and the road-side infrastructure (RSEs) and could be DSRC, Cellular or Hybrid.
3. V2X (and X2V) represent the communication between travelers (including pedestrians or transit) and a processing center (TMC, Transit center) and typically takes place over cellular communication.

Table 7-2: Data-flow Matrix for DMA Applications

Application	V2V	V2I/I2V	V2X/X2V
Q-WARN			▲
SPD-HARM		▲	
CACC	▲		
I-SIG		▲	
TSP		▲	
PED-SIG			▲
PREEMPT		▲	
FSP		▲	

The within the modeling chain modeling of communication errors will use the python based open-source tool TCA (Trajectory Converter Analysis). The TCA tool is designed to test different strategies for producing, storing, and transmitting Connected Vehicle Probe Data Message (PDM) and Basic Safety Message (BSM) information. The TCA reads in and uses vehicle trajectory information, Roadside Equipment (RSE) location information and strategy information to produce a series of snapshots that the vehicle would produce and a record of RSEs and other vehicles to which the messages would be transmitted. The current version of TCA cannot simulate service disruptions or errors and losses, but can be modified to randomly drop some messages or truncate for testing purposes.

The TCA-V is an extension to TCA that can work in parallel with a VISSIM simulator to collect trajectory information and disperse the connected vehicle message sets. Apart from the trajectory input, the TCA tool requires a strategy file (which defines DSRC and cellular communication strategy and parameters) and an RSE location file (which defines the locations of the RSEs). Figure 7-2 demonstrates a possible data-flow diagram to use TCA in conjunction with the San Mateo Test bed.

There are several advantages of using the TCA tool with the San Mateo Test bed for communications modeling. They are:

- Easier simulation set-up and modifiable TCA code.
- Bi-level set up makes it easy to monitor the simulation process.
- Communication attributes can be changed directly.

However, the use of current build of TCA would encounter the following disadvantages:

- Assumes perfect communication with no service disruptions.
- Slower simulations due to interaction between multiple modules of software.
- Not applicable for macroscopic simulations.

Effectively, TCA tool would be a good addition to the Test bed in order to simulate communications between different components using different modes and different data-flow types.

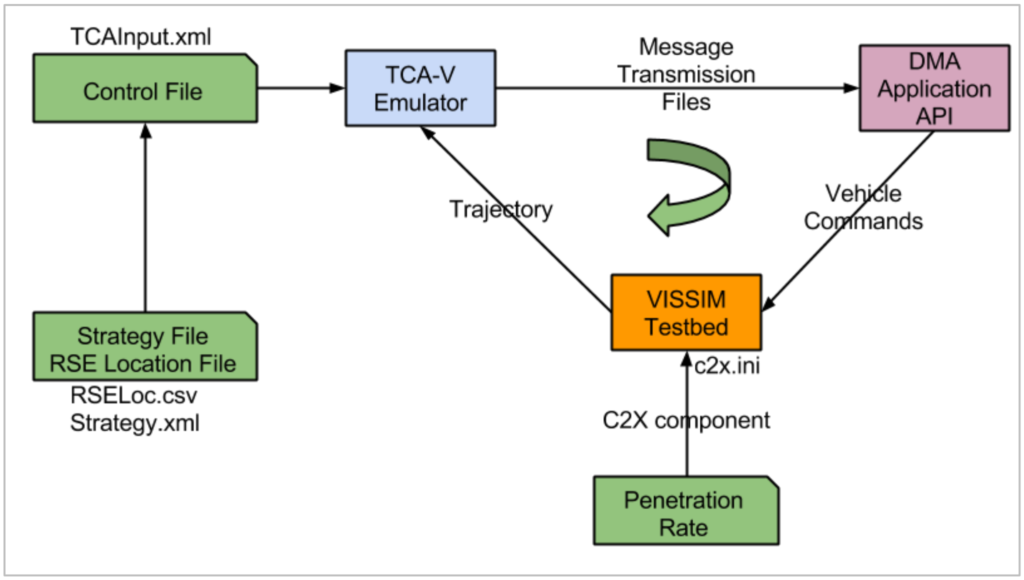

Figure 7-2: TCA Tool Interactions with the Testbed [Source: Booz Allen]

7.3 Risks

This section provides a summary of known risks to the execution of the work.

Since the Testbed is already up and running within a simulation model environment, there are relatively few technical risks. Model run and data processing times are known. The primary unknowns are:

1. The ability of the DMA emulators to work with the San Mateo Testbed.
    a. The TTI SPD-HARM and Q-WARN prototype has been interfaced in one direction with VISSIM 5.4. The prototype software reads VISSIM output, but VISSIM does not currently read prototype output. This will require the team to write the necessary software.
        i. One aspect that reduces this risk is that the prototype has already been written and tested for its ability to read VISSIM output.
        ii. The team is reducing this risk by borrowing the entire prototype software. Thus only the reverse direction, VISSIM reading prototype output needs to be programmed.
    b. The UC PATH CACC Algorithm was developed and tested with a different network and therefore modifications might be needed to use it with the San Mateo Testbed.
    c. The University of Arizona MMITSS Algorithm was developed and tested with a different network and therefore modifications might be needed to use it with the San Mateo Testbed.
2. The results of the Phase 1, Phase 2, and Phase 3 analyses.
    a. Phase 1 analysis may suggest different directions for Phase 2.

Regarding the TTI SPD-HARM/Q-WARN algorithm, we have recently developed and tested the two way interface as part of the INFLO Impact Assessment project. This is no longer a risk. Regarding the UC PATH CACC and UA MMITSS algorithms we have on our team professors with knowledge of both algorithms to assist in identifying and overcoming interface issues.

7.4 Satisfaction of AMS Requirements

This section enumerates the AMS requirements that every Testbed attempts to satisfy. Table 7-3 shows the list of AMS requirements and the Testbed capability once the Testbed 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 7-3: The AMS requirements and the capability of the Testbed.

SNo	ID	Requirement	San Mateo 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	3
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),.	3
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.	2
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.	1
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.	2
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	2
11	SU-11	The AMS Testbed shall emulate fixed route/fixed schedule transit, flexible route bus, rail transit and paratransit.	1
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

SNo	ID	Requirement	San Mateo Testbed
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
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.	3
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.	3
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.	3
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.	3
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.	3
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	3
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.	2
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

SNo	ID	Requirement	San Mateo Testbed
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.	2
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	2
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.	2
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.	1
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.	1
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, Car	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.	1
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.	1
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.	1
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.	3
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	1
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.	1
46	OD-2	The AMS Testbed shall emulate the processing time associated with performing Data Quality Control and Aggregation processes.	1
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.	1

SNo	ID	Requirement	San Mateo Testbed
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.	1
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.	1
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.	1
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.	3
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.	3
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.	2
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.	2
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	2
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.	1

SNo	ID	Requirement	San Mateo Testbed
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	2
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.	1
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.	2
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.	2
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.	2
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.	2
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	2
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.	1
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)	1
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.	1
75	AP-1	The AMS Testbed shall emulate Dynamic Shoulder Lanes.	3
76	AP-2	The AMS Testbed shall emulate driver behaviors in Dynamic Shoulder Lanes that are distinct from behaviors on regular lanes.	3
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+).	3
78	AP-4	The AMS Testbed shall emulate Dynamic Lane Use Control, including shoulder lanes.	3
79	AP-5	The AMS Testbed shall emulate Dynamic HOV/Managed Lanes.	3
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.	1
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.	1

SNo	ID	Requirement	San Mateo Testbed
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.	1
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.	1
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.	1
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.	1
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.	1
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).	1
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.	3
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	3
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.	3
93	AP-19	The AMS Testbed shall emulate Intelligent Dynamic Transit Operations (IDTO), including transit connection protection and dynamic dispatch.	3
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.	3
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.	1
97	AP-23	The AMS Testbed shall emulate Dynamic Junction Control	3
98	AP-24	The AMS Testbed shall emulate Dynamic Merge Control	3
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.	3
100	AP-26	The AMS Testbed shall emulate freight operations, including drayage optimization and freight Traveler information	3

SNo	ID	Requirement	San Mateo Testbed
101	OC-1	The AMS Testbed shall emulate a range of Operational Conditions, including variations in travel demand, weather, and incident patterns.	1
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	1
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.	1

Chapter 8. Model Calibration

The US 101 freeway VISSIM Model was calibrated for the freeway only against floating car travel time runs for given observed demand levels (clear weather, no incident conditions). This calibration must be extended to include El Camino Real, the cross connecting streets, and the freeway as well.

For weather and incident conditions, capacity affecting parameters will be drawn from literature, such as the FHWA weather simulation guide. An examination of corridor flow data suggests that the demand effects of the mild weather in the corridor can be neglected. Similarly, the incidents to be evaluated (single lane closures persisting no more than 1 hour) will have minor effects on demand, therefore, the minor demand effects of these incident types will be neglected. The San Mateo team will document the calibration process of the Testbed as part of Task 8 of the project.

8.1 Model Calibration Approach

The model was previously calibrated according to the calibration criteria set forth by FHWA's Volume III Microsimulation Guidelines (see Table 8-1). For this analysis, the calibration will be revisited for the augmented model.

The augmented model (freeway plus parallel arterial) will be recalibrated/validated for three specific operational conditions:

- Recurring congestion conditions (no incidents, fair weather)
- Non-Recurring congestion conditions
    - Rain
    - Lane Blocking Incidents

Volume Audit: The model simulated flows will be compared to observed traffic volumes on the freeway mainline segments (between ramps) by direction throughout the network, according to the Wisconsin/FHWA criteria.

Travel Time Audit: Model simulated travel times will be compared to observed travel times through various segments of US 101. Freeway travel time data will be pulled for 2010-2012 for three conditions: recurring congestion (no incidents, fair weather), rain, and for lane blocking incidents.

The objective will be to obtain simulated end-to-end freeway travel times generally within 15% of the observed average values for each condition, for 85% of the cases.

Satisfactory historic travel time data is not available for El Camino Real, so the team will compare simulated operations on the street to field observations of the general degree of congestion present at each signal during PM peak periods with under recurring congestion conditions, only.

Visual Audits: Visual audits of the VISSIM model animation will be conducted to compare against field observed conditions. This latter test can only be conducted for recurring congestion conditions because the aerial photos and field observations of existing congestion were conducted only for recurring congestion conditions.

Table 8-1: Microsimulation Model Calibration Criteria

Criteria & Measures	Calibration Acceptance Targets
Individual Link Flows	
Within 1% for flows between 700 and 2700 veh/h	> 85% of cases
Within 100 veh/h for flows less than 700 veh/h	> 85% of cases
Within 400 veh/h for flows greater than 2700 veh/h	> 85% of cases
Sum of all link flows	Within 5%
GEH statistic < 5 for individual link flows	> 85% of cases
GEH statistic for sum of all link flows	GEH < 4
Journey Times within 15% (or 1 minute if higher)	> 85% of cases
Speeds, Bottlenecks	To analyst's satisfaction

Adapted from Guidelines for Applying Traffic Microsimulation Modeling Software, Volume III, Traffic Analysis Toolbox, FHWA, 2004

8.2 VISSIM Model Calibration Parameters

Some of the parameters that will be adjusted during this calibration effort are listed below.

- Freeway Driver Behavior: This parameter is related to the aggressiveness of drivers, and has the effect of increasing or reducing headways between vehicles. For this model, the default setting will be adjusted to obtain a reasonable calibration.
- Lane Change Headway: Similar to the behavior parameter, this parameter will be adjusted to better account for more aggressive drivers than the default within VISSIM software.

The above two parameter sets will be the primary model calibration tools. However, some fine tuning will be made of the routing and estimated weaving volumes to better match observed operations in the field.

- Vehicle Routing: Some of the vehicle routing percentages that were initially input directly from the origin-destination survey data will be revised to obtain a better calibration of operations at the major weaving sections between Hillsdale and SR92 on US101 and on SR92 near Delaware.
- Input Volumes: A review of the output animation will be conducted in comparison to the aerial photographs taken during the data collection effort. Where it is noted that vehicle density in both directions of US101 is less than in the photographs, the input volumes for critical locations and times will be fine-tuned to better match the weaving densities observed in the aerial photos.

Finally, additional freeway driver behaviors will be examined during the calibration process to handle heavy weave and merge sections, lane drop with heavy traffic situations, and reduced capacity due to weaving, etc.

1. Freeway (free lane selection)/Following/ CC1 (Headway Time)
2. Freeway (free lane selection)/Lane Change/ parameters
3. Freeway Heavy Weave Merge/Following/parameters
4. Freeway Heavy Weave Merge/Lane Change/parameters
5. Freeway Heavy Lane Drop/Following/parameters
6. Freeway Heavy Lane Drop/Lane Change/parameters

7. Freeway Heavy Merge 92 EB/Following/parameters
8. Freeway Heavy Merge 92 EB/Lane Change/parameters
9. Freeway Heavy Weave_LowCap1/Following/parameters
10. Freeway Heavy Weave_LowCap1/Lane Change/parameters

Note that the last 4 parameter sets (Freeway Heavy Merge 92 EB, Freeway Heavy Weave_LowCap1) are custom sets of parameters that have been created to address the reduced capacity of some of the freeway weave sections in the vicinity of the SR92/US101 interchange.

8.3 Model Adjustments for Non-Recurring Congestion

The San Mateo Testbed will be used to test the operational benefits of DMA under light rain and moderate incident conditions. Two additional operating conditions to address more severe weather will also be evaluated (as described later), but the model will not be calibrated to those severe weather conditions (since they do not occur in the geographic area where the testbed is located).

8.3.1 Weather Scenario Calibration

The corridor experienced 26 rain days during the PM peak period in 2012. Travel time, spot speed, and mainline volumes are available for these days, and will be used for the rainy day calibration of the model adjustments. A representative (median travel time value) rainy day will be selected. Volumes, travel times, and spot speed will be drawn from the California Performance Measurement System (PeMS) database for the PM peak period of that day. The free-flow speed and capacity adjustment factors recommended by Chapter 36 of the 2010 Highway Capacity Manual will be converted into the appropriate VISSIM car following and desired speed profiles adjustments. The model ramp and mainline demands will be factored to match the observed rainy day mainline volumes. The model will be run with the rainy day demands and the end to end travel times compared to the observed rainy day times (averaged for each hour in the peak period). The desired speed profiles and car following parameters will be adjusted to meet the calibration criteria. The spot speeds observed by PeMS will be used to identify fine tuning adjustments for rainy day operation.

8.3.2 Incident Scenario Calibration

The corridor experienced 473 incidents in the NB direction during the PM peak period in 2012. Approximately half of these were crashes blocking one or more lanes. The median (50%) duration of crashes was 12 minutes. Travel time, spot speed, and mainline volumes are available for days with lane blocking incidents, and will be used for the incident calibration of the model adjustments. A representative (median travel time value) incident day will be selected. Volumes, travel times, and spot speed will be drawn from the PeMS database for the PM peak period of that day. The free-flow speed and capacity adjustment factors recommended by Chapter 36 of the 2010 Highway Capacity Manual will be converted into the appropriate VISSIM car following and desired speed profiles adjustments. The model ramp and mainline demands will be factored to match the observed representative incident day mainline volumes.

The incident location, lanes blocked, start time, and duration will be coded into the model for the representative incident day. The model will be run with the selected representative incident day demands and the end to end travel times compared to the observed times (averaged for each hour in the peak period). The desired speed profiles and car following parameters will be adjusted to meet the calibration criteria. The spot speeds observed by PeMS will be examined to determine if fine tuning adjustments are also required for incident day operation.

Chapter 9. Evaluation Approach

As described earlier, the analysis scenarios are designed to answer the different research questions defined for this project. This section maps the analysis scenarios to the research questions categories. This section shows the system evaluation plan to answer the DMA research questions based on the analysis conducted and the approach to conducting sensitivity analysis. Key features of this approach are:

- Use of the Testbed microsimulation tool to evaluate fundamental variations in DMA bundle performance for varying operating conditions, varying market penetrations, and varying communication loss/latencies. (See the Question #1 discussion in Table 9-1)
- Post model analysis and extrapolations of the core microsimulation results to address other "what-if" issues raised in the remaining research question list. (See the discussions for Questions 2-19, 21-25 in Table 9-1)
- Use of the microsimulation tool again to evaluate tradeoffs between DMA market penetration and ATDM infrastructure investment intensities. (See Question #20 discussion in Table 9-1)

9.1 Evaluation Plan to Answer DMA Questions

Table 9-1 below highlights how each DMA research question will be addressed through a combination of baseline scenarios, microsimulation model analyses, sensitivity analyses using the model, and off-model sensitivity analyses using model results.

Table 9-1: The different DMA Research Questions and Preliminary Hypothesis

ID	DMA Research Question	Preliminary Hypothesis	Evaluation Approach	Initial results
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 and MMITSS 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.	Answering these questions will require microsimulation testing of different levels of connected vehicle response rates (which are in turn a function of the penetration rates and communication loss rates) against different levels of roadside detection (loops, CCTV, etc.) to see what the impacts are on the TMC's knowledge of traffic conditions on the facility. These tests would be performed over a range of demand, weather, and incident conditions for the facility. For this question, legacy system will be assumed to be at its currently baseline level in the corridor. These tests will NOT look at different legacy system investment levels	Phase 1
II	**Synergies and Conflicts**			
2	Are the DMA applications and bundles more beneficial when implemented in isolation or in combination?	DMA bundles that are synergistic such as Q-WARN and SPD-HARM will be more beneficial when implemented in combination than in isolation.	This question can be answered qualitatively through a technical examination of the previously completed microsimulation results for Question #1, and an examination of the concepts of operations for the applications within the INFLO and MMITSS bundles to identify synergies between them in terms of the objectives (mobility, safety). No new simulation analysis would be required	Phase 1

ID	DMA Research Question	Preliminary Hypothesis	Evaluation Approach	Initial results
3	What DMA applications, bundles, or combinations of bundles complement or conflict with each other?	Certain combinations of INFLO and MMITSS will complement each other resulting in increased benefits, while others will conflict with each other resulting in no benefits or reduced benefits.	This question can be answered qualitatively through a technical examination of the previously completed microsimulation results for Question #1, and an examination of the concepts of operations for the applications within the INFLO and MMITSS bundles to identify synergies between them in terms of the objectives (mobility, safety). No new simulation analysis would be required	Phase 1
4	Where can shared costs or cost-effective combinations be identified?**	Bundles that are highly synergistic will have shared connected vehicle technology deployment costs	Not Addressed using this Testbed	
5	What are the tradeoffs between deployment costs and benefits for specific DMA bundles and combinations of bundles?**	Incremental increase in deployment will result in higher benefit-cost ratio up to a certain deployment cost threshold, after which benefit-cost ratio will reduce.	Not Addressed using this Testbed	
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?	Certain DMA bundles or combinations of bundles will yield the highest benefits under specific operational conditions. For example, a combination of INFLO and MMITSS will have greater impact on	This question would be answered by examining the results of the Question #1 tests, looking at how INFLO and MMITSS contributed to the result.	Phase 1

ID	DMA Research Question	Preliminary Hypothesis	Evaluation Approach	Initial results
		days with high-demand.		
7	Under what operational conditions are specific bundles the most beneficial?	A DMA bundle will yield the highest benefits only under certain operational conditions. For example, under sever congested conditions, SPD-HARM will have limited impact.	This question would be answered by examining the results of the Question #1 tests, looking at how INFLO and MMITSS contributed to the result. Additional microsimulation analyses of individual DMA bundles will NOT be performed.	Phase 1
8	Under what operational conditions do particular combinations of DMA bundles conflict with each other?	Certain combinations of bundles will conflict with each other under specific operational conditions, resulting in no benefits or reduced benefits.	This question would be answered by examining the results of the Question #1 tests, looking at how INFLO and MMITSS contributed to the result. Additional microsimulation analyses of individual DMA bundles will NOT be performed.	Phase 1
9	Which DMA bundle or combinations of bundles will be most beneficial for certain modes and under what operational conditions?	Certain DMA bundles or combinations of bundles will yield the highest benefits for specific modes and under certain operational conditions.	Not Addressed	
10	Which DMA bundle or combinations of bundles will be most beneficial for certain facility types (freeway, transit, arterial) and under what operational conditions?	Certain DMA bundles or combinations of bundles will yield the highest benefits for specific facility types and under certain operational conditions.	This question would be answered by examining the results of the Question #1 tests, looking at how INFLO and MMITSS contributed to the result. Additional microsimulation analyses of individual DMA bundles will NOT be performed.	Phase 1

ID	DMA Research Question	Preliminary Hypothesis	Evaluation Approach	Initial results
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?	(1) Certain synergistic DMA bundles will yield the most benefits when deployed together on individual facilities rather than as system-wide or region-wide deployments and under certain operational conditions. (2) Certain synergistic DMA bundles will yield the most benefits when deployed together on a system rather than as facility-specific or region-wide deployments and under certain operational conditions. (3) Certain synergistic DMA bundles will yield the most benefits when deployed together in a region rather than as facility-specific or system-wide deployments and under certain operational conditions.	This question would be answered by examining the results of the Question #1 tests, looking at how INFLO and MMITSS contributed to the result. Additional microsimulation analyses of individual DMA bundles will NOT be performed.	Phase 1
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?	Benefits or negative impacts from bundles will be unevenly distributed by facility or other sub-element of the network.	This question would be answered by examining the results of the Question #1 tests, looking at how INFLO and MMITSS contributed to the result. Since the Testbed is a corridor, this question will be evaluated for the individual facility and overall corridor levels.	Phase 1
IV	**Messaging Protocols**			

ID	DMA Research Question	Preliminary Hypothesis	Evaluation Approach	Initial results
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?	(1) BSM Part 1 data transmitted every 10th of a second via DSRC is not critical for the effectiveness of DMA applications, with the exception of CACC. (2) DMA bundles will be more effective with alternate messaging protocols in addition to BSM Part 1	This question would be answered by examining the sensitivity analysis results employing the TCA prototype.	Initial Results in Phase 1; Final Results in Phase 2
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?	Bundles that most significantly influence or are impacted by travelers' trip making decisions (EnableATIS, IDTO) or pedestrian movements (MMITSS, R.E.S.C.U.M.E.) will have the most critical need for messaging by pedestrians, and pre-trip and en route travelers. This criticality will 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?	DMA applications, with the exception of component applications of the INFLO and MMITSS bundles, will not need data to be transmitted via DSRC as	**Not Addressed**	

ID	DMA Research Question	Preliminary Hypothesis	Evaluation Approach	Initial results
		higher-latency communications media (e.g., cellular) will suffice.		
VI	**Communications Latency and Errors**			
16	What are the impacts of communication latency on benefits?	As communication latency increases, benefits will decrease. Most significant decrease will be observed for MMITSS and INFLO than for the other bundles.	This question would be answered by examining the sensitivity analysis results employing the TCA prototype.	Initial Results in Phase 1; Final Results in Phase 2
17	How effective are the DMA bundles when there are errors or loss in communication?	Effectiveness of some DMA bundles will be more impacted than others due to errors or loss in communication. MMITSS and INLFO will be most impacted by errors or loss in communication.	This question would be answered by examining the sensitivity analysis results employing the TCA prototype.	Initial Results in Phase 1; Final Results in Phase 2
VII	**RSE/DSRC Footprint**			
18	What are the benefits of widespread deployment of DSRC-based RSEs compared with ubiquitous cellular coverage?	(1) In comparison to widespread cellular coverage, widespread deployment of DSRC-based RSEs will be excessive for DMA bundles. (2) Concentrated deployment of DSRC-based RSEs will be more cost-beneficial in highly congested urban areas than in non-urban or low	This question would be answered by examining the sensitivity analysis results employing the TCA prototype.	Initial Results in Phase 1; Final Results in Phase 2

ID	DMA Research Question	Preliminary Hypothesis	Evaluation Approach	Initial results
		to moderate congested urban areas.		
19	Which technology or combination of technologies best supports the DMA bundles in terms of benefit-cost analysis?**	More cost-effective benefits will be observed when connected vehicles transmit and receive messages using dual mode communications (e.g., both DSRC and cellular).	Not Addressed	
VIII	**Prediction and Active Management Investment**			
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 (individually and in combination) will be more cost-effective only when coupled with prediction and active management.	Not Addressed	
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?	BSM Part 1 sent via DSRC is critical only to CACC; however other DMA applications will also need some elements of BSM Part 1 (i.e., position, speed, and acceleration) to be effective even in the near term. This is valid for all operational conditions.	This question would be answered by examining the sensitivity analysis results employing the TCA prototype.	Phase 3

ID	DMA Research Question	Preliminary Hypothesis	Evaluation Approach	Initial results
22	At what levels of market penetration of connected vehicle technology do the DMA bundles (collectively or independently) become effective?	Benefits will increase with increase in market penetration of connected vehicle technology; some bundles will yield significant benefits even at lower market penetration levels.	This question would be answered by examining the results of the Question #1 tests, looking at how INFLO and MMITSS contributed to the result.	Phase 1
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)? **	Bundles that influence traveler decision-making and leverage widely deployed mobile device technology, such as EnableATIS, FRATIS, and IDTO, will yield measureable but geographically diffused system-level impacts under near-term deployment 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)?	Effectiveness of some DMA bundles will be more impacted than others due to availability of PII. Bundles that influence traveler decision-making, such as EnableATIS, FRATIS, and IDTO, will be most impacted with availability of PII versus no PII.	Not Addressed	

ID	DMA Research Question	Preliminary Hypothesis	Evaluation Approach	Initial results
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?	Effectiveness of DMA bundles will be impacted by the lack of participation by local agencies/entities.	Not Addressed	

9.2 Analysis Scenarios

The four operating conditions plus the two extra severe weather operating scenarios described in Chapter 4 will be the baseline against which the DMA applications will be evaluated.

9.3 Performance Measures

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

- Safety – surrogate safety measures;
- Mobility –travel time and delay;
- Reliability –the relative predictability of the travelers travel time;
- Emissions – carbon monoxide (CO), carbon dioxide (CO2), Nitrogen Oxides (NOx) and Hydrocarbons (HC);
- Fuel Consumption– The consumed gallons per mile (Gallons/mile).

Table 9-2 identifies the performance measures that will be produced by the San Mateo test bed for the DMA application evaluations. The measures will be reported separately for the freeway and for the coordinated parallel arterial street. In some cases, such as shockwaves, the performance measure will be reported only for the freeway.

In the case of fuel consumption and carbon dioxide equivalent emissions, EPA approved rates for quick estimation planning purposes will be used to convert VMT by speed bin into the appropriate performance measure.

Table 9-2: Performance Measures for the San Mateo Test Bed

Category	*Type*	*Performance Measure*
Safety	Shockwaves & Speed Variance	1a. Mean and maximum speed difference between adjacent sub-links. (fwy) 1b. Mean and max variance of individual vehicle speeds within each sublink (fwy) 1c. Total number of stops (fwy)
	Lane changes	2. Total number of lane changes
	Queues	3a. Number of Queues on freeway 3b. Vehicle-Hours in Queue (VHQ).
Mobility	Throughput	4. Vehicle-Miles Traveled (VMT) (served)
	Travel Time	5. Vehicle hours traveled (VHT), including entry delay.
Reliability	Travel Time Index	6. The 95th Percentile Travel Time Index (TTI).
Emissions	Carbon Emissions	7. CO2 equivalent tons per peak period
Fuel	Fuel Consumption	8. Gallons Gasoline or Diesel consumed per peak period

Performance measures would be reported separately for the US 101 freeway mainline and for El Camino Real. Some measures (identified above) would be reported only for the freeway.

9.4 Sensitivity Analyses

This section describes how specific combinations of inputs/parameters that reflect uncertainty in assumptions will affect outputs or performance measures and ultimately decisions made.

The following sensitivity analyses will be performed:

- **Demand (Recurring Congestion) Sensitivity:** The microsimulation model reported hourly performance of the DMA applications will be examined within each peak period to assess how demand/capacity ratios for recurrent congestion affect the measured performance of the freeway and the parallel arterial under the various DMA applications.
- **Market Penetration Sensitivity:** The microsimulation model runs involving DMA applications will be done for two to three different levels of driver response rates.
    - The exact response rate values will be determined based on a progressive examination of the simulation runs. Initially a 10% response rate and a 25% response rate will be tested inside the simulation model for the first DMA scenarios. Depending on the initial results a third value response rate may be selected for a third model run. Depending on these results, different initial values of driver response rates may be selected for subsequent DMA scenario runs.
    - A post-processing sensitivity analysis will then be performed on the two to three simulation model runs for each DMA applications to identify the various combinations of market penetration rate and communication loss rate that would yield the assumed driver response rate for each model run. The model run results would then be extrapolated to

construct a graph showing the facility performance results for a wider range of different combinations of market penetration rate and communication loss.

- **Communication Loss Sensitivity:** See above discussion on Market Penetration Sensitivity. In addition, some selected modeling of communication loss using a communications model in the microsimulation modeling chain will be performed on one or more selected DMA scenarios to assess the range of communication losses and performance degradation that might be expected. These sensitivity tests would assume one or more fixed market penetration rates for connected vehicles.
- **Road Detector Infrastructure Sensitivity:** Two or three extra microsimulation model runs will be made for one or two selected DMA scenarios to assess the performance tradeoffs between connected vehicle market penetration rates and road detector densities. This will address the question of the extent to which connected vehicles can substitute for greater investments in road detectors.
- **DMA Application Parameter Sensitivity:** The initial tests in Phase 1 would use a fixed set of default DMA application parameters. At the end of Phase 1, the team, in consultation with the stakeholders will review the results and determine if and how resources might be allocated to investigate the effects of alternate parameter settings for the DMA Applications.
    - For example the detection thresholds for identifying queues and determining recommended speeds in Q-WARN and SPD-HARM might be modified to examine the effects of varying “false alarm” rates on DMA performance. The priority weightings for pedestrians, transit and heavy vehicles might be modified in MMITSS to assess their effects on MMITSS performance.

9.5 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

This section presents the execution plan including a detailed schedule, budget and key roles of staff.

10.1 Execution Summary

This section provides a brief overview of the analysis plan.

10.1.1 Data Needs

Historic performance and demand data will be assembled for the freeway to assist in calibrating the simulation model for representative incident and rain conditions. Highway Capacity Manual capacity and speed adjustment factors will be used for adapting the model to model snow conditions. See Chapter 5, Data Needs and Availability for details

10.1.2 Operational Conditions

Six operational conditions (4 real world and 2 hypothetical snow conditions) will be modeled. See Section 2.2, Operational Conditions for details.

10.1.3 Network Modeling and Calibration

The original freeway only network will be extended to include the parallel arterial street, El Camino Real, and re-validated for the extended network.

The model will also be validated/calibrated for the specific rain and incident conditions to be included in the operational conditions. This will be done by pulling performance data for the freeway for those days in 2012 when rain or an incident was present and selecting one afternoon peak period for each condition to validate the model against.

Historic demand and performance data for El Camino Real is significantly more limited than for the freeway, so the surface street validation will be more qualitative, against field observations of general congestion levels, than quantitative.

See Chapter 8, Model Calibration for details.

10.1.4 Application Specific Modeling

The INFLO and MMITS DMA bundles will be modeled using prototype software developed by others. The Q-WARN and SPD-HARM applications will be modeled using a TTI prototype. The CACC application will be modeled using a UC PATH prototype. The MMITSS bundle will be modeled using a University of Arizona prototype. See Chapter 7, Modeling Approach for details.

See Table 9-2: Performance Measures for the San Mateo Test Bed, in Chapter 9, Evaluation Approach for the performance measures to be computed.

10.1.5 Analysis Scenarios & Sensitivity Analysis

Twenty-four analysis scenarios will be formally tested by the microsimulation model, each scenario representing a different combination of one or more DMA applications and operational conditions.

Sensitivity analyses of different market penetration rates, communication loss rates, road detector infrastructure densities will performed using a combination of additional model runs and off-model post-processing to interpolate and extrapolate the model results. Demand sensitivity will be assessed by evaluating hour by hour performance within each peak period for each scenario.

Communication loss effects will be assessed through a combination of direct communications loss sensitivity modeling and off-model sensitivity analysis. See Section 7.2, Modeling Communication Loss for details.

The analysis will proceed in three phases with 8 scenarios assigned to Phase 1, and a tentative list of 16 additional scenarios assigned to Phases 2 and 3. The intent is to evaluate the results at the end of Phase 1 in consultation with the stakeholders, and refine/revise the scenarios and sensitivity analyses to be conducted in Phases 2 and 3. See Table 4-2: DMA Application Analysis Scenarios, in Chapter 4, Analysis Scenarios for details.

Appendix: Operational Conditions

This section documents the process used to identify four baseline operational conditions, combining different levels of demand, incident, and weather conditions for testing the performance effects of Dynamic Mobility Applications (DMA) on the San Mateo Testbed.

The hypothesis is that the traffic congestion and safety benefits of DMA vary for different levels of recurring congestion (congestion associated with high demand levels) and non-recurring congestion (congestion associated with incidents and bad weather, sometimes in combination with high demand levels). In order to assess the benefits of DMA, it is necessary to test various DMA applications on a variety of operational conditions combining different levels of demand, weather conditions, and incident types. Study resources, however, do not allow microsimulation of every possible combination of the factors. The San Mateo team's approach to reducing the number of operational conditions that need to be tested with full microsimulation analysis employs data collection and exploration employing the steps listed below.

1. Examine real world conditions at the test site,
2. Identify all of the possible combinations of demand, incidents, and weather that occurred on approximately 250 non-holiday weekday afternoon periods,
3. Observe the impacts of these factors (demand, incidents, and weather) separately and in combination on travel times,
4. Remove from further consideration factors that appear to have little effect on observed travel times in the corridor,
5. Identify the frequency of occurrence for each operational conditions,
6. Remove from further consideration low probability conditions (However, keep a few rare but severe conditions in the analysis so that a range of DMA effects may be evaluated later),
7. Assemble a set of operational conditions that span the range of observed congested conditions on the corridor.

Our experimental objective is to estimate the travel time performance and safety benefits of DMA. Our hypothesis is that these benefits will be a function of the severity of the baseline congestion and the degree to which the congestion is caused by non-recurring events (such as adverse weather and lane blocking incidents), in addition to factors related to the implementation of DMA. Based on this hypothesis, we have identified the following factors relevant for identifying the baseline operational conditions for analysis: demand, weather, and incidents.

We don't have data on the actual performance and safety effects of DMA, but we can use the baseline travel times for each operational condition as a proxy for the likely effects of DMA (DMA is hypothesized to be more effective at higher congestion levels, which are indicated by higher travel time indices).[7]

The final number of operational conditions to be used in the analysis was determined to be four, based on the two objectives of the selection process:

[7] Travel time index is the ratio of the actual travel time to the theoretical travel time at free-flow speeds (close to the posted speed limit).

- To identify a full range of operational conditions for testing the improvements, while
- To ensure remaining sufficient project resources for adequate testing options related to the specific design and implementation of the DMA improvements.

The Appendix is divided into the following sections: Data Collection, Data Exploration, Initial Stratified Analysis Scheme and Cluster Analysis Approach.

DATA COLLECTION

The analysis required travel time, demand, weather, and incident data.

Travel Time Data

Travel time data for 251 non-holiday weekday PM peak periods (2-8 PM) for the year 2012 were obtained from the Caltrans PeMS database[8] for 9 miles of US 101 between Woodside Road (milepost 406) and Third Avenue (milepost 416).

The following PeMS defined holidays for 2012 were excluded from the travel time data:

- 01/02/2012 New Year's Day Monday
- 01/16/2012 Martin Luther King, Jr. Day Monday
- 02/20/2012 Washington's Birthday Monday
- 05/28/2012 Memorial Day Monday
- 07/04/2012 Independence Day Wednesday
- 09/03/2012 Labor Day Monday
- 10/08/2012 Columbus Day Monday
- 11/12/2012 Veterans Day Monday
- 11/22/2012 Thanksgiving Day Thursday
- 12/25/2012 Christmas Day Tuesday

The PeMS database computes travel time for each direction of the freeway by examining the spot speeds reported by the various loop detectors located on the selected length of freeway. Five minute average spot speeds for each lane loop detector are archived. The spot speeds are converted to travel time indices for each lane using a nominal 60 mph free-flow speed. The 5-minute lane-by-lane TTIs are then averaged across all lane detectors in the selected study section and direction of the freeway and aggregated to our desired temporal aggregation level. In this case, one hour aggregations were selected.

For the 8.5 mile section of US 101 selected for analysis, there were 30 mainline loop detector stations in each direction (each station recording lane-by-lane speeds for 4 lanes)

Demand Data

Demand data in the form of vehicle miles traveled (VMT) was downloaded from the PeMS database for the subject freeway study section and directions for the year 2012. PeMS estimates the VMT by tallying the volume measured at each lane loop detector and multiplying that volume by the sum of the average distances to the nearest upstream and downstream detectors. The volumes, available at the 5 minute level of aggregation, were aggregated to full daily and PM Peak Period VMT for each of the study days, by direction, over the length of the freeway study section.

[8] http://pems.dot.ca.gov/?redirect=%2F%3Fdnode%3DState#37.7743,-122.2023,10, Accessed June-July 2014.

Figure A-1 shows the variation in measured daily VMT by direction for non-holiday weekdays over the year 2012. The chart shows that the measured daily VMT varies by no more than plus or minus 10% from the annual average over 90% of the non-holiday weekdays of the year.

Weather Data

Twenty-four hours weather data for the year 2012 was extracted from the University of Utah on-line database http://mesowest.utah.edu/ for the San Francisco International airport, which is the closest weather-reporting station to the Testbed. Weather data was then examined for the weekday, non-holiday PM peak periods. Twenty six days of rainy weather were observed at the airport in 2012 during the weekday PM peak period. There was no snow, ice, or ground fog conditions during 2012.

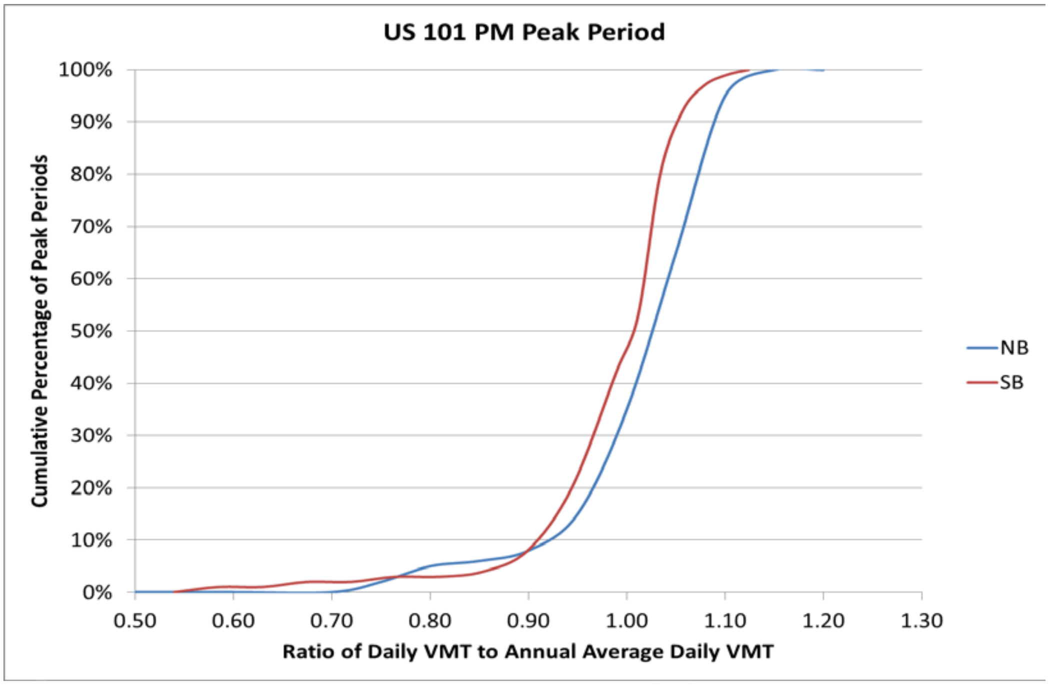

Figure A-1: Cumulative Distributions of Daily VMT [Source: Kittelson]

Incident Data

Incident logs for the California Highway Patrol (CHP) Computer Aided Dispatch (CAD) log were obtained from the PeMS database for the year 2012. This source provides starting time, duration, and location information on incidents by type, but does not indicate if or how many lanes were closed. To help estimate which incidents might have involved lane closures, collision data was obtained from the Caltrans Accident Reporting System (TASAS) for the latest available year, 2010. This source provides greater detail on the accidents, including number of lanes closed.

These two sources were compared to determine if the lane closure data in TASAS could be used to identify the incidents in the CHP database that were likely to have involved lane closures. It was found that lane closure was related to accident duration. So the correlations found in the TASAS database were applied to the accidents in the CHP database to identify which accidents probably resulted in the temporary closure of one or more lanes. Lane blocking incidents were aggregated into categories as shown in Table A-1.

Table A-1: Categorization of Incident Durations

Incident Duration	*Category*
< 16 minutes or unspecified	Other category
16-45 minutes	Assigned to 30 minute category
>45 minutes	Assigned to 60 minute category

The following discussion of incident data focuses primarily on the northbound direction of travel (the peak direction of travel during the PM peak period on the study section of freeway). According to the CHP Incident Log there were a total of 1,268 incidents in the northbound direction in the test corridor (from Woodside Rd to 3rd street) in all of 2012 (24 hours, 7 days a week). There were 473 incidents in the pm peak study period (2:00 to 8:00 PM) during weekdays. Figure A-2 shows the distribution of incidents. By way of comparison, there were a total of 336 incidents recorded in the southbound direction of the San Mateo Testbed, lower than the 473 incidents recorded in the northbound direction. The proportion of recorded incidents that were accidents in the southbound direction (42%) was slightly lower than the accident occurrence (47%) in the northbound direction.

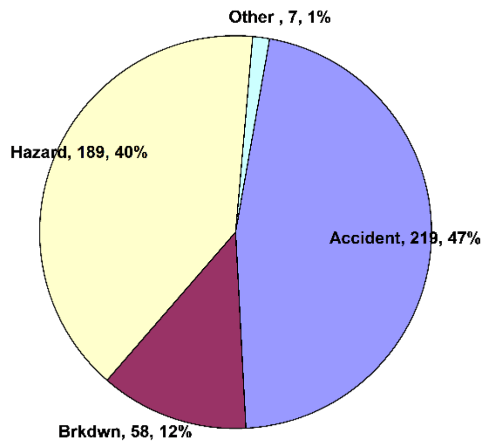

Figure A-2: Incident Classification, US 101 Northbound PM Peak 2012 [Source: Kittelson]

Figure A-3 shows the spatial distribution of all the incidents and accidents along the study corridor. The majority of events occur between mileposts 408 and 409 (South of or Upstream of Whipple Avenue) and mileposts 413 and 414 (downstream of Hillsdale Blvd). Figure A-4 shows a contour plot (heat map) of the accident occurrence along the corridor. The highest frequency of accidents occurs in these locations between 4 and 6 pm.

The distributions of accident durations for both the northbound and southbound directions are shown in Figure A-5. Most of reported accidents lasted less than 3 minutes, but there are several accidents with longer durations. The average weekday PM peak period accident duration is 23.3 minutes for the northbound direction and 25.4 minutes for the southbound direction.

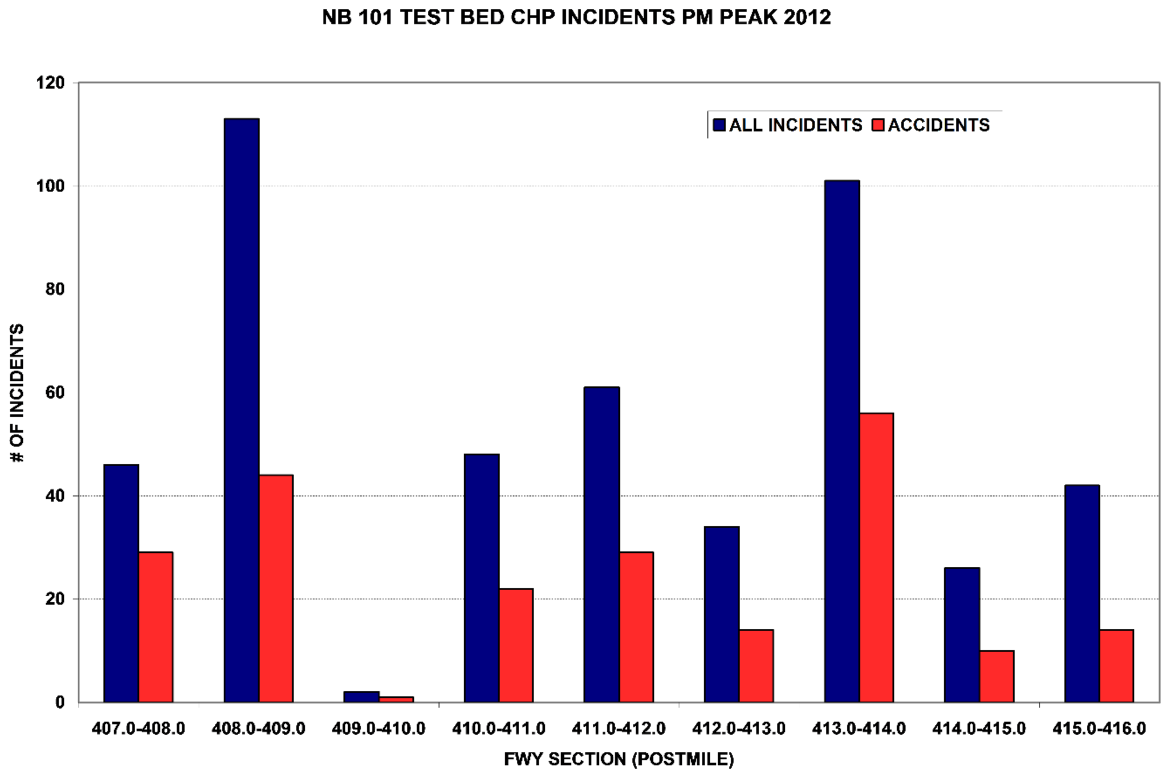

Figure A-3: Spatial Distribution of Incidents along NB US101 [Source: Kittelson]

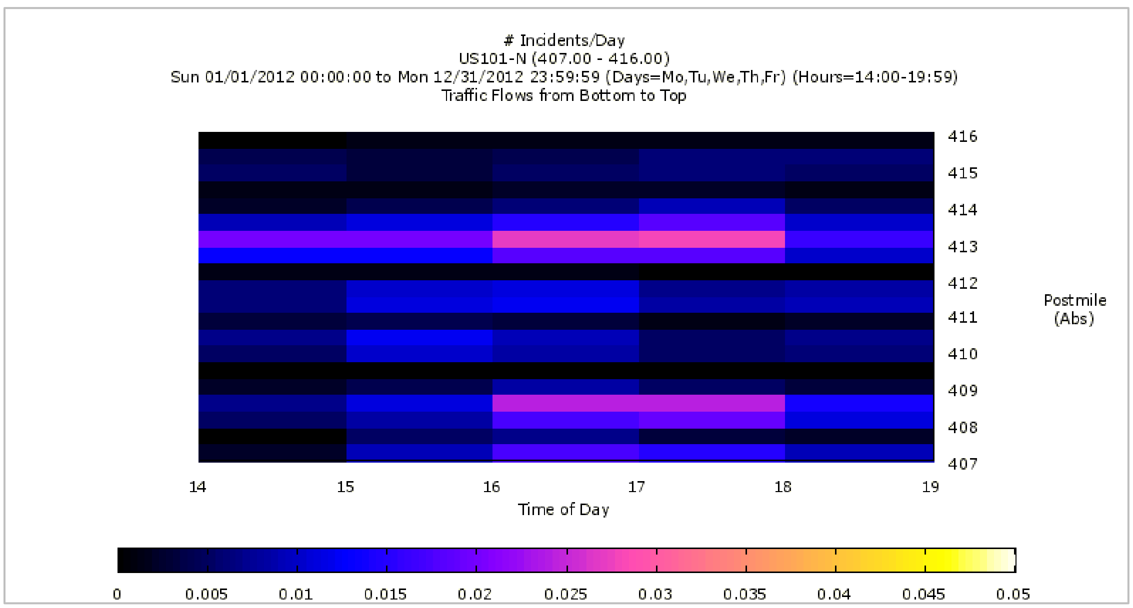

Figure A-4: Heat Plot of Accidents – US 101 Northbound [Source: Kittelson]

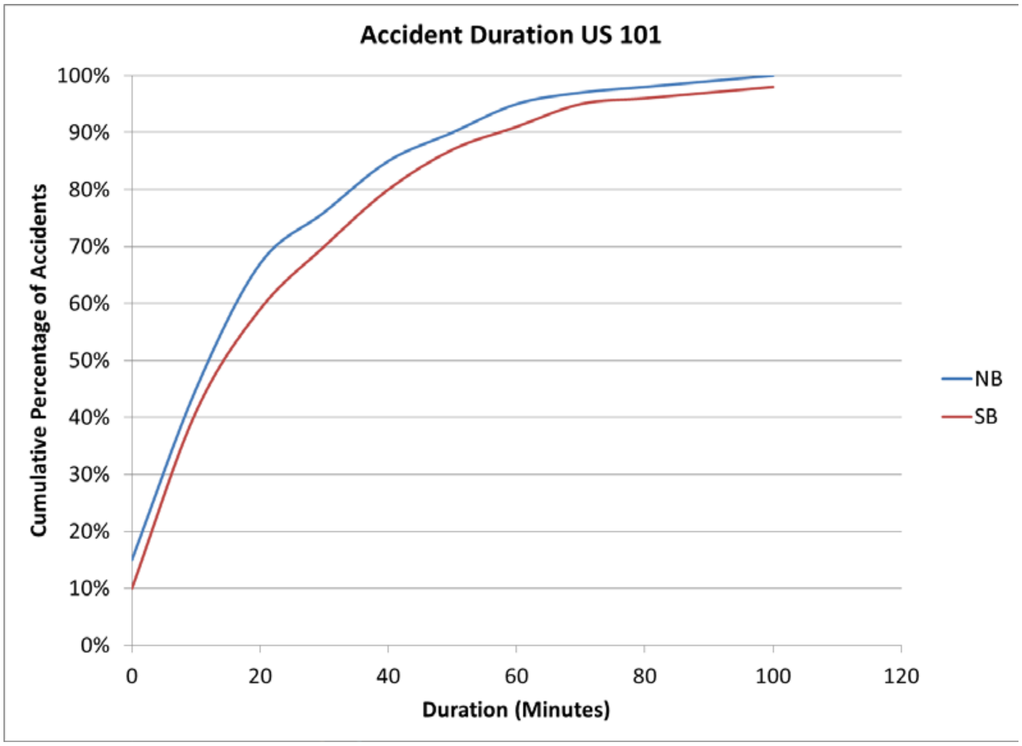

Figure A-5: Distribution of Accident Durations [Source: Kittelson]

Comparison of CHP and TASAS Accidents for NB 101

We compared the number and type of accidents reported on the CHP/CAD and TASAS database for the NB direction of the San Mateo Testbed in the 2010 year, the closest TASAS reporting year. There were 210 CHP recorded accidents in NB 101 in the weekdays PM peak period. The TASAS database reports 107 accidents for the same interval. Almost 13% are injury accidents and 78% are lane blocking accidents.

The spatial distribution of accidents given by the reporting source is shown in Figure A-6. The distribution is similar for both accident sources. There is a higher frequency of accidents in postmile 407-408 (Woodside Rd) and a lower frequency in postmile 408-409 compared to the accident frequency in year 2012 (Figure A-3).We also analyzed CHP reported incidents for the period 2010 through 2013. Figure A-7shows the number of all incidents and accidents. The number of all incidents decreases from 540 in 2010 to 420 in 2013. However the number of accidents remains about the same over the last four years. The maximum difference of about 6% in the number of reported accidents is not statistically significant.

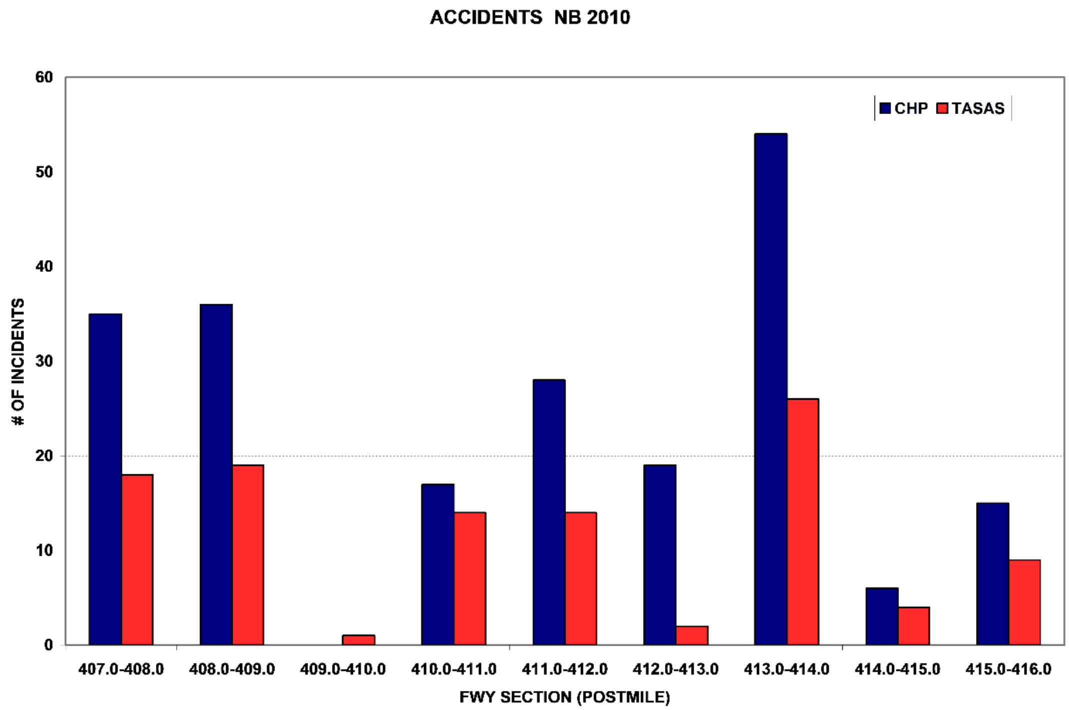

Figure A-6: Comparison of CHP and TASAS Reported Accidents [Source: Kittelson]

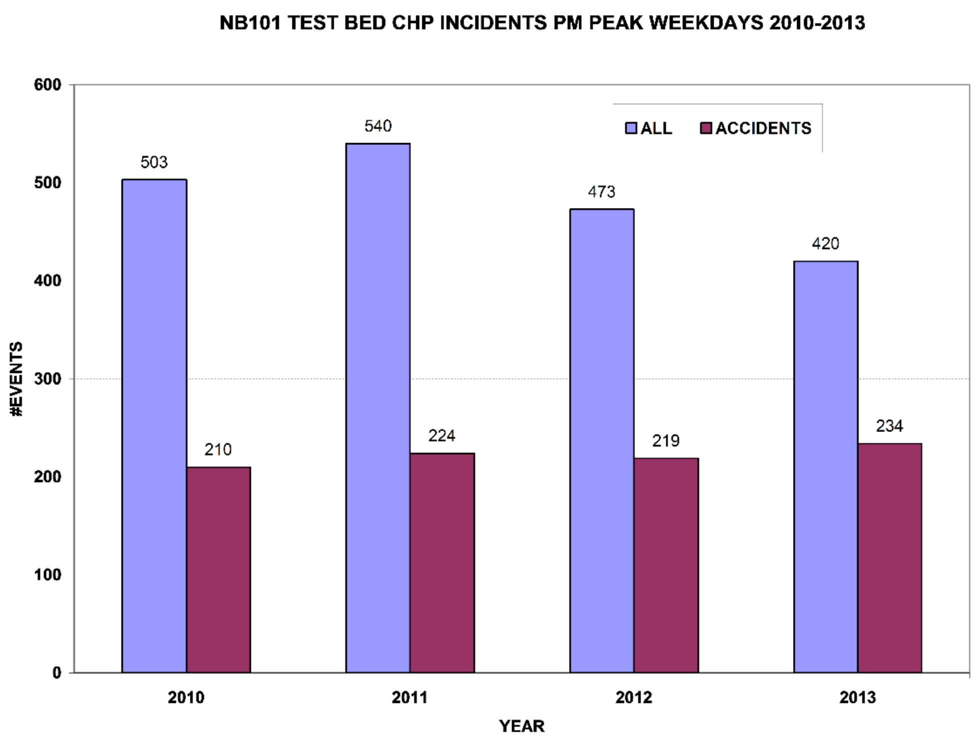

Figure A-7: CHP Reported Incidents 2010-2013 [Source: Kittelson]

Determining Incident Rates

We determined incident rates using incident and traffic information in the PeMS system for the 2012 year. The VMT data from all weekdays in the PM peak (2 pm -8 pm) along the test section of NB 101 was used. The traffic volumes and VMT from detector data are reported for each detector station, as shown in Figure A-8. Figure A-9 shows the variation of VMT during the PM hours. In order to calculate the incident rates, the VMT volumes per the one mile roadway segment that the incidents are reported (see Figure A-3) was investigated. The incident rates and accident rates in #/events per million vehicle-miles of travel for all incidents are shown in Figure A-10. The average accident rate was 3.1 incidents/million vehicle miles.

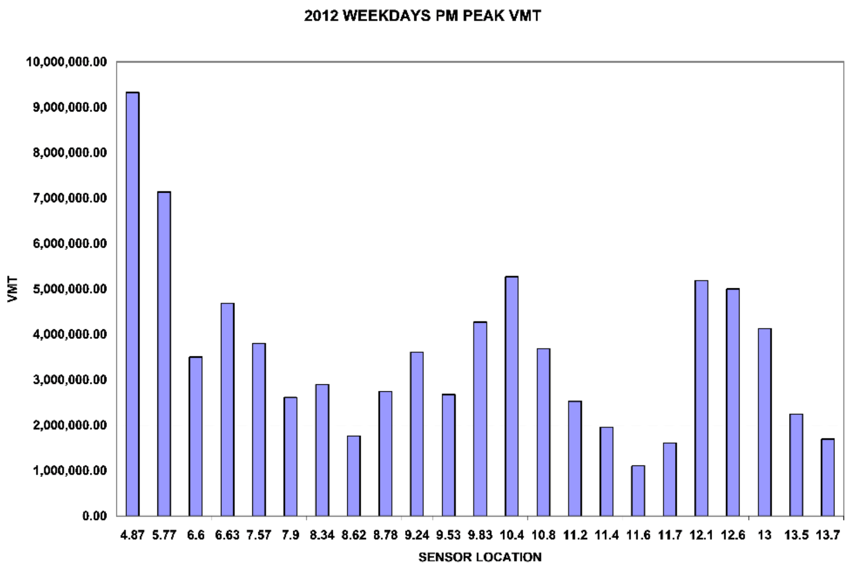

Figure A-8: VMT Distribution US 101 Northbound Weekdays PM Peak 2012 [Source: Kittelson]

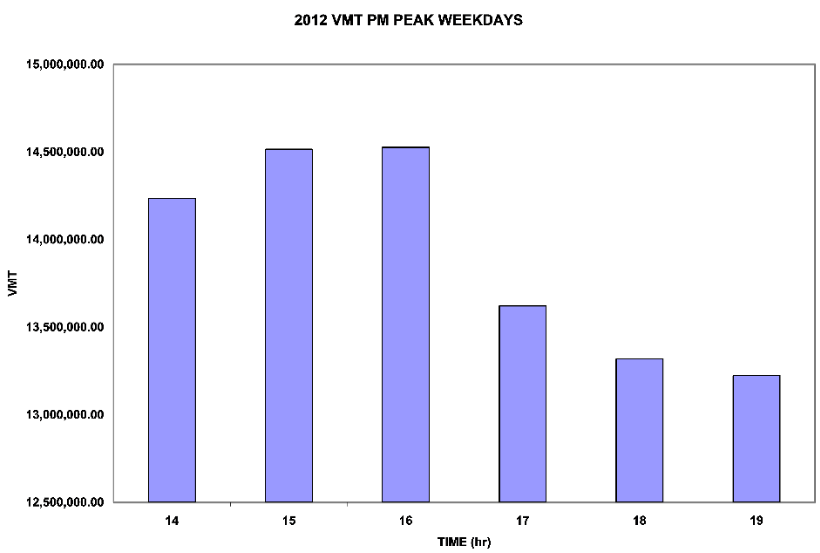

Figure A-9: Hourly Traffic Variation in the PM Peak Period – US 101 NB [Source: Kittelson]

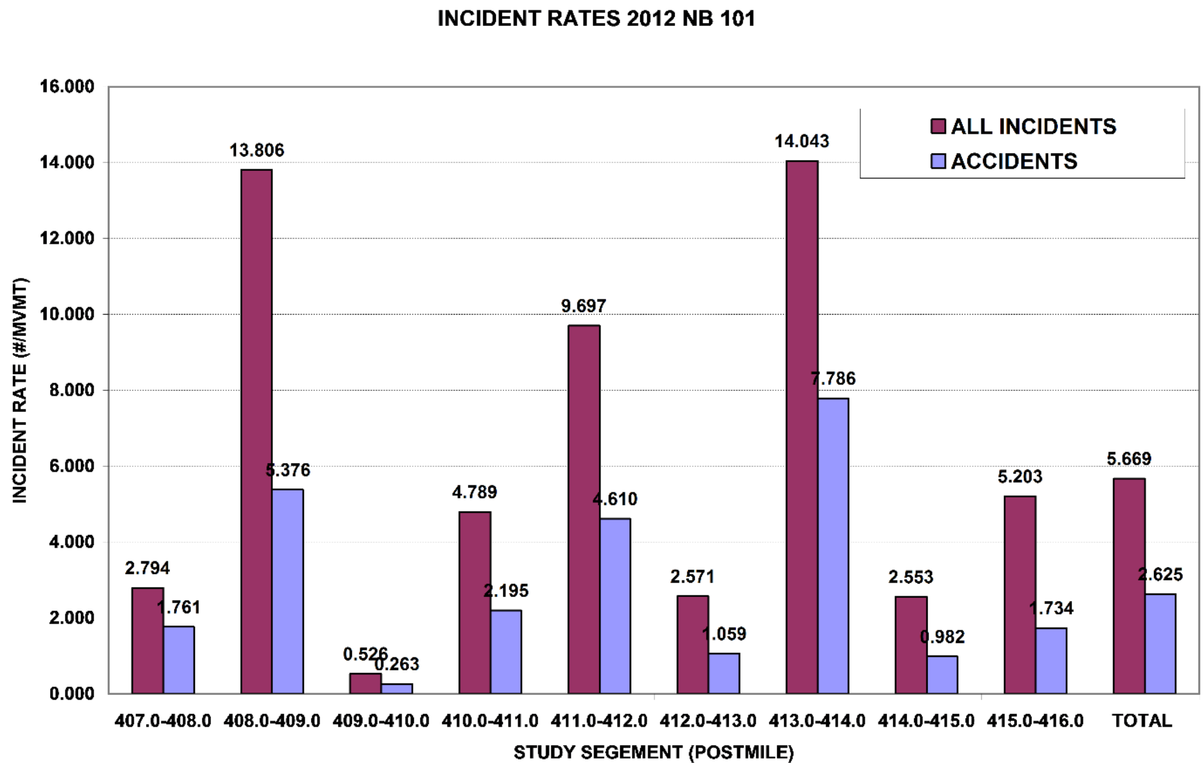

Figure A-10: Incident Rates US 101 Northbound Testbed [Source: Kittelson]

Data Assembly

Traffic data was obtained for both directions (NB and SB) of the US 101 freeway during the PM peak period (2:00-8:00 pm) for 251 weekdays in the year 2012. This data include flows and speeds (travel times) from loop detector data as archived and processed in the PeMS system, weather data from an adjacent weather station, and incident data from the California Highway Patrol (CHP) computed aided dispatch (CAD) logs and the Caltrans accident reporting system (TASAS). The data for each of the 251 weekdays for both directions (NB and SB) was classified into three traffic demand levels (low, medium, and high), three incident types (no incident, incident 30 minutes, and incident 60 minutes), and two weather types (dry and rain). Table A-2 presents the NB 101 data and Table A-3 presents the SB 101 data. Incident data that was classified as “incident not defined” was reclassified as incident 30 minutes and incident 60 minutes based on the travel time associated with that incident. This was done because there were many incidents in the incident logs where the duration was not defined.

Table A-2: Northbound Data for Analysis

Day	Demand	Incident	Weather	Avg Travel Time
1/3/2012	1	3	5	8.58
1/4/2012	1	4	5	8.91
1/5/2012	1	3	5	11.43
1/6/2012	1	3	5	11.35
1/9/2012	1	3	5	9.64
1/10/2012	1	3	5	9.05
1/11/2012	0	4	5	9.52
1/12/2012	1	42	5	12.57
1/13/2012	1	42	5	13.53
1/17/2012	1	3	5	10.66
1/18/2012	1	3	5	13.75
1/19/2012	1	4	5	16.41
1/20/2012	0	4	5	19.31
1/23/2012	1	3	5	8.95
1/24/2012	1	3	5	9.29
1/25/2012	1	3	5	12.2
1/26/2012	1	3	5	12.47
1/27/2012	1	3	5	16.41
1/30/2012	1	4	5	8.91
1/31/2012	1	4	5	10.3
2/1/2012	1	3	5	9.22
2/2/2012	1	4	5	12.78
2/3/2012	1	41	5	14.34
2/6/2012	1	4	5	8.01
2/7/2012	1	3	5	11.94
2/8/2012	1	3	5	10.01
2/9/2012	1	4	6	11.73
2/10/2012	1	4	6	15.23
2/13/2012	1	4	5	11.85
2/14/2012	1	4	5	12.17
2/15/2012	1	3	5	13.5
2/16/2012	0	3	5	18.17
2/17/2012	1	4	5	12.81
2/21/2012	0	3	5	8.57
2/22/2012	1	4	5	11.92
2/23/2012	1	41	5	10.97
2/24/2012	2	3	5	11.25
2/27/2012	1	42	5	11.66
2/28/2012	1	3	5	8.08
2/29/2012	1	4	5	8.96
3/1/2012	1	4	5	9.85
3/2/2012	1	41	5	11.91
3/5/2012	1	3	5	10.39
3/6/2012	1	3	5	12.18
3/7/2012	1	4	5	13.45
3/8/2012	1	4	5	13.74

Day	Demand	Incident	Weather	Avg Travel Time
3/9/2012	1	3	5	12.7
3/12/2012	1	3	5	9.23
3/13/2012	1	4	6	8.89
3/14/2012	1	4	5	14.23
3/15/2012	1	3	5	12.08
3/16/2012	1	4	5	14.26
3/19/2012	1	3	5	8.34
3/20/2012	1	3	5	10.19
3/21/2012	1	4	6	11.12
3/22/2012	1	42	6	12.72
3/23/2012	1	3	5	11.9
3/26/2012	1	3	5	8.27
3/27/2012	1	3	5	17.26
3/28/2012	1	3	5	9.59
3/29/2012	2	4	5	10.67
3/30/2012	1	3	5	10.95
4/2/2012	1	3	5	8.69
4/3/2012	1	4	5	8.6
4/4/2012	2	4	5	9.62
4/5/2012	2	41	5	10.74
4/6/2012	1	3	5	9.72
4/9/2012	1	3	5	8.13
4/10/2012	1	41	5	11.38
4/11/2012	2	4	5	8.57
4/12/2012	2	3	5	11
4/13/2012	1	3	5	11.67
4/16/2012	1	3	5	10.17
4/17/2012	2	41	5	12
4/18/2012	2	3	5	13.58
4/19/2012	2	4	5	13.11
4/20/2012	1	41	5	10.94
4/23/2012	1	4	5	9.07
4/24/2012	1	4	6	10.61
4/25/2012	2	3	5	11.81
4/26/2012	1	4	5	12.48
4/27/2012	1	4	5	15.69
4/30/2012	1	4	5	9.36
5/1/2012	2	4	5	11.24
5/2/2012	2	4	5	12.3
5/3/2012	1	4	5	11.46
5/4/2012	1	3	5	14.29
5/7/2012	1	3	5	8.73
5/8/2012	1	4	5	10.21
5/9/2012	1	3	5	10.19
5/10/2012	1	4	5	13.1
5/11/2012	1	4	6	14.7
5/14/2012	1	3	5	8.96

Day	Demand	Incident	Weather	Avg Travel Time
5/15/2012	1	41	6	11.45
5/16/2012	2	3	5	14.12
5/17/2012	1	4	6	13.35
5/18/2012	1	42	6	14.98
5/21/2012	1	4	5	9.51
5/22/2012	1	4	5	10.04
5/23/2012	1	3	5	13.49
5/24/2012	1	3	5	21.32
5/25/2012	1	41	5	13.84
5/29/2012	1	3	5	10.4
5/30/2012	1	4	5	11.85
5/31/2012	1	4	5	11.63
6/1/2012	1	3	5	11.68
6/4/2012	1	4	5	8.5
6/5/2012	1	4	6	13.37
6/6/2012	1	4	5	14.1
6/7/2012	1	4	5	11.48
6/8/2012	1	4	5	15.41
6/11/2012	1	3	5	9.16
6/12/2012	1	4	5	13.64
6/13/2012	1	4	6	14.6
6/14/2012	1	4	5	14.44
6/15/2012	1	4	5	14.46
6/18/2012	1	41	5	10.15
6/19/2012	1	3	5	10.5
6/20/2012	1	4	5	15.58
6/21/2012	1	3	5	14.83
6/22/2012	1	3	5	12.25
6/25/2012	1	3	5	10.07
6/26/2012	2	41	6	13.36
6/27/2012	2	3	5	12.01
6/28/2012	1	4	5	16.6
6/29/2012	1	4	6	14.54
7/2/2012	1	3	5	8.28
7/3/2012	1	4	5	11.86
7/5/2012	1	3	5	7.72
7/6/2012	1	3	5	8.49
7/9/2012	1	3	5	9.95
7/10/2012	0	42	5	9.66
7/11/2012	1	3	5	13.54
7/12/2012	1	41	5	15.65
7/13/2012	0	4	5	14.53
7/16/2012	1	3	5	9.02
7/17/2012	1	4	5	11.72
7/18/2012	1	3	5	10.81
7/19/2012	1	3	5	14.36
7/20/2012	1	4	5	11.22

Day	Demand	Incident	Weather	Avg Travel Time
7/23/2012	1	3	5	9.21
7/24/2012	1	4	5	9.72
7/25/2012	1	3	5	15.34
7/26/2012	1	3	5	16.07
7/27/2012	1	3	5	13.75
7/30/2012	1	4	5	8.76
7/31/2012	1	3	5	11.18
8/1/2012	1	3	5	11.09
8/2/2012	1	41	6	11.35
8/3/2012	1	3	5	8.88
8/6/2012	1	3	5	9.1
8/7/2012	1	4	5	11.26
8/8/2012	1	42	5	13.71
8/9/2012	1	3	5	13.96
8/10/2012	1	3	5	15.54
8/13/2012	1	4	5	10.67
8/14/2012	1	3	5	13.35
8/15/2012	1	3	5	13.26
8/16/2012	1	4	5	15.16
8/17/2012	1	42	5	10.79
8/20/2012	1	4	5	11.9
8/21/2012	1	3	5	10.11
8/22/2012	1	3	5	10.57
8/23/2012	1	4	5	13.44
8/24/2012	1	41	5	11.97
8/27/2012	1	3	5	10.52
8/28/2012	1	4	5	10.34
8/29/2012	1	41	5	11.24
8/30/2012	1	3	5	18.31
8/31/2012	1	3	5	8.94
9/4/2012	1	3	5	12.46
9/5/2012	1	4	5	10.13
9/6/2012	1	3	5	19.96
9/7/2012	1	4	5	13.23
9/10/2012	1	42	5	8.52
9/11/2012	0	4	5	8.83
9/12/2012	1	3	5	11.53
9/13/2012	1	4	5	15.68
9/14/2012	1	4	5	16.62
9/17/2012	1	3	5	8.65
9/18/2012	1	41	5	11.32
9/19/2012	1	41	5	14.04
9/20/2012	1	41	5	14.56
9/21/2012	1	3	5	13.54
9/24/2012	1	3	5	8.37
9/25/2012	1	3	5	8.84
9/26/2012	1	4	5	11.68

Day	Demand	Incident	Weather	Avg Travel Time
9/27/2012	1	3	6	13.4
9/28/2012	1	4	5	14.56
10/1/2012	0	3	5	10.18
10/2/2012	0	3	5	10.67
10/3/2012	1	4	5	13.92
10/4/2012	1	4	5	10.7
10/5/2012	1	42	5	11.14
10/9/2012	1	3	5	10.73
10/10/2012	1	4	5	12.64
10/11/2012	1	3	5	15.33
10/12/2012	1	4	5	10.85
10/15/2012	1	42	5	10.86
10/16/2012	1	3	5	13.39
10/17/2012	1	3	6	10.22
10/18/2012	1	3	5	15.84
10/19/2012	1	3	5	10.63
10/22/2012	1	3	5	8.38
10/23/2012	1	4	5	9.71
10/24/2012	1	3	5	9.52
10/25/2012	1	3	6	12.96
10/26/2012	1	3	5	10.88
10/29/2012	0	3	6	8.67
10/30/2012	1	4	5	12.96
10/31/2012	1	3	5	8.71
11/1/2012	1	4	5	14.4
11/2/2012	1	4	5	13.04
11/5/2012	1	42	5	10.57
11/6/2012	1	3	5	12.81
11/7/2012	1	3	5	11.94
11/8/2012	1	3	5	12.71
11/9/2012	1	3	6	12.04
11/13/2012	1	4	5	14.12
11/14/2012	0	3	6	15.85
11/15/2012	1	4	5	14.7
11/16/2012	1	42	5	17.95
11/19/2012	1	3	6	11.56
11/20/2012	1	4	5	11.21
11/21/2012	0	4	5	10.09
11/23/2012	0	3	5	7.34
11/26/2012	1	3	5	9.82
11/27/2012	1	3	6	10.43
11/28/2012	1	3	5	9.9
11/29/2012	0	3	5	13.65
11/30/2012	0	3	5	13.5
12/3/2012	1	3	5	11.83
12/4/2012	1	3	5	11.52
12/5/2012	1	4	5	13.07

Day	Demand	Incident	Weather	Avg Travel Time
12/6/2012	0	3	5	20.81
12/7/2012	1	4	5	18.63
12/10/2012	1	3	5	10.33
12/11/2012	1	3	6	14.42
12/12/2012	1	3	5	11.69
12/13/2012	1	3	5	18.07
12/14/2012	1	4	5	18.77
12/17/2012	1	41	5	9.73
12/18/2012	1	3	5	16.68
12/19/2012	1	4	5	19.23
12/20/2012	1	3	6	12.94
12/21/2012	0	4	5	15.29
12/24/2012	0	3	5	7.31
12/26/2012	0	3	6	7.62
12/27/2012	0	3	5	8.07
12/28/2012	1	3	5	8.67
12/31/2012	1	3	5	7.45

Legend:

Quantitative Value:	Description
0	= Low Demand
1	= Moderate Demand
2	= High Demand
3	= No Incident
4	= Incident Not Defined
41	= Incident 30 Minutes
42	= Incident 60 Minutes
5	= Dry
6	= Rain

Assumption: If a 4 incident has average travel time less than and equal to 15.65 than it is assumed to be a 41. If not, it is assumed to be 42

Table A-3: Southbound Data for Analysis

Day	Demand	Incident	Weather	Avg Travel Time
1/3/2012	1	4	5	8.82
1/4/2012	1	4	5	8.99
1/5/2012	1	4	5	8.91
1/6/2012	1	3	5	9.18
1/9/2012	0	4	5	9.05
1/10/2012	1	3	5	9.12
1/11/2012	0	3	5	8.93
1/12/2012	1	4	5	11.13
1/13/2012	1	4	5	11.25

Day	Demand	Incident	Weather	Avg Travel Time
1/17/2012	1	4	5	8.88
1/18/2012	1	4	5	11.16
1/19/2012	0	4	5	10.32
1/20/2012	0	3	5	10.13
1/23/2012	1	3	5	8.57
1/24/2012	1	3	5	8.79
1/25/2012	1	4	5	9.06
1/26/2012	1	3	5	9.9
1/27/2012	1	3	5	9.38
1/30/2012	1	4	5	8.58
1/31/2012	1	4	5	8.87
2/1/2012	1	4	5	8.91
2/2/2012	1	4	5	8.97
2/3/2012	1	3	5	9.87
2/6/2012	1	4	5	9.05
2/7/2012	1	3	5	8.73
2/8/2012	1	4	5	8.9
2/9/2012	1	3	6	9.23
2/10/2012	1	3	6	9.63
2/13/2012	1	4	5	9.14
2/14/2012	1	3	5	9.5
2/15/2012	1	3	5	9.26
2/16/2012	0	4	5	8.69
2/17/2012	2	4	5	8.67
2/21/2012	1	3	5	8.72
2/22/2012	1	4	5	9.2
2/23/2012	1	3	5	8.72
2/24/2012	1	4	5	10.46
2/27/2012	0	4	5	8.61
2/28/2012	1	41	5	8.57
2/29/2012	1	4	5	8.64
3/1/2012	1	4	5	8.52
3/2/2012	1	3	5	8.75
3/5/2012	1	3	5	8.66
3/6/2012	1	3	5	10.01

Day	Demand	Incident	Weather	Avg Travel Time
3/7/2012	1	4	5	10.19
3/8/2012	1	3	5	9.21
3/9/2012	1	3	5	8.78
3/12/2012	1	3	5	8.58
3/13/2012	1	42	6	9.33
3/14/2012	0	3	5	11
3/15/2012	1	4	5	9.3
3/16/2012	1	3	5	9.69
3/19/2012	1	4	5	8.57
3/20/2012	1	3	5	9.17
3/21/2012	2	3	6	8.63
3/22/2012	1	3	6	9.83
3/23/2012	1	4	5	10.86
3/26/2012	1	3	5	8.52
3/27/2012	1	3	5	10.49
3/28/2012	1	3	5	8.52
3/29/2012	1	4	5	12.98
3/30/2012	2	3	5	8.4
4/2/2012	1	3	5	8.3
4/3/2012	1	3	5	8.75
4/4/2012	1	3	5	8.54
4/5/2012	1	4	5	11.88
4/6/2012	1	3	5	8.37
4/9/2012	1	3	5	8.78
4/10/2012	0	4	5	10.22
4/11/2012	1	3	5	8.37
4/12/2012	1	3	5	8.67
4/13/2012	1	3	5	8.54
4/16/2012	1	3	5	8.48
4/17/2012	1	3	5	8.87
4/18/2012	1	3	5	8.87
4/19/2012	1	3	5	9.47
4/20/2012	0	4	5	8.42
4/23/2012	1	3	5	8.6
4/24/2012	1	4	6	9.38

Day	Demand	Incident	Weather	Avg Travel Time
4/25/2012	1	3	5	8.87
4/26/2012	1	3	5	8.97
4/27/2012	1	3	5	8.72
4/30/2012	1	3	5	8.55
5/1/2012	1	3	5	8.99
5/2/2012	1	41	5	9.05
5/3/2012	1	42	5	11.06
5/4/2012	1	4	5	8.6
5/7/2012	1	3	5	8.61
5/8/2012	1	4	5	8.76
5/9/2012	1	3	5	8.64
5/10/2012	1	3	5	9.77
5/11/2012	2	4	6	8.57
5/14/2012	1	3	5	8.43
5/15/2012	1	3	6	8.9
5/16/2012	2	4	5	9.06
5/17/2012	1	4	6	10.26
5/18/2012	1	3	6	8.7
5/21/2012	1	3	5	8.88
5/22/2012	1	3	5	12.47
5/23/2012	1	3	5	9.24
5/24/2012	0	4	5	17.18
5/25/2012	1	3	5	8.69
5/29/2012	1	3	5	8.63
5/30/2012	1	3	5	8.64
5/31/2012	1	3	5	10.16
6/1/2012	1	3	5	8.87
6/4/2012	1	4	5	8.72
6/5/2012	1	3	6	10.47
6/6/2012	1	3	5	9.21
6/7/2012	1	4	5	9.06
6/8/2012	1	41	5	9.29
6/11/2012	1	3	5	9
6/12/2012	1	3	5	8.99
6/13/2012	1	3	6	10.61

Day	Demand	Incident	Weather	Avg Travel Time
6/14/2012	1	4	5	10.26
6/15/2012	1	4	5	10.28
6/18/2012	1	4	5	8.73
6/19/2012	1	3	5	9.06
6/20/2012	1	4	5	11.07
6/21/2012	1	4	5	10.74
6/22/2012	1	42	5	10.95
6/25/2012	1	3	5	8.73
6/26/2012	1	4	6	9.02
6/27/2012	1	3	5	8.78
6/28/2012	1	4	5	8.97
6/29/2012	1	3	6	8.67
7/2/2012	0	41	5	8.45
7/3/2012	1	3	5	8.51
7/5/2012	0	3	5	8.43
7/6/2012	1	4	5	8.91
7/9/2012	1	3	5	8.67
7/10/2012	0	3	5	9.27
7/11/2012	1	4	5	9.12
7/12/2012	0	3	5	10.14
7/13/2012	0	4	5	8.94
7/16/2012	1	3	5	8.7
7/17/2012	1	4	5	8.9
7/18/2012	1	4	5	8.73
7/19/2012	1	3	5	8.93
7/20/2012	1	4	5	8.55
7/23/2012	0	4	5	10.16
7/24/2012	1	4	5	9.23
7/25/2012	1	3	5	9.42
7/26/2012	1	3	5	9.78
7/27/2012	1	3	5	9.06
7/30/2012	0	3	5	9.06
7/31/2012	1	3	5	8.51
8/1/2012	1	3	5	8.85
8/2/2012	1	3	6	8.72

Day	Demand	Incident	Weather	Avg Travel Time
8/3/2012	0	3	5	8.6
8/6/2012	1	3	5	8.57
8/7/2012	0	4	5	8.69
8/8/2012	1	3	5	8.76
8/9/2012	0	3	5	9.45
8/10/2012	0	4	5	8.79
8/13/2012	0	3	5	9.92
8/14/2012	1	4	5	10.19
8/15/2012	1	41	5	9.18
8/16/2012	1	3	5	10.11
8/17/2012	1	4	5	8.61
8/20/2012	1	3	5	8.94
8/21/2012	1	4	5	8.67
8/22/2012	1	3	5	9
8/23/2012	1	3	5	9.15
8/24/2012	1	4	5	9.33
8/27/2012	0	41	5	8.85
8/28/2012	1	3	5	8.94
8/29/2012	0	3	5	9.59
8/30/2012	1	4	5	13.41
8/31/2012	1	3	5	8.46
9/4/2012	1	3	5	8.67
9/5/2012	1	3	5	8.81
9/6/2012	1	3	5	9.26
9/7/2012	1	3	5	8.88
9/10/2012	1	3	5	8.31
9/11/2012	0	3	5	8.49
9/12/2012	1	3	5	8.94
9/13/2012	0	4	5	9.39
9/14/2012	1	3	5	9.06
9/17/2012	1	3	5	8.49
9/18/2012	1	4	5	10.49
9/19/2012	1	3	5	9.84
9/20/2012	2	3	5	9.8
9/21/2012	1	3	5	8.96

Day	Demand	Incident	Weather	Avg Travel Time
9/24/2012	1	3	5	8.75
9/25/2012	1	3	5	8.45
9/26/2012	2	42	5	9.84
9/27/2012	1	3	6	8.94
9/28/2012	0	3	5	9.38
10/1/2012	0	3	5	8.3
10/2/2012	0	3	5	8.34
10/3/2012	1	4	5	10.91
10/4/2012	2	3	5	8.76
10/5/2012	1	3	5	8.36
10/9/2012	2	3	5	9.08
10/10/2012	1	3	5	9.96
10/11/2012	1	4	5	9.33
10/12/2012	1	3	5	9.36
10/15/2012	0	3	5	8.85
10/16/2012	0	3	5	9.35
10/17/2012	1	3	6	9.3
10/18/2012	0	4	5	10.19
10/19/2012	1	3	5	8.75
10/22/2012	1	4	5	8.58
10/23/2012	1	3	5	8.61
10/24/2012	1	3	5	8.99
10/25/2012	0	3	6	8.9
10/26/2012	2	4	5	9.27
10/29/2012	0	3	6	8.72
10/30/2012	1	41	5	8.88
10/31/2012	1	3	5	9.41
11/1/2012	1	3	5	8.78
11/2/2012	1	4	5	8.81
11/5/2012	2	3	5	9.11
11/6/2012	1	3	5	9.12
11/7/2012	1	3	5	10.65
11/8/2012	1	3	5	9.08
11/9/2012	1	3	6	9.69
11/13/2012	1	3	5	9.17

Day	Demand	Incident	Weather	Avg Travel Time
11/14/2012	0	3	6	9.99
11/15/2012	2	4	5	9.81
11/16/2012	1	4	5	11.1
11/19/2012	1	3	6	8.57
11/20/2012	1	3	5	9.26
11/21/2012	1	3	5	8.67
11/23/2012	0	3	5	8.39
11/26/2012	1	3	5	8.94
11/27/2012	1	3	6	9.09
11/28/2012	0	3	5	9.02
11/29/2012	0	3	5	10.88
11/30/2012	0	3	5	9.71
12/3/2012	1	4	5	9.27
12/4/2012	1	42	5	10.38
12/5/2012	2	3	5	10.79
12/6/2012	0	4	5	15.03
12/7/2012	1	3	5	9.63
12/10/2012	1	4	5	9.14
12/11/2012	1	3	6	9.11
12/12/2012	1	3	5	8.76
12/13/2012	1	3	5	9.69
12/14/2012	1	3	5	9.69
12/17/2012	2	3	5	8.82
12/18/2012	2	3	5	9.21
12/19/2012	2	42	5	9.44
12/20/2012	0	4	6	9.26
12/21/2012	0	4	5	9.5
12/24/2012	0	3	5	8.27
12/26/2012	2	3	6	8.42
12/27/2012	2	3	5	8.64
12/28/2012	2	3	5	8.73
12/31/2012	2	3	5	8.34

Legend:

Quantitative Value:	Description
0	= Low Demand
1	= Moderate Demand
2	= High Demand
3	= No Incident
4	= Incident Not Defined
41	= Incident 30 Minutes
42	= Incident 60 Minutes
5	= Dry
6	= Rain

Assumption: If a 4 incident has average travel time less than and equal to 15.65 than it is assumed to be a 41. If not, it is assumed to be 42

DATA EXPLORATION

This section explores the structures apparent in the data set.

Travel Time Distribution

The cumulative hourly travel time distributions by direction are shown in Figure A-11 and in Table A-4 in terms of the travel time index (TTI), the ratio of the actual travel time to the theoretical travel time at 60 mph. The median TTI for the northbound direction is 1.23, implying a median speed of 49 mph during the PM peak period. In the southbound direction, the median TTI is 0.97, for a median speed of 62 mph.

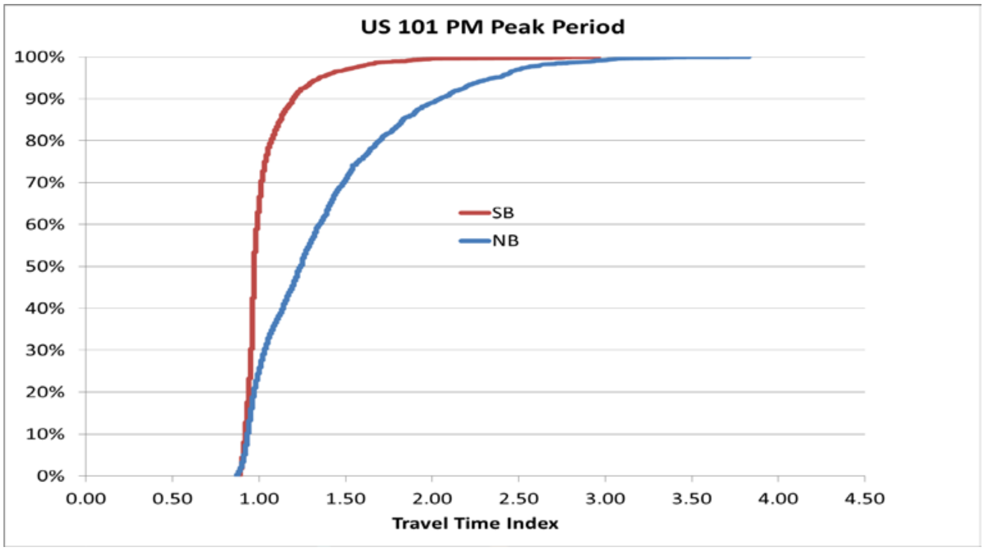

Figure A-11: Cumulative Travel Time Distributions US 101 [Source: Kittelson]

Table A-4: Cumulative Travel Time Statistics – US 101 PM Peak Period

Statistic	*Northbound*	*Southbound*
5th Percentile	0.91	0.91
25th Percentile	1.00	0.95
Median (50%)	1.23	0.97
75th Percentile	1.56	1.03
95th Percentile	2.32	1.33

Travel time index was computed in relation to an assumed 60 mph free-flow speed. From this data, it can be determined that the northbound direction is the peak travel direction during the PM peak period and that it is subject to both recurring and non-recurring congestion. The recurring congestion in the southbound direction is comparatively minor.

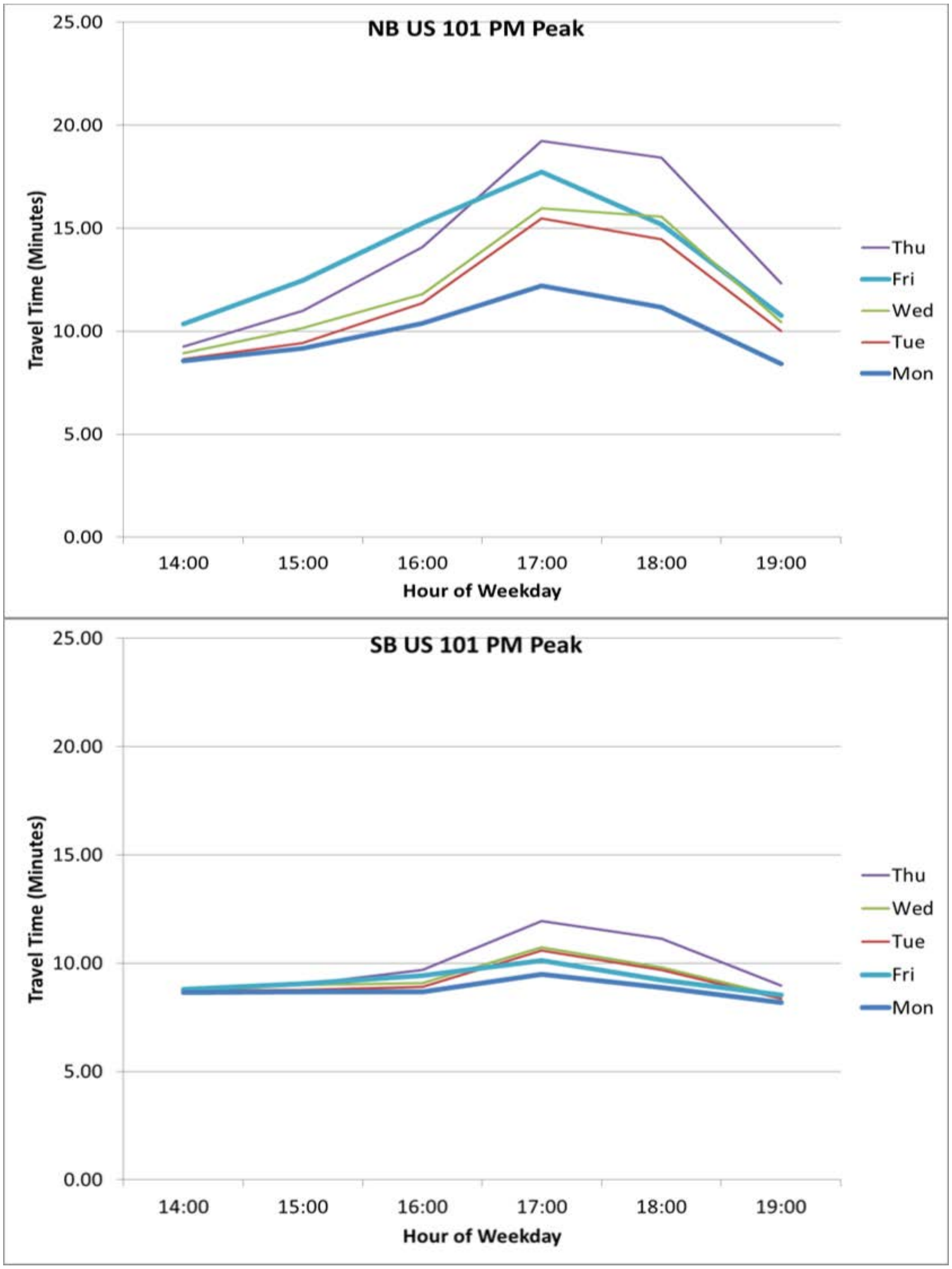

Figure A-12: Weekday Variation of Mean Travel Times [Source: Kittelson]

Figure A-12 shows by direction how average annual travel times during the PM peak periods vary by day of week and hour of the year. Thursdays and Fridays tend to be the most congested days of the week, with the greatest congestion (largest travel times) occurring at 5 PM (17:00). This data suggests that recurring variations in demand are a significant contributing cause to congestion on the freeway. The 2 PM hour appears representative of generally uncongested conditions, especially on Mondays and Tuesdays. Figure A-13 shows the hourly travel times (by hour of day) by direction over the course of a year. The charts indicate no strong seasonality in congestion. The northbound direction experiences several severe congestion events pretty much every season over the course of the year. The southbound direction experiences relatively few severe congestion events.

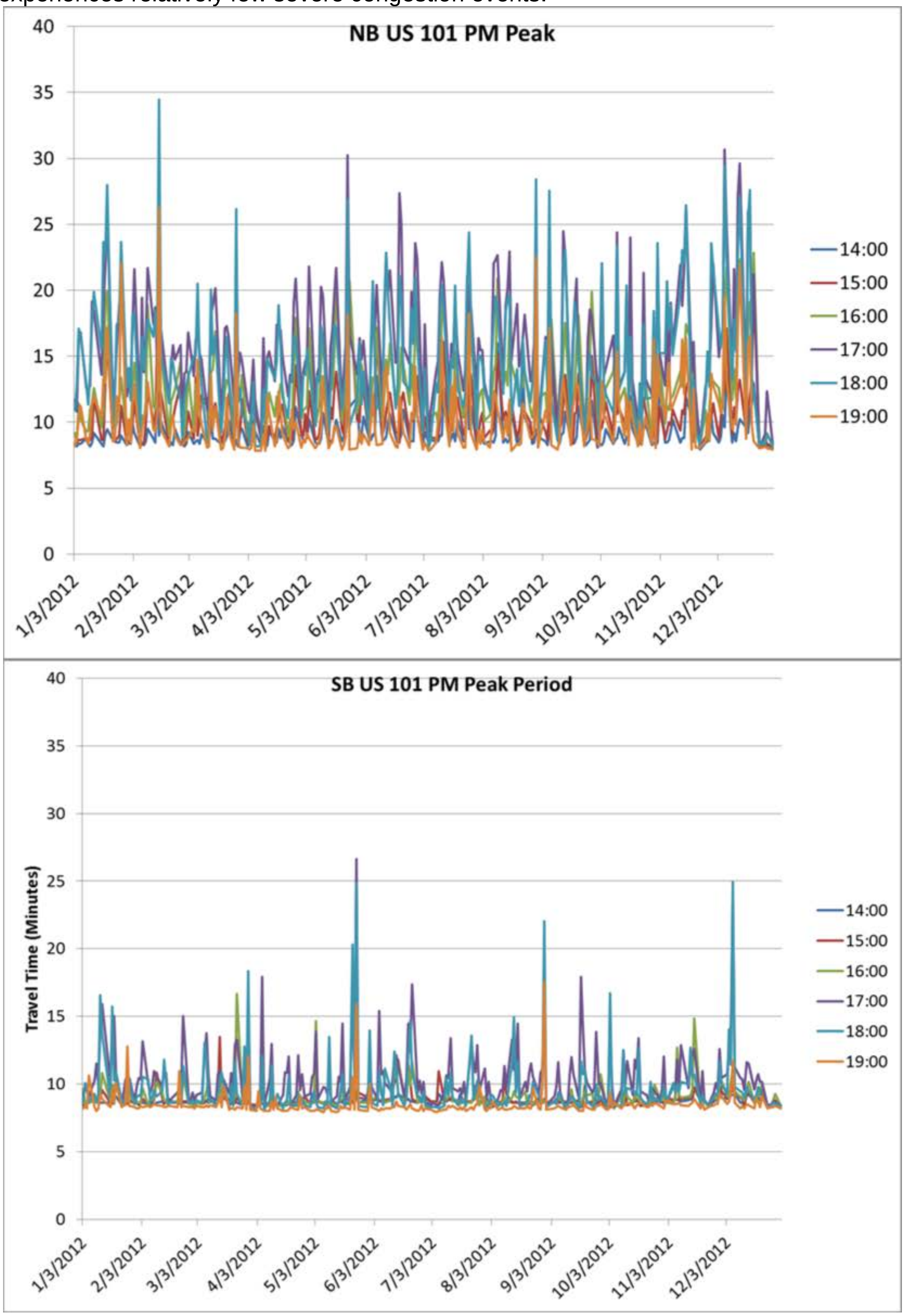

Figure A-13: Seasonal Variation in Travel Time [Source: Kittelson]

Effects of Daily Demand Variation on Peak Period Travel Times

The effects of daily variations in VMT on peak period travel times were examined and it was found that peak period travel times were generally poorly correlated or inversely correlated with daily VMT. This may be attributed to the high demand to capacity ratios on the freeway in this corridor, causing daily VMT to be more an indicator of daily throughput than demand. Consequently daily VMT was dropped as a factor for consideration in the generation of operational conditions.

The examination did reveal a noticeable positive correlation between the hour within the peak period and travel time. Earlier hours in the peak period (e.g. 14:00) had noticeably lower travel times than the 17:00 and 18:00 hours of the PM peak period. Consequently it was determined that hourly performance results within each peak period should be examined when each operational condition and DMA application scenario is run through the microsimulation analysis.

Effects of Demand, Weather, Incidents on Travel Time

Figure A-14 shows how the annual average travel time for each hour within the peak period is affected by lane blocking incidents and weather. The effects of demand can be indirectly gauged by comparing how the travel times vary from the early hours to the later hours in the peak period. At presumably low demand levels (see 14:00 hour) incidents and rain have negligible effects on travel times. At presumably higher demand levels (see 17:00 hour), the effects of incidents and rain on travel times are significantly more pronounced. Note that the effects of incidents and rain are significantly lower in the southbound direction (than the northbound direction) due to the presumably lower demands in the southbound direction.

The conclusion is that Incidents and rain significantly affect travel times, but only at high demand levels. It is apparent from these charts that the effects of demand can be obtained by examining the microsimulation results in the northbound direction, hour by hour within the peak period.

Combined Event Probabilities

The frequencies of combinations of weather, incidents, and demand that were observed during the weekday PM peak periods on US 101 are shown in Table A-5 for both directions. The freeway experienced rainy weather approximately 10% (26 days) of the year during the 251 weekday PM peak periods in 2012. Fog (reduced visibility at ground level), snow, ice, high wind, low temperature, and other adverse weather conditions were not observed in 2012. Lane blocking incidents occurred sometime during the weekday PM peak periods, somewhere on the freeway, approximately 49% of the year in 2012 in the northbound direction, and 36% of the year in the southbound direction. In the northbound direction approximately 13% of the PM peak periods of the year saw lane blocking incidents lasting at least 30 minutes. In the southbound direction approximately 5% of the PM peak periods saw lane blocking incidents lasting at least 30 minutes. Although the probability of an incident during rainy weather is higher than during dry weather, the combined occurrence of incidents with rainy weather was only 2% in the northbound direction and 4 tenths of one percent in the southbound direction. This is primarily because rainy weather is relatively infrequent in the corridor.

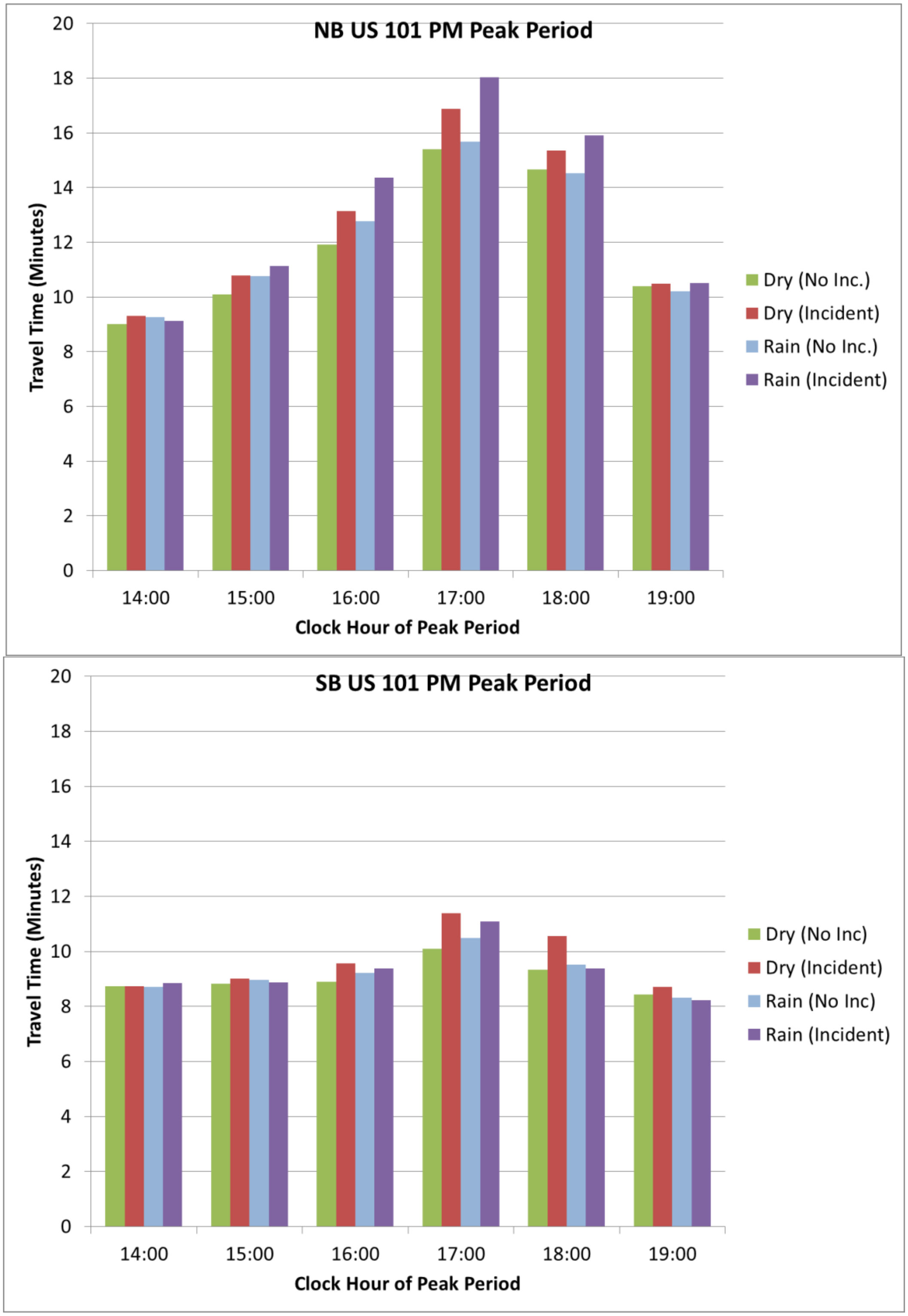

Figure A-14: Combined Effects of Weather and Incidents on Travel Time [Source: Kittelson]

Table A-5: Combined Frequencies of Demand, Weather, and Incidents by Duration

WEATHER	*INCIDENTS*	*Northbound*	*Northbound*	*Southbound*	*Southbound*
Dry	No Incidents	117	46.6%	140	55.8%
	Incidents 30 min	16	6.4%	7	2.8%
	Incidents 60 min	11	4.4%	5	2.0%
	Incidents Other	81	32.3%	73	29.1%
	Subtotal	225	89.6%	225	89.6%
Rain	No Incidents	11	4.4%	20	8.0%
	Incidents 30 min	3	1.2%	0	0.0%
	Incidents 60 min	2	0.8%	1	0.4%
	Incidents Other	10	4.0%	5	2.0%
	Subtotal	26	10.4%	26	10.4%
TOTAL		251	100.0%	251	100.0%

Frequencies are number of non-holiday weekdays when condition occurred during PM peak period over a year.

INITIAL STRATIFIED ANALYSIS SCHEME

The initial investigation into the effects of demand, weather, and incidents on travel times in the Testbed found that all three factors significantly affected travel times. Thus, an initial stratification scheme was developed for evaluating how DMA and ATDM performance would vary under the different operating conditions. Splitting daily demand into three levels (low, medium, high), weather into two types (rain, dry), and incidents into three types (none, 30 minute duration, and 60 minute duration) resulted in 18 possible combinations, and therefore 18 possible operational conditions for analysis (see Table A-6). This number of operational conditions exceeds the available resources for microsimulation analysis. Consequently, additional analyses were conducted to identify means for consolidating the operational conditions to four conditions by using cluster analysis techniques.

Table A-6: Initial Set of Operational Conditions

Operational Condition	Daily Demand	Incident Type	Weather Type	Probability NB	Probability SB
1	25th% (Low)	None/Other/Short	Dry Pavement	6%	15%
2	50th% (Median)	None/Other/Short	Dry Pavement	68%	64%
3	95th% (V.High)	None/Other/Short	Dry Pavement	5%	6%
4	25th% (Low)	1 Lane – 30 min	Dry Pavement	<1%	1%
5	50th% (Median)	1 Lane – 30 min	Dry Pavement	6%	2%
6	95th% (V.High)	1 Lane – 30 min	Dry Pavement	1%	<1%
7	25th% (Low)	1 Lane – 60 min	Dry Pavement	<1%	<1%
8	50th% (Median)	1 Lane – 60 min	Dry Pavement	4%	1%
9	95th% (V.High)	1 Lane – 60 min	Dry Pavement	<1%	1%
10	25th% (Low)	None/Other/Short	Wet Pavement	1%	2%
11	50th% (Median)	None/Other/Short	Wet Pavement	7%	7%
12	95th% (V.High)	None/Other/Short	Wet Pavement	<1%	1%
13	25th% (Low)	1 Lane – 30 min	Wet Pavement	<1%	<1%
14	50th% (Median)	1 Lane – 30 min	Wet Pavement	1%	<1%
15	95th% (V.High)	1 Lane – 30 min	Wet Pavement	<1%	<1%
16	25th% (Low)	1 Lane – 60 min	Wet Pavement	<1%	<1%
17	50th% (Median)	1 Lane – 60 min	Wet Pavement	1%	<1%
18	95th% (V.High)	1 Lane – 60 min	Wet Pavement	<1%	<1%

Notes: Daily Demands expressed as a cumulative percentile of demands observed over course of year. Incidents expressed in terms of lanes closed and duration. Non-lane blocking incidents and lane blocking incidents of short duration (under 16 minutes) are grouped under “None/Other/Short”.

Recommended Stratified Analysis Scheme

Review of the travel time distribution data determined that the Northbound direction regularly experienced much greater recurring and non-recurring congestion during weekday PM peak periods. So data for this direction was used to select the operational conditions.

Review of the daily VMT variability data suggested that it could not be effectively used as a proxy for changes in total peak period demand. Consequently it was decided to model only one overall peak period demand level in the operational conditions. The examination of effects by hour within the peak period suggested that a similar hour-by-hour examination of the microsimulation results for each operational condition could be used to determine the effects of different demand levels on the performance of DMA. The selected peak period is long enough to span both uncongested and congested conditions, providing a sufficiently robust demand basis for assessing the benefits of DMA under varying demand conditions. Upon examining these eleven representative operational conditions, we can conclude the following:

- Operational Conditions 3 and 5 can be combined into one condition
- Operational Conditions 4, 7, and 11 can be combined into one condition

In summary, by dropping the different daily (VMT) demand variation levels from the analysis and dropping the exceptionally low probability conditions and considering the wet-pavement condition, 4 recommended baseline operational conditions were concluded for full microsimulation analysis, as shown in Table A-7.

Table A-7: Recommended Set of Operational Conditions

Operational Conditions	*Daily Demand*	*Incident Type*	*Weather Type*	*NB Probability*
1	50^{th}% (Median day) (varying by hour within peak)	None/Other/Short	Dry Pavement	79%
2	See above	1 Lane – 30 minutes	Dry Pavement	7%
3	See above	1 Lane – 60 minutes	Dry Pavement	4%
4	See above	1 Lane – 60 minutes	Wet Pavement	1%
			Total	**91%**

Notes: 1 Lane – 30 minutes = one lane closed for 30 minutes.

CLUSTER ANALYSIS APPROACH

As part of the DMA/ATDM evaluation process, the San Mateo Testbed team identified the number of operational scenarios using the clustering analysis approach developed by Noblis as a part of Traffic Analysis Toolbox (Volume 3) and is summarized in the steps below.

1. Identify data to represent underlying phenomena as well as to represent non-recurring measurements. In this analysis, end-to-end freeway VMT, amount of precipitation, and incident duration measured are used to describe the underlying phenomena variables.
2. Identify data to represent system outcomes. In this analysis, the average peak period travel time, end-to-end, by direction is used. This data definition is given in section 5.1.3.
3. Normalize underlying phenomena data and system outcomes data as follows:

   Normalize values X' = MinX + (X – MinMin) * (MaxX-MinX) /(MaxMax – MinMin)
   where:

   X': normalized value
   X: attribute value
   MinMin: the smallest value recorded for the attribute
   MaxMax: the largest value recorded for the attribute
   MinX: The lower bound of the normalized values
   MaxX: The upper bound of the normalized values
4. For a pre-specified number of clusters (e.g., n=3), group the peak periods into clusters so as to minimize the sum of the differences between the peak period values and the mean for each cluster.
5. Report the results of each cluster which includes
   a. Sum of the Squared Error (SSE)
   b. The coefficient of variation (CV) for each variable for all clusters
   c. The list of peak periods in each cluster
6. Repeat steps 4 and 5 after incrementing the number of clusters by 1 (i.e., number of clusters = n+1)
7. Stop if the number of clusters n reaches a certain pre-specified maximum number. The maximum number of clusters is a function of number of data records. In this analysis, the procedure stops when the number of clusters n is equal to 14 (the maximum possible number of clusters that might be considered for the simulation analysis).

8. Analyze the result of each clustering pattern to determine the operational conditions.

A special purpose software that was developed by the research team is used to perform this analysis. The next section represents a brief overview of the data followed by the cluster analysis results.

Data Used for Cluster Analysis

In general, there are three types of data needed (as illustrated in the figure below) for conducting the cluster analysis and identifying the prevalent operational conditions:

1. Type 1 data represents the underlying phenomena, i.e., data that 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.

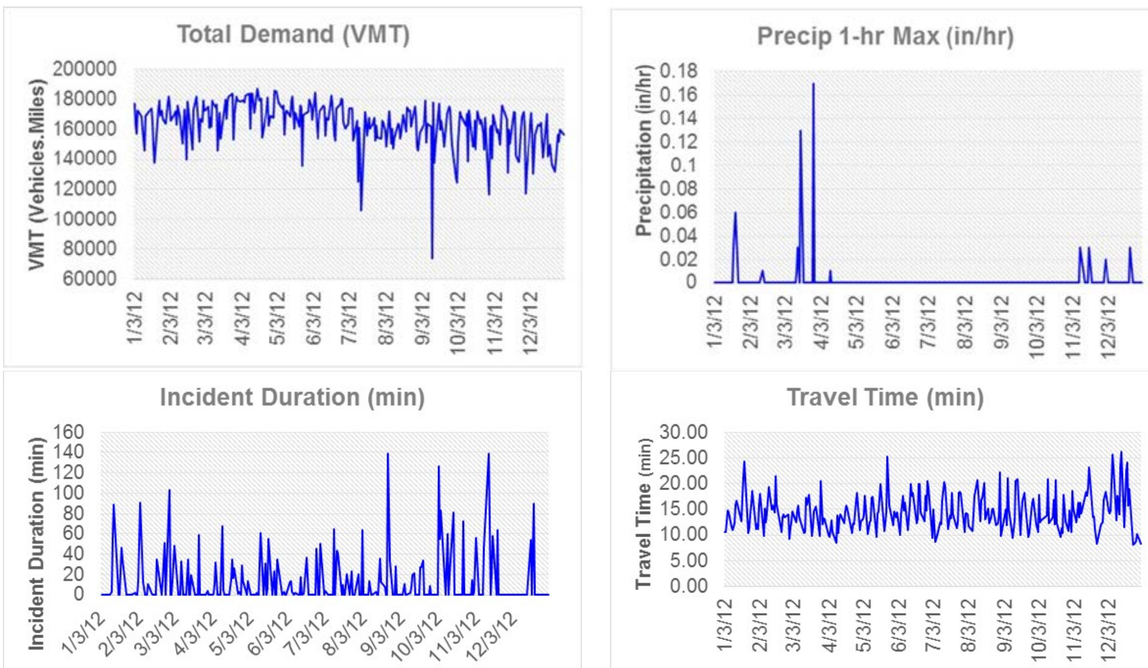

Figure A-15: The distribution of the different datasets for San Mateo Testbed [Source: Kittelson]

Data to Represent Underlying Phenomena

Demand: Traffic data was obtained for both directions (NB and SB) of the US 101 freeway during the PM peak period (2:00-7:00 pm) for 251 weekdays in the year 2012. However, the research team focused on the PM peak period NB only for conducting the analysis. This data include flows and speeds (travel times) from loop detector data as archived and processed in the PeMS system The vehicle miles traveled (VMT) is used in this analysis to provide information on the demand level in the corridor. The VMT is obtained by multiplying the hourly traffic flow rate observed at each detector by the average spacing between the detectors. The VMT data could be determined for the entire peak period or for each hour in the peak period. The VMT spatial distribution could also be determined to provide information on sections along the freeway that are heavily traveled.

Data to Represent Non-recurring Measurements

Weather: Twenty-four hours weather data for the year 2012 was extracted from the University of Utah on-line database (http://mesowest.utah.edu/) for the San Francisco International airport, which is the closest weather-reporting station to the Testbed. Weather data was then examined for the weekday, non-holiday PM peak periods. Twenty six days of rainy weather were observed at the airport in 2012 during the weekday PM peak period. There was no snow, ice, or ground fog conditions during 2012.

Incident: Incident logs for the California Highway Patrol (CHP) Computer Aided Dispatch (CAD) log were obtained from the PeMS database for the year 2012. This source provides starting time, duration, and location information on incidents by type, but does not indicate if or how many lanes were closed. Collision data was obtained from the Caltrans Accident Reporting System (TASAS) for the latest available year, 2010, which provides greater detail on the accidents, including number of lanes closed. The team, however, did not use this data since 2012 data was not available. Instead, the number of lanes closed was assessed using the loop-detector data for the 2012 model year.

Data to Represent System Outcomes

Travel Time: Travel time data for 251 non-holiday weekday PM peak periods (2-7 PM) for the year 2012 were obtained from the Caltrans PeMS database[9] for 9 miles of US 101 between Woodside Road (milepost 406) and Third Avenue (milepost 416). The following PeMS defined holidays for 2012 were excluded from the travel time data:

- 01/02/2012 New Year's Day Monday
- 01/16/2012 Martin Luther King, Jr. Day Monday
- 02/20/2012 Washington's Birthday Monday
- 05/28/2012 Memorial Day Monday
- 07/04/2012 Independence Day Wednesday
- 09/03/2012 Labor Day Monday
- 10/08/2012 Columbus Day Monday
- 11/12/2012 Veterans Day Monday
- 11/22/2012 Thanksgiving Day Thursday
- 12/25/2012 Christmas Day Tuesday

The PeMS database computes travel time for each direction of the freeway by examining the spot speeds reported by the various loop detectors located on the selected length of freeway. Five minute average spot speeds for each lane loop detector are archived. The spot speeds are converted to travel time indices for each lane using a nominal 60 mph free-flow speed. The 5-minute lane-by-lane TTIs are then averaged across all lane detectors in the selected study section and direction of the freeway and aggregated to our desired temporal aggregation level. In this case, one hour aggregations were selected. For the 8.5 mile section of US 101 selected for analysis, there were 30 mainline loop detector stations in each direction (each station recording lane-by-lane speeds for 4 lanes)

Cluster Analysis Process

The results for the cluster analysis for the evening peak period are presented in Figures A-16 through A-18. Figure A-16 gives the results for different clustering patterns in which the number of clusters is varied from 3 to 8. For each case, the total Sum of Squared Errors (SSE), the minimum and maximum numbers

[9] http://pems.dot.ca.gov/?redirect=%2F%3Fdnode%3DState#37.7743,-122.2023,10, Accessed June-July 2014.

of peak periods in each cluster, the coefficient of variations (CV) for the different variables, and the normalized indices that describe the overall performance of the clustering patterns are given.

As shown in the first row of Figure A-16 and A-17, increasing the number of clusters systematically reduces the SSE. For example, a total SSE for 11.5 is recorded when the number of clusters is set at 3. The SSE is reduced to 6.83 when the number of clusters is increased to 8. These results indicate that more homogeneous clusters (i.e., less variation within each cluster) can be obtained by increasing the number of clusters. However, increasing the number of clusters could result in clusters with few data records. Figure A-16 also gives the maximum and minimum CV for the four analyzed variables (VMT, incident duration, precipitation level, and travel time). The maximum CVs for travel time and VMT are recorded to be less than 0.20.

As proposed in the memorandum shared by Noblis with the research team, the last row in Figure A-17 gives the values of a clustering index which is computed by multiplying the (0-1) normalized value of the SSE by the (1-2) normalized number of clusters. This index is used to determine a clustering pattern that is characterized by having small number of clusters while still provide distinct clusters with a reasonable level of homogeneity within each cluster.

Figure A-18 shows the values of this index for the different clustering patterns considered in the analysis. The values of this index tends to form a convex pattern with the smallest value of the index is obtained when the number of clusters is five. To further investigate the properties of these clusters, the average time-varying travel time for the US 101 freeway in the NB direction is obtained for each cluster. The time-varying travel time pattern for these five clusters is shown in Figure A-18 where all clusters are shown to have distinct time-varying travel time implying certain operational condition. The average values for all data records are summarized in Table A-9 to help define the number of selected clusters.

Table A-8: A Summary of the Clustering Analysis for the PM Peak Period [Source: Booz Allen]

No. of Clusters	3	4	5	6	7	8
Total SSE	11.50	9.86	8.55	7.82	7.37	6.83
Min no. of elements in Cluster	31	27	27	14	10	10
Max no. of elements in Cluster	155	93	82	76	61	58
Max CV - VMT	0.11	0.10	0.13	0.15	0.16	0.16
Max CV- Incident	2.07	3.15	3.29	3.36	3.08	3.12
Max CV - Rain	8.75	9.59	9.00	8.25	7.75	7.55
Max CV- Travel Time	0.17	0.18	0.18	0.18	0.18	0.14
Min CV - VMT	0.07	0.05	0.04	0.05	0.03	0.03
Min CV- Incident	0.41	0.36	0.36	0.36	0.36	0.36
Min CV – Rain	3.59	3.11	0.00	0.00	0.00	0.00
Min CV- Travel Time	0.14	0.09	0.10	0.07	0.06	0.06
AVG CV for VMT	0.08	0.08	0.07	0.08	0.07	0.07
AVG CV for Travel Time	0.16	0.13	0.13	0.11	0.10	0.10
AVG CV for all attributes	1.81	2.08	1.73	1.32	1.45	1.16
No of clusters * SSE	34.51	39.42	42.76	46.92	51.59	54.66
No of clusters * AVG CV	5.42	8.32	8.63	7.91	10.14	9.24
No of clusters * AVG CV Travel Time	0.47	0.51	0.64	0.69	0.72	0.78
Normalizing Cluster Numbers (0,1)	0	0.2	0.4	0.6	0.8	1
Normalizing SSE (0,1)	1	0.647	0.368	0.212	0.115	0
Normalizing Cluster Numbers (1,2)	1	1.2	1.4	1.6	1.8	2
Normalizing SSE (1,2)	2	1.647	1.368	1.212	1.115	1
Index Nor(No.Clusters)xNor(SSE)	2	1.977	1.916	1.939	2.007	2

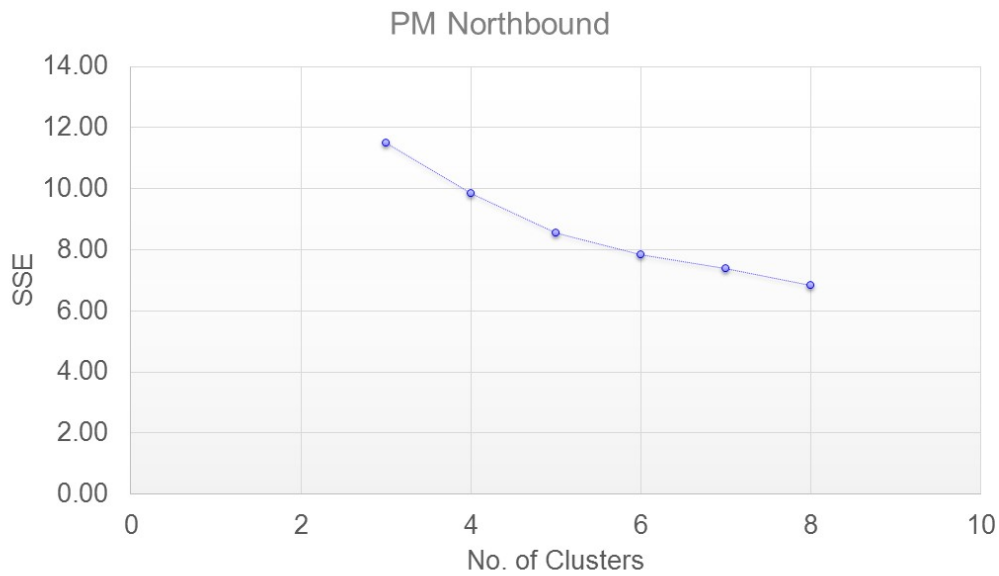

Figure A-16: The SSE for Different Clustering Patterns for the PM Peak Period [Source: Booz Allen]

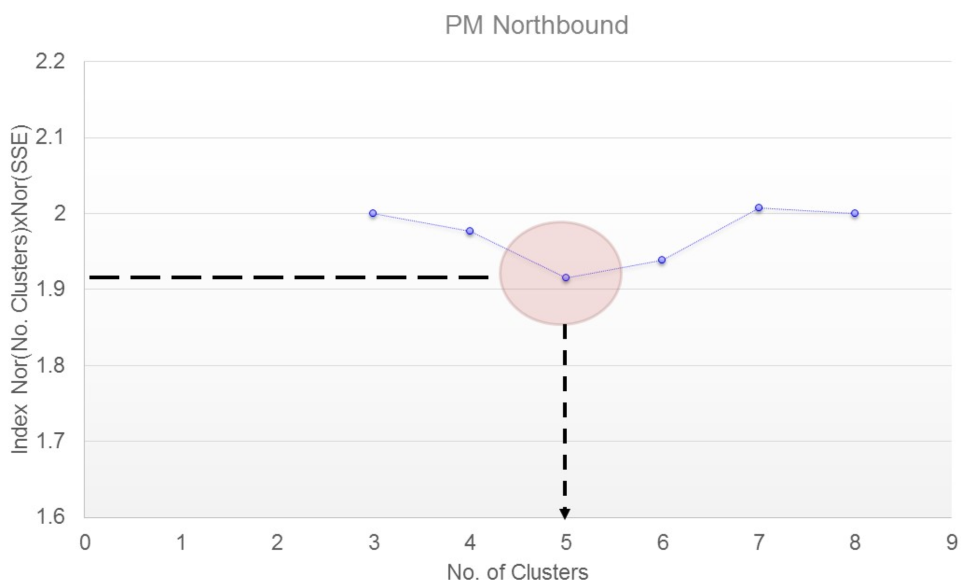

Figure A-17: The clustering index for the PM Peak Period [Source: Booz Allen]

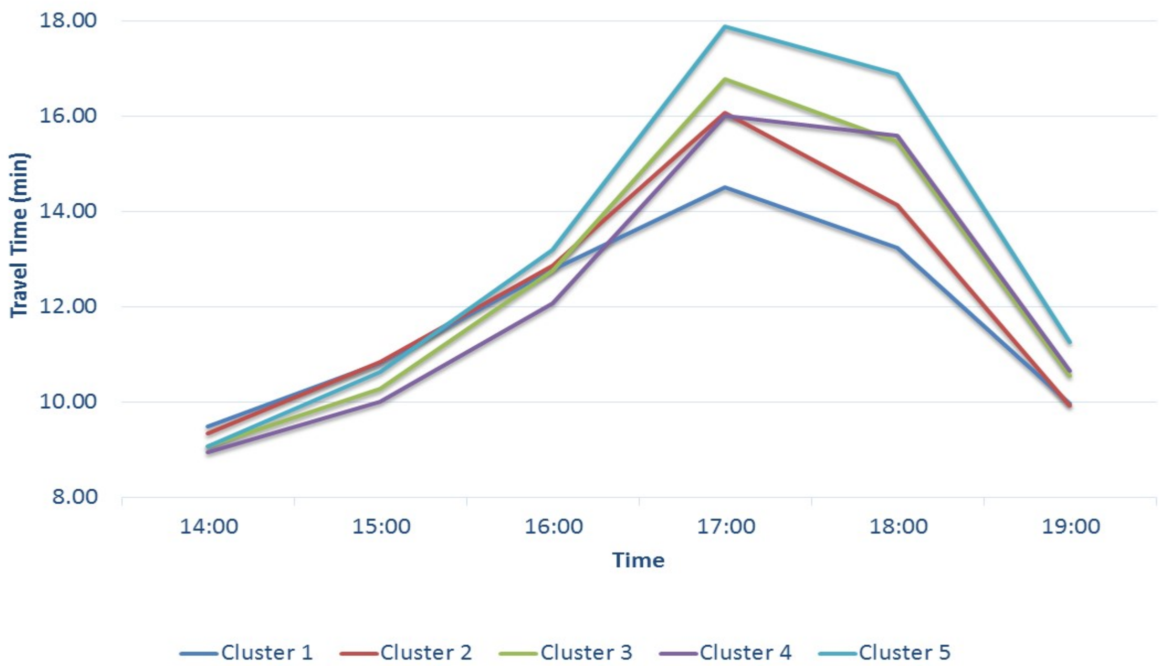

Figure A-18: The Time-Varying Travel Time for the five Clusters for the PM Peak Period (Average travel time for US-101 Northbound) [Source: Booz Allen]

Cluster Analysis Final Results

Based on the cluster analysis process, five clusters have been selected for representing the PM peak traffic conditions in the San Mateo region. Comparing the values of these variables against the average values for all data records, the clusters could be summarized as follows:

- Cluster 1: **Medium Demand + Major Incident + Dry**
- Cluster 2: **Medium Demand + Major Incident + Wet**
- Cluster 3: **Normal Day**
- Cluster 4: **High Demand + Minor Incident + Dry**
- Cluster 5: **High Demand + Major Incident + Dry**

These clusters are defined by the characteristics shown in Table A-9.

Table A-9: Characteristics that Define the Clusters

	Cluster 1	***Cluster 2***	***Cluster 3***	***Cluster 4***	***Cluster 5***
Definition	Medium Demand + Major Incident + Dry	Medium Demand + Major Incident + Wet	Normal Day	High Demand + Minor Incident + Dry	High Demand + Major Incident + Dry
VMT	159,388	160,052	163,672	165,590	170,017

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Incident Duration	64 min	68 min	0	27 min	54 min
Weather Condition	Dry	Wet (0.01 in/hr)	Dry	Dry	Dry
Average Travel Time	14.11 min	13.93 min	9.56 min	16.73 min	11.62 min

Based on the analysis, four operational scenarios, Cluster 1-Cluster 4 are selected to represent the main operational conditions in the PM peak period.

Identification of Representative Days

Given the results of the cluster analysis, the next step is to pick a peak period from each cluster as a representative for that cluster. The model is then calibrated to replicate the operational conditions for each of these days representing the baseline scenarios.

A good representative peak period for a cluster is recommended to be as close as possible to the center of this cluster. For each cluster, a proximity measure is calculated for each peak period in this cluster. This proximity measure is computed as the Euclidian distance between the peak period and the center of the cluster. Figures A-19 to A-22 provides a summary of the computed Euclidian distances (proximity to the center) for the peak periods in the four clusters. As shown in the figures, the Euclidian distances for the different peak periods in each cluster are sorted from the smallest (left) to the largest (right). Peak periods in each cluster are examined. A peak period is selected to represent a cluster if it satisfies the following two conditions: a) the peak period is close to the center of the cluster (i.e., small Euclidian distance), and b) the travel time and average incident duration observed for this peak period is consistent with the average value observed in the cluster. As shown in Figures A-19 to A-22, the day selected for each cluster is marked using a different color.

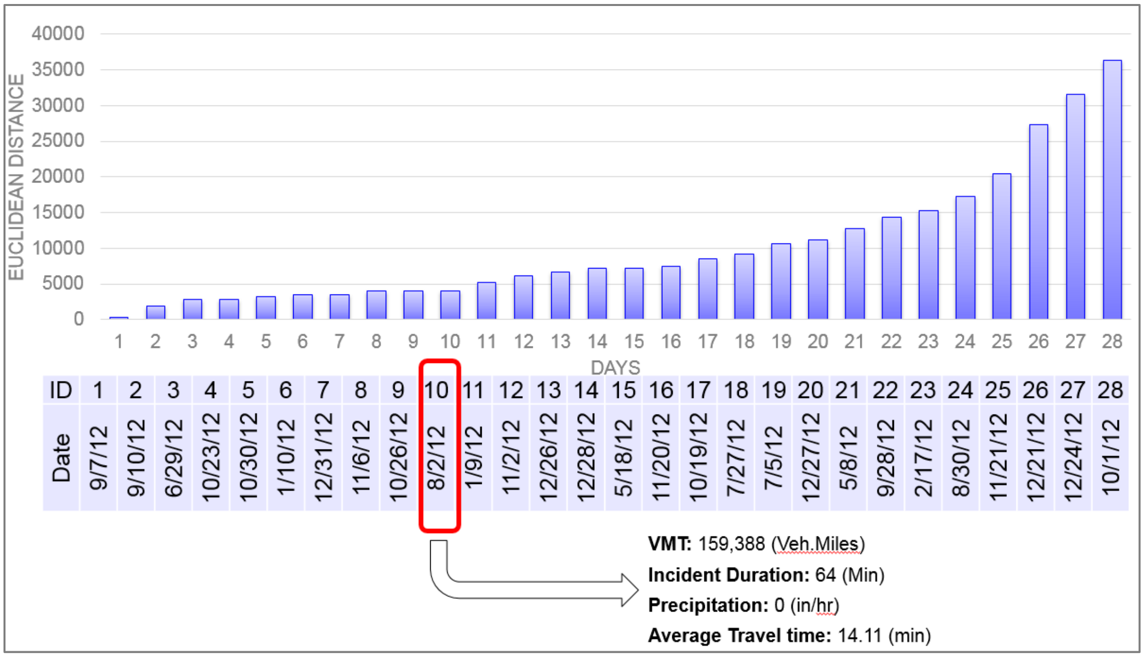

Figure A-19: Cluster 1 - Medium Demand, Major Incident, Dry (Rep. Day 8/2/2012) [Source: Booz Allen]

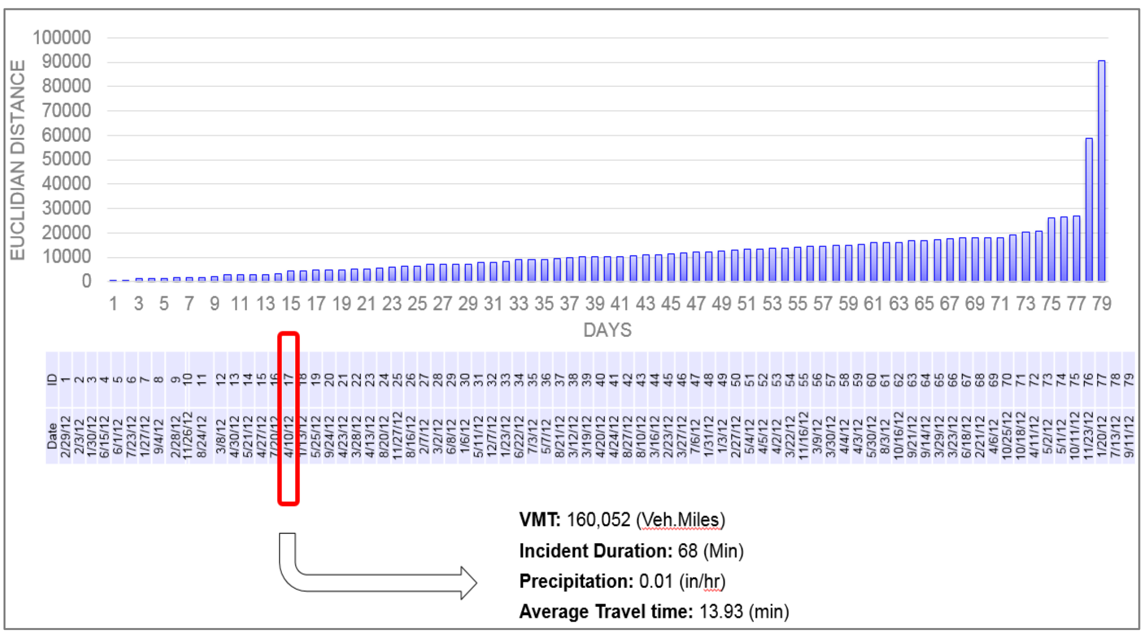

Figure A-20: Cluster 2 - Medium Demand, Major Incident, Wet (Rep. Day 4/10/2012) [Source: Booz Allen]

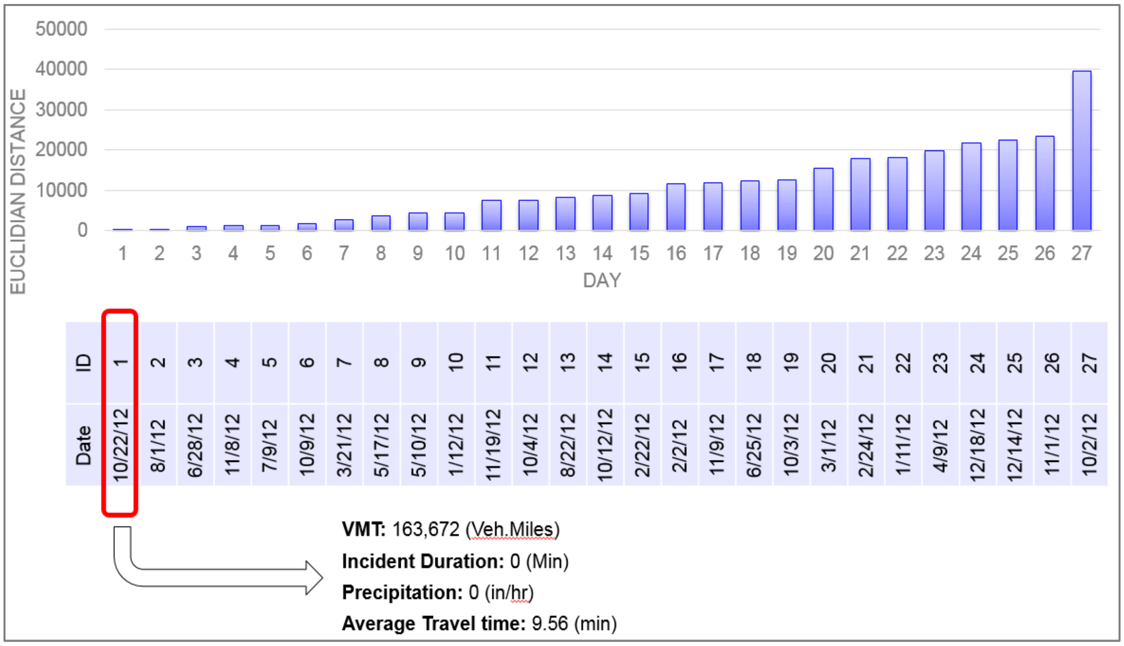

Figure A-21: Cluster 3 - Normal Day (Rep. Day 10/22/2012) [Source: Booz Allen]

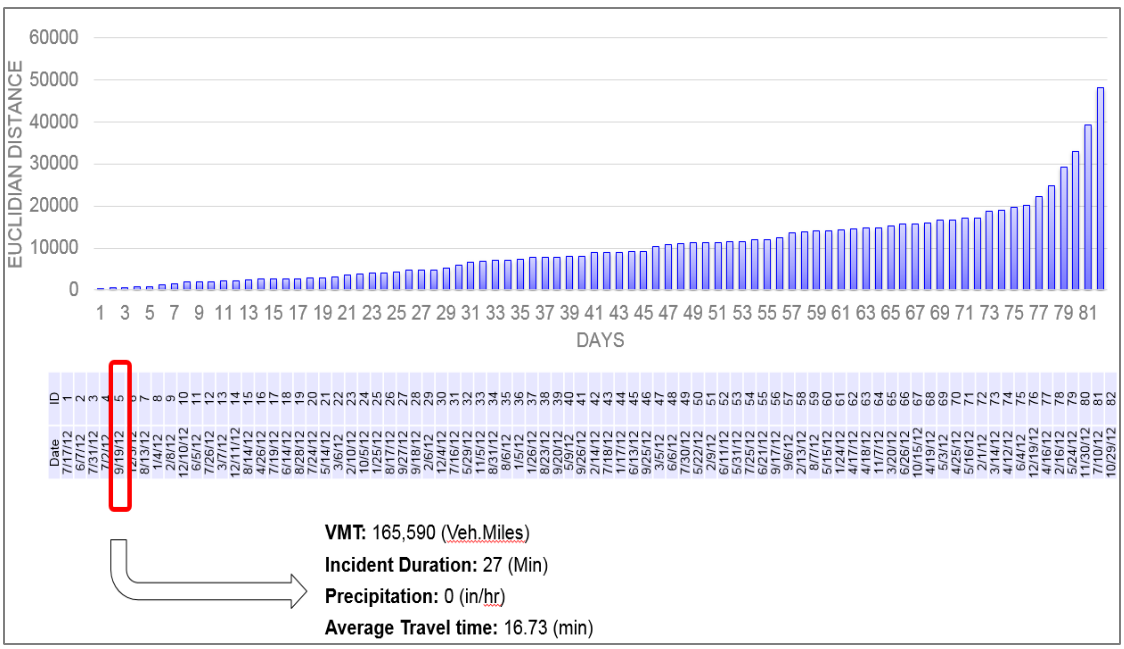

Figure A-22: Cluster 4 - High Demand, Minor Incident, Dry (Rep. Day 9/19/2012) [Source: Booz Allen]

In summary, the VISSIM model will calibrated to replicate the operational conditions for the representative days above, 8/2/2012, 4/10/2012, 10/22/2012, and 9/19/2012. The cluster analysis was also extended to identify representative days from 2014 since the arterial calibration data was available only for the year 2014. These days are given below: 9/16/2014, 10/14/2014, 3/4/2014 and 4/14/2014.

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