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

Calibration Report for San Mateo Testbed

www.its.dot.gov/index.htm

Final Report — August 22, 2016

FHWA-JPO-16-377

U.S. Department of Transportation

Produced by
Booz Allen Hamilton
U.S. Department of Transportation
Intelligent Transportation System (ITS) Joint Program Office (JPO)

Notice

[Cover Image by Booz Allen Hamilton]

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-16-377		

4. Title and Subtitle Analysis, Modeling, and Simulation (AMS) Testbed Development and Evaluation to Support Dynamic Mobility Applications (DMA) and Active Transportation and Demand Management (ATDM) Programs — Calibration Report for San Mateo Testbed	**5. Report Date** August 22, 2016 **6. Performing Organization Code**
7. Author(s) Balaji Yelchuru, Brandon Nevers, Richard Dowling, Anxi Jia, Ismail Zohdy, Raj Kamalanathsharma	**8. Performing Organization Report No.**
9. Performing Organization Name And Address Booz Allen Hamilton 20 M St SE, Suite 1000 Washington, DC 20003	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** DTFH61-12-D-00041
12. Sponsoring Agency Name and Address U.S. Department of Transportation Intelligent Transportation Systems–Joint Program Office (ITS JPO) 1200 New Jersey Avenue, SE Washington, DC 20590	**13. Type of Report and Period Covered** **14. Sponsoring Agency Code**

15. Supplementary Notes

FHWA Government Task Manager: James Colyar

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 calibration process for AMS San Mateo Testbed. The report discusses the field observed data used to calibrate the simulation models, calibration methodology, calibrated data and also the margins of error for the efforts for each baseline operational condition.

17. Key Words	18. Distribution Statement
ATDM, DMA, AMS, Selection criteria, Testbeds, active transportation demand managements, modeling, dynamic mobility application, San Mateo	

19. Security Class if. (of this report)	20. Security Class if. (of this page)	21. No. of Pages	22. Price
		39	

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

Acknowledgements

The Booz Allen Hamilton team thanks the U.S.DOT and project team members for their valuable input.

Name	Organization
Chung Tran	Federal Highway Administration (FHWA)
David Roden	AECOM
James Colyar	Federal Highway Administration (FHWA)
Jim Sturrock	Federal Highway Administration (FHWA)
John Halkias	Federal Highway Administration (FHWA)
Karl Wunderlich	Noblis
Khaled Abdelghany	Southern Methodist University (SMU)
Matthew Juckes	Transport Simulation Systems (TSS)
Meenakshy Vasudevan	Noblis
Peiwei Wang	Noblis
Pitu Mirchandani	Arizona State University (ASU)
Ram Pendyala	Arizona State University (ASU)
Roemer Alferor	Federal Highway Administration (FHWA)
Sampson Asare	Noblis
Thomas Bauer	Traffic Technology Solutions (TTS)
Xuesong Zhou	Arizona State University (ASU)

Table of Contents

List of Tables

List of Figures

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 objective of the AMS Testbed work is to:

1. Develop and calibrate multiple Analysis, Modeling, and Simulation (AMS) Testbeds,
2. Evaluate the system-wide impacts of individual Dynamic Mobility Applications (DMA), individual DMA bundles, and logical combinations of bundles and applications, and identify conflicts and synergies for maximum benefit,
3. Evaluate the system-wide impacts of Active Transportation and Demand Management (ATDM) strategies when implemented individually and in logical combinations, and identify conflicts and synergies for maximum benefit, and
4. Evaluate the impacts of the DMA bundles and ATDM strategies when prediction and active management are coupled with data capture and communications technologies that can systematically capture the motion and state of mobile entities, and enable active exchange of data with and between vehicles, travelers, roadside infrastructure, and system operators.

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. At the conclusion of the AMS Testbed selection process, six (6) AMS Testbeds were selected to form a diversified portfolio to achieve rigorous DMA bundle and ATDM strategy evaluation: San Mateo (US 101), Pasadena, ICM Dallas, Phoenix, Chicago and San Diego Testbeds.

In a preceding set of deliverables, the analysis plans developed for the selected AMS Testbeds are presented. These analysis plans describe the baseline operation scenarios to be considered for each Testbed. These baseline scenarios were obtained based on a cluster analysis that is conducted to determine common operational conditions for each Testbed. A primary task of this research project is to calibrate the traffic network simulation models that are used to simulate the traffic conditions of these Testbeds to ensure that the models are capable of replicating the observed traffic patterns in the network.

The primary purpose of this report is to document the model selection, development, calibration effort for the San Mateo Testbed to represent the different baseline scenarios. The San Mateo Testbed is developed for the roadway network in San Mateo County located approximately 10 miles south of the San

Francisco International Airport (SFO). The Testbed is an 8.5 mile long stretch of the US 101 freeway, a parallel arterial street (El Camino Real), and six cross connecting streets. The calibrated model consist of these roadway segments with demands for afternoon peak hour traffic between 2:30 PM and 7:30 PM. This Testbed will be used to test model the different analysis scenarios of interest to the DMA program.

Chapter 2. Testbed Description

2.1 Regional Conditions

This section presents a detailed description of the Testbed along with its capabilities to model the different analysis scenarios of interest to DMA and ATDM programs.

The 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).

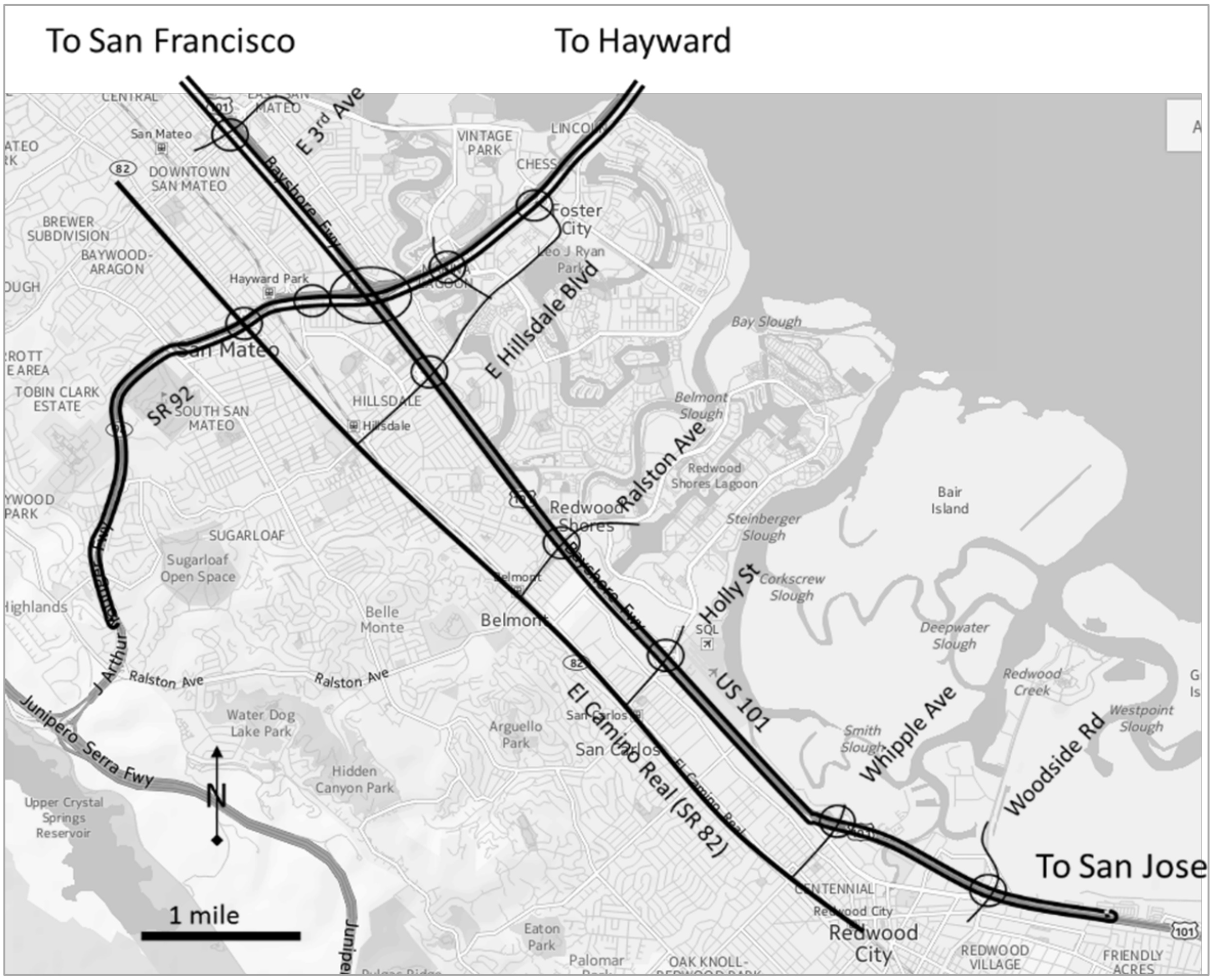

Figure 2-1: San Mateo Testbed with US 101 and SR 82 [Source: Google Maps]

2.2 Testbed Characteristics

The Testbed consists of the US 101 freeway, a parallel arterial street (El Camino Real), six cross connecting streets (East Hillsdale Boulevard, Ralston Avenue, Holly Street, Brittan Avenue, Whipple Avenue and Woodside Road), plus express bus routes using the freeway. 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. The HOV lanes are continuously accessible from the mixed flow lanes, operating as mixed flow lanes outside of the PM peak period (3-7 PM) weekdays. The freeway carries between 200,000 and 250,000 AADT of which 15% are HOV 2+ vehicles. El Camino Real (State Route 82) is a 4 to 6 lane signalized divided arterial with a posted 35 mph speed limit, carrying 25,000 to 50,000 AADT.

SamTrans (San Mateo County Transit) currently operates 2 express bus routes on the freeway during the peak periods. The US 101 freeway is regularly congested in the northbound direction during weekday PM peak periods. The lane reductions between the SR 92 interchange (5 lanes) and the Third Avenue interchange (4 lanes) and the high influx from SR 92 cause bottlenecks on the US 101 Northbound freeway. The freeway-to-freeway connector ramps at SR 92 also regularly experience queuing due to the high volume of vehicles exiting the freeway on to the two-lane ramp. Traffic is heavy in the southbound direction as well, but it is not usually congested during weekday PM peak hours (see Figure 2-2).

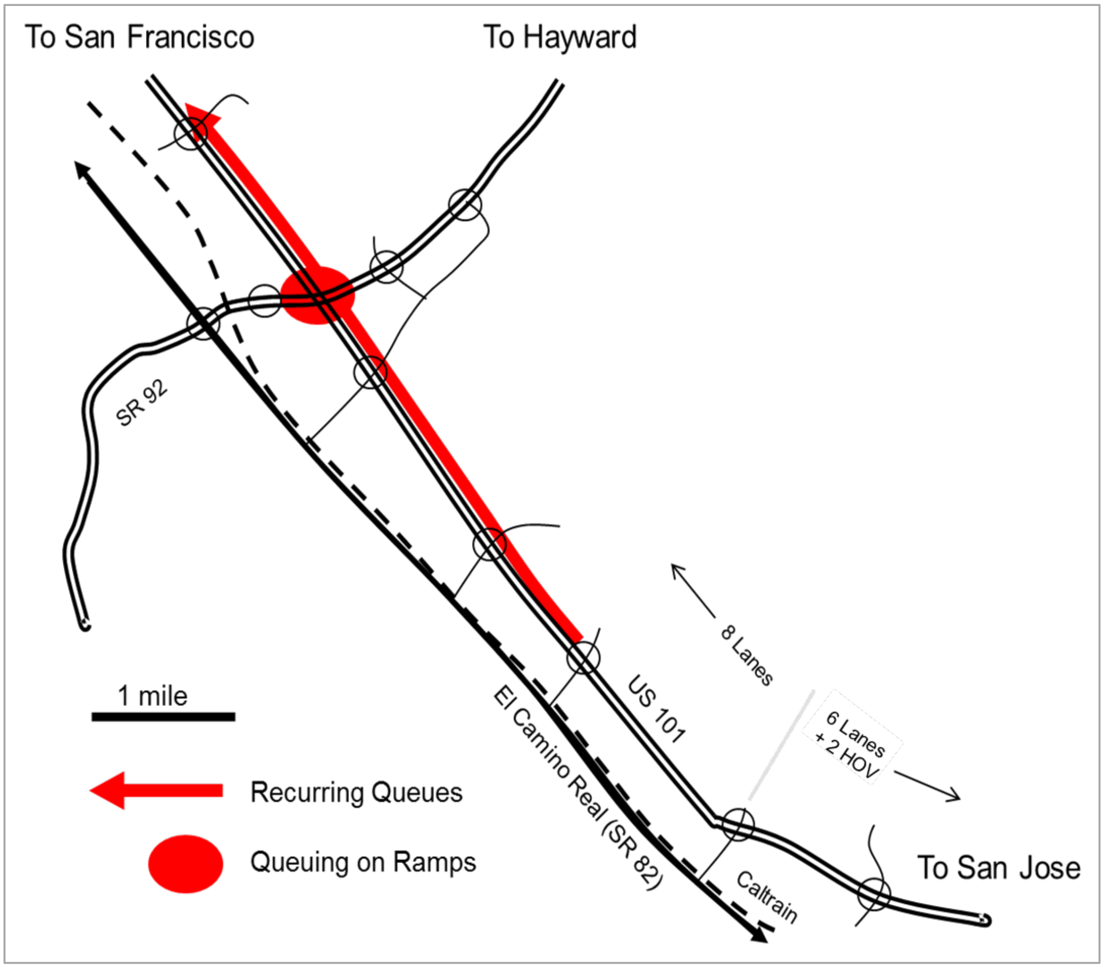

Figure 2-2: Recurring Congestion on US 101/SR 82 Testbed [Source: FHWA]

Chapter 3. Testbed Development

The original model from the FHWA SPDHARM/QWARN Impact Assessment project consisted of solely a freeway model. For AMS Testbed purposes it was desired to have a more general purpose model that could also test arterial DMA applications and the interactions between freeway and arterial DMA deployments.

3.1 Adding El Camino Real to US 101 Model

The purpose of adding the El Camino Real to the US 101 model was to enable testing of the operational effects of MMITSS. It was also desired to test the effects of diversion between the freeway and the parallel arterial. However, there are certain inherent limitations in the DMA bundle implementations (as currently implemented in the VISSIM environment) that will limit the diversion management strategies that can be tested:

- The current functionality of the MMITSS prototype does not include proactive response to incidents on the freeway or proactive response to SPDHARM/QWARN guidance on the freeway to connected vehicles.
- The SPDHARM and QWARN prototypes are not designed to proactively respond to off-freeway conditions. For example, the current prototype implementation of QWARN does not suggest an alternate route, or even if the driver should consider an alternate route.

There are also additional limitations built into the current implementations of the DMA flow bundles:

- The currently available SPDHARM and QWARN prototypes are not designed to operate on arterial streets (among other reasons, their speed thresholds for identifying queues are too high for arterials).
- The current implementation of MMITSS is impractical to apply to large signal systems.

Thus a fully dynamic joint implementation of MMITSS and SPDHARM/QWARN in a freeway corridor is not practical at this time. A fully dynamic predictive routing model would exceed the capabilities and capacities of both DMA bundles, in their current state of development and implementation within the VISSIM simulation environment.

Therefore the following strategy has been employed for linking El Camino Real to the US 101 freeway model:

1. The MMITSS controlled signals are limited to the original 8 signals at the north end of El Camino Real for which the University of Arizona has coded, tested, and validated for the operation of MMITSS.
    - The results for the 8 signal system should be extensible in concept to larger systems.
    - The signal timings were retrieved from a Synchro model built in previous study conducted by university of California, Berkeley. It should be noted the signal settings in the field may be modified to represent the actual controller types, but the overall cycle-length and splits were consistent with the values used in the analysis. Table 3-1 shows the signal timing information coded in the testbed:

Table 3-1: Signal Timing Information Coded in Testbed

Intersection ID	Street Names	Signal Timings Source	Type of Operation
115	El Camino Real & 20th Avenue	UCB-PATH Synchro model	Coordinated
116	El Camino Real & 25th Avenue	UCB-PATH Synchro model	Coordinated
117	El Camino Real & 27th Avenue	UCB-PATH Synchro model	Coordinated
118	El Camino Real & 28th Avenue	UCB-PATH Synchro model	Uncoordinated, fully actuated
119	El Camino Real & 31st Avenue	UCB-PATH Synchro model	Uncoordinated, fully actuated
122	El Camino Real & 37th Avenue	UCB-PATH Synchro model	Uncoordinated, fully actuated
123	El Camino Real & 41st Avenue	UCB-PATH Synchro model	Coordinated
124	El Camino Real & 42nd Avenue	UCB-PATH Synchro model	Coordinated

2. A skeleton network of only the major signals has been coded for the rest of El Camino Real and the cross-connecting arterials to the freeway interchanges. These signals are not controlled by MMITSS and are coded as standard fully actuated uncoordinated signals.
   - Signals in between the major signals have not been coded.
   - The skeleton network is coded in sufficient detail to produce accurate diversion times between freeway and arterial, but is not coded to sufficient detail for evaluating intersection operations, outside of the 8 MMITSS signals.
   - The coding and data collection for the 30+ signals in between the major signals was not practical given resource limitations and the fact that counts for the year 2012, are simply not available for most of the signals. While a volume estimation process for the minor signals is indeed possible, it was judged to be of low value to the project, given that MMITSS would not be applied to control the added signals, and the need only to predict route travel times for diversion routes, not signal by signal delays.
3. Five hour turning movements were synthesized for the major signals (i.e., all major intersections on the ECR, including signals controlled and not controlled by MMITSS) from historic peak hour counts (where available) or from historic approach counts, extrapolated to 2012. Signal controller settings (initial green, maximum green, etc.) were based on defaults contained in the Synchro model. Lane geometry was obtained from 2015 Google Map photos.
4. A corridor level OD table was never developed for the model (see following section explaining the origin of the model).
   - This was a “value-to-the-project” decision. Since the currently available implementations of the MMITSS and INFLO prototypes do not facilitate coordination between freeway and arterial operations, the value of an OD table was judged to be of lesser immediate value to the AMS Testbed project than other needs of the Testbed (selection of cluster days, development of sufficient data for validation of different days, validation to multiple days, and development of sufficient model functionality to independently test INFLO and MMITSS). These other needs were judged to be more immediate and critical to the success of the Testbed than the OD table.
5. Travel time calibration was conducted on ECR:

- National Performance Management Research Data Set (NPMRDS) was used for the travel time calibration. NPMRDS provides 5 minute travel time observations at Traffic Management Center (TMC) level. The research team downloaded the data and aggregated the data as hourly corridor travel time for both NB and SB of ECR.
- It should be noted that NPMRDS only have data for ECR in 2014. Therefore, the cluster analysis process (explained in Chapter 5) was extended to identify representative days in 2014 closest to the representative days in 2012. This is shown as follows:
  - Representative Day-1 8/2/2012 : 9/16/2014
  - Representative Day-2 4/10/2012 : 10/14/2014
  - Representative Day-3 10/22/2012 : 3/4/2014
  - Representative Day-4 9/19/2012 : 4/14/2014
- The travel time calibration is conducted by varying the arterial demand and the desired speed on the ECR. Through iterative process, the travel time on ECR were calibrated against the NPMRDS travel time observations.

6. Instead, the model is being set up to allow users to manually test the effects of different levels of freeway to arterial diversion (and vice versa) on the independent operation of MMITSS and SPDHARM/QWARN, and to combine those results into total corridor performance effects.

3.2 Evolution of the San Mateo AMS Testbed

The addition of El Camino Real to the US 101 freeway model for the AMS Testbed project is the latest step in a long series of development steps of the model under the current AMS Testbed project and prior projects. This long history explains the approach taken to adding El Camino Real to the US 101 model.

3.2.1 Origins of the US 101 Freeway Model

The original VISSIM 5.4 model of US 101 (The MTC 101 Model) was created in 2009 and finalized in 2013 to model the 4 hour PM peak period for a Metropolitan Transportation Commission project to evaluate options for improving the US 101/SR 92 interchange. An extensive data collection program was conducted at that time (ramp counts, OD patterns, and OD travel times) to calibrate and validated the model for that purpose. It covered approximately 5 miles of the US 101 freeway from Holly Street north to Third Avenue.

3.2.2 Adaptation and Extension of Freeway Model for DMA Testing

The MTC 101 Model was selected for testing the operational impacts of the Battelle-TTI SPDHARM/QWARN prototype under the PD/IA DMA project. Two COM (Component Object Model) interfaces were written under the PD/IA project to feed freeway performance data, connected vehicle performance, and recommended speeds for connected vehicles to and from the VISSIM model and the SPDHARM/QWARN prototypes. One, written by TTI, read data from VISSIM and generated recommended speeds during the simulation run. The other, written by KAI, converted the recommended speeds into “desired speeds” for the connected vehicles, for input to VISSIM.

In addition, the northbound direction of the freeway was split into tenth mile long sublinks within the model for polling connected vehicles, identifying queues, and setting SPDHARM recommended speeds for the connected vehicles. A fifth hour was added to the simulation period to better clear the buildup of congestion during the simulation period under lane closing incident conditions.

The MTC 101 Model was extended approximately 3 miles farther south on the US 101 freeway to Whipple Avenue under the PD/IA project to provide sufficient distance to better capture the likely benefits of SPDHARM and QWARN. No new data was gathered in the field. Historic volumes and freeway mainline speeds were obtained from a prior MTC congestion management and ramp metering study of the US 101 freeway. The OD for the extended freeway was synthesized from the ramp volumes. The extended model was validated to this historic data under the PD/IA project. The year 2012 was the selected validation year because it coincided with the availability of ramp count data from the earlier MTC project. (Mainline volumes and spot speeds are continuously monitored on US 101, however, ramps are not).

3.3 VISSIM Settings

This section describes some key settings in the VISSIM model for the adaptation of the San Mateo Testbed for use in impact analysis.

3.3.1 Analysis Hours, Warm-up Period and Cool-down Period

The simulation was run for 5 hours (from 14:30-19:30). A one-hour warm up period was coded with 60% of the first hour's demand. The demand in warm-up period is the initial and unrealistic demand inputs of the model. The purpose of warm-up period is to prevent the data collection and performance calculation from being conducted when there is no vehicles in the network. A one-hour cool down period was coded with zero demand (i.e., no vehicle inputs) to enable more of the unserved demand in the previous simulation period to leave the network. It has been found that about 20% of the coded demand in the more severe scenarios need use the cool down period to leave the network.

3.3.2 Coding of Connected Vehicles and Data Collection Points

Vehicle type "C_Car" (i.e., connected vehicle) were created with the same characteristics as vehicle type "Car" (i.e., normal passenger car). The connected types were the source of the data for the SPDHARM prototype and were the only vehicles affected by the recommendations of the prototype.
Nineteen data collection stations are placed on US 101 northbound from the south of the Woodside Road interchange to the south of the State Route 92 interchange. The space between the adjacent data collection stations is 0.5 mile. Each detection station can represent a "sublink" of the roadway for the SPDHARM prototype. The data collection stations collect the volume, speed and occupancy.
Desired speed decision points were also placed on US 101 northbound from the south of the Woodside Road interchange to the south of the State Route 92 interchange. The space between the adjacent desired speed decision points is 0.1 mile. As soon as a connected vehicle reaches the speed decision points, it will adjust its traveling speed if the SPDHARM prototype recommends one different from its previous desired speed.

3.3.3 Coding of Incident

There is no incident function readily available in VISSIM. Therefore, the team used the bus stop to approximate the lane-block effect of the incident. The basic idea is to block the certain number of lane(s) by making the bus stop at the incident location for certain minutes. In VISSIM, this can be done by adjusting the dwell distribution of the bus. The network requires a set of "virtual ramps" to directly feed the bus in to each incident location. This will not only prevent the movement of bus to the incident location from effecting the overall network flow until the incident happens, but also enables easy exit and release of the incident closure.

Figure 3-1 demonstrates the lane-block by the bus (shown in green color). At the end of the incident period, the bus will leave the facility from the left-side ramp, which is coded as a bus-only facility.

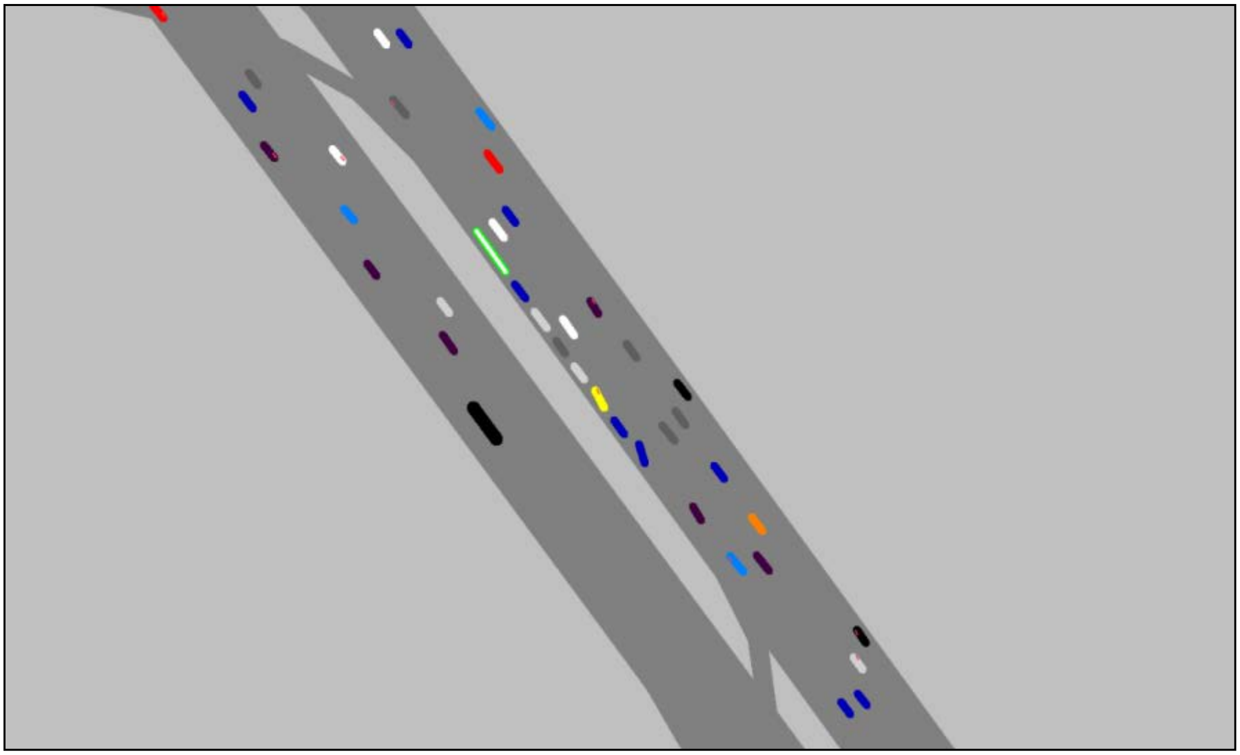

Figure 3-1: Lane-Block Approximation for Incident Scenario [Source: Kittelson]

Chapter 4. Addition of El Camino Real to AMS Testbed

This chapter provides additional details on the addition of the El Camino Real to the AMS Testbed.

The VISSIM microsimulation software (version 6.00-22) was used to create a final merged microsimulation model of the US 101 and El Camino Real corridors for the San Mateo, California Testbed. The extents of the merged model are Whipple Avenue to the south and State Highway 92 to the north. The total length is approximately six miles along a general north-south line, with four major east-west arterials connecting the two corridors.

A previously calibrated microsimulation Vissim model for the US 101 corridor was used as the foundation for the merged model. The base model was created primarily for purposes of analyzing mainline operations and was used in the INFLO Impact Assessment conducted for USDOT. The base model includes seven interchanges along US 101, ramp metering, and State Highway 92 which also includes six interchanges. Given the scale of the model, the level of detail determined for the original effort did not require the base model for US 101 to be expanded.

The El Camino Real corridor had previously been modeled in Synchro. To enable modeling of DMA applications for arterials and freeways in combination, the El Camino Real corridor was coded into Vissim and merged with the US 101 network to form a single VISSIM model.

4.1 VISSIM Network Enhancements

In order to stitch together the US 101 and ECR Vissim models a series of east-west connectors were coded into the Vissim network to link the two facilities. These include (from south to north): Whipple Avenue, Holly Street, Ralston Avenue, and Hillsdale Boulevard. All have traffic signals at their intersections with El Camino Real (ECR), the US 101 Interchange ramps, and at major intersections between US 101 and ECR. The following items summarize the enhancements made to the Vissim network:

- Traffic Signals:
  - Added traffic signals where the four east-west connectors intersect along ECR.
  - Added traffic signals at the south end of the ECR network.
  - Added traffic signals at major locations along the east-west connectors.
  - Added traffic signals at US 101 interchange ramps.
- Vehicle Routing:
  - Based on a review of traffic patterns in the area, the majority of vehicles exiting northbound US 101 were directed to the east. For the southbound direction, approximately 50-percent of vehicles were directed east and 50-percent to the west.
  - A route was added to have about one percent of the US 101 traffic take the Ralston Avenue exit.
  - Routing along ECR was assigned at individual intersections.
- Connecting the Corridors:

- o No connections were present between ECR and US 101 at the four links. Apart from adding a physical connection, a traffic sink and source was added to allow for adjustment of volume for cars accessing/coming from US 101. The traffic sink and source is the artificial link coded between freeway and arterial to balance the traffic volumes on the connections. The traffic sink and source was added after the ECR was calibrated. The corridor connections will enable vehicles exiting from the freeway to reappear on the arterial. Say 800 cars come from ECR and Whipple Ave. (the sum of NBRT, SBLT, and EBTH) and the NB on-ramp for the EB traffic carries 1000. The source, the artificial entrance on the connection between US 101 and ECR, would add 200 cars. Similarly, if 1000 cars come from ECR/Whipple (the sum of NBRT, SBLT, and EBTH) and the NB on-ramp for the EB traffic carries 800, 200 vehicles will leave the network through the sink, the artificial exit on the connection between US 101 and ECR. Once on the on-ramp, they will follow existing routing on the US 101. Similarly, say 1800 cars come from the off-ramps and are directed west. The WB volume at ECR/Whipple is 900 and the rest of it would be taken by the sink. Some routing changes were made to have vehicles enter the network earlier to have them pass through signals.

4.2 VISSIM Model Adjustments

Microsimulation networks rely on four general types of elements to simulate conditions on the roads, and each needed to be adjusted to allow the merging of the two models, those being roadway geometry, traffic control, vehicle demand, and vehicle routing. The changes made to each element are provided below.

4.2.1 Roadway Geometry

The four east-west links were added to the merged model in addition to traffic signals on El Camino Real. Off-ramp geometry and connectivity were adjusted to allow vehicles to access the US 101 interchanges and ultimately the El Camino Real corridor to the west. The geometry for the east-west connectors (number of lanes, storage lengths, movements allowed, etc.) was configured based on aerial photographs. Additional signalized intersections were included along the El Camino Real corridor to enable the necessary network connectivity within the model. A few smaller signalized intersections were not included on ECR because they do not play a role in the traffic assignment network (e.g., a local shopping center). The model excludes any non-signalized intersections along the arterials.

4.2.2 Traffic Control

Traffic signals were added at the interchanges along US 101 at the four arterial connections. Traffic signals were also added at the four intersections along El Camino Real. Given that travel time was used as a calibration tool and would be used to determine congestion, signals were also added at three major intersections along the east-west arterials. These intersections were modeled assuming a cycle length of 120 seconds for a four-legged intersection and 90 seconds for a three-legged intersection.

The model was reviewed to ensure appropriate priority movements at all intersections. Link speeds were refined for links that exit US 101 to reflect a free flow speed of 45 mph for travel on the arterials. The vehicle composition (percentages of cars, trucks, HOV, taxis, etc.) was reviewed for the entire merged network for consistency. In general, any added volumes along the El Camino Real network were modeled assuming the same vehicle composition as US 101.

4.2.3 Vehicle Demand

Volume data were already included in the original US 101 model based on archived detector volumes downloaded from PEMS. This represents a five hour simulation period for the weekday p.m. peak hour.

Peak hour volume data for the four east-west connector intersections along El Camino Real were obtained from historical counts. The peak hour volumes were extrapolated to extend across the five hour simulation period.

4.2.4 Vehicle Routing

The routing decisions from the original US 101 model were not adjusted for mainline movements given the model had already been calibrated. The on-ramp routes were adjusted to provide for the inclusion of vehicles coming from El Camino Real, including the HOV specific routes. The routing at off-ramps was also adjusted to account for vehicles destined to El Camino Real. Traffic operation at the US 101 interchange ramps was reviewed to ensure the routing decisions resulted in traffic conditions that match baseline conditions.

In the merged model the northbound US 101 on-ramp input volumes and westbound input volumes approaching El Camino Real were replaced with vehicles already within the network. As an example, vehicles travelling along US 101 that take either the northbound or southbound Ralston Avenue exit to head towards El Camino Real form the westbound approach volume at the El Camino Real and Ralston Ave intersection. These vehicles then turn either left, right, or go through the signalized intersection based on the turning movement count percentages and proceed through the network.

For vehicles traveling along El Camino Real that turn onto Ralston Ave or go through at the signal, these vehicles now form the on-ramp volume recorded at the Ralston NB on-ramp.

Within VISSIM, data collection points were set up along the four east-west arterials to help validate volumes. With US 101 and El Camino Real approximately half a mile apart, and the study corridor being in an urban/commercial environment, there are several businesses between the corridors that people are likely to visit, therefore adjustments were made to allow for a portion of vehicles to enter and exit the network from the east-west connectors.

A source was added midway along the east-west connectors in the case of too few vehicles coming from US 101 or El Camino Real. A route was also added midway along the connector in the case of too many vehicles heading toward US 101 or El Camino Real. For each half-hour period, the volumes were reviewed along the east-west connectors and adjustments were made to bring the volumes in line with observed counts.

Using Ralston Avenue as an example, during the second half-hour period (following a half-hour warm up period to populate the model) the number of vehicles coming from the US 101 off-ramps was found to be 178, but 294 were assumed to be approaching El Camino Real, so during that half-hour period an input of 116 vehicles was added to the model to supplement the off-ramp volumes. For traffic flowing toward US 101, 261 vehicles were counted coming from El Camino Real while only 150 were assumed to be entering the NB US 101 on-ramp, so the vehicle routing was employed to syphon off those extra 111 cars from the network. It should be noted that within the VISSIM software, volume inputs are used to guide a randomly assigned and timed input of vehicles which differentiates microsimulation from deterministic models such as SYNCHRO. Therefore, an input of 116 vehicles does not equate to exactly 116 vehicles. It should also be noted the volumes used in the example and to adjust the model were based on one run of the model.

The results in Table 4-1 come from two runs of the simulation model, the first providing the ‘Counted’ data, that being what was counted as being the potential volume source coming from the parallel corridor. Those volumes were then adjusted and the approach volumes at the intersections were collected and are presented as ‘Final’. Comparison of the Original and Final volumes shows vehicles in the merged model are able to travel between the two corridors at a profile consistent with assumed (observed) conditions.

Table 4-1: Summary of vehicles in the Merged Vissim model along Ralston Avenue

End Time Period -		***0.5***	***1.0***	***1.5***	***2.0***	***2.5***	***3.0***	***3.5***	***4.0***	***4.5***	***5.0***	**5.5**
NB On-Ramp	*Original*	*150*	*150*	*300*	*300*	*350*	*350*	*350*	*350*	*250*	*250*	200
	Counted	*151*	*261*	*275*	*354*	*368*	*400*	*444*	*365*	*342*	*270*	280
	Adjust	*-1*	*-111*	*25*	*-54*	*-18*	*-50*	*-94*	*-15*	*-92*	*-20*	-80
	Final	*132*	*171*	*267*	*298*	*341*	*370*	*335*	*237*	*243*	*325*	249
El Camino Real	*Original*	*196*	*294*	*294*	*392*	*392*	*490*	*490*	*392*	*392*	*294*	294
	Counted	*134*	*178*	*279*	*245*	*255*	*233*	*271*	*275*	*313*	*304*	299
	Adjust	*62*	*116*	*15*	*147*	*137*	*257*	*219*	*117*	*79*	*0*	0
	Final	*189*	*291*	*288*	*398*	*391*	*466*	*497*	*390*	*383*	*299*	298

Note: Negative Adjust volumes indicate an excess of counted vehicles and those were routed from the network.

Chapter 5. Cluster Analysis Results

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. These data definitions are given in sections 5.1.1 and 5.1.2.
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
   - Sum of the Squared Error (SSE)
   - The coefficient of variation (CV) for each variable for all clusters
   - 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

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.

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

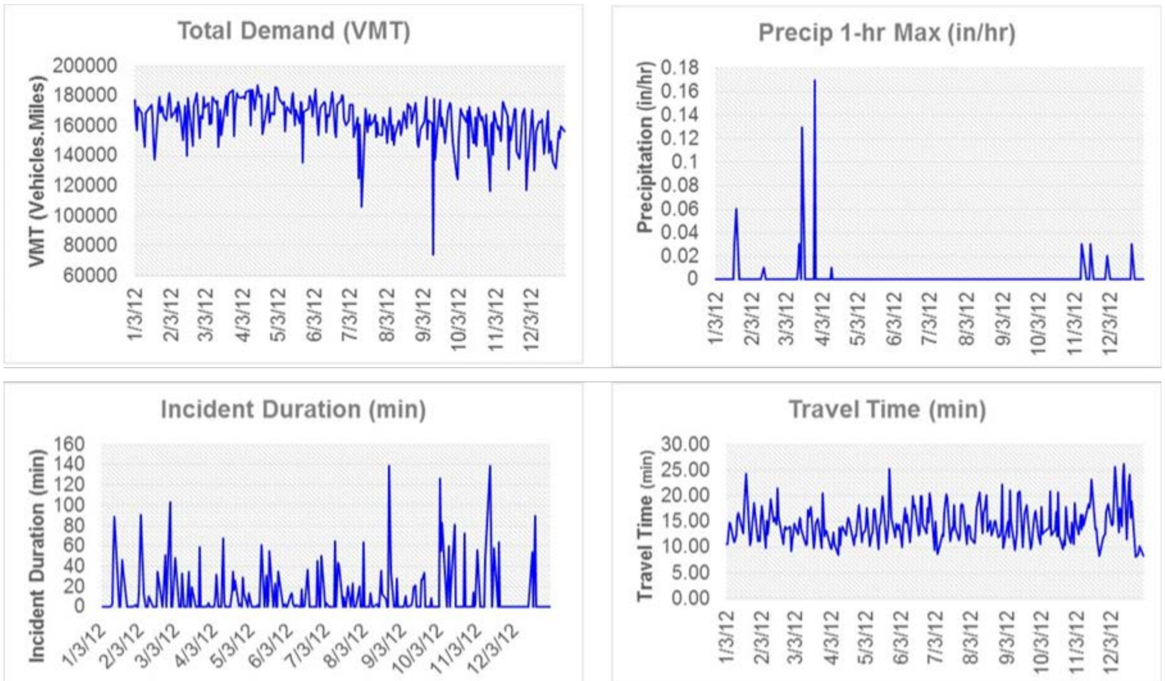

Figure 5-1: The Distribution of the Different Datasets for San Mateo Testbed [Source: Kittelson]

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.

5.1.1 Type 2: 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.

5.1.2 Type 3: 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[1] 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)

5.2 Cluster Analysis Process

The results for the cluster analysis for the evening peak period are presented in Figure 5-2 through Figure 5-4. Figure 5-2 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 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 5-2 and Figure 5-3Figure 5-4, 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 5-2 also gives the maximum and minimum CV for the four analyzed

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

variables (VMT, incident duration, and 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 5-2 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 5-3 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 5-4 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 5-1 to help define the number of selected clusters.

Table 5-1: A Summary of the Clustering Analysis for the PM Peak Period

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

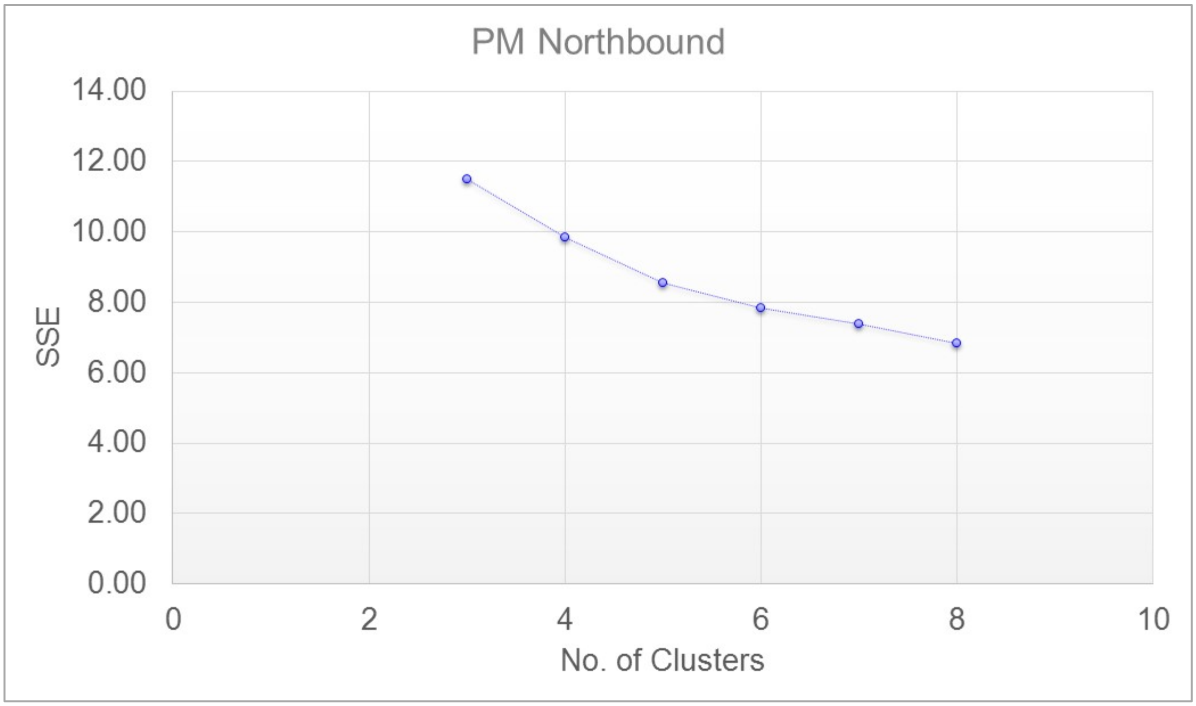

Figure 5-2: The SSE for Different Clustering Patterns for the PM Peak Period [Source: Kittelson]

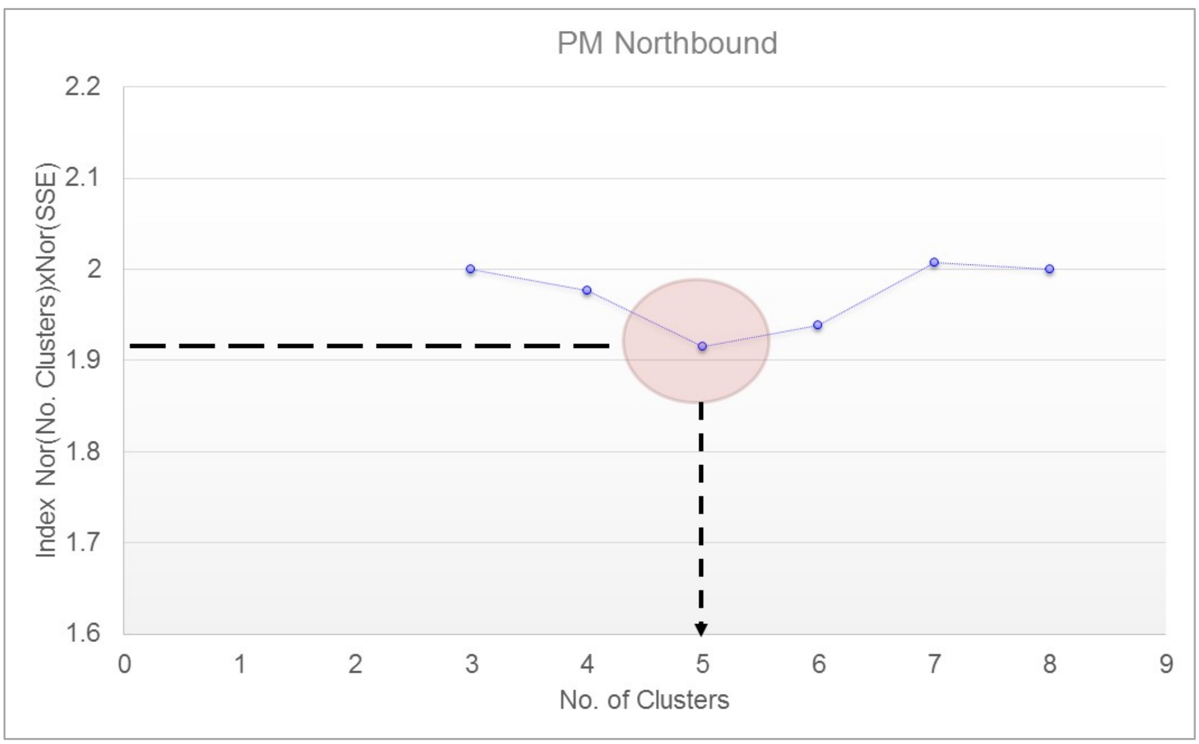

Figure 5-3: The Clustering Index for the PM Peak Period [Source: Kittelson]

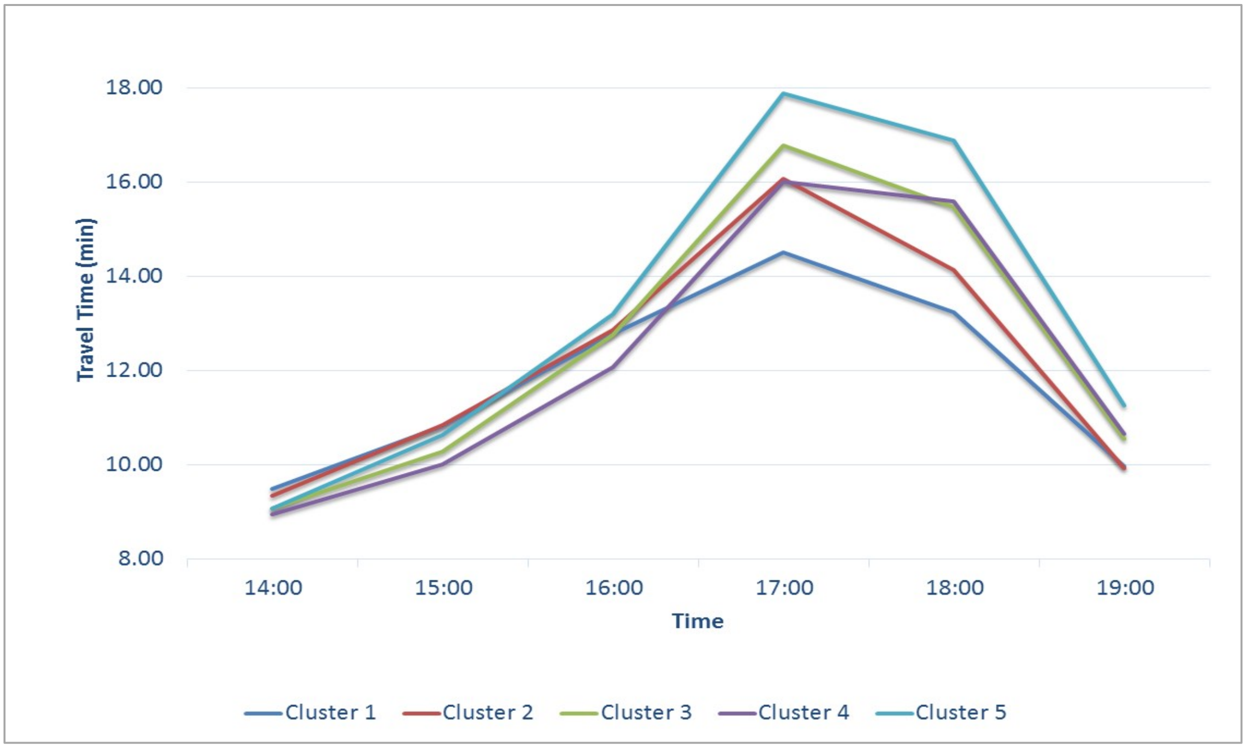

Figure 5-4: The Time-Varying Travel Time for the Five Clusters for the PM Peak Period (Average Travel Time for US 101 Northbound) [Source: Kittelson]

5.3 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 5-2.

Table 5-2. 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
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.

5.4 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. Figure 5-5 to Figure 5-8 provide 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 Figure 5-5 through Figure 5-8, the day selected for each cluster is marked using a different color.

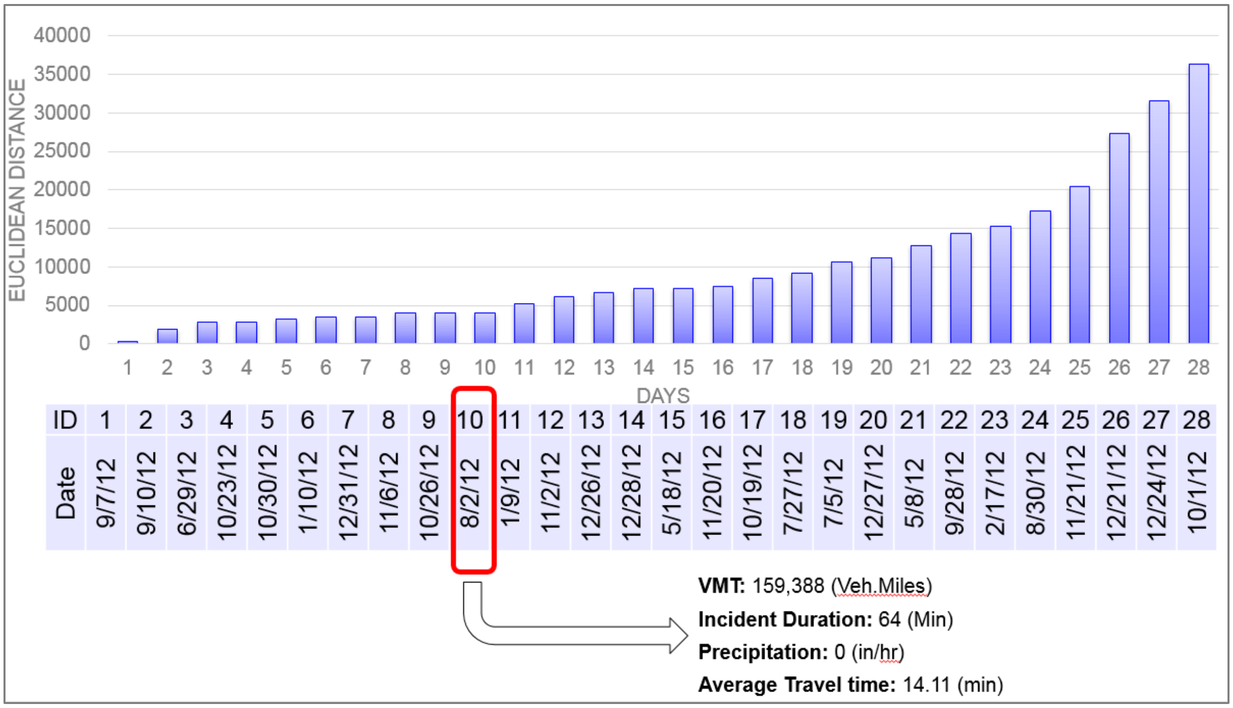

Figure 5-5. Cluster 1 - Medium Demand, Major Incident, Dry (Rep. Day 8/2/2012) [Source: Kittelson]

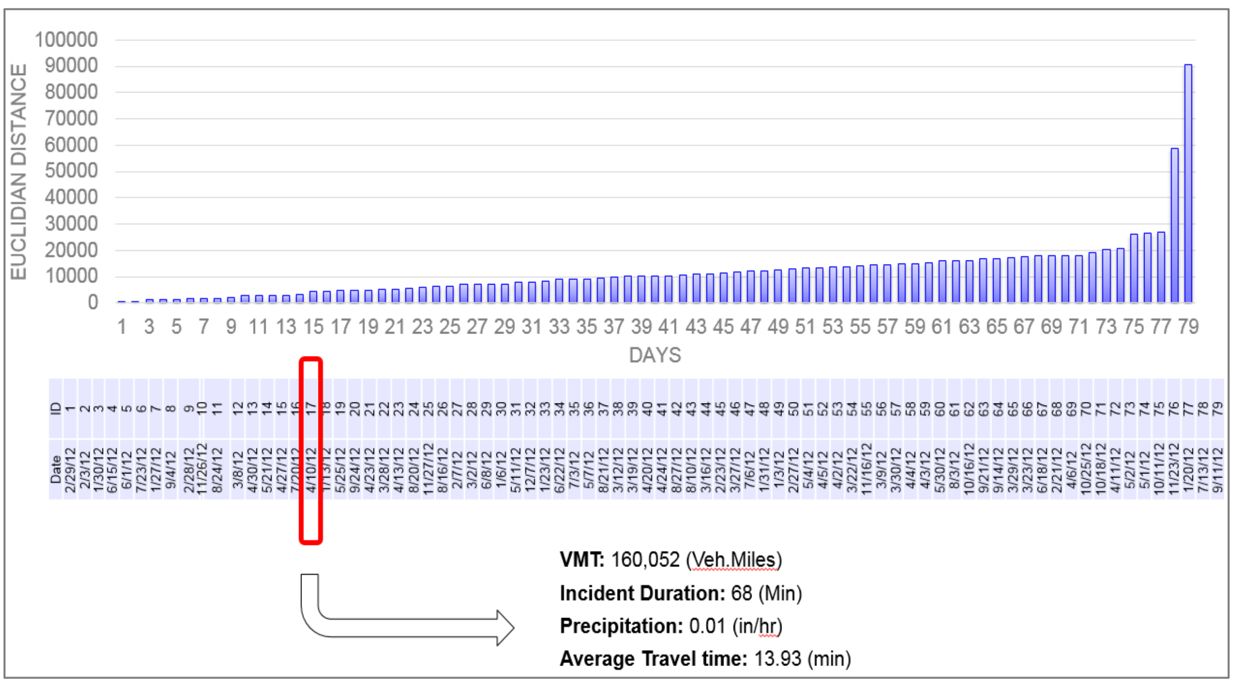

Figure 5-6. Cluster 2 - Medium Demand, Major Incident, Wet (Rep. Day 4/10/2012) [Source: Kittelson]

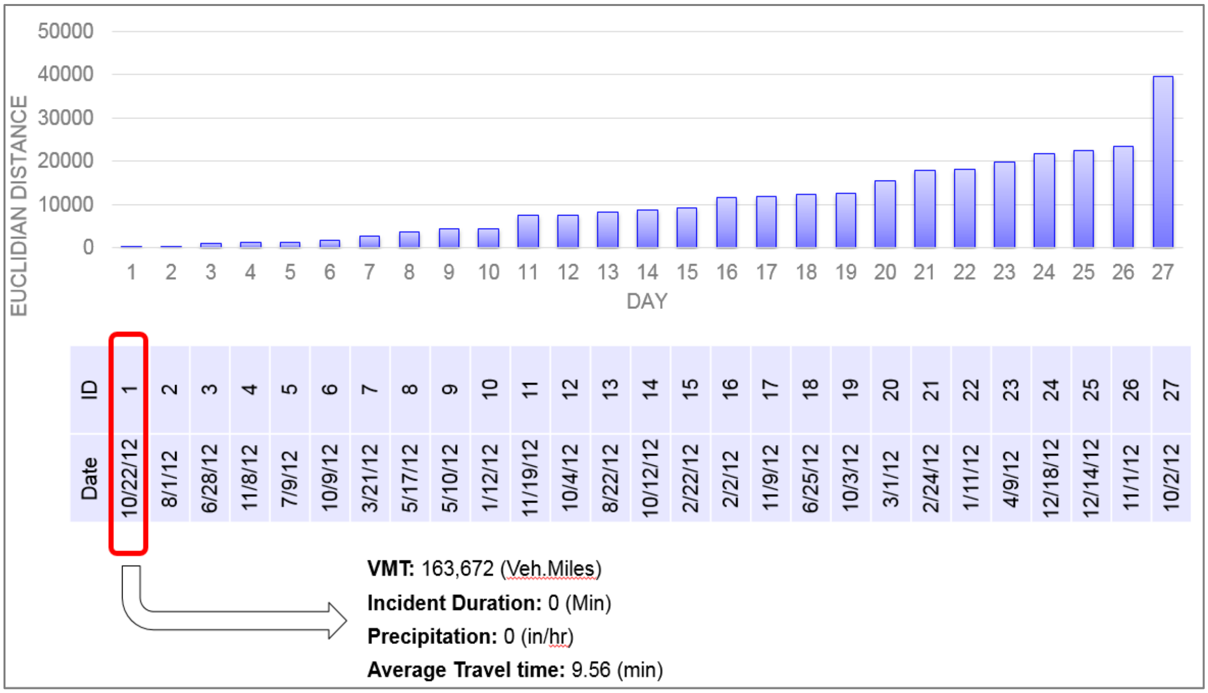

Figure 5-7. Cluster 3 - Normal Day (Rep. Day 10/22/2012) [Source: Kittelson]

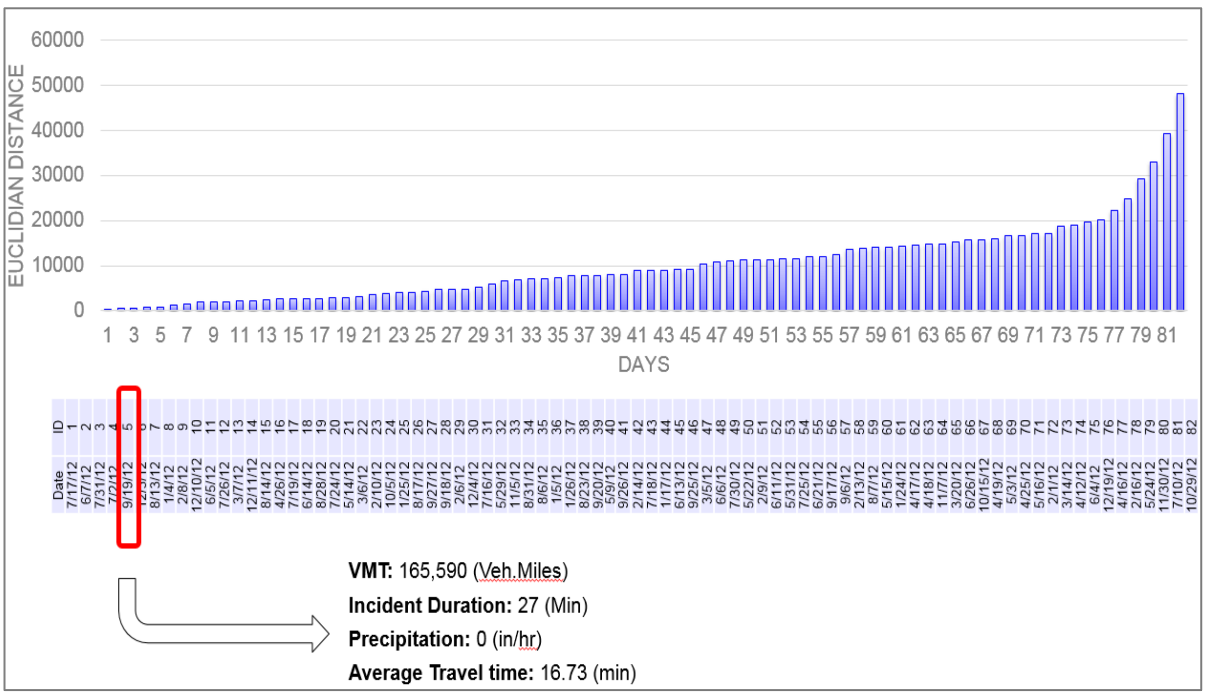

Figure 5-8. Cluster 4 - High Demand, Minor Incident, Dry (Rep. Day 9/19/2012) [Source: Kittelson]

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.

Chapter 6. Model Calibration

Based on the results of the cluster analysis, the VISSIM model of San Mateo Testbed were calibrated to representative days of Cluster 1~4. Prior to the model calibration, the following field measurements were collected:

- Time-dependent hourly volumes/speed from detectors along the freeway study corridor (i.e., US 101 NB), obtained from PeMS;
- Time-dependent hourly travel time of the freeway study corridor, obtained from PeMS;
- Time-dependent hourly travel time of the arterial study corridor, obtained and calculated from NPMRDS

As discussed previously, there are incidents in cluster 1, cluster 2 and cluster 4. Table 6-1 summarizes the incident characteristics, including incident location, number of lanes blocked, start time and end time.

Table 6-1: Incident Characteristics for Different Clusters

Cluster	Incident #	Location	Lanes	Start Time	End Time
1	1	US 101 NB (Between Whipple Ave and Woodside)	3 left lanes	5:30 PM	6:03 PM
2	1	US 101 NB (Prior to Woodside Rd Exit)	1 left lane	5:28 PM	5:56 PM
	2	US 101 NB (Between Whipple Ave and Woodside Rd)	All 5 lanes	5:30 PM	5:36 PM
	3	US 101 NB (Between Holly St and Ralston Ave)	2 right lanes	3:59 PM	4:33 PM
4	1	US 101 NB (North of SR 92 Exit)	2 left lanes	5:39 PM	6:06 PM

An iterative procedure is used to calibrate the model against each representative day. The models were calibrated by adjusting the demand pattern and the parameters of driver behavior model to match: 1) the throughput of the bottleneck, 2) the traffic counts along the study corridor, and 3) the time-dependent travel time of the study corridor. The model calibration criteria/targets are:

- Bottleneck throughput: within 10% of field count
- Simulation volumes vs. traffic counts: within 15% of field flow for >85% of cases and sum of all flows within 5% of sum of all traffic counts
- Corridor travel time: within 15% (or 1 minute, if higher) of field measurement
- Visual Audits: reasonable bottleneck formation and queuing

The model calibration results for each representative day are summarized in the following sections.

6.1 Calibration Results of Cluster 1

Based on the cluster analysis, the operation conditions of Cluster 1 represent a Medium Demand, No Incident, and Dry scenario. The representative day of cluster 1 is 8/2/2012. There are 21 detectors on US 101 NB. On 8/2/2012, there are 16 healthy detectors and 5 bad detectors (i.e., detectors have zero/unreasonable observation data on 8/2/2012) as shown in Figure 6-1.

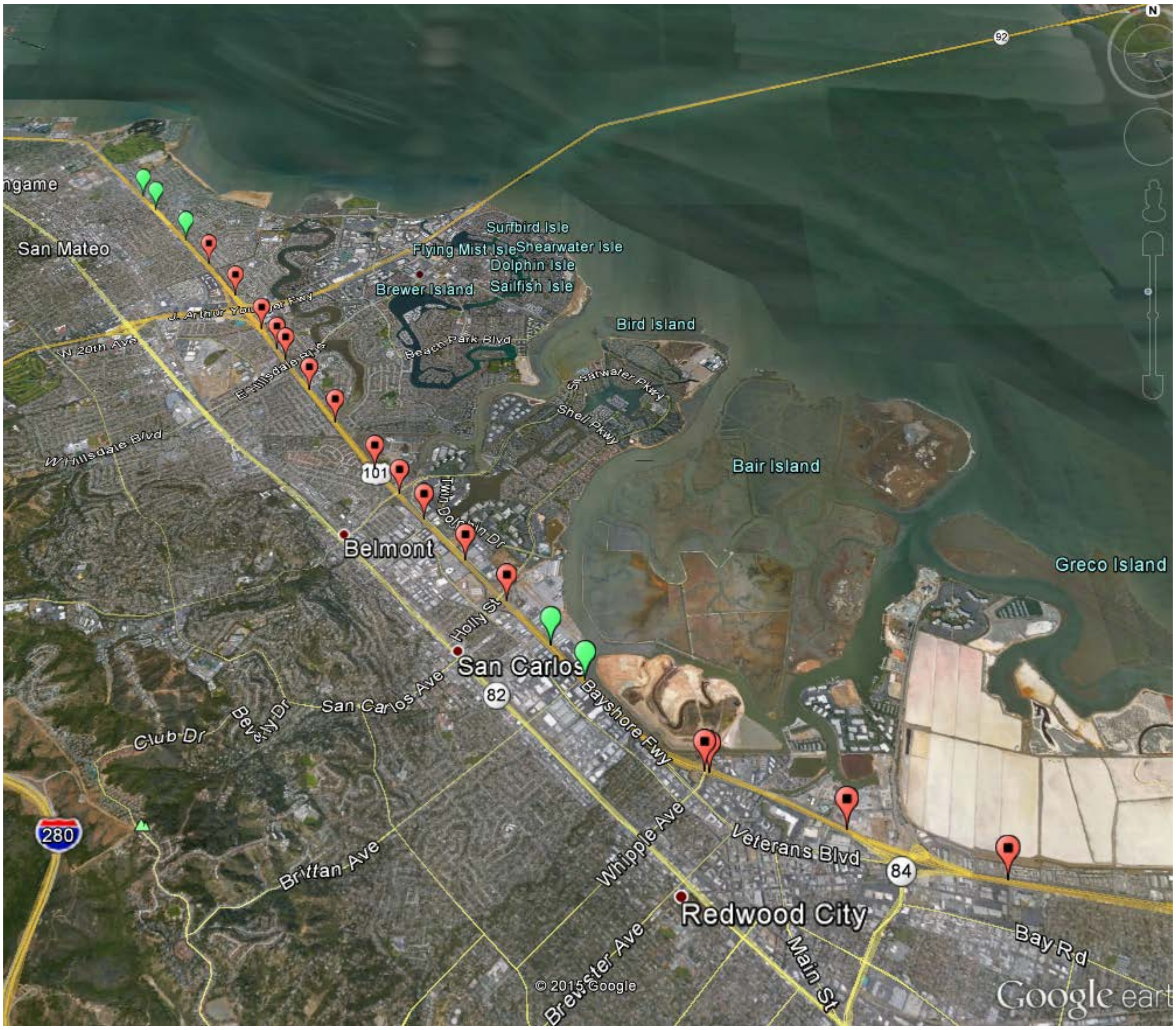

Figure 6-1. Available Detectors on US 101 NB on 10/22/2012 [Source: Google Earth]

6.1.1 Bottleneck Throughput

The active bottleneck on US 101 NB is located in the weaving segment between SR 92 and Hillsdale Blvd. Figure 6-2 shows the comparison of bottleneck throughputs between simulation and field counts. In each time period, the absolute difference between simulation and field count is less than 10%. The sum of simulation throughput is 23,974 and sum of field counts is 26,473. Percentage Error is -9% which meets the calibration target.

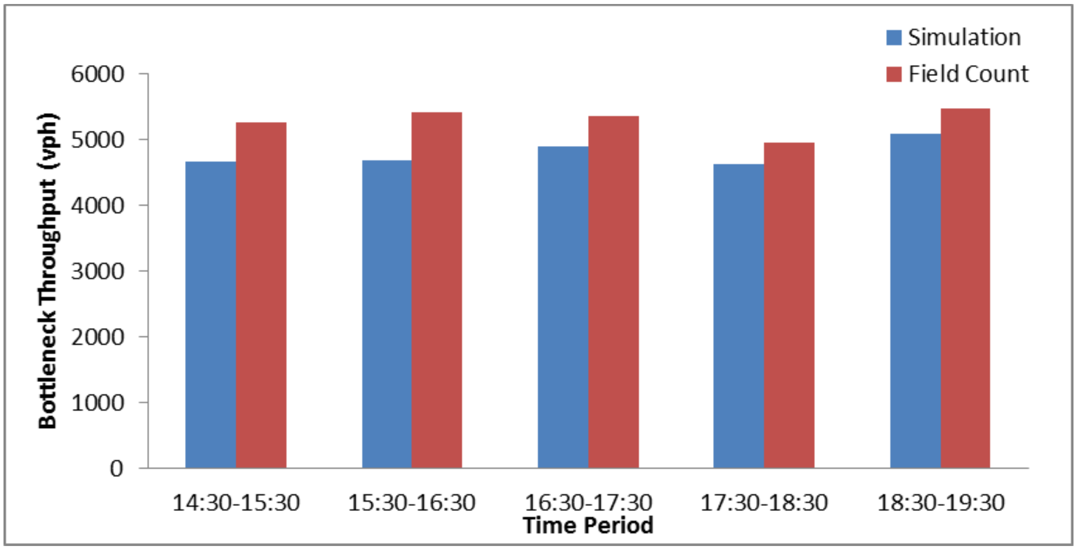

Figure 6-2. Bottleneck Throughput Comparison [Source: Kittelson]

6.1.2 Traffic Counts of Freeway Study Corridor

Table 6-2 summarizes the percentage error in the hourly traffic volumes for the US 101 NB. As shown in the figure, 87.1% of the hourly volumes have percentage error less than 15%. Sum of simulation flows is 513,387 and sum of field counts is 514,152. Percentage Error is 1.44%. The highlighted cells shows the sections where the calibration error percentages were greater than the target of 15 percent.

Table 6-2. Hourly Traffic Volume Comparison

Detectors	Percentage Errors (%)					Traffic Counts				
	14:30-15:30	15:30-16:30	16:30-17:30	17:30-18:30	18:30-19:30	14:30-15:30	15:30-16:30	16:30-17:30	17:30-18:30	18:30-19:30
401874	12%	3%	-6%	-9%	10%	6494	6752	6760	6413	6152
401835	10%	-4%	-3%	-4%	19%	6069	6392	6346	6027	5850
401834	2%	-6%	-4%	-10%	17%	5833	5903	5594	5533	5424
401833	-2%	-13%	-1%	-5%	13%	7061	7561	6606	6347	6346
401882	-16%	-20%	-2%	8%	37%	6007	5926	5265	4524	4055
401869	-2%	-13%	-2%	-4%	14%	6087	6588	5953	5764	5672
401859	-13%	-17%	-5%	-5%	4%	6825	6899	6191	5852	6322
401910	-10%	-14%	-4%	-3%	5%	6532	6560	6075	5629	6277
401443	3%	-2%	6%	15%	18%	7123	7261	6941	6341	6817
402383	44%	62%	10%	-5%	3%	4975	4382	6738	7661	7848
400661	6%	0%	10%	18%	26%	6623	7059	6694	6192	6414
401914	-9%	-13%	-6%	-1%	0%	6614	7047	6730	6103	6514
400291	-3%	-4%	1%	2%	5%	6666	6848	6613	6178	6488
400645	-11%	-13%	-9%	-7%	-7%	5264	5413	5366	4962	5468
402385	-8%	-8%	-3%	-1%	-2%	7713	8098	8270	7637	7682
402387	-11%	-11%	-7%	-5%	4%	7527	8035	8165	7583	6868

6.1.3 Travel Time of Study Corridors

Corridor travel time was examined for freeway study corridor (US 101 NB). Figure 6-3 shows that the percentage error of hourly travel time of freeway study corridor between simulation and field measurements. As shown in the figure, the percentage errors for all five hours are within the 15% calibration target.

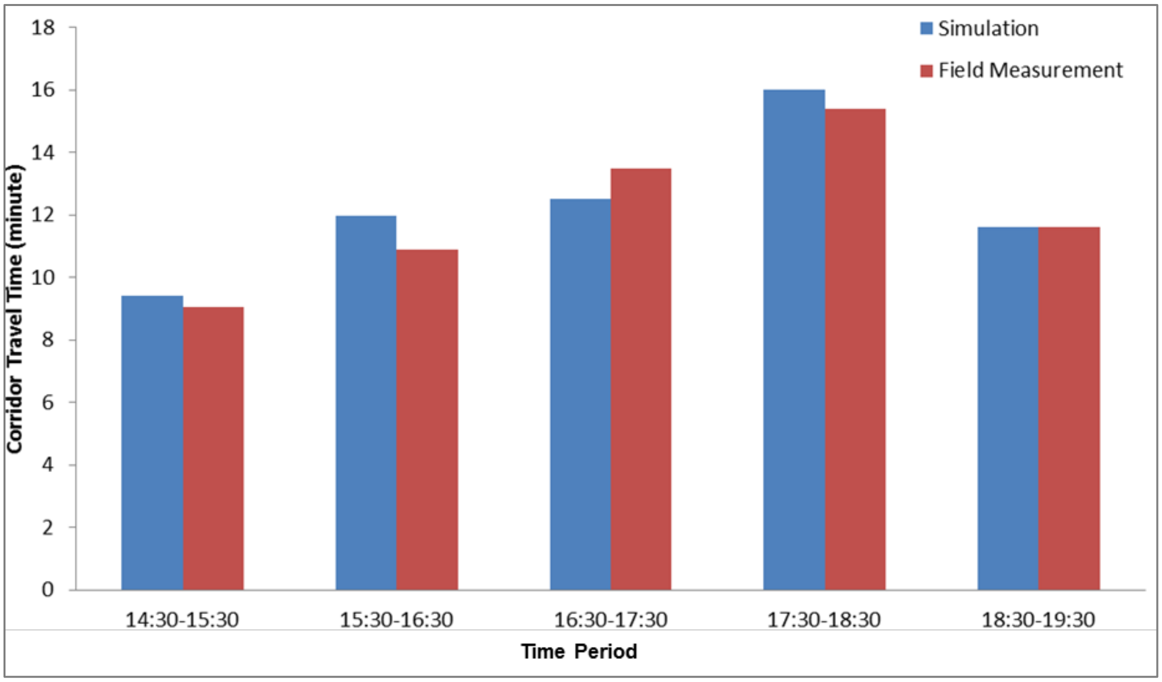

Figure 6-3. Freeway Corridor Travel Time Comparison [Source: Kittelson]

Figure 6-4 and Figure 6-5 demonstrate the comparison of arterial corridor travel time between simulation and field counts for NB and SB, respectively. As shown in the figures, the percentage errors for all five hours are within the 15% calibration target.

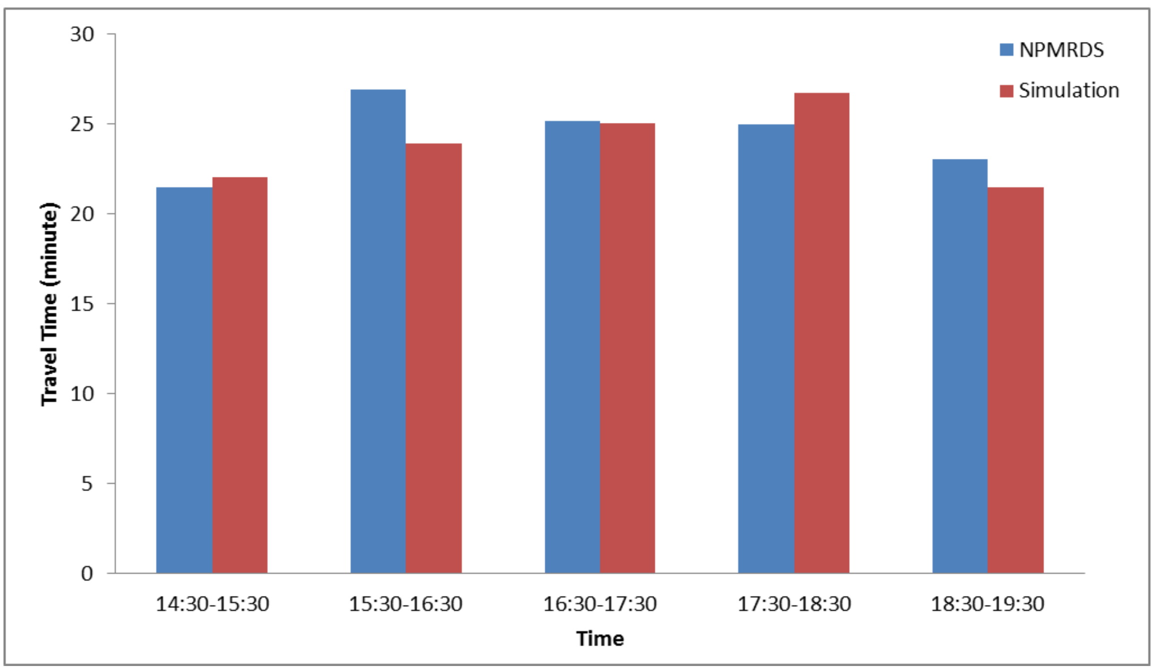

Figure 6-4: ECR NB Corridor Travel Time Comparison [Source: Kittelson]

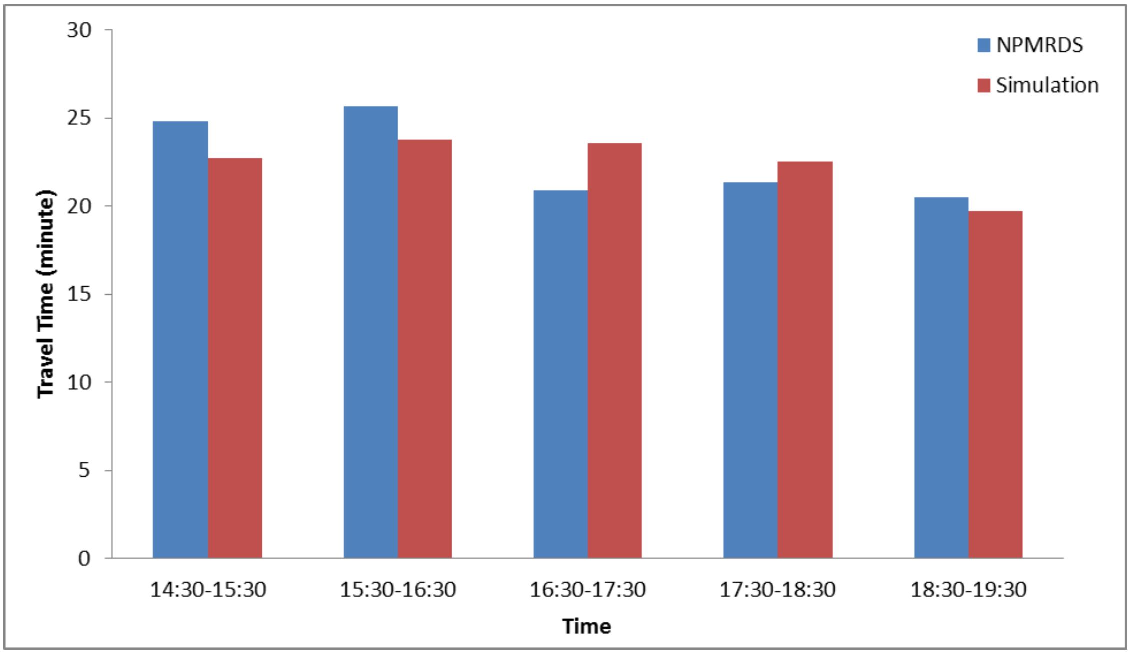

Figure 6-5. ECR SB Corridor Travel Time Comparison [Source: Kittelson]

Table 6-3 summarizes the calibration results of Cluster 1 for all the calibration criteria/targets. In sum, all the calibration targets, including bottleneck throughput, link flows and study corridor travel time, are satisfied.

Table 6-3. Summary of Calibration of Cluster 1

Criteria					
Individual Link Flows	**Target**	**Cases**	**Cases Met**	**% Met**	**Target Met?**
Within 15% of field counts	>85%	85	74	87.1%	Yes
Sum of All Link Flows	**Sum Counts**	**Sum Link Flows**		**Percent Error**	**Target Met?**
Within 5% of sum of all link counts	513,387	514,152		1.44%	Yes
Corridor Travel Time	**Target**	**Cases**	**Cases Met**	**% Met**	**Target Met?**
Within 15% (or 1 min) of field measurement	>85%	15	14	93%	Yes
Bottleneck Throughput	**Target**	**Cases**	**Cases Met**	**% Met**	**Target Met?**
Within 10% of field counts	100%	5	5	100%	Yes

6.2 Calibration Results of Cluster 2

Based on the cluster analysis, the operation conditions of Cluster 2 represent a Medium Demand, Major Incident, and Wet scenario. The representative day of cluster 2 is 4/10/2012. There are 21 detectors on US 101 NB. On 4/10/2012, there are 18 healthy detectors and 3 bad detectors (i.e., detectors have zero/unreasonable observation data on 4/10/2012) as shown in Figure 6-6.

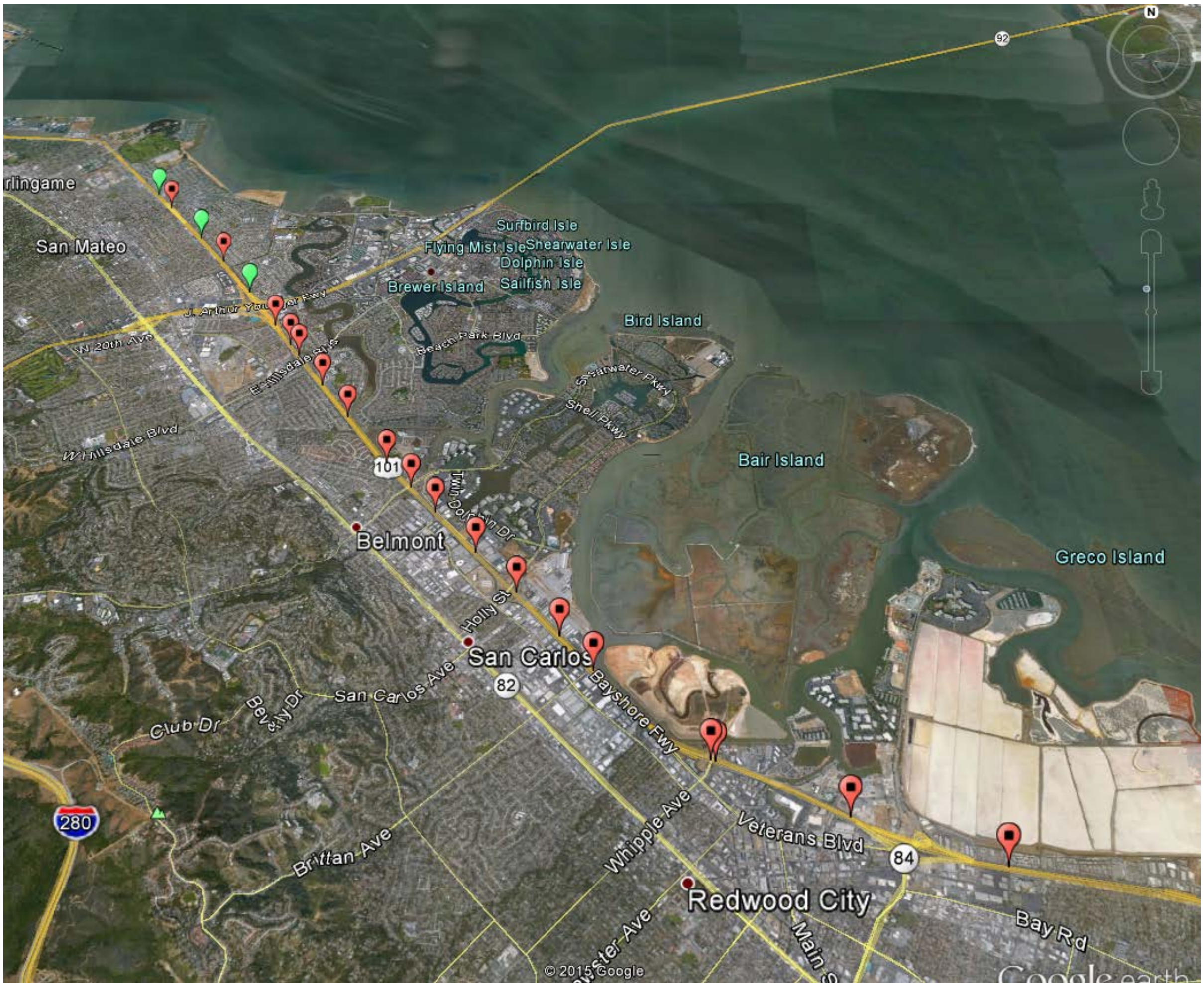

Figure 6-6. Available Detectors on US 101 NB on 4/10/2012 [Source: Kittelson]

6.2.1 Bottleneck Throughput

The bottleneck throughputs were not checked for this scenario because the detectors that measure the bottleneck throughputs did not provide valid observations on 4/10/2012.

6.2.2 Traffic Counts of Freeway Study Corridor

Table 6-4 summarizes the percentage error in the hourly traffic volumes for the US 101 NB. As shown in the figure, 84.4% of the hourly volumes have percentage error less than 15%. Sum of simulation flows is 554,706 and sum of field counts is 564,228. Percentage Error is -1.69%. The highlighted cells shows the sections where the calibration error percentages were greater than the target of 15 percent.

Table 6-4. Hourly Traffic Volume Comparison

Detectors	Percentage Errors (%)					Traffic Counts				
	14:30-15:30	15:30-16:30	16:30-17:30	17:30-18:30	18:30-19:30	14:30-15:30	15:30-16:30	16:30-17:30	17:30-18:30	18:30-19:30
401874	92%	60%	9%	11%	9%	3252	3976	5359	5189	4578
401835	-5%	-4%	-5%	7%	3%	6190	6024	5951	4895	5190
401834	-8%	-11%	-18%	-19%	1%	5717	5813	5709	4808	5277
401833	8%	7%	3%	2%	1%	5717	5813	5709	4808	6056
401929	-7%	-8%	-1%	-6%	1%	6671	6863	6109	5595	6137
401652	-7%	-8%	-1%	-6%	1%	6671	6863	6109	5595	6137
401882	-3%	3%	21%	-4%	-2%	4634	4350	4177	4046	5105
401869	-5%	8%	13%	-3%	-1%	5913	5310	5135	4900	5586
401859	-7%	-6%	-5%	-12%	-1%	5990	5939	5997	5707	5572
401910	-24%	-12%	-12%	-14%	0%	7257	6225	6317	5924	5503
401443	-3%	13%	16%	15%	2%	7257	6225	6317	5924	6589
402383	1%	11%	9%	14%	2%	6960	6249	6597	6093	6596
400661	36%	24%	-10%	-1%	2%	5148	5616	7923	7193	6602
401914	-3%	0%	-4%	10%	3%	6148	6106	6580	5567	4906
400291	0%	7%	2%	13%	6%	6395	6115	6542	5655	5199
400645	-22%	-22%	-17%	-11%	5%	5945	6146	6024	5517	3928
402387	44%	20%	2%	8%	3%	4206	5564	7594	6539	6153
403261	14%	5%	-8%	-11%	2%	4379	5486	7863	7428	5969

6.2.3 Travel Time of Study Corridors

Corridor travel time was examined for both freeway study corridor (US 101 NB). Figure 6-7 shows that the percentage error of hourly travel time of freeway study corridor between simulation and field measurements.

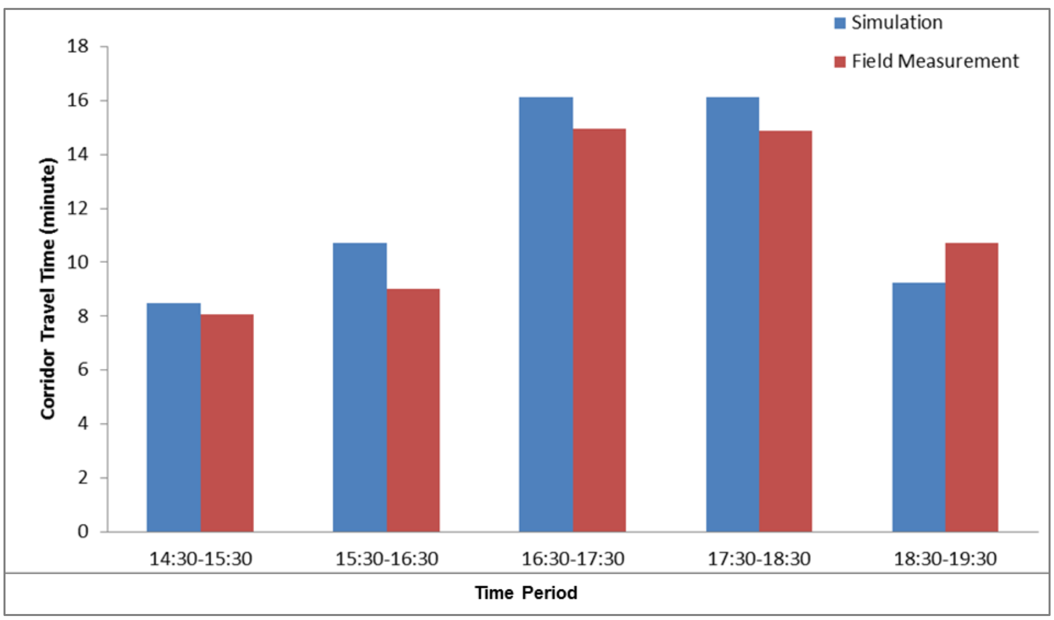

Figure 6-7. Freeway Corridor Travel Time Comparison [Source: Kittelson]

Figure 6-8 and Figure 6-9 demonstrate the comparison of arterial corridor travel time between simulation and field counts for NB and SB, respectively. As shown in the figures, the percentage errors for all five hours are within the 15% calibration target.

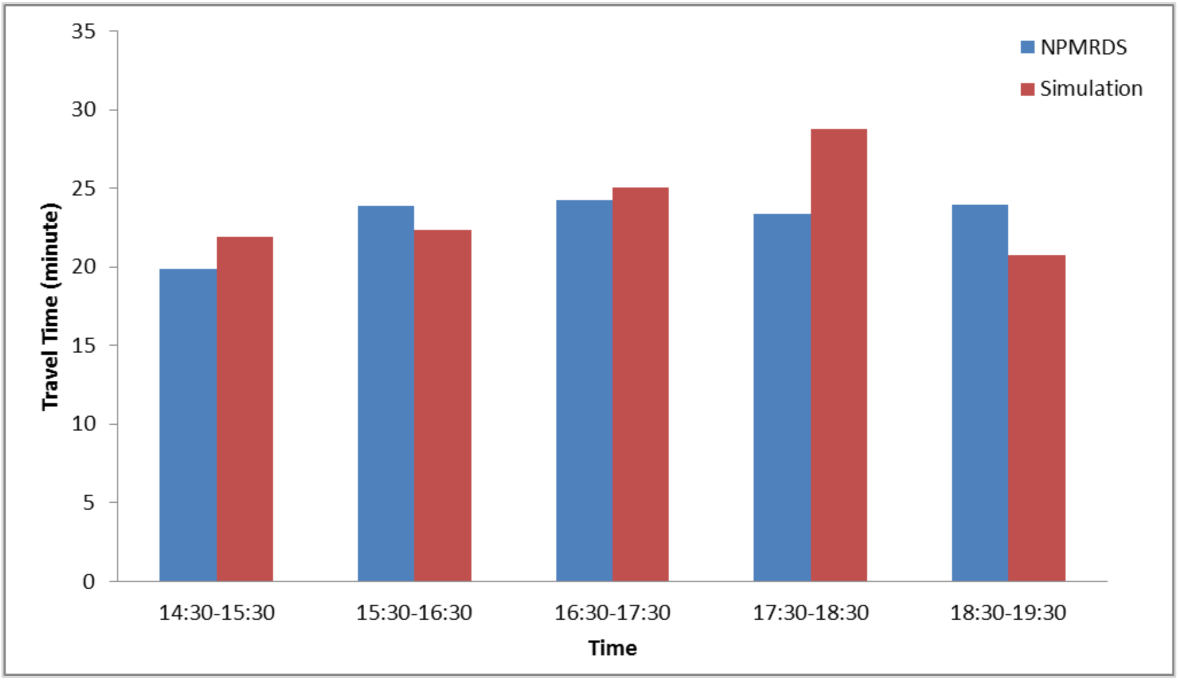

Figure 6-8. ECR NB Corridor Travel Time Comparison [Source: Kittelson]

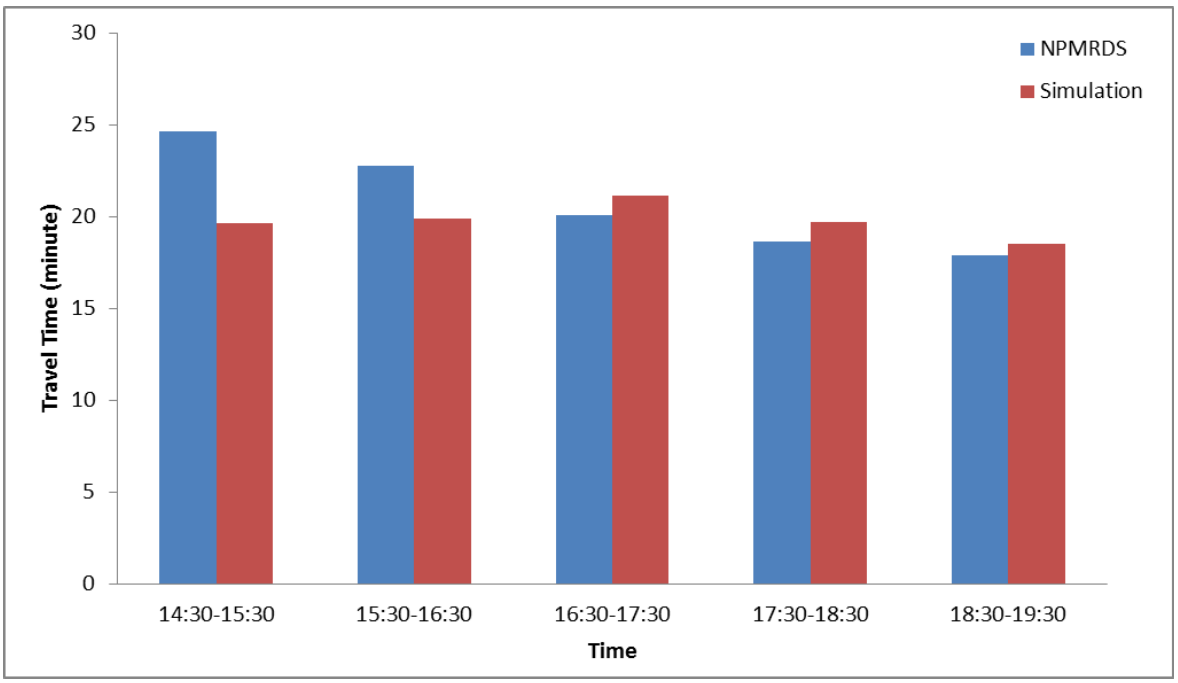

Figure 6-9. ECR SB Corridor Travel Time Comparison [Source: Kittelson]

Table 6-5 summarizes the calibration results of cluster 2 for all the calibration criteria/targets. The calibration criteria that are not included in this cluster are marked as N/A (Not Applicable).

Table 6-5. Summary of Calibration of Cluster 2

Criteria					
Individual Link Flows	**Target**	**Cases**	**Cases Met**	**% Met**	**Target Met?**
Within 15% of field counts	>85%	90	76	84.4%	No
Sum of All Link Flows	**Sum Counts**	**Sum Link Flows**		**Percent Error**	**Target Met?**
Within 5% of sum of all link counts	554,706	564,228		1.69%	Yes
Corridor Travel Time	**Target**	**Cases**	**Cases Met**	**% Met**	**Target Met?**
Within 15% (or 1 min) of field measurement	>85%	15	13	87%	Yes
Bottleneck Throughput	**Target**	**Cases**	**Cases Met**	**% Met**	**Target Met?**
Within 10% of filed counts	100%	5	N/A	N/A	N/A

*N/A represent the calibration targets not used.

6.3 Calibration Results of Cluster 3

Based on the cluster analysis, the operation conditions of Cluster 3 represent a normal operational scenario (medium demand, no incident, and dry). There are 21 detectors on US 101 NB. On 10/22/2012, there are 16 healthy detectors and 5 bad detectors (i.e., detectors have zero observed data on 10/22/2012) as shown in Figure 6-10.

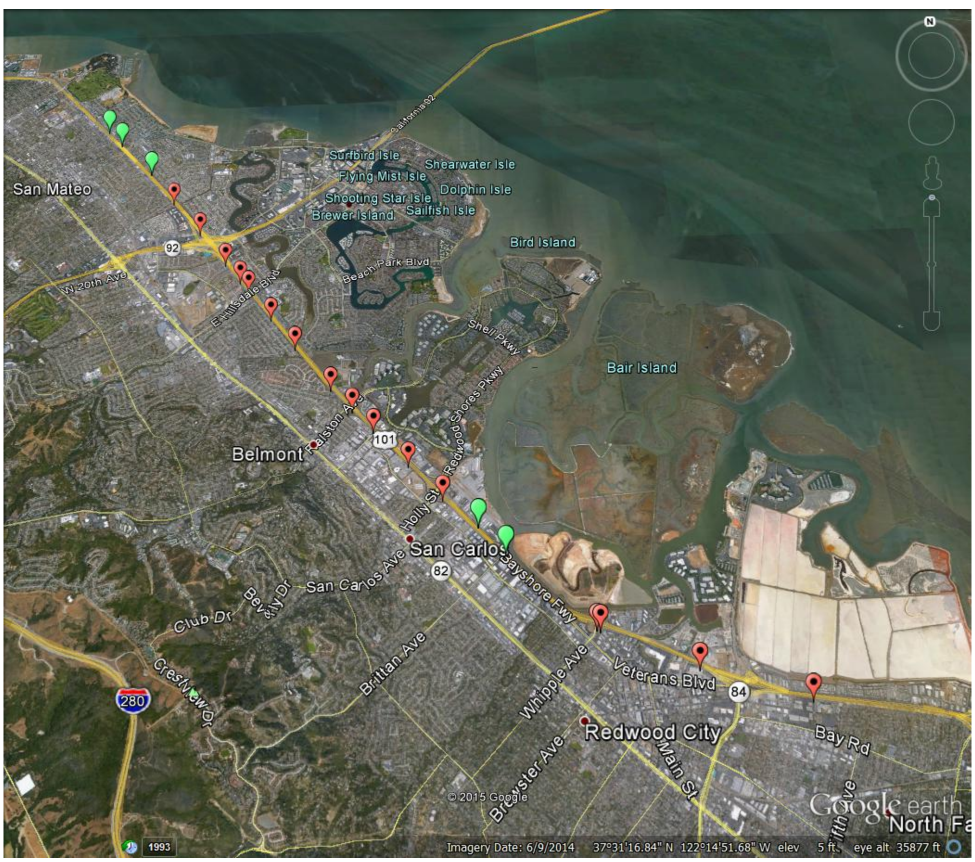

Figure 6-10. Available Detectors on US 101 NB on 10/22/2012 [Source: Google Earth]

6.3.1 Bottleneck Throughput

The active bottleneck on US 101 NB is located in the weaving segment between SR 92 and Hillsdale Blvd. Figure 6-11 shows the comparison of bottleneck throughputs between simulation and field counts. The sum of simulation throughput is 24,874 and sum of field counts is 25,338. Percentage Error is -1.9%, which meets the calibration target.

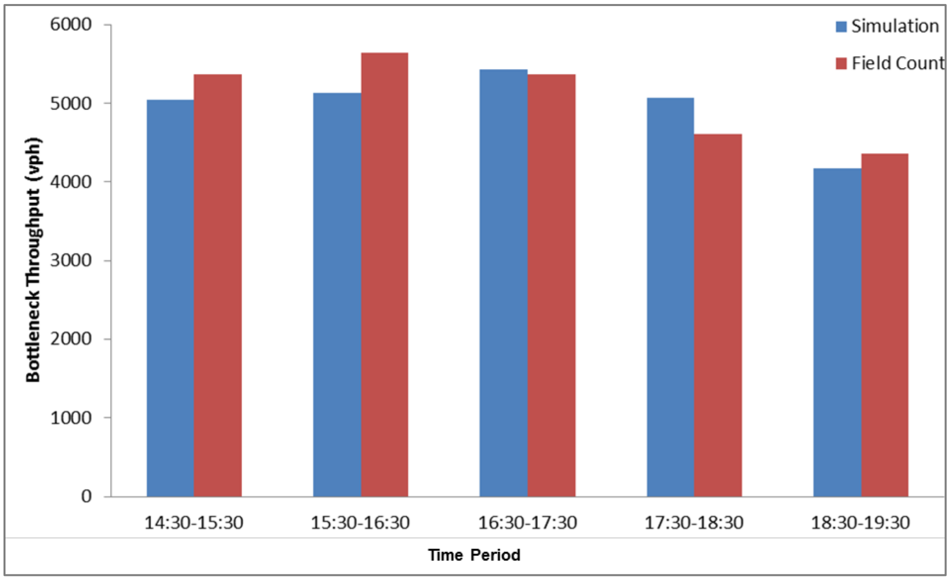

Figure 6-11. Bottleneck Throughput Comparison [Source: Kittelson]

6.3.2 Traffic Counts of Freeway Study Corridor

Table 6-6 summarizes the percentage error in the hourly traffic volumes for the US 101 NB. As shown in the figure, 87.5% of the hourly volumes have percentage error less than 15%. Sum of simulation flows is 498,480 and sum of field counts is 498,641. Percentage Error is -0.03%. The highlighted cells shows the sections where the calibration error percentages were greater than the target of 15 percent.

Table 6-6. Hourly Traffic Volume Comparison

Detectors	Percentage Errors (%)					Traffic Counts				
	14:30-15:30	15:30-16:30	16:30-17:30	17:30-18:30	18:30-19:30	14:30-15:30	15:30-16:30	16:30-17:30	17:30-18:30	18:30-19:30
401874	-1%	-1%	0%	0%	-9%	6510	6679	6462	5950	5522
401835	0%	-6%	1%	6%	11%	6052	6337	6109	5640	5266
401834	-4%	-10%	-7%	-5%	8%	5626	5929	5775	5274	4973
401833	-9%	-12%	-5%	-2%	9%	7004	7332	7022	6102	5683
401882	-2%	-6%	13%	15%	18%	4701	4973	4556	3958	3894
401869	-13%	-16%	-8%	9%	10%	6321	6574	6568	5203	4725
401859	-10%	-11%	4%	12%	6%	6078	6202	5833	5053	4908
401910	-17%	-18%	-6%	3%	0%	6608	6739	6427	5523	5158
401443	-2%	-1%	12%	21%	16%	7166	7392	7043	6061	5499
402383	-11%	-13%	-6%	0%	0%	7925	8216	8408	7486	6352
400661	2%	-1%	1%	24%	21%	6845	7070	7863	6048	5279
401914	-8%	-10%	0%	8%	-3%	6572	6758	6847	5943	5338
400291	-4%	-3%	6%	13%	3%	6921	6958	6740	5970	5246
400645	-6%	-9%	1%	10%	-4%	5368	5636	5369	4611	4354
402385	-2%	-5%	6%	15%	6%	7877	8397	8274	7205	6304
402387	-3%	-4%	8%	15%	5%	7527	7927	7662	6889	6046

6.3.3 Travel Time of Study Corridors

Corridor travel time was examined for both freeway study corridor (US 101 NB) and arterial study corridor (El Camino Real (ECR) NB and SB). Figure 6-12 shows that the percentage error of hourly travel time of freeway study corridor between simulation and field measurements. As shown in the figure, the percentage errors for all five hours are within the 15% calibration target.

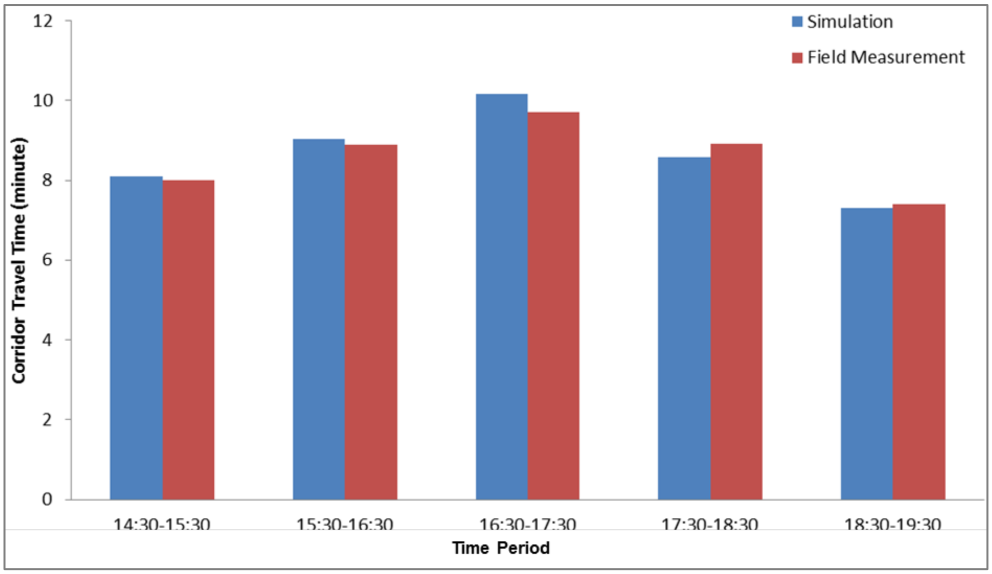

Figure 6-12. Freeway Corridor Travel Time Comparison [Source: Kittelson]

Figure 6-13 and Figure 6-14 demonstrate the comparison of arterial corridor travel time between simulation and field counts for NB and SB, respectively. As shown in the figures, the percentage errors for all five hours are within the 15% calibration target.

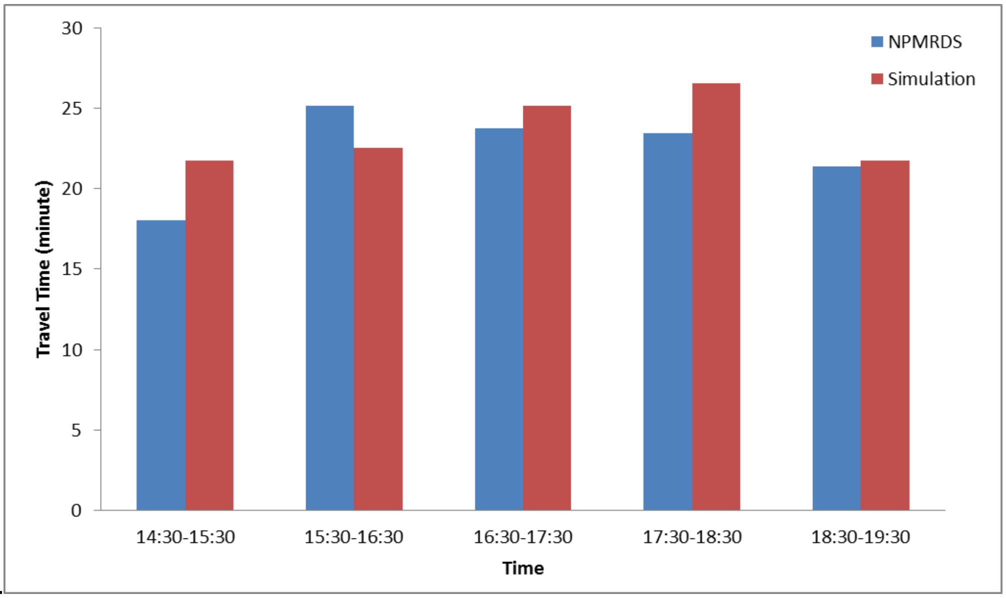

Figure 6-13. ECR NB Corridor Travel Time Comparison [Source: Kittelson]

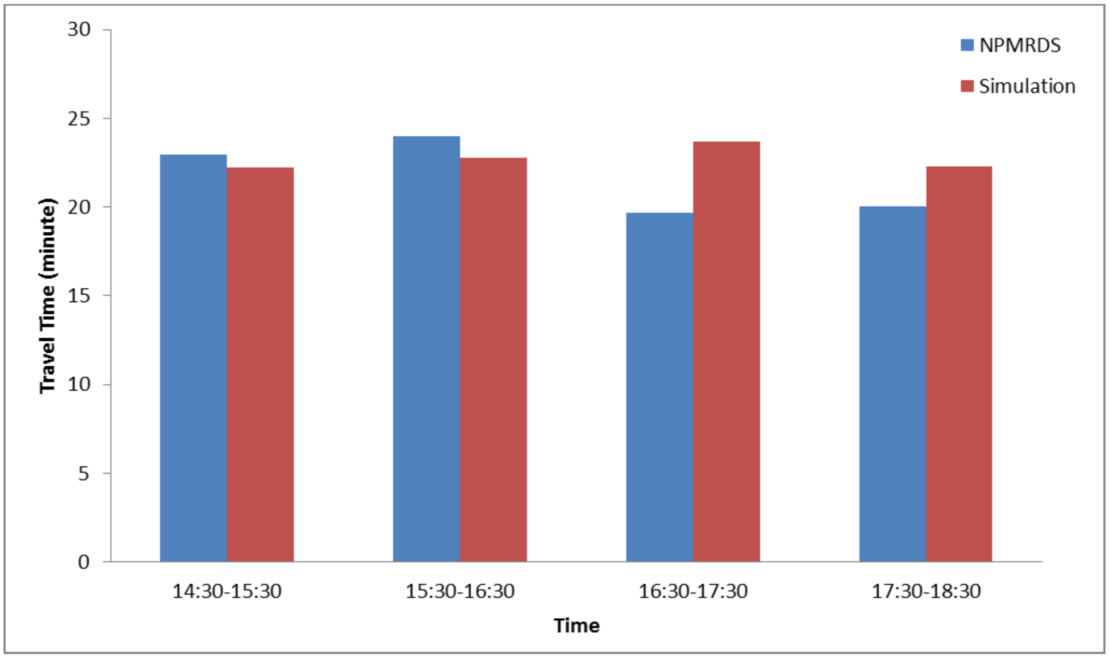

Figure 6-14. ECR SB Corridor Travel Time Comparison [Source: Kittelson]

Table 6-7 summarizes the calibration results of cluster 3 for all the calibration criteria/targets. In sum, all the calibration targets, including bottleneck throughput, link flows and study corridor travel time, are satisfied.

Table 6-7. Summary of Calibration of Cluster 3

Criteria					
Individual Link Flows	**Target**	**Cases**	**Cases Met**	**% Met**	**Target Met?**
Within 15% of field counts	>85%	80	70	87.5%	Yes
Sum of All Link Flows	**Sum Counts**	**Sum Link Flows**		**Percent Error**	**Target Met?**
Within 5% of sum of all link counts	498,641	498,480		-0.03%	Yes
Corridor Travel Time	**Target**	**Cases**	**Cases Met**	**% Met**	**Target Met?**
Within 15% (or 1 min) of field measurement	>85%	15	14	93%	Yes
Bottleneck Throughput	**Target**	**Cases**	**Cases Met**	**% Met**	**Target Met?**
Within 10% of field counts	100%	5	5	100%	Yes

6.4 Calibration Results of Cluster 4

Based on the cluster analysis, the operation conditions of Cluster 4 represent a High Demand, Minor Incident, and Dry scenario. The representative day of cluster 4 is 9/19/2012. There are 21 detectors on US 101 NB. On 4/10/2012, there are 18 healthy detectors and 3 bad detectors (i.e., detectors have zero/unreasonable observation data on 9/19/2012) as shown in Figure 6-15.

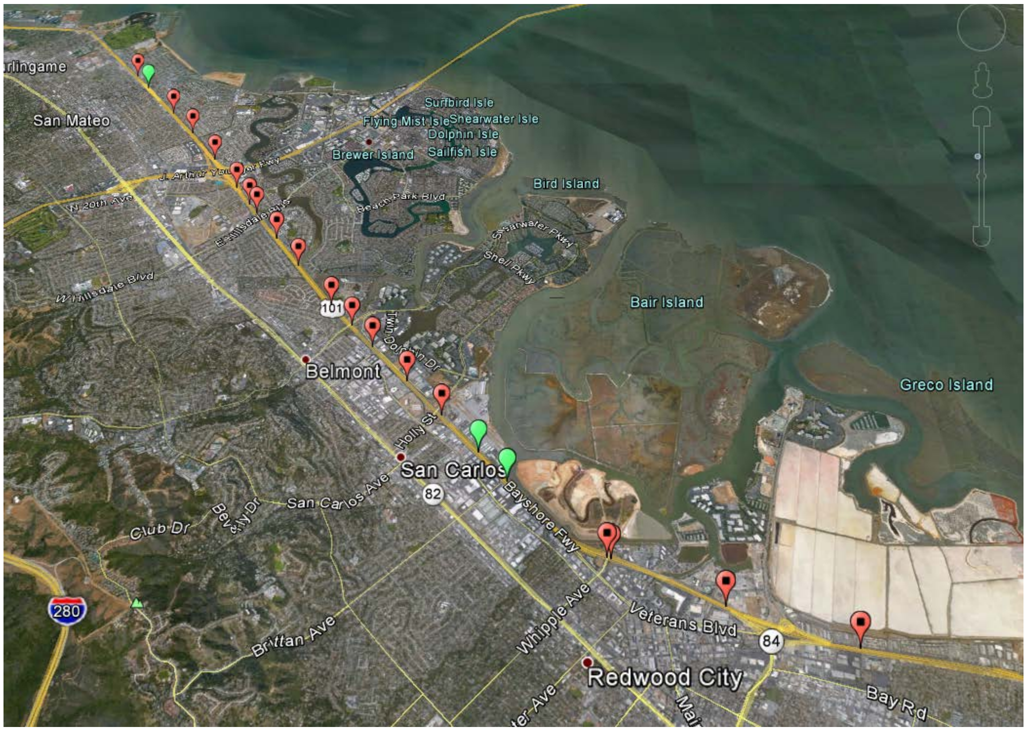

Figure 6-15. Available Detectors on US 101 NB on 9/19/2012 [Source: Google Earth]

6.4.1 Bottleneck Throughput

The active bottleneck on US 101 NB is located in the weaving segment between SR 92 and Hillsdale Blvd. Figure 6-16 shows the comparison of bottleneck throughputs between simulation and field counts. The sum of simulation throughput is 23,503 and sum of field counts is 25,089 Percentage Error is -6.3%, which meets the calibration target.

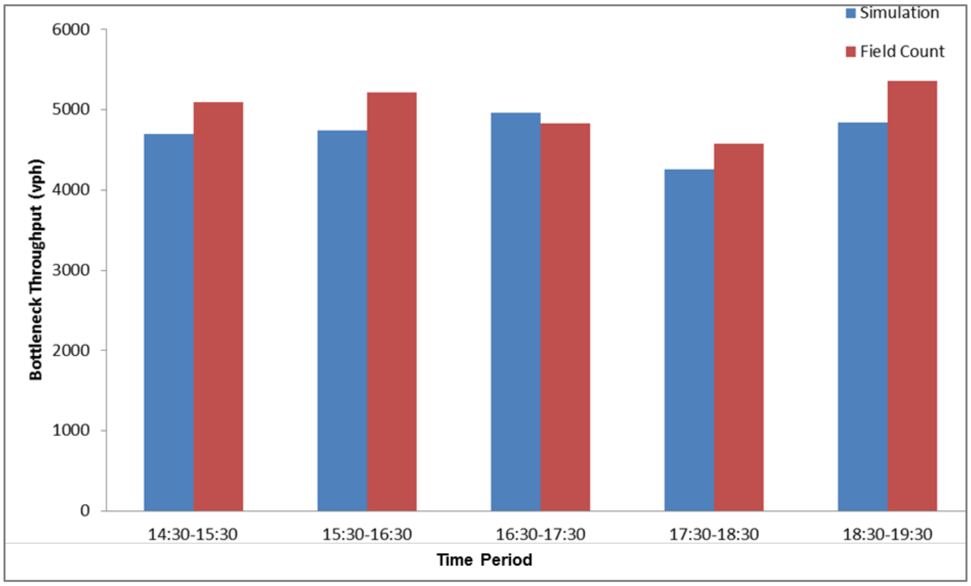

Figure 6-16. Bottleneck Throughput Comparison [Source: Kittelson]

6.4.2 Traffic Counts of Freeway Study Corridor

Table 6-8 summarizes the percentage error in the hourly traffic volumes for the US 101 NB. As shown in the figure, 88.9% of the hourly volumes have percentage error less than 15%. Sum of simulation flows is 578,412 and sum of field counts is 561,709. Percentage Error is 2.97%. The highlighted cells show the sections where the calibration error percentages were greater than the target of 15 percent.

Table 6-8. Hourly Traffic Volume Comparison

Detectors	Percentage Errors (%)					Traffic Counts				
	14:30-15:30	15:30-16:30	16:30-17:30	17:30-18:30	18:30-19:30	14:30-15:30	15:30-16:30	16:30-17:30	17:30-18:30	18:30-19:30
401874	12%	14%	6%	-23%	-11%	6633	6305	6331	5974	6396
401835	10%	10%	3%	-18%	-3%	6236	5785	5807	5292	6079
401834	1%	-1%	-4%	-22%	-6%	6009	5751	5095	4781	5620
401833	-4%	-3%	-7%	-16%	4%	7298	7010	6163	5402	6351
401882	-20%	-16%	-8%	0%	6%	6242	5656	4618	4290	5291
401869	-7%	-11%	-10%	-10%	-5%	6466	6495	5545	5549	6434
401859	-14%	-15%	-11%	-9%	-7%	6947	6777	5627	5443	6625
401910	-11%	-14%	-6%	-2%	-2%	6627	6503	5423	5022	6202
401443	4%	-1%	16%	16%	11%	7127	7071	6083	5710	6709
402383	7%	3%	6%	-6%	-7%	6713	6798	6800	7007	7991
400661	6%	5%	22%	19%	14%	6678	6746	5980	5510	6547
401914	-10%	-9%	7%	0%	-2%	6672	6723	5935	5452	6157
400291	-2%	1%	15%	3%	-1%	6707	6642	5954	5646	6581
400645	-8%	-9%	3%	-7%	-10%	5099	5222	4835	4573	5360
402385	-4%	-6%	4%	0%	0%	7548	7935	7714	7263	7360
402387	-11%	-11%	-1%	-1%	-2%	7658	8017	7708	6908	7197
402389	-8%	-8%	-2%	-6%	-6%	7580	7930	7944	7548	7634
400753	-14%	-10%	-5%	-9%	-8%	7642	7871	8405	7934	7488

6.4.3 Travel Time of Study Corridors

Figure 6-17 shows that the percentage error of hourly travel time of freeway study corridor between simulation and field measurements. As shown in the figure, the percentage errors for all five hours are within the 15% calibration target.

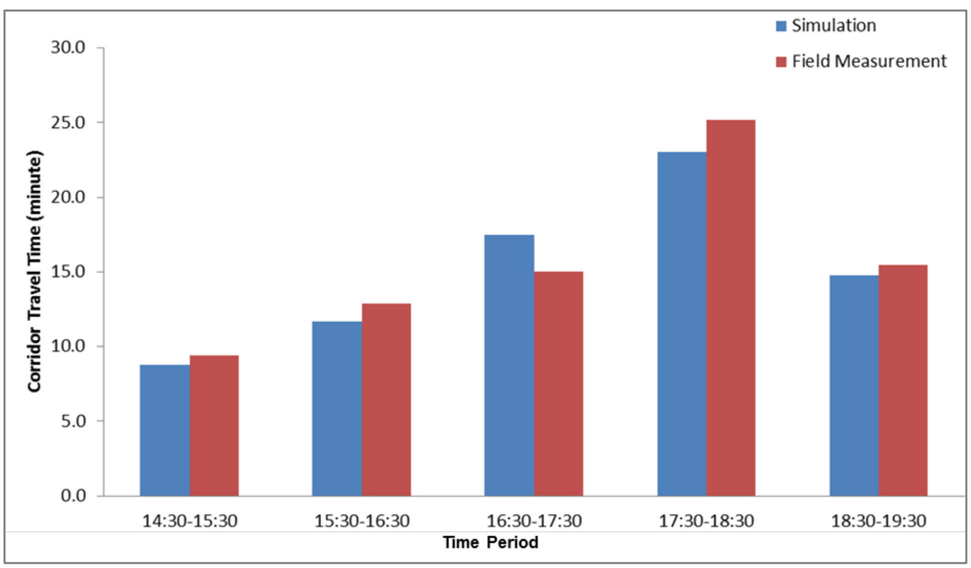

Figure 6-17. Freeway Corridor Travel Time Comparison [Source: Kittelson]

Figure 6-18 and Figure 6-19 demonstrate the comparison of arterial corridor travel time between simulation and field counts for NB and SB, respectively. As shown in the figures, the percentage errors for all five hours are within the 15% calibration target.

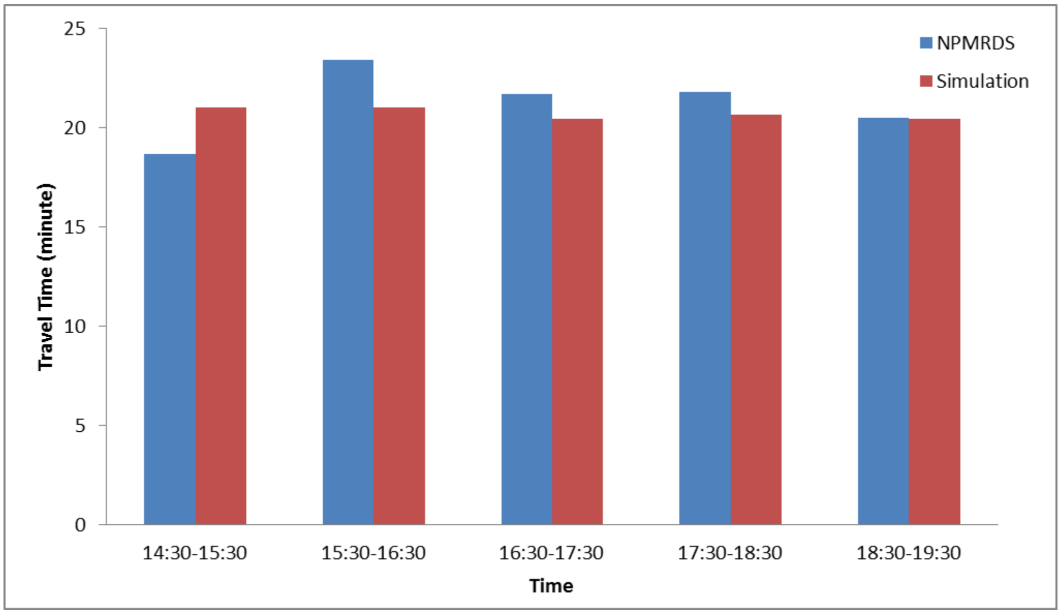

Figure 6-18. ECR NB Corridor Travel Time Comparison [Source: Kittelson]

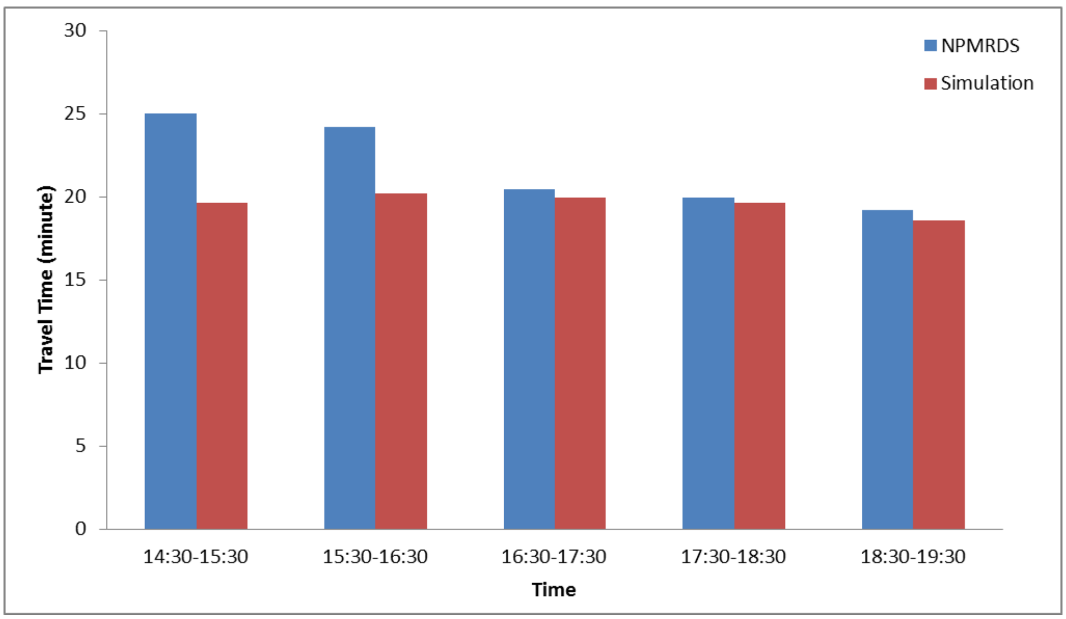

Figure 6-19. ECR SB Corridor Travel Time Comparison [Source: Kittelson]

Table 6-9 summarizes the calibration results of cluster 4 for all the calibration criteria/targets. In sum, all the calibration targets, including bottleneck throughput, link flows and study corridor travel time, are satisfied.

Table 6-9. Summary of Calibration of Cluster 4

Criteria					
Individual Link Flows	**Target**	**Cases**	**Cases Met**	**% Met**	**Target Met?**
Within 15% of field counts	>85%	90	80	88.9%	Yes
Sum of All Link Flows	**Sum Counts**	**Sum Link Flows**		**Percent Error**	**Target Met?**
Within 5% of sum of all link counts	578,412	561,709		2.97%	Yes
Corridor Travel Time	**Target**	**Cases**	**Cases Met**	**% Met**	**Target Met?**
Within 15% (or 1 min) of field measurement	>85%	15	13	87%	Yes
Bottleneck Throughput	**Target**	**Cases**	**Cases Met**	**% Met**	**Target Met?**
Within 10% of field counts	100%	5	5	100%	Yes

At the end, the objective of this report is to summarize all the efforts to develop, enhance and calibrate the VISSIM models for four different operational conditions of the San Mateo Testbed that will be used as different baseline scenarios to examine the effectiveness of the different the DMA and ATDM concepts. The calibration methodology involves simultaneously adjusting the time-dependent demand pattern and the driver behavior models in order to replicate the observed traffic conditions for these baseline scenarios.

All the calibration targets have been met. The next steps involve finalizing the experimental design and perform the simulation experiments to answer the research questions defined as part of this project.

Chapter 7. Summary and Conclusions

This report documents the calibration approach, targets and methodology used for calibrating the San Mateo Testbed network to the operational conditions identified by the cluster analysis to enable the Analysis, Modeling and Simulation of Dynamic Mobility Applications. Four operational conditions have been calibrated for this network and the calibration approach used a combination of data from loop-detectors and NPMRDS travel-time data. As given in this report, the network consists of two parts – US 101 freeway part and SR 82 arterial part. The freeway part is calibrated for the North Bound direction using the California PeMS data and the arterial part is calibrated using the travel-time data from NPMRDS.

The report also documents the testbed description, model resolution and geographic extent of the Vissim-based San Mateo Testbed as well as the cluster analysis approach used in narrowing down the representative days for individual clusters. Additionally, the report also summarizes the various calibration targets that are met or unmet for each of the operational conditions.

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

Toll-Free "Help Line" 866-367-7487
www.its.dot.gov

FHWA-JPO-16-377

U.S. Department of Transportation