

**Evaluation of Potential ITS
Strategies under Non-Recurrent
Congestion using Microscopic Simulation**

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Lianyu Chu ¹
Henry X. Liu ²
Will Recker ³

¹ Institute of Transportation Studies
University of California, Irvine, lchu@uci.edu

² Department of Civil and Environmental Engineering
Utah State University; Logan, UT 84322, xliu@cc.usu.edu

³ Department of Civil and Environmental Engineering and
Institute of Transportation Studies
University of California, Irvine, wwrecker@uci.edu

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Institute of Transportation Studies
University of California, Irvine
Irvine, CA 92697-3600, U.S.A.
<http://www.its.uci.edu>

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Lianyu Chu

Institute of Transportation Studies
University of California, Irvine
Irvine, CA 92697
Tel: 949-824-1876 Fax: 949-824-8385
Email: lchu@translab.its.uci.edu

Henry X. Liu

Department of Civil and Environmental Engineering
Utah State University
4110 Old Main Hill
Logan, UT 84322
Tel: 435-797-8289 Fax: 435-797-1185
Email: xliu@cc.usu.edu

Will Recker

Institute of Transportation Studies
University of California, Irvine
Irvine, CA 92697
Tel: 949-824-5642 Fax: 949-824-8385
Email: wwrecker@uci.edu

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ABSTRACT

This paper presents a micro-simulation method to evaluate the effectiveness of potential ITS strategies under the incident scenarios. The evaluation is conducted over a corridor network located at the city of Irvine, California. The potential ITS strategies include incident management, local adaptive ramp metering, coordinated ramp metering, traveler information systems, and the combination of above. Based on the calibrated simulation model, we implement and evaluate these scenarios in the microscopic simulation model, PARAMICS. The evaluation results show that all ITS strategies have positive effects on the network performance. Because of the network topology (one major freeway with two parallel arterial streets), real-time traveler information system has the greatest benefits among all single ITS components. The combination of several ITS components, such as integrated control, can generate better benefits.

1 INTRODUCTION

Many Intelligent Transportation Systems (ITS) technologies and strategies, such as vehicle actuated signals, ramp metering, and variable message signs (VMS) have been applied to the transportation systems and improving the real-world traffic condition. In the near future, some more complex ITS applications, such as adaptive signal control, adaptive ramp metering and the combination of several ITS strategies, have the potentials to be implemented in the real world. Field operational tests of these strategies may be difficult and costly; however, without prior testing, some ITS applications may not work properly, or positively impact traffic conditions (Pearce, 2000). For decision makers, questions related to whether an ITS strategy is warranted, which kind of strategy is suitable, the level of complexity to implement the strategy, and how to calibrate and optimize the operational parameters of the strategies, ought be investigated.

Microscopic traffic simulation is a software tool to model the real-world traffic system, including the road, drivers, and vehicles, in fine details. In a micro-simulation process, the state of an individual vehicle is continuously or discretely calculated and predicted based on vehicle-vehicle and vehicle/road interactions. The car-following, lane-changing and gap-acceptance models are the basic elements of a microscopic traffic simulator. Notable instances of micro-simulators include PARAMICS, CORSIM, VISSIM, AIMSUN2, TRANSIM, and MITSIM, etc (Yang et al., 1996, Jayakrishnan et al., 2000). With the advancement of computer technology and modeling traffic flow in the microscopic level, microscopic simulation is becoming a popular and effective tool for many applications, such as modeling and evaluating ITS, which are not amendable to study by other means.

The purpose of the study is to use microscopic simulation as an evaluation tool to evaluate ITS. This research will make a simulation-based study on how potential ITS strategies can help solve the non-recurrent traffic congestion over a corridor network. These ITS strategies include incident management, local adaptive ramp metering and coordinated ramp metering, adaptive signal control, traveler information, and the

combination of several ITS components. PARAMICS simulation model, with capacity enhancement through its Application Programming Interface (API) will be used to model and quantitatively evaluate potential ITS strategies.

This paper is organized as follows. Section 2 explains the methodology of modeling ITS strategies in PARAMICS simulation environment. Section 3 introduces the study site and the potential problem of the evaluation network. The potential ITS strategies are designed and described in details. The methods how to implement these strategies are explained. Section 4 provides the evaluation results and analyzes the performance of each strategy. Section 5 concludes the paper.

2. MODELING AND IMPLEMENTING ITS STRATEGIES

2.1 Study site and identified problem

The study site is located in Orange County, California. As shown in Figure 3, the network includes a 6-mile section of freeway I-405, a 3-mile section of freeway I-5, a 3-mile section of freeway SR-133 and the adjacent surface streets.

Based on the analysis of the loop detector data and floating car data from the study site, we found that the northbound of freeway I-405 is highly congested from 7:30 to 8:30 AM due to the large amount of traffic merging to freeway I-405 from freeway SR-133 and Jeffery Dr. The bottleneck generated at Jeffery often spreads to the upstream as a backward shockwave, which further deteriorates the traffic condition at the upstream bottleneck at SR-133 since there is no additional lane on I-405 after SR-133 merges to I-405. The historical incident data also shows that the merge area of SR-133 and I-405 (on the northbound I-405) is the location where incidents happen most frequently.

Freeway incidents may take the form of complete blockage of one or more lanes or causing vehicle slowdown by incidents on the shoulder. Here we assume the occurrence of a shoulder incident on the merge area of SR-133 and I-405 (on the northbound I-405) at 7:45 AM, which is the time that incidents happen most frequently based on the historical incident data. This incident causes the speed of passing vehicles to be 10 mph for the first ten minutes and 15 mph thereafter (i.e. for 23 minutes without any incident management).

2.2 Potential solution strategies

If an incident happens at the merge area with SR-133 on northbound I-405, the following ITS strategies can be used to improve the system performance: (1) Incident management; (2) Adaptive ramp metering; (3) Traveler information system; (4) Arterial management.

The current corridor network is operating under coordinated actuated signal control (for arterials) and fixed-time ramp metering control (for freeway). Based on the data from California Department of Transportation (Caltrans), without any incident management,

the average incident clearance time is 33 minutes. This is scenario #1 (IM-33) of this evaluation study. All other evaluation scenarios will compare to this benchmark scenario.

Data from Caltrans show that the incident clearance time is 26 minutes with the deployment of the existing incident management policy and is expected to be further reduced to 22 minutes in the future. Scenario #2 (IM-26) and #3 (IM-22) correspond to the existing and improved incident management scenarios. No other ITS strategies are involved in Scenarios #2 and #3 because we want to find out how the traffic system is benefited from the incident management, which has been significantly invested by traffic agencies.

Then we study on how other potential ITS strategies can help relieve this non-recurrent congestion based on the existing incident management (26 minute of the clearance time). Scenario #4 (RMA) and #5 (RMB) correspond to the two adaptive ramp metering strategies, ALINEA and BOTTLNECK. ALINEA is a local adaptive ramp metering algorithm and BOTTLNECK is a coordinated ramp metering algorithm.

Scenario #6 (TIS) is the scenario with the deployment of traveler information systems but without any traffic control supports. Scenarios #7 (C-1) incorporates the freeway control with traffic information systems. Scenario #8 (C-2) corresponds to the integrated control case that applies freeway ramp metering, arterial management, and traveler information systems together.

Each evaluation scenario includes one or more than one ITS strategies. Simulation scenarios with their corresponding ITS strategies are summarized in Table 1.

2.3 Modeling ITS

2.3.1 Micro-simulator: PARAMICS

In order to evaluate ITS strategies in a micro-simulation environment, the selected micro-simulator should have capability to model these ITS strategies. PARAMICS (PARAllel MICROscopic Simulation) is selected to evaluate ITS strategies in this research.

PARAMICS is a suite of microscopic simulation tools used to model the movement and behavior of individual vehicles on urban and highway road networks (Smith, et al, 1994). It offers very plausible detailed modeling for many components of the traffic system. Not only the characteristics of drivers, vehicles and the interactions between vehicles but also the network geometry can influence simulation results. PARAMICS is fit to ITS studies due to its high performance, scalability and the ability of modeling the emerging ITS infrastructures, such as loop detectors and VMS. In addition, PARAMICS provides users with Application Programming Interfaces (API) through which users can access the core models of the micro-simulator, and customize and extend many features of the underlying simulation model without having to deal with the underlying proprietary source codes. Though PARAMICS can model some simple ITS strategies, API is eventually required to implement more complicated ITS strategies.

2.3.2 Framework of the enhanced PARAMICS

PARAMICS has been enhanced through API programming in order to better model traffic condition in the real world and ITS strategies (Chu, et al., 2003a). Figure 1 shows the framework of our capability-enhanced PARAMICS simulation environment. The plug-in module in the enhanced PARAMICS environment exchanges dynamic data with the core PARAMICS model and other advanced plug-in modules through the Dynamic Linking Library (DLL) mechanism.

2.3.3 Modeling Complex ITS strategy

A complex ITS strategy can be classified into two types, advanced control algorithm and integrated control. Advanced control algorithm, such as adaptive ramp metering algorithm, are designed to respond to the traffic change dynamically through the communication of field devices in a real time basis. Integrated control combines and coordinates different ITS components. For example, when the alternative route information is displayed on the variable message sign, the traffic signal timing can be changed on the fly to respond to the diverted traffic. Both advanced control and integrated control can be regarded as advanced plug-in modules, which can be developed on top of basic enhancement modules, such as actuated signal control, ramp metering, and loop data aggregation. This hierarchical plug-in development approach, demonstrated in Figure 2, can thus re-use the codes developed in the basic modules.

This hierarchical development of a plug-in module enables customization and enhancements of various aspects of simulation modeling. The plug-in modules provide users more freedom to control the simulation processes and hence overcome some challenges faced in modeling different ITS features. As a result, various ITS applications, can be easily tested and evaluated in this capability-enhanced micro-simulation environment.

2.4 Implementation of evaluated ITS strategies

2.4.1 Incident and incident management

Scenario #1 is the benchmark scenario, in which a shoulder incident is occurred on the merge area of SR-133 and I-405 (on the northbound I-405) at 7:45 AM, as described in section 2.1. In order to model the shoulder incident, we develop an incident plugin with three control parameters, i.e. the location of the incident, the time when the incident happened, and the duration of the incident.

Scenarios #2 and #3 apply incident management to relieve the congestion caused by the incident on the freeway shoulder. Incident management generally decreases the incident duration time through the fast responses to the incident. Through changing the value of the plug-in parameter, i.e. duration of the incident, we can easily model these two incident management scenarios.

The incident management also includes the following parameters: incident detection (and verification) time, response time, and clearance time. ITS strategies are generally activated after the incident is detected, verified, and responded by traffic agencies to make and implement a corresponding freeway and arterial traffic management plan. Here we assume that the time taken by the incident detection and response is 5 minutes. This parameter will be reflected in the implementation of Scenario #7 and #8.

2.4.2 Actuated signal control

In the studied network, some signals are currently under actuated signal control and others are under the coordinated actuated signal control.

Actuated signal control plug-in is a basic control module in our enhanced PARAMICS environment. Based on this plug-in, the actuated signal coordination plug-in was further developed for controlling those coordinated signals. The details about this plugin's control logic and how we implement it can be found in our previous report (Liu, et al, 2001).

2.4.3 Adaptive ramp metering

Scenarios #4 and #5 apply local adaptive ramp metering and coordinated ramp metering, respectively.

2.4.3.1 ALINEA

The local adaptive ramp-metering algorithm we use is ALINEA (Papageorgiou, et al, 1990, 1991). ALINEA is a local feedback ramp metering policy, which attempts to maximize the mainline throughput by maintaining a desired occupancy on the downstream mainline freeway. Two detector stations are required for the implementation of the ALINEA algorithm. The first loop detector is located on the mainline freeway, immediately downstream of the entrance ramp, where the congestion caused by the excessive traffic flow originated from the ramp entrance can be detected. The second loop station is on the downstream end of the entrance ramp, and used for counting the on-ramp volume.

For an on-ramp under ALINEA control, its metering rate during time interval $(t, t + \tau)$ is calculated as:

$$r(t) = \tilde{r}(t - \Delta t) + K_R \bullet (O^* - O(t - \Delta t)) \quad (1)$$

where τ is the update cycle of ramp metering implementation; $\tilde{r}(t - \Delta t)$ is the measured metering rate of the time interval of $(t - \tau, t)$; $O(t - \tau)$ is the measured occupancy of time interval $(t - \tau, t)$ at the downstream detector station; K_R is a regulator parameter, used for adjusting the constant disturbances of the feedback control; O^* is the desired occupancy at the downstream detector station. The value of O^* is typically set equal to or slightly

less than the critical occupancy, or occupancy at capacity, which can be found in the volume-occupancy relationship.

2.4.3.2 BOTTLENECK

The coordinated ramp-metering algorithm used in this research is BOTTLENECK, applied in Seattle, Washington (Jacobsen, et al, 1989). Basically, there are three components in the algorithm: a local algorithm computing local-level metering rates based on local conditions, a coordination algorithm computing system-level metering rates based on system capacity constraints, and adjustment to the metering rates based on local ramp conditions. The original BOTTLENECK algorithm uses the occupancy control as its local metering algorithm. In this study, we replace its native local control algorithm with ALINEA because ALINEA is easier to be calibrated and performs better than the occupancy control, as shown on our previous research (Chu, et al. 2003c).

The coordination algorithm is the unique aspect of BOTTLENECK. The freeway segment under control is divided into several sections, each of which is defined by the stretch of freeway between two adjacent mainline loop stations. A section is identified as a bottleneck if it satisfies two conditions, i.e. capacity condition and vehicle storage condition. The capacity condition can be described as:

$$O_{down}(i, t) \geq O_{threshold}(i) \quad (2)$$

where $O_{down}(i, t)$ is the average occupancy of the downstream detector station of section i over the past one-minute period $(t-1, t)$; $O_{threshold}(i)$ is a pre-defined loop station occupancy threshold when it is operating near capacity. The vehicle storage condition can be formulated as:

$$Q_{reduction}(i, t) = (Q_{up}(i, t) + Q_{on}(i, t)) - (Q_{off}(i, t) + Q_{down}(i, t)) \geq 0 \quad (3)$$

where $Q_{reduction}(i, t)$ is the number of vehicles stored in section i during the past minute. $Q_{up}(i, t)$ and $Q_{down}(i, t)$ are the volume entering section i across the upstream detector station and the volume exiting section i across the downstream detector station during the past minute, respectively; $Q_{on}(i, t)$ is the total volume entering section i from on-ramps during the past minute; $Q_{off}(i, t)$ is the total volume exiting section i to off-ramps during the past minute.

The number of vehicles stored in the bottleneck section $Q_{reduction}(i, t)$ should be reduced. Each section needs to define an area of influence that consists of a number of upstream on-ramps for the volume reduction. The amount of volume reduction from an on-ramp is determined by a weighting factor, pre-defined according to how far it is to the downstream detector station of the bottleneck section and the historical demand pattern from the on-ramp. If on-ramp j involves in the volume reduction of any bottleneck section, its system-level metering rate is calculated as:

$$r(j, t) = Q_{on}(j, t-1) - \underset{i=1}{\overset{n}{MAX}}(Q_{reduction}(i, t) \cdot ((WF_j)_i / \sum_j (WF_j)_i)) \quad (4)$$

where $\underset{i=1}{\overset{n}{MAX}}$ is defined as the operator of selecting the maximum volume reduction if the on-ramp is located within more than one section's area of influence. $Q_{on}(j, t-1)$ is the entrance volume from on-ramp j during the past minute; $(WF_j)_i$ is the weighting factor of on-ramp j within the area of influence for section i ; $Q_{reduction}(i, t) \cdot ((WF_j)_i / \sum_j (WF_j)_i)$ is the volume reduction of on-ramp j because of section i .

The more restrictive of the local rate and the system rate will be selected for further adjustments, including queue adjustment, ramp volume adjustment and advanced queue override. The queue adjustment and advanced queue override are used for preventing traffic spillback onto arterials. Ramp volume adjustment copes with the condition that more vehicles have entered the freeway compared to the number of vehicles assumed to enter, which may be caused by HOV traffic or HOV lane violators. The metering rate to be finally implemented should be within the range of the pre-specified minimum and maximum metering rates.

2.4.4 Traveler information systems

Scenario #6 considers the involvement of all kinds of traveler information systems, including the VMS and all other information systems from information agencies, but without any traffic control supports. PARAMICS can simulate this scenario by using dynamic feedback assignment, in which traveler's route choice is calculated based on the instantaneous traffic information. The compliance rate is the control parameter to this scenario.

2.4.5 Arterial management

The arterial management means to change the traffic signal timing along diversion routes in order to accommodate diverting traffic on arterials.

Based on our analysis on the target corridor network, there are two major diversions when an incident happens on the merging area with SR-133 on the northbound I-405. For vehicles from the freeway I-5 to the northbound I-405, the diversion route is to continue to take the northbound I-5 until exiting at off-ramp Alton to westbound Alton Parkway, and then travel to the freeway I-405 at the on-ramp of Sand Canyon. For vehicles from southbound SR-133 and southbound I-5, the diversion route is exiting at the Barranca parkway, going through to the Banting street, turning right to the Alton Parkway and finally entering freeway I-405 at the on-ramp of Sand Canyon.

Because the current actuated signal control system in the studied network cannot change the signal timing adaptively, a timing plan under the incident condition is developed for each of the involved signals based on estimated traffic volume on the two diversion routes. SYNCHRO, which is a software package for modeling and optimizing traffic

signal timings, is used to off-line optimize the signal control along diversion routes during the incident period. The optimized signal timing plans will be applied when the integrated control strategy is activated because of incident.

2.4.6 Combination

Both Scenario #7 and #8 investigate the integration of the traffic control systems help traffic information systems.

Scenario #7 incorporates the freeway control with traffic information systems. In this scenario, the freeway agency responds to the incident via VMS and ramp metering but the arterial traffic agency does not coordinate with the freeway control.

Scenario #8 implements the so-called integrated control or corridor control, which involves the coordination of freeway traffic control system and arterial traffic management system in order to support vehicles re-routing thanks to the traffic information system. So, the detailed integrated control strategy applied here is described as follows. After 5 minutes after the occurrence of the incident on the freeway, the freeway agency shows the diversion messages on VMSs and applying the adaptive ramp metering algorithm, ALINEA. The arterial agency activates the new signal timing along diversion routes.

3. SIMULATION RESULTS AND ANALYSIS

3.1 Calibration of simulation model

The simulation model of the study network was built based on aerial photos. The related road geometry, ITS infrastructure, traffic signal control and ramp metering data are obtained from Caltrans and the City of Irvine. The zone structure of the network was obtained from the Orange County Transportation Authority Model (OCTAM).

The calibration of a simulation model ultimately requires comparing simulated data with field-observed traffic data. Because field observations vary from day to day due to the stochastic nature of traffic, our calibration objective is to re-construct the typical real-world traffic variation in the PARAMICS simulation. The followings are the assumptions of our calibration:

- (1) Drivers' behaviors are determined by two factors, aggressiveness and awareness. We assume them to be normal distributed.
- (2) Due to the existence of freeways and its parallel streets in the study network, the routing algorithm adopted in the simulation is important. Stochastic assignment (with 5% perturbation) is used for this calibration process. Stochastic assignment in PARAMICS assumes that different drivers perceive different costs from a decision node to the destination. The perceived cost is calculated based on the given perturbation factor with a random number assigned to the vehicle, and the shortest perceived route is chosen at the decision node.

The flow chart of the calibration process is shown in Figure 4. The calibration efforts focused on the use of aggregated data (including traffic volume and travel time data) to calibrate route choice parameters, estimate dynamic OD matrix, and fine-tune parameters, such as the mean target headway, driver reaction time, and signposting settings of important freeway links in PARAMICS.

Based on the procedure, the simulation model was calibrated. The calibration results show that simulated traffic counts and section travel time data correspond well to the measurements and accurately capture the congestion patterns of the target network. As illustrated in Figure 5, the Mean Absolute Percentage Errors (MAPE) of traffic counts at selected measurement locations range from 5.8% to 8.7%. As illustrated in Figure 6, the simulated section travel time from the Irvine Center Drive junction to the Culver Drive junction for the northbound I-405 has the MAPE error of 8.5% throughout the simulation period. Details about this calibration study can be found in the reference (Chu, L. et al 2003b).

3.2 Performance measures

The purpose of the evaluation study is to evaluate how ITS strategies can be used to improve the overall performance of the traffic system under the incident condition. The following measures of effectiveness (MOEs) employ the evaluation of the effectiveness of each evaluation scenario in this paper. A performance measure plugin was developed and used for computing, gathering and reporting these measures.

MOE #1 system efficiency measure: Vehicle Hour Traveled (VHT). VHT is defined as:

$$VHT = \sum_{\forall i,j} D_{i,j} \cdot \left(\frac{\sum_{k=1}^{N_{i,j}} T_{i,j}^k}{N_{i,j}} \right) \quad (5)$$

where N_{ij} is the total number of vehicles actually traveled between origin i and destination j . D_{ij} is the travel demand from original i to destination j for the whole simulation time period. T_{ij}^k is the travel time of the k^{th} vehicle traveled between origin i and destination j .

MOE #2 system reliability measure: average standard deviation of OD travel times (Std_ODTT) of the whole simulation period. Std_ODTT is calculated as the weighted standard deviation of the average travel times of all OD pairs for the whole study period:

$$Std_ODTT = \frac{\sum_{\forall i,j} (Std(T_{i,j}) \cdot N_{i,j})}{\sum_{\forall i,j} N_{i,j}} \quad (6)$$

where $Std(T_{i,j})$ is the standard deviation of the average OD travel time from origin i to destination j .

MOE #3 freeway efficiency measure

- (1) Average mainline travel speed of the entire simulation period (AMTS)
- (2) Average mainline travel speed during the congestion period (peak_AMTS).

MOE #4 on-ramp efficiency measure

- (1) Total on-ramp delay (TOD)
- (2) Time percentage of the on-ramp queue spillback to the local streets (POQS)

MOE #5 arterial efficiency measure

- (1) Average travel time from the upstream end to the downstream end of an arterial (ATT)
- (2) The standard deviation of ATT (std_ATT)

3.3 Determination of number of simulation runs

PARAMICS is a stochastic simulation model, which rely upon random numbers to release vehicles, assign vehicle type, destination and route, and determine their behavior as the vehicles move through the network. Therefore, the average results of several simulation runs using different seed number can reflect the traffic condition of a specific scenario.

In order to determine the number of simulation runs, we need to know the variance of a number of performance measures from simulation results, which are unknown before simulations. The flow chart to determine the number of runs is shown in Figure 7.

We execute nine simulation runs first and then calculate the number of runs needed according to the mean and standard deviation of a performance measure of these nine runs:

$$N = \left(t_{\alpha/2} \cdot \frac{\delta}{\mu \cdot \varepsilon} \right)^2 \quad (7)$$

where μ and d are the mean and standard deviation of the performance measure based on the already conducted simulation runs; ε is the allowable error specified as a fraction of the mean μ ; $t_{\alpha/2}$ is the critical value of the t-distribution at the significance level α . This calculation needs to be done for all performance measures of interest. The highest value from variances is the required number of runs. If the current number of runs is already larger than this value, the simulation of this scenario is ended. Otherwise, one additional run is performed and then the required number of runs needs to be recalculated.

3.4 Evaluation results

There were eight evaluation scenarios, as shown in Table 1. The simulation time periods for all scenarios are morning peak hours from 5:45 to 10:00 a.m. The first fifteen minutes of each simulation run are treated as the “warm-up” period. All control scenarios were compared with the no incident management scenario, i.e. Scenario #1.

The number of simulation runs for each scenario is determined by the method described in the last sub-section. Due to the purposes of this study, we select two measures, VHT and AMTS, for the calculation of the required number of runs. Based on multiple runs, the resulting value of each MOE for a scenario is equal to its average of all simulation runs.

3.4.1 Overall performance

The overall performance measures, including the system efficiency measure, i.e. VHT, and system reliability measure, i.e. average standard deviation of OD travel times, are shown in Table 2 and Figure 8. Because VHT is the most important measure of the evaluation, we conducted t-tests in order to statistically compare the VHTs of any two scenarios. Table 3 shows the confidence intervals of the comparisons. The higher a confidence interval is, the more significant the VHT difference of the two scenarios is.

The performance of the northbound freeway I-405, where the incident happened, is shown in Table 4 and Figure 9. The congestion period is defined from 7:30 to 9:30 AM based on the traffic condition of the benchmark scenario. Table 5 shows the performance of the arterials.

The evaluation results show that all ITS strategies have positive effects on the improvement of network performance. The more ITS components involved, the more benefits can be obtained, as shown in Figure 10.

3.4.2 Incident management

Incident management (Scenario #2 and #3) can improve system performance because it increases the average mainline travel speed on the northbound I-405, as shown in Figure 11, which compares the freeway mainline speed variation over time under these three incident management scenarios. The decrease of the incident duration from 33 minutes to 26 minutes or from 26 minutes to 22 minutes can statistically improve VHT at the confidence interval of 85%. When the incident duration is dropped from 33 minutes to 22 minutes, VHT is improved significantly (with 99% confidence interval).

3.4.3 Adaptive ramp metering

Theoretically, adaptive ramp metering benefits traffic system through adaptively adjusting metering rate based on the traffic condition of mainline freeway. Comparing Scenarios #4 (using the ALIENA algorithm) and #5 (using the BOTTLENECK algorithm) with Scenario #2, the application of adaptive ramp metering improves system performance. However, the performance improvement introduced by is not very significant. Both ALINEA and BOTTLENECK cannot improve VHT or freeway travel speed significantly. This can be seen from Figure 12, which shows the variation of the mainline freeway travel speed over time under 26-min incident management. This

explains that if the congestion becomes severe, the target level of service (LOS) could not be maintained by using ramp metering and the effectiveness of ramp control is marginal.

Comparing the two adaptive ramp metering algorithms, the coordinated ramp metering control, i.e. BOTTLENECK (Scenarios #5), performs slightly better than the local adaptive ramp-metering control, ALINEA (Scenarios #4) from the perspective of VHT. The reason is that BOTTLENECK can response to not only the local congestion but also the congestion appeared in a coordinated area. Both ALINEA and BOTTLENECK impose a certain amount of delay on vehicles from entrance ramps. ALINEA performs better than BOTTLENECK in the aspects of less TOD and less probability of vehicles on the entrance ramps spillback to the surface streets (i.e. POQS). Due to the coordination feature of BOTTLENECK, it causes the highest total on-ramp delay.

3.4.4 Traveler information

Scenario #6 is the scenario with the involvement of all kinds of traveler information systems, but without any traffic control support. We conducted a study on how the variation of the compliance rate influences the performance of the system. As shown in Figure 13, when the compliance rate is higher than 15-20%, the saving of VHT reaches a stable maximum (i.e. 5.3%). Based on the research conducted by other researchers, 20% was regarded as an optimal level for traveler information provision (Oh, et al, 2002). Our research validates their results. We will use 20% compliance rate in Scenarios #6, #7, #8 for the comparison with other scenarios.

Based on VHT, std_ODTT, AMTS, and peak_AMTS, Scenarios #6 has the greater benefits than adaptive ramp metering algorithms (Scenarios #4 and #5) and improved incident management (Scenario #3). The reason is the network topology -- one major freeway segment (I-405) with two parallel arterial streets (ALTON Pkwy and BARRANCA Pkwy), which allow the real-time traveler information systems divert traffic from the congested freeway to arterial streets. From the perspectives of on-ramp, TOD and POQS of this scenario are high because there is no ramp metering support from the freeway agency.

3.4.5 Combination

Scenarios #7 and #8 integrates traveler information with freeway traffic control. In the real world, institutional barriers may hamper the coordination between different traffic agencies. Scenario #7 implements the scenario that only freeway agency responds to the incident via the VMS routing and adaptive ramp metering (i.e. ALINEA) but the arterial agency does not support the freeway traffic control scheme. Scenario #8 implements the integrated control, in which the traffic signal control and ramp metering are also adjusted to facilitate the diversion of traffic. Compared to Scenario #6, Scenarios #7 and #8 significantly improved VHT. Comparing Scenarios #7 and #8, VHT of Scenario #8 got improved at 97.5% confidence interval.

To further validate if Scenario #8 is better than Scenario #7 (due to the traffic control coordination with the arterial agency), other MOEs of the two scenarios were compared statistically based on 90% confidence interval. In the aspects of std_ODTT, AMTS and peak_AMTS, the two scenarios have comparable performance. Based on TOD and POQS, Scenario #8 introduces more on-ramp delays and waiting than Scenario #7. In terms of ATT and std_ATT, a much shorter and stable arterial travel time has been obtained on the westbound ALTON Pkwy because of the application of the new signal timing plan to related signals along the diversion routes during the congestion caused by the incident.

As a result, Scenario #8 shows the best performance among all scenarios. Its performance was slightly better than that of Scenario #7. The reason of the good performance of Scenario #7 is that the traffic signal system in the study network is the actuated signal system. This signal system can try its best to accommodate the diversion traffic even without arterial management. The result from this study does not mean that the coordination with the arterial traffic agency is not important. If the arterial signal system is a pre-time system and the default signal timing does not favor the traffic diversion, the arterial management is especially important for the integrated control.

3.4.6 Benefit of ITS during the congestion period

As described above, the incident is injected to the network at 7:45 AM and its duration is 26 minutes for most scenarios except Scenario #1 and #3, whose incident duration times are 33 and 22 minutes, respectively. Base on Figure 10, 11 and 12, the time period between 8:05 and 8:20 is always the worst time of traffic congestion. The implementation of any ITS strategy in this study cannot help avoid and improve the worst time.

This result is reasonable for the incident management scenarios and adaptive ramp metering scenarios because they do not involve traffic diversion. For Scenarios #6, #7, and #8, in which traffic information and diversion is involved, there are two reasons that can explain this result. Firstly, the traffic assignment method of PARAMICS, i.e. dynamic feedback assignment, is used for the calculation of the shortest path based on instantaneous travel time information feedback from simulation. The feedback interval was set to 60 seconds in our study. If the alternative route (i.e. arterials) can save travel time compared to the original route (i.e. freeway), vehicles will use the alternative. Some time is needed to satisfy this condition because the alternative route actually has longer physical distance and some signalized intersections. Secondly, we considered the incident detection and response time in our study. It takes five minutes for traffic control facilities in scenarios #7 and #8 to apply the adaptive signal timing plans under incident condition. On the other hand, because of the involvement of traffic diversion, scenario #6, #7 and #8 clearly "recovers" faster (as much as 10-15 minutes faster) than the second scenario "IM-26".

4 CONCLUDING REMARKS

This paper presents a micro-simulation method to evaluate the effectiveness of potential ITS strategies in a capability-enhanced PARAMICS micro-simulation environment, developed by integrating various plug-in modules through API programming in order to model the current traffic conditions and various potential ITS strategies.

We evaluated the effectiveness of a number of potential ITS strategies under a non-recurrent incident scenario. The evaluated ITS strategies include incident management, local adaptive ramp metering and coordinated ramp metering, traveler information systems, freeway control, and integrated control, i.e. the combination of traveler information systems, arterial management and adaptive ramp metering. These ITS strategies were implemented and evaluated in the enhanced PARAMICS environment. Performance measures include the efficiency of the overall system, mainline freeway, on-ramp, and arterials and the reliability of the network.

Based on simulation results, all ITS strategies have positive effects on the improvement of network performance. The detailed findings can be summarized briefly as follows:

- (1) The most important ITS strategy to relieve traffic congestion caused by incident is to provide traffic information.
- (2) The adaptive ramp metering cannot improve system performance effectively under the incident scenario.
- (3) Fast incident management is important but it does not benefit the system significantly by itself. It needs to be applied with other ITS strategies, especially traveler information systems.
- (4) The proper combination of ITS strategies yields greater benefits.
- (5) If the integrated control is hard to be implemented practically and the arterial signal system is technically advanced, the integrated control without the involvement of arterial agency can still work well.
- (6) If the instantaneous traffic information is used for the traffic management under incident condition, a worst time of traffic congestion always exists no matter what ITS components are involved in the traffic management.

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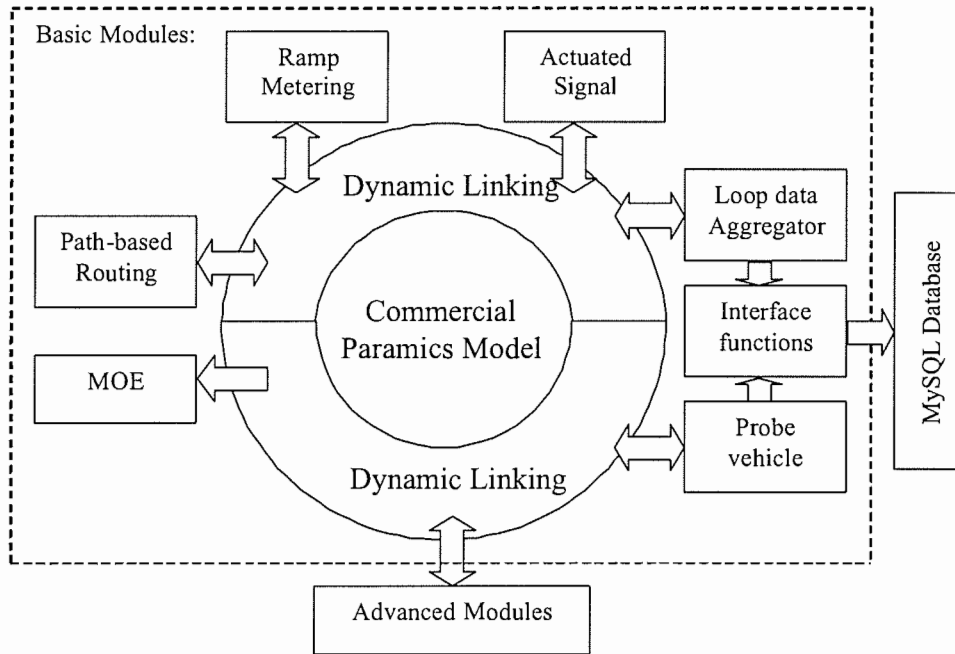


Figure 1 Framework of the capability-enhanced PARAMICS simulation

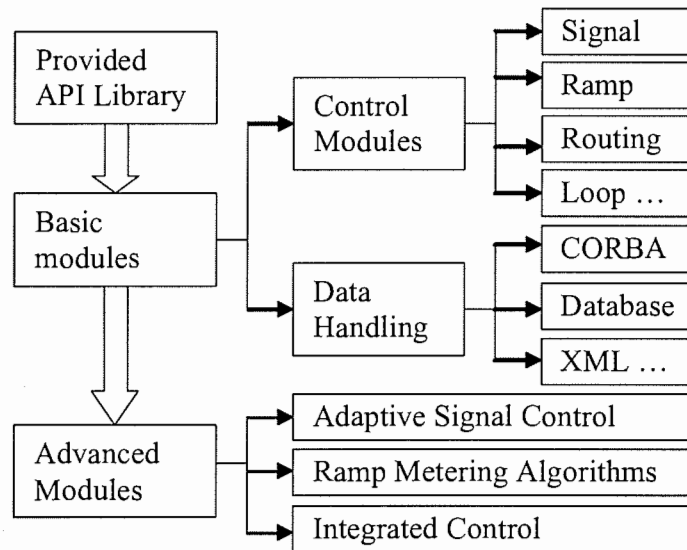


Figure 2 The hierarchical API development approach

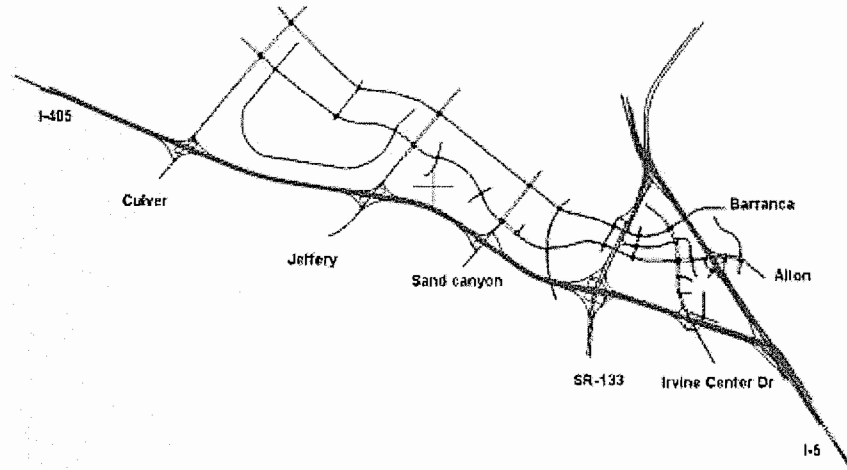


Figure 3 Overview of the study network

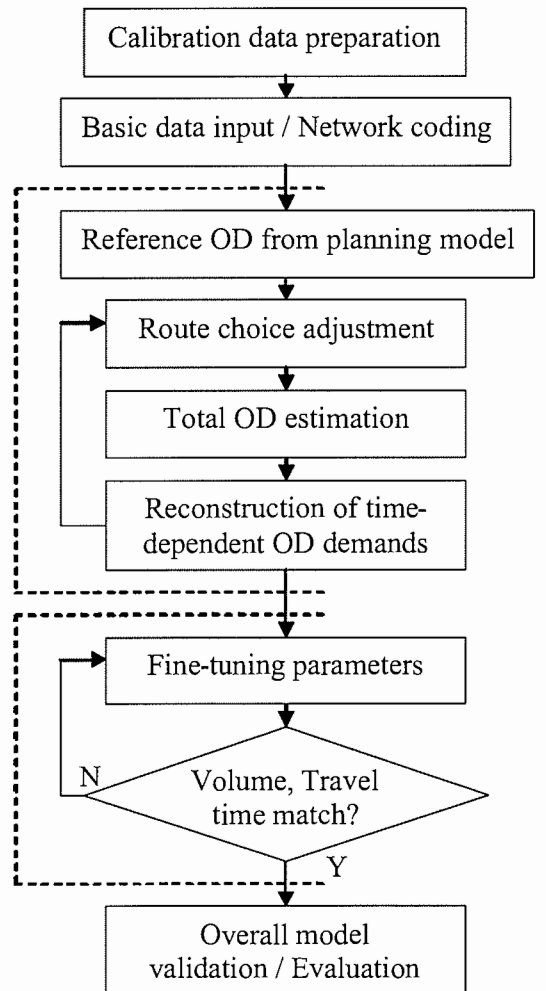


Figure 4 Flow chart of calibration procedure

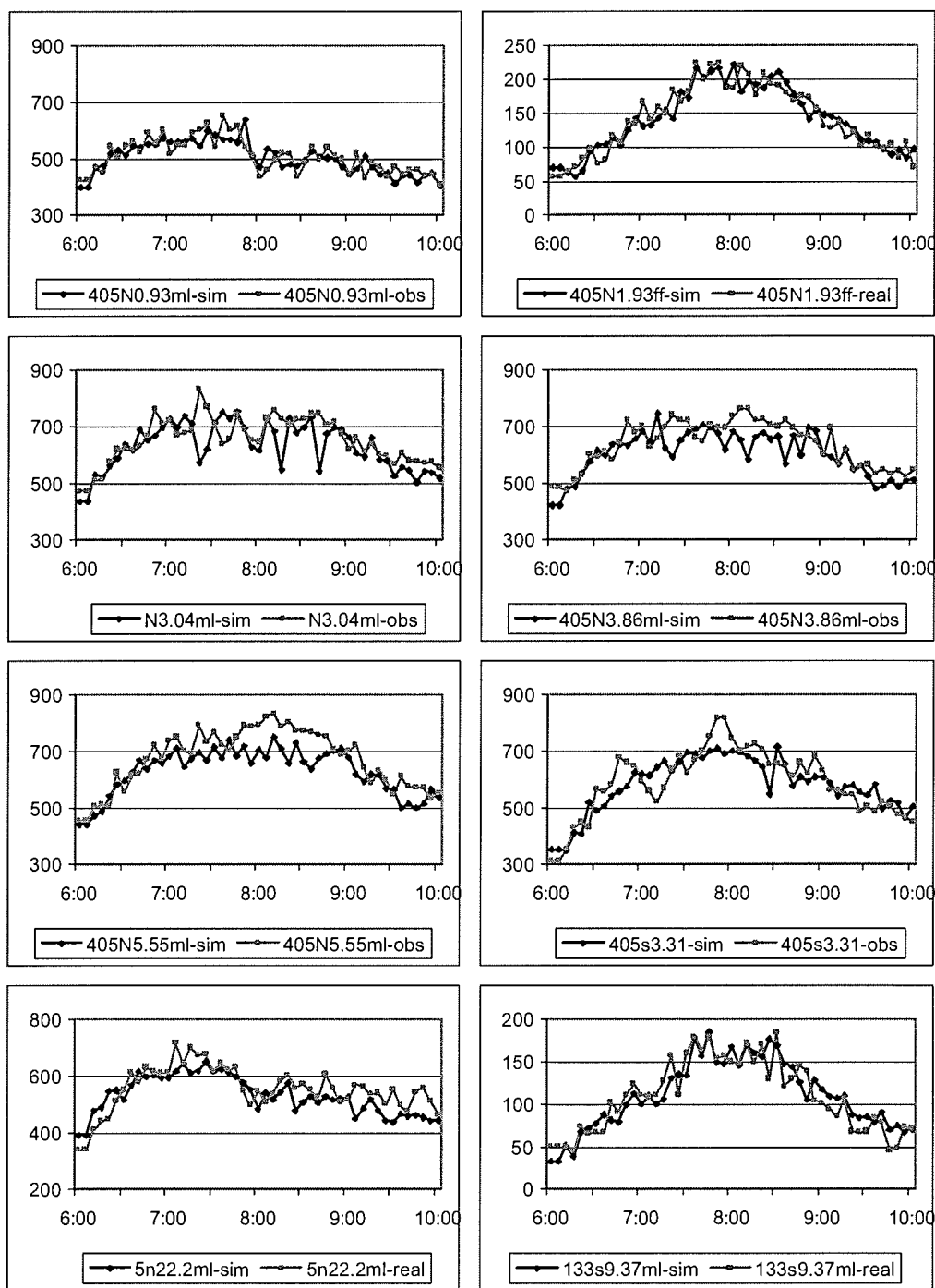


Figure 5 Traffic counts calibration (5-minute volume) at major freeway measurement locations

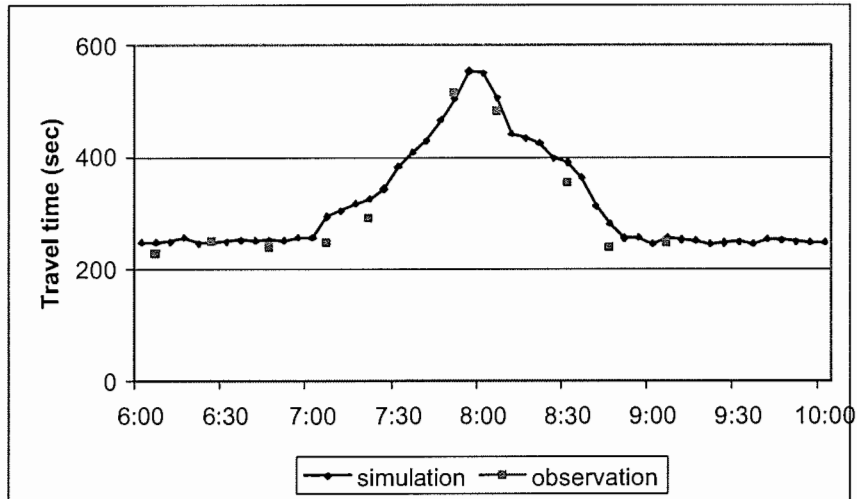


Figure 6 Observed and simulated travel time of northbound I-405

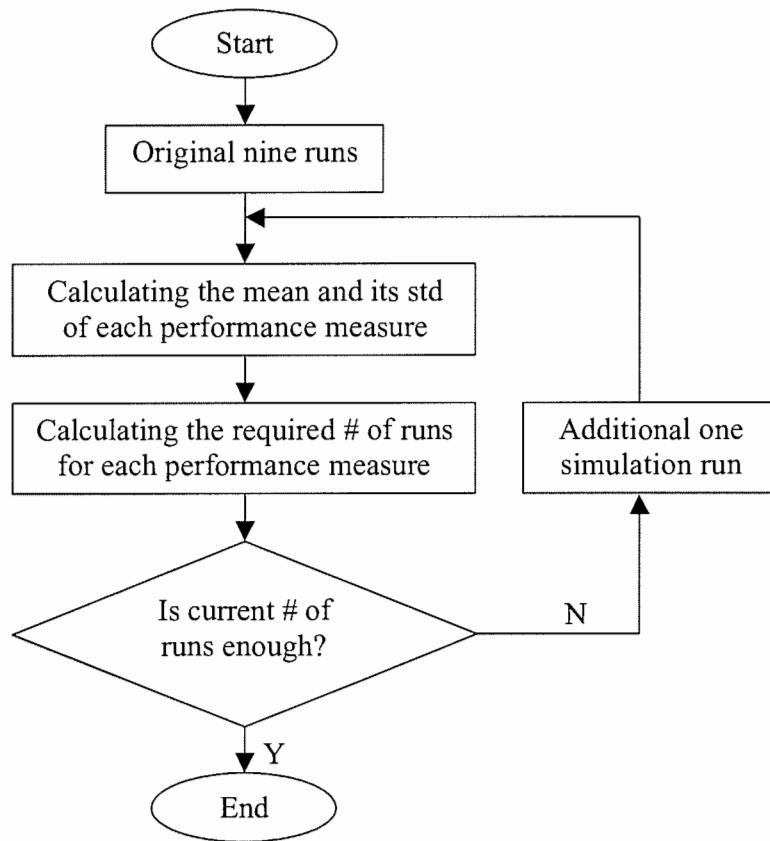


Figure 7 Flow chart of the determination of number of simulation runs

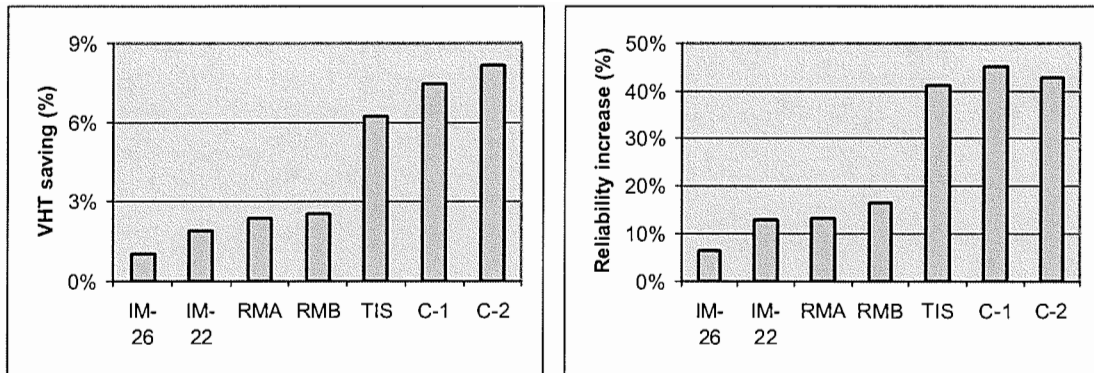


Figure 8 Comparison of the VHT saving and the increase of the network reliability

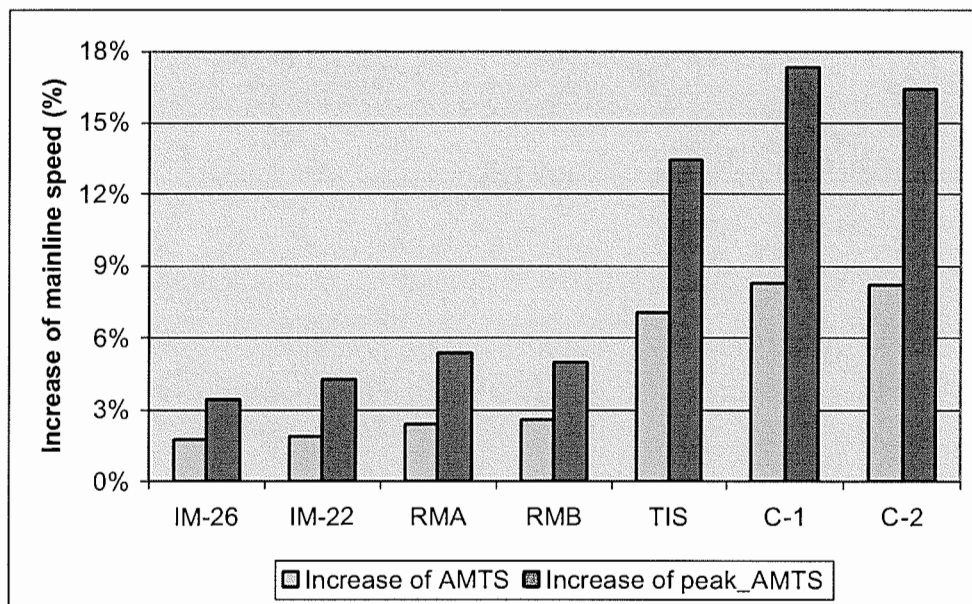


Figure 9 Comparison of the increase of average mainline speed of the northbound I-405

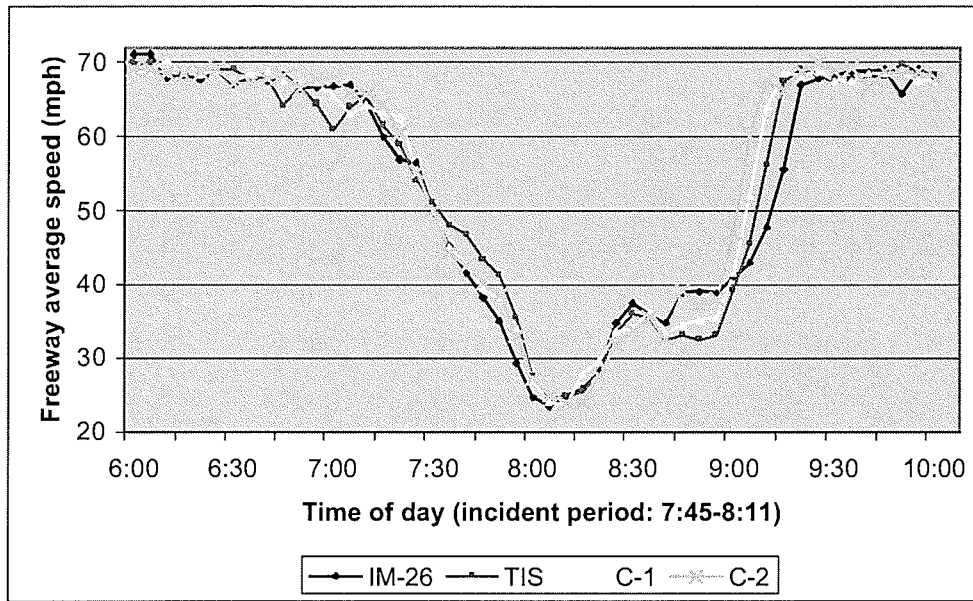


Figure 10 Comparison of the average travel speed along I-405N over time under scenarios with traveler information systems

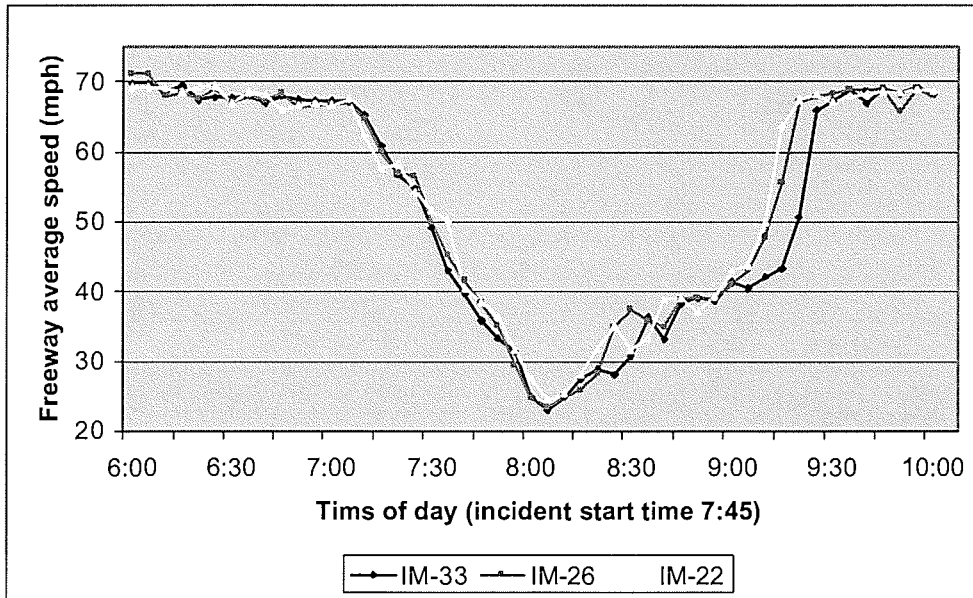


Figure 11 Comparison of the average travel speed along I-405N over time under incident management scenarios

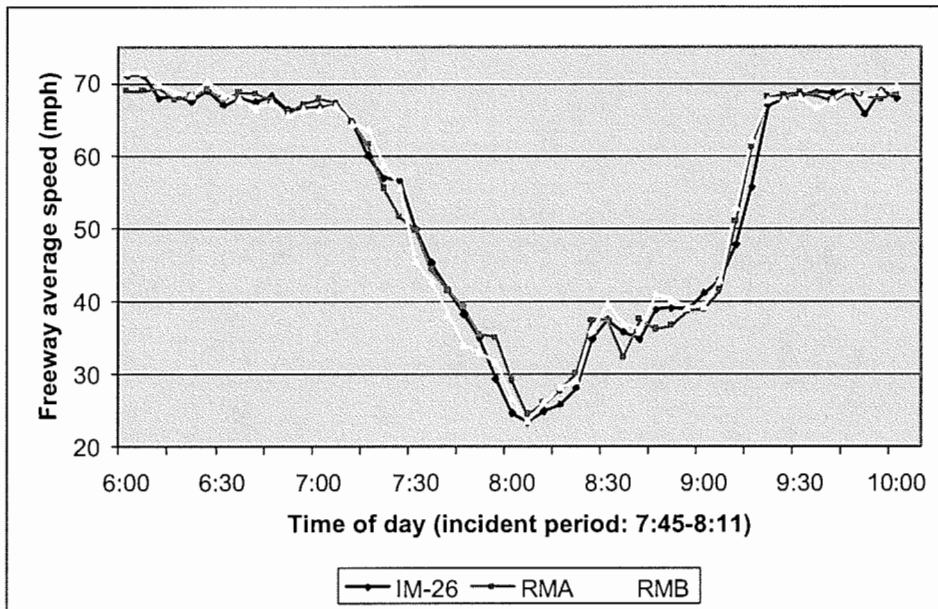


Figure 12 Comparison of the average travel speed along I-405N over time under adaptive ramp metering scenarios

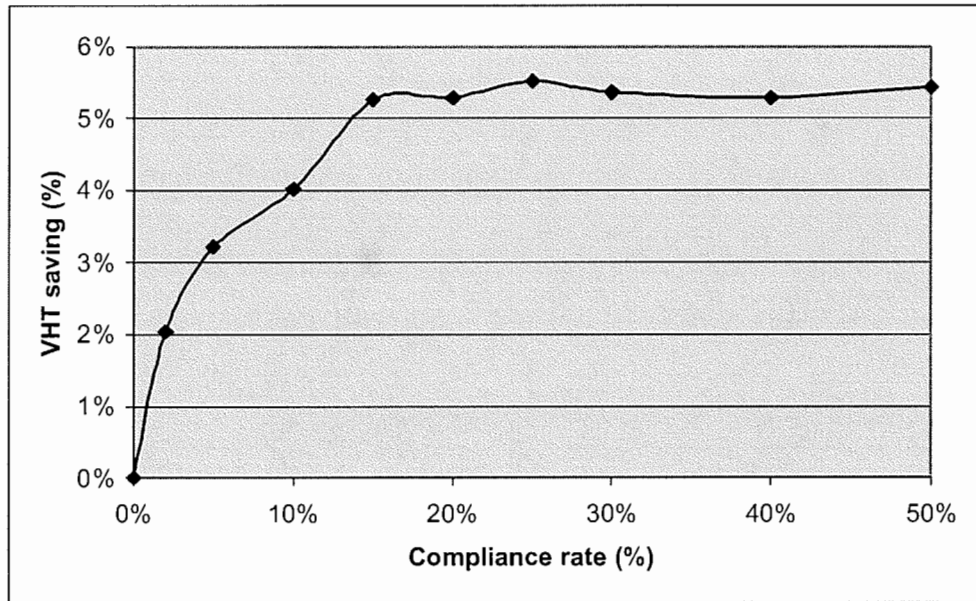


Figure 13 VHT saving under different compliance rates of traveler information systems

Table 1 Simulation scenarios and their corresponding control strategies

Scenario	ITS components			
	Ramp Metering	Signal Control	Traveler Information	Incident Management
(1) IM-33	Fixed time	Actuated	N/A	33 mins
(2) IM-26	Fixed time	Actuated	N/A	26 mins
(3) IM-22	Fixed time	Actuated	N/A	22 mins
(4) RMA	ALINEA	Actuated	N/A	26 mins
(5) RMB	BOTTLENECK	Actuated	N/A	26 mins
(6) TIS	Fixed time	Actuated	20% compliance	26 mins
(7) C-1	ALINEA	Actuated	20% compliance	26 mins
(8) C-2	ALINEA	Arterial Management	20% compliance	26 mins

Table 2 Overall performance of each strategy

Scenario	VHT	VHT saving (%)	std_ODTT	Reliability increase (%)
(1) IM-33	12837		139.6	
(2) IM-26	12703	1.0%	130.9	6.3%
(3) IM-22	12589	1.9%	121.7	12.8%
(4) RMA	12533	2.4%	121.3	13.2%
(5) RMB	12511	2.5%	116.5	16.6%
(6) TIS	12031	6.3%	82.3	41.1%
(7) C-1	11877	7.5%	76.8	45.0%
(8) C-2	11782	8.2%	79.7	42.9%

Notes: ASTT – Average system travel time

Std_ODTT— Average standard deviation of OD travel times of the entire simulation period, which represents the reliability of the network

Table 3 Confidence intervals of the VHT difference of any two scenarios

	IM-33	IM-26	IM-22	RMA	RMB	TIS	C-1	C-2
IM-33	•	0.85	0.99	0.995	0.9995	0.9995	0.9995	0.9995
IM-26		•	0.85	0.9	0.95	0.9995	0.9995	0.9995
IM-22			•	0.7	0.8	0.9995	0.9995	0.9995
RMA				•	0.6	0.9995	0.9995	0.9995
RMB					•	0.9995	0.9995	0.9995
TIS						•	0.995	0.999
C-1							•	0.975
C-2								•

Table 4 Performance of the northbound of freeway I-405

Scenario	AMTS (mph)	AMTS Increase (%)	peak_AMTS (mph)	Increase of peak_AMTS	TOD (hour)	POQS (%)
(1) IM-33	50.5		38.6		42.8	1.9
(2) IM-26	51.4	1.7%	39.9	3.4%	42.0	2.0
(3) IM-22	51.5	1.9%	40.2	4.3%	40.9	1.8
(4) RMA	51.7	2.4%	40.6	5.4%	47.6	1.1
(5) RMB	51.8	2.6%	40.5	5.0%	73.4	2.1
(6) TIS	54.1	7.1%	43.8	13.5%	51.8	2.7
(7) C-1	54.7	8.3%	45.2	17.3%	41.0	1.0
(8) C-2	54.6	8.2%	44.9	16.4%	43.3	1.2

Notes: AMTS – Average mainline travel speed of entire simulation period (6 – 10 AM)
 peak_AMTS – Average mainline travel speed of congestion period (7:30 – 9:30)
 TOD – Total on-ramp delay
 POQS – Time percentage of vehicles on the entrance ramps spillback to the surface streets

Table 5 Performance of arterials (Alton Parkway)

Scenario	Westbound ALTON		Eastbound ALTON	
	ATT (sec)	std_ATT	ATT (sec)	std_ATT
(1) IM-33	515	71.0	452	53.8
(2) IM-26	514	68.2	452	54.5
(3) IM-22	514	68.5	450	54.5
(4) RMA	514	69.7	451	54.7
(5) RMB	515	68.4	452	55.3
(6) TIS	519	73.1	452	56.7
(7) C-1	522	75.0	456	58.2
(8) C-2	428	55.5	453	61.5

Notes: ATT – Average travel time
 Std_ATT – Standard deviation of the average travel time