Evaluation of the Effectiveness of Potential ATMIS Strategies using Microscopic Simulation

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ABSTRACT

This paper presents a micro-simulation method to evaluate potential ATMIS applications. Based on the commercial PARAMICS model, a capability-enhanced PARAMICS simulation environment, PARAMICS-E, has been developed through integrating a number of plug-in modules implemented with Application Programming Interfaces (API). These APIs complement the functionalities of the commercial PARAMICS model and enable the mechanism of the real-time traffic data collection, processing, and communication, as well as control of operations through dynamic linking. This enhanced PARAMICS simulation can thus have capabilities to model not only the target traffic conditions and operations but also various potential ATMIS strategies. An evaluation study on the effectiveness of potential ATMIS strategies under the incident scenarios is conducted in PARAMICS-E over a corridor network located at the city of Irvine, California. The potential ATMIS strategies include incident management, local adaptive ramp metering, coordinated ramp metering, traveler information systems, corridor control, and the combination of above. Based on the calibrated simulation model, we implement and evaluate these scenarios. The evaluation results show that all ATMIS 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 ATMIS components. The combination of several ATMIS components, such as the corridor control and the combination scenarios, can generate better benefits.

1 INTRODUCTION

Many Advanced Transportation Management and Information Systems (ATMIS) 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 ATMIS applications, such as adaptive signal control, adaptive ramp metering and their combination, 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 ATMIS applications may adversely impact traffic conditions. For decision makers, questions related to whether an ATMIS 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.

With the advancement of computer technology and better modeling traffic flow in the microscopic level, microscopic simulation is becoming a popular and effective tool for the decision support of transportation applications. Basically, micro-simulation is used as an evaluation tool. It is regarded as a real world where algorithms, models, and control strategies can be easily tested.

As the first widely used micro-simulation software in the US, CORSIM was applied to the studies of signal control, transit, ramp metering and work zones, etc. (1, 2). However, most of these studies were only restricted to a small network. The new generation of
micro-simulators, including AIMSUN 2, PARAMICS and VISSIM, shows better
capabilities on modeling over a large network.

Current micro-simulation applications are mostly focused on calibration and validation
issues, and studies under simple networks, either a fictitious network with assumed travel
demands or a small-size real network. The following difficulties hinder the further
application of micro-simulations: (a) lacking of effective or practical OD estimation
methods; (b) limited knowledge on network calibration; (c) inability to simulate the
advanced algorithms when they are not available from the off-the-shelf model.

In this paper, we present a complete process to overcome the above problems, and apply
a commercial micro-simulator to quantitatively evaluate the effectiveness of various
potential ATMIS components. Based on the commercial PARAMICS model, we
establish a capability-enhanced PARAMICS simulation environment, PARAMICS-E,
through integrating a number of plug-in modules implemented by Application
Programming Interfaces (API). These APIs complement the functionalities of
PARAMICS and enables the mechanism required by various ATMIS applications,
including real-time traffic data collection, processing, and communication, as well as
control of operations. This enhanced PARAMICS simulation can thus have capabilities to
model not only the current traffic conditions and operations but also various potential
ATMIS strategies.

This paper is organized as follows. Section 2 presents the procedures of evaluating
ATMIS applications in a micro-simulation environment. Section 3 briefly describes our
efforts to establish the capability-enhanced micro-simulation environment in order to
represent the real-world traffic and model potential ATMIS applications. Section 4
describes the calibration of a corridor network in PARAMICS. Section 5 provides the
details of our evaluation studies on implementing potential ATMIS strategies and
evaluating the performance of them. Section 6 concludes the paper.

2 EVALUATION PROCESS

We take the following steps to evaluate an ATMIS application in a microscopic
simulation environment:

1. Identifying an appropriate micro-simulation environment
   The selected micro-simulator should have the capability to simulate the current
   real-world traffic conditions and traffic operations (such as actuated signals and
   pre-timed ramp metering), and model potential ATMIS strategies as well. If
   simulators do not have these functionalities, users can develop these modules by
   themselves using the API library through which users can customize and extend
   many features of the underlying simulation model. This requires a comprehensive
   API library provided by micro-simulators.

2. Network coding and calibration
   The study network need to be modeled in the simulator based on network layout
overlays or aerial photos of the target area and the related geometry and infrastructure information. Significant efforts may be required to calibrate the network. Without calibration, the model network cannot be used for any application.

3. Modeling the evaluated ATMIS strategies
   The evaluated ATMIS strategies, such as adaptive ramp-metering control or traffic diversion, can be modeled either by the micro-simulator itself or by API programming.

4. Implementation of ATMIS strategies in the simulation world
   Each ATMIS strategy may have some parameters, which should be set up based on the exclusive features of the study network or user’s assumptions. Some ATMIS applications, such as adaptive ramp metering, need a detailed calibration process.

5. Performance evaluation
   Based on the features of the evaluated ATMIS strategy and objectives of the evaluation study, a number of performance measures should be selected for benefit and performance analysis. These measures either can be extracted directly from the output of simulation runs or obtained from developed APIs.

6. Result discussions
   If there exist unexpected results, the previous steps need to be checked to ensure the correctness of the results. Results then can be used in the decision-making process.

3 PARAMICS-E: ENHANCED PARAMICS SIMULATION

PARAMICS (PARAllel Microscopic Simulation) is a scalable, ITS-capable, high-performance microscopic traffic simulation package developed in Scotland (3). PARAMICS Build 3.0.7 is used in this study. Some researchers have worked extensively with the PARAMICS model (4, 5, 6). We select PARAMICS as the micro-simulator to evaluate ATMIS strategies due to its potential to simulate a large network and its powerful abilities on API programming, which can be used for modeling not only the current traffic conditions and operations but also various ATMIS strategies.

Based on the commercial PARAMICS model, we establish a capability-enhanced PARAMICS simulation environment, PARAMICS-E, through integrating a number of plug-in modules implemented in PARAMICS API. Figure 1 shows the framework of PARAMICS-E. The core of PARAMICS-E is the commercial PARAMICS model. A set of API modules, including full-actuated signal controller, time-based ramp metering controller, VMS controller, path-based routing, loop data aggregator and performance measure API, are used for enhancing the capabilities of the commercial PARAMICS model. An API module exchanges dynamic data with the core PARAMICS model and other API modules through the Dynamic Linking Library (DLL) mechanism. Compared
to the commercial PARAMICS model, PARAMICS-E has functionality enhancements in the following aspects.

1. Basic control modules of signal, ramp metering and VMS
A set of basic ATMIS modules have been developed in PARAMICS-E, including full-actuated signal controller, time-based ramp metering controller, VMS controller. They work as the control centers of signal control, ramp metering and VMS in the simulation world. These control modules provide interface functions between users and the detailed traffic control facilities in the PARAMICS-E environment. Advanced ATMIS modules can be developed based on them. For example, the interface function for the signal control is in the following format:

```c
void uci_signal_set_parameters(Signal *sig);
Function:    Setting a new timing plan to a specific signal.
Return Value: None
Parameters:  sig stores the new timing plan.
```

```c
Signal* uci_signal_get_parameters(char *nodeName);
Function:    Querying the current signal timing plan of a specific actuated signal
Return Value: The current timing plan of an actuated signal.
Parameters:  nodeName is the name of the signal node.
Signal is the structure of actuated signal data
```

2. Traffic data collection, processing, and communication
In the real world, loop detectors are placed on freeways and arterials for collecting aggregated data at a certain time interval (typically, 30 seconds) for the purposes of traffic analysis and traffic control. These aggregated loop data are stored either in the database or shared memory. Other traffic operation components can get access to these data through data communication networks and use them for generating real-time control strategies.

The loop data aggregator API works as the traffic data collection and provision server in the PARAMICS-E environment. It emulates the real-world data collection from induction loop detectors and provides the latest aggregated loop data in the dynamic memory during simulation. Other API modules can obtain these data in real time through the interface function provided by this API. In addition, this API can report the aggregated loop data to text files or the MYSQL database as performance measures for data analysis and performance comparison.

Similarly, we develop a probe vehicle API to simulate point-to-point travel time data collection through GPS equipped vehicles. The sample rate, which is equivalent to the percentage of GPS equipped vehicles, can be specified through control interface. Point-to-point travel time data can be output to the dynamic memory and text files or the MYSQL database.

3. Path-based routing
PARAMICS is a link-based simulator and vehicles do not carry their whole routes but decide their route based on the routing table stored at each node along its route. The path-based routing API establishes the mechanism for vehicles to follow a given path, which is an essential requirement for the simulation of driver responses to the information supply and the resulting route choice. Only those vehicles that need to follow specific paths will be guided by this API and other vehicles will select route based on the internal routing method of PARAMICS.

4. Database connection
MySQL database is widely regarded as a highly efficient database. It can be used for storing intermediate or final results during the simulation process.

5. The hierarchical API development framework.
An advanced ATMIS module, such as a signal coordination strategy, adaptive ramp metering algorithm, or a corridor control strategy, involves the control of one or several components of the traffic system, such as signals, ramps, VMS, and routing vehicles, based on real-time traffic information. Through dynamic linking, PARAMICS-E established the mechanism of real-time traffic data collection and communication, real-time traffic control, and driver behavior control with these basic ATMIS modules. Therefore, an ATMIS strategy can be easily implemented in the PARAMICS-E environment based on the aforementioned basic ATMIS modules.

6. Performance measures
PARAMICS has strong abilities on the collection of statistics data. Except some general performance data, PARAMICS can output link-based, trip-based, intersection-based, detector-based data. With the increase of the size of the network, the number of links increases drastically in PARAMICS. The current difficulties are:

- Large amount of data are required to be processed after simulation runs in order to obtain the expected performance measures.
- Some performance measures cannot be extracted from output measurement data.

To be more efficient to simulation studies, we developed some APIs for obtaining a number of user-preferred overall performance measures, which will describe later in section 5 of this paper. In addition, as mentioned earlier, the aforementioned loop data aggregator and probe vehicle API can report aggregated loop data and point-to-point travel time data.

In summary, PARAMICS-E complements the functionalities of the commercial PARAMICS model in many aspects. In addition, PARAMICS-E provides users a hierarchical API development framework, which facilitates the development of advanced ATMIS strategies.

4 CALIBRATION
The study network is a highly congested corridor network in the city of Irvine, Orange County, California, illustrated in Figure 2. 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.

We built this network in PARAMICS based on the aerial photo of the target area and related road geometry and infrastructure information obtained from Caltrans and the city of Irvine. The simulated network has the same geometry, the same traffic control operations, including actuated signal control and time-based ramp metering, and the same configuration of ITS facilities, including loop detectors and VMS, as those in the real world. There are 38 actuated signals and 16 fixed-time metered on-ramps, which are modeled by the full-actuated signal API and ramp metering API respectively. The signal timing and ramp metering plans currently in place are used as the baseline of this study.

The zone structure of the network is based on information obtained from the OCTAM (Orange County Transportation Authority travel demand Model) model. A static AM peak OD matrix, sub-extracted from the OCTAM 2000 model, is used as the reference OD matrix of this study.

The calibration efforts for a simulation study ultimately require 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 calibration efforts are focused on the use of aggregated data to calibrate the most critical parameters in PARAMICS, including OD matrix adjustment, the route choice parameters, the mean target headway and driver reaction time, and the signposting setting of some important freeway links in PARAMICS.

4.1 Calibration data preparation

4.1.1 Data preparation

The following data sets are obtained in order to calibrate the study network in PARAMICS.

1. Arterial volume data
   - 15-minute interval traffic counts at arterial links acquired from the City of Irvine (most of them collected at January of 2002, and June of 2901). Some of links are located at cordon points of the network and others are located at important links inside the network;
   - Traffic counts at important cordon points of the network (not covered by the data from the City of Irvine), obtained from data processing of the surveillance video data (taped between March 27, 2002 to April 19, 2007).

2. Freeway loop detector data
   All available loop data of freeway loop detectors (including mainline, on-ramp and off-ramp loops in the study area) at 30-second interval, acquired from the database for
the time period from Oct 1, 2001 to Oct 30, 2001. These 30-second data are further aggregated to 5 minutes interval for the traffic volume match.

3. Travel time data
Freeway floating car data (Nov. 17, 2001) of northbound and southbound freeway I-405, obtained from Caltrans District 12.

4. Reference OD matrix
The O-D matrix derived from the OCTAM model is only for the morning peak hour from 6 to 9 AM. Since the congestion happened in the study network cannot be totally cleared at 9 AM, the OD demand matrix is further expanded to 4 hours, i.e., from 6 to 10 AM, based on the observed 15-minute traffic counts and freeway loop data at cordon points.

5. Vehicle performance and characteristics data, including vehicle length, maximum speed, maximum acceleration and deceleration rate, etc., which are obtained from Caltrans.

6. Vehicle mix by type, which is determined by the statistical analysis of vehicle types, based on the surveillance videos at two locations in the network.

4.1.2 Preliminary data analysis
Since the study network is a corridor network where freeways play an important role, we need to make a preliminary data analysis on freeway loop data in order to find a set of typical loop data that can reflect the real-world traffic variations for this calibration study.

We select several loop data stations located at the upstream end of each freeway, all on-ramps and all off-ramps for this analysis. 11 weekdays within a month of loop data at these stations are obtained from our database. Then the total volume of peak hour, i.e. 7-8 AM, and the whole period, i.e. 6-10AM, of each loop station are calculated and compared. Since more than 85% of total volumes at loop stations on October 17, 2001 are close to the mean of the 11 days, the loop data of October 17, 2001 can represent the typical traffic condition of the study network and are used to calibrate our model network.

4.2 Calibration procedures
As the basic input data of micro-simulation, data of vehicle performance and characteristics, and data of vehicle mix by type of the target network needs to be determined. In addition, the following options are required to be assumed first:

1. Driver behavior (including aggressiveness and awareness) distribution, which is assumed to be normal distribution.
2. Stochastic assignment (with 5% perturbation) is used as the traffic assignment method for this calibration process.

The flow chart for the calibration procedure is shown in Figure 3.
4.2.1. Checking coding errors

At this step, the reference OD matrix is evenly loaded for the whole simulation period (subject to a flat demand “profile”), without considering the variation of demands over time. All critical parameters of PARAMICS use default values. The vehicles are observed as vehicles move through the network. Abnormal behaviors always correspond to network coding errors, which need to be identified and solved.

4.2.2. Adjustment of the OD matrix and modification of route choices

The reference OD matrix obtained from the OCTAM model is not accurate because the data sets of OCTAM model are generally limited to the nearest decennial census year and the sub-extracted OD matrix is generated based on the four-step model of TRANPLAN. Since we have 15-minute interval traffic counts at all cordon points of the network, the total traffic attractions and generations (or the total inbound and outbound traffic counts) of each zone are known. We assume the same trip distribution as that of the reference OD matrix is applied to all zones in the adjusted OD matrix. The FURNESS technique is then used for balancing the OD table. If the total attractions are not equal to the total generations, the total generations are used as the total.

Then we evenly load this adjusted OD matrix for the whole simulation period (subject to a flat demand “profile”). Based on the simulation results, we can compare the observed and simulated total traffic counts at selected measurement locations with the objective function shown in Equation 1, which is to minimize the deviation between the observed and corresponding simulated traffic counts at selected measurement locations for the whole simulation period. Selected measurement locations include the freeway loop stations at on-ramps, off-ramps and along the mainline freeway, and several important arterial links.

\[
\min \sum_{n} (M_{obs}(n) - M_{sim}(n))^2
\]  

(1)

where \(N\) is the total number of measurement locations, which are generally loop detector stations in the real world; \(M_{obs}(n)\) and \(M_{sim}(n)\) are total observed and simulated traffic counts at measurement location \(n\) for the whole study period, respectively.

The measure of the overall quality of the calibration is the GEH statistic, used by British engineers (7):

\[
GEH = \frac{(M_{obs}(n) - M_{sim}(n))^2}{(M_{obs}(n) + M_{sim}(n))/2}
\]  

(2)

If the GEH values for more than 85% of the measurement locations are less than 5, the adjusted OD is acceptable.

An iteration process is required in order to obtain a satisfactory whole OD matrix. If the above indices cannot be satisfied, we need to make some modifications to the reference OD matrix and vehicle routing as well. Vehicle routing is determined by the traffic
assignment method used, i.e. stochastic assignment, in this study. Since the travel delays caused by the intersection signal and freeway ramp control are not considered for traffic assignment in PARAMICS, the route choice may need to be adjusted through adding tolls to related decision links.

The calibration results at this step, i.e. the comparison of observed and simulated traffic counts at selected measurement locations are shown in Table 1, which have satisfied the calibration acceptance criteria of this step.

4.2.3 Reconstruction of time-dependent OD demand

PARAMICS has an enhanced feature of demand loading, i.e. the ability to specify different profiles for each OD pair. Through the use of “matrix” and “profile” files, a different profile can be specified for a different OD pair. Since the 15-minute interval traffic counts at all cordon points of the network are known, the profile of vehicle generation from any origin zone and that of the vehicle attraction to any destination zones are thus known.

The next question is how to find the demand profile for each OD pair. We further assume a number of initial demand profiles for all OD pairs based on the following criteria:

- The demand profile from an arterial origin zone to any an arterial destination zone has the same profile, which is the same as the vehicle generation profile from this origin zone.
- The demand profiles from a freeway origin zone to a freeway destination zone, from a freeway origin zone to an arterial destination zone, from an arterial origin zone to a freeway destination zone will be based on the traffic count profile at correspondent loop detector stations located at freeway mainline, off-ramp, and on-ramp, respectively.

Since the mean target headway and driver reaction time are two key user-specified parameters in the car-following and lane-changing models that can drastically influence overall driver behaviors of the simulation, we select a couple of smaller values of them (i.e., 0.8 and 0.6, respectively) in order to test the correctness of our assumptions of demand profiles without the involvement of strong queuing phenomena in the network.

This step has two calibration objective functions. The first one is to minimize the deviation between the observed and corresponding simulated traffic counts at selected measurement locations for the peak hour of the simulation period:

$$\min \sum_{i=1}^{N} (M_{\text{obs}}(s_{peak,T}) - M_{\text{sim}}(n_{peak,T}))^2$$ (3)

where $N$ is the total number of measurement locations; $M_{\text{obs}}(s_{peak,T})$ and $M_{\text{sim}}(n_{peak,T})$ are total observed and simulated traffic counts for the peak hour at measurement location $i$, respectively. The selected measurement points are the same as those in last step. The peak hour is defined as from 7 to 8 AM. The following criteria are required to be satisfied for this objective:
• The modeled peak hour volumes at measurement locations must be within 15 percent of the observed volumes for flows greater than 700 vphpl, or within 100 vph for flows less than 700 vph. These targets must be satisfied for 85 percent of the cases;
• Total screenline flows (normally >5 links) to be within five percent for nearly all screenlines;
• The GEH statistic to be less than five for individual flows for 85 percent of the cases, and less than four for screenline totals for nearly all screenlines;

The second objective function is to minimize the deviation between the observed and corresponding simulated traffic counts at selected measurement locations at five-minute interval. It can be formulated as:

$$\min \sum_{i=1}^{N} \sum_{t=1}^{T} (M_{obs}(n,t) - M_{sim}(n,t))^2$$  \hspace{1cm} (4)

where N and T are the number of measurement locations and time periods, respectively; \(M_{obs}(n,t)\) and \(M_{sim}(n,t)\) are observed and simulated traffic counts of time period \(t\) at measurement location \(i\), respectively. The length of each period is 5 minutes in this study.

The measure of goodness of fit we used is the mean abstract percentage error (MAPE), which can be calculated by:

$$MAPE = \frac{1}{T} \sum_{t=1}^{T} \frac{|(M_{obs}(t) - M_{sim}(t))/M_{obs}(t)|}{T}$$ \hspace{1cm} (5)

We expect to obtain smallest MAPE errors at all measurements. Note that this step of calibration is an iterative process. We mainly modify the demand profiles from a freeway origin zone to a freeway destination zone, from a freeway origin zone to an arterial destination zone, and from an arterial origin zone to a freeway destination zone in order to match the traffic counts at selected measurement locations and the floating-car travel time data. The traffic count calibration at this step is just an initial match of volume data and the next step will fine-tune this volume calibration.

The calibration results of this step are shown in Table 1, which shows the comparison of traffic counts of peak hour at those selected measurement locations. Figure 4 shows the calibrated demand profiles for several major OD pairs.

4.2.4. Parameter fine-tuning

This step will fine-tune various parameters in order to re-construct the traffic variations during the study period. These parameters include:

• Link specific parameters, including the signposting setting or the target headway of those links at critical bottleneck locations where a very minor change in capacity can have a major effect on congestion.
• Parameters for the car-following and lane-changing models, i.e., the mean target headway and driver reaction time. They are two key user-specified parameters in the car-following and lane-changing models that can drastically influence overall driver behaviors of the simulation.
Point-to-point travel time is the major factor in this step because the main purpose of this step is to match the congestion pattern of the study network. In our study, the floating car data we have only covers two trips, i.e., between the interchanges at Irvine Center Drive and Culver Drive of both northbound and southbound freeway I-405. Since our network features a recurrent congestion along the northbound I-405, we select several loop detector stations on the northbound I-405 as the measurement points for volume match with the loop data of the same day of each run.

The objective function of this step is to minimize the deviation between the observed and corresponding simulated point-to-point travel time measurements between two selected measurement locations, and also traffic counts at measurement points. It can be formulated as Equation 4, but M can be traffic volume or point-to-point travel time. Point-to-point travel time and traffic counts are compared at 5-minute intervals.

Due to the high traffic demands during the peak hour, some network coding problems may show up and need to be corrected. Moreover, congestion and queueing phenomena on the northbound I-405 may take extra effort to modify demand profiles of some specific OD pairs. This step needs a lot of iterative simulation runs in order to find out the good combination of these aforementioned parameters. For the individual measurement locations, the smallest MAPE error is expected.

4.3 Calibration results

The final calibration cannot only be based on one single run because of the randomness of micro-simulations. For our case, we conducted 31 runs and pick the simulation results of the median one (based on the average system travel time) for the final comparison of calibration results.

We compare the simulation results with the loop data and the floating car data of Oct. 17, 2001. Figure 4 show that MAPE error of traffic counts at selected measurement locations range from 5.8% to 8.7%. Figure 5 and 6 show the comparison of observed and simulated point-to-point travel time for the northbound and the southbound I-405, which have the MAPE errors of 8.5% and 3.1%, respectively.

In general, simulated traffic counts and point-to-point travel time data correspond well to the measurements and accurately capture the congestion patterns of the target network shown on Oct. 17, 2001.

5 EVALUATION STUDY

5.1 Problem description

Based on the analysis of the real-world loop data and floating car data, we found 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 J effery 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 than one lane or slowdowns caused by incidents taken place on the shoulder. Here we simulate the latter to the simulation network. A shoulder incident is injected to the merge area of SR-133 and I-405 (on the northbound I-405) at 7:45 AM that is the time that incidents happen most frequently based on historical incident data. This incident causes the speed of passing vehicles to be 10 mph for the first ten minutes and 15 mph thereafter.

5.2 Solution Strategies

Based on the data from Caltrans, without any incident management, the average incident clearance time is 33 minutes; the existing incident management can decrease the clearance time to 26 minutes. An improved incident management is expected to further decrease the clearance time to 22 minutes. We then compare the following three scenarios for the incident management:

- Scenario 1: Non-incident management
- Scenario 2: Existing incident management
- Scenario 3: Improved incident management

Then we study on how other potential ATMIS strategies can help to relieve this non-recurrent congestion based on the existing incident management (26 minute of the clearance time). The potential ATMIS strategies we will evaluate in this paper are as follows.

- Scenario 4: Local adaptive ramp metering, ALINEA
- Scenario 5: Coordinated ramp metering, BOTTLENECK
- Scenario 6: Traveler information system
- Scenario 7: Corridor control (VMS + Adaptive signal control + ramp metering)
- Scenario 8: Combination (Scenario 4 + 6 + 7)

5.3 Modeling and Implementation of evaluated ATMIS strategy in PARAMICS

Each evaluation scenario corresponds to one or more than one ATMIS strategies. We have described in Section 2 about the framework of PARAMICS-E, featuring a hierarchical API development framework, which facilitates the development of advanced ATMIS strategies based on basic ATMIS modules having been established.

5.3.1 Incident management

Scenario 1 is actually the baseline of this study. Scenario 2 and 3 apply incident management to relieve the congestion caused by the incident on freeway shoulder, i.e. decreasing the incident clearance time through the fast responses to the incident. We
develop an incident API to simulate this type of shoulder incident. Through changing the clearance time of the incident, we can easily model these three incident management scenarios.

5.3.2 Adaptive ramp metering

Scenario 4 and 5 apply local adaptive ramp metering and coordinated ramp metering, respectively. The local adaptive ramp-metering algorithm we use is ALINEA, which is proposed by Papageorgiou et al. (8, 9). ALINEA is a local feedback ramp metering policy, which attempts to maximize the mainline throughputs by maintaining a desired (near critical) occupancy on the downstream mainline freeway.

The coordinated ramp-metering algorithm we use is BOTTLENECK, applied in Seattle, Washington (10). 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.

We have developed these two adaptive ramp-metering algorithms in PARAMICS API based on basic ATMSI modules in PARAMICS-E. The adaptive ramp-metering algorithm API works as the following: at each time increment the advanced algorithm API obtains up-to-date traffic information provided by the loop data aggregator API and historical metering rates provided by ramp metering API, and then sends its computed metering rates to the ramp metering API for implementation. This process of real-time data exchange and the implementation of new control strategy are realized by calling the interface functions of related ATMSI modules.

Since the incident happens on the northbound I-405, we only apply the ALINEA and BOTTLENECK control to seven on-ramps of the northbound I-405, other on-ramps in the network keep using the current fixed-time control plan. We have calibrated the parameters of these two algorithms in this section of freeway in our previous studies (11).

5.3.3 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. The instantaneous travel information is used for the calculation of the resulting route choice.

PARAMICS can simulate this scenario by using dynamic feedback assignment. The compliance rate of traveler information is set to 5% in this paper.

5.3.4 Corridor control

Scenario 7 implements the corridor control strategy, which involves VMS, adaptive signal control and ramp metering together in response to the injected incident.
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 recommended by VMS is taking the northbound I-5 until exiting at off-ramp Alton to the arterial street, Alton Parkway, and then traveling 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 Banning street, turning right to the Alton Parkway and finally entering freeway I-405 at the on-ramp of Sand Canyon.

The detailed corridor control strategy is described as follows: five minutes after the occurrence of the incident, the freeway operation agency and arterial management agency activate the new control schemes, including showing diversion messages on 6 related VMS, applying new signal timing plans to traffic signals along diversion routes, and increasing ramp metering rate at the entrance ramp at Sand Canyon where most diverted vehicles enter the northbound of freeway I-405.

The path-based routing API controls the routing behaviors of diverted vehicles. Based on estimated diverted traffic volume, SYNCHRO is used to off-line optimize the signal control along the diversion route. This optimized signal timing plans will be applied when the corridor control strategy is activated because of incidents.

5.3.6 Combination

This scenario is the combination of the corridor control, traveler information systems and the ALINEA ramp-metering control. It can be regarded as a better corridor control strategy with the use of ALINEA ramp metering control.

5.4 Performance evaluation

5.4.1 Performance measures

The following measures of effectiveness (MOEs) are used to evaluate the effectiveness of each ATMIS strategy in this paper. The performance measure API is responsible for the computing, gathering and reporting these measures.

MOE #1 system efficiency measure: average system travel time (ASTT) of the whole simulation period. ASTT is calculated as the weighted mean of the average travel times of all OD pairs

\[
\text{ASTT} = \frac{\sum_{i,j} (N_{ij} \cdot T_{ij})}{\sum_{i,j} N_{ij}} \quad (6)
\]

where \( N_{ij} \) is the total number of vehicles that actually traveled from origin \( i \) to destination \( j \); \( T_{ij} \) is the average OD travel time from origin \( i \) to 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:

$$Std_{ODTT} = \frac{\sum_{i,j} (Std(T_{ij}) \cdot N_{ij})}{\sum_{i,j} N_{ij}}$$  \hspace{1cm} (7)$$

where Std(T_{ij}) 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). The congestion period is defined as the congestion period of the baseline scenario.

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)

5.4.2 Determination of number of simulation runs

PARAMICS is a stochastic simulation model, which rely upon random numbers to release vehicles, select vehicle type, select their destination and their route, and to determine their behavior as they 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 model 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 simulation runs is shown in Figure 8. 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:

$$N = \left( \frac{\delta}{\mu} \right)^2$$  \hspace{1cm} (8)$$

where $\mu$ and $\delta$ are the mean and standard deviation of the performance measure based on the already conducted simulation runs; $\varepsilon$ is the allowable error specified as a fraction of the mean $\mu$; $t_{\alpha/2}$ is the critical value of the t-distribution at the confidence interval of $\alpha$.

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.

5.4.3 Evaluation results

There are eight evaluation scenarios. All simulation scenarios and their corresponding ATMIS strategies are illustrated in Table 3. Since the coordinated actuated signal control is operated at some signalized intersections, we developed this advanced API module for controlling those coordinated signals. The simulation time periods in 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 are 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 section 5.4.2. Due to the purposes of this study, we select two measures, the average system travel time and the average mainline travel speed during the congestion period, for the calculation of the required number of runs. Based on multiple runs, the value of each performance measure for a scenario is equal to the average value of all simulation runs of the scenario.

The overall performance measures, including the system efficiency measure and system reliability measure are shown in Table 4 and Figure 9 and 10. The performance of the northbound freeway I-405, where the incident happened, is shown in Table 5 and Figure 11. Table 6 shows the performance of the arterials. The evaluation results show that all ATMIS strategies have positive effects on the improvement of network performance. In addition, if more ATMIS components involved, more benefits can be obtained, as shown in Figure 12.

Incident management (Scenario #2 and #3) can improve system performance because it effectively increases the average mainline travel speed during the congestion period and the whole study period on the northbound I-405, as shown in Figure 13, which compares the freeway mainline speed variation over time under these three incident management scenarios. Therefore, fast incident response is of particular importance to freeway traffic management and control. In order to achieve this, comprehensive freeway surveillance system and automatic incident detection are both required.

Theoretically, adaptive ramp metering (Scenario #4 and #5), which can adjust metering rate based on the traffic condition of mainline freeway, can benefit vehicles that are already on the freeway. However, based on our simulation results, we find the performance improvement introduced by adaptive ramp metering is minor under the incident scenarios. Both ALINEA and BOTTLENECK cannot improve system travel time or freeway travel speed significantly. This can be seen from Figure 14, which shows the variation of the mainline freeway travel speed over time under scenarios of existing 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. In addition, adaptive ramp metering performs
worse than the improved incident management scenario, which means shorter incident clearance time can generate more benefits than a complex adaptive ramp metering under the non-recurrent congestion.

Comparing these ramp-metering controls (Scenario #4 and #5), the coordinated ramp metering control, i.e. BOTTLENECK, performs a little bit better than the local adaptive ramp-metering control, ALINEA. The reason is that BOTTLENECK can respond to not only the local congestion but also the congestion appeared in a coordinated area. Both of ALINEA and BOTTLENECK imposes a certain amount of delay on vehicles from entrance ramps. ALINEA performs better than BOTTLBNECK at the aspect of less total on-ramp delay and less probability of vehicles on the entrance ramps spillback to the surface streets. Due to the coordination feature of BOTTLENECK, it causes the highest total on-ramp delay.

Scenarios #6, #7 and #8 not only improve the system efficiency but also increase the system reliability significantly. All these three scenarios involve real-time traveler information systems. The finding here demonstrates that traveler information systems can greatly improve the overall system performance if they are deployed properly. Also, because of the network topology -- one major freeway segment (I-405) with two parallel arterial streets (ALTON and BARRANCA), real-time traveler information system can divert traffic from congested freeway to arterial streets, therefore has the greater benefits than adaptive ramp metering algorithms (Scenario #4 and #5) and improved incident management (Scenario #3).

Scenario #7 tries to integrate traveler information with traffic control. Unlike Scenario #6, the traffic signal control and ramp metering in scenario #7 are adjusted to facilitate the diversion of traffic. An updated signal timing plan and non-metering scheme are applied to related signals and ramp meters along the diversion routes during the period of corridor control, which may lead to shorter travel time along diversion routes, as shown in Table 6. The combination scenario (#8) can be regarded as a better corridor control strategy, which has the involvement of ALINEA ramp-metering control. It shows the best performance among all scenarios. It generates more benefits to the average system travel time, average mainline travel speed though it also introduces a little bit more on-ramp delays than the corridor control scenario.

Our findings from the above analysis can be summarized briefly as follows. Firstly, real-time traveler information systems have the strong positive effects to the traffic systems. Secondly, adaptive ramp metering cannot improve the system performance effectively under incident scenario. Thirdly, fast incident response is important to the performance improvement. Finally, proper combination of ATMIS strategies yields greater benefits.

6 CONCLUSION REMARKS

This paper presents a micro-simulation method to evaluate the effectiveness of potential ATMIS strategies. We established a capability-enhanced micro-simulation model, PARAMICS-E, by integrating various plug-in modules through Application
Programming Interfaces in order to model the current traffic conditions and various potential ATMIS strategies.

The simulation-based evaluation study involves many technical details if applying to a real network in order to obtain quantitative evaluation results. The procedures of how to evaluate ATMIS strategies in PARAMCIS-E have been demonstrated. We use a practical method to calibrate a real corridor network, which includes three freeways and several major arterials. Based on this calibrated model network, we evaluated the effectiveness of a number of potential ATMIS strategies under a non-recurrent incident scenario. The evaluated ATMIS strategies include incident management, local adaptive ramp metering and coordinated ramp metering, traveler information systems, corridor control, and the combination of traveler information systems, corridor control and adaptive ramp metering. These ATMIS strategies were implemented and evaluated in PARAMCIS-E. Performance measures include the efficiency of the overall system, mainline freeway, on-ramp, and arterials and the reliability of the network. The evaluation results show that all ATMIS strategies have positive effects on the improvement of network performance. If applying only one single ATMIS strategy, the adaptive ramp metering and incident management are not effective compared with real-time traveler information. The combination of several ATMIS components, such as the corridor control and the combination scenarios can generate the better benefits.

For the future works, we will use the established PARAMCIS-E model for some more detailed studies on how a real-time traveler information system affects the traffic condition, how to integrate the dynamic traffic assignment with traffic control, how to decide the diversion plans based on the network features and traffic conditions, etc. Development and implement effective ATMIS strategies to solve traffic congest problem is our ultimate goal.

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Scott Aitken and Ewan Speirs, from Qadstone in Scotland, provided invaluable technical supports in the process of applying the PARAMCIS model. Their continuous collaboration to the project greatly facilitated the work.

REFERENCES


Figure 1 Framework of PARAMICS-E

Figure 2 Overview of the study network
Figure 3 Flow chart of calibration procedure
Figure 4 Demand profiles for major OD pairs
Figure 5 Traffic counts calibration (5-minute volume) at major freeway measurement locations
Figure 6 Comparison of observed and simulated travel time of northbound I-405

Figure 7 Comparison of observed and simulated travel time (unit: second) of southbound I-405
Figure 8 Flow chart of the determination of number of simulation runs
Figure 9 Comparison of the saving of average system travel time

Figure 10 Comparison of the increase of the network reliability
Figure 11 Comparison of the increase of average mainline travel speed of the northbound I-405 during the congestion period (7:30 - 9:30 AM) and the entire simulation period (6:00 - 10:00 AM).

Figure 12 Comparison the freeway mainline speed (unit: mph) variation over time under scenarios with traveler information.
Figure 13 Comparison the freeway mainline speed variation (unit: mph) over time under incident management scenarios

Figure 14 Comparison the freeway mainline speed (unit: mph) variation over time under adaptive ramp metering scenarios
List of Tables

Table 1 Traffic counts calibration results of the whole AM peak period and the peak hour
Table 2 Travel time calibrations
Table 3 Simulation scenarios and their corresponding control strategies
Table 4 Overall performance of each strategy
Table 5 Performance of the northbound of freeway I-405
Table 6 Performance of arterials (Alton Parkway)
<table>
<thead>
<tr>
<th>Table 1 Traffic counts calibration results</th>
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<tr>
<td><strong>Mainline Detectors</strong></td>
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<tr>
<td><strong>Peak Hour (7-8 AM)</strong></td>
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<tr>
<td><strong>AM Peak Period (6-10 AM)</strong></td>
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<td><strong>Detectors</strong></td>
</tr>
<tr>
<td><strong>Observed</strong></td>
</tr>
<tr>
<td><strong>Simulated</strong></td>
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<td><strong>% diff</strong></td>
</tr>
<tr>
<td><strong>GEH</strong></td>
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<td><strong>Detectors</strong></td>
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<tr>
<td>Barranca SR133-ICD</td>
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<td>625</td>
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<tr>
<td>Mainline Trip Analysis</td>
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<tr>
<td>Southbound I405 from Culver to ICD</td>
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<tr>
<td></td>
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<tr>
<td></td>
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AMPE: 3.1%

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<th>Start time</th>
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<th>Observed</th>
<th>Start time</th>
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<td>248</td>
<td>6:20:00</td>
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<td>481</td>
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<td>8:30:00</td>
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<td>9:05:00</td>
<td>208.0</td>
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AMPE: 8.5%

Notes: AMPE – Abstract mean percentage error

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<tr>
<th>Scenario description</th>
<th>Ramp Metering</th>
<th>ATMS Components</th>
<th>Traveler Information</th>
<th>Incident Management</th>
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<td>0 BASELINE 2000</td>
<td>Fixed time</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>1 Non-incident</td>
<td>Fixed time</td>
<td>Coordinated</td>
<td>N/A</td>
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<tr>
<td>management</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Existing</td>
<td>Fixed time</td>
<td>Coordinated</td>
<td>26 mins</td>
<td></td>
</tr>
<tr>
<td>incident management</td>
<td></td>
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<td></td>
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<tr>
<td>3 Improved</td>
<td>Fixed time</td>
<td>Coordinated</td>
<td>22 mins</td>
<td></td>
</tr>
<tr>
<td>management</td>
<td></td>
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<td></td>
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<tr>
<td>4 Local adaptive</td>
<td>ALINEA</td>
<td>Coordinated</td>
<td>26 mins</td>
<td></td>
</tr>
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<td>ramp metering</td>
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<td>5 Coordinated ramp</td>
<td>BOTTLENECK</td>
<td>Coordinated</td>
<td>26 mins</td>
<td></td>
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<tr>
<td>6 Traveler</td>
<td>Fixed time</td>
<td>Coordinated</td>
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<tr>
<td>information</td>
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<td>5% compliance</td>
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<td>7 Corridor control</td>
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<td>Synchro-Adaptive</td>
<td>26 mins</td>
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</tr>
<tr>
<td>Coordinated</td>
<td></td>
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<td>8 Combination</td>
<td>ALINEA</td>
<td>Synchro-Adaptive</td>
<td>26 mins</td>
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32
### Table 4 Overall performance of each strategy

<table>
<thead>
<tr>
<th>Control strategy</th>
<th>ASTT (sec)</th>
<th>ASTT Saving (%)</th>
<th>std_ODITT (sec)</th>
<th>Reliability Increase (%)</th>
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<tr>
<td>Baseline</td>
<td>271.3</td>
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<td>51.7</td>
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<tr>
<td>IM-33</td>
<td>297.0</td>
<td>0.0%</td>
<td>139.6</td>
<td>0.0%</td>
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<tr>
<td>IM-26</td>
<td>293.9</td>
<td>1.0%</td>
<td>130.7</td>
<td>6.4%</td>
</tr>
<tr>
<td>IM-22</td>
<td>289.1</td>
<td>2.7%</td>
<td>112.6</td>
<td>19.4%</td>
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<tr>
<td>ALINEA</td>
<td>289.7</td>
<td>2.4%</td>
<td>118.9</td>
<td>14.9%</td>
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<tr>
<td>BOTTLENECK</td>
<td>289.2</td>
<td>2.6%</td>
<td>115.5</td>
<td>17.3%</td>
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<tr>
<td>Tl</td>
<td>284.4</td>
<td>4.2%</td>
<td>95.3</td>
<td>31.8%</td>
</tr>
<tr>
<td>Corridor control</td>
<td>280.5</td>
<td>5.5%</td>
<td>93.2</td>
<td>33.3%</td>
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<td>Combination</td>
<td>279.6</td>
<td>5.9%</td>
<td>97.2</td>
<td>30.4%</td>
</tr>
</tbody>
</table>

Notes:
- ASTT — Average system travel time
- Std_ODITT — Average standard deviation of OD travel times of the entire simulation period, which represents the reliability of the network

### Table 5 Performance of the northbound of freeway I-405

<table>
<thead>
<tr>
<th>Scenario</th>
<th>AMTS (mph)</th>
<th>AMTS Increase (%)</th>
<th>peak_AMTS (mph)</th>
<th>Increase of peak_AMTS</th>
<th>TOD (hour)</th>
<th>POQS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>57.3</td>
<td>0.0%</td>
<td>56.1</td>
<td>0.0%</td>
<td>55.1</td>
<td>1.8%</td>
</tr>
<tr>
<td>IM-33</td>
<td>50.5</td>
<td>1.8%</td>
<td>49.7</td>
<td>0.0%</td>
<td>56.5</td>
<td>1.9%</td>
</tr>
<tr>
<td>IM-26</td>
<td>51.4</td>
<td>2.8%</td>
<td>50.1</td>
<td>0.0%</td>
<td>54.6</td>
<td>2.0%</td>
</tr>
<tr>
<td>IM-22</td>
<td>51.9</td>
<td>2.8%</td>
<td>49.3</td>
<td>0.0%</td>
<td>56.9</td>
<td>0.9%</td>
</tr>
<tr>
<td>ALINEA</td>
<td>51.6</td>
<td>2.1%</td>
<td>50.4</td>
<td>0.0%</td>
<td>57.6</td>
<td>0.9%</td>
</tr>
<tr>
<td>BOTTLENECK</td>
<td>51.9</td>
<td>2.7%</td>
<td>49.7</td>
<td>0.0%</td>
<td>58.1</td>
<td>1.9%</td>
</tr>
<tr>
<td>Tl</td>
<td>51.9</td>
<td>2.8%</td>
<td>49.7</td>
<td>0.0%</td>
<td>58.1</td>
<td>1.8%</td>
</tr>
<tr>
<td>Corridor control</td>
<td>52.2</td>
<td>3.3%</td>
<td>50.9</td>
<td>0.0%</td>
<td>59.5</td>
<td>1.9%</td>
</tr>
<tr>
<td>Combination</td>
<td>52.3</td>
<td>3.5%</td>
<td>49.8</td>
<td>0.0%</td>
<td>60.0</td>
<td>1.0%</td>
</tr>
</tbody>
</table>

Notes:
- AMTS — Average mainline travel speed of the entire simulation period (6 – 10 AM)
- peak_AMTS — Average mainline travel speed of the 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>
<thead>
<tr>
<th>Scenario</th>
<th>Westbound ALTON</th>
<th>Eastbound ALTON</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ATT (sec)</td>
<td>std_ATT</td>
</tr>
<tr>
<td>Baseline</td>
<td>515.8</td>
<td>70.3</td>
</tr>
<tr>
<td>IM-33</td>
<td>515.5</td>
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<tr>
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<td>68.1</td>
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<tr>
<td>IM-22</td>
<td>512.4</td>
<td>68.1</td>
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<tr>
<td>ALINEA</td>
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<td>67.3</td>
</tr>
<tr>
<td>BOTTLENECK</td>
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<td>69.0</td>
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<tr>
<td>TI</td>
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<td>70.2</td>
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<tr>
<td>Corridor control</td>
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<td>51.4</td>
</tr>
<tr>
<td>Combination</td>
<td>423.2</td>
<td>51.0</td>
</tr>
</tbody>
</table>

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