

## **Final Report**

July 2017

# INTEGRATING MESO- AND MICRO-SIMULATION MODELS TO EVALUATE TRAFFIC MANAGEMENT STRATEGIES – Year 2

SOLARIS Consortium, Tier 1 University Transportation Center Center for Advanced Transportation Education and Research Department of Civil and Environmental Engineering University of Nevada, Reno Reno, NV 89557

Pitu B. Mirchandani, Sc.D., Principal Investigator Pengfei Li, Ph.D., Project Manager Xuesong Zhou, Ph.D., Co-Principal Investigator Ira A. Fulton Schools of Engineering Arizona State University Tempe, AZ 85281

## DISCLAIMER:

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the information presented herein. This document is disseminated under the sponsorship of the U.S. Department of Transportation's University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

#### **EXECUTIVE SUMMARY**

In the Year 1 Report, the Arizona State University (ASU) Project Team described the development of a hierarchical multi-resolution simulation platform to test proactive traffic management strategies. The scope was to integrate an easily available micro-simulation model VISSIM [2, 4] with an open-source mesoscopic DTA simulator being developed at ASU, DTALite [9, 20], develop an integrated model referred to as *METROSIM* (MultirEsolution TRaffic Operations SIMulator). The ASU project team developed METROSIM systems architecture and started the development of the METROSIM system. Based on the nature of the component software systems, the ASU team realized in Year 1 that it would be difficult to develop a single stand-alone METROSIM platform [17], especially due the proprietary nature of VISSIM and the differences in the underlying models of traffic flow phenomena and different fidelities of VISSIM and DTALite.

In Year 2 phase, the ASU team continued the development of the METROSIM Platform, now with the systems architecture focusing on the process of integrating VISSIM and DTALite using a fidelity interface which is referred to high-resolution DTA (HD-DTA). Concurrently, the project team started using METROSIM in a synergetic effort on study of strategies for *Dynamic Mobility Applications* (DMA) [11], and *Active Traffic and Demand Management* (ATDM) strategies [12], for FHWA, through a subcontract on a FHWA contract to Booz-Allan-Hamilton [1]. The combined efforts allowed the ASU team to conduct many more tests with METROSIM, some of which are reported in this report.

The two main applications evaluated in this project using METROSIM were *adaptive ramp metering* and *proactive traffic signal control*. The goal was to evaluate two new applications: *Proactive Multimodal Traffic Signal Control (PMTSC*<sup>1</sup>) and *Multimodal Adaptive Ramp Metering* (*MARM\**), but given the limitation of time, a new version of RHODES [3, 14, 15, 16, 18] which is essentially a proactive traffic control system and a rudimentary adaptive ramp metering (ARM) scheme based on earlier research [13, 14], discussed in detail in this report, were evaluated instead. The development and algorithms for RHODES and ARM are discussed in this report.

<sup>&</sup>lt;sup>1</sup> PMTSC and MARM are applications being developed by the principal investigators and do not appear in the literature

EXECUTIVE SUMMARY

METROSIM was used to evaluate the operation of ARM and RHODES, both individual and joint operations.

Two ATDM applications that influence the operation of ARM, and expected to improve its performance, are (a) traffic prediction and (b) traveler information systems that recommends dynamic rerouting to travelers; these were also evaluated using METROSIM. There synergistic operation of these applications with ARM was also evaluated.

Finally, other factors that influence the performance of the ATDM applications are: (1) representative traffic conditions under which the ATDM applications may operate, (2) limitations of the technologies being used, (3) market penetration of the users of the ATDM technologies, that is, the percentage of population being affected, and (4) synergies among the implemented ATDM components. These issues were studied and are reported here.

## Acknowledgements:

The Arizona State University Project team thanks the assistance of many students and support staff at ASU. In addition, it specifically acknowledges the following:

- The support provided by SOLARIS, a USDOT Tier One University Transportation Center
- Professor Zong Tian at the University of Nevada at Reno
- Booz Allen Hamilton team working with the ASU team on the synergistic FHWA project on ATDM/DMA [1], especially Dr. Balaji Yelchuru who led the BAH team
- ASU's Advanced Traffic and Logistics Algorithms and Systems (ATLAS) Laboratory.

*Keywords*: Key words: Multi-resolution simulation, Traffic operations, Dynamic traffic assignment, Traffic signal systems, Traffic simulation, Regional Traffic Management

## TABLE OF CONTENTS

1. "B	SIG P	ICTURE" MOTIVATION: ATDM AND ITS APPLICATIONS
1.1	Int	troduction6
1.2	De	evelopment of the Overall Simulation Modeling Framework7
2. ST	RAT	EGIES STUDIED 11
2.1	Pr	edictive Traveler Information and Dynamic Routing11
2.2	Ac	aptive Ramp Metering11
2.2	2.1	Scenario and Application Description11
2.2	2.2	Adaptive Ramp Metering Algorithm
2.2	2.3	Modeling Approach13
2.2	2.4	Scenarios Modeled14
2.3	Pr	oactive Traffic Signal Control15
2.3	3.1	Application Description15
2.3	3.2	RHODES Proactive Control Architecture
2.3	3.3	Adaptive Signal Control Modeling Approach in Tempe Testbed 17
2.3	3.4	Implementing Proactive Signal Control in Mesoscopic Simulation
2.3	3.5	Scenarios for Proactive Signal Control Simulation
2.4	Μ	odeling Simultaneous Adaptive Ramp Metering and Proactive Signal
Cont	trol .	
2.4	4.1	Coupling Link 1: Time synchronization between HD-DTA and ASC/3 (VISSIM) 22
2.4	4.2	Coupling Link 2: Real-time signal timing exchange between HD-DTA and ASC/3
(VI	ISSIN	1)
2.4	4.3	Coupling Link 3: Time synchronization between ASC/3 (VISSIM) and RHODES 22
2.4	4.4	Coupling Link 4: Data Exchange between RHODES and ASC/3 and HD-DTA 23
2.4	4.5	Coupling Link 5: Data Exchange between HD-DTA and DTALite

3.	EVA	ALUATION OF ATDM STRATEGIES	26
	3.1	Representative traffic conditions2	26
	3.2	Limitations of needed technologies	27
	3.3	Market penetration of users	28
	3.4	Synergies among the ATDM applications	28
	3.5	Performance metrics	28
4.	EVA	ALUATION RESULTS	30
4	4.1	Adaptive Ramp Metering and Proactive Traffic Signal Control	30
	4.1.	1 Impact of Adaptive Ramp Metering	30
	4.1.	2 Impact of Proactive Traffic Signal Control	31
	4.1.	3 Impact of Combination of ARM and RHODES	31
4	4.2	Impact of Dynamic Routing and Predictive Traveler Information	35
4	4.3	Impact of Latency, Predication Horizon and Market Penetration	36
	4.3.	1 Prediction Horizon and Communication Latency	37
	4.3.	2 Penetration rate of ATDM applications	38
	4.3.	3 Prediction Accuracy	39
4	4.4	Summary of Impacts of Traveler Information and Related Attributes4	10
5.	SUN	MMARY AND CONCLUSIONS	12
6.	REF	ERENCES	13

#### 1. "BIG PICTURE" MOTIVATION: ATDM AND ITS APPLICATIONS

#### 1.1 Introduction

According to the vision of USDOT, *Active Transportation and Demand Management* (ATDM) is the dynamic active management, control, and influence of travel demand and traffic flow on transportation facilities. Through adoptions of various emerging technologies, traffic flow as well as traveler behaviors can be influenced, in real time, to improve travel mobility on highways, such as preventing or delaying breakdown conditions, improving safety, promoting sustainable travel modes, and reducing emissions. Under an ATDM approach, the transportation system is continuously monitored. Using archived data, new data, and predictive analytics, actions can be performed in real-time to achieve or maintain system performance.

There are three mobility strategies within the ATDM scope: (i) Active Traffic Management (ATM); (ii) Active Demand Management (ADM) and (iii) Active Parking Management (APM). Each of these strategies further includes various component applications. The research team have focused, in this project and other research, on the development of simulation-based approaches to evaluate two ATDM applications: (1) proactive signal control, and (2) adaptive ramp metering as well as their combined influences, and to a limited extent as they impact the above two applications, predictive traveler information system and dynamic routing/rerouting system.

Although it is possible to evaluate dynamic routing and predictive traveler information system on a city-wide network, for example in our Phoenix metropolitan simulation model which has a total length of about 48 miles, it is neither realistic nor practical to implement proactive signal control and adaptive ramp metering in a large scale city wide simulation model. For our applications, the Arizona State University (ASU) team decided to focus on three intersections along the McClintock Rd and Freeway 101 between Rio Salado Parkway and Broadway Road in a City of Tempe simulation model. The selected subnetwork is fully connected that allows travelers multiple alternative routes to reach their destinations. This subnetwork (see Figure 1.1) includes: 985 links; 914 nodes, 3 signalized intersections and 3 interchanges.

6

Travel demands and O-D pairs for four selected afternoon scenarios (these are defined later, in section 3.1) were considered in the evaluations. This results in a total of 155-160 thousand vehicles during the 5 hours of that includes PM peak period in the four scenarios.



Figure 1-1 Scope of network work for ATDM simulation in Tempe

## 1.2 Development of the Overall Simulation Modeling Framework

The required simulation resolution, network details and network fidelities are very different for the ATDM applications simulated (adaptive ramp metering, proactive signal control, dynamic routing and predictive traveler information system). For example, adaptive ramp metering strategies typically need to update the ramp metering rate every 10 to 300 seconds and therefore **mesoscopic traffic simulators** are suitable for evaluating adaptive ramp metering. On the other hand, proactive signal control strategy is by nature **microscopic** and requires high resolution network details. In contrast, simulation resolution fidelity requirements are more flexible for evaluating dynamic routing and predictive traveler information systems. Ideally, all the ATDM applications studied by the ASU team should run together on the same network work under various configurations. However, up to now, this has not been possible by the ASU team due to lack of a single simulator suitable for all applications considered and the limitations of the *METROSIM* development as discussed in the Phase 1 Progress Report [Mirchandani et al, 2015]. As a result, multiple traffic simulators were adopted. As shown in Figure 1-2, in addition to the standard DTALite simulator [Zhou and Taylor, 2014], a special version of DTALite was also developed to allow external adaptive ramp metering strategy to change the ramp metering rate according to the real-time traffic condition extracted from the special DTALite. A third high-definition DTA simulator (HD-DTA) was also developed in a parallel project and enhanced to meet the requirements for proactive signal control in mesoscopic-level simulation, which includes second-by-second, high-fidelity modeling of <u>only the intersections</u> in the simulation model. Since the HD-DTA is closely coupled with the signal emulator ASC/3 in microscopic VISSIM, these together become a platform for evaluating proactive signal control strategies. HD-DTA, Special HD-DTA, ASC/3 (VISSIM) all composes of a multi-resolution simulation platform METROSIM.



Figure 1-2 Multiresolution Modeling Framework for Evaluating ATDM applications

Initially, ASU team wanted to evaluate the performance of **Proactive Multimodal Traffic Signal Control (***PMTSC*<sup>2</sup>**)** and **Multimodal Adaptive Ramp Metering (***MARM*\***)**, individually and jointly in urban areas. After the year 1 efforts, the ASU team determined that simulating both an

<sup>&</sup>lt;sup>2</sup> PMTSC and MARM are applications being developed by the principal investigators and do not appear in the literature

adaptive ramp metering scheme and a proactive signal control simultaneously was currently not possible in the project's scope; therefore, the team designed an iterative approach to approximately simulate the joint operations of of proactive signal control and adaptive ramp metering, as will be described later.

After simulation runs were completed, the raw outputs are all sent into the post-processing program, NexTA [9] to analyze and visualize the MOEs of our interest.

All simulators used the same traffic network converted from a microscopic simulation model and all used the same O-D demands. Nonetheless, the demand loading processes were somewhat different within the various component simulators and so the corresponding results need to be carefully interpreted as will be described later.

Standard Dynamic Traffic Assignment (DTA) software allows a certain portion of travelers to recalculate their paths to avoid congestions as well as allows the use of historical travel times and the real-time travel time measurements to predict future link travel time [e.g., 7, 8, 20]. As such, the project team's DTALite [20] is suitable to simulate applications such as dynamic routing and predictive traveler information systems.

A feature of adaptive ramp metering is to adjust the ramp metering rate dynamically. This feature can be simulated by adjusting the ramp link capacities in the DTALite simulator. Given that it is complicated to change the kernel of standard DTALite simulator, the ASU team decided to modify the standard DTALite to allow interactions between DTALite and external programs. In doing so, various control strategies can be implemented and evaluated. At each period, the real-time conditions are exported to intermediate files with time stamp, such as the travel volumes and traffic states. Then, an external control program can re-calculate a new ramp metering rates according to its own objectives, and subsequently input new ramp link capacities back to DTALite to continue the simulation for the next period.

The proactive signal control application cannot currently be simulated within DTALite or special DTA because the minimum time step of existing DTA simulator(s) is six seconds which cannot meet the requirement of proactive signal control applications. As such, the ASU team developed an enhanced version of DTA simulator, referred to as high-definition DTA (HD-DTA), which has one-second simulation resolution as well as interfaces with external control algorithms such as for proactive signal control. Through such interfaces, HD-DTA is coupled with the high-

fidelity signal emulator, ASC/3, that is included in the microscopic simulation engine VISSIM. The inherent control algorithm in ASC/3 can be overridden by other adaptive/proactive signal control algorithms via the standard communication protocol for traffic signal controllers.

## 2. STRATEGIES STUDIED

## 2.1 Predictive Traveler Information and Dynamic Routing

Predictive traveler information and dynamic routing applications are highly related and therefore the ASU project team decided to put those two ATDM applications together. With the predictive traveler information and dynamic routing applications, travelers may not only get the real-time link travel times but also get the short-term prediction of travel times along the routes. Such information would allow travelers to switch to the alternative routes to avoid congestions. While the travelers calculate new best routes periodically, it is very important to consider in travelers' decision making both the latest experienced travel times, but also the near-future predicted travel times for the downstream links that travelers may experience. To address these issues, several preliminary DTALite runs are necessary to understand the historical trend of link travel time changes. Using agent-based DTALite, the ASU team was able to include dynamic path choices and dynamic routing in METROSIM for travelers' rerouting in presence of incidents. It was assumed that all travelers seek the least-cost paths from their origins to destinations and most travelers would like to switch their paths if necessary to avoid congestions.

## 2.2 Adaptive Ramp Metering

## 2.2.1 Scenario and Application Description

The purpose of ramp metering is to limit vehicles on ramps to enter the mainline freeway and reduce the interferences in weaving areas and increase the throughput. Members of the ASU team have developed some sophisticated proactive ramp metering strategies [3, 13, 14]. However, most of the implemented adaptive ramp metering dynamically adjust ramp metering rate based only on the mainline traffic on freeways. In order to simulate such adaptive ramp metering strategies, a customized version of DTALite was developed to not only measure the observed travel demand but also predict the near-future demand based on both current and historical data. This new feature also makes the proposed adaptive ramp metering strategy somewhat proactive to predicted traffic conditions.

Data of recorded incidents did not show many incidents within the selected network. To create "challenging-enough" traffic scenarios, to evaluate the benefits of adaptive ramp metering, it was necessary to introduce additional incidents at certain locations where the mainline travel demand is close or exceeds the road capacities. Figure 2-1 shows the locations of incidents introduced. These incidents take place after the on ramps (blue lines) where ramp metering will most likely have the best performance. When incidents occur, the mainline capacities near three interchanges (from north to south) were on average reduced by  $\alpha$ =20%, 40% and 60% respectively.



Figure 2-1 Locations of incidents

#### 2.2.2 Adaptive Ramp Metering Algorithm

Through measuring the mainline travel demand at several locations, it is possible to ascertain if the traffic volume has exceeded or will exceed the reduce road capacities. The goal of the adaptive ramp metering implemented here is always to keep the mainline traffic volume lower than the (reduced) road capacity and reduce the interferences between mainline traffic and vehicles on ramps. To achieve that goal, the capacities on the corresponding ramp links are reduced by D\_(main\_Line)+D\_ramp-C\_(a%) where D is the time-dependent travel demand and C is the timedependent link capacity reduced by  $\alpha$ % during incidents. Figure 2-2 shows the procedure of adaptive ramp metering implementation in the special version of DTALite.



Figure 2-2: Procedure to Simulate Adaptive Ramp Metering

## 2.2.3 Modeling Approach.

Once the total demand on the main line and on ramps exceeds the link capacities, including during the incidents, the adaptive ramp metering strategy is activated. The ramp metering strategy modeled is as follows: maintain the total demand on the mainline plus ramps to be always less than or equal to the mainline capacity. In doing so, the interference in weaving areas is minimized and traffic mobility is improved. Note that the adaptive ramp metering assumes that variable message signs and/or dynamic routing is activated also to proactively effect travel demand.

The standard DTALite does not contain adaptive ramp metering mechanism. For this project, a special version of DTALite was developed to output the real-time travel demands on certain

links to other program as well update the ramp metering rate from the external program. Specifically, while this special DTALite is running, it periodically outputs the travel demand on selected links into time-stamped text files and will not proceed until the updated ramp metering rate generated by an external program (that algorithmically updates ramp rates) is read. Like, the adaptive ramp metering program cannot proceed either unless it finds the latest travel demand in the time- stamped text files. This allows for changes in ramp capacities (to reflect ramp metering rates) when DTALite is running. See Figure 2-3.



Figure 2-3 Special DTALite interfaced with an external ramp-metering program

#### 2.2.4 Scenarios Modeled

Using cluster analysis [see e.g. 10, 19], which is described in section 3.1, we were able to use four scenarios to represent the whole year; traffic and the travel demands were therefore derived from those four scenarios. Three additional incidents on the freeway segment were introduced in the simulations for one of the scenarios to more comprehensively evaluate the adaptive ramp metering strategies in the four different representative scenarios.

## 2.3 Proactive Traffic Signal Control

#### 2.3.1 Application Description

The proactive traffic signal control used was RHODES (Real-time Hierarchical Optimizing Distributed Effective System) strategy. RHODES does not employ defined traffic cycles or signal timing plans. It utilizes traffic flow models that **predict** vehicle arrivals at the intersections, and adjust the timing of each phase to optimize an objective function such as delay and/or stops. Because it emphasizes traffic prediction, this system can respond to the natural statistical variations in traffic flow as well as to flow variations caused by traffic incidents or other non-recurring events. Intersection control equipment for proactive systems is often more complex than for the other control categories.

For this project, three intersections were modeled for RHODES implementation as shown in Figure 2-4. The time-dependent arriving vehicles and turning ratios are derived from the calibrated HD-DTA models of City of Tempe.



Figure 2-4 Locations of three signalized intersections for ATDM applications

#### 2.3.2 RHODES Proactive Control Architecture

Implemented RHODES signal control strategy utilizes advance detector calls. In this application it is assumed that no vehicles exit the road between advance detectors and stop lines and no new vehicles enter the road between advance detectors and stop lines. Figure 2.5 shows the control architecture for RHODES. The real-world traffic network is highly dynamic and such dynamics can be captured through a varieties of sensing technologies from the traditional inductive loops to the latest connected vehicle technologies. However, any sensing technologies will to some extent have measurement errors or model approximations and as such when any raw data (y(t) in Figure 2-5) are sent to RHODES estimation/prediction algorithms . RHODES will process the newly incoming data, such as new detection of vehicles, and estimate the current vehicle traffic state and then predict the vehicles' trajectories for a short-term, including when they will join the queue and the predicted turns (left-turn, through or right turn). In other words, the short-term prediction of traffic states  $x^{(t)}$  is created. At this point, the core module of RHODES begins to proactively optimize the traffic performance, as measured from the estimated traffic states, by iteratively determining which approaches should be given green time and for how long (u(t) in the figure).



Figure 2-5 RHODES Control Architecture

There are three essential inputs for RHODES' prediction to work (see Figure 2-6) are (a) road saturation rate (i.e., discharge rates), (b) travel time from advance detectors to stop lines, and (c) turning ratios, some of which are estimated from the passage and presence detector data.



Figure 2-6 Essential inputs for adaptive signal control systems

## 2.3.3 Adaptive Signal Control Modeling Approach in Tempe Testbed

The optimization in RHODES is based on dynamic programming (DP). The idea is to select the best solutions among millions of feasible signal timings from now to the end of time horizon (e.g., 10 minutes from now). Each feasible solution (two examples shown in Figure 2-7) is composed of a phase sequence and each phase has a green time, from a specified minimum green time to the specified maximum green time. Whenever an approach is given green, all other conflicted approaches must be given red, creating control delays. A phase sequence and green times will result in a total delay (or some other measurable performance) The DP optimizes this measured performance.



Figure 2-7: Two Examples of Feasible Signal Phase Timings

Through the DP technology, the RHODES can quickly reach the best signal timings and implement them in the field. To further improve the performance due to prediction inaccuracies, RHODES has adopted the rolling horizon technique to update future scheduled timings (the part of timings that is still not implemented). As shown in the example of Figure 2-8, for each optimization cycle, the time horizon is long, such as 30 minutes. After every roll period, say of 5 minutes, a new timing schedule is optimized for 30 minutes, say from t = 5 to t =35. That is, after every 5 minutes a new 30 minutes prediction and optimum phase timing schedule is obtained. This approach can effectively diminish the sub-optimality created by the traffic measurement errors.



Figure 2-8: Concept of Rolling Horizon in RHODES

#### 2.3.4 Implementing Proactive Signal Control in Mesoscopic Simulation

Normally adaptive or proactive signal control strategies are simulated and evaluated in a microscopic simulation traffic environment [e.g., 4, 5, 6]. However, in this project, it is necessary to evaluate the integral performance of proactive signal control with other ATDM applications, specifically adaptive ramp metering and dynamic routing. As such, the project team developed a multi-resolution simulation platform to enable proactive signal control within a DTA-type simulator.

HD-DTA is similar to DTALite but with higher simulation resolution (second-by-second). The ASU team first defined a group of special links within intersections to match them with particular signal phase(s), as shown in Figure 2-9. The signal links will be opened and closed alternatively according to exogenous signal control mechanism, since red light essentially prohibits vehicles to enter the intersection or prohibit a particular movement within an intersection.

It would be very difficult to implement signal control system within the environment of HD-DTA alone since the complexity that includes signal safety systems will take a lot of effort beyond the scope of this project. Therefore, a different approach was adopted. In parallel with this project, the ASU-maintained proactive signal control system, RHODES, has been seamlessly integrated within VISSIM. Based on these efforts, the ASU project team decided to build additional synchronous link between HD-DTA and VISSIM. At each simulation step, VISSIM sends all realtime signal phase status generated by a signal emulator to HD-DTA simulator. Through a mapping data structure, HD-DTA decides which signal links should be opened and which closed. Note that the signal phase in VISSIM can be either determined based entirely on the inherent control logic for a programmed signal emulator such as for ASC/3, or can be overridden by an external control logic (in our case, the external control logic is RHODES). The latter approach can have RHODEdetermined signal phase statuses be reflected in HD-DTA simulation.



Figure 2-9 Matching signal phases with special links in HD-DTA

19

Another issue is how to trigger detector calls for RHODES according to on-going traffic conditions. Since VISSIM is only used as a carrier of ASC/3 signal emulator, all detector calls must be generated in HD-DTA. According to the attributes of detectors, whenever a HD-DTA vehicle enters a link on which detectors are placed, a future detector call will be scheduled according to the travel time from the link start to the detector location. With time elapsing, this scheduled detector call will be sent to RHODES to let RHODES know a new vehicle is approaching. Figure 2-10 shows the concept of how to place detector calls from HD-DTA to RHODES.





#### 2.3.5 Scenarios for Proactive Signal Control Simulation

The ASU project team evaluated the benefits of proactive signal control along an arterial with three intersections. The major MOE in the evaluation is the travel time along the arterial. For each scenario (derived from the cluster analysis to be described later), two signal control strategies were simulated: (1) standard actuated signal timing corresponding to the travel condition and (2) proactive signal control strategy. There are also some differences on the detector configurations. Compared to the standard signal control strategies, proactive signal control needs additional advance detectors to predict intersection arrivals (see Figure 2-11).



**Figure 2-11** Detector configurations (Left: Standard Actuation Control; Right: Proactive Signal Control)

## 2.4 Modeling Simultaneous Adaptive Ramp Metering and Proactive Signal Control

Modeling the joint operation of adaptive ramp metering and proactive signal control requires either further modifying special DTALite to be compliant with proactive signal control (e.g., introduce more data structure and reduce the resolution to 1 second); or modifying HD-DTA to be able to simulate adaptive ramp metering (e.g., introduce adaptive ramp metering module as well as other functions in DTALite). Neither option is realistic given the project timeline. As such, the ASU team adopted an approximate approach to model these two ATDM applications together. Specially, DTALite with adaptive ramp metering and HD-DTA with proactive signal control strategy are iteratively simulated with one simulator providing inputs to the other. Figure 1-12 shows the architecture of this interacting simulation procedure, referred to as METROSIM. There are four major components on METROSIM: DTALite/NEXTA, High-Definition (HD) DTA simulator, ASC3 signal control emulator (VISSIM) and RHODES proactive traffic signal control system.



Figure 2-12: Architecture of the METROSIM Simulation Platform

There are several necessary coupling links within METROSIM to synchronize simulation clocks and establish real-time data exchange. The following explains how those coupling links are set up:

#### 2.4.1 Coupling Link 1: Time synchronization between HD-DTA and ASC/3 (VISSIM)

Using any of APIs provided in VISSIM, such as signal API, driving behavior API, or emission API, it is possible to open a synchronous connection and continuously listen to any connections while VISSIM is launching. In the meantime, HD-DTA also populates a synchronous port to couple with VISSIM while launching. Through correct configuration, at each simulated second, HD-DTA need to correctly connect and communicate with VISSIM in order to proceed both HD-DTA and VISSIM. Through this synchronous connection, the clock synchronization is achieved.

## 2.4.2 Coupling Link 2: Real-time signal timing exchange between HD-DTA and ASC/3 (VISSIM)

The latest version of ASC/3 in VISSIM also includes a fully functional communication module like in the real hardware ASC/3 signal controller. This new feature efficiently exacts real-time signal status in ASC/3 for external programs. Taking advantages of this feature, at each time stamp, the HD-DTA collects signal status from ASC/3 using NTCIP commands and then translate them into the open or close status of the corresponding signal links. If a signal link is open, then vehicles are allowed to enter intersections whereas if a signal link is close, then vehicles will have to wait at stop lines the signal link is re-opened.

#### 2.4.3 Coupling Link 3: Time synchronization between ASC/3 (VISSIM) and RHODES

There are additional challenges to synchronize the clocks between ASC/3 (VISSIM) and RHODES in that there might be many RHODES-controlled intersections and, if we set up an independent synchronous connection for each intersection, the communication overhead might significantly slow down the simulation speed. To address this issue, a different solution was adopted. From preliminary experiments, it was found out that microscopic simulation engine, VISSIM, is almost always slower than RHODES' speed. In other words, RHODES optimization routines have to usually wait for VISSIM to finish it current simulation step to proceed. This phenomenon provides us with the possibility of setting up an asynchronous server to broadcast VISSIM's simulation step and then RHODES does not proceed until it was notified so.

Specifically, any API provided in VISSIM can be used to establish a separate connection to broadcast the current simulation step, all RHODES-controlled intersections continuously monitor

that broadcast simulation time to decide if it's ready to proceed. In this way, the clock synchronization is established between VISSIM and all RHODES routines.

#### 2.4.4 Coupling Link 4: Data Exchange between RHODES and ASC/3 and HD-DTA

In general, RHODES needs to two data sources to conduct its optimization task: the on-going traffic signal status and the detector calls from newly incoming vehicles. Using NTCIP commands, RHODES retrieves real-time traffic signal status from ASC/3 (VISSIM) which is also providing the current signal timing for HD-DTA simulation. RHODES also needs to set up another data exchange link with HD-DTA. As described before, HD-DTA schedules detector calls according to vehicle movements and detector configurations on certain links. At each time step, the HD-DTA will send all detector events occurring at that time step to the corresponding RHODES controller. RHODES will translate the incoming detector calls into vehicle arrivals on various approaches and can then predict the queue lengths of left-turn, through and right-turn on each approach. Figure 2-13 illustrates the coupling link mechanism.



Figure 2-13 Linkages between HD-DTA/ASC/3 (VISSIM)/ RHODES

#### 2.4.5 Coupling Link 5: Data Exchange between HD-DTA and DTALite

At this time, the DTALite for adaptive ramp metering and HD-DTA for proactive traffic signal control are not coupled through automated data exchange. Instead, the data exchange between DTALite and HD-DTA was established through manual file exchange. Specifically, in each iteration, DTALite provides new vehicle trajectories that satisfy dynamic user equilibrium. The trajectories are loaded into HD-DTA network to create new travel demand along the arterial. Since HD-DTA can provide high-fidelity signal control mechanism and the resulting travel times measured along the arterial are likely lower than that from HD-DTA. At the end of simulation, the HD-DTA will generate updated link travel times along the arterial. Then some of the link travel times in DTALite

are updated based on the HD-DTA output and a new dynamic user equilibrium is calculated with a new set of vehicle trajectories as well. This process is iteratively repeated between DTALite and HD-DTA until a specified threshold is satisfied that they are approximately converged.

Based on the multi-resolution simulation platform, the ASU team evaluated the possible benefits, in terms of travel time savings along the freeway and arterial, under the joint operation of proactive signal control and adaptive ramp metering. As discussed before, we considered four representative scenarios to represent traffic conditions in the Phoenix area. Our evaluations were also conducted for these four scenarios respectively. Figure 2-14 shows the locations of three signalized intersections and three interchanges. We calculated there are approximately 150~160 thousand vehicles entering and leaving this area during the 5-hour evening peak period for the four scenarios. Although there are few incidents in the study area, the ASU project team decided to arbitrarily introduce more incidents in some simulation scenarios to better compare the benefit of various ATDM applications.

The first step is to determine the baseline scenario in which neither adaptive ramp metering strategy or RHODES are turned on. Then, for each scenario, multiple iterations of simulation were conducted. In each iteration, the baseline condition was re-simulated in DTALite/NexTA platform while the adaptive ramp metering strategies at three interchanges were turned on. Obviously, a new user equilibrium was reached because of the impact of adaptive ramp metering strategy on the freeways. The most comprehensive output of DTALite is in the form of vehicle trajectories including both paths and travel times. Those vehicle trajectories were then filtered and re-loaded in the multi-resolution simulation platform. Since RHODES is expected to reduce the travel times along the arterial, the resulting travel times along the arterials were also changed, resulting in the violation of the user equilibrium between the arterial and freeway. At this point, one iteration was completed. In the next iteration, the DTALite/NexTA would reached a new user equilibrium based on the updated link travel times along the arterials and then a new set of vehicle trajectories sent to the multi-resolution simulation platform. This process is repeated multiple times until approximate convergence.

24



**Figure 2-14** Simulation study area for METROSIM to evaluate joint operation of adaptive ramp metering and proactive signal control.

### 3. EVALUATION OF ATDM STRATEGIES

One of the major considerations in evaluating a traffic management strategy is "when is it effective?" or, in other words, "under what conditions?" There are four predominant groups of factors to consider: (1) representative traffic conditions under which the ATDM applications may operate, (2) limitations of the technologies being used, (3) market penetration of the users of the ATDM technologies, that is, the population being affected and (4) synergies among the implemented ATDM components. These issues are discussed in the following subsections.

#### 3.1 Representative traffic conditions

The Phoenix region covers an area of 9,200 square miles and is characterized by a low density development pattern with population density just about 253 people per square mile. The region has one city with more than 1 million people (Phoenix) and eight cities/towns with more than 100,000 people each. The focus of the simulation modeling was Tempe area which covers an area of 40 square miles. The project team considered only PM peak traffic between 3PM and 7PM. **Error! Reference source not found.** shows the Google Earth geographic region with simulation network for Tempe, Arizona overlaid on it.



Figure 3.1 Google Earth Map Showing the Tempe Testbed

The baseline scenarios were defined over four different representative operational conditions. These operational conditions were identified from a cluster analysis [e.g., 10, 19]. Each operational condition represents a bin of multiple days in the analysis year and one representative day was selected for each cluster that is closest to the cluster centroid. The four different scenarios are defined over the PM peak hours of 3:00 PM - 7:00 PM as is shown in Table 3-. The

clusters are named based on the representative values of traffic demand, travel speeds, incident severity and weather conditions. The traffic demand is represented by the average hourly volume in the network. The travel-speed is represented by the average speed of vehicles on the freeways in miles per hour and incident severity is represented by the product of number of incidents and the number of lane closures resulted from it. For example, cluster 1 consists of higher traffic volumes, higher vehicle speeds and low number of incidents and is therefore abbreviated as HD-LI (for High Demand and Low Incident Severity). The location of incidents is of extreme importance in modeling and is computed using the data patterns (loop-detector data) from freeways. Clusters 1 through 3 represent dry weather conditions, while Cluster 4 is associated with wet pavement (or rain at 0.01 in/hour).

	HD-LI	HD-HI	LD-LI	HD-MI-WW
Representative Day	7/17/2014	5/21/2014	6/29/1014	11/22/2013
Operational Condition	High Traffic + High Speed + Low Incidents	High Traffic + High Speed + High Incidents	Low Traffic + High Speed + Low Incidents	High Traffic + Low Speed + Medium Incidents + Wet
Avg. Volume (veh/hr)	8383	8782	6004	7708
Avg. Speed (mph)	65	65.4	65.4	38.4
Weather Condition	Dry	Dry	Dry	Rainy (0.01 in/hour)
Number of Incidents*Lane Closure	9	22	3	23

Table 3	-1: Tem	be Operat	ional Con	ditions
---------	---------	-----------	-----------	---------

#### 3.2 Limitations of needed technologies

In this subsection we discuss (1) computational technologies to operationalize the METROSIM platform, (2) the available controller capabilities for adaptive ramp-metering, proactive control and traveler advisory systems, and (3) limitation of real-time operational equipment, basically the communication and computation latencies.

Given that the users of METROSIM would have access to table-top PCs and servers, perhaps on the high end side, the METROSIM platform was developed over such equipment. We note that access to cloud computing and/or super computers could make its performance, in terms of computation times, better and more user friendly.

Although RHODES and adaptive ramp metering can be done through several of-the-shelf traffic controllers, the project team decided to use the ASC/3 controller already implemented and configurable on VISSIM, and thus so in METROSIM. Other emulators of controllers may be used

provided that they may be implemented in VISSIM, the simulation system used at the micro-level in METROSIM. As for traveler advisory systems that would be operation in the field, the project team visualized that a simple smart-phone based system would suffice to provide traveler advisories and dynamic rerouting recommendations.

Latencies introduced by communication delays and computational times could result in significant degradation of performance for real-time systems, such as the ATDM systems that the project team was developing and testing. For example, if computation of of travel time predictions was excessive, the traveler advisory system would be lagging and would not provide effective travel advisories and rerouting recommendations on time. Likewise, if latencies from detector actuations to the RHODES computational engine was excessive, the performance of RHODES would degrade rapidly since it is crucial for RHODES that phase timing decisions are provided in time for the arriving traffic at signals. The project team conducted some limited testing of the latency delays of in the ATDM applications being evaluated in this project.

#### 3.3 Market penetration of users

The main issues here are "how many people will be using the traveler information system" and "how many people will follow the advice". Clearly, the higher the market penetration, the better performance will be expected from the ATDM applications. Limited evaluation was conducted on the effect of market penetration for the MTEROSIM platform.

#### 3.4 Synergies among the ATDM applications

Clearly, when both the adaptive ramp meters and the proactive traffic controls are operationalized we would accept a better traffic performance than when only one these systems is in operations. Likewise, it would be expected that adaptive ramp meters would be more effective when travelers were given re-routing advisories. The project team conducted some limited evaluations how various bundles of ATM applications performed and evaluated the synergies among some of the applications.

#### 3.5 Performance metrics

Table 3-2 shows the selected Measures of Effectiveness (MOE) for various ATDM applications and the corresponding simulation platform. Since traffic prediction for traveler information systems and dynamic rerouting plays a role in adaptive ramp metering, we have included metrics for this ATDM strategy.

ATDM Application	MOE	Simulation Platform
Dynamic Routing/Predictive	Average total travel time	DTALite
Traveler Information	(min)	
Adaptive ramp metering	Average travel time on	Special DTALite
	freeway	
Proactive signal control	Average travel time along	HD-DTA
	arterial	
Adaptive ramp metering plus	Average travel time on	METROSIM
proactive signal control	freeway and arterial	

## Table 3-2 MOE matrix of ATDM simulation in Phoenix

## 4. EVALUATION RESULTS

For the Tempe simulation case, two combinations of strategies were assessed for synergies by comparing the cases where individual applications were implemented in simulation and compared them with results for a combined implementation. They are given below.

## 4.1 Adaptive Ramp Metering and Proactive Traffic Signal Control

In order to compare the impact of Adaptive Ramp Metering (ARM) and Proactive Traffic Signal control (implemented as RHODES) and their combinations, special DTALite, HD-DTA and the METROSIM simulation platform were utilized respectively.

## 4.1.1 Impact of Adaptive Ramp Metering

Adaptive Ramp Metering was assessed using DTALite for different operational conditions; results shown in the Figure 4.1. The MOE compared was average travel-time of vehicles in the network including arterials and freeways.



**Figure 4-1** Travel time comparison with and without adaptive ramp metering under a given configuration

As shown in the Figure 4-1, ARM consistently reduces the travel time of vehicles in the network with the highest reduction found for the operational condition with High Demand, Medium Incident and Wet Weather, where the strategy was able to reduce the travel time by up to 9 percent. High Demand and High Incident showed least benefits.

## 4.1.2 Impact of Proactive Traffic Signal Control

Proactive Signal Control (RHODES) was also evaluated under different operational conditions using the HD-DTA platform. As shown in Figure 4.2, RHODES was able to reduce the travel time of vehicles on the arterial significantly.





## 4.1.3 Impact of Combination of ARM and RHODES

The combined operation proactive signal control strategy (RHODES) and adaptive ramp metering (ARM) were evaluated on the METROSIM platform. The four scenarios were evaluated based on several MOEs: overall average travel time; average travel time along the freeway; average travel time along the arterial. For each scenario, five iterations were simulated between METROSIM and DTALite. After some preliminary experiments, the project team decided to introduce additional accidents along the freeway segment in order to examine the performance of the combined ARM and RHODES together. Without much loss of generality, we did not consider latency or prediction horizon and assumed 10% of penetration rate.

The results are given in Figure 4-3. The combination of strategies gave significantly lower benefits than isolated strategies under High Demand, Dry Weather operational conditions. Under the operational conditions with low demand and wet weather, the combination provided more benefits than ARM alone, but was still significantly lower than the benefits provided by an advanced proactive traffic signal control (ACS) such as RHODES alone.



Figure 4-3 Travel time comparison between baseline and ACS+ARM

From the simulation results, it appears that the overall traffic mobility can be increased by 5%~15% in terms of average travel time. Based on the vehicle trajectory samples which went through the whole freeway segment or went through the whole northbound and southbound

arterial mainline, it was noticed that the simulated travel time under control of RHODES had increased. After carefully examination of the simulation results both in DTALite and in METROSIM, the ASU project team explains this as follows: DTALite, like many other DTA-type simulators, model traffic signal control approximately and, as a result, it might have overestimated the link capacities at signalized intersections. In contrast, the METROSIM platform adopts high-fidelity traffic signal emulator close to the reality and so exactly estimates the link capacities. Consequently, the travel time along the arterial witnesses an increase rather than decrease. Table 4-1 summarizes all the simulation results. For each scenario, the METROSIM platform was iterated five times and the iteration which has the best simulation outputs were selected.

## Table 4-1 Simulation results for Adaptive Ramp Metering and Proactive Signal Control using METROSIM Platform

Scenario 1		Iteration1		Iteration2		Iteration3		Iteration4		Iteration5
	Baseline	ARM+RHODES (METROSIM)	Baseline	ARM+RHODES (METROSIM)	Baseline	ARM+RHODES (METROSIM)	Baseline	ARM+RHODES (METROSIM)	Baseline	ARM+RHODES (METROSIM)
Total Vehicles	169,942	169,946	169,942	169,946	169,942	169,946	169,942	169,946	169942	169,946
Total Travel Time (min)	5,595,234	5,025,889.8	5595,234	5,512,988.4	5595,234	5,464,226.9	5595,234	5,083,148.1	5595234	5,066,257.1
Average Travel Time (min)	32.9243	29.5735	32.9243	32.4396	32.9243	32.1527	32.9243	29.9104	32.9243	29.811
Ave travel time along freeway based on samples (min)	16.39	15.13	16.39	14.87	16.39	15.30	16.39	15.24	16.39	15.88
Ave travel time along arterial based on samples(min)	15.96	17.83	15.96	18.26	15.96	17.45	15.96	17.24	15.96	16.24

Scenario 2		Iteration1		Iteration2		Iteration3		Iteration4		Iteration5
	Baseline	ARM+RHODES (METROSIM)	Baseline	ARM+RHODES (METROSIM)						
Total Vehicles	161,920	159,632	161,920	156,995	161,920	157,762	161,920	159,154	161,920	156,726
Total Travel Time (min)	5,519,425	5,227,224.42	5,519,425	4,950,019.8	5,519,425	4,935,420.86	5,519,425	5,757,596.51	551,9425	4,998,639.34
Average Travel Time (min)	34.0874	32.7455	34.0874	31.5298	34.0874	31.284	34.0874	40.0398	34.0874	31.8941
Ave travel time along freeway based on samples (min)	15.11	13.5	15.11	13.85	15.11	13.73	15.11	13.93	15.11	14.38
Ave travel time along arterial based on samples(min)	14.51	16.56	14.51	16.58	14.51	16.31	14.51	15.52	14.51	14.42

Scenario 3		Iteration1		Iteration2		Iteration3		Iteration4		Iteration5
	Baseline	ARM+RHODES (METROSIM)								
Total Vehicles	184590	184590	184590	184590	184590	184590	184590	184590	184590	184590
Total Travel Time (min)	5065451	4636148.4	5065451	4269526.3	5065451	4637546	5065451	4035679.7	5065451	4035679.7
Average Travel Time (min)	27.4416	25.1159	27.4416	23.1298	27.4416	25.1235	27.4416	21.8629	27.4416	21.8629
Ave travel time along freeway based on	17.8	13.77	17.8	13.74	17.8	13.57	17.8	13.65	17.8	14.44
samples (min)										
Ave travel time along arterial based on	14.31	16.11	14.31	16.69	14.31	15.79	14.31	15.38	14.31	15.15
samples(min)										

Scenario 4		Iteration1		Iteration2		Iteration3		Iteration4		Iteration5
	Baseline	ARM+RHODES (METROSIM)								
Total Vehicles	183296	180677	183296	180915	183296	180677	183296	180677	183296	180915
Total Travel Time (min)	5406016	4713679.89	5406016	4701935.92	5406016	4713679.89	5406016	4713679.89	5406016	4701935.92
Average Travel Time (min)	29.4934	26.089	29.4934	25.9898	29.4934	26.089	29.4934	26.089	29.4934	25.9896
Ave travel time along freeway based on samples (min)	17.42	13.29	17.42	13.37	17.42	13.53	17.42	13.86	17.42	13.88
Ave travel time along arterial based on samples(min)	14.94	15.87	14.94	16.78	14.94	16.42	14.94	15.85	14.94	14.79

#### 4.2 Impact of Dynamic Routing and Predictive Traveler Information

For the sake of comprehensive explanation of the simulation results we briefly describe the role of dynamic routing and predictive traveler information. Dynamic routing and predictive traveler information systems are crucial to active travel demand management. Through dynamic routing and predictive traveler information systems, travelers can be guided and suggested to switch to alternative routes to reach their destinations according to the predictive traveler information system. In doing so, travel demand can be re-distributed temporarily and spatially. There are two types of dynamic routing approaches that we assumed in this project: (a) variable message sign focuses on route switching at specific locations; and (b) mobile-device-based dynamic routing systems focus on suggesting to individual travelers better routes to their destinations. Dynamic routing and predictive traveler information systems should operate together because good routing policies rely on good traveler information systems. In the Tempe testbed, we focused on the mobile-device-based dynamic routing system integrated with predictive traveler information system. Such two modules are standard in DTALite. During the preliminary simulation runs to reach user equilibrium, the DTALite records the time-dependent historical travel times on all links. When simulations are run for our evaluations, a portion of travelers are allowed to recalculate their routes to the scheduled destination according to the latest traffic conditions. The real-time link travel times are calculated based on the latest link travel times as well as the historically future link travel time. If a traveler finds a considerably better route than its original route, it may choose to re- route.

By default, the DTALite allows a user-defined portion (0%~50%) of total travelers to switch their routes to avoid congestions and reach their destinations. During the preliminary runs of DTALite, historical travel times were recorded so as to provide historic link travel time information during the formal simulation runs. For all four scenarios, we compared the baseline (0% dynamic routing travelers) with the 20% travelers with dynamic routing. In the preliminary simulation runs, it was found that the largest congestion events occurred around incident sites and users with dynamic routing switch their routes to avoid such congestion. For the same number of travelers with the same O-Ds, Table 4-2 shows the benefits of dynamic routing and predictive traveler information system in terms of average travel time for a larger Phoenix Metropolitan area. We remark that the observed dramatic reduction in average travel time is because providing such information to travelers on a network-wide basis when there are incidents would result in a large number of travelers choosing alternative routes.

	Total	Baseline average travel time (min)	Average total travel
	agents	(0% dynamic routing users)	time (min)
			(20% dynamic routing
			users)
Scenario 1	169,946	42.28	24.92
Scenario 2	178,394	52.45	26.54
Scenario 3	184,590	44.96	24.42
Scenario 4	183,296	54.85	30.3

 Table 4-2: Average Network-wide Travel Times Under Different Scenarios for

 Dynamic Routing and Predictive Traveler Information Systems

#### 4.3 Impact of Latency, Predication Horizon and Market Penetration

The effectiveness of most real-time and short-term ATDM strategies will significantly depend on (a) latencies due to communication and computation technologies used in the ATDM systems, (b) accuracy and time horizon of predictions and (c) market penetration of the traveler advisory units. As described before, the adaptive ramp metering (ARM) strategy implemented in the Tempe testbed is capable of reflecting the impact of prediction horizon, prediction accuracy and communication latency.-Thus we used the ARM application to test these factors. The project team conducted some limited testing of these factors for the effective operation of ARM.

ARM coverage is typically few miles or more and therefore the performance of ARM could very well be affected by the above three factors. Using the special version of DTALite, the ASU team evaluated the impact of those factors on the ARM strategy. This report examines the travel time changes for those vehicles which travel all three interchanges along the Freeway 101. Realistic values were selected as: 5 min and 10 min for latency; 10%, 20% and 50% for penetration rates of mobile computing devices (i.e., a traveler uses a traveler information device and is willing to accept the guidance); and 5 min and 10 min for prediction horizons.

On the simulation platform, the communication latency is simulated by holding the latest ramp metering rate until the latency timer expires. For instance, if the latency is set 5min, then the new ramp metering latency is calculated at, say, 15:00 but it will not take into place until 15: 05. The

penetration rate is simulated by diverting specified percentage of vehicles from the mainline to other routes to reduce the congestion level along the freeway segment where multiple incidents occur. As for the prediction horizon for ARM, the special DTALite first runs multiple times to get the time-dependent travel demands which are later used for predicting demand. When the ARM system operates, the system calculates the appropriate metering rate not only considering newly measured demand but also uses for prediction for the time horizons of 5 mins and 10 mins. The ASU project team decided to conduct these evaluations for scenarios 2 and 3, representing the high and medium travel demand in the Tempe area.

#### 4.3.1 Prediction Horizon and Communication Latency

Figure 4-4 shows the average travel time along the freeway segment under different prediction horizon (5 min vs. 10 min), for latencies of 5and 10 minutes. It appears that the longer prediction horizon will bring the reduction of freeway travel time. This makes sense and is consistent with our expectations. However, the improvements appears marginal. After carefully examination of the simulation results, the ASU team considered that these results were caused by two reasons. First reason is that travel times do not fluctuate much within 15 minutes, since the time-dependent travel demand is provided every 15 minutes. The second reason is that the overall travel time along the freeway segment is between 10 minutes to 20 minutes our selected scenarios. Therefore, the gained travel time reductions represent only 1%~3% of total travel time. We expect that the total travel time reduction will increase and will be more sensitive to the prediction horizon if ARM strategies are applied to large areas where travel demand fluctuations are large.

We also examined the sensitivity of ARM to the communication latency. Figure 4-4 also shows consistent reduction of travel time if the communication latency is reduced from 10 minutes to 5 minutes. It is expected that the communication latency issue may become more pronounced if the ARM strategies are applied to larger areas.





#### 4.3.2 Penetration rate of ATDM applications

In this simulation experiment, two ADTM applications are considered together: dynamic routing traveler information and ARM for different penetration rates. Figure 4-5 shows the freeway travel times for this ATDM configuration for various penetration rates for traveler information, with a 5 min. prediction horizon and a 5 min. latency. The figure shows that higher penetration rate will help reduce the travel time. It makes sense because dynamic routing traveler information would

divert some vehicles from the freeway to the surface roads and therefore the level of congestions on the freeway would be lower than the baseline.



Figure 4-5 Travel times for different traveler information penetration rates for the tested ATDM configuration

#### 4.3.3 Prediction Accuracy

Prediction accuracy is another major concern of ARM because the ramp metering rate is dependent on the prediction of mainline travel demand. If the mainline travel demand prediction has errors, ARM may over meter or under meter the vehicles on ramps. Although over metering may benefit freeway travel time, it may considerably increase the delay on the adjacent surface streets. To estimate the impact of prediction accuracy, after the mainline travel demand is predicted, additional (-20%~20%) random errors are first added to the accurate travel demand and then the metering rates are calculated at the three on-ramps in the Tempe platform. Figure 4-6 shows the travel time differences with and without random error for different configurations of penetration rates, latencies and accuracies. Observe that the freeway travel time is quite sensitive to the prediction accuracy.



Figure 4-6 Travel times with and without prediction errors

### 4.4 Summary of Impacts of Traveler Information and Related Attributes

Table 4-3 summarizes freeway travel times using ARM for different conditions. We can see that if we provide a longer prediction horizon, the average travel time decreases only slightly; the impact of latency is also slight. However, in contrast, the traveler information penetration rate of has a much larger impact. In particular, if the penetration rate increases to 50%, the average travel time savings along the freeway can be 10% -15% for different scenarios.

Also, it is found that the performance of ARM is very sensitive to the prediction accuracy. After some system errors are included, ARM will underestimate or overestimate metering rates. If the system errors make the mainline travel demand lower, then the ramp will allow excessive vehicles to enter the mainline.

		Prediction	[	Total Num of Vehicles	Average_Travel
Scenario	Penetration Rate (%)	Horizon (min)	Latency (min)	traveling from the top to bottom on	_time (min) (100% accurate/(- 20%~20%
				freeway	superimposed noise)
2	10	5	5	10,608	13.46/15.53
2	10	5	10	10,608	13.716/15.806
2	10	10	5	10,608	13.451/15.543
2	10	10	10	10,608	13.698/15.742
2	20	5	5	10,024	13.114/14.856
2	20	5	10	10,024	13.334/14.384
2	20	10	5	10,024	12.882/10.799
2	20	10	10	10,024	13.314/11.172
2	50	5	5	8,269	12.193/9.563
2	50	5	10	8,269	12.353/13.83
2	50	10	5	8,269	12.18/9.642
2	50	10	10	8,269	12.378/13.875
3	10	5	5	16,859	11.999/12.342
3	10	5	10	16,859	11.865/10.756
3	10	10	5	16,859	11.866/13.134
3	10	10	10	16,859	11.868/10.759
3	20	5	5	15,829	9.5932/10.802
3	20	5	10	15,829	7.8638/11.016
3	20	10	5	15,829	9.5948/10.803
3	20	10	10	15,829	9.8363/11.017
3	50	5	5	12,308	9.7143/11.269
3	50	5	10	12,308	10.085/11.607
3	50	10	5	12,308	9.7162/11.27
3	50	10	10	12,308	10.089/8.5713

Table 4-3 Performance of ARM under Different Conditions

#### 5. SUMMARY AND CONCLUSIONS

The Arizona State University (ASU) project team developed and/or modified and/or enhanced simulation software, including VISSIM, DTALite, HD-DTA, VISSIM/ASC3 and integrated them to design a multiresolution traffic simulation platform METROSIM, for evaluating active travel demand management (ATDM) applications, particularly, Adaptive Ramp Metering (ARM), Advanced Proactive Traffic Signal Control, and related applications. Specifically, (a) the mesoscopic simulation engine, DTALite, was customized to allow external ARM strategies to interact with DTALite during the simulation; (b) an ARM system was developed in MATLAB to interact a the customized DTALite; (c) an Advanced Proactive Traffic Signal Control, based on RHODES, was designed to interact with VISSIM and ASC3 emulator; and a multi-resolution simulation platform, METROSIM, was configured, to simulate and evaluate the joint operation of ARM and proactive RHODES.

Based on the simulation results, the ASU team summarizes the findings as:

- ARM will be beneficial in all congested conditions, especially there are incidents on the mainline and the mainline travel demand is high (close to capacity).
- Proactive traffic signal control will improve the traffic mobility along the arterials in terms of travel time reductions.
- When ARM and proactive signal control are deployed together in a road network consisting of both urban freeways and arterials, it is more likely that they will be synergistic and improve the overall traffic mobility
- Dynamic routing/predictive traveler information system can help travelers to avoid bottlenecks and therefore the overall travel delays may be considerably reduced.

The ASU team also studied attributes of ATDM applications, including communication latency, prediction horizon and prediction accuracy. Under different configurations and simulation results suggest:

- Shortened prediction horizon and communication latencies will help improve travel times with ARM;
- Travel times improvements are sensitive to prediction accuracy in some ATDM applications under congested traffic condition, such as ARM strategies; and
- Traveler information penetration rate of has a large impact: penetration rates of 50%, the travel time savings along the freeway decrease by 10% -15%,

## 6. **REFERENCES**

- 1. Booz Allen Hamilton for U.S. Department of Transportation, *Analysis, Modeling, and Simulation* (*AMS*) Testbed Development and Evaluation to Support Dynamic Mobility Applications (DMA) and Active Transportation and Demand Management (*ATDM*) Programs—Gaps, Challenges, and Future Research FHWA-JPO-16-391, Draft Report — July 2017, <u>www.its.dot.gov/index.htm</u>
- 2. Fellendorf, M., Vortisch, "Microscopic traffic flow simulator VISSIM". In *Fundamentals of Traffic Simulation* (pp. 63-93). Springer New York, 2010
- 3. Ciarallo Frank W., Pitu B. Mirchandani, *RHODES ITMS MILOS: Ramp Metering System Test, Report FHWA-AZ02-48*1, Arizona Department of Transportation, April 2002 (46 pages)
- 4. http://vision-traffic.ptvgroup.com/en-us/products/ptv-vissim/, last accessed Jan 2014
- 5. http://www-mctrans.ce.ufl.edu/featured/TSIS/Version5/corsim.htm, last accessed Jan 2014.
- 6. http://www.aimsun.com/wp/. last accessed Jan 2014
- 7. http://www.fhwa.dot.gov/research/deployment/dynasmart.cfm last accessed Jan 2014
- 8. http://dynust.net/ last accessed Jan 2014
- 9. https://github.com/xzhou99/dtalite\_software\_release
- 10. https://www.stat.berkeley.edu/~s133/Cluster2a.html
- 11. http://www.its.dot.gov/dma/, last accessed Jan 2014
- 12. http://www.its.dot.gov/active\_traffic.htm, last accessed Jan 2014
- 13. Gettman, D.M., K.L. Head, P.B. Mirchandani. A multi-objective integrated large-scale optimized ramp metering control system (MILOS) for freeway traffic management, *78th Annual TRB Meeting*, Washington, DC. January 1999
- 14. Gettman, D., K.L Head, and P.B. Mirchandani, *RHODES-ITMS Corridor Control Project, Final Report, FHWA-AZ99-462*, Arizona Department of Transportation, May 1999 (208 pages)
- 15. Head KL and P.B. Mirchandani, Hierarchical Control Architecture for Real-Time Traffic Management, *Proceedings of the 12th triennial World Congress of the International Federation of Automatic Control.* Vol. 3, 1994, pp 239,242
- 16. Mirchandani, Pitu and Larry Head, A real-time traffic signal control system: Architecture, algorithms, and analysis, *Transportation Research Part C: Emerging Technologies*. 2001;9(6):415-432.
- 17. Mirchandani, Pitu, Penfie (Taylor) Li and Xuesong Zhou, *METROSIM Development*, Progress Report on ASU Project (Task A), Arizona State University, October-2015
- 18. Mirchandani Pitu, Principal Investigator, *MIDAS Project: Proactive traffic management with temporal-spatial monitored vehicles and distributed network control,* National Science Foundation, (with ASU co-PIs Dijuang Huang and Baoxin Li and University of Florida co-PI Yafeng Yin) September 2012 Date.
- 19. Transportation Research Board, Workshop on Traffic and Transportation Simulation— Looking Back and Looking Ahead: Celebrating 50 Years of Traffic Flow Theory, *Transportation Research Circular,* Number E-C195, April 2015, Washington, D.C
- 20. Zhou, X., Taylor, J. (2014). DTALite: A queue-based mesoscopic traffic simulator for fast model evaluation and calibration. *Cogent Engineering*, 1(1): 1-19.