ADOT System-Wide Ramp Metering Evaluation

ADOT
Transportation Technology Group

November 2013

UCG
United Civil Group

ADOT System-Wide Ramp Metering Evaluation

Prepared for

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Ramp metering is one of the well-established and well-practiced active traffic management strategies to regulate the flow of traffic entering the freeway during peak traffic periods. It improves the overall freeway throughput by reducing recurring congestion and providing sufficient gap for merging and diverging traffic, which makes the transition more comfortable for the drivers especially for aged commuters. This active traffic management strategy helps to increase the efficiency of traffic operation on freeways by providing a smooth traffic flow which saves drivers' travel time, reduces fuel use and vehicle emissions, and increases highway safety. Despite of all benefits, ramp metering introduces a few adverse effects and may cause traffic spill over on surface street intersections due to insufficient storage on entrance ramps.

This project included a study of the existing ramp metering operation and recommends new operation that will more effectively manage the flow of traffic entering the freeway system from the surrounding arterial street network. The project scope entailed research, evaluation, analysis, simulation, and recommendations to improve the effectiveness of ADOT's ramp metering system. The recommendations are based on the limitations of the current hardware and software capabilities, with a focus on optimizing metering rates and ramp metering time of day at each ramp meter. Additionally, two documents, the ADOT Ramp Metering Design Guide and the ADOT Ramp Metering Operations and Maintenance Guide have been developed to standardize ramp metering design and operations.</td></tr>
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SI (MODERN METRIC) CONVERSION FACTORS*

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	square millimeters	mm^2	mm^2	square millimeters	0.0016	square inches	in^2
ft^2	square feet	0.093	square meters	m^2	m^2	square meters	10.764	square feet	ft^2
yd^2	square yards	0.836	square meters	m^2	m^2	square meters	1.195	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	square kilometers	km^2	km^2	square kilometers	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	cubic meters	m^3	m^3	cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	cubic meters	m^3	m^3	cubic meters	1.308	cubic yards	yd^3
	NOTE: Volumes greater than 1000L shall be shown in m^3.								
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000lb)	0.907	megagrams (or "metric ton")	mg (or "t")	Mg	megagrams (or "metric ton")	1.102	short tons (2000lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION					**ILLUMINATION**		
fc	foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2	cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE AND PRESSURE OR STRESS					**FORCE AND PRESSURE OR STRESS**		
lbf	poundforce	4.45	Newtons	N	N	Newtons	0.225	poundforce	lbf
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa	kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380

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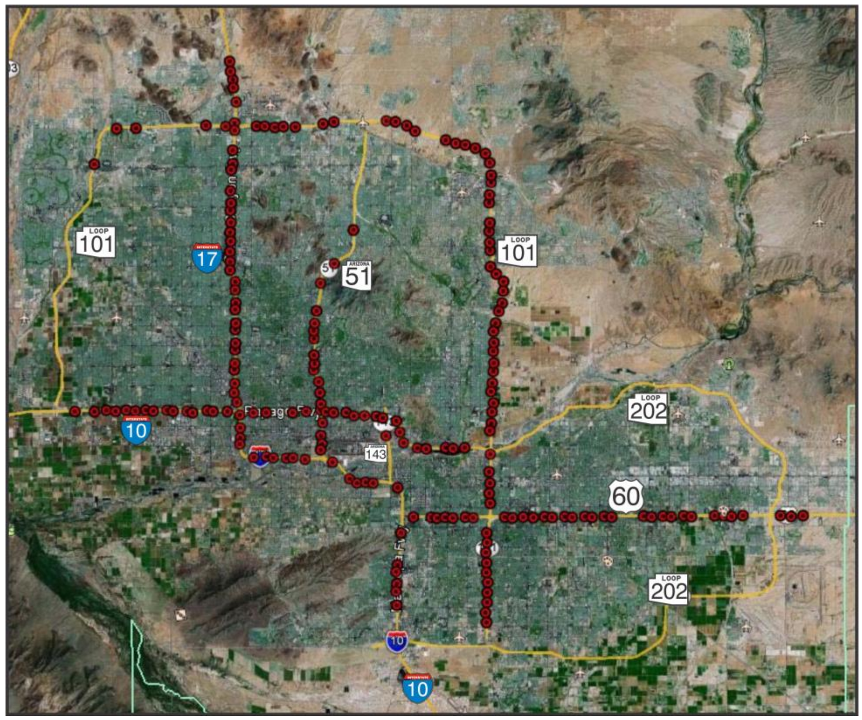
EXECUTIVE SUMMARY

INTRODUCTION

Ramp metering is an active traffic management strategy that regulates the flow of traffic entering the freeway during peak traffic periods in order to improve overall throughput, travel time, safety, fuel use and emissions. The Arizona Department of Transportation (ADOT) first started using ramp meters in the late 1990s. By 2012, ramp meters were installed on over 200 entrance ramps throughout the Phoenix Metropolitan region.

Recently, ADOT replaced all Type 179 ramp meter controllers with higher-capability Type 2070 controllers. ADOT initiated this project to capitalize on the investment of the new ramp meter controller functions. This project included a study of the existing ramp metering operation and recommends new operation that will more effectively manage the flow of traffic entering the freeway system from the surrounding arterial street network. The project scope entailed research, evaluation, analysis, simulation, and recommendations to improve the effectiveness of Arizona's ramp metering system. The recommendations are based on the limitations of the current hardware and software capabilities, with a focus on optimizing metering rates and ramp metering time of day at each ramp meter. Additionally, two documents, the *ADOT Ramp Metering Design Guide* and the *ADOT Ramp Metering Operations and Maintenance Guide* were prepared to standardize future ramp metering design and operations.



Source: Arizona Department of Transportation, United Civil Group (map: Google Earth)

Ramp Meter Locations

This report recommends fixed time of day operations coupled with local traffic responsive metering rates for every ramp meter. Initially, the project team tested dynamic on/off times. However, limitations of the ramp metering software restrict its use and should be resolved in the future so that dynamic on/off times can be used.

The future recommendations of this report support smart ramp metering also known as corridor traffic adaptive ramp metering. Smart ramp metering uses a ramp metering algorithm which utilizes traffic data from multiple upstream and downstream locations to optimize traffic flow at each ramp meter. Because of the complexity of these smart ramp metering systems, their successful implementation depends both on hardware (loop detectors at key locations) and software. Loop detectors may be beneficial at certain points at spacing less than 1 mile, such as at a freeway lane drop. Prior to implementation, algorithms will need to be field-tested to determine the ramp metering algorithm best-suited for ADOT. Smart ramp metering algorithms recommended for detailed evaluation include: CARMA, SWARM, Minnesota Zone, ALINEA, Helper Algorithm, Bottleneck Algorithm, Fuzzy Logic, and MILOS.

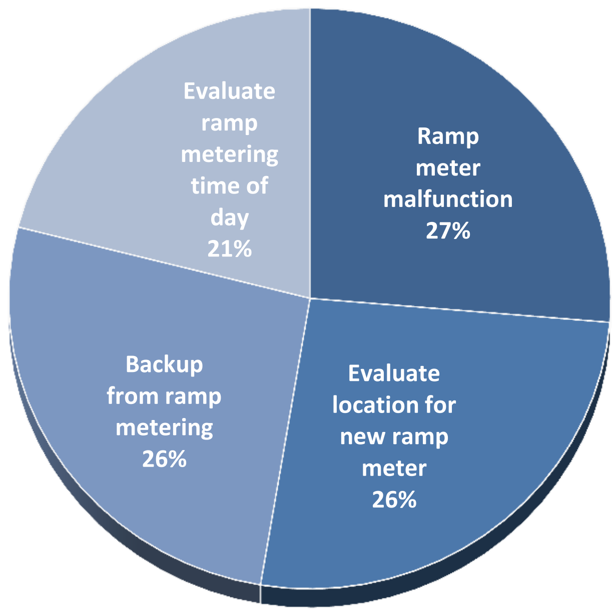
Technical Advisory Committee

The Technical Advisory Committee (TAC) met six times over the 24-month evaluation process and provided important guidance on the development of the *ADOT System-Wide Ramp Metering Evaluation* report. The committee membership included representatives from Federal Highway Administration, Arizona Department of Transportation, Arizona Department of Public Safety, Maricopa Association of Governments, Maricopa County, and representatives from local cities and towns.

Perceptions of Ramp Metering

ADOT Communications and Community Partnerships Division (CCP) and representatives from the TAC provided 18 public comments for review and analysis from 2010 through 2012 regarding ramp metering. The purpose of this review was to understand public concerns and perceptions of the ramp meters. The comments are summarized into four categories on the figure to the right.

Additionally, a ramp metering enforcement survey was performed with 150 Arizona Department of Public Safety (DPS) sergeants and line level officers. As a result of this survey, no significant ramp metering enforcement issues were identified. Compliance related comments received for specific ramp meters were considered in recommending ramp metering operation.



(Summary of 18 public comments)

Public Comments

State-of-the-Practice/Literature Review

Ramp metering installation and operation practices of 20 state departments of transportation were explored to identify ramp metering practices throughout the nation. Additionally, ramp metering literature, state of the practice and case studies were reviewed to identify methods of ramp metering. Benefits cited in the case studies for ramp metering include increased freeway speeds, decreased travel times, increased freeway throughput, improved safety, congestion reduction, improved air quality and a reduction in fuel consumption.

Existing ADOT Ramp Metering System

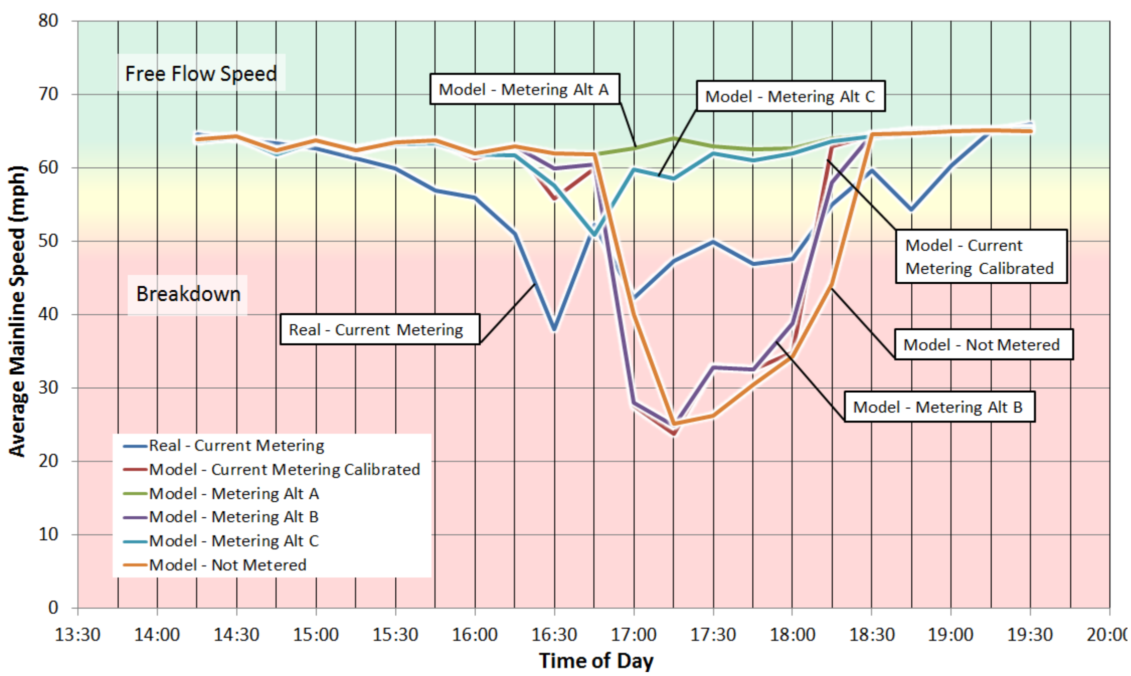
The project team reviewed and inventoried the existing ramp metering system. Data collected included entrance ramp geometric characteristics, traffic conditions, and GIS locations of all field devices. A database was developed to provide easy access to organized and up-to-date ramp metering information. The current times of operation were also documented for ADOT's use.

Vehicle detectors are used by ADOT for two purposes: controlling ramp metering rates and reporting traffic data. Vehicle detectors connected to ramp meters collect and report real-time freeway and entrance ramp traffic data in the Phoenix-Metro region every 20 seconds, 24 hours a day, 7 days a week. Freeway and entrance ramp traffic data is reported through the following websites:

Website Address	Real-Time	Historical	Speed	Volume	Occupancy	Classification
http://www.aztechrads.org/monitor/dataDump.jsp?logId=detstn_mc2070	●		●	●	●	●
http://www.aztechrads.org/fms/	●		●	●	●	●
ftp://ftp.az511.gov/pub/webdata/ips.out	●		●	●	●	
http://www.az511.gov/adot/files/traffic/	●		●			
ftp://ftp.az511.gov/pub/traffic/		●	●	●	●	

Ramp Metering Simulation Model

Ramp metering simulation was performed to assist in developing the recommended ramp metering time of day and metering rate. Simulation models were prepared for five different areas using VISSIM modeling software and were calibrated to actual loop detector speed data. The following figure illustrates the modeling results for alternative ramp metering operation at an example location.



Source: United Civil Group

Modeling Results at Example Location (I-10 Eastbound at Elliot Road)

RAMP METERING OBJECTIVES

The project team identified five ramp metering objectives to maximize the quality of service for drivers and to satisfy ADOT's requirements for this project.

- Minimize trip travel time
- Minimize fuel use and vehicle emissions
- Minimize crashes
- Avoid queue spillback
- Recommendations must be easily implementable

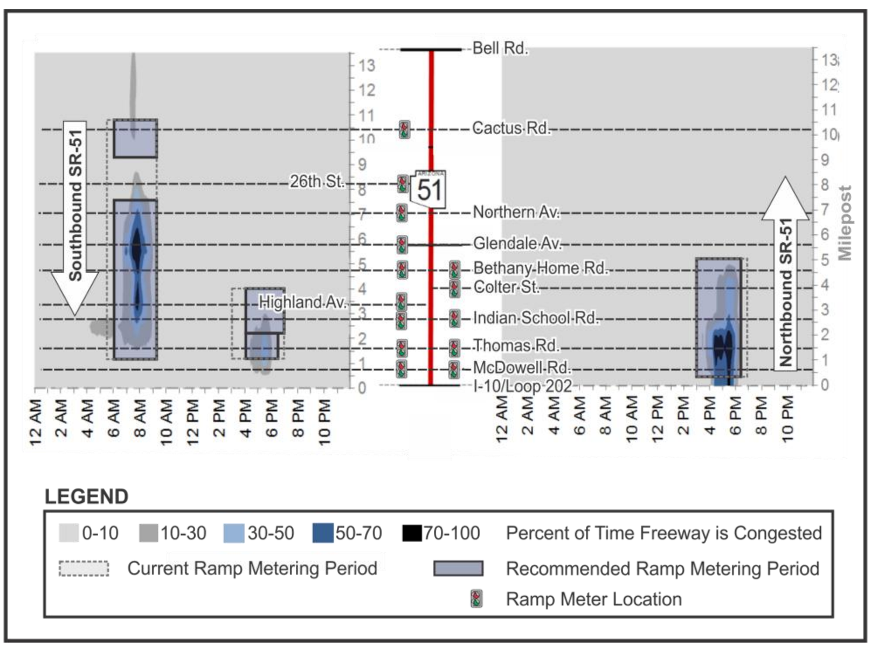
These objectives apply to all ramp metering control modes. Currently, ADOT uses local traffic responsive ramp metering control with fixed time of day operation. In the future, when corridor traffic adaptive ramp metering control is used, these objectives will still apply.

RECOMMENDATIONS FOR IMPLEMENTATION

The recommendations for implementation were developed to meet the above objectives without the need to modify ADOT's current ramp metering equipment and software. Detailed descriptions of the methodologies used in developing these recommendations are provided in the *ADOT System-Wide Ramp Metering Evaluation* report.

Recommended Ramp Metering Time of Day

Fixed ramp metering time of day is specifically recommended for each ramp meter. Ramp meters located upstream from a freeway bottleneck are recommended to start metering before (and stop metering after) periods of historically recurring freeway congestion or periods that congestion is anticipated to occur if the ramp meter was off. Archived traffic data collected by the ramp meter detectors was analyzed to determine the recommended ramp metering time of day. The figure above graphically depicts the recommended ramp metering time of day on an example freeway corridor.



Source: Maricopa Association of Governments, United Civil Group

Recommended Ramp Metering Time of Day - Example Location

Recommended Ramp Metering Rate

ADOT's ramp metering system supports local traffic responsive ramp metering; operation is automatically controlled utilizing real-time traffic data from the vehicle detectors connected to the ramp meter. Ramp metering rates are recommended as illustrated.

Base Metering Rate

ACTION: If freeway speed is high, the rate will be faster. If the freeway slows, the rate will reduce.

PUPROSE: Avoid unnecessary ramp meter delay and limit entrance ramp flow rate in an attempt to keep the freeway below capacity

LOGIC:

Metering Level	Freeway Speed (mph)	Metering Rate (vph per lane)	
		Single-Lane Ramp Meter	Dual-Lane Ramp Meter
Level 1	61 +	1,200	720
Level 2	60 to 56	960	600
Level 3	55 to 51	800	480
Level 4	50 to 46	600	400
Level 5	45 to 41	480	300
Level 6	40 to 0	400	240

Rate Increase #1

ACTION: If there is constant demand is detected, the rate will slowly increase up to a limit

PUPROSE: Avoid queue from reaching the *Queue Detectors* which will trigger *Rate Increase #2* and reduce benefit to freeway

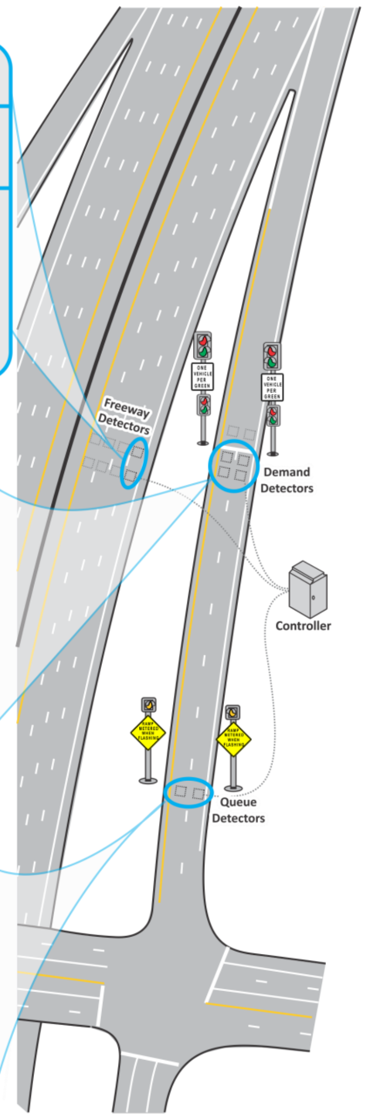
LOGIC: If the occupancy is above 75% for more than 80 seconds, then the base metering rate will automatically increase one level every 100 seconds, up to three times, until the occupancy of the demand detectors falls below 70% or level 1 is reached

Rate Increase #2

ACTION: If queue is detected, the rate will increase to a maximum

PUPROSE: Avoid ramp meter queue spillback into the intersection

LOGIC: If occupancy is greater than 60%, then the rate will increase to 870 vehicles per hour per lane at dual-lane ramp meters (1,440 vehicles per hour per lane at single-lane ramp meters) until the occupancy falls below 40%



Recommended Ramp Metering Rate Operation

Recommended Management of Non-Recurring Congestion and Incidents

Ramp metering operation during non-recurring congestion and incidents should be determined by ADOT staff on a case-by-case basis. Ramp meters can be turned on or off, and fixed metering rates can be set in real-time from remote sites to manage traffic flow during traffic detours, crashes, weather, freeway closure, and special events. During freeway closures, it is recommended to turn off ramp meters on entrance ramps used by traffic re-entering the freeway after bypassing the closed portion.

Implementation

The ramp metering recommendations have been field-tested at a sample of ramp meter locations. Ramp meter operation and traffic conditions were observed and parameters were fine-tuned to minimize unexpected results during full-scale implementation. Unexpected issues may still be encountered during implementation. Therefore, the recommended ramp metering time of day and metering rate parameters should be implemented in groups of one to five ramp meters to limit the number of issues encountered at one time. Additionally, implementation should begin in outlying areas, working towards more congested sections of freeway to more easily address issues. Traffic should be observed and the operation fine-tuned until there is confidence that each ramp meter is operating as desired. Before and after studies are recommended to be conducted prior to implementation on the next set of ramp meters to ensure congestion is not being adversely affected.

RAMP METERING GUIDELINES

As part of the ADOT System Wide Ramp Metering Evaluation, two guideline documents were prepared detailing ramp meter design, operation, and maintenance.

ADOT Ramp Metering Design Guide, 2013

This document gives designers and planners guidance in the design of ramp metering. Ramp metering designs will be approved by the ADOT Transportation Technology Group and project stakeholders. Ramp metering warrants are provided in this document as a guide in determining the suitability of ramp meter installation. Additional information includes ramp metering design criteria, hardware, and field equipment placement.

ADOT Ramp Metering Operation and Maintenance Guide, 2013

The purpose of this document is to give ADOT maintenance personnel guidance in the operation and maintenance of ramp metering. This document presents recommended ramp metering rates and time of day operations for each ramp meter location. Additional documentation provided includes justification for values used within the *ADOT Ramp Metering Design Guide*.

FUTURE RAMP METERING RECOMMENDATIONS

In the future, the following tasks are recommended to further improve ADOT's ramp metering system.

- Implement the ramp metering time of day and metering rate programming recommended by this project.
  - Observe and fine-tune ramp metering operation during implementation
  - Evaluate before-and-after results
- Develop integrated corridor management plans to improve ramp metering operation during non-recurring congestion and incidents.
- Communicate ADOT's ramp metering strategies to the Arizona Department of Public Safety Highway Patrol Division.
- Upgrade to a "smart ramp metering" system that centrally-processes traffic data and controls metering accordingly to further enhance traffic management capabilities. To upgrade, the following tasks would need to be performed:
  - Identify desired functions and operational capabilities of the system
  - Determine the control algorithm that will be used
  - Identify new detection at locations that will allow the algorithm to monitor freeway bottlenecks.
  - Test and adjust operation of the "smart ramp metering" system
  - Implement the "smart ramp metering" system
  - Evaluate before-and-after results

INTRODUCTION

Adding lanes to increase capacity is a countermeasure often used to mitigate freeway congestion. However, as the physical footprint of freeways reach their right-of-way boundaries and budget constraints are imposed, effective ramp metering becomes essential in achieving peak-performance from existing freeways.

Ramp metering is an active traffic management strategy that regulates the flow of traffic entering the freeway during peak traffic periods in order to improve overall throughput, travel time, safety, fuel use and emissions. This project was a comprehensive ramp metering evaluation of the following:

Research:
- Ramp metering state-of-the-practice
- Literature review
- Case studies

Evaluations:
- Perceptions of ramp metering
- Current ADOT ramp metering system
- Define ramp metering objective and measures

Simulation:
- VISSIM computer modeling analysis of 5 corridors

Implementations:
- Published *ADOT Ramp Metering Design Guide*
- Published *ADOT Ramp Metering Operations and Maintenance Guide*
- Implemented improved vehicle classification data provided by ramp meters
- Implemented improved ramp metering holiday operation
- Implemented recommended ramp metering operation at test locations

Recommendations:
- Recommended ramp metering time of day
- Recommended ramp metering rate programming
- Future smart ramp metering system

Project Goals

The project goals are as follows:

- **Goal 1: Improve ramp metering operation by maximizing benefits to all drivers.**
    - Identify ramp metering concerns of local agencies and the public
    - Research ramp metering literature and the practices used throughout the United States
    - Develop measures for evaluating ramp metering effectiveness
    - Model current and recommended alternatives of ramp metering operation

- ❖ Recommend operation for each ramp meter that can be easily implemented
- ❖ Test recommended ramp metering operation at a sample of ramp meters

✦ **Goal 2: Create well-planned ramp metering documents that will guide Arizona's ITS Professionals over the next 10 years.**

- ❖ Develop ramp metering warrants that provide consistent criteria for future implementation
- ❖ Update ADOT's ramp metering design, operations, and maintenance guidelines to the best practices and procedures

Project Documents

A summary of the documents prepared for this project are as follows:

This ***ADOT System-Wide Ramp Metering Evaluation*** is the final report and is a compilation of Working Papers A through D.

> ***Working Paper A: Public Perception and Literature Review*** – Focuses on a literature review of ramp metering and addresses the public perception of ramp meters in the Phoenix-Metro region. Arizona Department of Public Safety officers were surveyed to better understand their perspective in citing motorists at ramp meters and ramp metering traffic control enforcement.

> ***Working Paper B: Existing Conditions and State of the Practice*** – Comprehensively documents the current Arizona Department of Transportation ramp metering system including: current conditions, equipment, and freeway geometrics. Presents holiday schedules for immediate implementation. Presents ramp metering practices of other State Departments of Transportation.

> ***Working Paper C: Quality of Service Measures*** – Identifies measurable objectives for ramp metering control. The mathematical relationships presented are based on ideal theories. The level of detail and variables that are needed to calculate the quality of service measures are complex. As a result, the application of these ideal formulas was difficult to translate into ramp meter control. Therefore, this paper was revised and included in Working Paper D.

> ***Working Paper D: Proposed Ramp Metering Operation*** – Describes how ramp metering affects the roadway network and the measures used for quality of service. All information provided in Working Paper C is superseded by Working Paper D. This paper also details the proposed ramp metering control for the Arizona Department of Transportation system.

Executive Summary for the ADOT System-Wide Ramp Metering Evaluation – Provides a summary of the project findings and results detailed in the *ADOT System-Wide Ramp Metering Evaluation* report.

ADOT Ramp Metering Design Guide – A stand-alone guidance document for designers for planning and design of new ramp meters. This report includes ramp metering warrants, acceleration length, queue length, and ramp metering geometry.

ADOT Ramp Metering Operations and Maintenance Guide – A stand-alone guidance document for Arizona Department of Transportation staff for operation and maintenance of ramp meters. This document includes ramp metering time of day and metering logic for specific locations. It also includes the justification and background of ramp metering warrants and guidance presented in the *ADOT Ramp Metering Design Guide*.

Technical Advisory Committee

A technical advisory committee (TAC) was formed for this project, comprised of key agency stakeholders with the expertise to assist in the project's development. Representatives from local cities and towns, Maricopa County, Maricopa Association of Governments, Federal Highway Administration, Arizona Department of Public Safety, and Arizona Department of Transportation served on the TAC. Throughout the project, the TAC members provided valuable feedback and direction.

Committee Member	Representing
Reza Karimvand	ADOT – Transportation Technology Group
Farzana Yasmin	ADOT – Transportation Technology Group
Lydia Warnick	ADOT – Transportation Technology Group
Sanjay Paul	ADOT – Transportation Technology Group
Darrell Bingham	ADOT – Information Technology Group
Tim Wolfe	ADOT – Phoenix Maintenance District
Bashir A. Hassan	ADOT - Phoenix Maintenance District
Chuck McClatchey	ADOT – Phoenix Maintenance District
Madhu Reddy	ADOT – Phoenix Construction District
Mark Catchpole	ADOT – Multimodal Planning Division
Maysa Hanna	ADOT – Traffic Engineering Group
Scott Orrahood	ADOT – Traffic Engineering Group
Richard Moeur	ADOT – Traffic Engineering Group
Lars Jacoby	ADOT – Communications and Community Partnership
Owen Mills	ADOT – Valley Project Management
Jennifer Brown	FHWA
Faisal Saleem	MCDOT
Sarath Joshua	MAG
Leo Luo	MAG
Burley Copeland	Department of Public Safety
Bennie Robinson	City of Avondale
Mike Mah	City of Chandler
Erik Guderian	Town of Gilbert
Debbie Albert	City of Glendale
Luke Albert	City of Goodyear
Alan Sanderson	City of Mesa
Ron Amaya	City of Peoria
Jamal Rahimi	City of Peoria
Marshall Riegel	City of Phoenix
Bruce Dressel	City of Scottsdale
Cathy Hollow	City of Tempe

Table 1: Ramp Metering Technical Advisory Committee

PERCEPTIONS OF RAMP METERING

This section presents the perceptions of ramp metering from a point of view of local agencies, the public, media, and the Arizona Department of Public Safety.

Local Agency Interviews

Representatives from local cities and towns, Maricopa County, Maricopa Association of Governments, and the Federal Highway Administration were interviewed to gain perspective from the agencies affected by ramp metering. These agencies are all members of the Technical Advisory Committee formed for this project. A brief summary of some of the paraphrased responses from the interviews is shown in Table 2.

	General Comments	Locations of Concern
Federal Highway Administration	-Satisfy MAG's desire for good holiday programming -Consider diversion based on driver delay	SR-101L/Beardsley SR-51/32nd Street
Maricopa County	-Perform before and after studies	I-17/Thunderbird
Maricopa Association of Governments	-Meter at right location and times -Prepare an objective study -Improve operations and travel times -Provide a responsibility chart in report	US-60/Higley US-60/Greenfield US-60/Val Vista
Chandler	-Evaluate ramp metering time of day	SR-101L/Chandler
Gilbert	-Does not really affect Gilbert	SR-202L/Val Vista SR-202L/San Tan
Mesa	-Evaluate US60/Ellsworth	US-60/Val Vista US-60/Higley
Peoria	-Meters are not needed on L101	None cited
Phoenix	-Evaluate queue detector function	None cited
Scottsdale	-Develop event timing for ramp metering	SR-101L/Raintree
Tempe	-Improve time of day operation	US-60/Mill I-10 Baseline I-10 Broadway SR-202L/Priest

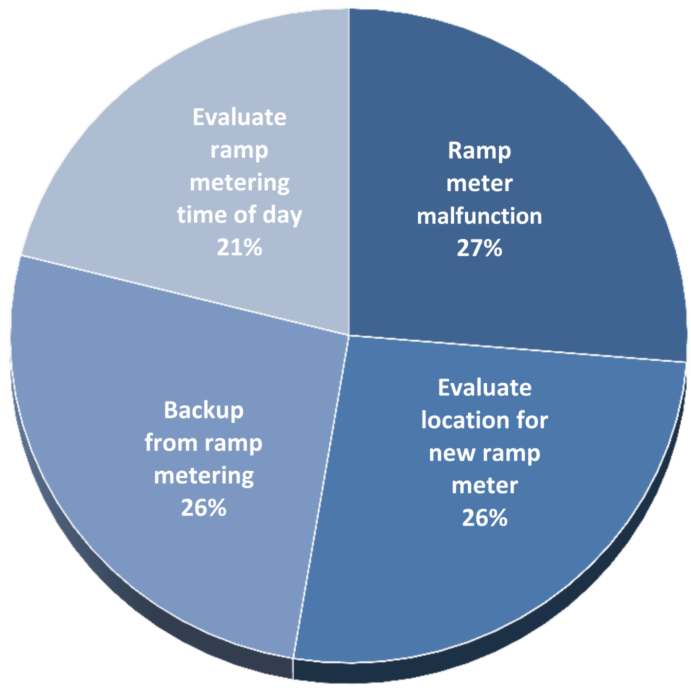
Table 2: Brief Summary of Local Agency Interviews

Public Comments

United Civil Group collected public comments regarding ramp metering to ensure past public comments are considered. The public comments that were received by the Arizona Department of Transportation and the Technical Advisory Committee members from 2010 to 2012 are summarized in the figure below. These comments have been addressed by the Arizona Department of Transportation.

United Civil Group received a total of 24 public comments. The details of the past public comments are provided in Appendix A. Of the 24 public comments, 6 were from memory with limited detail. The remaining 18 public comments were provided with adequate detail and are summarized in Figure 1 by the following categories:

- *Evaluate ramp metering time of day* – comments concerning metering during the time of day when it is perceived that the ramp meter should be off.
- *Back-up from ramp metering* – comments regarding back-ups due to ramp metering. The installation of the new 2070 controllers has reduced ramp metering backups.
- *Ramp meter malfunction* – comments about ramp meters malfunctioning. Examples include: ramp meter operating on a weekend, sunlight reflection creating a false appearance of an active signal indication, or ramp meter not detecting motorcycles.
- *Evaluate location for new ramp meter* – comments requesting a new ramp meter at a location.



(Summary of 18 public Comments)

Figure 1: Public Comments

Media Journalism

Newspaper articles published by the Arizona Republic and the Phoenix New Times related to ramp metering in Arizona were researched using online search tools. No ramp metering articles from the Phoenix New Times were found. United Civil Group found 8 articles published by the Arizona Republic related to ramp metering. The complete articles are included in Appendix A. The Arizona Republic articles are summarized below.

- 2008 - Two articles were written that discuss the activation of new ramp meters on SR-101L and on US-60.

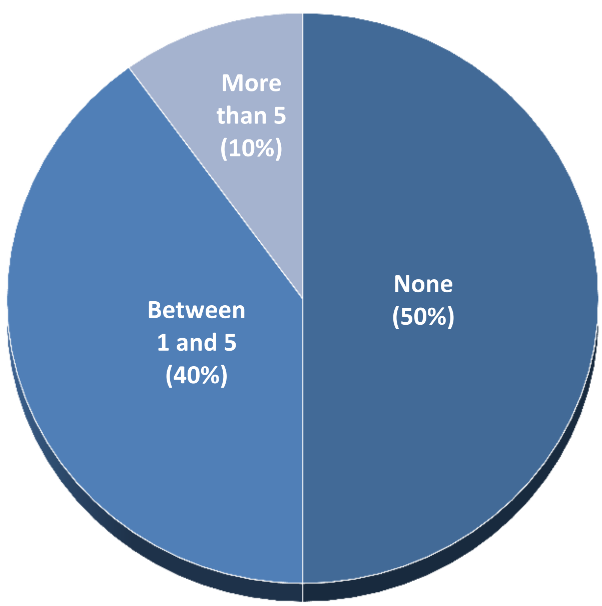
- 2010 - Four articles written on ramp metering are critical addressing their intended purpose, need during various times of day when traffic appears light on the freeway and what could improve ramp metering operation. One article reported on an experimental ramp metering control system being tested on I-10.
- 2011 - Article answered a question asked by a reader regarding the need to stop and wait for a green indication at a ramp meter.

Enforcement by the Arizona Department of Public Safety

United Civil Group worked with Captain Burley Copeland of the Arizona Department of Public Safety who prepared and distributed a ramp metering enforcement survey to 150 sergeants and line-level officers assigned to the Phoenix-Metro region's freeway system. Results were gathered from August through September of 2011. The Arizona Department of Public Safety is dedicated to protecting human life and property throughout Arizona, especially on the State's highway system. Within the Arizona Department of Public Safety, the Highway Patrol Division ensures the safe and expeditious use of the highway transportation system including ramp meter compliance enforcement.

As a result of this survey, no significant ramp metering enforcement issues were identified. Compliance-related comments received for specific ramp meters were considered in recommending ramp metering operation. In the future, it is recommended that ADOT's ramp metering strategies and ideal operation is communicated to the Arizona Department of Public Safety Highway Patrol Division. The survey questions and responses are summarized below.

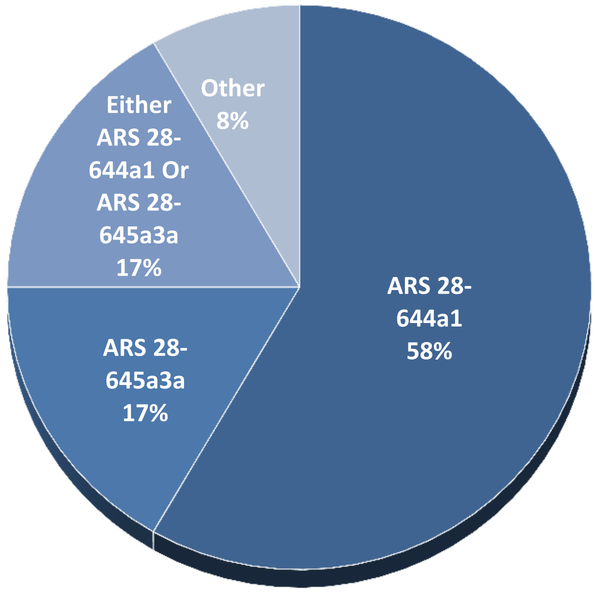
Question #1: *How many times a year do you issue a traffic citation for running a red light at a ramp meter?*



Source: Arizona Department of Public Safety (20 Responses)

Figure 2: Number of Ramp Metering Citations

Question #2: *Which Arizona Revised Statute(s) would you cite for running a red light at a ramp meter?*

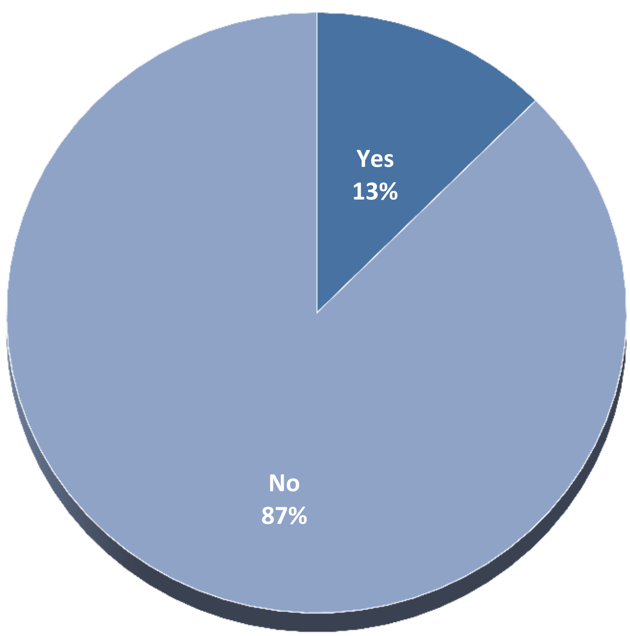


Source: Arizona Department of Public Safety (24 Responses)

ARS 28-644a1 - Failure to obey a traffic control device
ARS 28-645a3a - Failure to stop at a red light

Figure 3: Arizona Revised Statue Cited

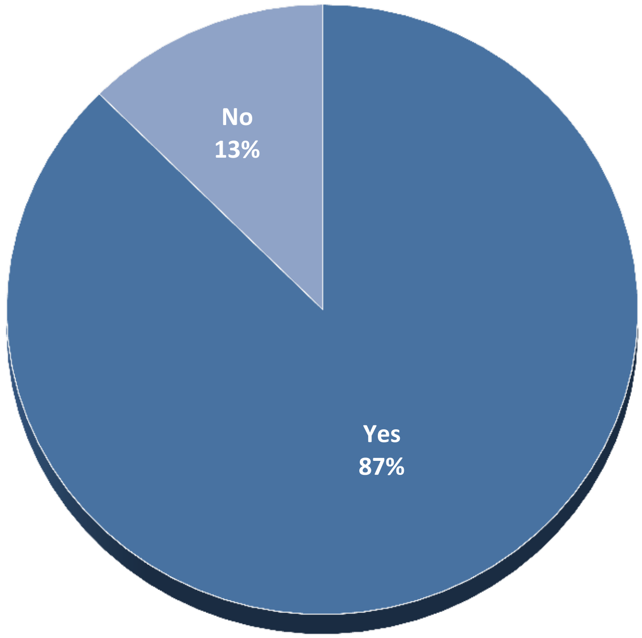
Question #3: *If you cited for running a red light at the ramp meter, have you ever had to defend the citation in a court of law?*



Source: Arizona Department of Public Safety (24 Responses)

Figure 4: Defense of Citation in Court

Question #4: *Do you feel you have the ability with the current laws to adequately enforce red light running at ramp meters?*



Source: Arizona Department of Public Safety (24 Responses)

Figure 5: Enforceable with Current Laws

Question #5: *What ramp meters do drivers frequently ignore?*

- *"US-60 WB entrance ramps" (two respondents listed these locations)*
- *"US-60 EB at Gilbert Road and Val Vista after 6 PM"*
- *"I-17 central area"*
- *"I-17 at 7th Avenue and 7th Street"*
- *"SR-51 SB at Highland and Bethany Home Road"*
- *"SR-101L SB"*
- *"SR-202L EB at 24th Street and 32nd Street"*
- *"All over, but all stops have been made when no one is in line on the on-ramp and the driver just merges on to the freeway without stopping."*

Question #6: *List any comments that you have regarding ramp metering.*

- *"Good idea, just need a specific law that is prima fascia evidence."*
- *"I will pay more attention to them. I have had rear-end collisions due to metering ramp violations, and cited ARS 28-701A (Reasonable and Prudent Speed) for those collisions."*
- *"If I saw a violation where someone blatantly ran the light I would write a citation for it."*
- *"The metering lights cycle through too fast to adequately enforce a red light violation particularly if traffic is not stopped on the ramp. Motorists will slow down to time the light to catch the green upon entering the ramp. The lights do not function at the same rates on all the freeways all the time making it difficult to testify in court. The lights function at a 3, 5, or 10 second interval on all metering lights."*
- *"More education. I do not believe drivers understand the purpose of ramp meters and are aware that they are enforceable by law. Also ramp meters need more specific signing. One driver said that the light turned green as he approached so he didn't have to stop. It's too hard to enforce when there is not a sign that says they have to stop or must stop before the lights turn green."*
- *"In regards to ramp meters, my opinion is the public does not view the meter in the same regards as a traffic control device like a stop light when it is red."*
- *"I definitely get called to more collisions because of the red lights and issue tickets."*

RAMP METERING STATE-OF-THE-PRACTICE

Throughout the nation various forms of ramp control have been in place since the 1960s in Chicago, Detroit, and the Los Angeles areas (Arnold 1998). The Arizona Department of Transportation first started using ramp metering in the late 1990s to reduce congestion and provide more reliable travel times on the freeway system. Ramp metering systems throughout the United States are listed as follows:

Large Systems (more than 50 ramp meters)	Small Systems (less than 50 ramp meters)
• Phoenix-Metro region, AZ	• Sacramento, CA
• Fresno, CA	• Denver, CO
• Los Angeles, CA	• Miami, Fort Lauderdale, Pompano, FL
• Orange County, CA	• Kansas City, KS/MO
• Riverside, San Bernardino, Ontario, CA	• Detroit, MI (Program currently on hold)
• San Diego, CA	• Las Vegas, NV
• San Jose/San Francisco, CA	• Cincinnati, OH
• Atlanta, GA	• Columbus, OH
• Chicago, IL	• Allentown, Bethlehem, Easton, PA-NJ
• Minneapolis/St Paul, MN	• Philadelphia-Metro region, PA
• New York, NY	• Houston & San Antonio, TX
• Portland, OR	• Provo, UT
• Seattle, WA	• Salt Lake City, UT
• Janesville, WI	• Northern Virginia, VA
• Milwaukee, WI	• Washington DC/Arlington, VA

Source: United Civil Group, Delcan Corporation

Details for a sample of different ramp metering systems are presented in Table 3. These details were collected by telephone conversations with the agencies or by firsthand knowledge.

Table 3: Ramp Metering Details by State

Location	Los Angeles (District 7) , CA	Minneapolis/St Paul, MN	Seattle, WA	Portland, OR	Kansas City, MO/KS
Number of Meters	1,000	425	205	140	15
Urbanized Ramps Metered	80%	89%	48%	93%	3%
Signal Indication	RYG on upper head, RG on lower head	RYG	RYG-Yellow used on startup only	RYG-Yellow used on startup only	RG
Startup/ Shutdown	Yellow on startup	Yellow on startup	Yellow on startup	Flashing yellow on startup	Green on startup until ramp is clear or max time, Green on shutdown for 20 sec then dark

Table 3: Ramp Metering Details by State

Location	Los Angeles (District 7) , CA	Minneapolis/St Paul, MN	Seattle, WA	Portland, OR	Kansas City, MO/KS
Signing	METER ON	FLASHERS ON	RAMP METER AHEAD with flasher	RAMP METER ON (lighted)	PREPARE TO STOP with flasher, 1 (or 2) CARS PER GREEN, STOP HERE ON RED
Metered Lanes	1 lane and 2 lanes	Mostly 1 lane	Mostly 2 lanes: 1 metered, 1 HOV bypass	Mostly 2 lanes	1 lane and 2 lanes
Stop Bar at Meter	Yes	No	Yes	Yes	Yes
Lane Line at Stop Bar	Mixed: 30% Dashed/ 70% Solid	N/A: Mostly single lane ramps	Solid	Dashed	Dashed
Central Control	Yes	Yes	Yes	Yes	Yes
Central Algorithm	System Wide Adaptive Ramp Metering (SWARM)	Stratified Zone Algorithm	Fuzzy Logic Algorithm	System Wide Adaptive Ramp Metering (SWARM)	Corridor Adaptive Ramp Metering Algorithm (CARMA)
Controller	170 & 2070	170	170	170 (Linux soon)	Linux
Software	In-house	In-house	In-house	Wapiti	Delcan
NTCIP Compliant	No	No	No	No	Yes
Local Fixed time	Yes	Yes	No	Yes	Yes
Local Traffic Responsive	Yes	No	Yes	Yes	Yes
Hours of Operation	5:00 AM to 7:00 PM	5:30 to 9:00 AM and 2:00 to 6:30 PM (varies by traffic)	5:00 to 10:00 AM and 2:30 PM to 7:30 PM (varies by traffic)	6:30 AM -9:30 AM and 3:00 PM to 6:30 PM (varies by traffic)	7:00 AM to 9:00 AM and 3:00 PM to 7:00 PM (varies by traffic)
When Not Metering	Green	Flashing Yellow	Dark	Dark	Dark
Queue Detected	Increase rate	Flush on max queue	Increase Rate	No action taken	Middle and long queue detectors with separate strategies
Release of 2-lane ramps	Simultaneous	Staggered	Staggered	Staggered	Staggered
Detection	Loops- Including Freeway, Demand, Passage, Queue, and some Merge	Loops- Including Freeway, Demand, Passage, and Queue	Loops- Including Freeway, Demand, Passage, and Queue	Loops- Including Freeway, Demand, Passage, and Queue	Loops- Including Freeway, Demand, Passage, and 2 Queue
Enforcement	None	None	Spot	Spot	None
Contact	Wahib Jreij	Brian Kary	Morgan Balogh	Dennis Mitchell	Jason Sims
Agency Phone	(213) 761-6545	(651) 234-7022	(206) 440-4485	(503) 731-8218	(816) 347-2200
Agency Email	wahib_jreij@ dot.ca.gov	brian.kery@ state.mn.us	baloghm@ wsdot.wa.gov	dennis.j.mitchell@ odot.state.or.us	ervin.Sims@ modot.mo.gov

Source: United Civil Group, Delcan Corporation

Ramp Meter Controller Families

In the United States, the controller families commonly used for ramp metering are as follows:

Model 170/179 Controllers

- Technology was developed in the 1980s, but still in significant use
- Very limited storage and computing power
- Does meet NTCIP 2107, 2101, and 2109 requirements

Model 2070 Controller (used by ADOT)

- Interchangeable upgrade to the 170/179 controller using the same cabinet hardware
- Deployed in many current systems
- Operating system is Microware OS-9 multi-tasking with DOS-like commands which can present limitations in computing capabilities
- Requires an OS-9 programmer, which consists of a small pool of professionals
- Flash drive and cannot run Linux (Based on the Motorola controller with a VME backplane)
- CPU board swap can allow Linux operating system
- Meets NTCIP 2107, 2101, and 2109 requirements

2070 ATC Controller

- Similar operation to a personal computer.
- Very fast processor that can handle virtually any programming requirements
- Runs on a PC104 or an embedded board designed for one
- Linux operating system enables an open architecture system, as well as a robust, flexible, and expandable platform that is compatible with multiple vendor's software
- Meets NTCIP 2107, 2101, and 2109 requirements.

Ramp Metering Software

In the United States, the known suppliers of off-the-shelf or custom ramp metering software are listed below. The software contains the control program used to perform ramp metering and is loaded on each ramp meter controller. In addition, the ramp metering software processes the electronic signals received from the vehicle detection and converts it into traffic data.

Supplier/Developer	Controller Platforms	NTCIP Compliant
Wapiti Micro Systems	170, 2070, and Linux	Unknown
Delcan	Linux	Yes
Siemens	2070	Yes
McCain*	170 and 2070	Yes – 1207
CoVal Systems	2070	Not Currently
Astart Technologies	2070	Unknown

*The McCain ramp metering software is used by ADOT, Utah DOT, Windsor-Ontario DOT, and Wisconsin DOT.

Source: United Civil Group, Delcan Corporation

Table 4: Ramp Metering Software

Vehicle Detection Technologies

Vehicle presence detection and traffic data collection may be performed by different detection technologies which commonly include:

- Induction Loops
- Magnetometers
- Radar
- Video
- Infrared

These technologies provide different advantages and disadvantages and are important to understand their limitations before choosing a technology. Regardless of the detection technology, many agencies have a failure management process to monitor the data quality and have backup procedures in place to identify and mitigate vehicle detection failures.

The most common detection used on entrance ramps are induction loops. They are well suited for both presence detection and traffic data collection due to their unique capability to define a precise detection zone. For freeway detection, any sensor that measures traffic flow data effectively can be used, but induction loop detection is again the most common technology.

Signal Head Arrangements

All ramp metering systems in the United States use red and green signal indications. Some systems use a yellow indication and some do not. A portion of the following information was provided to United Civil Group for this project in a report prepared by Delcan Corporation. The advantages and disadvantages of each approach are listed below.

Signal Head Arrangement	Advantages	Disadvantages
Red/Green	• High capacity due to ability to have quick cycle lengths	• Startup of the ramp meter from a dark state to red or green may be a concern
Red/Yellow/Green	• Yellow indication used to reduce startup issues • Yellow indication allows meter to rest in Green • Single vehicles able to proceed without stopping	• Ramp meter capacity limited due to longer cycle length • Increased cost for installation and maintenance of yellow indication
Red/Yellow/Green (Yellow used on startup only)	• Yellow indication used to reduce startup issues • High capacity due to ability to have quick cycle lengths	• Increased cost for installation and maintenance of yellow indication

Table 5: Signal Head Arrangements

Ramp Metering Control Modes

Ramp metering rates are controlled by using one of the control modes listed below, in order of increasing complexity with their advantages, disadvantages, and technology requirements. The following information was provided to United Civil Group for this project in a report prepared by Delcan Corporation.

Fixed-Rate Ramp Metering

Fixed-rate ramp metering control consists of using a schedule of predetermined metering rates for different times of the day. The schedule and metering rates are determined based on historical traffic data.

Fixed-rate requires the simplest of control technology requirements: a controller that can store tables of metering rates, dates, times, and holidays. All NTCIP-compliant ramp metering software can operate in a fixed-rate mode.

Advantages	Disadvantages
• Can reduce freeway congestion • Freeway detection is not needed • An effective control mode if more complex control modes fail and backup control is needed	• Does not respond to real-time traffic conditions or congestion • Requires maintenance of metering rate and schedule to account traffic conditions

Local Traffic Responsive Ramp Metering

Local traffic responsive ramp metering is a mode where a single ramp meter uses traffic data only from the vehicle detectors on the entrance ramp and on the freeway adjacent to the entrance ramp. The metering rate selection is performed within the local controller and is typically based on an algorithm that uses the local freeway volume, occupancy and/or speed data. This mode is included in all NTCIP compliant ramp metering software.

Local traffic responsive ramp metering requires freeway detectors near the ramp meter and a controller that can access the local freeway traffic data.

Advantages	Disadvantages
• Very capable of improving freeway congestion • Ability to respond to a non-recurring incident such as a crash • Responds to local freeway traffic conditions • Responds to entrance ramp traffic conditions • Requires little ongoing parameter maintenance	• Not responsive to downstream or upstream traffic conditions • Enhanced vehicle detection is required

Corridor Traffic Adaptive Ramp Metering

Corridor traffic adaptive ramp metering, commonly referred to as "smart ramp metering", includes all the capabilities of local traffic responsive ramp metering plus the enhanced ability for a group of ramp meters to work together to reduce congestion. Corridor traffic adaptive ramp metering responds to traffic conditions by controlling multiple ramp meters within a freeway corridor based on real-time data from multiple freeway detectors and entrance ramp detectors.

Corridor traffic adaptive ramp metering requires a centralized communication system, a corridor traffic adaptive algorithm, freeway detectors, and controller software that can accept metering rates in real time.

Advantages	Disadvantages
• Highest potential for improving freeway congestion • Multiple ramp meters work together to mitigate downstream freeway congestion • Excessive ramp meter delay can be mitigated by increasing its rate, while the rates of other ramp meters are decreased, resulting in the traffic flow arriving at a freeway bottleneck still being regulated • Ability to respond to a non-recurring incident such as a crash • Requires little maintenance of parameters	• Algorithms complex and difficult to understand • Centralized communications system required

In the future, ADOT should upgrade to a "smart ramp metering" system that centrally-processes traffic data and controls metering accordingly to further enhance congestion management capabilities. To upgrade, the following tasks would need to be performed:

- Identify desired functions and operational capabilities of the system
- Determine the corridor traffic adaptive algorithm that will be used (popular algorithms are listed in the following section)
- Identify new detection at locations that will allow the algorithm to monitor freeway bottlenecks.
- Test and adjust operation of the "smart ramp metering" system
- Implement the "smart ramp metering" system
- Evaluate before-and-after results

Corridor Traffic Adaptive Ramp Metering Algorithms

The algorithms for corridor traffic adaptive ramp metering commonly-used in the United States are summarized below. These algorithms evaluate data received from multiple freeway detectors and entrance ramp detectors and then calculate an appropriate metering rate for each ramp meter. These metering rates are continuously re-calculated and updated based on new data received. The data required and how the data is handled differs depending on the algorithm. Portions of the following information were provided to United Civil Group for this project in a report prepared by Delcan Corporation.

Multi-objective, Integrated, Large-Scale, Optimized System (MILOS)

MILOS was developed at the University of Arizona Advanced Transportation and Logistics: Algorithms and Systems (ATLAS) Research Center, along with guidance and support from the Arizona Transportation Research Center (ATRC). MILOS takes traffic demand data from detectors on the freeway and entrance ramps to determine a metering rate.

Although MILOS was not tested on real traffic, computer simulations completed with the MILOS algorithm showed promise for the algorithm. The simulation studies revealed that MILOS has the capabilities of decreasing delays, creating smoother traffic flow, and recovery from oversaturated conditions. One of MILOS's main objectives is to improve conditions on freeways during congested periods and help recover when oversaturation occurs. The capability of MILOS to communicate remotely to a controller in the field was successfully tested on I-10 at Broadway Road in Phoenix, Arizona.

Corridor Adaptive Ramp Metering Algorithm (CARMA)

CARMA computes a metering rate at each freeway vehicle detection station (VDS) regardless of whether there is an associated metered ramp or not. VDS's are ordered by geography and are processed starting with the furthest downstream location. The concept is based on the assumption that an entrance ramp should allow a maximum flow rate when the freeway speed is high and should theoretically allow no vehicles when the freeway speed is at a jam condition. A linear relationship is assumed to compute a slope and intercept to determine a metering rate for various freeway speeds as follows:

- Slope = Local Maximum Rate / (Speed at Max – Speed at Zero rate)
- Intercept = Local Maximum Rate – Slope x Speed at Max

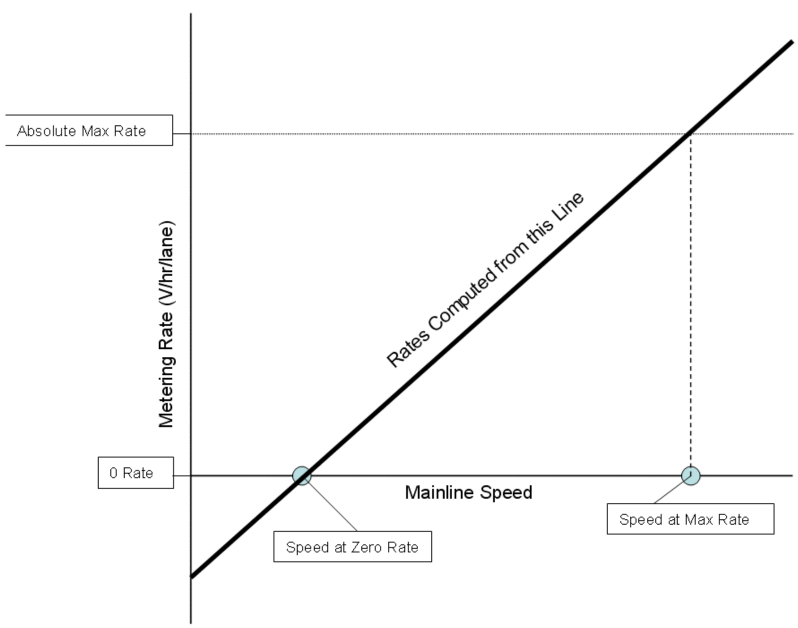


Figure 6: CARMA Strategy

The algorithm allows for computing raw metering rates that are above the local Absolute Max Rate and metering rates below Absolute Min Rate (and possibly negative). Conceptually, the Raw Rate represents the desirable number of vehicles to allow entry solely based on local freeway traffic conditions. The metering rate is computed as follows:

- Compute the smoothed speed using an exponential smoothing factor
- Compute the raw rate = smoothed speed x slope + intercept
- Compute the Adjusted Rate = Raw Rate + Excess x Propagation Factor ^ d

  Where:

  - Excess = Excess number of vehicles that were propagated from downstream VDS's. Positive values indicate that after the downstream ramps allowed the maximum number of vehicles to enter that there is still room for more vehicles downstream. Negative values indicate that after allowing vehicles to enter downstream that exceed the desirable number and there is not room downstream for additional vehicles.
  - Propagation Factor = User selected value representing the ratio of Excess to propagate between 0 and 1 allowing Excess to decrease over distance.
  - d = Distance between the current freeway VDS and the next downstream VDS
- Compute the Final Rate which is bounded by the Local Absolute Maximum and Absolute Minimum Rates
- Re-compute the Excess = Adjusted Rate – Final Rate
- The Final Rates are then applied to ramp meters

Initial Values:
The only non-zero initial value for a variable that must be initialized prior to starting CARMA is Smoothed Speed [SS(i,s)] which is initialized to the value of Speed at Max [SpeedatMax].

Local Minimum and Maximum Metering Rates:
Because it is possible to operate CARMA on a selected set of ramps, the algorithm must know which ramps are selected for non CARMA operation and adjust. This is accomplished through the concept of Local Max and Min rates. First, the actual mode of operation is used as a bounds to the Local Min Rate and Local Max Rate. The following table shows all the cases:

Actual Mode	Local Minimum	Local Maximum
CARMA at freeway detector with a metered ramp	Absolute Minimum Rate	Absolute Maximum Rate
CARMA at freeway detector with no metered ramp	Default Minimum Rate	Default Maximum Rate
Non-CARMA and currently metering	Current Rate from the controller	Current Rate from the controller
Non-CARMA and not metering	Absolute Maximum Rate	Absolute Maximum Rate
Ramp Queued	Current Rate from the controller	Current Rate from the controller

Table 6: CARMA Modes of Operation

<u>*System Wide Adaptive Ramp Metering (SWARM)*</u>

The SWARM algorithm uses a forecasting methodology based on density and apportions rates across an entire system. SWARM is currently in operation in Caltrans District 7 and Portland, Oregon.

SWARM Forecasting:
Based upon recent conditions, SWARM attempts to estimate the density at a time in the future. How far into the future (T_{crit}) the algorithm will estimate is a tunable parameter and is limited by the algorithm and the necessary lead time for metering rates to take effect. Figure 7 depicts this forecasting methodology. The heavy line on the drawing represents density rising in a typical fashion. In the Figure, the forecast indicates that density will rise above saturation before T_{crit} minutes. The heavy line above the saturation density line represents the amount that the density must be reduced during the next T_{crit} minutes to avoid saturation. Every polling interval (typically one minute) a new forecast is made and if saturation density will occur before the T_{crit} minutes, a new density reduction is computed.

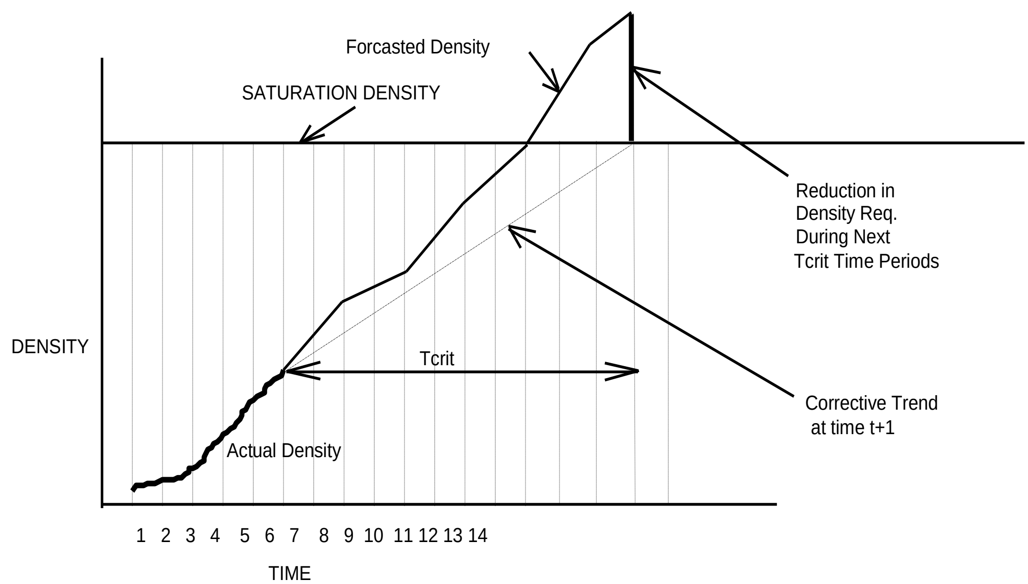


Figure 7: SWARM Forecasting

Density values used by SWARM:

- Current Density (CD) - This represents the Density at the Vehicle Detector Station (VDS).
- Saturation Density (SD) - Each VDS has a computed value of SD which represents the value of Density at saturation at the VDS and that should not be exceeded to achieve optimal system performance. SD is computed by capturing values of CD when the measured vehicle speed is between 30 mph and 50 mph, volume is less than 10, and CD between 30 and 60 vpm. When these three conditions are true, SD is recomputed by smoothing in the CD according to the formula $SD_{new} = CD*k + (1-k)*SD_{old}$. k is a tunable smoothing parameter.

- Forecast Density (FD) - Each VDS has a computed Forecast Density (FD). This forecast is computed with a linear regression based on a tune-able number of samples of Density (Forecast Size) and a tune-able number of samples into the future (Forecast Lead Time).
- Required Density (RD) - This value is key to SWARM apportionment and represents the maximum density that should be striven for at each VDS reporting to its bottleneck. The RD value is always between SD and SD/2 and is computed for each bottleneck as follows:
    - Free-flow Case: If CD <= SD and FD <=SD, Then RD=SD
    - Forecasting Congestion Case: If CD <= SD And FD > SD, Then RD = SD – (FD-SD)/Forecast Lead Time
    - Forecasting Free-flow Case: If CD > SD and FD <=SD, Then RD = SD
    - Jammed Case: If CD > SD and FD > SD, Then RD = SD – (FD-SD)

These four cases are shown graphically in Figure 8.

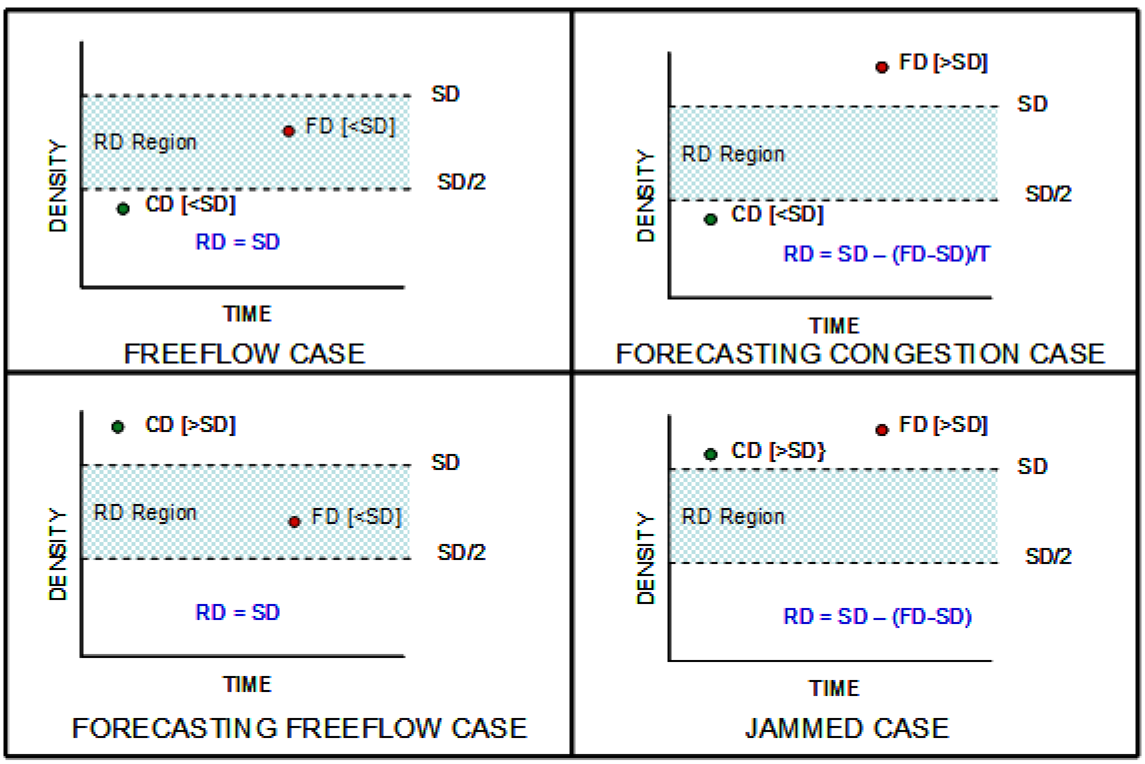


Figure 8: SWARM Density Values

SWARM Dynamic Bottlenecks:

A process is run continuously that looks for VDS's that are exhibiting bottleneck behavior. The process looks at individual freeway directions starting at the furthest downstream point. The furthest VDS on a freeway direction is always set as a bottleneck to insure that there is always a downstream bottleneck. Then searching from downstream to upstream each VDS is examined to see if it has a saturation density less than the current downstream bottleneck. If its saturation density is less, then it is classified as a new bottleneck. If not, its distance from the current upstream bottleneck is tested against a parameter (around 5 miles) and to the VDS with the lowest Saturation Density plus or minus 2 miles of this distance is also established as a new bottleneck. After completion this algorithm flags all VDS that are currently bottlenecks to be used by SWARM.

Using the resulting value of Required Density at each bottleneck defines the maximum value of density at all ramps upstream reporting to that bottleneck location. This used in conjunction with the current local densities and the apportionment algorithm define the metering rates at each ramp. Each new bottleneck's Required Density controls all of its upstream ramps.

SWARM Desired Metering Rates:
SWARM desired metering rates are computed independent of all constraints. This rate can be negative or positive and is computed as follows:

$$MR(\textit{desired}) = AbsMax - (CD \times N - RD \times Nbn) \times D - Excess$$

Where:

AbsMax = The Absolute Maximum Metering Rate at the ramp

CD = Current Density at the ramp. If the VDS has no valid data, CD is set to SD

RD = Required Density

N = The number of lanes at the ramp

Nbn = The number of lanes at the bottleneck

D = The distance to the next downstream ramp

Excess = The number of vehicles that were not handled from downstream ramps. Excess can be positive (vehicles were not handled) or negative (extra room is available).

The final SWARM metering rate is computed in two steps:

1. Ensure the SWARM rate is bounded between the Local Minimum and Local Maximum rates The rate is smoothed as follows:
   - If the rate is increasing ensure that it increases by no more than the Up Rate Smoothing parameter (in vehicles per minute)
   - If the rate is decreasing ensure that it decreases by no more than the Down Rate Smoothing parameter (in vehicles per minute)
2. After smoothing ensure the final SWARM rate is bounded between the Local Minimum and Local Maximum rates. If SWARM is not a chosen mode, the bounding of Local Minimum and Local Maximum rates ensures proper operation.

SWARM Excess Computations:
In SWARM, metering rates are computed in a specific order. The order starts at the furthest downstream ramp and proceeds upstream. Excess is the value that is used to allow SWARM to adapt to areas of congestion by propagating upstream those vehicles that cannot be handled at each ramp. Excess can be thought of as the number of vehicles that should be removed from the freeway to obtain

stable flow. Negative Excess can be thought of as holes where vehicles can be added without affecting stability. Excess starts at zero at the furthest downstream ramp.

After the *final* SWARM metering rate is computed, a new value of Excess is computed to be used at the next upstream ramp as follows:

Excess(*new*) = (MR(*final*) - MR(*desired*)) x Ramp Inter-section Propagation Factor ^ (Dist btwn ramps)

The tunable values for Inter and Intra Section Propagation Factors control how fast the Excess dissipates. The smaller the values the faster the dampening effect.

Stratified Zone Metering (Minnesota Zone Algorithm)

The objective of stratified zone metering is to regulate zones through metering so that the total volume exiting a zone exceeds the volume entering. For this to happen, the relationship of inputs and outputs within a given zone is as follows:

$$M + A + U \leq B + X + S$$

Therefore,

$$M \leq B + X + S - A - U$$

Through this calculation, M is the maximum number of vehicles allowed to pass through all meters in any given zone between stations A and B. The key to stratified zone metering is to disperse the volume M throughout the zone suitably depending on demand (D) on the metered entrance ramps. D is the total number of vehicles that need to enter a freeway through all metered entrances within a given zone. In order to disperse M appropriately, calculations are made one zone at a time from upstream to downstream (beginning with Zone 1-1) as follows:

$$R_n = M*Dr/D$$

Where:
R_n is the proposed rate for meter n (n is a meter within the zone)
D_n is the demand for the meter n

Therefore, based on demand, this calculation gives a proposed rate for every meter to run in according to a percentage of M. This calculation begins with Zone 1-1 in the first layer. After R_n has been calculated for the first layer, the proposed rates for all meters are compared to the demand and minimum rates for each corresponding meter.

For all meters where the proposed rate is less than the minimum release rate, the proposed rate is set to the minimum release rate. The meters that have a proposed rate greater than the demand and the meters that have proposed rate less than the minimum release rate need to have their proposed rates recalculated. These, therefore, have their proposed rates recalculated upstream to downstream using the second layer (beginning with Zone 2-1). The same process is involved for the second layer as the first. However, those meters that have been set to the minimum release rate are “locked in” at that minimum release rate, and this is also factored into the calculation of the zones in the second layer. This process will continue one layer at a time until all proposed rates are less than or equal to demand but greater than or equal to the minimum rates.

After all proposed rates for meters have been established, the zones that were involved with calculating the final proposed rates must be inspected. If the sum of release rates in one of these zones is less than M for that zone, this is a “broken zone” and needs to be corrected. If not corrected, meters in this zone would be more restrictive than necessary. If a broken zone is found, the meters that have proposed rates controlled by that zone are temporarily set to the maximum release rate. These meters alone are processed again beginning in the first layer as they were before. This will correct the problems of the broken zones and the proposed rates will all be finalized and implemented for the next 30-second period.

Various zones may be disqualified from being used in some cases. If any detector in the upstream freeway volume station malfunctions, the zone is disqualified. Also, if there is a drop in density greater than 50 vehicles per mile from one freeway detector to the next downstream detector in the same lane, the zone is disqualified. This scenario suggests that there is an incident on the roadway or heavy congestion and stratified zone metering is inappropriate. If this scenario occurs, each meter in that zone is set to its “simple plan” rate which is 130% of its expected maximum hourly volume.

One of the top priorities for the algorithm is to ensure that the wait time on a metered ramp is less than approximately four minutes. In order to keep wait times below this threshold, a unique “minimum release rate” is applied to each metered ramp. A minimum release rate is designed so that even if vehicles are backed up to (but not over) the queue detector, the last vehicle on that ramp will not have to wait longer than four minutes. To calculate the minimum release rate, first, the number of vehicles (T) that can be stored on the ramp is estimated using average vehicle lengths, ramp density, current release rates, and ramp dimensions. To assure that no vehicle waits over four minutes, four minutes is divided by the estimated maximum number of vehicles stored on the ramp to produce the maximum cycle time (C_{max}) for the meter. Maximum cycle time can be converted to a minimum hourly release rate (R_{min}) by dividing one hour by the maximum cycle time. No meter cycle time can be greater than 15 seconds; therefore, 240 vehicles per hour is the absolute minimum release rate for any meter.

If a queue detector reads an occupancy level of over 25%, it is assumed that the queue is backed up near or over the queue detector. When this occurs, the demand for that meter is incrementally increased until the queue detector is no longer covered. Also, as a safeguard, the minimum release rate is set to the demand at the meter. By raising the minimum release rate to the ramp demand, the queue will shrink and ramp wait times will remain acceptable. As explained later, a higher demand rate for a meter will cause a faster cycle time and a higher release rate. The demand is increased appropriately (by 150 vehicles per hour every 30 seconds) so that the meter will reach the maximum release rate (2.1-second cycle time; 1714 vehicles per hour) within four minutes.

<u>Asservissement Liéaire d'Entre Autroutiére (ALINEA)</u>

The ALINEA algorithm is a feedback method that attempts to maximize the freeway throughput by maintaining a desired occupancy on a downstream freeway station. Two detector stations are required for the implementation of the ALINEA algorithm. The first station is located on the freeway immediately downstream of the entrance ramp. The second station is on the downstream end of the entrance ramp and is used for counting the entrance ramp volume.

The metering rate for an entrance ramp under ALINEA control during time interval (t, $t+\Delta t$) is calculated as

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

Where:
Δt is the update cycle
O^* is the desired occupancy
O(t) is the measured occupancy
K_R is a regulator parameter used for adjusting the constant disturbances of the feedback control

The ALINEA algorithm has four parameters to be calibrated: the location of the downstream detector station, the desired occupancy of the downstream detector station O^*, the update cycle of each metering rate Δt , and a constant regulator K_R. The following is a summary of parameter settings used in previous research and implementations.

1. The desired occupancy, O^*, is set equal to or slightly less than the critical occupancy
2. The algorithm has been determined to perform well for $K_R = 70$.
3. The downstream detector should be placed at a location where the congestion caused by the excessive traffic flow originated from the ramp entrance can be detected. In reported implementations, this site was located between 120 ft m and 1,750 ft downstream of the entrance ramp nose.
4. A wide range of values for the update cycle of metering control has been used: from 40 seconds to 5 minutes. In theory, if the value is small, the location of the downstream detector station should be close to the entrance ramp otherwise there is a risk of congestion build-up between ramp nose and the detector station.

Denver Colorado Helper Algorithm

The metering rate is normally determined by local traffic conditions. If a downstream ramp meter is operating at its lowest rate and if a queue is detected at ramp meter, the algorithm reduces the metering rate by one level.

Seattle Bottleneck Algorithm

The metering rate is normally determined by local traffic conditions. If a downstream freeway bottleneck is detected, indicated by both high occupancy and a difference in flow rates of two freeway detectors, the metering rate is decreased. The metering rates for multiple ramp meters upstream from one bottleneck are decreased equally based on the difference in flow rates of the freeway detector before and after the bottleneck. If there are multiple bottlenecks dictating the metering rate at a ramp meter, the most restrictive metering rate is used. If a queue is detected at the ramp meter, the local software increases the metering rate. The central algorithm does not account the metering rate increases due to ramp meter queue.

Washington State Fuzzy Logic

The algorithm uses speed and occupancy from the local freeway detector and multiple downstream freeway detectors and the entrance ramp queue detector to determine the metering rate. Considerations for entrance ramp queues are included in the algorithm.

Ramp Metering Literature Review

This section summarizes national and state ramp metering standards and practices, and notable ramp metering study efforts. Additional ramp metering literature was reviewed but is not summarized for brevity. Useful findings of all reviewed literature were applied to this project.

National Ramp Metering

The design of ramp metering and their operations should conform to the American Association of State Highway and Transportation Officials (AASHTO) and Manual on Uniform Traffic Control Devices (MUTCD) standards. While the national manuals on ramp metering are useful tools in standardizing ramp metering installations, the guidance for ramp metering operation is not specific.

AASHTO A Policy on Geometric Design of Highways and Streets

The American Association of State Highway and Transportation Officials (AASHTO) Manual, *A Policy on Geometric Design of Highways and Streets, 2011*, briefly discusses ramp meters and their function. AASHTO discusses types of metering releases and the need for advanced algorithms if traffic actuated metering is used. AASHTO recommends referencing the Freeway Management and Operations Handbook and the Ramp Management and Control Handbook for further guidance (American Association of State Highway and Transportation Officials 2011).

Manual on Uniform Traffic Control Devices

The Manual on Uniform Traffic Control Devices (MUTCD) covers ramp metering in Chapter 4I. It gives minimal information on ramp meter warrants and operation. It specifies that ramp meters shall meet all of the standard design specification for traffic signals except for a few details outlined in the ramp metering section. The MUTCD states the installation of ramp meters should be preceded by an engineering study of the physical and traffic conditions on the highway facilities likely to be affected. The study should include: ramps, connections, surface streets, and the freeway section concerned. It also states that periods of operation, metering rates and algorithms, and queue management should be determined by the operating agency prior to the installation of the ramp meter, and should be closely monitored and adjusted as needed. The MUTCD states that additional information can be found in the FHWA Ramp Management and Control Handbook (Federal Highway Administration 2009).

FHWA Ramp Management and Control Handbook

The purpose of this FHWA handbook is to improve the operation of freeways and ramps by providing information to professionals responsible for the operations of freeway management. The handbook also addresses the need to provide professionals with a technical reference that offers guidance and recommended practices on managing and controlling traffic on ramps with freeway facilities. Chapter 5 of the handbook specifically addresses ramp metering through the following sections:

Ramp Metering Strategies – an effective and successful ramp metering strategy meets the goals and objectives it was intended to address. A successful implementation balances freeway congestion and vehicle wait times and queuing on the entrance ramps.

Geographic Extent – the geographic extent of ramp metering is based on goals and objectives of the governing agency and the locations of congestion or concerns on the freeway itself. The geographic extent it determined by assessing if the concerns are isolated or linked together.

Metering Approaches – There are multiple approaches to ramp metering. The systems can have isolated or coordinated control and also pre-timed or traffic responsive metering. The section defines the approaches and discusses the advantages and disadvantages of the combinations.

Metering Algorithms – This section describes several ramp metering algorithms used in traffic adaptive systems.

Queue Management – The success of a ramp metering approach depends on the ability to smooth the flow of traffic entering the freeway while adequately containing queues on the ramp. When demand exceeds the metering flow rate, traffic could queue onto the adjacent arterials and cause increased delay. Therefore ramp metering approaches must work together with queue management.

Flow Control – refers to the rate that vehicles enter the freeway from a ramp meter. The flow rate depends on ramp length, number of lanes, type of controller and traffic volumes.

Signing – appropriate signing must be installed to alert motorists of the presence of a ramp meter. This section describes signing for metered ramps.

National Transportation Communications for ITS Protocol (NTCIP)

The NTCIP is a family of standards commonly used in ITS that provides both the rules for communicating and the vocabulary necessary to allow electronic traffic control equipment from different manufacturers to operate with each other as a system. The NTCIP is the first set of standards for the transportation industry that allows traffic control systems to be built using a "mix and match" approach with equipment from different manufacturers. NTCIP standards reduce the need for reliance on specific equipment vendors and customized one-of-a-kind software. NTCIP is a joint product of the National Electronics Manufacturers Association (NEMA), the American Association of State Highway and Transportation Officials (AASHTO), and the Institute of Transportation Engineers (ITE). (NTCIP 2012)

Highway Capacity Manual

The Highway Capacity Manual 2010 addresses ramp metering in a new chapter in active traffic management based on information compiled from the FHWA Ramp Management and Control Handbook. This section of the HCM describes various strategies to relieve highway congestion and gives general guidance on evaluating active traffic management techniques. The HCM also discusses freeway traffic flow theory and provides a method for estimating freeway capacity.

Synthesis of Active Traffic Management Experiences in Europe and the United States

This report from the FHWA presents a synthesis on European active traffic management techniques. 11 US transportation professionals in planning, design and operations visited five European nations to study how each country addresses freeway congestion using actively managed traffic management techniques. One of the techniques used in Europe is ramp metering; however, ramp metering is more prevalent in the United States. Germany noted that ramp metering effectively prevents the drop in traffic speeds normally associated with merges and allows for the harmonization of traffic flow on major controlled access roadways (Federal Highway Administration 2006).

Highway Traffic Operations and Freeway Management State of the Practice

This FHWA report is broad in nature and discusses the benefits of ramp metering if installed properly. This report does not give much detail into the operations of ramp metering. However the report clearly states that through a review of many past studies, ramp metering clearly provide benefits to freeway traffic defined as: reducing total crashes from 15 to 50%, increasing freeway speeds from 8 to 60%, and increasing vehicle throughput from 8 to 22% (Jacobson 2003).

Recurring Traffic Bottlenecks: A Premier Focus on Low Cost Operational Improvements

This report discusses the nation’s bottlenecks and the opportunity to apply low cost operational fixes at spot specific locations. This report focuses on recurring congestion and the operational influences that cause them. Some of solutions that this study focuses on are widening, lengthening, retiming, metering, and bypassing. As a mitigation measure, ramp metering is recommended on heavy demand ramps, and may be helpful at lane drops, narrow lanes, or inadequate acceleration or deceleration lanes (Margiotta and Spiller 2009).

State DOT Ramp Metering Design Guidelines

State DOTs typically have their own design guidelines. Two examples are summarized below. Additional ramp metering design guidelines were reviewed by United Civil Group. Useful findings were applied to this project, but are not summarized for brevity. For a complete review see the 2013 *ADOT Ramp Metering Operations and Maintenance Guide.*

***California Department of Transportation Ramp Meter Design Manual*:**
The Caltrans Ramp Meter Design Manual contains design criteria for storage requirements, acceleration lanes, stop bars, signal placement, detectors, controllers, and signing and marking. Additionally, Caltrans prepared a Ramp Metering Development Plan in 2011 to guide practitioners when designing new or modifying existing ramps. Most ramp meters currently operate local traffic responsive software. The software in-use includes: Traffic Operations System (TOS), Semi-Automatic Traffic Management System (SATMS), San Diego Ramp Metering System (SDRMS), System Wide Adaptive Ramp Metering (SWARM), and Orange County Ramp Metering System (OCRMS). Caltrans is working towards supporting one ramp metering software algorithm, Universal Ramp Metering Software (URMS). (California Department of Transportation 2011)

Development of Criteria and Guidelines for Installing, Operating, and Removing Texas Department of Transportation Ramp Control Signals:
In 2009, the Texas Department of Transportation developed their ramp meter installation criteria and guidelines for installing, operating, and removing ramp control signals. The main purpose of this document is to assist decision makers in effectively installing ramp meters where necessary to optimize traffic flow. This document also discusses removing existing ramp meters that no longer provide a benefit to freeway traffic (Balke, et al. 2009).

Ramp Metering Case Studies

Studies have been conducted throughout the nation addressing the effects of ramp metering. Benefits credited to ramp metering include increased freeway speeds, decreased travel times, increased freeway throughput, improved safety, congestion reduction, improved air quality, and a reduction in fuel consumption. Summaries of a few notable studies are summarized below. Additional studies were reviewed by United Civil Group but were not summarized in this work effort.

California Department of Transportation

Caltrans, in conjunction with California Partners for Advanced Transportation Technology (PATH), are conducting a demonstration project to field-test the concept and benefit of local street signals and ramp meter coordination. The project is in the initial stage of site selection and scheduled for completion in two years (California Department of Transportation 2011).

One study evaluated the benefits of ramp metering on State Route 94 in San Diego. This evaluation found that the installation of ramp meters improved freeway speeds from below 30 mph to above 55 mph (California Department of Tranpsortation 1999).

Another ramp meter evaluation study prepared by Caltrans consisted of performing before and after travel time runs over an 18-mile-long stretch of I-580 in Alameda. This study found that the operation of ramp meters shortened travel time by 30 percent (California Department of Tranpsortation 2008).

The Metropolitan Transportation Commission (MTC) in California published the "Freeway Performance Initiative: Regional System Efficiency & Integration in the Works" facts sheet which details the effect of ramp metering deployments since 2007. The facts sheet shows a 30 percent or greater delay reduction on 80 percent of the freeway segments analyzed.

Minnesota Department of Transportation

In a commonly-cited 2001 study by the Minnesota Department of Transportation, the traffic flow and safety impacts of ramp metering were evaluated by turning off all 430 ramp meters in the Minneapolis/St. Paul region for six weeks as mandated by the 2001 Minnesota Legislature. The results indicated when ramp meters were turned off, freeway throughput reduced by 9 percent, travel time increased by 22 percent, speed dropped by 7 percent, and the number of crashes increased by 26 percent. (Cam012)

Wisconsin Department of Transportation

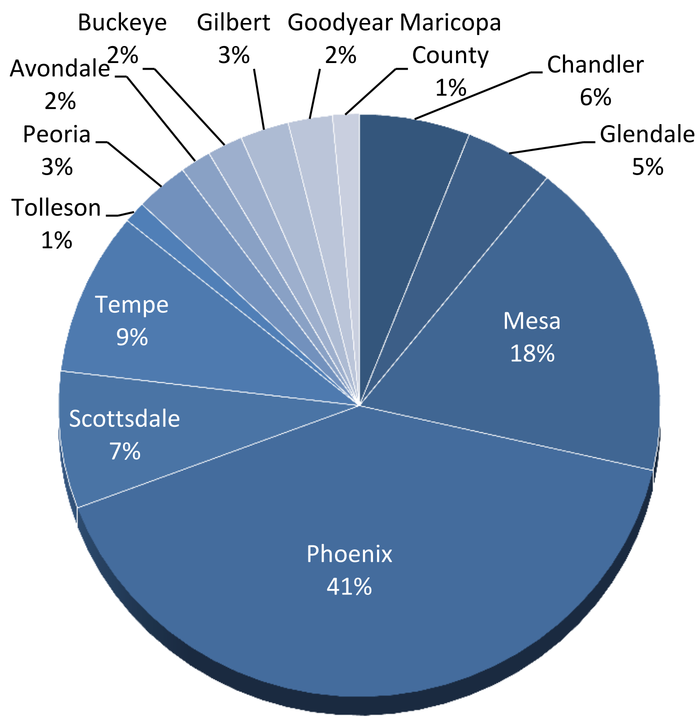
In 2004, Wisconsin Department of Transportation conducted a ramp meter evaluation study along approximately 18 miles of US 45. The study consisted of evaluating the 6 existing ramp meters along the corridor. The State then added 6 new ramp meters to measure the effects of the new system. A number of travel runs were performed with and without the new meters. The results of the study include a slight increase in freeway traffic volumes, but a decrease in vehicle hours of travel by 2 percent in the morning peak hour and 5 percent in the evening peak hour. Freeway speeds increased during both peaks when the new ramp meters were operational. Entrance ramp delays increased by 64 percent in the morning and 34 percent in the evening peak hours (Drakopoulos, Patrabansh and Vergou 2004).

Washington State Department of Transportation

The Washington State Department of Transportation conducted a before and after evaluation study on I-405 to test new controller logic. The new software was installed in 9 ramp meter controllers for evaluation. The results of the new logic showed that there was a decrease in travel time during the morning commute, but not during the afternoon. The study also concluded that ramp metering is effective when the speeds on the freeway range between 33 and 55 mph, however there was no supporting documentation (Trinh 2000).

CURRENT ADOT RAMP METERING SYSTEM

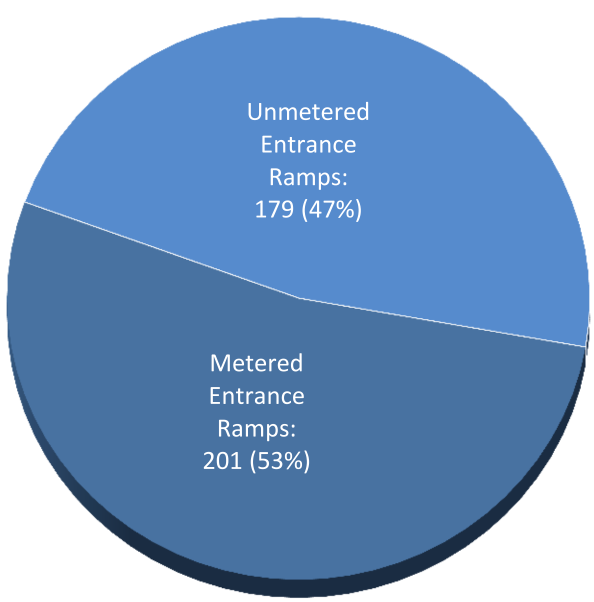
The Arizona Department of Transportation has 380 freeway entrance ramps within the Phoenix-Metro region. These entrance ramps are within Arizona Department of Transportation right-of-way and neighbor 13 different agency jurisdictions, distributed as depicted in Figure 9.



(Entrance ramps on agency boundaries are listed with both agencies)
Source: United Civil Group

Figure 9: Phoenix-Metro Region Entrance Ramps by Agency

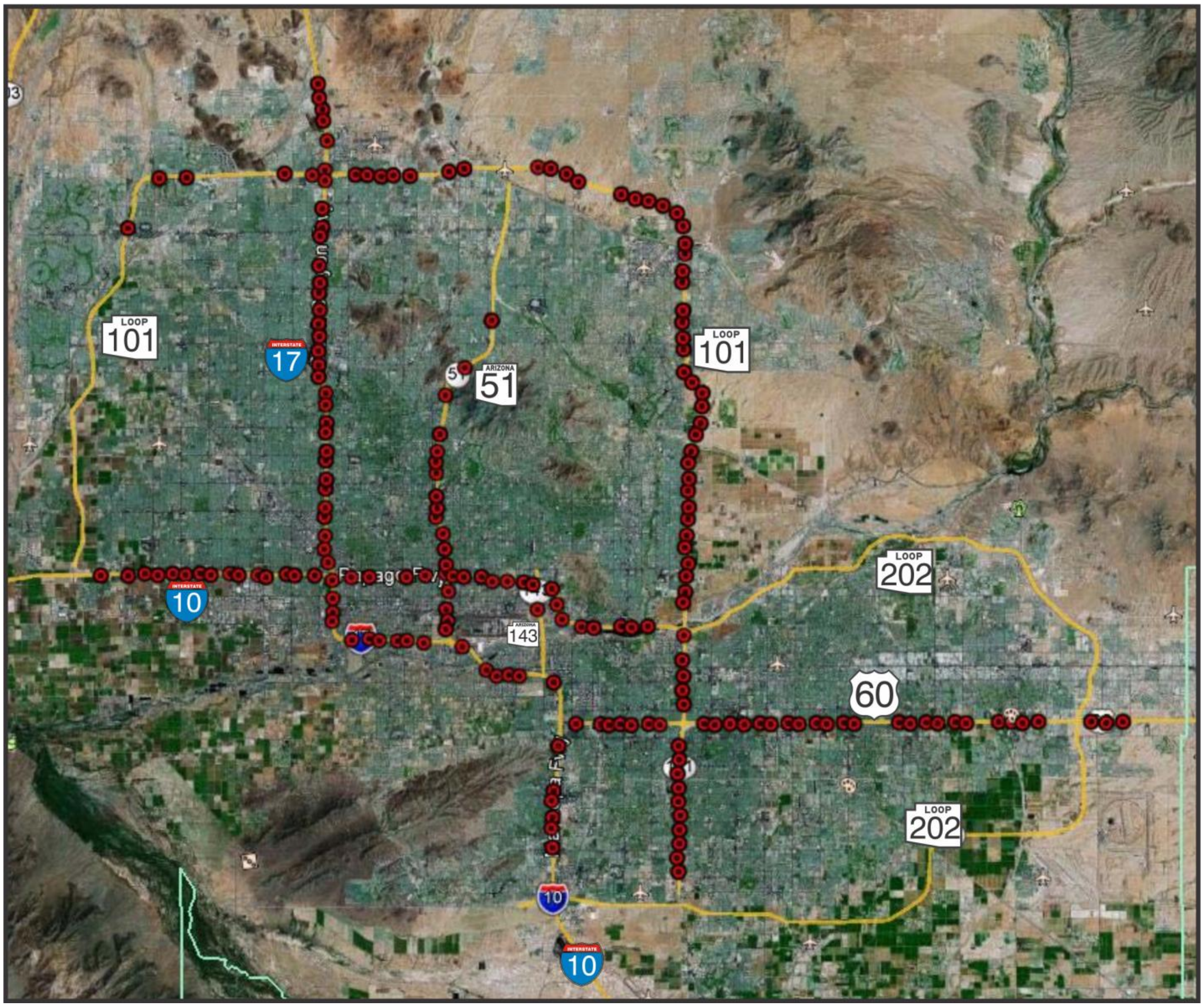
As of summer 2012, The Arizona Department of Transportation operates 201 ramp meters in the Phoenix-Metro region. Figure 10 depicts the division of metered and unmetered entrance ramps.



Source: United Civil Group, ADOT, July 2012

Figure 10: Entrance Ramps Metered

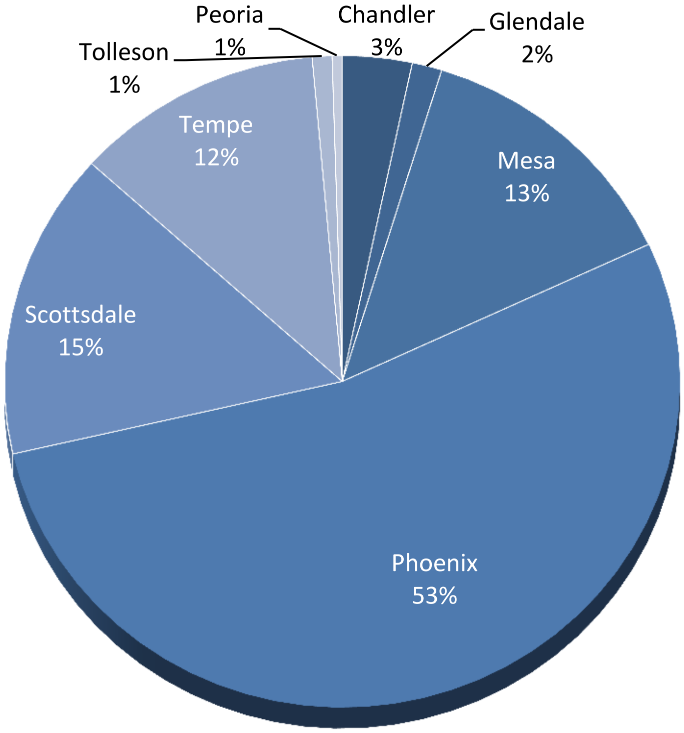
Ramp meters are typically located in sections of freeways with completed Intelligent Transportation System (ITS) deployments, named Freeway Management System (FMS) Phases. In special circumstances, ramp meters have been installed outside of completed FMS Phases and are referred to as a stand-alone ramp meters. Figure 11 shows the locations of all Arizona Department of Transportation ramp meters.



Source: United Civil Group, July 2012 (map: Google Earth)

Figure 11: Ramp Metering Locations

Eight agencies neighbor metered entrance ramps, distributed as depicted in Figure 12.

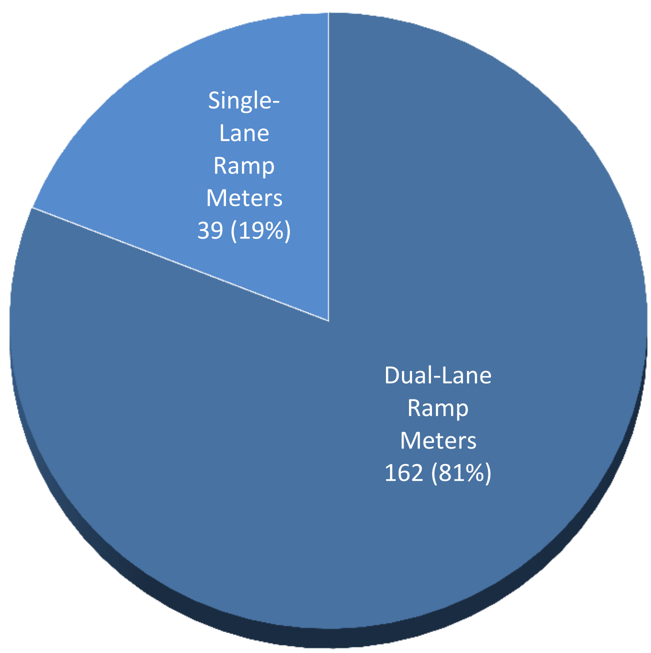


(Entrance ramps on agency boundaries are listed with both agencies)

Source: United Civil Group, July 2012

Figure 12: Ramp Metering by Agency

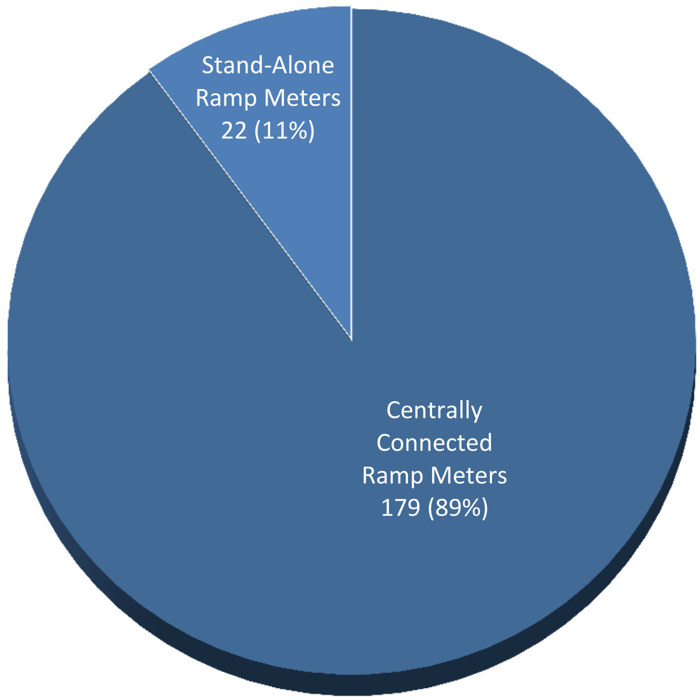
Ramp meters in the Phoenix-Metro region control either one lane or two lanes of traffic, as depicted in Figure 13.



Source: United Civil Group, July 2012

Figure 13: Number of Lanes Metered

Of the 201 ramp meters in the Phoenix-Metro region, 179 are connected to the Arizona Department of Transportation communications network and are able to be centrally monitored and controlled, and also transmit traffic data. The remaining 22 ramp meters are not yet connected to a communications network and cannot be centrally monitored and controlled, nor transmit traffic data.



Source: United Civil Group, July 2012

Figure 14: Ramp Meter Communications Connectivity

Ramp Metering Inventory and Database

The existing Arizona Department of Transportation ramp metering system was comprehensively documented by United Civil Group. Approximately 23,000 pieces of information regarding the Arizona Department of Transportation current ramp metering system were collected. A database with the information was prepared to:

- easily access ramp metering data by ADOT staff
- Uniformly evaluate and apply changes to ramp meters
- Consolidate and organize multiple sources of data, allowing coordinated and up-to-date ramp metering information between ADOT staff from different departments
- Provide an easy-to-use database to quickly and accurately answer public inquiries

Ramp Metering System GIS Survey

United Civil Group completed a GIS survey using Global Positioning System (GPS) equipment with accuracy of ±6 inches. The survey was imported into the ADOT Geographical Information System managed by the ADOT Multimodal Planning Division. Additionally, the survey was provided in a format viewable in Google Earth.

Current Ramp Metering Operation

Ramp Metering Software

ADOT uses ramp metering software by McCain, Inc. which is installed in each ramp meter's controller and executes two primary functions:

1. Controls ramp metering operation such as the metering rate, metering time of day, and the startup and shutdown phases.
2. Reports volume, occupancy, speed, and vehicle length based on the electric pulses received from multiple vehicle detectors

ADOT uses TransSuite FMS Software, developed by TransCore, to enable two-way communications between the ramp meter controller and central control sites which include the ADOT Traffic Operations Center and the Phoenix Maintenance District ITS office. Every 20 seconds TransSuite polls the McCain software for ramp metering status and traffic data accumulated since the previous polling.

Current Ramp Metering Rate

ADOT uses two ramp metering rate selection methods depending on the vehicle detection capabilities at the ramp meter:

- **Fixed Rate Metering** – A fixed metering rate is used at typical stand-alone ramp meter locations which do not have freeway detectors to monitor and respond to traffic conditions. All stand-alone ramp meters operating in this mode are planned to be upgraded in the near future to provide two-way central communications and freeway detection, allowing operation in local traffic responsive metering mode.

- **Local Traffic Responsive Ramp Metering** – The metering rate adjusts based on real-time traffic data received from the vehicle detectors that are connected to each ramp meter. The metering rate for local traffic responsive metering is one of six metering levels selected based on the average speed of the two right-most freeway lanes as follows:

Metering Level	Freeway Speed	Metering Rate
	(Miles/Hour)	(Vehicles/Hour)
1	>65	1,440
2	65 to 56	1,320
3	55 to 46	1,200
4	45 to 36	1,080
5	35 to 11	960
6	10 to 0	840

Table 7: Current Local Traffic Responsive Metering Rates

Current Ramp Metering Time of Day

Ramp meters operate Monday through Friday during fixed times corresponding to peak traffic periods. Typically, entrance ramps heading towards Central Phoenix start metering in the morning at either 5:30 AM or 6:00 AM and end at 9:00 AM. Entrance ramps in the opposite direction, heading away from Central Phoenix, start metering in the afternoon at 3:00 PM and end at 7:00 PM. There are exceptions to the above patterns such as the SR-L101 Pima freeway in Scottsdale, where ramp meters are active in both directions in the morning and afternoon.

Holidays

The Arizona Department of Transportation turns off ramp meters on holidays that are historically not congested. United Civil Group recommended new programming that automatically deactivates ramp meters during holidays. This new programming was tested and was successfully implemented into all ramp meters in November of 2012. Ramp meters are inactive during the holidays listed in Table 8.

Holiday	Day Ramp Meter Is Inactive		McCain Software Parameter											
			Line	Month	Day	Plus Days	Week of Month	Day of Week						
								S	M	T	W	T	F	S
New Year's Day	January 1st (or nearest weekday)	*if holiday is on weekday*	1	1	1	0	0	-	2	3	4	5	6	-
		if holiday is on Saturday and observed on Friday	2	12	31	0	0	-	-	-	-	-	6	-
		if holiday is on Sunday and observed on Monday	3	1	2	0	0	-	2	-	-	-	-	-
Dr. MLK Jr./Civil Rights Day	3rd Monday in January		4	1	0	0	3	-	2	-	-	-	-	-
Memorial Day	Last Monday in May		5	5	25	6	0	-	2	-	-	-	-	-
Independence Day	July 4th (or nearest weekday)	*if holiday is on weekday*	6	7	4	0	0	-	2	3	4	5	6	-
		if holiday is on Saturday and observed on Friday	7	7	3	0	0	-	-	-	-	-	6	-
		if holiday is on Sunday and observed on Monday	8	7	5	0	0	-	2	-	-	-	-	-
Labor Day	1st Monday in September		9	9	0	0	1	-	2	-	-	-	-	-
Veterans Day	November 11th (or nearest weekday)	*if holiday is on weekday*	10	11	11	0	0	-	2	3	4	5	6	-
		if holiday is on Saturday and observed on Friday	11	11	10	0	0	-	-	-	-	-	6	-
		if holiday is on Sunday and observed on Monday	12	11	12	0	0	-	2	-	-	-	-	-
Thanksgiving	4th Thursday in November and the following Friday		13	11	**X***	1	0	-	-	-	-	5	-	-
Christmas	December 25th (or nearest weekday)	*if holiday is on weekday*	14	12	25	0	0	-	2	3	4	5	6	-
		if holiday is on Saturday and observed on Friday	15	12	24	0	0	-	-	-	-	-	6	-
		if holiday is on Sunday and observed on Monday	16	12	26	0	0	-	2	-	-	-	-	-

*Thanksgiving Day must be manually entered each year because of a limitation in the number of lines and holidays that can be entered.

Table 8: Holiday Parameters

Other Ramp Meter Operations

Other current parameters are listed in the following table:

Parameter	Value
Minimum Green Time	1.5 Seconds
Maximum Green Time	1.5 Seconds
Minimum Red Time	1.5 Seconds
Startup - Phase	Red
Startup - Pre-Metering Flash Time	20 Seconds
Queue Detection Activation Trigger	50% occupancy
Queue Detection De-activation Trigger	10% occupancy
Queue Detection Response	Metering Level 1 (fastest)

Table 9: Current General Parameters

Descriptions of other current operations controlled by ramp metering include:

- **Start-up Metering** – The time interval and operation from the non-metering state to the metering state. Currently, this consists of the beacon flashing for 20 seconds on the warning flasher assembly prior to metering (ramp meter is dark)

- **Shut-down** – The time interval and operation from the metering state to the non-metering state. This may include the ramp meter resting in green for a set time after metering ends. A shut-down interval is not used because a queue of traffic will "self-meter". Meaning drivers take visual cues from stopped traffic, not recognizing the ramp meter is dark, and stop for a second or two to wait for a green. "Self- metering" typically continues until the ramp meter queue clears. From an operations standpoint, this phenomenon works well. If the ramp meter were to indicate a steady green at shut-down, all vehicles that are queued could be flushed onto the freeway all at once, potentially causing issues.

- **Priority Vehicle Passage** – The operation that grants priority passage when a special type of vehicle is detected such as a public bus or emergency vehicle. Any method of detection may be used to detect a priority vehicle. Priority vehicle passage is not currently used at any locations.

Ramp Metering Hardware

Controller

The ADOT Transportation Technology Group recently completed a major milestone in the ramp metering system by installing Siemens model 2070 controllers system-wide. These controllers allow central control and enhanced flexibility as compared to the model 179 ramp meter controllers. Taking full advantage of the new controllers was one of the primary reasons for initiating this project.

Signal Heads

ADOT uses dual-indication signal heads with red and green indications. When space allows, the desirable setup is two signal heads per lane, roadside-mounted on a 10 ft signal pole. The upper signal head is aimed for best viewing for approaching vehicles and the lower head is aimed for best viewing while stopped at the ramp meter stop bar. When space is restricted, the signal heads are mounted overhead on a mast arm.

Ramp meters typically incorporate lights on the back of the signal indications to aid in the enforcement of ramp meters. These lights are referred to as “tattle-tale” lights and consist of a small LED cluster.

Warning flasher beacons with a “RAMP METERED WHEN FLASHING” sign are installed on entrance ramps in advance of all ramp meters.

Signing and Pavement Marking

Signing and pavement markings for ramp metering vary based on policies in place when the design plans were prepared. Below is a summary of the current signing and pavement markings at ramp meters.

Stop Bar	100% of ramp meters have a stop bar present
Type Of Lane Line Prior To Stop Bar	46% have a skip line, 54% have a solid line
***ONE VEHICLE PER GREEN* Signing (R10-28 or R10-29aAZ)**	194 out of 201 ramp meters have this sign
***STOP HERE ON RED* Signing (R10-6 or R10-6a)**	50% of ramp meters have this signing
***RAMP METERED WHEN FLASHING* Sign (W3-8)**	100% of ramp meters have this sign

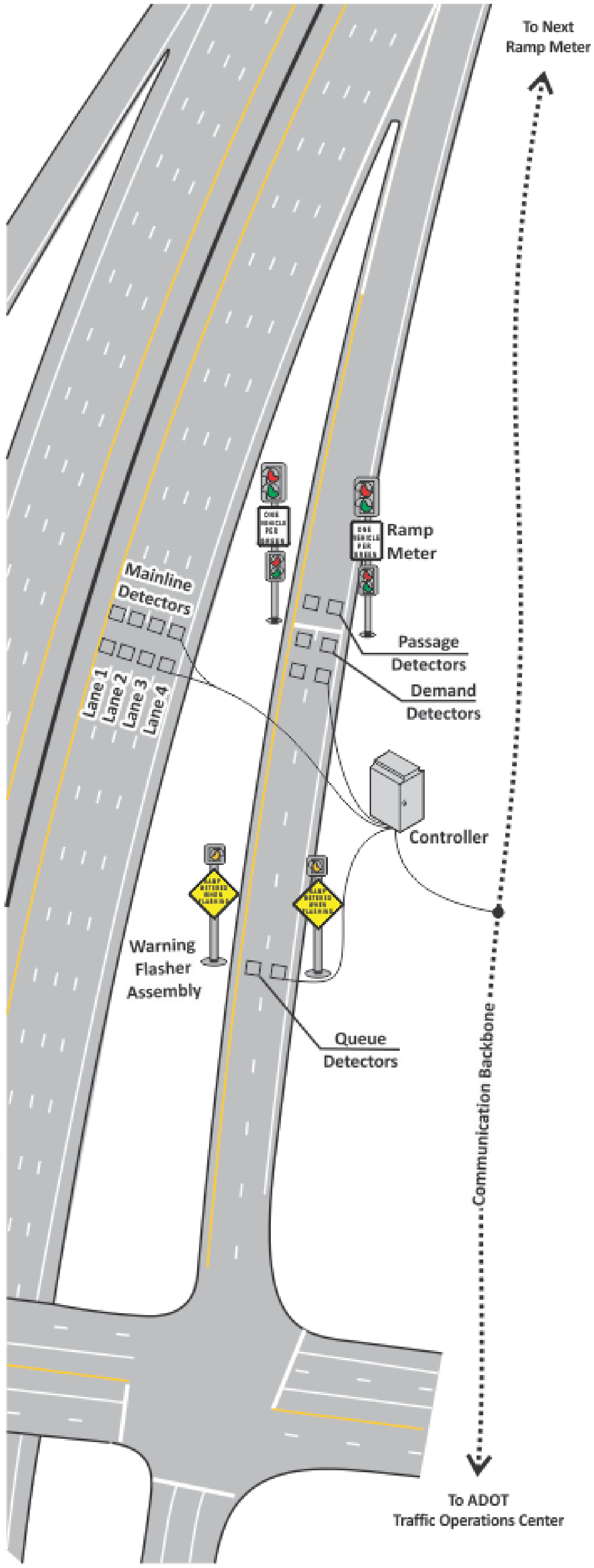
Source: United Civil Group

Table 10: Signing and Pavement Marking

Vehicle Detection

On the entrance ramp, all ramp meters use a standard arrangement of loop detectors consisting of queue detectors, demand detectors, and passage detectors as depicted in Figure 15. The queue detectors consist of either one 6 foot by 6 foot loop in each lane, or one 6 foot by 20 foot loop detector spanning two lanes. The demand detectors consist of a pair of 6 foot by 6 foot loops in each lane, separated by 10 ft and wired in series to act as one detector.

Freeway detectors are located in each freeway lane and are typically located adjacent to the ramp meter stop bar. The majority of freeway detectors consist of a pair of 6 foot by 6 foot loops in each lane. Passive acoustic detectors (PAD) are used at some locations and one location uses radar detection.



Source: United Civil Group

Figure 15: Ramp Meter Configuration

Traffic Data Collection and Reporting

Ramp meters collect and report real-time freeway and entrance ramp traffic data in the Phoenix-Metro region every 20 seconds, 24 hours a day. Ramp meters that are not centrally-connected do not report freeway traffic data.

Freeway and entrance ramp traffic data is also collected and reported by traffic data collection stations which are located where long gaps between ramp meters occur so that traffic data can be obtained at approximate one-mile intervals. Traffic data collection stations utilize the same controller, software, detection equipment, and centralized communications as a ramp meter.

Real-time freeway and entrance ramp traffic data is used to automatically adjust ramp metering operation, monitor traffic, and report travel times. Traffic data is also archived and is used for transportation planning and design. Freeway and entrance ramp traffic data is reported through the following websites:

Website Address	Real-Time	Historical	Speed	Volume	Occupancy	Classification
http://www.aztechrads.org/monitor/dataDump.jsp?logId=detstn_mc2070	●		●	●	●	●
http://www.aztechrads.org/fms/	●		●	●	●	●
ftp://ftp.az511.gov/pub/webdata/ips.out	●		●	●	●	
http://www.az511.gov/adot/files/traffic/	●		●			
ftp://ftp.az511.gov/pub/traffic/		●	●	●	●	

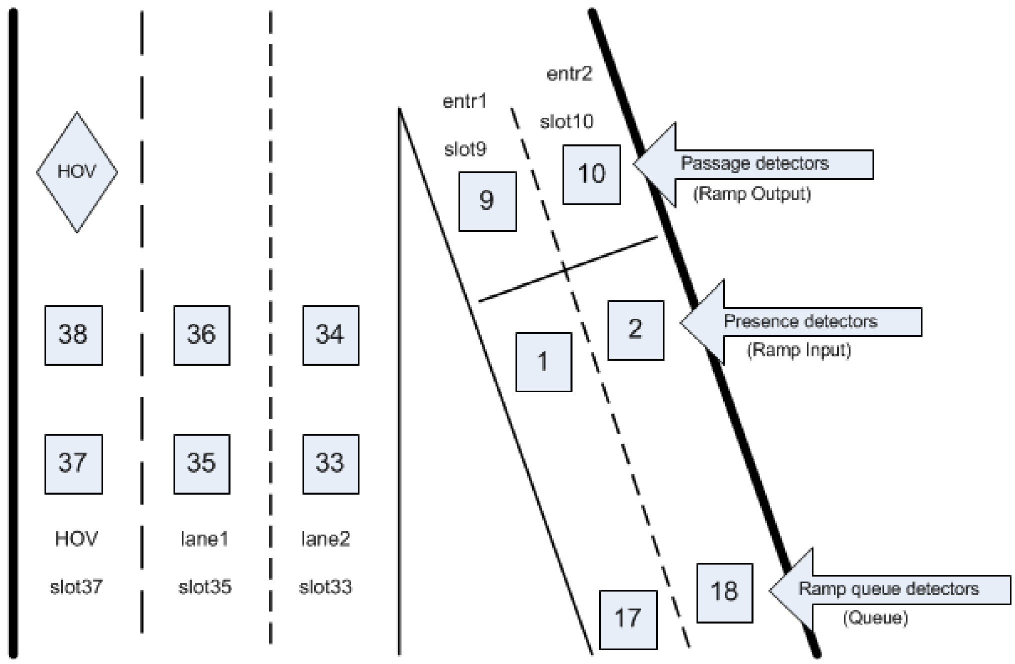
Table 11: Freeway and Entrance Ramp Traffic Data Websites

The units of traffic data provided in the above webpages are defined in the following tables and figures.

Lane Label	Lane Definition
HOV	left-most freeway lane
lane1	
lane2	
lane3	
lane4	
lane5	
lane6	right-most freeway lane
entrance from	entrance-ramp lane

Note: Right and left is in reference to facing the same direction as direction of travel

Table 12: "Lane" Definition



Detector Numbers & Lane Designations:

1 – 8 Ramp presence / demand detector
9 – 16 Ramp passage detector
17 – 32 Ramp queue detector
33 – 80 Mainline lane detector
81 – 88 Ramp other detector

Source: Oz Engineering

Figure 16: "Slot" Definition

Volume

Traffic volume is reported for each freeway lane by the freeway detectors and for each entrance ramp lane by the passage detectors. The locations of these detectors are shown in Figure 15.

Speed

Vehicle speed is reported for each freeway lane by pairs of freeway detectors. The freeway detector pairs are typically located adjacent to the ramp meter stop bar as shown in Figure 15. The ramp metering software reports an average vehicle speed every 20 second calculated from the average trap time per vehicle. Trap time is the time elapsed from detection of a vehicle by the leading detector to the detection by the trailing detector, measured in units 1/385th of a second.

Occupancy

Occupancy is reported for each freeway lane by the freeway detectors and for each entrance ramp lane by the passage detectors. The locations of these detectors are shown in Figure 15. Occupancy is the measure of the proportion of time that vehicles are detected, expressed as a percentage. To convert the reported occupancy to occupancy as a percentage, use the conversion calculation in Table 13.

Reported Unit	Unit Conversion
occ_200pct	multiply reported occupancy by 0.5 to get occupancy as a percent
occ_.01pct	multiply reported occupancy by 0.1 to get occupancy as a percent

Table 13: Occupancy Unit Conversion

Vehicle Classification

United Civil Group coordinated with the ADOT Transportation Technology Group and the ADOT Multimodal Planning Division and recommended a new method to classify vehicles by length, distinguishing motorcycles, passenger vehicles, and heavy vehicles. The new classification method was implemented system-wide on February 15, 2013.

Because the ADOT Multimodal Planning Division operates a separate system of traffic data collection stations, this improvement was an important step towards the Multimodal Planning Division using the traffic data from the Transportation Technology Group's system and eliminating two separate freeway traffic data collection systems in the Phoenix-metro region.

Vehicles classification is reported for each freeway lane by the freeway detectors shown in Figure 15. Vehicles are now classified according to the lengths listed in Table 14. The old vehicle classification lengths are listed in Table 15.

Reported Bin Label	Vehicle Classification Group	Detected Length*
bin1	Classification Group 1 – Motorcycles	0 to 5 feet
bin2	Classification Group 2 – Passenger Vehicles	6 to 20 feet
bin3	Classification Group 3 – Single Unit Heavy Vehicles	21 to 55 feet
bin4	Classification Group 4 – Single Trailer Heavy Vehicles	56 to 75 feet
bin5	Classification Group 5 – Multi-Trailer Heavy Vehicles	76 to 98 feet
bin6	Not used	Not used
bin7	Not used	Not used
bin8	Special Permit Required	99 feet and longer

*The length depends upon the detectable length of the vehicle and may be different than bumper-to-bumper length.

Table 14: New Vehicle Classification (after Feb 15, 2013)

Reported Bin Label	Detected Length
bin1	0 to 9 feet
bin2	10 to 19 feet
bin3	20 to 29 feet
bin4	30 to 39 feet
bin5	40 to 49 feet
bin6	50 to 59 feet
bin7	60 to 69 feet
bin8	70 feet and longer

Table 15: Prior Vehicle Classification (before Feb 15, 2013)

RAMP METERING OBJECTIVES

According to the *Highway Capacity Manual* (Transportation Research Board 2010), the measures that influence driver-perceived quality of service consists of:

- Travel time (includes travel time reliability)
- Fuel used (includes vehicle emissions and number of stops incurred)
- Safety

"Quality of service" describes how well a transportation system operates from a driver's perspective. Although, many factors may affect the quality of service of a transportation system, this evaluation only considers ramp metering and its effects on quality of service. The following objectives were developed to guide ramp metering operation strategies in order to maximize the quality of service for drivers and to satisfy ADOT's requirements for this project:

Objective A

Minimize trip travel time. The trip travel time affects travel delay and productivity of motorists.

Objective B

Minimize fuel use and vehicle emissions. Fuel used and vehicle emissions affects fuel cost and environmental impacts.

Objective C

Minimize crashes. Crashes affect personal safety and property damage.

Objective D

Avoid queue spillback. Ramp meter queue spillback into the cross-street intersection affects cross-traffic if vehicles do not clear the intersection.

Objective E

Recommendations are easily implementable. The effort required to implement recommendations affects how soon improvements can be realized.

These objectives apply to all ramp metering control modes. Currently, ADOT uses local traffic responsive ramp metering control. In the future, if corridor traffic adaptive ramp metering control (smart ramp metering) is used, these objectives will still apply.

Meeting the Ramp Metering Objectives

This section presents the methodology used to develop the ramp metering recommendations to meet the ramp metering objectives. This methodology identifies key traffic variables and equations for trip travel time, fuel use, crashes, and the other ramp metering objectives which primarily utilizes traffic data provided by the ramp meter detectors. This allows, the methodology to be easily used in the future to compare conditions before and after ramp metering changes are made.

Minimizing Trip Travel Time

Minimizing trip travel time is identified by Objective A. Ramp metering regulates the flow rate of traffic entering the freeway, and therefore can affect the flow rate of the freeway and improve freeway speed and freeway travel time by keeping demand below the capacity of the freeway. However, when a ramp meter is on, it also creates delay on the entrance ramp. Therefore, ramp meters are recommended to only be on during the times of day when ramp metering is anticipated to reduce the total trip travel time, considering both the entrance ramp delay created and improvement to freeway speed. The following information in this section provides the justification and background for this strategy.

Factors effecting trip travel time

The travel time of a trip, from origin to destination, can be dictated by several sources of delay including ramp meters, traffic signals, stop signs, congestion, speed limits, incidents, construction, and weather. However, this evaluation only includes the effects on trip travel time as a result of ramp metering. The specific effects on trip travel time as a result of ramp metering are:

- ramp metering effect on freeway speed and freeway travel time
- ramp metering control delay and entrance ramp travel time

The justification for two effects on trip travel time that are not included in this evaluation, because they are not anticipated to be significantly affected by ramp metering, is included in the following paragraphs:

> *Cross-Street Intersection Effect on Trip Travel Time*
> Travel time at the intersection of a cross-street and metered entrance ramp will be unaffected by ramp metering as long as the queue from a ramp meter does not spillback into this intersection. Because ramp meter queue spillback will be mitigated, as identified in Objective D, the travel time of the cross-street will not be affected by ramp metering and is not considered in the trip travel time measurement.
>
> *Route Diversion Effect on Trip Travel Time:*
> Ramp metering has the potential to affect trip travel time if it changes traffic demand through route diversion. Drivers typically choose a route for a trip considering the fastest travel time. Therefore, ramp metering can affect a driver's route choice because

it requires vehicles to wait for a green light, creating delay. Two specific route diversion effects were identified as a result ramp metering:

- A surface-street may be used as an alternative to a metered entrance ramp and freeway.
- One metered entrance ramp may be by-passed for the next downstream entrance ramp, with less delay.

These effects are not included in the study because predicting these effects on trip travel time would require an extensive evaluation of traffic conditions on the surface-street network. In addition, these effects on trip travel time are anticipated to be minor. After ramp metering changes are implemented, a before-and-after study can be conducted to measure route diversion. Summaries of two before-and-after studies prepared for other agencies, justifying this are provided below:

- A Minneapolis/St Paul, Minnesota study showed that only 1% of all peak period travelers changed routes after new ramp metering operation was deployed, even though a large number of them, 14%, were delayed by the operation. (Cam012)

- A Wisconsin study discovered that after ramp metering was implemented, diversion from the freeway to alternative surface-street routes and from congested ramps to more desirable ramps did occur. Diversion was more prominent if frontage roads existed alongside the freeway. However, the study concluded that diversion occurs in very complex ways and was difficult to measure using standard traffic data collection techniques (Wu 2005).

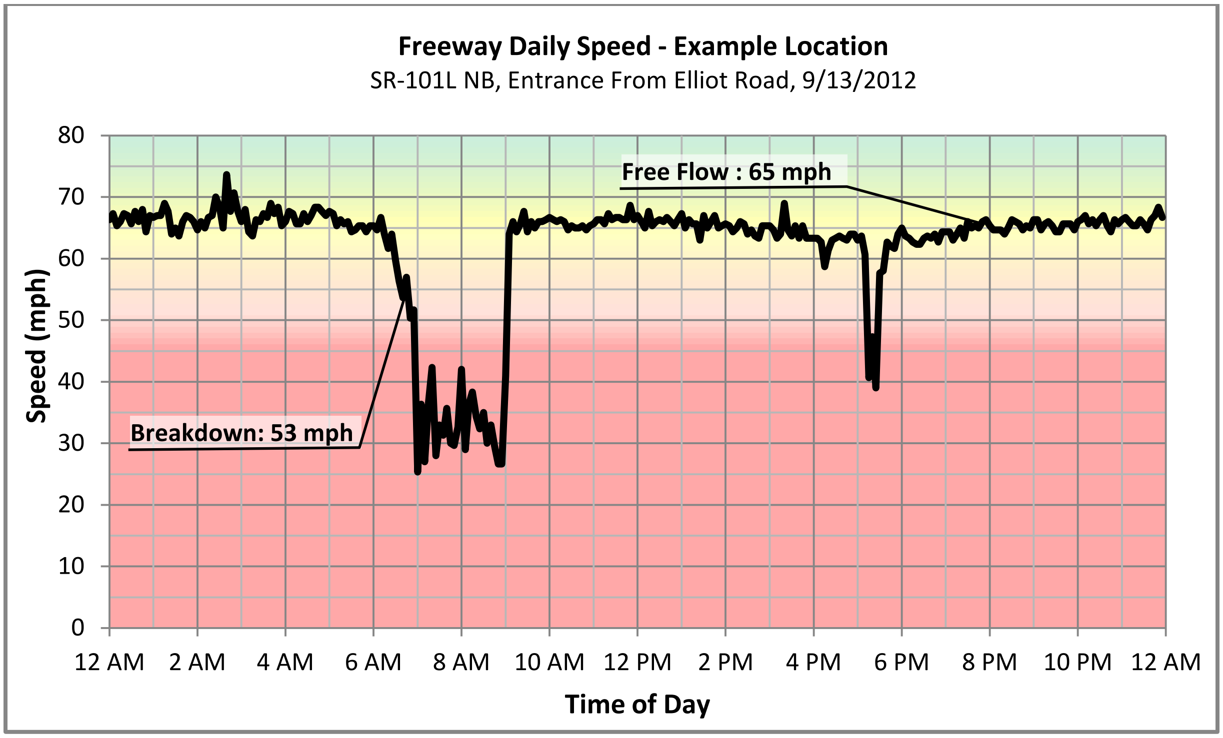
Ramp metering effect on freeway speed and freeway travel time

The following equation presents the mathematical relationship of freeway travel time and freeway speed data reported from the ramp meter detectors:

$$\text{Freeway Travel Time} = \frac{\text{Freeway Segment Length}}{\text{Freeway Detector Speed}}$$

From the above relationship, as speed increases the calculated freeway travel time decreases. This equations assumes the freeway spot speed reported from the ramp meter detectors is the average speed of the freeway segment being evaluated. This assumption is validated in the following section.

Freeway travel time increases significantly when a breakdown in speed occurs. This can be seen by examining the speed data of a typical freeway detector. Speed data at an example location is provided in Figure 20, which shows a breakdown speed that occurs between 6:00 am and 9:00 am and at 5:00 pm. Breakdowns in speed typically occur very quickly as shown by the sudden drops in speed at 7:00 am from 50 mph to 25 mph, resulting in freeway travel time doubling.



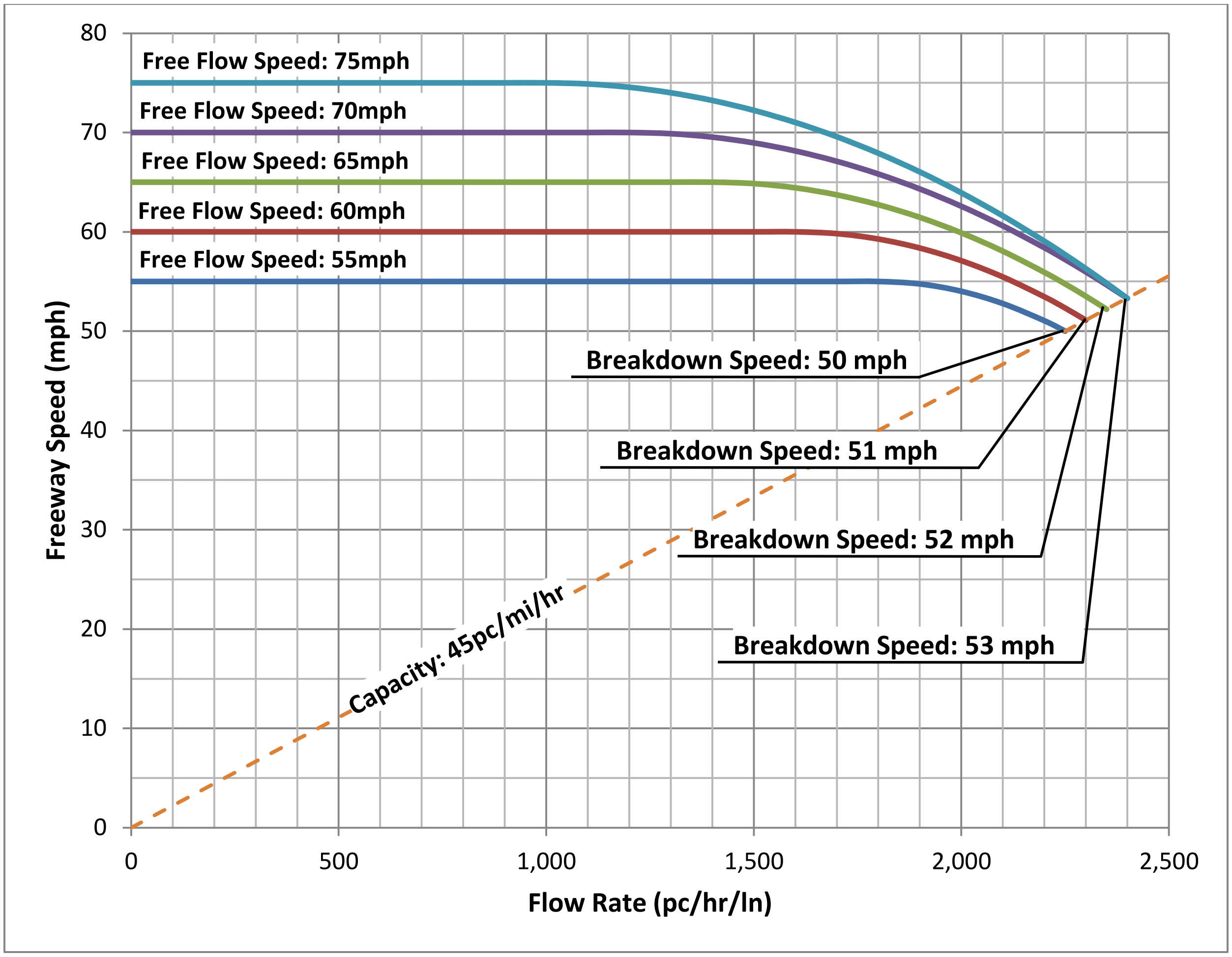
Source: United Civil Group (traffic data from ftp://ftp.az511.gov/pub/traffic/)

Figure 17: Freeway Breakdown

The traffic flow theory in the 2010 *Highway Capacity Manual* (HCM) is used to describe the cause of the sudden decrease in freeway speed. The HCM states that when freeways near capacity, traffic flow becomes highly volatile because there are virtually no usable gaps within the traffic stream, leaving little room to maneuver. Any disruption to the traffic stream, such as vehicle entering from a ramp, can create a disruption wave that propagates throughout the upstream traffic flow, resulting in queuing and a breakdown in traffic speed and significant increase in travel time. Breakdown is a result of flow-constricting bottlenecks caused by:

- Merging
- Diverging
- Weaving
- Lane drops
- Roadside construction
- Crashes
- Debris
- Disabled vehicles

The HCM defines a correlation between freeway speed and flow rate of freeways of different free-flow speeds as depicted in the following figure:

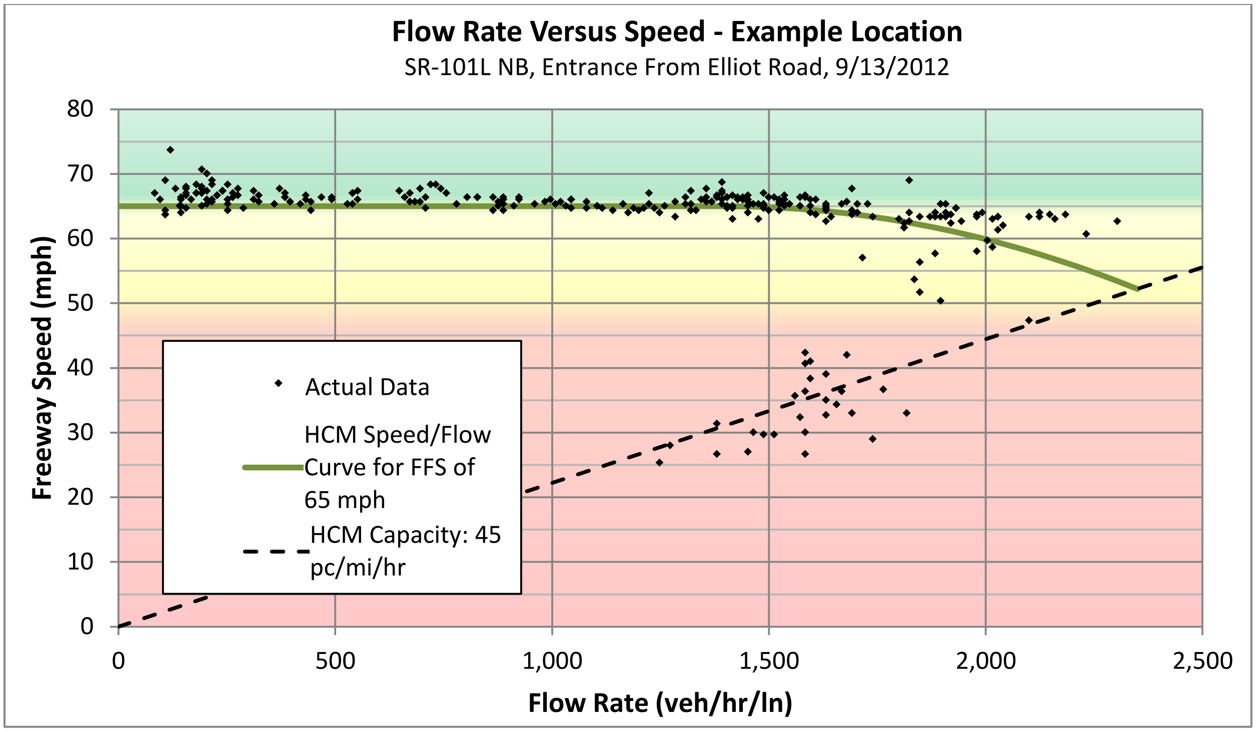


Source: Reproduced by United Civil Group from Highway Capacity Manual 2010

Figure 18: HCM Freeway Speed and Flow Curves

As can be seen by examining the freeway speed/flow curves, speed (and travel time) is unaffected by flow rates less than 1,000 to 1,800 pc/hr/ln. After these flow rates are exceeded, freeway speed gradually reduces up to the freeway capacity flow rate of 2,250 to 2,400 pc/hr/ln. When the demand flow rate exceeds freeway capacity, traffic flow breakdowns and speed drastically reduces (the HCM does not define the speed/flow curves for this condition).

Figure 22 shows the same speed data from Figure 20, except it is plotted against flow rate rather than time of day. The HCM 65 mph free-flow curve is overlaid on this data. As can be seen, the actual data plots very close the HCM speed/curve, validating the HCM traffic flow theory. At many freeway locations, actual traffic conditions have been observed to correlate well with the HCM speed/flow curves.



Source: United Civil Group (data from ftp://ftp.az511.gov/pub/traffic/)

Figure 19: Example Speed and Flow Relationship

Because ramp metering regulates the flow rate of traffic entering the freeway, it can therefore affect the flow rate of the freeway and improve freeway speed and freeway travel time by keeping demand below the capacity of bottlenecks. However, due to limitations in the existing ramp metering system's capabilities, it may not be possible to always keep the demand below the capacity of bottlenecks.

Validation of Freeway Travel Time Calculation

The method provided above for calculating freeway travel time relies on spot speeds reported by freeway loop detectors. Because these loop detectors collect speed at one point on the freeway (spot speed), an evaluation was performed to validate whether spot speeds can be used to adequately reflect the average speed over a 1-mile study segment. This validation was performed by comparing data collected by BlueTOAD Bluetooth detectors to the loop detector data.

The BlueTOAD Bluetooth devices collect travel time between two points by detecting a unique code (MAC addresses) wirelessly-emitted by Bluetooth-enabled devices in vehicles, such as phones, headsets, and music players. The BlueTOAD system records and timestamps each MAC address. The collected data is then provided to Trafficast, the supplier of BlueTOAD devices, and travel time data is obtained by comparing timestamps of matching MAC addresses from one detector to another detector. BlueTOAD Bluetooth data was collected at three 1-mile freeway segment locations:

- WB US-60 at Val Vista Drive
- EB I-10 at Broadway Road

- SB SR-51 at Indian School Road

BlueTOAD Bluetooth speed was calculated by dividing the distance between the Bluetooth detectors by the travel times collected. The BlueTOAD Bluetooth speeds from were then plotted against the freeway loop detector spot speeds for the three 1-mile freeway segments studied. Figures 17 through 19 present the results.

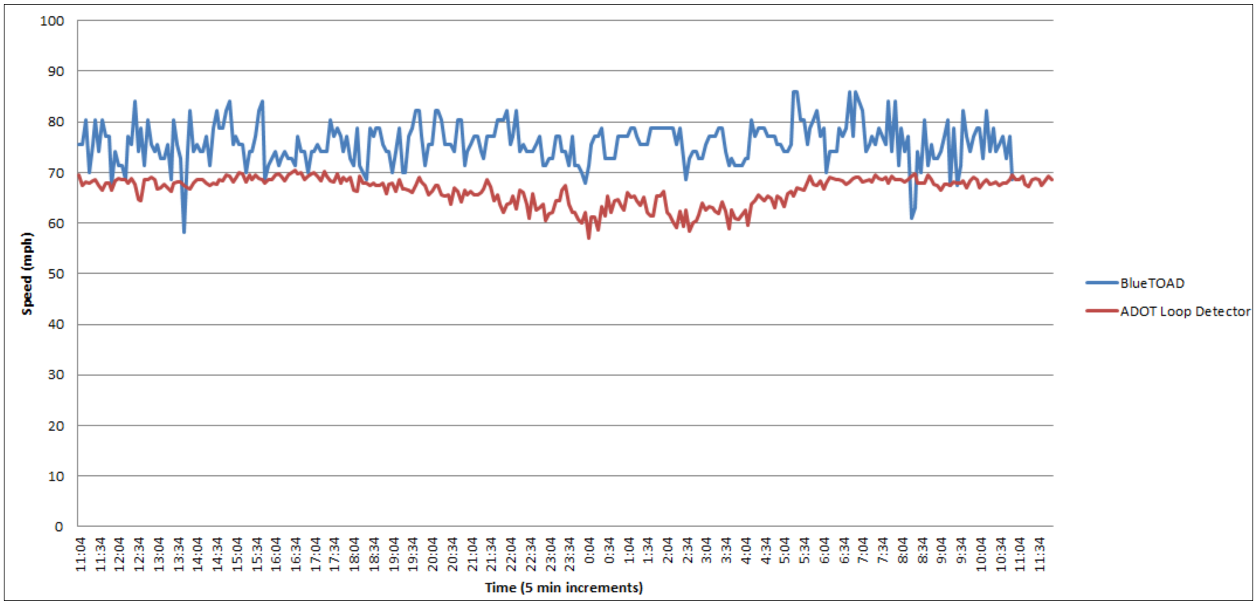


Figure 20: Loop Detector versus Bluetooth Speed - WB US-60 at Val Vista Dr, Oct 25, 2012

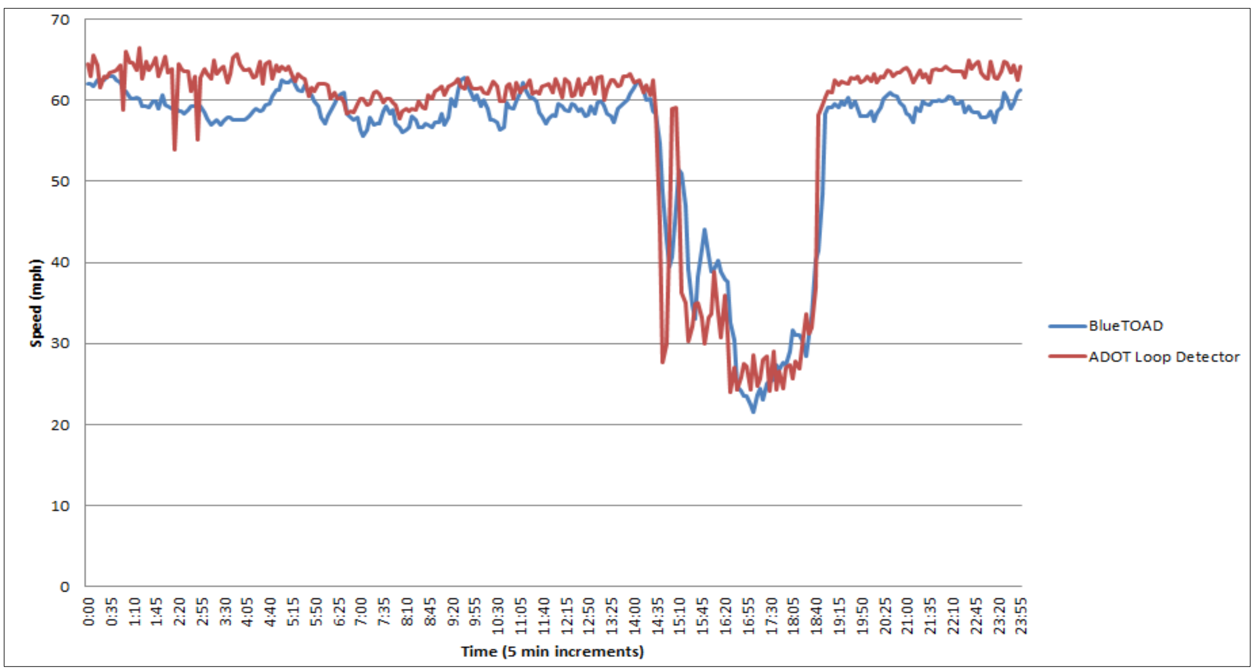


Figure 21: Loop Detector versus Bluetooth Speed - EB I-10 at Broadway Road, Jan 22, 2013

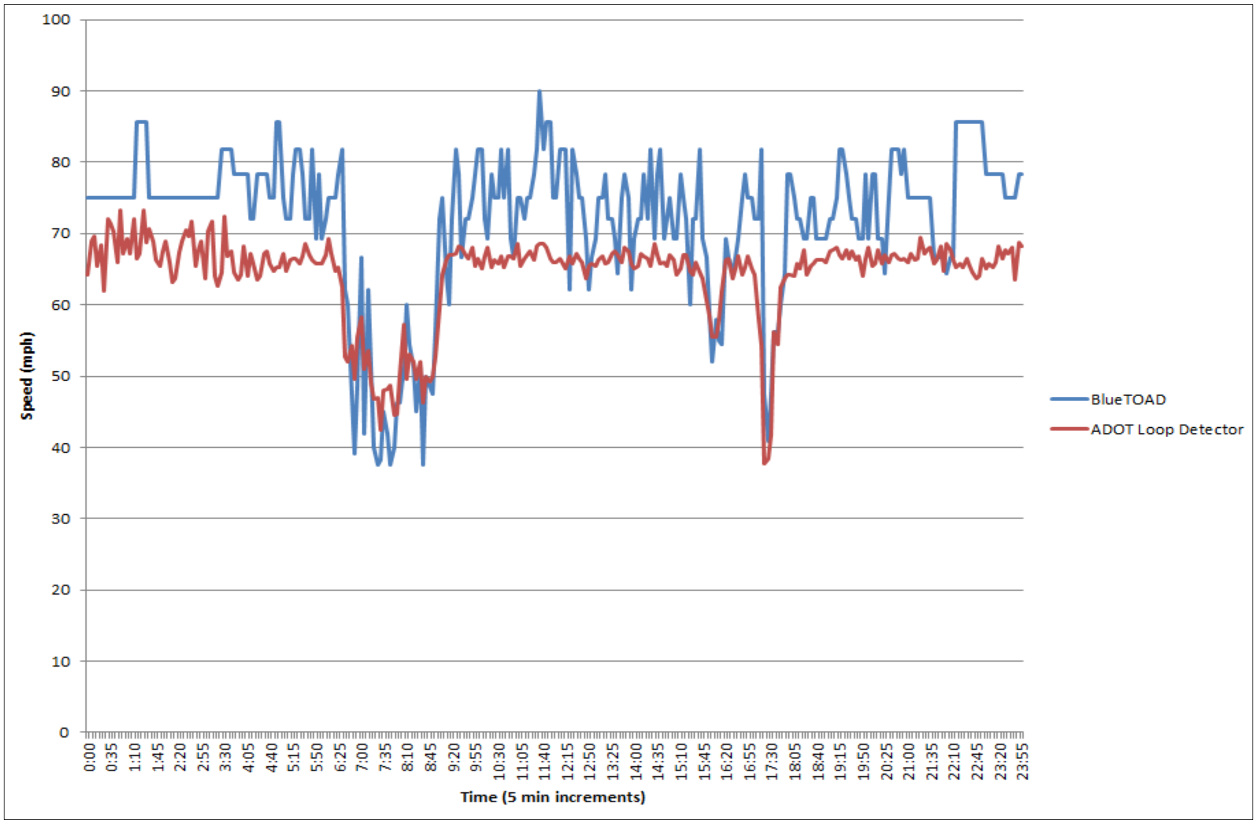


Figure 22: Loop Detector versus Bluetooth Speed - SB SR-51 at Indian School Rd, Apr 2, 2013

It was found that by comparing the BlueTOAD Bluetooth data to the loop detector data, it shows that loop detector data adequately reflects breakdowns in traffic flow on freeway segments 1-mile long. This comparison should not be considered as an evaluation for using loop detector to report travel times. Rather, the purpose of this comparison was to evaluate whether a spot speed can be used to adequately reflect average speed over a 1-mile segment. It can be seen that the BlueTOAD Bluetooth data showed higher variability between intervals as compared to the freeway loop detector data. This variability in speed may represent the true speed or may be due to small number of samples in each interval.

As a result of these comparisons, the freeway spot speed collected by the loop detectors provides an adequate estimate of average speed over a 1-mile freeway segment and the loop detector spot-speed data can be used to control ramp meters to minimize travel time.

Ramp Meter Control Delay

When a ramp meter is on, it creates delay because it requires vehicles to wait for a green light. However, ramp metering may be justified if it results in an overall improvement in trip travel time by improving the freeway travel time. Ramp meter control delay is made up of two components as shown in the following equation:

Ramp Meter Control Delay = Stop Delay + Queue Delay

Stop Delay:
The delay due to stopping at a ramp meter is 11.3 seconds per vehicle on average and represents the delay as a result of deceleration when approaching the ramp meter, waiting for a green light, and then accelerating. This time was determined by taking the difference in field-measured travel times on entrance ramps when ramp meters were off versus when ramp meter were on and without a queue. These travel times were collected with a stop watch at a sample of entrance ramps. The details of this data collection are presented in Appendix B. The stop delay was found to not vary significantly based on length or grade of the entrance ramp. This value represents vehicles that come to a complete stop, slow down, and do not slow down prior to receiving a green light at a ramp meter.

Queue Delay:
The delay due to a queue at a ramp meter must be manually field-measured. A method to accurately predict ramp meter queue delay requires detailed traffic data which is not currently obtainable through ramp meter detectors. Ramp meter queue delay is grouped into one of two categories:

1. *Ramp meter queues last less than one minute* **–** short queue delay is created when platoons of vehicles arrive after the green phase of the surface-street traffic signal. The ramp meter queue clears between signal phases. This occurs when the ramp metering rate is greater than the entrance ramp demand flow rate. Ramp meter queue delay in this category is unavoidable when a ramp meter is on.

2. *Ramp meter queues last longer than one minute* **–** the ramp meter queue does not clear between signal phases. This occurs when the ramp metering rate is less than the entrance ramp demand flow rate and ramp meter queue delay can continue increase if not mitigated. Queue delay in this category is avoidable, but may be acceptable and justified if significant freeway congestion exists.

Minimizing Fuel Use and Vehicle Emissions

Minimizing fuel use and vehicle emissions is identified by Objective B. Fuel use is calculated based on a vehicle's distance traveled, stopped time delay, number of stops, and speed. The following formula provides the relationship of these factors to fuel use and is based on the formula used by traffic optimization software programs such as TRANSYT 7-F and Synchro.

Fuel = (Distance x k1) + (Delay x k2) + (Stops x k3)

Where:
Fuel = Fuel use (gallons)

Distance = Distance traveled (miles)

k1 = $0.075283 - 0.0015892 \times Speed + 0.000015066 \times Speed^2$

Speed = Vehicle Speed (mph)

Delay = Stopped Time Delay (hour)

k2 = 0.7329

Stops = Number of stops

k3 = $0.0000061411 \times Speed^2$

Fuel use as a result of the first term of the fuel use equation (Distance x k1) is minimized at a travel speed of approximately 50 mph. Speeds greater than approximately 50 mph and less than 50 mph will result in higher fuel use. As was previously described in the Minimizing Trip Travel Time section, speeds less than 50 mph indicate a freeway is overcapacity which will result in a significant increase in freeway travel time. Therefore, when travel time is minimized, by keeping the freeway above capacity and above 50 mph, the first term of the fuel-use equation also is minimized. When the freeway speed is greater than 50 mph, it is not recommended to attempt to reduce the freeway speed for purposes of minimizing fuel use.

Fuel use as a result of the second term of the fuel use equation (Delay x k2) is minimized when the delay is minimized. Therefore, As was previously described in the Minimizing Trip Travel Time section, when the trip travel time is minimized (meaning delay is minimized), the second term of the fuel-use equation is also minimized.

Fuel use as a result of the third term of the fuel use equation (Stops x k3) is minimized when the number of stops incurred is minimized. Because ramp metering requires vehicles to stop, fuel use from the third term the equation increases. Therefore, this increase in fuel use should be offset by minimizing the first two terms of the equation, to result in an overall reduction in fuel use.

Vehicle emissions are calculated based on multiplying the gallons of fuel consumed by an emission rate factor. The emission rate factors are based on an unpublished letter to the Federal Highway Administration from Oak Ridge National Labs and are typically used by traffic optimization software programs such as TRANSYT 7-F and Synchro.

Carbon Monoxide Emissions -CO (grams) = Fuel x 69.9

Carbon Monoxide Emissions - NOx (grams) = Fuel x 13.6

Volatile Organic Compounds Emissions - VOC (grams) = Fuel x 16.2

From the above equations, when the fuel use is minimized, emission rates are also minimized.

Minimizing Crash Effect

Minimizing crash effect is identified by Objective C. To minimize overall crash effect, four potential crash effects as a result of ramp metering should be considered as described below:

> **Crash Effect 1 - Difference in the speeds of freeway traffic and traffic merging onto the freeway from the entrance ramp is affected by the acceleration distance from the ramp meter.** When there is a significant speed difference in two streams of merging traffic, turbulence typically increases, raising potential for crashes. ("Turbulence" characterizes sudden braking, accelerating, and lane changes.)
>
> **Crash Effect 2 - Greater maneuverability at the entrance ramp/freeway merge point as a result of ramp metering.** Ramp metering increases the time and distance between entering vehicles. As a result, entering vehicles have better maneuverability, turbulence is reduced, and potential for crashes is decreased. ("Maneuverability" characterizes the ease of changing lanes.)
>
> **Crash Effect 3 - Increased potential for rear-end crashes at the back-of-queue of the ramp meter.** Ramp metering requires vehicles to wait for a green light. This creates a queue of stopped vehicles, and increases the potential for rear-end crashes by inattentive drivers. This effect may be more prominent at ramp metering start-up, when the ramp meter goes from dark to being on.
>
> **Crash Effect 4 - Merging on the entrance ramp from two lanes to one lane is controlled by ramp metering.** At the merge point of dual-lane entrance ramps, where two lanes merge into one entrance ramp lane, ramp metering controls merging by assigning alternating right-of-way to each lane and reduces the potential for side-swipe crashes.

Research was completed on the preceding potential crash effects in an attempt to discover correlations that could be accurately applied to a ramp metering. The results of this research are summarized below:

Crash Factors:
Safety studies often use predetermined factors to predict the safety benefits of installing specific countermeasures. For example, increasing the width of a shoulder from 2 feet to 6 feet has a published safety benefit. These factors are commonly referred to as: Crash Modification Factor (CMF), Crash Reduction Factor (CRF), or Accident Reduction Factor (ARF). Upon research of crash factor databases and the AASHTO *Highway Safety Manual*, a predetermined crash factor is not available which relates ramp metering to crash effect.

Other States' Experiences:
Several states have conducted studies on crashes before and after operating ramp metering. Results typically show reductions in crashes during peak periods as a result of operating ramp metering. However, these studies simply compare crashes before installing ramp metering and after installing ramp metering.

To reasonably apply a ramp metering strategy based on past experience of ramp metering's effect on crashes, a correlation to a traffic conditions is needed. In other words, under what circumstances will ramp metering improve crashes? As an example, a crash benefit could be predicted and a ramp metering strategy applied when the freeway traffic flow rate is above a specific threshold. But the same crash benefit would not be expected when the freeway traffic flow rate is below that threshold. This type of correlation was not discovered in research of the other states' experiences. Therefore, other states' experiences were not used to apply ramp metering strategies to minimize crash effect.

Safety Literature Research:
Research of previously conducted safety studies was completed in an attempt to correlate crash effects to ramp metering. For Crash Effects 2, 3, and 4, no evidence was discovered that could accurately be applied to a ramp metering strategy to minimize crash effect. However, one study was discovered that presented useful results that could be applied to a ramp metering strategy, which was the relationship between crash rate and a vehicle's deviation from the mean speed of traffic.

The study showed that in a traffic stream, as the difference in speeds of vehicles increased, the likelihood of a crash also increased (Research Triangle Institute 1970). This study evaluated crashes on an Indiana highway using in-road sensors to determine the speed of vehicles prior to their involvement in a crash. The results of the study determined a crash rate based on a vehicle's deviation from the mean speed of traffic and is shown in the following table:

Deviation from Mean Speed	Crashes per million vehicle miles traveled
15.5 mph or less below the mean	6.3
15.5 to 5.5 mph below the mean	0.7
5.5 mph below to 5.5 mph above the mean	0.8
5.5 to 15.5 mph above the mean	1.0
15.5 mph or more above the mean	6.9

Source: (Research Triangle Institute 1970)

Table 16: Crash Rates and Speed Deviation

The above relationship between crash rate and deviation from mean speed should be used to minimize *Crash Effect 1 - Difference in the speeds of freeway traffic and traffic merging onto the freeway from the entrance ramp is affected by the acceleration distance from the ramp meter.*

The acceleration distance provided after the ramp meter dictates the speed that will be reached by vehicles prior to merging. When the acceleration distance limits the speed that can be reached by entrance ramp traffic, a differential in speed will be created between the merging entrance ramp traffic and freeway traffic, and a resulting crash effect is anticipated.

At existing ramp meter locations, during periods when the speed of the freeway is greater than the speed that can be reached by entrance ramp traffic, ramp meters should be off.

At new ramp metering locations, acceleration distance should be provided after the stop bar to allow entrance ramp traffic to reach adequate speed prior to merging onto the freeway. The location of ramp meter divides the entrance ramp into two segments: acceleration distance and queue storage distance.

Therefore, providing adequate acceleration distance may result in reduced queue storage distance and this should be accounted for in ramp metering operation.

Avoiding Queue Spillback

Avoiding queue spillback is identified by Objective D. Queue spillback is a result of the entrance ramp traffic demand flow rate exceeding the metering rate for a long enough period of time that the queue of vehicles waiting at a ramp meter grows so long that it reaches into the cross-street intersection. Queue spillback can cause gridlock when drivers who are waiting to turn onto the entrance ramp, do not give way and block cross-traffic. When this happens, an increase in travel time and degradation of other quality of service measures is experienced. The magnitude of the effects of queue spillback varies by location. Queue spillback should be monitored through the use of the advance queue detector located on the entrance ramp near the cross-street intersection. To mitigate the risk of queue spillback, the ramp metering software should automatically respond by immediately increasing the metering rate or turning the ramp meter off. In addition, the traffic signal timing that feeds the entrance ramp may also be manually changed where queue spillback is a recurring issue. The flow rate of vehicles arriving at the ramp meter can be limited by reducing the traffic signal green time of applicable approaches. This strategy limits the queue at the ramp meter by shifting some of the queue onto the cross-street and where necessary can be beneficial to the roadway network as a whole.

Easily Implementable Recommendations

Providing recommendations that are easily implementable is identified by Objective E. The recommended ramp metering control will be easy to implement if existing ramp metering hardware and software are used, and field observation and fine-tuning needed during implementation is minimal at each ramp meter location. The required level of precision of software parameters and field-testing needed for system-wide implementation was considered for the recommended ramp metering improvements. The recommended ramp metering control has been tested to ensure it will operate as anticipated upon full-scale implementation. The recommended ramp metering control was observed and fine-tuned on multiple occasions at a small sample of ramp meter locations to identity unexpected results and provide the best operation.

RAMP METERING MODEL SIMULATION

Simulation modeling is a useful tool in the planning of improvements to urban freeway systems. Modeling allows an engineer to predict outcomes of recommended changes prior to implementation, and to measure quality of service objectives.

VISSIM version 5.4 is the microscopic traffic simulation software that was used to create detailed ramp metering models. VISSIM was selected as the modeling environment based on a review of available microscopic simulation models. This model combines driver behaviors with vehicle performance characteristics. VISSIM is developed to analyze the operations of highway and urban street systems. It can model individual vehicle movements on a second or sub-second basis under a variety of constraints such as roadway geometry, vehicle characteristics, driving behavior and traffic control (ptv vision 2011).

The purpose of this effort is to model a sample of areas with ramp metering, calibrate each area, develop alternative ramp metering strategies, and measure the resulting travel time within each corridor. Five different modeling areas were chosen because locations are affected by ramp metering differently due to traffic volumes, freeway geometrics, and recurring congestion within the area.

Simulation Model Areas

Five areas and time periods were chosen for modeling simulation and evaluation.

Modeling Area 1: US-60 from Val Vista to Gilbert:

- US-60 WB at Higley entrance
- US-60 WB at Greenfield entrance
- US-60 WB at Val Vista entrance
- US-60 WB at Gilbert entrance

This five-mile stretch of freeway typically sustains congestion in the morning peak hour. The recurring congestion appears to be a result of a bottleneck on US-60 east of SR-101L. The area has four metered entrance-ramps and is equipped with loop detection that gathers volume, speed, and occupancy data. This traffic data was used as the input for this area, and was collected on September 18, 2012. A random mid-week, fall day was chosen due to the higher traffic volumes when reviewing the seasonal traffic variations in this area. Currently, the ramp metering starts at 6:00 AM and stops at 9:00 AM. This model was developed to incorporate the turn start/stop times of the ramp meters. The modeling period was 5:00 AM through 10:00 AM. Modeling Area 1 is presented in Appendix C.

Modeling Area 2: I-10 EB from Elliot Road to Ray Road:

- I-10 EB at Elliot entrance
- I-10 EB at Warner entrance
- I-10 EB at Ray entrance

This three-mile stretch of freeway sustains congestion in the evening peak hour. The congestion appears to develop due to entering traffic from Ray Road, Warner Road, and Elliot Road. The area has two metered entrance ramps at Elliot and Warner, and is equipped with loop detection that gathers volume, speed, and occupancy data. This traffic data was used as the input for this area, and was collected on February 21, 2012. A random mid-week, fall day was chosen due to the higher traffic volumes when reviewing the seasonal traffic variations in this area. Currently, the ramp meters start at 3:00 PM and stop at 7:00 PM. This model was developed to incorporate the start/stop time of the ramp meters. The modeling period was 2:00 PM through 7:30 PM. Modeling Area 2 is presented in Appendix C.

Modeling Area 3: I-10 WB from 32nd Street to SR-143:

- I-10 WB at 32nd St entrance
- I-10 WB at 40th St entrance
- I-10 WB at SR-143 entrance (not metered)

This three-mile stretch of freeway sustains congestion in the morning peak hour. The congestion at this area appears to result from traffic exiting the freeway at 32nd Street. Based on volume patterns, it appears that recurring congestion results from a significant amount of drivers exiting 32nd Street in a short period of time: 6:00 am to 6:30 am. There is a large trip generator on 32nd Street. The area has two metered entrance ramps and is equipped with loop detection that gathers volume, speed, and occupancy data. This traffic data was used as the input for this area, and was collected on September 18, 2012. A random mid-week, fall day was chosen due to the higher traffic volumes when reviewing the seasonal traffic variations in this area. Currently, the ramp meters start at 6:00 AM and stop at 9:00 AM. This model was developed to incorporate the start/stop time of the ramp meters. The modeling period was 5:00 AM through 10:00 AM. Modeling Area 3 is presented in Appendix C.

Modeling Area 4: I-17 NB from 7th Street to Adams:

- I-17 NB at 7th St entrance
- I-17 NB at 7th Ave entrance
- I-17 NB at Grant entrance
- I-17 NB at Adams entrance

This four-mile stretch of freeway sustains congestion in the evening peak hours. This congestion may be due to the ramp meters and the short acceleration distance due to the length of the entrance-ramps. This area has four metered entrance-ramps and is equipped with loop detection that gathers volume, speed, and occupancy data. This traffic data was used as the input for this area, and was collected on February 21, 2012. A random mid-week, fall day was chosen due to the higher traffic volumes when reviewing the seasonal traffic variations in this area. Currently, the ramp meters start at 2:30 PM and stop at 7:00 PM, except at Grant which starts at 3:00 PM and stops at 7:00 PM. This model was developed to incorporate the start/stop of the ramp meters. The modeling period was 1:45 PM through 7:30 PM. Modeling Area 4 is presented in Appendix C.

Modeling Area 5: SR-101L at 7th Avenue:

- SR-101L WB at 7th Ave entrance

This one-mile stretch of freeway sustains congestion in the evening peak hours. The area has one metered entrance ramp and is equipped with loop detection that gathers volume, speed, and occupancy data. This traffic data was used as the input for this area, and was collected on February 21, 2012. A random mid-week, fall day was chosen due to the higher traffic volumes when reviewing the seasonal traffic variations in this area. Currently, the ramp meter starts at 3:00 PM and stops at 7:00 PM. This model was developed to incorporate the start/stop of the ramp meter. The modeling period was 2:00 PM through 7:30 PM. Modeling Area 5 is presented in Appendix C.

Simulation Model Inputs

Network Geometry:

Each of the five modeling areas were coded separately and do not interact together. The geometry was developed using scaled aerial photographs obtained from Google Earth. Links and connectors were then traced on the background image in VISSIM. Other incorporated geometry includes the location of the entrance and exit ramps, the number of freeway lanes, lane drops, freeway curvature, auxiliary lanes, weaving sections, the location of ramp meters, stop bars, and loop detectors. VISSIM requires a detailed and complete description of the layout of the area in order to produce realistic output.

Traffic Data:

The traffic demand was defined in VISSIM as a set of origin/destination matrices, which contain the average number of vehicles traveling from mile to mile segments in 15-minute intervals. Additionally, traffic entering from entrance ramps were compiled and added onto the network. The traffic volumes were collected using the archived traffic data from the Regional Archived Data System (RADS), and was formatted to fit within the parameters of VISSIM. This data is cohesive and collected on a single day at all ramps in each model.

Because the longest area modeled was five miles, traffic from the entrance ramps was assumed to stay on the freeway throughout the network. Traffic that was on the network prior to the first entrance ramp was allowed to exit the freeway. This assumption was needed because traffic volume data was not collected at the modeled exit ramps. The exiting volume was calculated based on the difference in freeway volume and entering volume from the previous entrance ramp.

Traffic turning movement data from the ADOT Traffic Data Management System (ADOT 2012) was used to determine percentages of traffic flowing onto the entrance ramps from left or right turn approaches. The date the traffic data was collected varied but was less than three years old and was the most recent data available as of October 2012. This data was used to accurately model the platooning of vehicles from the protected or protected/permissive left-turn movement from the upstream traffic signal.

Driver Behavior:

Driver behavior involves a classification of reactions in response to the perceived relative speed and distance with respect to the preceding vehicle. Four driving modes were defined: free driving, approaching, following, and braking. In each mode, the driver behaves differently, reacting either to its following distance or trying to match a prescribed target speed. These reactions result in a command acceleration given to the vehicle, which is processed according to its capabilities. Drivers can also make the decision to change lanes. This decision can either be user-defined by a routing requirement or made by the driver in order to access a faster moving lane. The parameters of the driver behaviors were developed by VISSIM software developers to provide the most realistic behaviors during merging and weaving. Therefore, UCG began the analysis using the existing software parameters to address the driver behaviors at entrance ramps. The driver behaviors were modified based on research materials by Gabriel Gomes, Adolf May, and Roberto Horowitz in the report: *Calibration of VISSIM for a Congested Freeway*. This information is presented in the *Simulation Model Calibration* section.

Signal Control:
Traffic signals are simulated and controlled in VISSIM allowing the user to specify signal control logic, vehicle detection, and timing commands. The signaling features were used to simulate ramp metering control.

The existing timing of the ramp meters were used to simulate the existing field conditions. The ramp meters were programed to start and stop at fixed times to mimic current field operations. Because the ramp meters are currently local traffic responsive, the ramp metering rates were increased at appropriate times during ramp metering to best mimic current field operations.

Traffic Composition:
The traffic composition in VISSIM is categorized into vehicle types that share common vehicle performance attributes. These attributes include minimum and maximum acceleration, deceleration, weight, power, and length. Two vehicle types were created in this model and include passenger vehicles and heavy vehicles. The model assumed 5% heavy vehicles and 95% passenger vehicles on the freeway and entrance ramps, except on the I-17 corridor which used 12% heavy vehicles and 88% passenger vehicles.

Simulation Model Calibration

For a simulation model to correctly predict outcomes, it must first represent the current freeway conditions. The procedure to change model parameters to reflect actual conditions is known as calibration. Calibrating a model requires a large amount of traffic data collection to prove that the model is actually producing real-world results for the existing conditions.

The usual method of computing variations and errors in a model compared to actual conditions (speed and volume data) and tuning the model parameters to minimize those variations is difficult given the assumptions for output at the exit ramps. Added to this difficulty is the fact that the model would need to closely measure the breakdown of each system, and the Highway Capacity Manual states that speeds decline at an increasing rate until capacity is reached. The Manual also provides the speed versus the flow rate curves for varying free flow speeds but does not give any indication on estimating speeds once the flow rate reaches 45 pc/mi/ln (HCM 2010). Furthermore, there seems to be more variability in the freeway measurements than appears in the entrance ramp flows, suggesting the influence of unseen factors, such as the variations in day to day driver behaviors, traffic incidents, and input delays at the outlying nodes of the model. These same issues were found in another research document. Therefore, UCG used a similar calibration method to the research done in the report: *Microsimulation Model of a Congested Freeway using VISSIM* by Gomes, 2004.

The goal for the calibrations was to match more qualitative aspects of the freeway operation. These were:

- present comparison graphs of times when the freeway breaks down, but not actual measurements of the breakdown speeds themselves
- locations of known identified bottlenecks within the modeled areas
- extent of queues on both the freeway and ramp
- Entrance ramp performance (Gomes 2004)

For the first parameter, graphs of the actual freeway speeds compared to the model outcome were developed and overlaid on one another for comparison. The graphs are presented as speed versus time. The modeling results in Figure 24 illustrate a sample of graphs for comparison purposes. All other graphs are presented in Appendix C.

For the remaining parameters, visual evaluation of the results using speed contour plots and manual adjustments of the parameters were used to calibrate the model. These adjustments were compared to the known bottlenecks on the freeway system and by the physical interpretation of the driving behavior parameters and right lane parameters in the model. The iterative procedure was stopped when the visual calibration goals were met and the comparison graphs were accurately depicted. This method was favored over a more automatic method due to the potentially huge number of parameter variations and the advantage that it leads to a more sensible result (Gomes 2004). UCG found similar results in the driver behavior parameters that were used in the Gomes report. Table 17 presents the driving behavior parameters that were used from the Gomes report.

Calibration Measures	Gomes Model 2004	Default Values
CC0	1.7	1.5
CC1	0.9	0.9
CC4	-2.0	-0.35
CC5	2.0	0.35

Sources: VISSIM default values 2012, Gomes, Calibration of VISSIM for a Congested Freeway, 2004.

Table 17: Calibrated Driver Behavior Parameters

Time was spent matching the actual queues with queues presented in the model. These queues were measured according to start time, stop time, and length of queue. The iterative process of modifying input and behavior parameters was completed when the response fell within the observed queues.

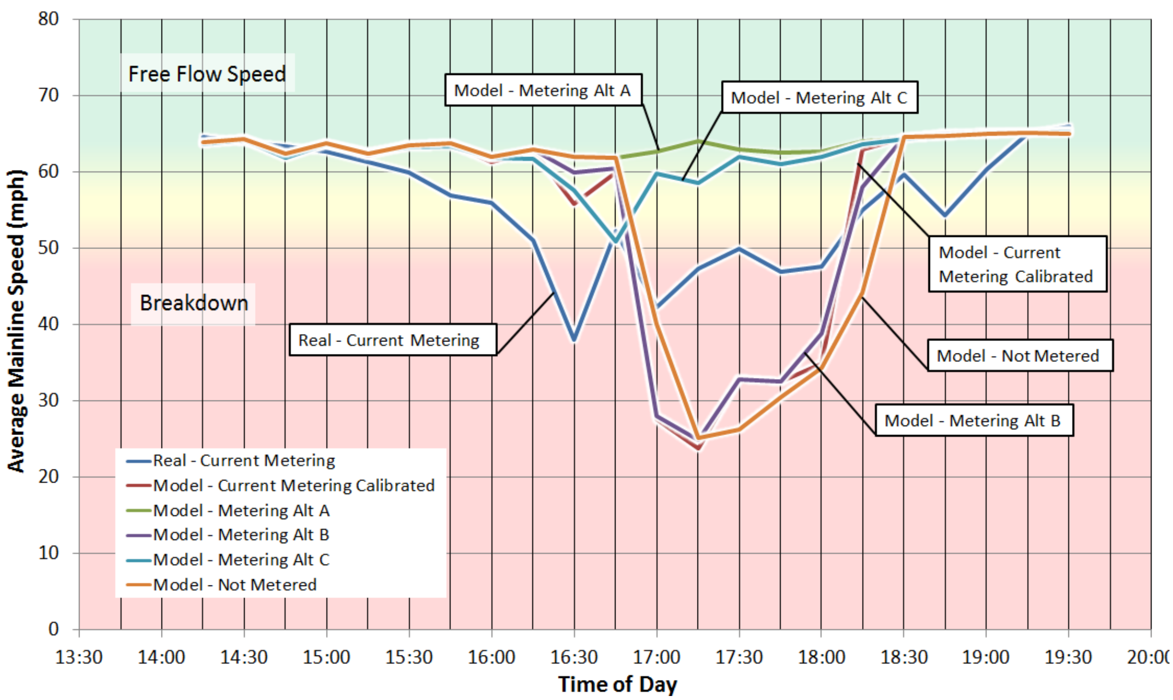
The calibration of these models, while challenging, proved to provide adequate results when comparing the existing speeds to the modeled speeds. By altering the right lane and driver behavior parameters from the default values, the simulation model is capable of reproducing the field measured response on the entrance ramps and along the freeway until the freeway experiences a traffic break down. The simulation follows closely with actual conditions. After the breakdown speed, the model underestimates the speed variation between the simulation and the actual speeds. Meaning, the actual speeds from field measurements are lower than those produced in the model after breakdown and before recovery.

Simulation Model Results

Three ramp metering alternative were modeled at each model area along with a non-metered alternative. These alternatives are presented below:

- **Model – Metering Alternative A:** An aggressive metering strategy to help the freeway by restricting cars on the entrance ramp.
- **Model – Metering Alternative B:** A rapid metering strategy to allow vehicles onto the freeway at a much faster rate. No back-up on the entrance ramp.
- **Model – Metering Alternative C:** Timing scheme in-between strategies of A and B.
- **Model – Not Metered:** Ramp meter off throughout the peak period.

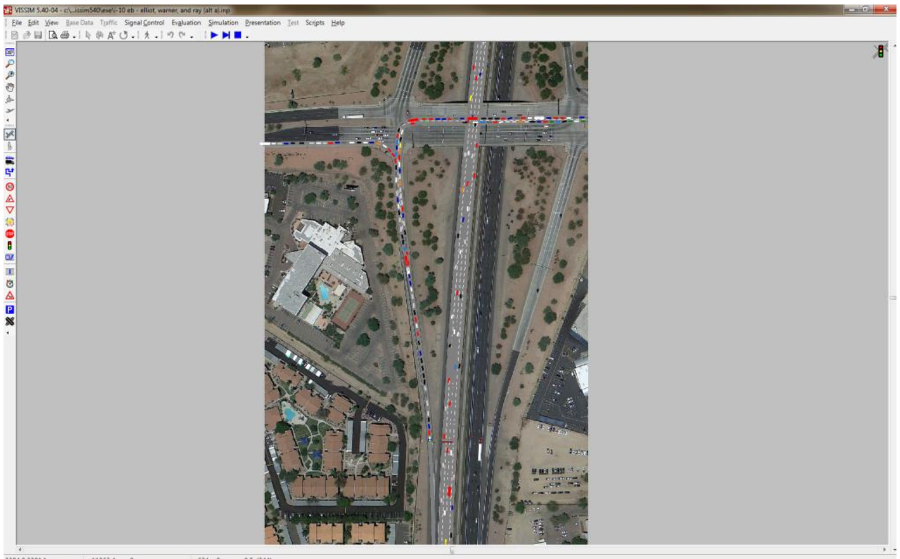
The following figure illustrates a sample of the comparisons from Model Area 2: Eastbound I-10 from Elliot Road to Ray Road. The actual speed is also plotted for reference and calibration purposes.



Source: United Civil Group

Figure 23: Modeling Results for I-10 Eastbound at Elliot Road

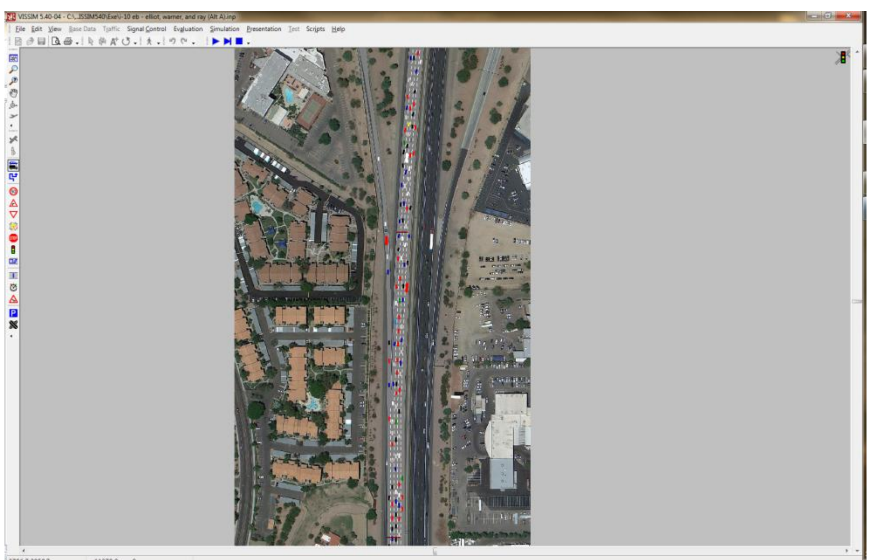
At this location, the model is showing a breakdown at approximately 4:45 which closely matches the breakdown in actual data at 4:45 pm. The model breaks down and presents a slower speed than actual data; but the more significant correlation factor is the time of breakdown. Alternative A ramp meter timing shows that with aggressive metering, there will be no breakdown of the freeway conditions. However, this alternative results in significant queue on the entrance ramps and arterial congestion. Figure 24 provides a snap shot of the Alternative A model at approximately 5:15 pm, during a low metering rate of 360 to 514 vehicles per hour.



Source: United Civil Group

Figure 24: Model Alternative A (Low Metering Rate) – I-10 at Elliot Road

Figure 25 illustrates the freeway congestion due to the increase in vehicles entering from Elliot. This alternative shows turbulence in the weave area that is causing upstream freeway congestion.

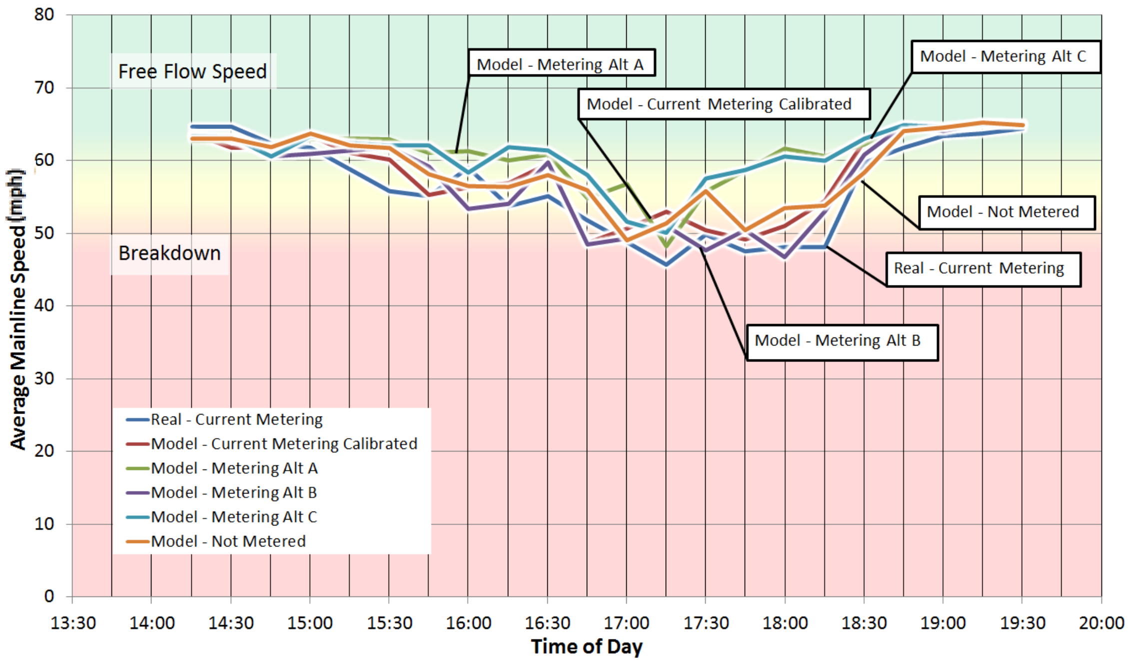


Source: United Civil Group

Figure 25: Model Alternative B (High Metering Rate) - I-10 at Elliot Road

Therefore, UCG is recommending Alternative C, a varying ramp metering rate that is between the strategies of Alternative A and Alternative B. Alternative C shows the freeway slow to capacity, but not breakdown below the 50 mph breakdown speed.

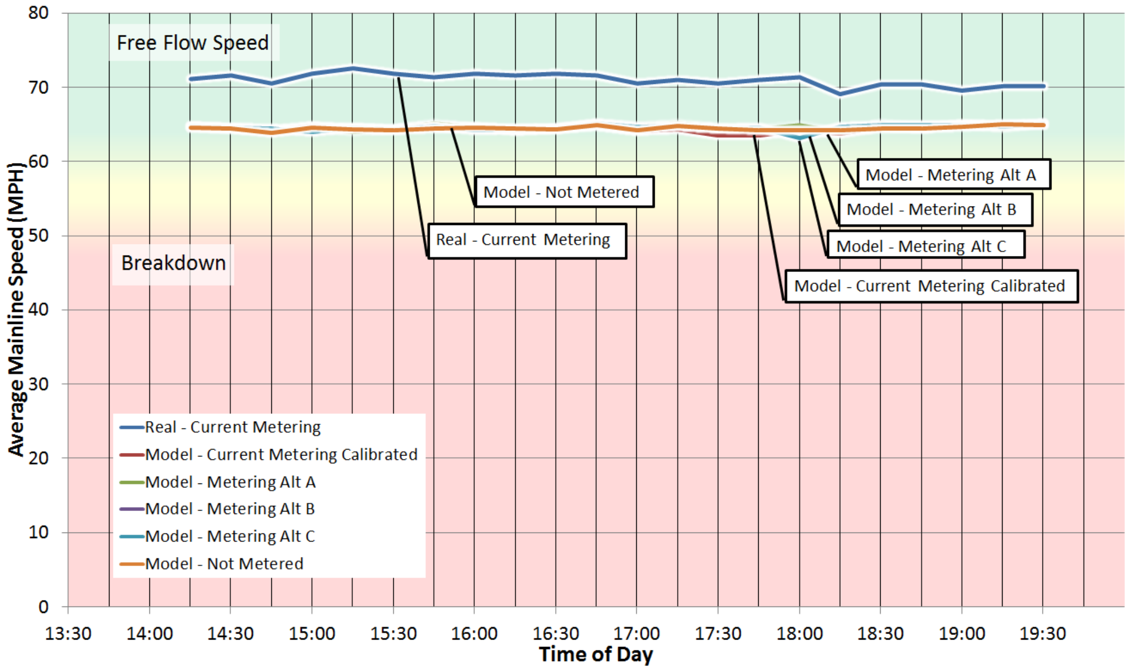
The next ramp meter on I-10 in the eastbound direction is Warner Road. The model and actual traffic data show a close approximation in both breakdown time and speed.



Source: United Civil Group

Figure 26: Modeling Results for I-10 Eastbound at Warner Road

The final ramp in this model is Ray Road. This ramp is not shown to break down with either the model or the actual traffic data. This location does not currently have a ramp meter and does not appear to be needed until traffic volumes increase.



Source: United Civil Group

Figure 27: Modeling Results for I-10 Eastbound at Ray Road

RECOMMENDATIONS FOR IMPLEMENTATION

The recommendations for implementation were developed to meet the objectives of ramp metering without the need to modify ADOT's current ramp metering equipment and software.

Recommended Ramp Metering Time of Day

The following rules were used to determine the recommended ramp metering time of day for each ramp meter. These rules were developed based on the strategies outlined in the *Meeting the Ramp Metering Objectives* section, the ramp metering model simulation results, ADOT policy, and engineering judgment.

1. A ramp meter starts metering before (and stops metering after) the times of day (to the nearest 30-minute increment) that historically-recurring freeway congestion occurs adjacent to the ramp meter or within 2 miles downstream from the ramp meter. "Congestion" refers to freeway speeds less than 50 mph.

2. During the times of day a ramp meter is currently on, it was turned off (to the nearest 30-minute increment) if historically-recurring freeway congestion did not occur adjacent to the ramp meter or within 2 miles downstream from the ramp meter, and the combined flow rate of the freeway right-lane and entrance ramp at the ramp meter was less than 2,000 to 2400 vph.

3. Ramp meters were turned off at locations where the entrance ramp continues as an added freeway lane where changing lanes is not required for approximately 1 mile. Changing lanes is required where an exit ramp or entrance ramp exists, or if the added entrance ramp lane ends.

4. Ramp meters are off at taper-type freeway entrances which provide less than 350 feet of acceleration distance after the ramp meter stop bar. Very short acceleration distance after the ramp meter causes vehicles, and especially trucks, to enter the freeway slowly and can cause congestion rather than mitigate it.

Commentary for Rule 1: By turning on ramp meters based on their distance relative to the upstream end of congestion rather than their distance relative to the beginning source of congestion at a downstream bottleneck, it accounts for the severity of congestion caused by a bottleneck. This results in the preferred strategy of using more ramp meters when congestion is severe and using less ramp meters when congestion is minor.

Commentary for Rule 2: During times of day when ramp meters are currently on, if congestion does not typically occur, it is possible that congestion is being mitigated by the ramp meter. Therefore, it must be predicted whether congestion would occur if the ramp meters were turned off. After, extensive observation of freeway traffic flow, it was found that a congestion-causing bottleneck is likely to form when the flow rate of the freeway right-lane plus the entrance ramp is above 2,000 to 2400 vph. This range of flow rate capacity was used because it was observed that the specific flow rate at which congestion begins depends upon a complex interaction of multiple factors (some non-quantifiable) including merge geometry, proximity to system-to-system interchanges, flow rate of freeway lanes other than the rightmost lane, heavy lane changing between the freeway detector and merge point, speed of entering traffic, size of platoons from left-turn lane, freeway geometry, percent heavy vehicles, and random interactions between individual drivers. Therefore, a range of flow rates was used coupled with engineering judgment of the project team to determine the recommended ramp metering time of day.

Locations that required exceptions to the above time-of-day rules are listed below with justification for the exceptions.

- Eastbound I-10 at the entrance ramp from 24th Street, the ramp meter is off in the morning because the congestion downstream is not due to an overcapacity freeway. Rather the auxiliary lane between the 32nd Street entrance ramp and 40th Street exit ramp is overcapacity due to the combined flow rate of the 32nd Street entrance ramp and 40th Street exit ramp. Therefore, using ramp metering upstream would limit the flow rate of the freeway, but would be ineffective at mitigating the cause of congestion at this location. It is recommended to meter the entrance ramp from 32nd Street only to limit the combined flow rate of the 32nd Street entrance ramp and 40th Street exit ramp to allow freeway traffic to smoothly exit at 40th Street.

- Westbound I-10 at the entrance ramp from Sky Harbor, the ramp meter is off because there is no traffic signal within several miles which would cause traffic to enter the freeway in platoons. Therefore, ramp metering would not smooth or limit the entering flow rate. Ramp metering at this location would cause delay at the ramp meter without benefit to the freeway.

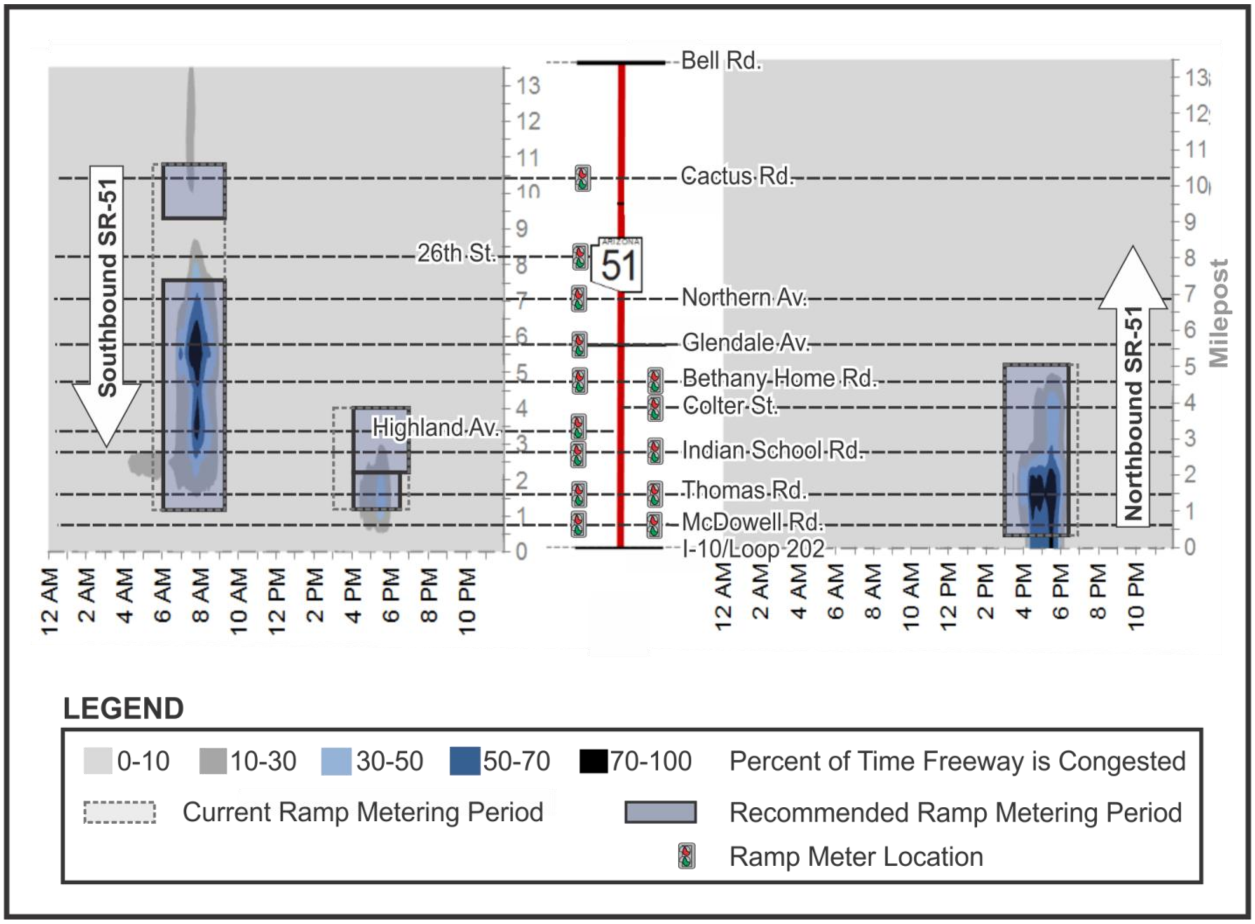
- Southbound I-17 at the entrance ramp from 19th Avenue the ramp meter should be turned off and traffic observed when the 7th Avenue ramp meter is turned off. Traffic enters the freeway from 7th Avenue at slow speeds due to short acceleration distance from the ramp meter stop bar and congestion may be improved once the 7th Avenue ramp meter is turned off.

- Southbound SR-51 at the entrance ramp from 26th Street, the ramp meter is off because there is no traffic signal within several miles which would cause traffic to enter the freeway in platoons. Therefore, ramp metering would not smooth or limit the entering flow rate. Ramp metering at this location would cause delay at the ramp meter without benefit to the freeway.

In the future, the ADOT ramp metering system should be upgraded to allow ramp meters to monitor, in real-time, the traffic conditions of vehicle detectors located several miles downstream. This upgrade would be used to improve ramp metering times to be more precise by varying the start and stop times based on actual downstream traffic conditions (rather than predicting congestion based on historical traffic conditions for the time of day). This upgrade could also be used to turn ramp meters on during times of non-recurring congestion. This type of ramp meter control is typically referred to as "smart ramp metering" or "corridor traffic adaptive."

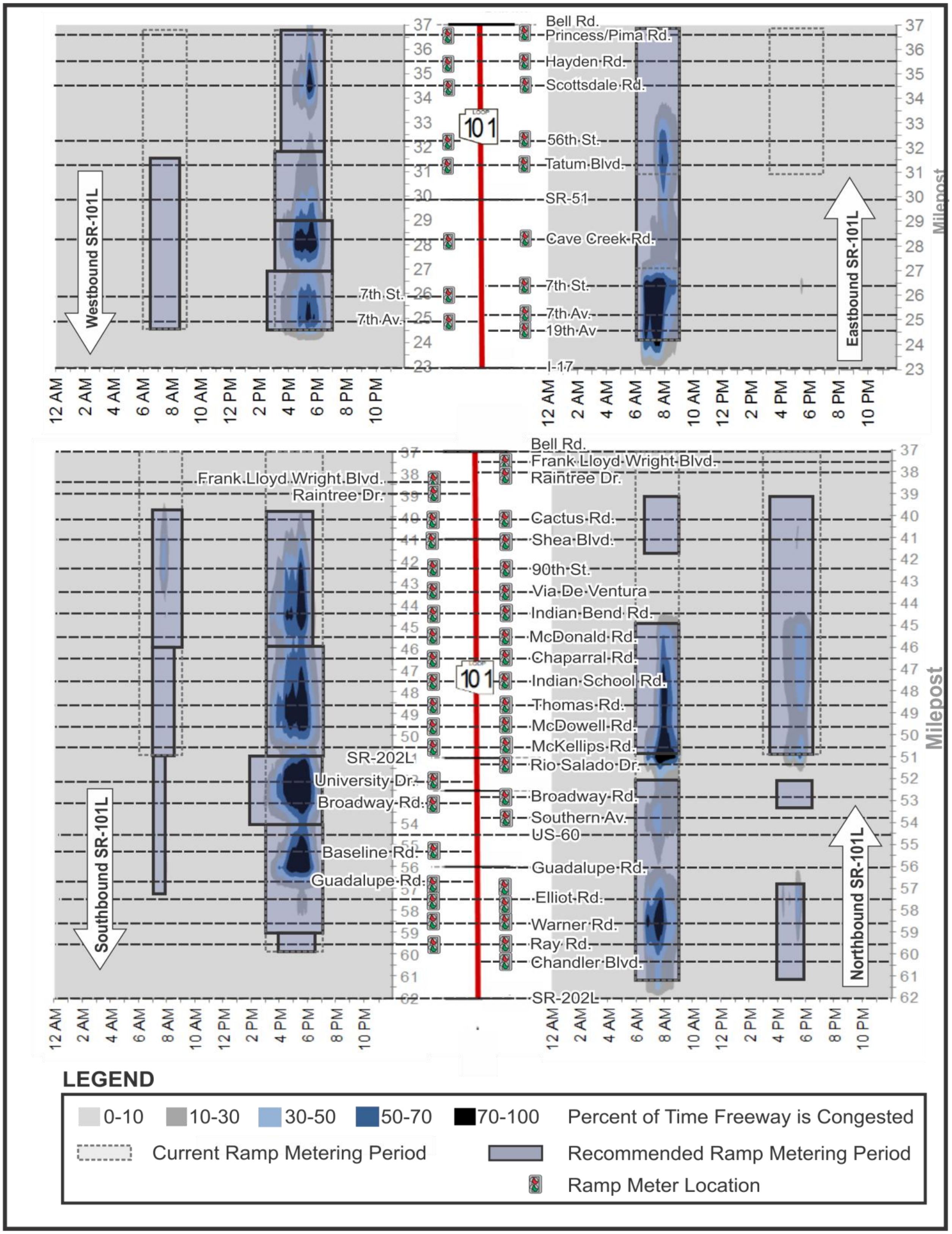
This recommended ramp metering time of day only considers historically-recurring congestion. The recommended ramp metering operation during non-recurring congestion is detailed in this report in the Recommended Management of Non-recurring Congestion and Incidents section.

The recommended ramp metering time of day for each ramp meter is graphically depicted in the following figure. The percent of time the freeway is congested shown below was calculated by Maricopa Association of Governments (MAG) from freeway speed data collected by ramp meters during the 250 non-holiday weekdays in year 2012. MAG used a threshold for congestion of 45 mph or less, rather than less than 50 mph, which is used by United Civil Group for this project. Therefore, the figure below may not show all congestion.



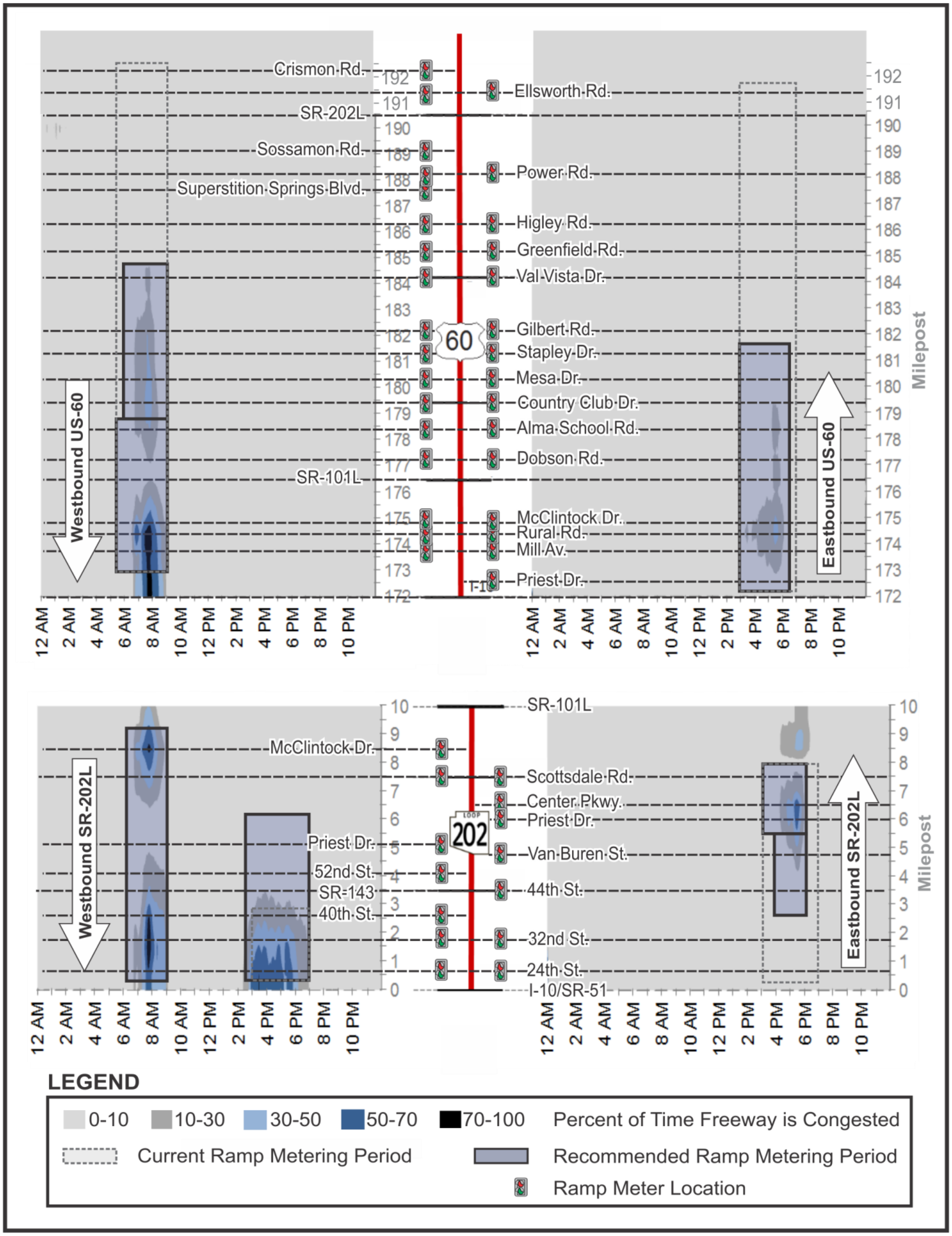
Source: Maricopa Association of Governments, United Civil Group

Figure 28: Ramp Metering Time of Day



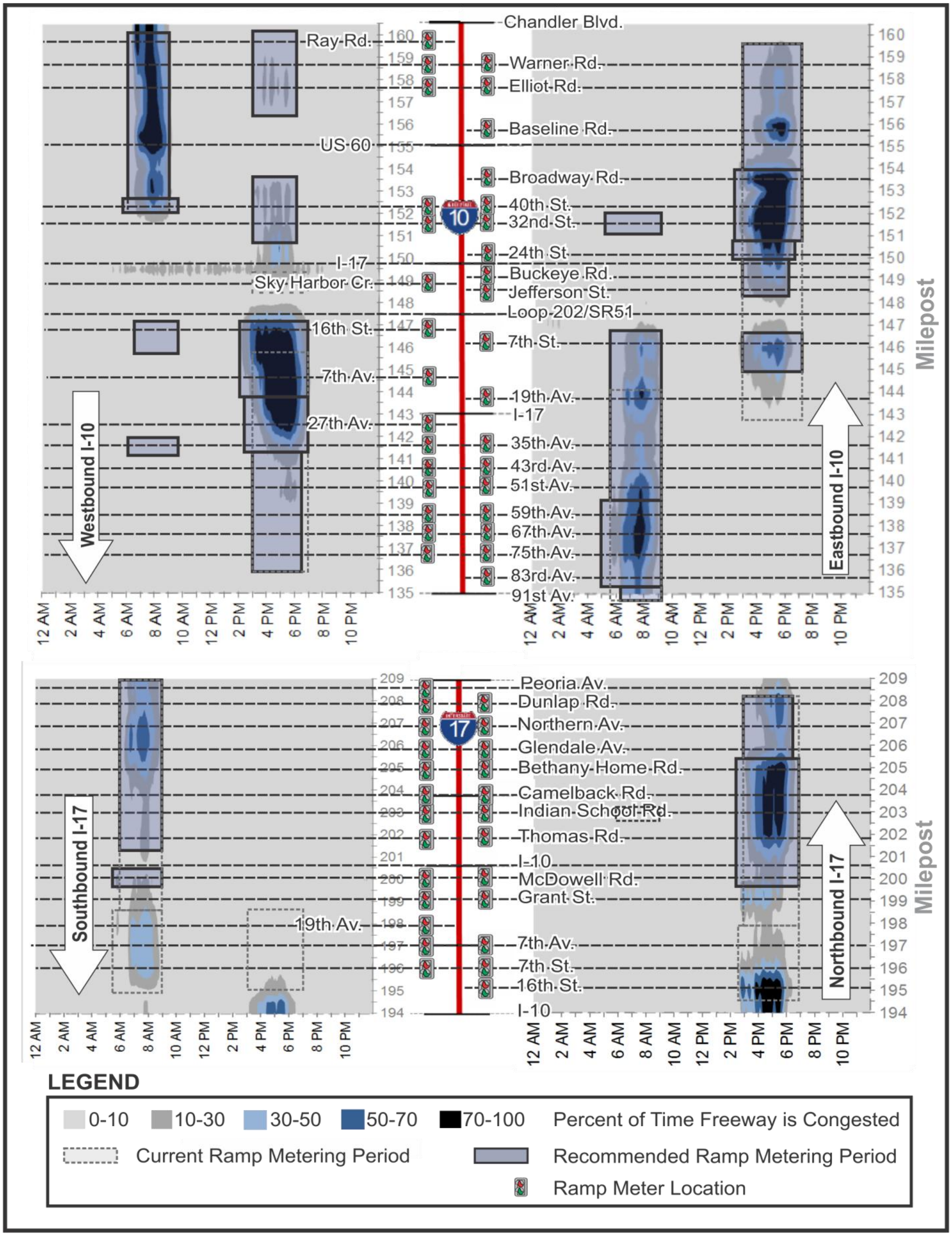
Source: Maricopa Association of Governments, United Civil Group

Figure 28: Ramp Metering Time of Day (Continued)



Source: Maricopa Association of Governments, United Civil Group

Figure 28: Ramp Metering Time of Day (Continued)



Source: Maricopa Association of Governments, United Civil Group

Figure 28: Ramp Metering Time of Day (Continued)

Recommended Ramp Metering Rate

The recommended metering rate automatically varies depending on the condition of the entrance ramp and the condition of the freeway adjacent to the ramp meter. The recommended metering rate operation was developed based on the strategies outlined in the *Meeting the Ramp Metering Objectives* section, the ramp metering model simulation results, field testing, ADOT policy, and engineering judgment.

The metering rate is defined as the maximum vehicles per hour **from each metered lane** that are given a green signal indication when the ramp meter is on. For example, a single-lane ramp meter set at a metering rate of 500 vph will indicate 500 greens in one hour at full demand. A dual-lane ramp meter set at a metering rate of 500 vph will indicate at total of 1,000 greens in one hour at full demand, 500 greens to lane 1 and 500 greens to lane 2 in one hour. Figure 29 depicts the recommended metering rate operation graphically.

Base Metering Rate

ACTION: If freeway speed is high, the rate will be faster. If the freeway slows, the rate will reduce.

PUPROSE: Avoid unnecessary ramp meter delay and limit entrance ramp flow rate in an attempt to keep the freeway below capacity

LOGIC:

Metering Level	Freeway Speed (mph)	Metering Rate (vph per lane)	
		Single-Lane Ramp Meter	Dual-Lane Ramp Meter
Level 1	61 +	1,200	720
Level 2	60 to 56	960	600
Level 3	55 to 51	800	480
Level 4	50 to 46	600	400
Level 5	45 to 41	480	300
Level 6	40 to 0	400	240

Rate Increase #1

ACTION: If there is constant demand is detected, the rate will slowly increase up to a limit

PUPROSE: Avoid queue from reaching the *Queue Detectors* which will trigger *Rate Increase #2* and reduce benefit to freeway

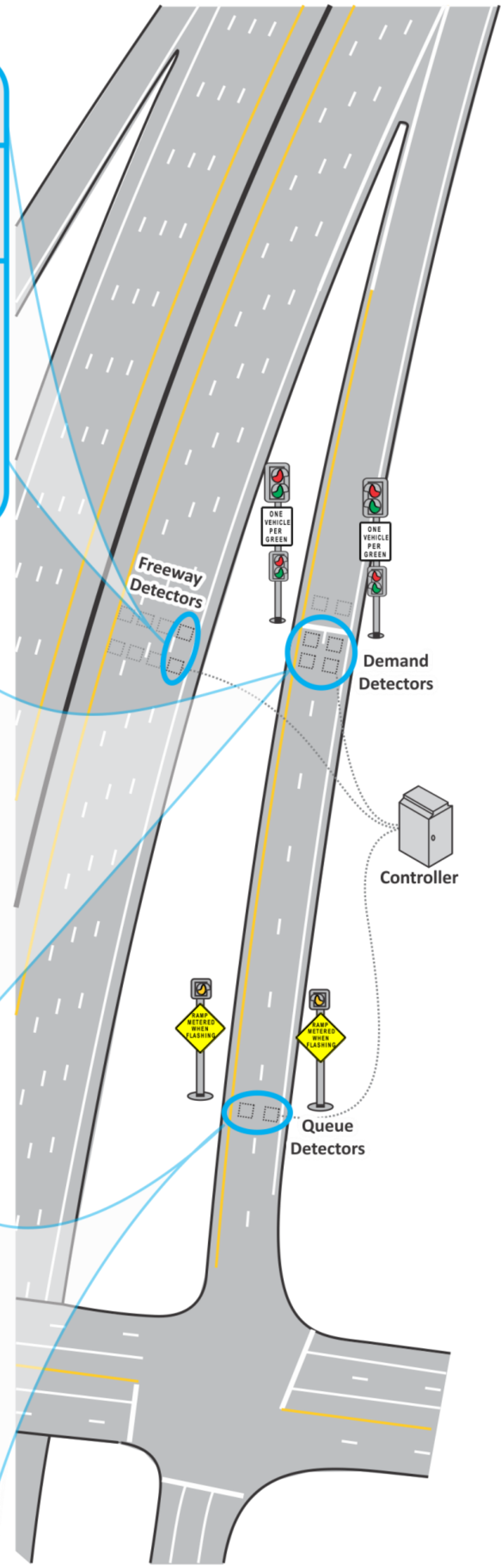
LOGIC: If the occupancy is above 75% for more than 80 seconds, then the base metering rate will automatically increase one level every 100 seconds, up to three times, until the occupancy of the demand detectors falls below 70% or level 1 is reached

Rate Increase #2

ACTION: If queue is detected, the rate will increase to a maximum

PUPROSE: Avoid ramp meter queue spillback into the intersection

LOGIC: If occupancy is greater than 60%, then the rate will increase to 870 vehicles per hour per lane at dual-lane ramp meters (1,440 vehicles per hour per lane at single-lane ramp meters) until the occupancy falls below 40%



Source: United Civil Group

Figure 29: Recommended Metering Rate

Recommended General Control Parameters

Recommended general ramp metering control parameters are listed in Table 18. For detailed definitions of these parameters refer to the McCain software user manual.

Parameter	Value
Minimum Green Time	1.5 Seconds
Maximum Green Time	1.5 Seconds
Minimum Red Time	1.5 Seconds
Startup Phase	Red
Startup Flash Time	20 Seconds
Green Offset Time	2.1 Seconds
Freeway Lane Data for Local Traffic Responsive Control	Lane 1 (rightmost)
Data Calculation Interval	20 Seconds
Number of Data Calculation Intervals for Smoothing	1

Table 18: General Ramp Metering Control Parameters

Holidays

All changes recommended by this project for holiday operation have been implemented system-wide. The holiday operation is described in the *Current ADOT Ramp Metering System* section under *Holidays*.

Traffic Data Collection and Reporting

All changes recommended by this project for traffic data collection and reporting have been implemented system-wide. Traffic data collection and reporting is described in the *Current ADOT Ramp Metering System* section under *Traffic Data Collection and Reporting*.

Recommended Detection Failure Backup

Fail-safe backup control is recommended so that ramp metering may continue to operate if a detector fails. The ramp metering software will monitor the activity of detectors and if a problem occurs, will perform a failure backup action as listed in the table below.

	Freeway Detectors *(Speed Data Collection)*	Demand Detectors *(Ramp Meter Presence)*	Passage Detectors *(Entrance Ramp Volume Data)*	Advance Queue Detectors *(Queue Spillback Detection)*
Erratic Count (vehicles per 20 seconds)	30	25	25	25
Constant Detection (minutes)	300	300	300	300
No Activity (minutes)	60	60	60	60
Failure Backup Action	Constant Call	Constant Call	Constant Call	Constant Call

Table 19: Detection Failure Backup

Implementation

To meet Objective E, the ramp metering recommendations have been field-tested at a sample of ramp meter locations. Ramp meter operation and traffic conditions were observed and parameters were fine-tuned to minimize unexpected results during full-scale implementation. Unexpected issues may still be encountered during implementation. Therefore, the recommended ramp metering time of day and metering rate parameters should be implemented in groups of one to five ramp meters to limit the number of issues encountered at one time. Additionally, implementation should begin in outlying areas, working towards more congested sections of freeway to more easily address any implementation issues. Ramp metering control plans can be remotely-uploaded to each controller in the field using the TransSuite software.

Traffic should be observed and the operation fine-tuned until there is confidence that each ramp meter works as desired. Before and after studies are recommended to be conducted prior to implementing the following set of ramp meters to ensure congestion is not being adversely affected.

Recommended Management of Non-recurring Congestion and Incidents

Ramp metering operation during non-recurring congestion and incidents is recommended to be determined by ADOT staff on a case-by-case basis. Ramp meters can be turned on, turned off, and a fixed metering rate can be set in real-time from remote sites to manage traffic flow during traffic detours, crashes, weather, freeway closure, and special events. These parameters can be changed using the TransSuite software to access the *Time of Day Schedule Table* which contains the start time, stop time, and fixed metering rate parameters.

In the future, integrated corridor management plans for non-recurring congestion and incidents should be developed that includes ramp metering plans. During freeway closures, it is recommended to turn off ramp meters on entrance ramps used by traffic re-entering the freeway after bypassing the closed portion.

Inquiries from outside ADOT regarding ramp metering during an incident should be made through the contacts listed in the following table.

Inquiry From	Ramp Metering Contact	
Emergency	Emergency Dispatch	911
General public	ADOT Communications	(602) 712-7355 -or- https://wwwa.azdot.gov/contact_adot/index.aspx
Traffic operations staff -or- Law enforcement	ADOT Traffic Operations Center (TOC) Control Room	(602) 712-4983 -or- (602) 712-4990
Local agency staff	ADOT Transportation Technology Group	(602) 712-8328

Table 20: Ramp Metering Contacts for Incident Management

FUTURE RAMP METERING RECOMMENDATIONS

In the future, the following tasks are recommended to further improve ADOT's ramp metering system.

- Implement the ramp metering time of day and metering rate programming recommended by this project.
    - Observe and fine-tune ramp metering operation during implementation
    - Evaluate before-and-after results
- Develop integrated corridor management plans to improve ramp metering operation during non-recurring congestion and incidents.
- Communicate ADOT's ramp metering strategies to the Arizona Department of Public Safety Highway Patrol Division.
- Upgrade to a "smart ramp metering" system that centrally-processes traffic data and controls metering accordingly to further enhance traffic management capabilities. To upgrade, the following tasks would need to be performed:
    - Identify desired functions and operational capabilities of the system
    - Determine the control algorithm that will be used
    - Identify new detection at locations that will allow the algorithm to monitor freeway bottlenecks.
    - Test and adjust operation of the "smart ramp metering" system
    - Implement the "smart ramp metering" system
    - Evaluate before-and-after results

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APPENDIX A

Public Comments

COMMENT NUMBER: 1

PUBLIC COMMENT SOURCE: ADOT

DATE RECIEVED: January 18, 2012 4:28 PM

CATEGORY: Ramp Meter Malfunction – Motorcycle Not Detected

LOCATION: WB US-60/Ellsworth On-Ramp

COMMENT: I received a phone call this afternoon from a gentleman who is having difficulty triggering the green light for the ramp meter on WB US-60 Ellsworth On-Ramp. He is on a motorcycle and has tried every which way to position a bike in the travel lane in order trigger the ramp meter. I explained to him that there are times that the traffic loops will not pick up 2-wheel motorists and I can advise the ADOT group responsible for ramp meters of his challenges. The guy's name is Stan Carlson (480-703-1594) and would like a call back with what can be done with this ramp meter such that he is not running the red light of the ramp meter each morning. Thanks, Adam Brahm, P.E. 48th Street Field Office

ACTION/RESPONSE: Detection at this location was checked and loop detection tuned to be as good as possible

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COMMENT NUMBER: 2

PUBLIC COMMENT SOURCE: ADOT 1130446167

DATE RECIEVED: 10/31/2011 12:45:37 PM

CATEGORY: Evaluate for New Ramp Metering

LOCATION: EB SR-L202 (Santan)/Gilbert Road

COMMENT: Hi - I was wondering if there were any plans for putting in any metering systems for the eastbound 202 Santan freeway in south Gilbert/Chandler, particularly at Gilbert Road? The reason I ask is because that particular spot has become a daily bottleneck due to the end of the carpool lane and the eastbound traffic entering the freeway all at once. IMO, the end of the carpool lane is a small factor, but that incoming Gilbert Rd. traffic that comes in waves causes a major slowdown everyday (vs. the smoother transition with the meters). It's kind of becoming a more dangerous spot than it even was before - the road is going uphill, and while groups of drivers are trying to get on all at once, many other drivers are jockeying to get over into that same far right lane for the Val Vista Rd. exit at the same time. Can someone go out there and take a look or look at some traffic flow data and consider putting in a meter there? IMO, it could really help right at that spot quite a bit. (BTW - It's kind of ironic that I'd request this considering how I here complaining here about how your department put up an eastbound US60 on-ramp metering system at Mill Ave not too long ago... :)) Thanks! Bryan R.

ACTION/RESPONSE: Ramp Meter not planned at present time at this location

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COMMENT NUMBER:	3
PUBLIC COMMENT SOURCE:	City of Mesa
DATE RECIEVED:	10/4/2011 12:42 PM
CATEGORY:	Ramp Meter Malfunction – Motorcycle Not Detected
LOCATION:	WB US-60/Alma School on-ramp
COMMENT:	Good afternoon, I am not really sure who this concerns or who I can contact about this but I have an issue with the traffic metering signals used on the westbound US-60 on-ramp at Alma School. I have recently started commuting to work on a motorcycle and have come to find out that the metering signals do not work for me when I ride my bike. I am not sure how these particular signals sense vehicles (by weight or electro magnet) but they only work when I am in a car or truck. And they are no longer timed like they used to be. I have sat for long periods of time while cars in the lane next to me get green light after green light. Just feel a little unsafe when trying to get onto the US-60 during rush hour. Not sure if there is anything that can be done about it but figured I would try to let someone know anyways. Thank you. KYLE JOHNSON
ACTION/RESPONSE:	Detection at this location was checked and loop detection tuned to be as good as possible

COMMENT NUMBER:	4
PUBLIC COMMENT SOURCE:	ADOT 1123729074
DATE RECIEVED:	9/1/2011 9:05:27 PM
CATEGORY:	Evaluate for New Ramp Metering
LOCATION:	WB SR-L202 (Santan)/Gilbert, Cooper, McQueen, Arizona, Alma School
COMMENT:	Thank you, yes, I was referring to ramp meters. I am wondering what needs to happen for ramp meters to be put in place on the westbound 202 from Gilbert to at least Dobson. Also, in the past week and a half there have been 3 accidents on the westbound 202 and McQueen. McQueen, Alma School and Gilbert seem to have the highest incidences of accidents but I'm not sure if or when it is enough that ramp meters are put in place. Not only for the accidents but for the traffic congestion. I've noticed since this new school year there is significantly more traffic on the 202 than there was at the end of the previous school year.
ACTION/RESPONSE:	Ramp Meter not planned at present time at this location

COMMENT NUMBER:	5
PUBLIC COMMENT SOURCE:	ADOT 1106147420
DATE RECIEVED:	3/2/2011 12:59:07 PM
CATEGORY:	Backup from Ramp Metering
LOCATION:	NB SR-L101/Shea, EB SR-L101/Tatum
COMMENT:	Who all of a sudden decided to turn every meter on in the North East Valley? Getting on at Tatum and 101 in the morning, at 6:45, I have never seen these meters on and now they are. Worse yet is trying to get on going North Bound at Shea at around 4:00 is a complete joke. There is a stoplight on 90th and Shea and you can now sit thru 3 or more lights trying to get on Shea because it is backed up so much because of the lights. Can someone please look into this

	and explain the reasoning? I can tell you my commute time just increased so whatever it is I would suggest it isn't working.
ACTION/RESPONSE:	New controller installed with higher flow rate

COMMENT NUMBER:	6
PUBLIC COMMENT SOURCE:	ADOT 1104247194
DATE RECIEVED:	2/11/2011 1:05:37 PM
CATEGORY:	Ramp Meter Malfunction - Red Appears Lit from Reflected Sunlight
LOCATION:	NB SR-L101/Ray
COMMENT:	The on ramp meter to Northbound 101 at Ray causes a backup every morning. There is no flashing light indicating meters are being used. However, at the bottom of the on ramp, the sun makes the red light look illuminated. So, people sit for up to 2 minutes each in both lanes watching that lamp waiting for it to change--it never does and they finally go, only to have the next person in line sit and wait for the green light that never comes!! If there is anything that could be done to re orient the meter a bit so it looks off when it is off, that would be great. Apparently the fact that a) the light ISN'T flashing on the sign that says 'ramp metered when flashing' and b) the green light never comes on, isn't enough of a clue for drivers! Thank you!
ACTION/RESPONSE:	Adjusted signal head to reduce reflection

COMMENT NUMBER:	7
PUBLIC COMMENT SOURCE:	ADOT 1100741776
DATE RECIEVED:	1/7/2011 11:30:32 AM
CATEGORY:	Evaluate for New Ramp Metering
LOCATION:	WB SR-L101/Scottsdale
COMMENT:	Hello. There are meters established at Scottsdale Road for entry onto Hwy 101 Westbound that are NEVER turned on during evening rush hour - 5 pm - 7 pm..... traffic continues to bunch up and cause major time delays because of everyone trying to get on at the same time. Is there a way to turn these on during these times? I have noticed the East bound entrance meters seem to be on... thank you... frustrated motorist!
ACTION/RESPONSE:	Ramp Meter Activated in the afternoon

COMMENT NUMBER:	8
PUBLIC COMMENT SOURCE:	ADOT 1033953726
DATE:	12/5/2010 2:51:34 PM
CATEGORY:	Evaluate for New Ramp Metering
LOCATION:	EB SR-L101/Tatum, 56th Street
COMMENT:	I commute every morning from the 101 at Cave Creek (Phoenix) to Rio Salado Parkway (Tempe). Every day, there's an unnecessary back up where too many cars enter the 101 all at once and then have to merge. This happens with the on ramps at Tatum and again at 56th Street. Both entrances are metered and

	yet both meters on not on during the AM rush hour drive. They are on, however, during the evening rush when there is no back up in that direction and there are no cars waiting at the meters. Can you please have someone observe the traffic patterns in this area and consider metering the entrances at Tatum and 56th Street (going South, toward Tempe) during the weekday mornings?
ACTION/RESPONSE:	Ramp Meter Activated in the morning

COMMENT NUMBER:	9
PUBLIC COMMENT SOURCE:	ADOT 1031664849
DATE RECIEVED:	11/12/2010 5:47:21 PM
CATEGORY:	Evaluate for New Ramp Metering
LOCATION:	WB SR-L101/Princess, Hayden, Scottsdale, 64th St, 56th St, Tatum
COMMENT:	I have a question regarding the ramp meters that are used during rush hour on the 101 between AZ 51 & Pima/Princess. It seems that west bound 101 meters from Pima/Princess to the 51 should be operating during the evening rush hour, but they are not. Do the traffic studies show there isn't much traffic during this time? 3 out of 5 nights, traffic slows around 56 Street. My recommendation would be to have the meters activating for the evening rush hour traveling west. This could be an area that needs to be activated in both the morning and evening rush hour???
ACTION/RESPONSE:	Ramp Meter Activated in the afternoon

COMMENT NUMBER:	10
PUBLIC COMMENT SOURCE:	ADOT 1027733493
DATE RECIEVED:	10/4/2010 9:13:32 AM
CATEGORY:	Ramp Meter Malfunction – Active on Weekend
LOCATION:	WB SR-L101/7th Ave
COMMENT:	I have a question as to why the Westbound Loop 101 On Ramp at 7th Ave meters are running on every Sunday? This makes no sense to me. I think whoever set up the meters just selected the wrong set up, but in any case it should be fixed.
ACTION/RESPONSE:	New controller installed to fix issue

COMMENT NUMBER:	11
PUBLIC COMMENT SOURCE:	ADOT 1025740341
DATE RECIEVED:	9/22/2010 9:28:13 AM
CATEGORY:	Evaluate Ramp Metering only at necessary Times of Day
LOCATION:	WB and EB SR-L101/Tatum in AM
COMMENT:	Thank you for actually responding, I never thought that would happen. ADOT is a large entity so for you to take the time to respond if very impressive. I would ask however if you would consider having one of your staff go out to this location to see the impact these ramp lights are having on the morning traffic. I have no doubt that the ramp lights are a huge help in the afternoon when the

freeway is so congested in both directions. But in the morning traffic on 101 heading either eastbound or westbound has never been congested at Tatum. So maybe the answer is that these meters should only be on for the afternoon hours. Again, I appreciate your timely response.

ACTION/RESPONSE: New controller installed with higher flow rate

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COMMENT NUMBER: 12

PUBLIC COMMENT SOURCE: ADOT 1025740341

DATE RECIEVED: 9/14/2010 11:10:44 AM

CATEGORY: Backup from Ramp Metering

LOCATION: WB SR-L101/Tatum in AM

COMMENT: Monday the ramp traffic lights were activated. And ever since there has been a huge back-up of traffic on Tatum. Monday morning I assumed there was an accident on the ramp because traffic was backed up to Deer Valley so I took Tatum up to bell and cut across to SR51. Today when I came out of my subdivision onto Tatum it again was backed up but this time to Melinda (past Deer valley). It is apparent that the lights on this ramp onto 101 Westbound are creating a problem. Traffic was never an issue on Tatum approaching the 101 ramp until Monday when the lights went on. This caused me an additional 15 minutes for my commute which I did not plan for, nor do I want to plan for. These lights need to be turned off as quickly as possible to alleviate the traffic back-up that they have caused. I recommend that you send some ADOT representatives out to Tatum between 6:45am and 7:30am to witness what I am telling you.

ACTION/RESPONSE: New controller installed with higher flow rate

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COMMENT NUMBER: 13

PUBLIC COMMENT SOURCE: ADOT 1017966561

DATE RECIEVED: 6/28/2010 6:27:22 PM

CATEGORY: Backup from Ramp Metering

LOCATION: SB I-17/Happy Valley in AM

COMMENT: I have lived in north Phoenix for the past two years. I normally get on I-17 @ Happy Valley each workday at approx 6:15am. After dealing with all the construction on I-17, we now must deal with a metered ramp for southbound traffic. This is ridiculous. It now takes 3 to 5 minutes of metered on-ramp waiting to get on the freeway. The traffic already on the freeway heading south is going between 65 and 75 miles per hour. Before the meter was installed, there was no backup of on-ramp traffic; there were no accidents (to my knowledge) and traffic moved smoothly. We must now wait in line, waste gas and accelerate quickly from a dead stop to merge with traffic. You put a meter where there was no problem. By the way, some drivers who don't want to wait in the on-ramp traffic which is backed up to and on Happy Valley, go through the round-about to get in front of some of us in line. An interesting thing is that the on-ramp meter lights at Bell Road (north and southbound) have been OFF for two weeks. Does anyone at ADOT know what's going on? Does anyone go out to watch the traffic flow? There is no need for a meter at Happy Valley. Why not spend your money widening Happy Valley over I-17. I look forward to your reply.

ACTION/RESPONSE:	Construction primarily caused delays (Actual ADOT response not provided by ADOT)
PUBLIC RESPONSE:	This seems like a canned answer. ADOT is causing more congestion and delay with the meter than without. I drive I17 southbound from Happy Valley every day. From Happy Valley until past Bell Road, I travel 65 MPH virtually every day. Congestion on I17 does not normally begin until Thunderbird Road. How does a meter back at Happy Valley affect the congestion that builds at Thunderbird which is about 7 miles south of Happy Valley?

COMMENT NUMBER:	14
PUBLIC COMMENT SOURCE:	ADOT 1017349026, 1017349026
DATE RECIEVED:	6/22/2010 1:35:52 PM
CATEGORY:	Evaluate Ramp Metering only at necessary Times of Day
LOCATION:	EB US-60/Mill in PM
COMMENT:	Hi - This is a complaint about a recently activated entry ramp metering system. Headed home each day, I get on the US60 eastbound (waiting at the left turn arrow, having come from downtown Tempe). Until recently, the on-ramp metering (the green/red light to throttle entry traffic to keep the traffic on the freeway moving more smoothly) was not in operation. Every time I used that on-ramp, the traffic on the US60 was really light, due to the widening project just completed. Because of this, everyone would enter the US60 all at once, with no metering, and the freeway would easily absorb it. This was the case whether I did it at 5PM, 530PM, or 6PM - some of the heaviest rush hour traffic. Unfortunately, someone in ADOT decided to turn on the on-ramp metering at Mill, and that was a big mistake. Now the entry ramp backs up, sometimes well over half way back to Mill Avenue. Meanwhile, the traffic on the US60 is still light and traveling at full speed, the same as it did before the meter went on. They are doing absolutely no good for the freeway traffic flow, and they are wasting drivers' gas and time, not to mention adding to the air pollution in the immediate area, due to the perpetual and unnecessary idling on the on-ramp. There may come a time in the future, as traffic flow increases on the eastbound US60 there at Mill during rush hour, but until then, PLEASE use some common sense and turn the meters back off on the eastbound US60 entry ramp and let the traffic flow. If you have any question about the validity of what I'm saying, please go out there and take a look at that ramp and the accompanying freeway conditions sometime. You'll realize just how unnecessary and wasteful that metering appears to be right now. Is there any reason this can't be done? Thanks - Bryan R
ACTION/RESPONSE:	Dear Constituent: We did look at Mill Ave ramp meter this morning and did not find any thing unusual. Last week there was a problem that was corrected with the timing, and since then we have kept an eye on it and it hasn’t been backing up to the intersection. It may not seem like the traffic is heavy at your location, but it is helping throughout other locations.
PUBLIC RESPONSE:	I appreciate you taking a look at the Mill intersection this morning, but the problem is in the afternoon, on the eastbound entry ramp. My main point also wasn't that the metering ramp was backing up too far. Instead, it was that there is no need for the eastbound metering at all, even during rush hour. I don't have hard statistical data, but from my experience, ever since the widening of the US60 eastbound in Tempe, the traffic has been flowing openly and smoothly, with more than wide enough gaps in the traffic flow to facilitate Mill Ave. eastbound entry traffic without metering. As for the meter helping elsewhere as you suggested, where is it helping? Perhaps you're referring to the Rural eastbound entry traffic, but that wasn't a problem just 2 weeks ago. Also, the

traffic will always back up daily at or near the 101/60 interchange about 2 miles to the west, with or without the Mill metering. Therefore, where else could it be helping? To be clear, I do understand the point of the meters and helping with heavy traffic on freeways, but again, that's just not the case at the Mill Avenue eastbound entrance since the widening of the 60 (at least at this point in time). All I'm asking is that you consider going back to how it was just 2 weeks ago with the meter turned off - even if it's just for a week-long trial run for comparison's sake - to see what happens. If traffic flows the same, then why not save us the gas, air pollution, and time? BTW - Regardless of your response(s), I really appreciate you responding at all. It's good to know that you guys take this feedback seriously. Take care - Bryan

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COMMENT NUMBER:	15
PUBLIC COMMENT SOURCE:	ADOT 1016160524
DATE RECIEVED:	6/10/2010 4:37:45 PM
CATEGORY:	Evaluate Ramp Metering only at necessary Times of Day
LOCATION:	(Not Specified)
COMMENT:	What purpose do these REALLY serve? I just read that more of these stupid things are being activated on Monday! They have no marked effect on traffic flow, so why have them? It makes it more difficult to merge with the traffic on the freeway when you're trying to get on when everyone on the freeway is ignoring the speed limit by driving as fast as they possibly can. You have to try to match/reach the traffic speeds flowing on the freeway when you've started from a complete stop. Like someone's comment on azcentral.com, the contractors that sold you guys on this idea are making "bank." They are a complete waste of time & money!!! While I understand your position, after all, you're department has probably spent millions of taxpayers' money on upkeep & installation, have you ever actually tried to get on the freeway when these meters are operating? As far as I'm concerned, they are quite a nuisance and I don't see how these could possible have any effect on the interchanges that are miles away from a meter. If the meter is on and you're in a whole line of cars waiting to enter the freeway, it's nearly impossible to get up to freeway speed from a dead stop in the short distance of most of our freeway on-ramps, especially when the meters are placed at the top of an on-ramp, right next to the gore area. I'm not a rocket scientist, but it would seem to me that having a slow-moving vehicle trying to merge into traffic that is doing 55mph would create more of a potential for an "incident" than having that same vehicle that was allowed to gather speed from the bottom of the on-ramp. You state that there is proof that these meters actually decrease the amount of incidents on our freeways. Well, I'd like to see the raw data, not some blathering report that was created by the contractors who sold you on the idea in the first place. Any data can be manipulated to make it LOOK like these meters are actually a good thing, when, in fact, I'd bet that the opposite is actually true. It's simply a matter of physics that if you have a vehicle traveling at 55 and another vehicle trying to merge in front of, or even behind, that is only doing 35, there's either going to be a crash, or at the very least, a ripple effect that causes all lanes of the freeway to slow down because everyone is hitting their brakes trying to avoid hitting the slower moving vehicle. Something to consider the next time a proposal comes up to install another one of these meters. Besides, with the status of the State budget, one would think that there are many other, more important, things that the funds could be used for instead of worthless on-ramp meter. As a taxpayer, I would much rather see my money spent more wisely.
ACTION/RESPONSE:	(Not Provided)

COMMENT NUMBER:	16
PUBLIC COMMENT SOURCE:	City of Mesa
DATE RECIEVED:	3/24/2010 9:20 AM
CATEGORY:	Ramp Meter Malfunction - Red Appears Lit from Reflected Sunlight
LOCATION:	EB US-60/Val Vista, Higley
COMMENT:	Jeff, This morning Bruce and I witnessed drivers on both eastbound on ramps at Val Vista as well as Higley treating the signal as if it was displaying a solid red. At about 6:45 AM, the sun is directly shining into the signal head and is creating the illusion that the red is active. Bruce suggested to the ADOT TOC that they louver the red indication that's when they referred him to the traffic signal shop. Derrick and Arthur were also able to observe this taking place. As a result, between the hours of 06:45 – 09:00, no benefit is being gained from having the ramp meters deactivated for the US60 & Greenfield ramp closures. Jerry
ACTION/RESPONSE:	This was an issue in the initial months of the turn-on when drivers were still learning how the ramp meters operate.

COMMENT NUMBER:	17
PUBLIC COMMENT SOURCE:	City of Mesa
DATE RECIEVED:	3/1/2010 4:13:17 PM
CATEGORY:	Backup from Ramp Metering
LOCATION:	WB US-60/Higley
COMMENT:	Citizen frustrated with other drivers blocking the north side of the interchange US 60 and Higley during the morning hours.
ACTION/RESPONSE:	This is not new at this location. Will observe the interchange tomorrow. This is the same problem as we have at US 60 and Val Vista and Gilbert. The ramp metering is causing the hold up on the ramp, when the signal has been optimized for the situation. No changes were made. The demand on WB on-ramp has exceeded the maximum capacity the ramp meter can handle. We have communicated with ADOT on this issue in the past. The ramp metering rate has been increased to the highest allowed, per our request. It is recommended to close this case.

COMMENT NUMBER:	18
PUBLIC COMMENT SOURCE:	ADOT 1003240879
DATE RECIEVED:	2/1/2010 11:06:46 AM
CATEGORY:	Evaluate Ramp Metering only at necessary Times of Day
LOCATION:	WB SR-L101/Cave Creek
COMMENT:	Thank you for giving me the opportunity to ask a question concerning the access to 101 going WEST from Cave Creek Road access. And thank you for forwarding this note to the responsible party. A few weeks ago, the ramp meter was turned on and every day I must line up with one or two other cars, or slow down until the light changes if there are no cars in line. I thought the purpose of ramp meters was to control traffic flow, particularly as it enters a freeway. For example in heavy traffic conditions it seems very reasonable to filter the amount of traffic entering, and also to slow down the access traffic to the slower speed

	of the traffic on the freeway. However, every morning I when enter at about 6:45AM the light is active (later in the morning it must be turned off as I have entered without having to stop for the light mid-morning). The problem is that at this early hour of the morning the traffic going west on the 101 is very light, at best. I can enter with a quarter mile of no traffic at all (meanwhile, the traffic on the other side of the freeway is bumper-to-bumper). So this means that I now must come to a stop, and then accelerate again (both of which consume more gasoline, contribute additional fumes to the environment, and cause one to enter traffic (if there is any) at a slower speed than the prevailing traffic which is always at the speed limit or higher (and this increases the danger as some cars merge at very slow speeds). Today I almost rear-ended a pick-up truck that was accelerating very slowly from the red-light right lane (in fact I passed it within about 100 feet of the traffic light still in the merge lane, which is probably not legal but it was the safest thing to do rather than have two very slow cars entering the freeway together). I can see no reason whatsoever to have the red light active before 7AM (and perhaps even later than 7AM as going west is traveling against the traffic in the mornings). Having the ramp light active in this location at this time increases the danger of merging into fast-moving traffic; it is an irritant to drivers as it is clearly not needed as most of the time traffic is very light at this time of day; having cars stop and start again is environmentally unfriendly, particularly since it serves no purpose at this hour of the morning. I respectfully request that the ramp meter at Cave Creek Road going west on the 101 not be active until such a time as the traffic volume necessitates it to be on, and this is certainly not before 7AM on most weekday mornings. I have never in four years of entering at this point on a daily basis seen a traffic volume where I would think metering is necessary or beneficial to the light traffic volume at this time of day. Thank you for your consideration of this request.
ACTION/RESPONSE:	(Not Provided)

COMMENT NUMBER:	19
PUBLIC COMMENT SOURCE:	City of Phoenix
DATE RECIEVED:	(Not Provided)
CATEGORY:	Evaluate Ramp Metering only at necessary Times of Day
LOCATION:	WB SR-L101/Cave Creek
COMMENT:	(Not Provided)
ACTION/RESPONSE:	(Not Provided)

COMMENT NUMBER:	20
PUBLIC COMMENT SOURCE:	City of Scottsdale
DATE RECIEVED:	(Not Provided)
CATEGORY:	Evaluate Ramp Metering only at necessary Times of Day
LOCATION:	(Not Provided)
COMMENT:	(Not Provided)
ACTION/RESPONSE:	(Not Provided)

COMMENT NUMBER: 21
PUBLIC COMMENT SOURCE: City of Scottsdale
DATE RECIEVED: (Not Provided)
CATEGORY: Backup from Ramp Metering
LOCATION: WB SR-L101/Raintree
COMMENT: (Not Provided)
ACTION/RESPONSE: (Not Provided)

COMMENT NUMBER: 22
PUBLIC COMMENT SOURCE: City of Tempe
DATE RECIEVED: (Not Provided)
CATEGORY: Backup from Ramp Metering
LOCATION: EB US-60/Mill
COMMENT: (Not Provided)
ACTION/RESPONSE: (Not Provided)

COMMENT NUMBER: 23
PUBLIC COMMENT SOURCE: ADOT
DATE RECIEVED: (Not Provided)
CATEGORY: Evaluate for New Ramp Metering
LOCATION: (Not Provided)
COMMENT: (Not Provided)
ACTION/RESPONSE: (Not Provided)

COMMENT NUMBER: 24
PUBLIC COMMENT SOURCE: FHWA
DATE RECIEVED: (Not Provided)
CATEGORY: Evaluate Ramp Metering only at necessary Times of Day
LOCATION: (Not Provided)
COMMENT: (Not Provided)
ACTION/RESPONSE: (Not Provided)

Arizona Republic Articles

1. Arizona Republic; Jane Larson; Ramp-meter installation planned along Loop 101; First Published 2-22-2008, Republished 2-26-2008

Ramp meters added to Scottsdale's Loop 101

Jane Larson
The Arizona Republic
Feb. 22, 2008 11:29 AM

SCOTTSDALE - Drivers will get help pacing their entrance on to the Loop 101 through most of Scottsdale when 19 new ramp meters begin blinking this spring.

The Arizona Department of Transportation is installing the meters at 12 southbound on-ramps and seven northbound on-ramps along Loop 101, between McDowell Road and Princess Drive.

Testing of the new meters may start in March or April, ADOT spokesman Doug Nintzel said. The agency expects to have the meters operating by early May.

The meters are a $2.2 million project designed to improve the flow of freeway traffic by limiting the n umber of vehicles entering the freeway at one time.

The system includes detectors that determine the amount of traffic on a ramp and help adjust the timing of the meters' red and green lights.

The project started last May. It is part of a larger project, to be completed late this year, to add high-occupancy-vehicle lanes to Loop 101 between the Loop 202 and Princess Drive.

ADOT next plans to install ramp meters at interchanges along Loop 101 between Princess Drive on the east and Interstate 17 on the west, Nintzel said. That project is expected to start in the fall.

An earlier project installed a southbound ramp meter at Thomas Road and northbound ones at McKellips, McDowell, Indian School and Indian Bend roads.

2. Arizona Republic; Kerry Fehr-Snyder; Ramp lights to greet US 60 motorists in Mesa, AJ; published 2-29-2008

Ramp lights to greet U.S. 60 motorists in Mesa, AJ

Kerry Fehr-Snyder
The Arizona Republic
Feb. 29, 2008 07:33 AM

Stop-and-go traffic takes on a new meaning for Southeast Valley drivers starting Monday.

Motorists will encounter traffic lights to enter the U. S. 60 during their morning commute westbound from Crismon to Gilbert roads. Metered on-ramps over the 10-mile stretch also will greet commuters entering the freeway eastbound during afternoon rush hours.

The doubled meter lights are being activated through Mesa and Apache Junction to regulate the flow of traffic entering the freeway during peak traffic times.

"I don't anticipate that this will add to anyone's drive time," said Laura Douglas, a spokeswoman for the Arizona Department of Transportation. "If anything, we're hoping this helps drivers access the freeway easier and safer than before."

The meters will be active from 5:30 to 9 a.m. and from 3 to 7 p.m. weekdays only.

The meters feature red and green lights that signal when motorists in the right and left lanes of the on ramps can enter the freeway. The lights alternate signals to give the right lane permission to enter and then the left lane, and so on.

ADOT added the meters over a larger stretch of the freeway as part of a two-year, $74 million widening project from Val Vista Drive to Crismon Road completed last year. Previously, the freeway had just a few ramp meters in that stretch, and they were turned off during the widening project.

Without the signaling ramp meters, cars pile up on the freeway entrance ramps as motorists navigate merging with each other to enter the freeway.

Ramp meters "have been shown to prevent some accidents but more to even traffic flow," Douglas said. The decision to add ramp meters depends on projected traffic needs and backups more than traffic volume, she added.

3. Arizona Republic; Cindy Hernandez; The problem with on-ramp meters; First Published 4-15-2010, Republished 4-16-2010 and 5-1-2010

The problem with on-ramp meters

In the bureaucrat's world, one size fits all. That works for socks, but it sure doesn't work for freeway-ramp meters.

Here's the problem: The Arizona Department of Transportation sets ramp meters to run at the same time across the Valley, as if a north Scottsdale interchange has the same issues as Seventh Street and Interstate 10. They clearly are different.

Take, for instance, Raintree Drive and Loop 101. Traffic on the freeway moves at the speed limit or above throughout rush hour. There's no congestion — except on the on-ramp. Traffic crawls there, wasting motorists' time and gas and polluting the air.

ADOT spokesman Doug Nintzel blames traffic patterns on nearby city streets for causing the ramp congestion. He says ADOT will work with Scottsdale to see if adjustments can improve traffic flow. Good, but that evades the real issue: The ramp meter backs up traffic nearly to Raintree. This, Nintzel defends.

Meters are designed to work together to improve traffic conditions throughout an area, Nintzel says. Freeway traffic near a particular ramp may be light, but metering reduces congestion farther down the freeway.

Only in a bureaucratic world.

Yes, traffic becomes congested a few miles to the south — in the same place it did before the meters started blinking. The Airpark meters have made little difference, other than delaying by four to six minutes any driver's arrival at the logjam.

But Nintzel and ADOT aren't done with their justifications.

Running meters at the same time provides motorists with consistency, Nintzel says.

So? Drivers don't care about on-ramps they're not using. They want to get onto a freeway as quickly as possible, and they're frustrated when bureaucracy prevents that.

Here's what ADOT should try:
--Adjust meters to local conditions. This is not impossible. ADOT starts ramp meters in central Phoenix at 5:30 a.m. to handle heavier traffic. If it can do that, it can start meters later or turn them off earlier in places with lighter traffic.
--Turn meters off at select interchanges and see whether it makes a difference. If traffic continues to move smoothly, then the meter isn't needed. If the immediate freeway traffic gets worse, ADOT can show skeptics the meters are needed for at least some portion of rush hour.
--Get better use of software and other technology. ADOT uses pavement sensors to adjust the timing of meters. When traffic is heavy, the meters allow 16 to 18 cars per minute. When traffic is lighter, the meters allow 20 to 22 cars per minute. There should be more than two choices, including an option to turn the meters off early.
Later this year, the agency will change software so ramps can detect when a single car is on a ramp and give it a green light sooner than a 10-second wait. But if a single car is waiting, why is the meter running at all?
--Put ADOT engineers in a car with regular people. Engineers need to get away from their studies and formulas and see how real people live in the real world. Then, just maybe, they'll drop their one-size-fits-all approach for something that actually works.

Your thoughts on freeway-ramp meters?

What do you think about Loop 101 ramp meters in Scottsdale? Do they make your rush-hour drive safer or more frustrating? Send your thoughts to ne.letters@scottsdalerepublic.com or mail them to The Arizona Republic, 8800 E. Raintree Drive, Scottsdale, AZ 85260.

4. Arizona Republic; Geoff Orton; On-ramp lights only impede traffic; Published 5-10-2010

On-ramp lights only impede traffic

May. 10, 2010 12:00 AM — 10 comments

Complaints about the installation of on-ramp meter lights are right on. They are not only unnecessary but will only impede the natural flow of traffic.

What bemuses me is that ADOT claims it is so strapped for money that it has to close Motor Vehicle Division offices statewide, yet it seems impelled to waste money installing these ridiculous meters.

How do they explain that? - **Geoff Orton**, *Carefree*

5. Arizona Republic; Alice Zombr; Reduce Ramp Rage, Make Meters Flexible; First Published 6-23-2010, Republished 7-17-2010

Reduce ramp rage, make meters flexible

Nothing stands out about the nondescript building at a nondescript intersection in southwest Phoenix. But inside is an impressive array of technology.

Staffers at the state's Transportation Operations Center monitor every highway in the Valley. TV screens fill one wall, allowing staffers to spot problems and advise the highway patrol about accidents. Staffers light up message boards to warn drivers about a wreck ahead.

But at least one thing remains beyond the powers of these engineers: If traffic backs up needlessly on an on-ramp, they can't do a thing about it. Drivers are left to rant about the idiocy of crawling along a ramp while highway traffic zips by.

Fortunately, there is hope. The Maricopa Association of Governments has set aside $1.5 million to tie the Valley's 180 ramp meters to the operations center.

This is good news for all those who have cursed the ramp meters or been tempted to blow past a red meter because no one else was on the ramp. (Why can't meters default to green instead of red when there is no traffic?)

"We've heard these complaints over the years," said Tim Tait, director of community relations for the Arizona Department of Transportation. "Flexibility is what we want. Flexibility is what drivers want. From our standpoint, this can help with traffic flow.

"Anything that makes people more comfortable with the system builds confidence."

Bingo.

Little about the ramp meters creates comfort or confidence. Several Airpark southbound on-ramps nearly back up into the adjoining intersection during the afternoon, though highway traffic is anything but congested. The meters flash from 3 to 7 p.m., sometimes stopping a single car early or late in the time frame.

A rigid one-size-fits-all rule doesn't work. The 2012 improvements cannot come soon enough.

In a recent meeting with editorial-board members, ADOT engineers defended the usefulness of ramp meters.

They cited a 2001 study from Minneapolis-St. Paul, where the state turned off all ramp meters for six weeks. The study found that without ramp meters, travel times increased 22 percent, freeway speeds dropped 7 percent and crashes increased 26 percent.

Point taken. Ramp meters serve a useful purpose.

The study, though, was a prelude to improvements in the ramp-meter system. The next year, the state launched a responsive ramp-meter timing system, with computers automatically adjusting the meters. The improvement promised shorter waits and meters that responded to congestion, operating only when needed.

This should be the goal for ADOT as well. The improvements slated for 2012 need to match the Twin Cities' goals. When we get meters that operate only when needed, drivers' comfort and confidence will rise.

Minneapolis-St. Paul system

Features of the Minneapolis-St. Paul responsive-ramp-meter system:

--Ramp-meter times are no more than four minutes on local ramps and no more than two minutes on freeway-to-freeway ramps.

--Vehicles waiting at meters will not back up onto adjacent roadways.

--Meter operation will respond to congestion and only operate when needed.

6. Arizona Republic; Sean Holstege; Valley to get modern ramp-metering lights; Published 7-20-2010

Valley to get modern ramp-metering lights

by Sean Holstege - Jul. 20, 2010 12:00 AM
The Arizona Republic

Freeways in the Valley are on the verge of getting more sophisticated ramp-metering lights to help reduce freeway-clogging knots of traffic.

Arizona's busiest stretch of freeway could have the most advanced on-ramp-metering lights in the world by the fall, according to a state researcher who has developed a sophisticated way to predict traffic flow.

In a monthlong experiment, the lights will be installed in the Broadway Curve area of Interstate 10 in Tempe, in hopes of sparing motorists about a third of the time they waste sitting in congestion. Computer models predict the freeway will accommodate more cars without reducing speeds. If the experiment is successful, the system could be expanded Valley-wide.

Meanwhile, the Arizona Department of Transportation also is set to modernize in a year the existing 180 Valley ramp-metering lights, many of which were installed in the early 1990s.

There are roughly 400 ramps, but most are not metered.

Both advances are part of a larger strategy to develop "intelligent" transportation systems, which use technology to squeeze the most efficiency out of highways.

The improvements are being paid for out of funds from a half-cent sales tax approved by Maricopa County voters in 2006. Proposition 400 set aside $140 million for such systems until 2025.

Other innovations to improve traffic flow in Arizona include electronic-message signs, which advise motorists about expected travel times or accidents ahead, and the 511 system, which uses embedded road sensors and mounted cameras to provide up-to-the-minute traffic conditions over the phone and Internet.

Other U.S. cities have introduced intelligent systems such as remote electronic toll collection, automated reversible lanes on freeways and variable speed-limit signs.

How metering works

Ramp-metering lights are one of the earliest, simplest and most common intelligent-transportation concepts.

But the lights are controversial, with many drivers questioning their value, especially when signals are operating on days traffic is light, such as holidays.

Arizona has two kinds of lights. The oldest and simplest are set to timers. When the carpool-lane hours are in effect, the ramps are metered, with green and red lights flashing at set intervals. Off-peak, the lights go off.

The other kind works by adjusting the cycle of the lights to the volume of traffic at the ramp. Embedded sensors in the ramps tell the light system how far back the line of cars s tretches, and freeway sensors measure traffic volume. Generally, the more cars that need to merge, the shorter the lights stay red.

The drawback is that the metering lights adjust for traffic only at their location, not along nearby ramps and stretches of freeway.

Many motorists find ramp lights frustrating. They wonder why they have to wait when there is room on the freeway to merge.

But the way ramp lights work is counterintuitive.

Stopping for a light forces merging drivers to take turns, rather than try to squeeze into a single lane of heavy traffic together. Consequently, vehicles on both the ramps and freeway move faster.

"You have to slow people down in order to speed them up," said Sarath Joshua, who manages the intelligent-transportation program for the Maricopa Association of Governments.

"Traffic is like water, and on-ramps are like turbulence in the water," he said. Plus, "in traffic, you have backups, rear-end crashes, sideswipes, and these create their own delays."

Ramp metering has proven benefits. In 2000, traffic engineers in Minnesota, responding to complaints, turned metering lights off for eight weeks.

They found that the freeway could handle 14 percent less traffic volume before getting congested and that the crash rate increased 26 percent. People needed more time to get where they were going.

An improved system

A MAG technical panel recommended last month that ADOT make improving the existing metering lights in the Valley its top priority.

Using the Proposition 400 money, MAG wants to begin wiring freeway ramps to communicate with a control center. The agency says controllers in the region's Traffic Operations Center could monitor traffic and make up-to-the-minute adjustments to the meters to get the most out of the system.

Many U.S. cities already have such systems.

"The problem is we still cannot do anything to override the metering lights," Joshua said. "It's important because it gives us the ability to respond to changing conditions."

With the upgrade, traffic engineers could preprogram unique cycles for holidays or manually change the metering cycle if they see traffic backing up or thinning out.

Work on the control-center system isn't set to begin for a year and will take a year to complete.

Modern meters

Research at Arizona State University and the University of Arizona promises a more intriguing advance.

Researchers have spent 10 years developing powerful software that uses sensors in highways, on-ramps and connecting surface streets to predict highway-traffic flows for up to 40 minutes.

More importantly, the computer models analyze data for a series of on-ramps so that one ramp-metering light can communicate with others nearby. This enables a string of interchanges to synchronize and more efficiently manage traffic flows.

"Nothing like this exists anywhere in the world," said Pitu Mirchandani, a professor who runs the project from his ASU traffic-engineering lab.

He said he hopes to run a full-scale experiment this summer on 8 miles of I-10 between Broadway and Ray roads.

The only impediment is getting the hardware to communicate. Once that's resolved, Mirchandani said, a month's worth of data will tell him if his computer models work.

He said he is 80 percent confident they will. If he's right, expanding the concept throughout the Valley would not be overly expensive. It would require entering traffic data for all the highways into the computer models and wiring existing ramp lights to communicate. Exact costs are unknown.

7. Arizona Republic; Alice Zombr; Meters back up traffic on ramps; Published 11-18-2010

Meters back up traffic on ramps

Ridiculous ramp meters put extra emissions in the air and cost commuters time and gas money. Here's what the Arizona Department of Transportation should try:

--Adjust meters to local conditions. This is not impossible. ADOT starts ramp meters in central Phoenix at 5:30 a.m. to handle heavier traffic. If it can do that, it can start meters later or turn them off earlier in places with lighter traffic.

--Turn meters off at select interchanges and see whether it makes a difference. If traffic continues to move smoothly, then the meter isn't needed. If the immediate freeway traffic gets worse, ADOT can show skeptics the meters are needed for at least some portion of rush hour.

They are backing up traffic unnecessarily on all the westbound ramps in the morning.

There is a huge difference, and everyone must plan to leave earlier for work due to our bureaucrats who can't seem to understand that "the devil's in the details." They are ridiculous.

They are adding to gas emission, commuter gas costs, and unnecessary delays, daily.

Same thing eastbound in the evening. I watch the traffic moving at 70 mph with no delays, no backups, on Tatum, Scottsdale, Hayden, Pima, and yet the ramp lights are running like mad.

Who are the idiots who can't figure this out?

--*Alice Zombr*, Scottsdale

8. Arizona Republic; Clay Thompson; Weather forecasts and on-ramps; Published 6-2-2011

Weather forecasts and on-ramps

Today's question:

Why is it that local TV stations insist on forecasting what the temperature will be in each Valley city? Who cares if there is going to be a 1-degree difference in temperature between Avondale and Tempe? Like anyone can tell anyway. How about an average temperature for all of the Valley?

Geez Louise, lighten up, Mr. Crabbypants. Are your shoes too tight?
Don't you have anything better to fret about than the TV weather forecasts? Are they cutting into your time for the latest Charlie Sheen news?
Is there any latest Charlie Sheen news? And if there is, who really gives a rodent's patootie?
Anyway, I assume they do those very specialized temperatures because they have the technology to do so. How accurate they are, I can't say.
But I suspect the thing of it is that people like seeing such information targeted at their hometown. If it's going to be 100 degrees in Avondale and 101 in Tempe, folks in Avondale can say, "This big-shot television network actually knows we're here." Or maybe, "Thank goodness we don't live in some really hot place like Tempe."
What I mean to say is, try not to worry about it, OK?

If you are on a freeway on-ramp and there are no other cars around you and the lights are red, do you have to stop and wait for a green light or can you just go ahead?
I suppose if nobody was looking you could get away with running the light. However, I can hardly advise it.
What's the big rush? You can't spare a minute or two?
There is a reason they have those red/green lights on on-ramps.
Green means go and red means stop whether there is anybody else around or not.

Reach Thompson at clay.thompson@ arizonarepublic.com or 602-444-8612.

Thursday, June 2, 2011 at 05:39 PM
Report a Violation

Topics: REPUBLIC COLUMNISTS

APPENDIX B

Stop Delay of a Ramp Meter

Introduction

Field measurements were collected to obtain an estimate of the stop delay imposed by stopping at a ramp meter. The stop delay represents the delay in time due to deceleration approaching a ramp meter, waiting for a green light, and then accelerating. The stop delay does not include the delay in time due to a queue at a ramp meter. The stop delay was found to not vary significantly from location to location and was independent of the geometry of the entrance ramp. The stop delay due to stopping at a ramp meter was found to be an average of 11.3 seconds per vehicle.

Data Collection

This value is the difference in field-measured travel times on entrance ramps when ramp meters were off versus when ramp meter were on and without a queue. Travel times were collected with a stop watch at a sample of entrance ramps. Data was collected in July and August of 2012 at five entrance ramp locations within the Phoenix Metropolitan area. Data was collected on entrance ramps with posted freeway speed limits of 55 and 65 mph, and of varying length, grade, and freeway merge geometry. 40 trials were typically conducted at the sample entrance ramps, 20 when the ramp meter was active and 20 when the ramp meter was inactive. Data was only recorded when there was no queue at the ramp meter. An observer using a stopwatch recorded the elapsed time from when a vehicle turned onto the entrance ramp from the surface-street intersection until they reached the end of the entrance ramp at the nose of the painted gore. The data includes a random sample of vehicles, including vehicles that come to a complete stop, slow down, and do not slow down prior to receiving a green light at an active ramp meter.

Analysis

The stop delay at each of the five studied ramp meters was calculated by taking the difference in the 85^{th} percentile entrance ramp travel times when the ramp meter was active with no queue present, versus when the ramp meter was inactive. Table 1 summarizes the calculated stop delay and key geometric properties at the five studied ramp meters.

Location	I-17 SB at McDowell Rd	SR-51 NB at Indian School Rd	SR-51 NB at Colter St	SR-101 NB at Indian School Rd	SR-51 SB at 26th St
Measured Stop Delay (sec/veh)	11.75	11.15	11.04	11.72	11.07
Average Grade Upstream of Ramp Meter*	-1.50%	+0.25%	-2.70%	+1.80%	-1.40%
Average Grade Downstream of Ramp Meter	+0.60%	+0.20%	+0.80%	-0.50%	-1.30%
Mainline Speed Limit (mph)	55	55	55	65	65
Entrance Ramp Length (feet)	2,465	1,521	1,438	1,972	1,623
Freeway Entrance Type	Parallel	Weave	Taper	Weave	Taper

* Represents average grade from approximately 300 feet upstream of the stop bar to the stop bar

Table 1: Entrance Ramp Properties

Upon analysis of the data in the above table, it was determined that the geometry of the ramp does not significantly affect the stop delay from a ramp meter. Therefore, the stop delay will be considered a fixed value, independent of entrance ramp geometry. The stop delay was derived by averaging the stop delay of the studied entrance ramps, resulting in a value of 11.3 seconds.

Raw Data

The raw data of the studied entrance ramps is provided below. The data represents the elapsed time, in seconds, from when a vehicle turned onto the entrance ramp from the surface-street intersection until they reached the end of the entrance ramp at the nose of the painted gore.

Location: I-17 (SB), entrance from McDowell Road

Trial Number	1	2	3	4	5	6	7	8	9	10
Ramp Meter Inactive	47.56	44.63	40.75	41.97	40.40	36.96	40.91	37.47	34.91	41.40
Ramp Meter Active	56.18	49.53	45.72	42.50	66.18	40.03	41.14	40.91	50.00	45.78
Trial Number	11	12	13	14	15	16	17	18	19	20
Ramp Meter Inactive	35.16	38.13	42.24	35.62	38.00	49.88	34.41	39.59		
Ramp Meter Active	52.28	49.25	48.25	66.09	49.63	48.91	44.56	54.87	45.88	47.97

Average Travel Time Inactive: 40.00 **Average Travel Time Active: 49.28** **Difference: 9.28**
85th Percentile Travel Time Inactive: 43.32 **85th Percentile Travel Time Active: 55.07** **Difference: 11.75**

Location: SR-51 (NB), entrance from Indian School Road

Trial Number	1	2	3	4	5	6	7	8	9	10
Ramp Meter Inactive	24.88	23.99	22.06	21.78	19.40	27.80	22.03	24.58	26.00	21.34
Ramp Meter Active	32.25	37.97	30.06	36.36	32.65	34.14	33.25	31.50	36.63	32.28
Trial Number	11	12	13	14	15	16	17	18	19	20
Ramp Meter Inactive	21.25	23.21	24.11	25.66	21.48	23.88	27.31	23.86	21.15	23.47
Ramp Meter Active	35.13	32.88	35.53	31.72	31.75	28.27	35.50	36.92	37.20	39.40

Average Travel Time Inactive: 23.46 **Average Travel Time Active: 34.07** **Difference: 10.61**
85th Percentile Travel Time Inactive: 25.81 **85th Percentile Travel Time Active: 36.96** **Difference: 11.15**

Location: SR-51 (NB), entrance from Colter

Trial Number	1	2	3	4	5	6	7	8	9	10
Ramp Meter Inactive	17.78	18.84	22.34	20.97	22.25	16.37	19.37	19.91	16.68	19.78
Ramp Meter Active	36.08	29.37	37.30	23.58	24.98	23.42	25.43	27.45	28.53	27.84
Trial Number	11	12	13	14	15	16	17	18	19	20
Ramp Meter Inactive	15.41	17.60	22.28	17.58	18.78	20.38	20.44	19.31	22.56	19.94
Ramp Meter Active	29.28	26.36	29.09	24.79	31.03	34.00	27.38	27.08	25.81	33.16

Average Travel Time Inactive: 19.43 **Average Travel Time Active: 28.60** **Difference: 9.17**
85th Percentile Travel Time Inactive: 22.25 **85th Percentile Travel Time Active: 33.29** **Difference: 11.04**

Location: SR-101 (NB), entrance from Indian School Road

Trial Number	1	2	3	4	5	6	7	8	9	10
Ramp Meter Inactive	26.65	26.97	25.19	26.18	28.37	25.03	27.78	27.59	28.99	27.06
Ramp Meter Active	39.04	35.13	40.81	38.08	39.94	40.31	36.98	34.72	40.00	33.56
Trial Number	11	12	13	14	15	16	17	18	19	20
Ramp Meter Inactive	22.68	32.66	27.78	27.31	26.97	28.34	31.56	26.18	26.81	28.97
Ramp Meter Active	31.50	35.68	31.47	36.28	41.90	41.10				

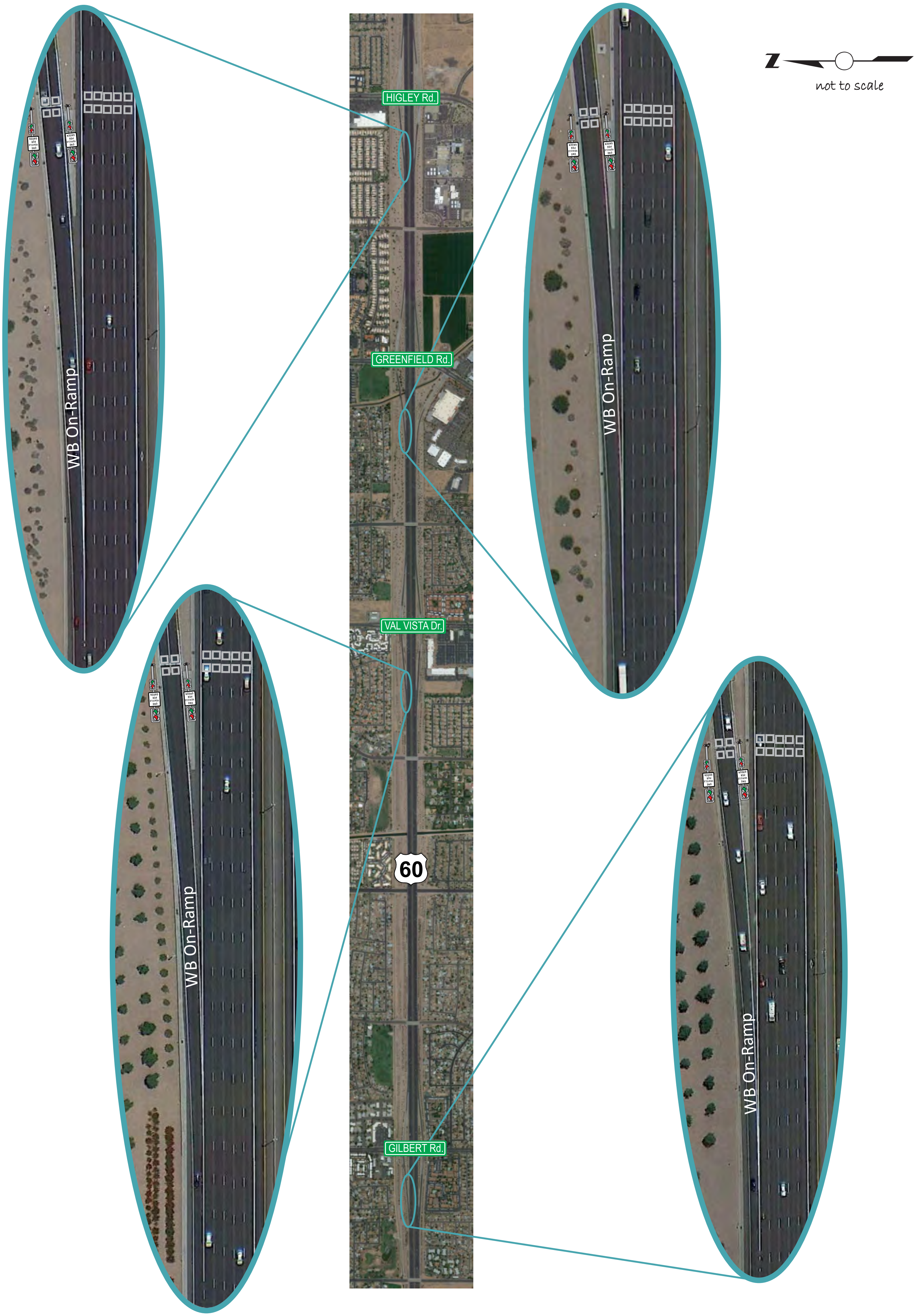
Average Travel Time Inactive: 27.45 **Average Travel Time Active: 37.28** **Difference: 9.83**
85th Percentile Travel Time Inactive: 28.97 **85th Percentile Travel Time Active: 40.69** **Difference: 11.72**

Location: SR-51 (SB), entrance from 26th Street

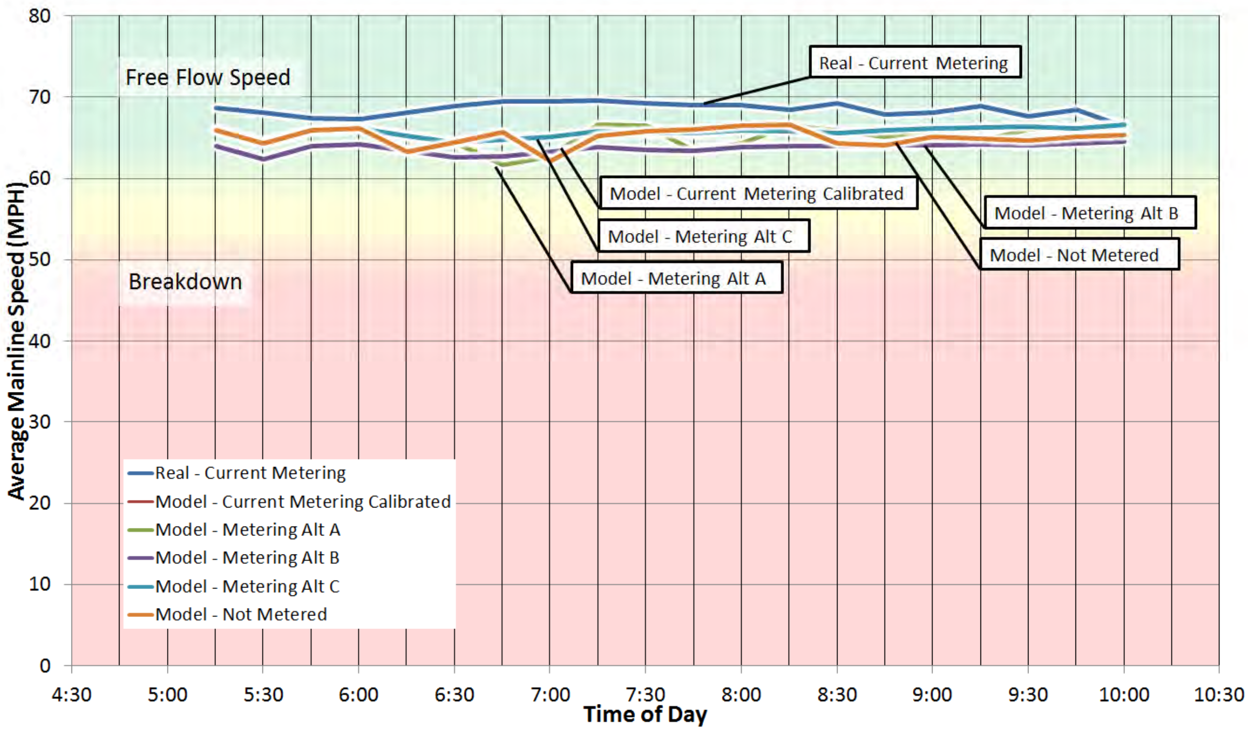
Trial Number	1	2	3	4	5	6	7	8	9	10
Ramp Meter Inactive	22.28	22.33	20.18	20.16	22.87	23.20	20.90	23.43	21.14	19.66
Ramp Meter Active	27.44	30.72	26.03	30.95	35.72	30.22	34.22	31.25	30.25	33.66
Trial Number	11	12	13	14	15	16	17	18	19	20
Ramp Meter Inactive	22.58	21.36	22.04	24.41	23.00	22.87	23.06	21.50	21.45	17.54
Ramp Meter Active	32.06	30.70	30.84	27.72	32.78	32.06	32.60	27.40	35.28	33.49
Trial Number	21	22	23	24	25	26	27	28	29	30
Ramp Meter Inactive	21.31	20.36	22.13	19.89	19.97	20.51	20.14	21.50	22.15	19.56
Ramp Meter Active	32.02	30.61	31.94	34.29	31.38	30.36	30.75	35.97	31.22	32.51

Average Travel Time Inactive: 21.45 **Average Travel Time Active: 31.55** **Difference: 10.10**
85th Percentile Travel Time Inactive: 22.95 **85th Percentile Travel Time Active: 34.02** **Difference: 11.07**

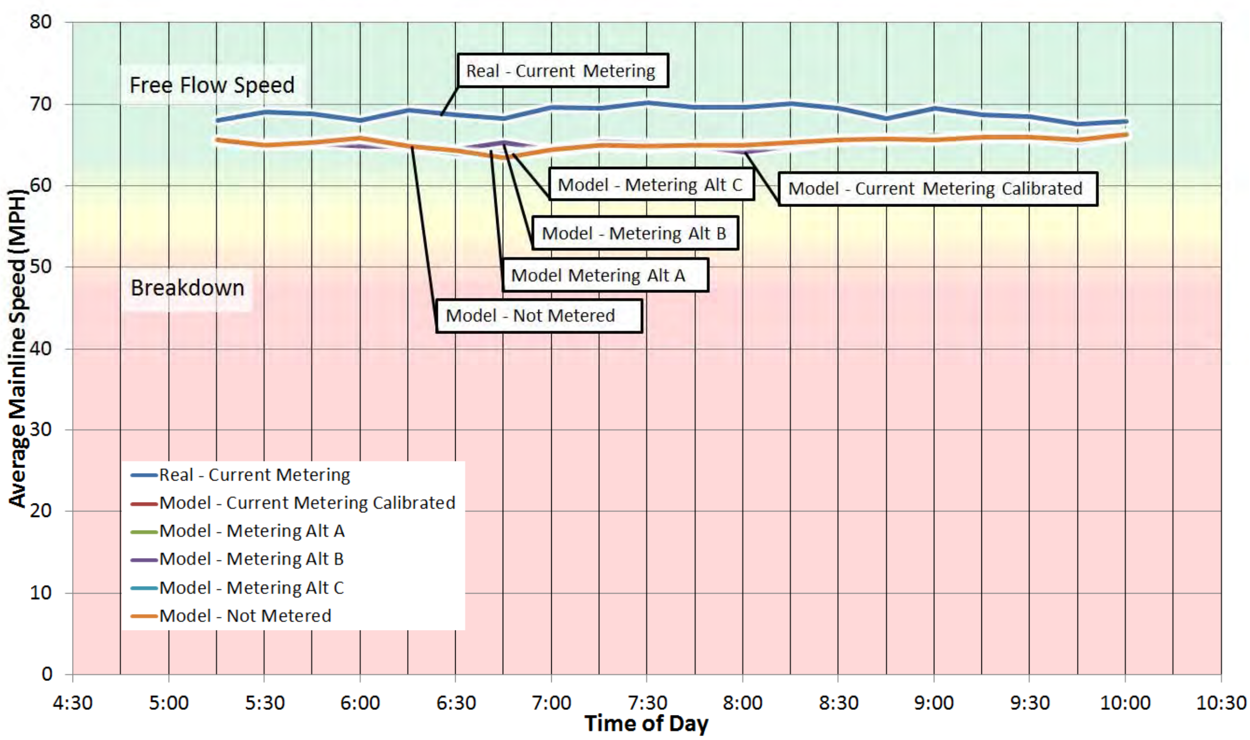
APPENDIX C



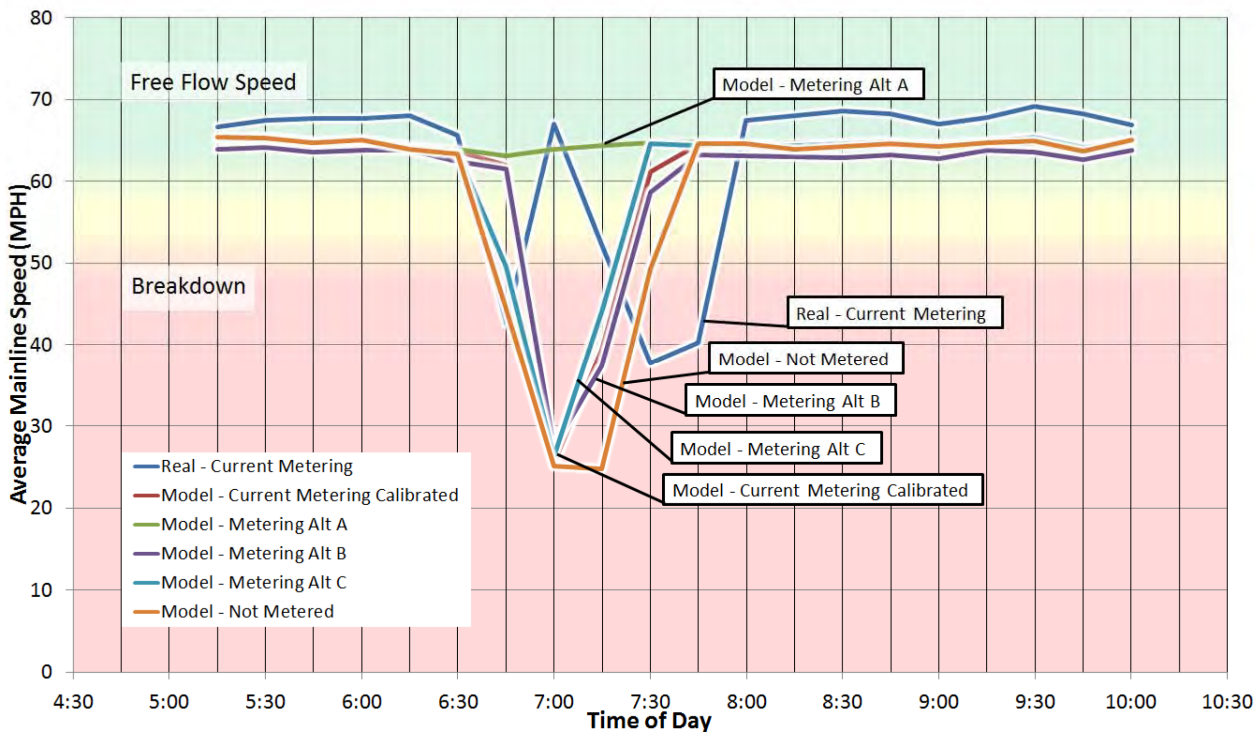
Modeling Area 1 - WB US-60 from Gilbert Road to Higley Road



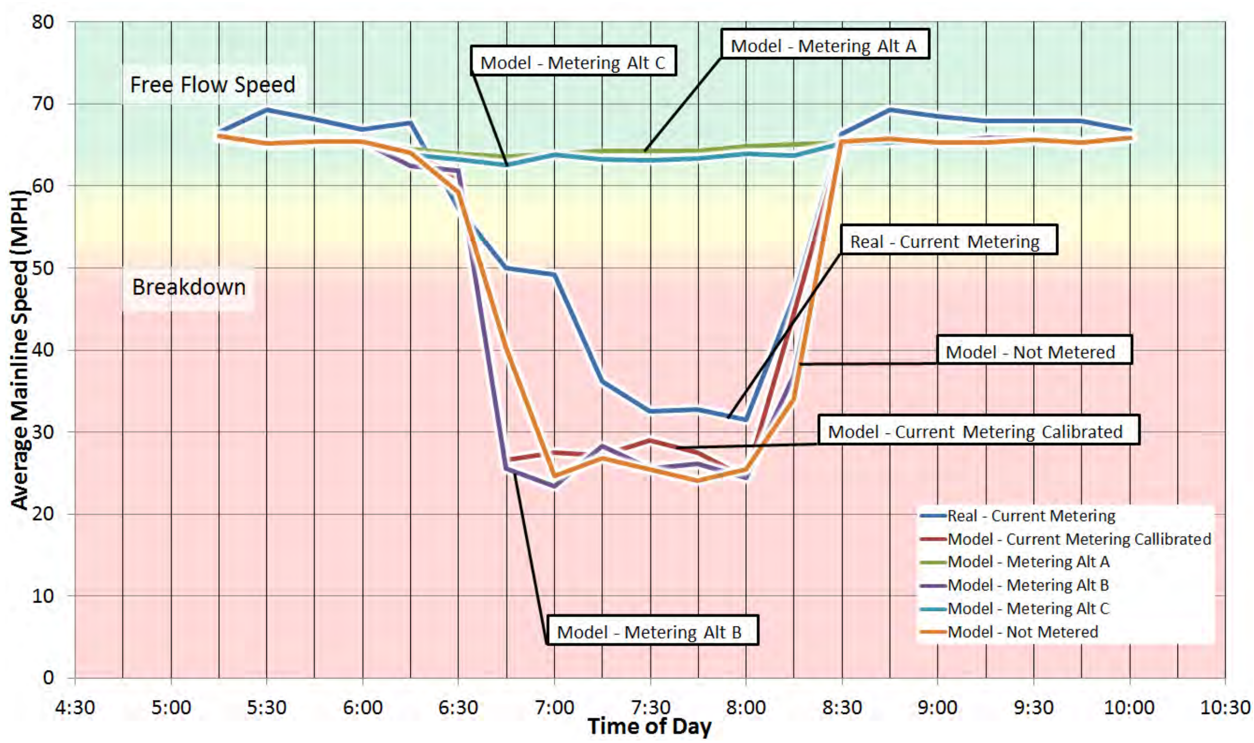
Modeling Results for US-60 Westbound at Higley Road



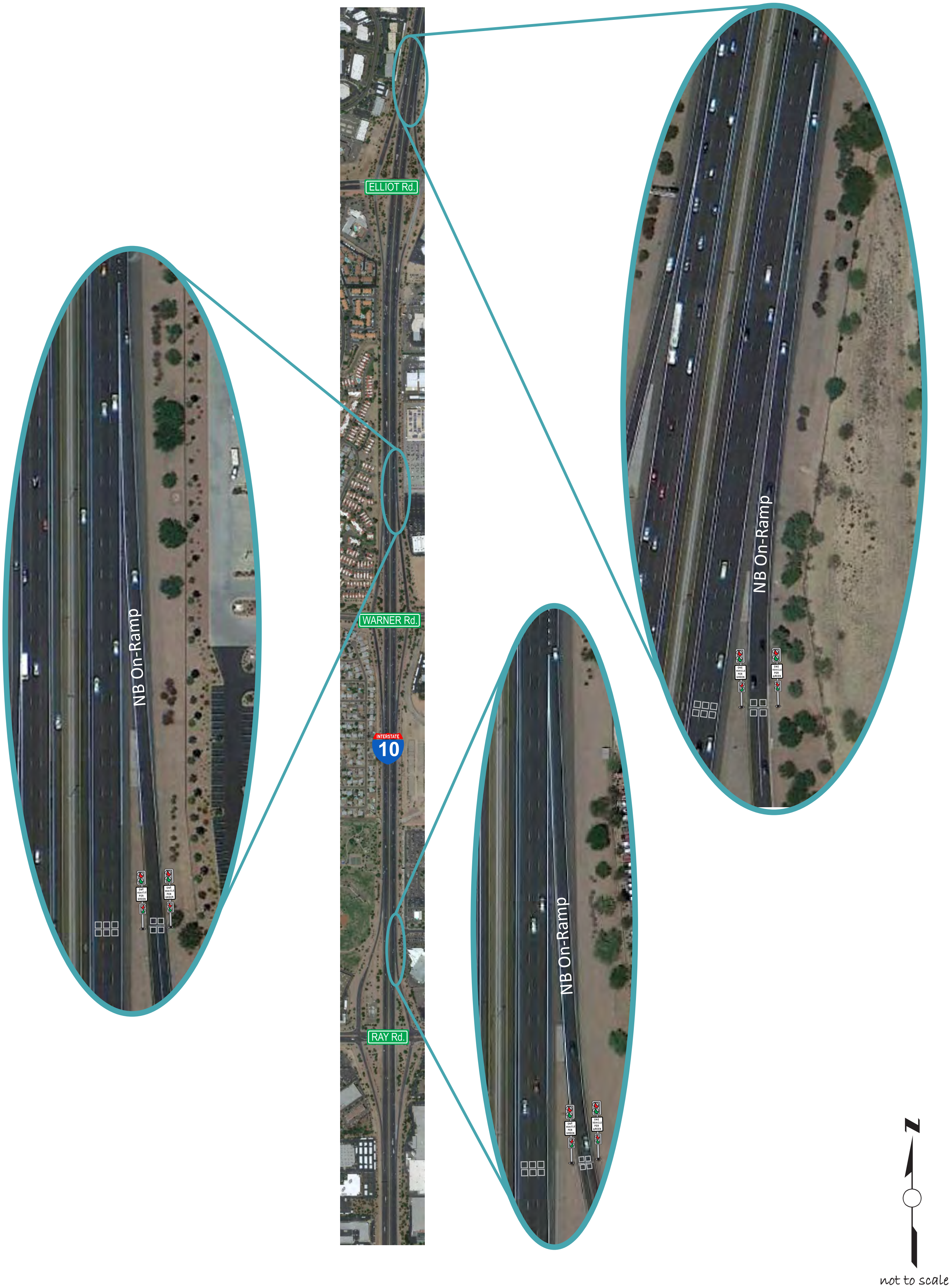
Modeling Results for US-60 Westbound at Greenfield Road



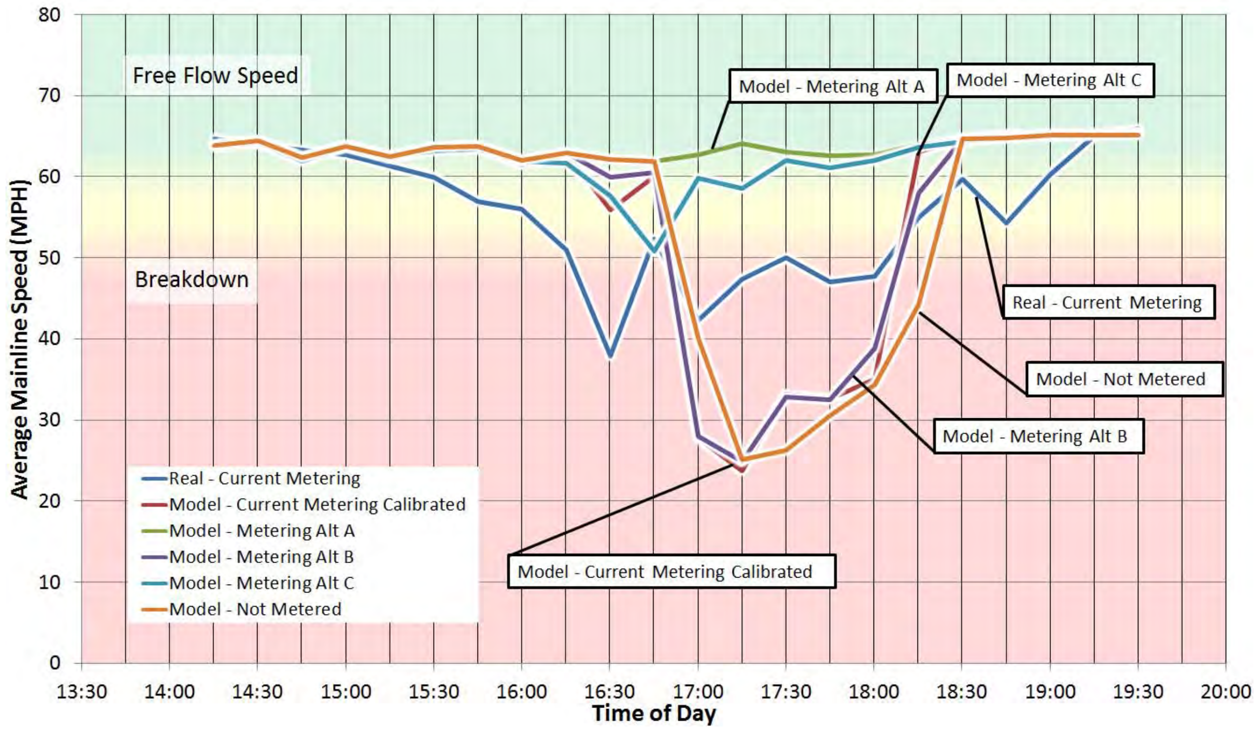
Modeling Results for US-60 Westbound at Val Vista Drive



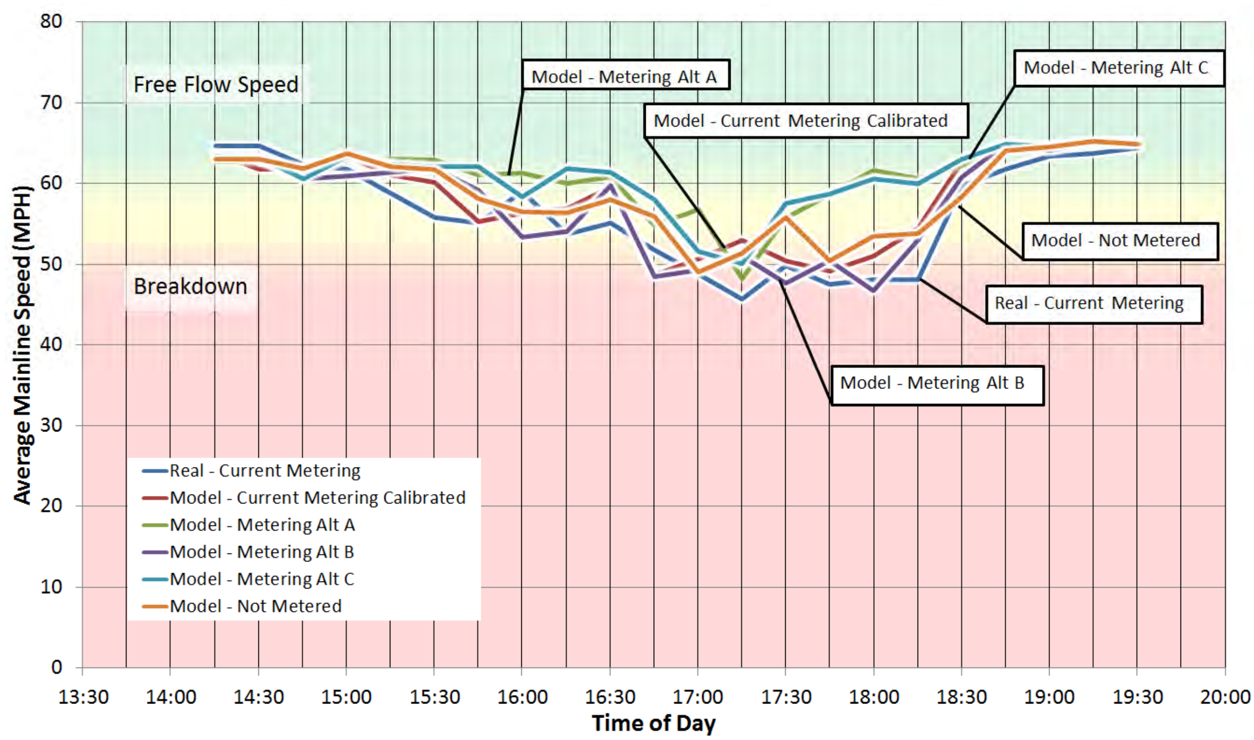
Modeling Results for US-60 Westbound at Gilbert Road



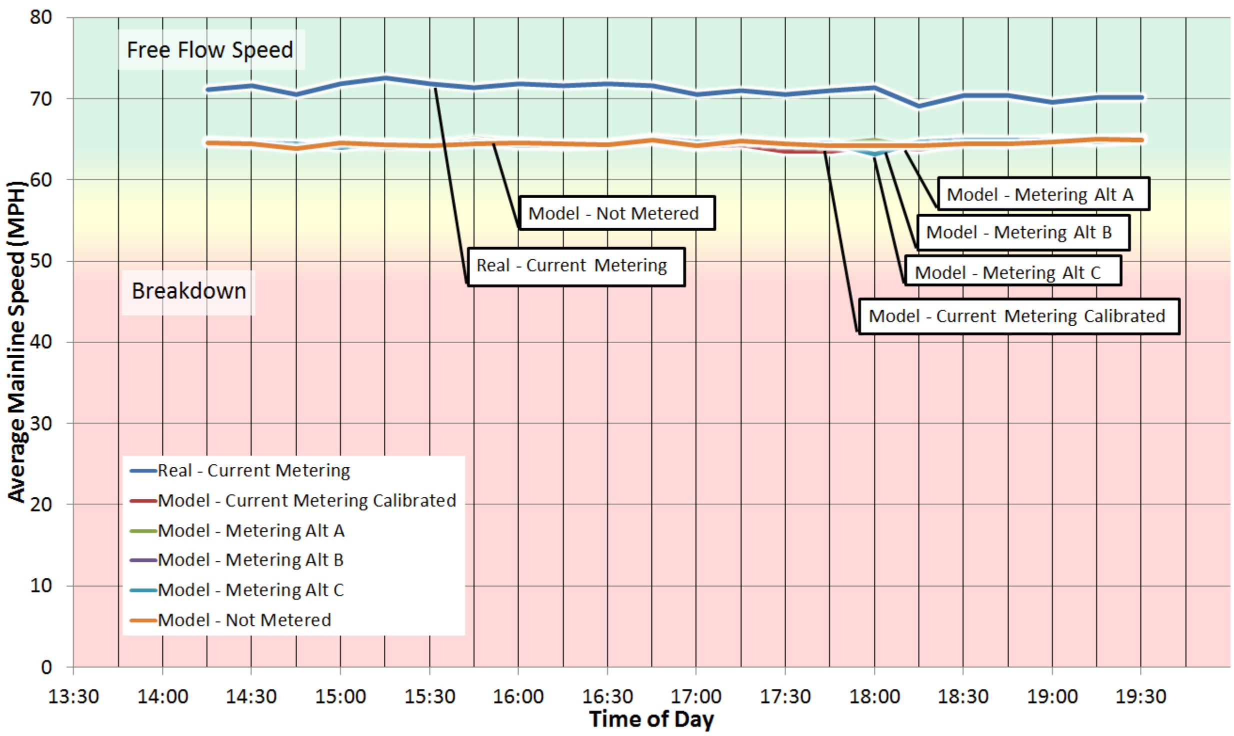
Modeling Area 2 - EB I-10 from Ray Road to Elliot Road



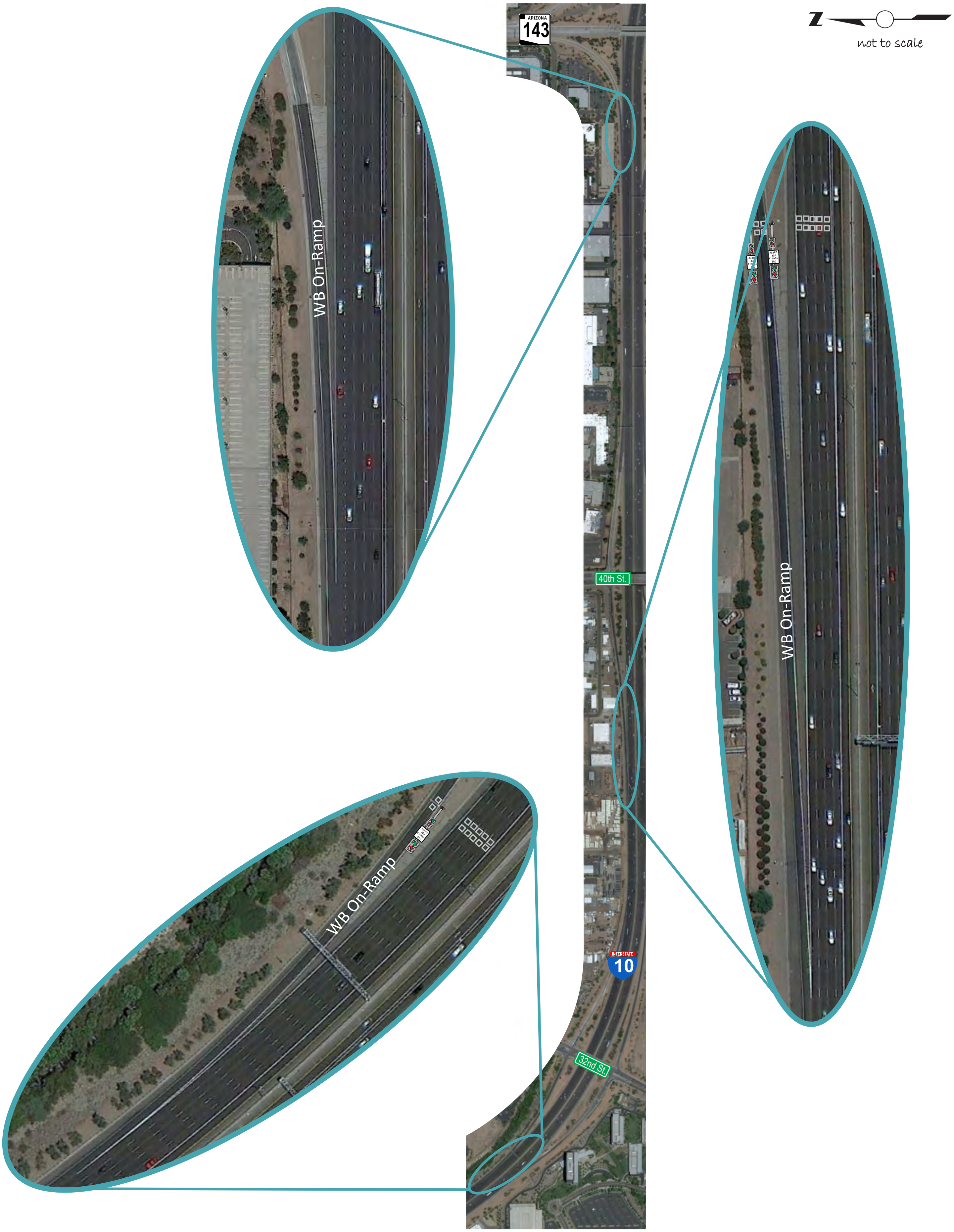
Modeling Results for I-10 Eastbound at Elliot Road



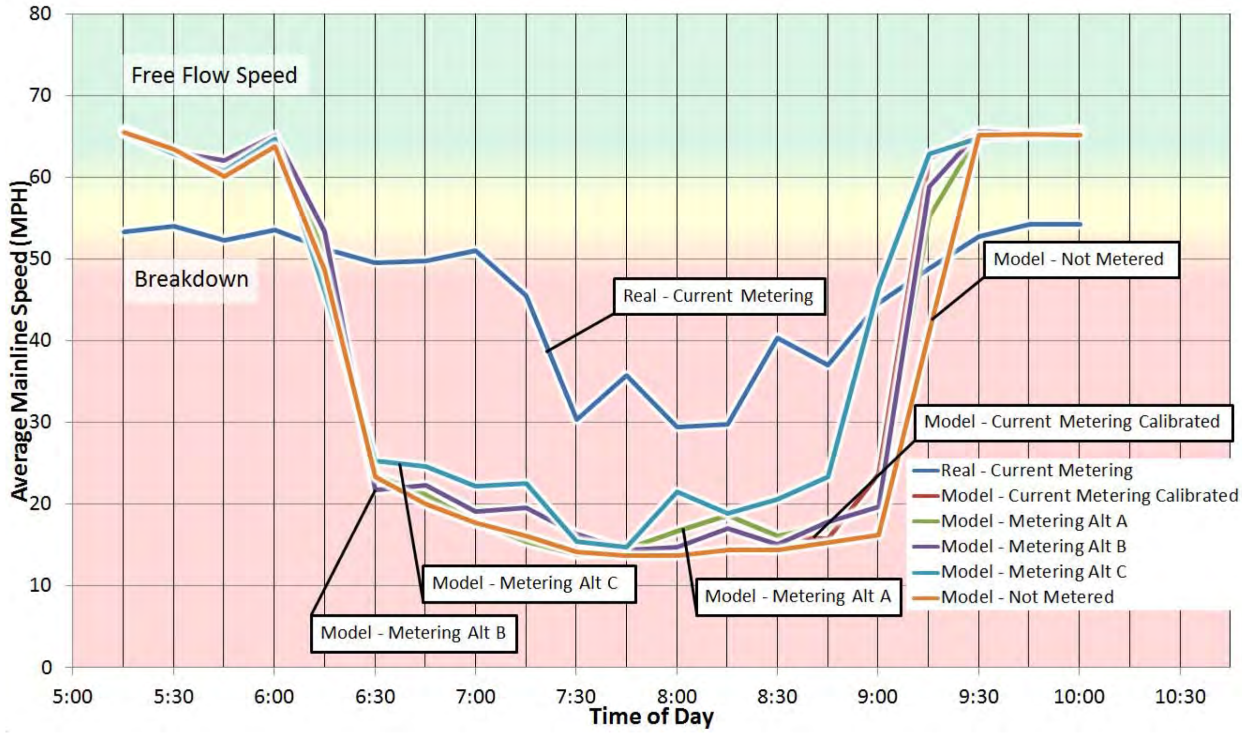
Modeling Results for I-10 Eastbound at Warner Road



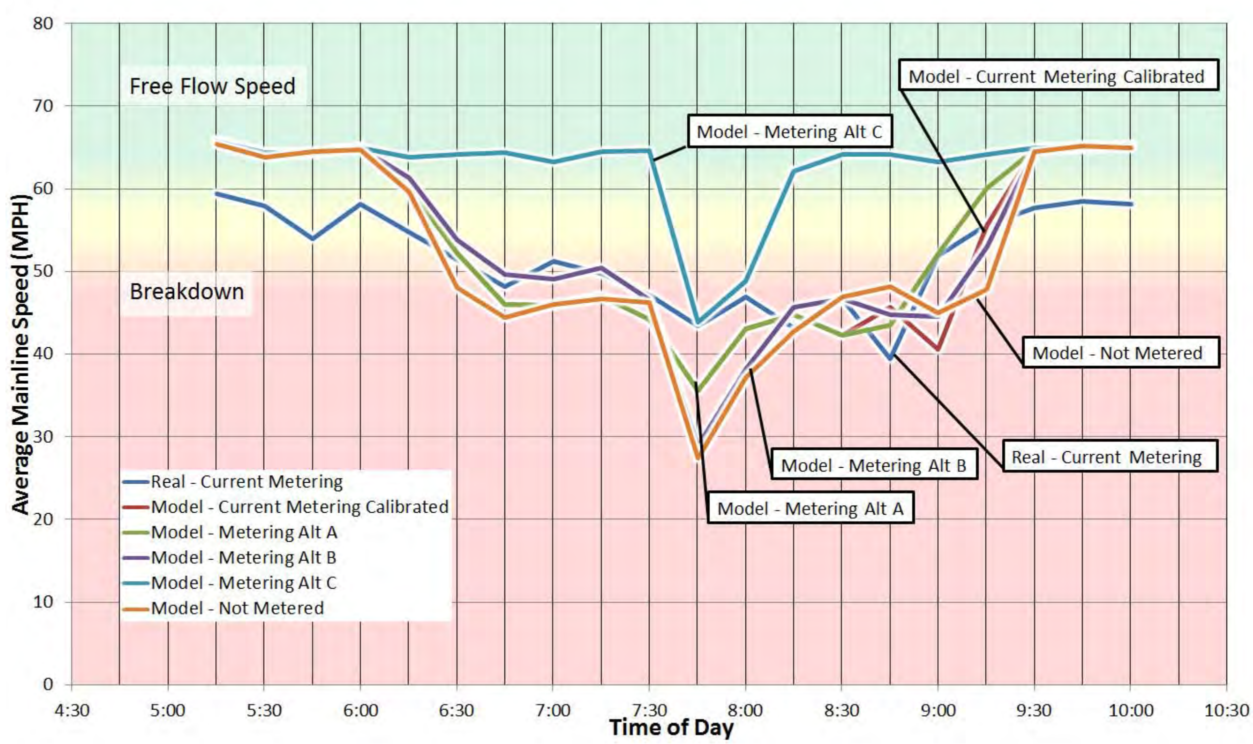
Modeling Results for I-10 Eastbound at Ray Road



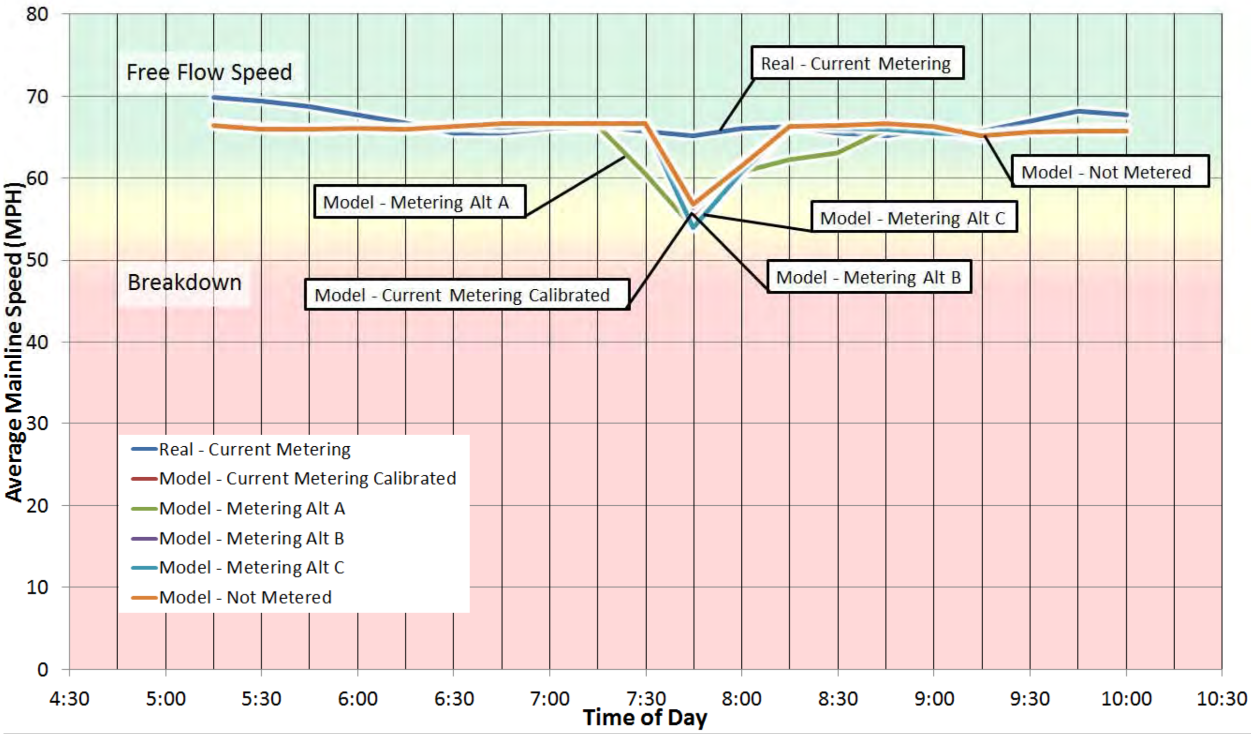
Modeling Area 3 - WB I-10 from SR-143 to 32nd Street



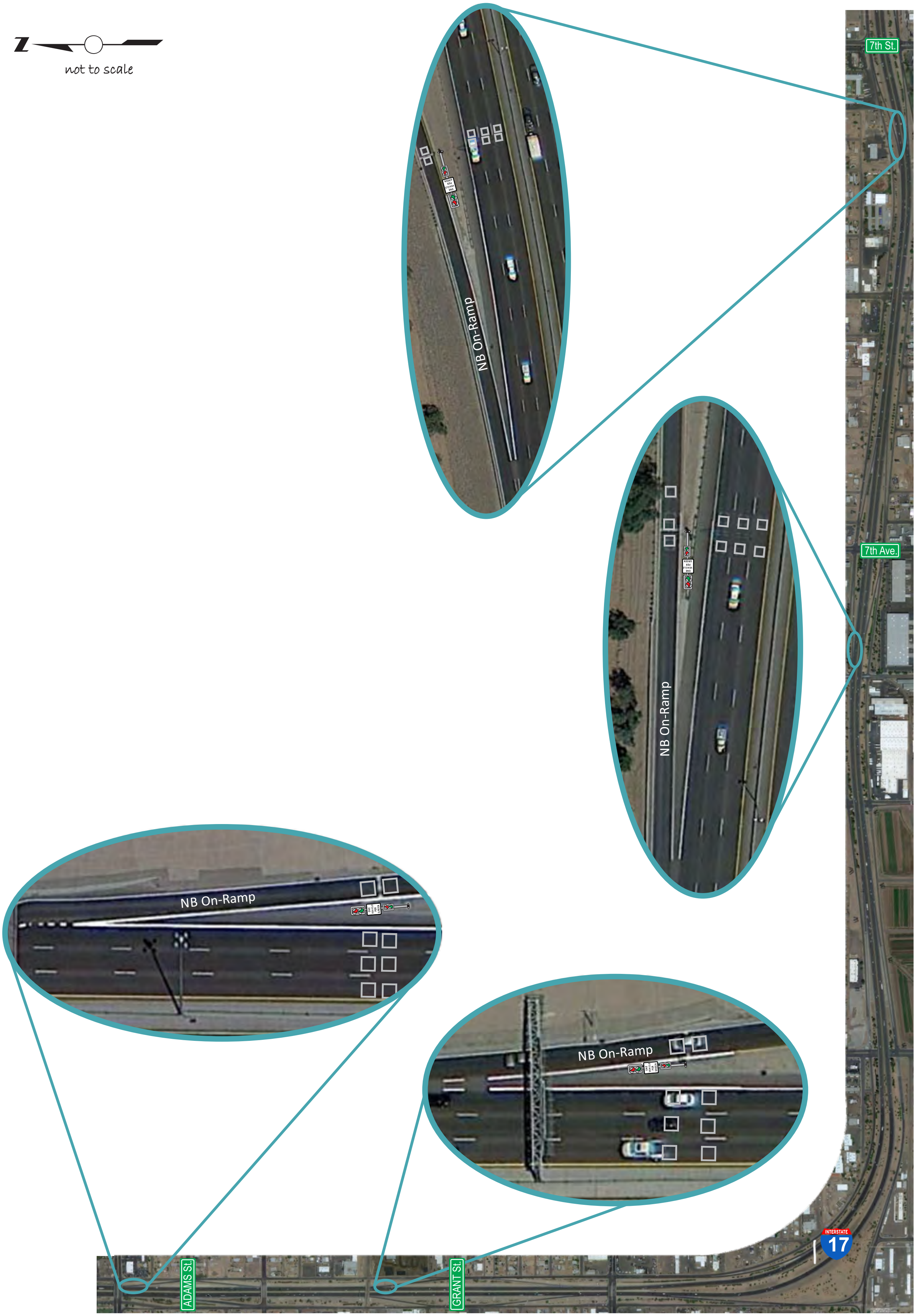
Modeling Results for I-10 Westbound at SR-143



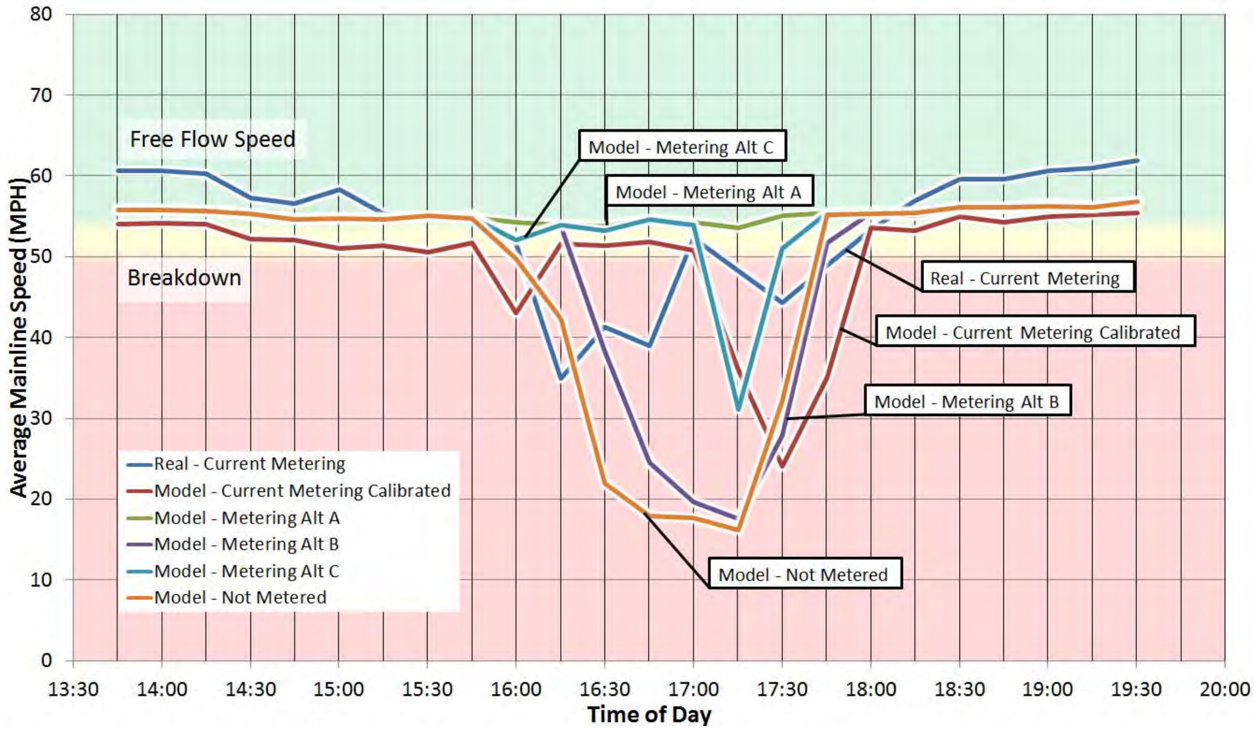
Modeling Results for I-10 Westbound at 40th Street



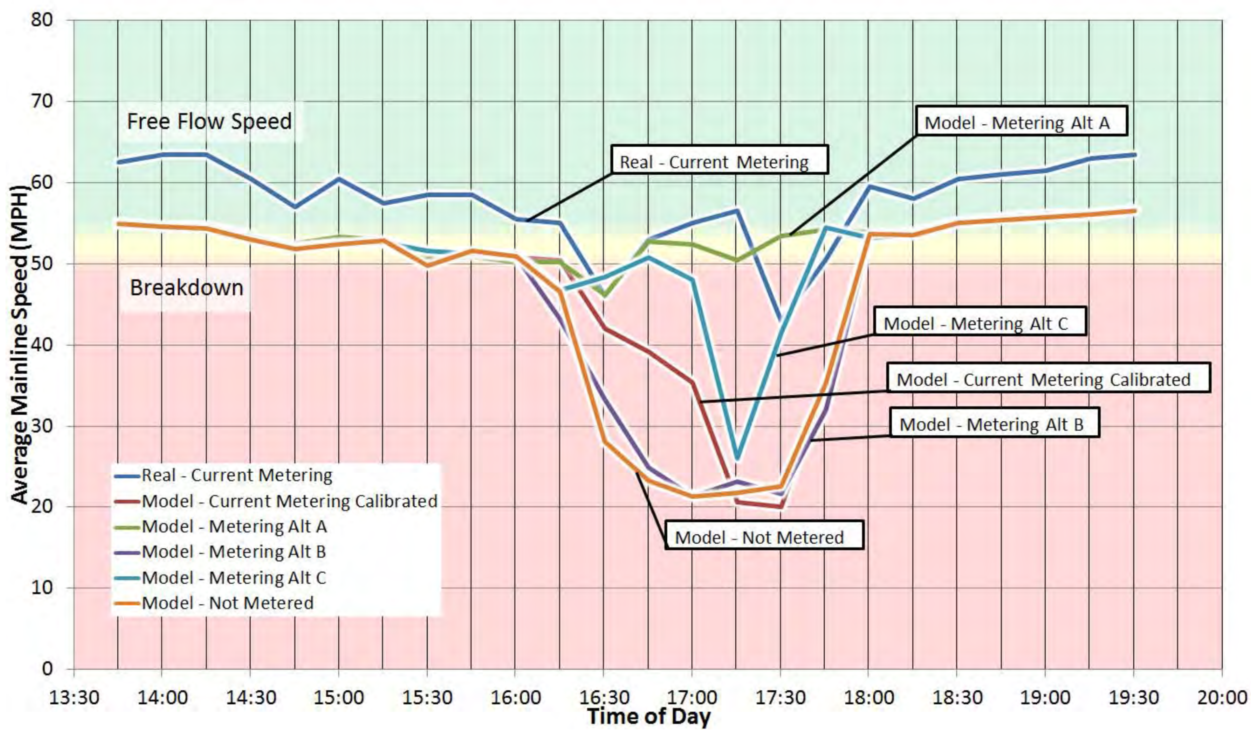
Modeling Results for I-10 Westbound at 32nd Street



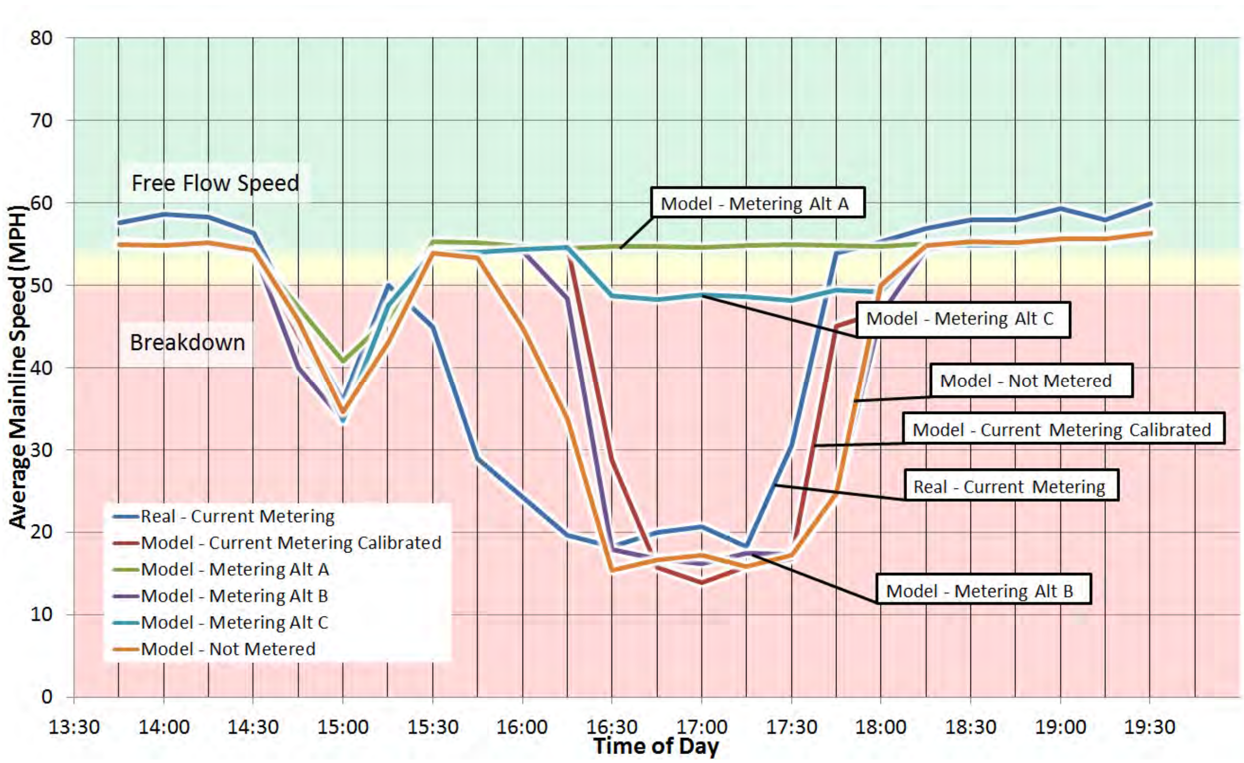
Modeling Area 4 - NB I-17 from 7th Street to Adams Street



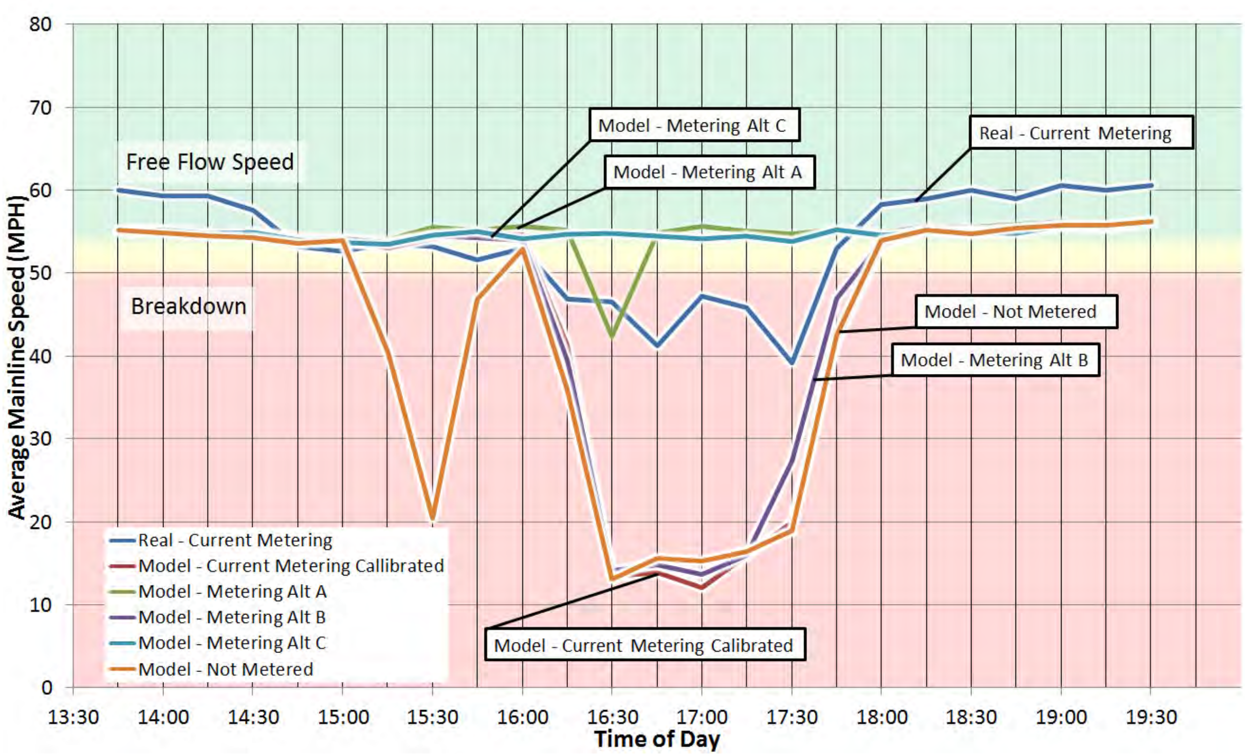
Modeling Results for I-17 Northbound at 7th Street



Modeling Results for I-17 Northbound at 7th Avenue

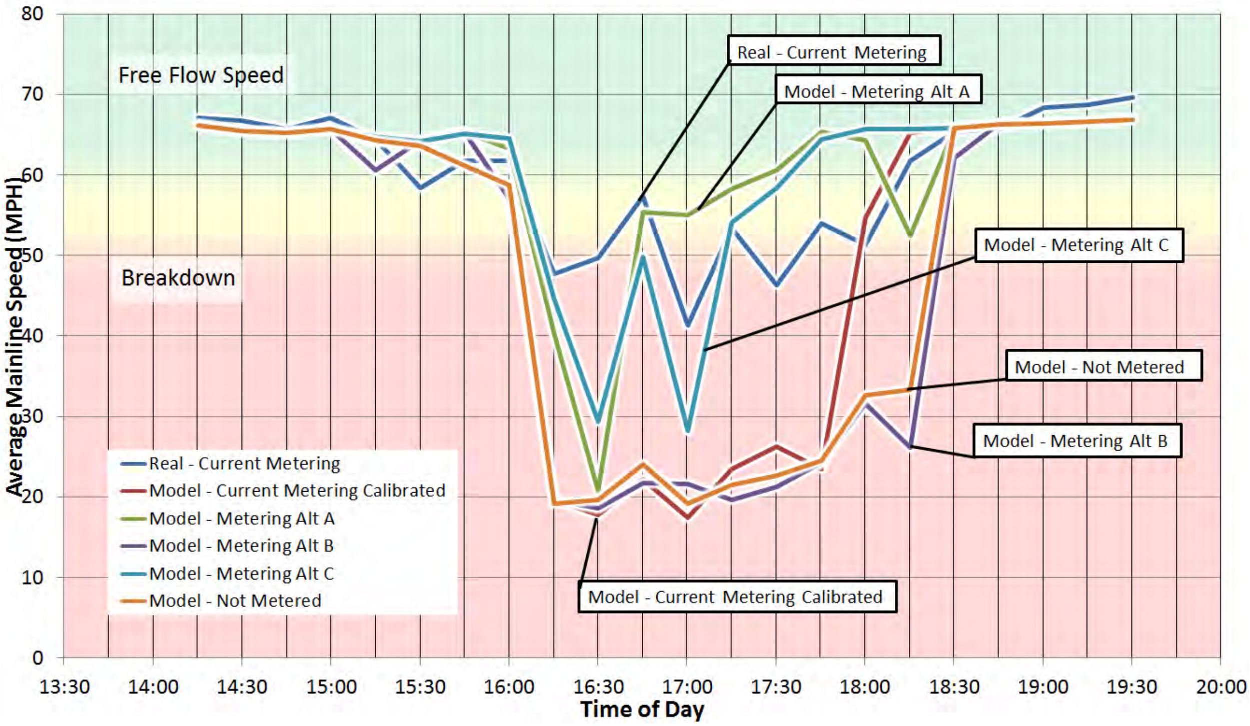


Modeling Results for I-17 Northbound at Grant Street



Modeling Results for I-17 Northbound at Adams Street

Modeling Area 5 - WB SR-101L at 7th Avenue



Modeling Results for SR-101 Westbound at 7th Avenue