Ramp Metering Installation and Maintenance Assessment – A Pilot Study

Houston, Texas

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Ramp Metering Installation and Maintenance Assessment – A Pilot Study

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This research was performed in cooperation with the Texas Department of Transportation (TxDOT). The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of TxDOT.

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Project Background

The Houston District of the Texas Department of Transportation (TxDOT) has operated ramp meters on continuously on Houston freeways since the late 1990's. One-hundred meters were installed on seven facilities as part of reintroducing ramp meters to the area, after having them previously in the 1980's. As some facilities were improved (IH-10 West) or brought under construction (US 290), meters were removed from operation. However, there are currently 60 meters in operation in the Houston area, and the district was interested in assessing a subset of the current ramp meter locations to determine if their operation should continue given updated ramp meter warrant guidelines, operation and maintenance considerations, and their overall benefits to mobility.

As part of this study, researchers examined ten entry ramps (both with existing ramp meters and without ramp meters) which, if metered, could contribute to improvements in freeway operations. The 2006 Texas Manual on Uniform Control Devices (TMUTCD) (*1*) and a recent TxDOT Research Report from Project 0-5294 "*Development of Criteria for Installation and Operation of Ramp Meters*" (*2*) provide criteria for installing and operating ramp meters on freeway entrance ramps. The revised 2012 version of the TMUTCD does not include specific criteria for installation of ramp meters, thus criteria from the 2006 TMUTCD and TxDOT research project 0-5294 was used for this study. However, prior to applying these criteria to all existing entrance ramps in the district, staff desired to complete an initial investigation on a subset of ramps. For this effort, researchers applied ramp meter installation criteria to 10 entrance ramps on IH-69 (US-59, Southwest Freeway) – six with existing ramp meters and four with no existing meters. These ramp locations are shown in Figure 1.

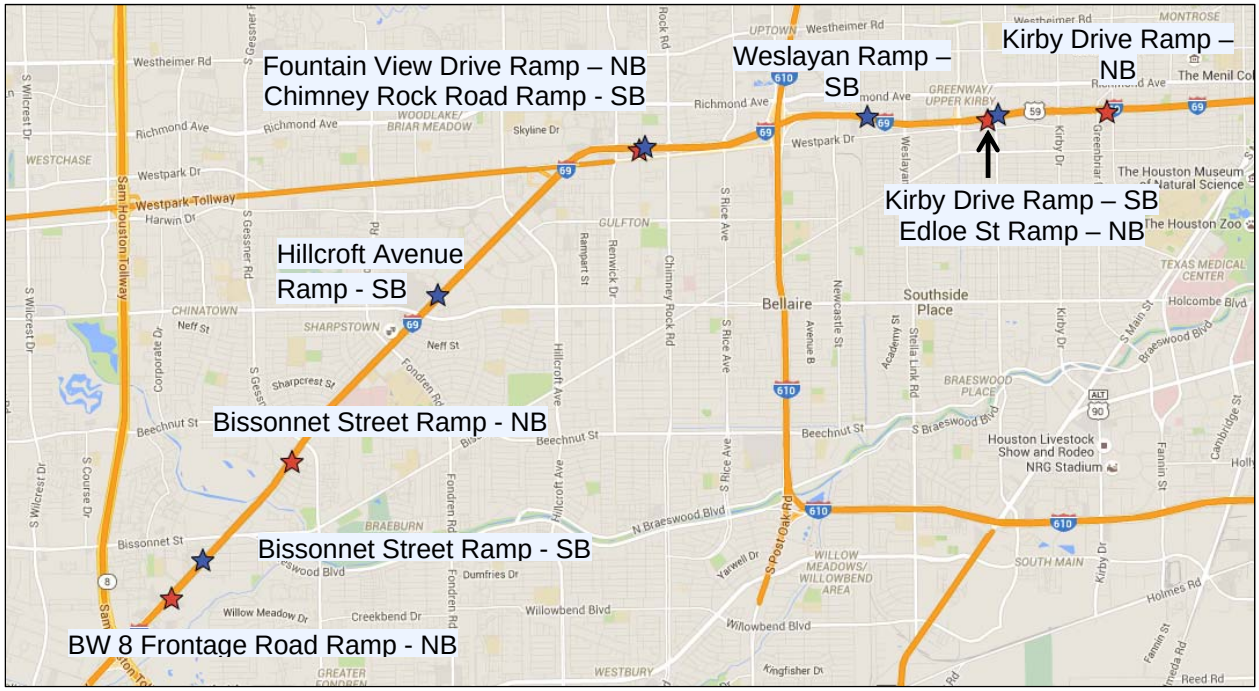

Figure 1. IH-69/US-59 Study Entry Ramp Locations (Map Data: Google)

There are six additional locations along IH 69 (Southwest Freeway) with existing ramp meters that were not included in this study as the objective of this study was to develop a template for applying the ramp metering installation criteria to locations with and without existing ramp meters. In addition, TxDOT tasked TTI researchers to investigate methods and/or infrastructure requirements to reduce the number of ramp meter knockdowns to reduce maintenance costs, and to assess the estimated benefit/cost for the metering system. This report documents the results of application of ramp meter installation criteria for the 10 ramps identified for this pilot study; the maintenance issues identified using TranStar Asset Management System (TAMS) database and conversations with TxDOT personnel; and possible strategies to help mitigate maintenance issues in general and ramp meter knockdowns in particular.

Methodology

The following steps were employed in completing this pilot study for ramp meter installation guidelines in the Houston District:

- Collect volume data for two rightmost freeway lanes and entrance ramp at each study location;
- Collect IH 69 corridor crash data between the Sam Houston Tollway (Beltway 8) and Kirby Drive for a time period of one year;
- Collect geometric characteristics for each entrance ramp, including acceleration lane length and storage length; among other elements;
- Collect information from the TAMS Database and TxDOT staff about current maintenance issues and flush mode operation times;
- Analyze all collected data and apply installation criteria at all 10 locations;
- Complete a literature search to identify methods or infrastructure that can help reduce ramp meter knockdowns;
- Complete an estimate of the benefit/cost ratio of ramp meter system operation; and
- Document the findings and develop recommendations for installation, operation, and maintenance of ramp meters based on data analysis.

Data Collection and Reduction

Traffic Volume Data

Researchers collected traffic volume data for the two rightmost freeway mainlanes and entrance ramp for a typical weekday using video for freeway mainlanes and pneumatic tubes for the entrance ramp. The data collection dates for each location are listed in Table 1.

Table 1. Traffic Data Collection Dates

Ramp Name/ Location	Travel Direction	Data Collection Dates (2016)		Ramp Meter Existing (yes/no)
		Video	Tube Counts	
US 59 @ Beltway 8 Frontage Road	Northbound	May 23-24	Week of May 23	No
US 59 @ Bissonnet Road	Northbound	March 21	March 21	Yes
US 59 @ Fountainview Road	Northbound	May 10	May 10	Yes
US 59 @ Edloe Street	Northbound	May 18-19	May 16	Yes
US 59 @ Kirby Drive	Northbound	May 19-20	May 16	No

US 59 @ Kirby Drive	Southbound	May 19-20	May 16	Yes
US 59 @ Weslayan Street	Southbound	May 18-19	May 16	No
US 59 @ Chimney Rock Road	Southbound	July 12-13	July 12	Yes
US 59 @ Hillcroft Avenue	Southbound	May 18-19	May 23	Yes
US 59 @ Bissonnet Road	Southbound	May 11	May 10	No

For data collection at the southbound Chimney Rock Road entry ramp, anomalies in data collection in May required that we recollect traffic data in July. The difference in 24-hour ramp volumes in May and July was found to be -3.9% (lower for July as compared to May). Since a 5%-10% change from day to day is considered normal, no adjustments were made to the July data when applying the ramp metering installation criteria.

Video data and pneumatic tube data were then reduced to determine traffic flow rates by 15-minute intervals for a typical weekday. We focused on the daily time period between 6 AM to 8 PM so as to identify time periods during the day that would most benefit from ramp metering installation and operation.

Video data for one weekday day were reduced from 6 AM to 8 PM while for the second day, video data were reduced for only eight 15-minute intervals that were identified as having the highest volumes from Day 1 Counts. The average of Day 1 and Day 2 volumes were then used in checking against the ramp meter installation criteria. Detailed traffic volume data (both reduced video data and pneumatic tube data) is included in Appendix A.

Crash Data

Corridor crash data were obtained from CRIS database using the following filters:

- Freeway: IH-69/US-59
- Limits: Sam Houston Tollway to Kirby Drive
- Time Period: January 1, 2015 to December 31, 2015

For the year 2015, TxDOT's CRIS database showed 1014 crashes along US 59 between Sam Houston Tollway and Kirby Drive. Researchers calculated crash rates per day per mile per 100 million vehicles using a segment length of 10.55 miles, annual average daily traffic (AADT) of 250,000 vehicles per day. AADT of 250,000 was used based on data available in CRIS for this segment of IH-69. Crash rate for the study segment of US 59 was calculated to be 105 crashes per mile per day per 100 million vehicles. Literature suggests use of ramp metering for a freeway corridor where volumes justify metering and crash rate is higher than 80 crashes/day/mile/100 million vehicles (*3*). However, most agencies and states do not specify a threshold crash rate for installing ramp meters, but apply it as subjective criteria based on local conditions and engineering judgment. The time period selected for calculating corridor crash rate was selected based on information available in literature (*3*).

Speed Data

In order to apply installation criteria for ramp metering, the guidelines suggest collecting two types of speed data:

- Average freeway operating speeds in the vicinity of the entrance ramp to see if recurring congestion criteria (Primary Criteria from TMUTCD 2006 version) justifies the installation of a ramp meter. Average speeds below 50 mph for at least a half hour period on weekdays are considered a good indicator of recurring freeway congestion. This data for study ramps was obtained from AVI/Bluetooth travel time archives by segment for the study corridor.
- Estimation of free-flow speeds in the freeway mainlanes near the ramp merge area and speeds of entrance ramp traffic when merging. For the study ramps along US 59, researchers estimated free-flow speeds of mainlanes traffic to be 50 mph during peak periods and ramp traffic speeds for merging to be close to 40 mph especially for times when ramp metering if installed would be active. Researchers also observed these speeds during field visits to the study locations.

Geometric Data

Researchers measured acceleration lane length and storage length using Google Earth Aerial Imagery using the following criteria:

- Acceleration lane length was measured as distance from stop bar (when available for existing meters and possible location of stop bar for locations with no existing meters) to the end of solid white stripe for auxiliary lanes and to the end of taper for acceleration lanes.
- Storage length was measured as distance from the beginning of solid white stripe between ramp lane and frontage road through lanes to the stop bar or potential stop bar. Storage length was also measured from the stop bar/potential stop bar to the upstream intersection if intersection was less than 1000 feet from the stop bar.

Maintenance Data

Researchers obtained operations and maintenance costs as well as a list of maintenance issues from TranStar Asset Management System. In addition to maintenance issues found in TAMS, conversations with TxDOT staff indicated that ramp meter knockdown is a frequent occurrence (as much as once a month at certain locations) requiring maintenance, with over 40 occurrences in 2015.

Ramp Control Installation Criteria Results

TxDOT research report 0-5294 and TMUTCD (2006) provide information about the installation criteria for ramp meters. Report 0-5294 developed guidelines and a ramp control signal authorization form that allows for assessment of all criteria in a concise and convenient way. The criteria on the form are divided in three categories: traffic considerations, safety considerations, and other considerations. Instructions for using the authorization suggest that traffic considerations should be used as a first step to justify the need for a ramp meter and the decision to install or not should be made using safety considerations, other considerations, and engineering judgment. The blank form is available online as an appendix in TxDOT research product 0-5294-P1 (*4*).

For this study, researchers used the authorization form for each of the 10 ramp locations to identify if a ramp meter is justified on the basis of traffic considerations and safety considerations. Other considerations were not included in the assessment as the final decision to install a ramp meter will be made by TxDOT staff using other considerations and engineering judgment. Table 2 presents a summary of ramp meter justification form for all 10 locations studied. Complete authorization form for each ramp is included in Appendix B.

A look at Table 2 shows that eight out of 10 ramp locations studied satisfied four out of five criteria for installation of ramp meters. Though research report 0-5294 suggested that ramp meters be installed if first five traffic considerations are met, but looking at the traffic volumes data for rightmost mainlane and ramp lane, researchers believe that these eight ramps can benefit from ramp metering strategies that are designed to not only improve freeway level of service during congestion periods but also manage queues and delays for the ramp traffic. Out of the eight ramp locations that can benefit from ramp metering, six locations are equipped with existing ramp meters while two locations (Bissonnet Street Ramp Southbound and Weslayan Street Ramp Southbound) do not have an existing ramp meter. The two ramps (Beltway 8 Frontage Road Ramp Northbound and Kirby Drive Ramp Northbound) that did not satisfy the installation criteria do not have existing ramp meters. During data analysis phase, researchers observed that four ramps operate at near capacity for a single lane ramp (traffic volumes >1200 vph but less than 1500 vph), another four ramps operate at over capacity for a single lane ramp (traffic volumes >1700 vph), while the remaining two ramps (where ramp metering installation is not warranted) operate at under capacity.

Collision rate considerations for US 59 corridor suggest installation of ramp meters for the entire corridor, however available storage lengths , acceleration lane lengths, and geometry of ramps should be investigated in detail prior to deciding corridor wide ramp metering.

Table 2. Summary of Results for Application of Ramp Meter Installation Criteria

Installation Criteria	**Beltway 8 FR Ramp - NB**	Bissonnet Ramp - NB	Fountain View Ramp - NB	Edloe Ramp - NB	**Kirby Ramp – NB**	Kirby Ramp – SB	**Weslayan Ramp – SB**	Chimney Rock Ramp - SB	Hillcroft Ramp – SB	**Bissonnet Ramp - SB**
Traffic Considerations:										
1. Does congestion routinely recur in the merge area because the traffic demand on the freeway exceeds the capacity of the merge area?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. Does the freeway regularly operate at speeds less than 50 mph for at least a half-hour period?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3. Does the ramp have a minimum flow rate of at least 300 vph during the peak periods?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4. Does the measured hourly flow rate of traffic in the two right-most freeway lanes exceed the threshold shown in Figure 2?	No	No	No	No	No	No	No	No	No	No
5. Does the measured hourly flow rate of the ramp plus the right-most freeway lane volume exceed the thresholds shown in Figure 3?	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
6. Does predictable, sporadic congestion occur on isolated sections of the freeway because of short- period peak traffic loads from special events or from severe peak loads of recreational traffic?	Not applied as study segment of US 59 corridor is congested on a recurring basis.									
Safety Considerations:										
7. Does the collision rate in the vicinity of the ramp exceed the mean collision rate in the metropolitan area?	Yes, This criteria was applied for the US 59 segment between Sam Houston Tollway and SH 288 and not for individual ramp locations.									
8. Can the primary cause behind the majority of these collisions be attributed to congestion in the merge area?	Not applied since crash data were not analyzed in detail to answer this question.									
9. Is there sufficient acceleration length to achieve an acceptable speed differential between the ramp traffic and freeway traffic (Figure 4)?	No	These 9 ramps studied have an auxiliary lane - as such the availability of an acceleration lane length is not applicable.								
10. Is there sufficient space to store vehicles between the stop line of the ramp meter without impeding traffic operations on the frontage road (Figure 5)?	Yes	Yes[1]	Yes[1]	Yes	No	Yes	Yes	Yes[1]	Yes[1]	Yes
Other Considerations:										
11. Is the ramp to be metered part of an existing ramp metering system?	To be applied by TxDOT as these are qualitative measures and were not specifically investigated as part of this study.									
12. Is ramp meter anticipated to cause significant increase in adjacent arterial traffic volume and/or congestion?										
13. Is ramp meter likely to increase traffic diversion into adjacent neighborhoods?										
14. Is ramp meter likely to increase noise level and/or negatively impact air quality in the vicinity of the ramp?										

1- Heavy ramp volumes justifying dual lane metering, it is recommended that queues at these ramps be actively monitored and managed.

Current Operational and Maintenance Status

Researchers used the TAMS database, conversations with TxDOT staff, and field observations to gather operational and maintenance information about the existing ramp meter operations. The TAMS database was queried to identify maintenance and operational issues for an 18 month period from January 1, 2015 to June 30, 2016 for all ramp meters in the Houston District. A total of 239 records were found where ramp meters were documented as the maintenance/problem equipment for the 18 month period. Table 3 provides a summary of reported issues and count that issue was reported in the TAMS database.

Table 3. Summary of TAMS Maintenance Records For Ramp Meters (1/1/2015 to 6/30/2016)

Brief Problem Description	Count of the Problem in Logs
Signal/AWS knockdowns	73
Signal/AWS not working	7
Loops/Communications Failure	14
No Power	4
None - Preventative maintenance	23
None - Repairs performed	81
Other Problems	37
Total Ramp Records	239

Other problems reported included signal pole leaning, AWS (advanced warning sign) problems, missing equipment, bad sensors, and ramp signal heads not working properly. However, TAMS data as well as conversations with TxDOT staff, indicated that equipment knockdowns and communication failures are the most common maintenance issues that are being reported and handled. As per records provided by TxDOT, maintenance cost of ramp metering operations in Houston is approximately $16,000/month.

Based on conversations with TxDOT staff, the six study ramp meters along US 59 operate in a “traffic responsive” mode (metering is activated when occupancy in the freeway mainlanes is 17% or more and is deactivated when occupancy falls below 14%) with a cycle length consisting of one second of green and one second of red. Field visits in the morning peak hours (between 7 and 8 am) showed only one ramp meter (the northbound Fountainview Drive ramp) to be active with a cycle consisting of approximately 2 seconds of green, 1 second of yellow, and 2 seconds of red time. During the field visits, another ramp meter (not a study ramp - Beechnut Street ramp) was also observed to be active in a queue management mode with cycle consisting of approximately 15 seconds of green, 1.5 seconds of yellow, and 2 seconds of red interval.

Researchers were unable to gather quantitative information about current operations (detection parameters, cycle lengths for normal operations, and percent of time meters operate in flush/queue management mode) since the existing meter controllers do not provide a known process for data logging and retrieval. The monitoring of ramp metering operations to ensure that detection and operations are working as intended is a very time consuming process since each location has to be monitored in the field when metering is active. Our observation experience during field visits demonstrates the need for the ability to remotely monitor ramp meter controllers and gather current

performance metrics, which in this case would likely require upgrade of controller technology so that data can be retrieved, analyzed and operational parameters adjusted as needed.

Potential Operational and Maintenance Strategies

FHWA's Ramp Management and Control Handbook (*5*) provides information on the benefits of ramp metering, issues and activities to consider for successful operation of ramp metering strategies, as well as information about maintenance strategies for effective ramp management operations. The handbook lists Coordination, Staffing, and Resources (standard operating procedures, operations, training and maintenance manuals, and operations and maintenance tools) as the three key components for successful operations of ramp management strategies (*5*).

Staffing Needs for Ramp Operations and Maintenance

Based on review of the various agencies that operate ITS devices including ramp meters, FHWA's Ramp Management and Control Handbook describes average personnel requirement for operation and maintenance of ITS devices. As per the handbook, one person for every 100 to 200 devices is a good estimate for general operation and maintenance of ITS devices. Furthermore, for devices of high complexity lower estimate should be used as a guideline. Researchers estimate one engineer working 50%, and one field technician working full-time a good estimate of staffing needs for TxDOT's ramp metering operational and maintenance needs as long as the system remains below 200 units and is upgraded to include central monitoring/operation and remote management capability. This estimate should be revised based on actual needs as identified once the ramp metering program is upgraded.

Assignment of personnel to ramp metering program should be accompanied by relevant training and development of policy and procedures for efficient operation of ramp metering strategies.

Summary of Operational Strategies

Ramp metering strategies can be divided into *local* versus *system-wide* and *pre-timed* versus *traffic responsive*. In general, a ramp metering strategy should be designed to strike a balance between freeway mainlane operations and vehicle wait times and queues on entrance ramps. When congestion reduction, regional mobility improvements, and safety improvements are systematic goals (as opposed to the goal to manage a single entry ramp) the control of the ramp meter system by a central computer may be optimal so that operations can be monitored and adjusted as needed. On the other hand, when safety or traffic problems occur at specific ramp locations without affecting the adjacent ramp locations, isolated ramp metering operations can be an effective solution. Traffic responsive ramp metering approaches tend to yield greater benefits both for local and system wide operations since the metering strategy responds to real-time traffic conditions in the field, however these systems require greater capital and maintenance costs due to additional detection needed in the field (*5*), over and above what is currently provided at most ramps metered in Houston.

For the IH-69/US-59 corridor studied, system-wide operations that employ an algorithm to improve freeway mainlane operations and manage entrance ramp queues would likely be expected to yield the best results. For best operations, further study should be undertaken to model various operational scenarios to ensure suitability of any selected algorithms and subsequent metering operations.

Maintenance Strategies

Maintenance strategies can be divided into two categories: 1) maintenance of proper operations; and 2) maintenance of metering equipment. For effective operations and desired results, ramp metering operations need to be monitored on a regular basis and adjustments made to ensure that operational approaches deployed remain suitable for changing traffic demands and conditions. Maintenance of the metering equipment includes replacing defective and broken components, logging repairs, testing equipment, and updating system software. Development of maintenance checklists and maintenance procedures can help with monitoring and maintaining proper operations and equipment. FHWA's *Ramp Management and Control Handbook* recommends preventative maintenance on a monthly basis for signals and controller assemblies and on a quarterly basis for detectors (*5*). Based on information available in TAMS, preventative maintenance was scheduled once in 18 months where all other maintenance was performed in response to an identified problem. To reduce the frequency of signal and sign knockdowns, these should be installed in the clear zone behind barriers. It may be helpful to install a camera at locations that experience higher frequency of knockdowns so that reasons for knockdowns can be further analyzed and specific mitigation measures deployed.

Benefits of Ramp Metering Operation

Agencies across the U.S. have deployed ramp meters to proactively manage traffic flow on highway facilities. Several references are available that document various ramp metering studies, which show benefits of ramp meter operations ranging from 10% to 50% increases in corridor travel speeds and equal travel time reductions, 20% to 40% reductions in collisions, and 20% to 50% reduction in emissions (*6*). A landmark study in the twin cities area of Minnesota (Minneapolis and St. Paul) showed that when meters were turned off, a 14% reduction in throughput was noted, decreased travel time reliability, and crashes increased by 26%. The benefit cost ratio for the Minnesota system was found to be 15 to 1 (*7*).

The Houston TranStar Annual Benefits Report uses a calculation of the estimated travel time and delay savings benefits of ramp metering operation in the Houston District as a portion of benefits attributable to ITS and Houston TranStar operations. In 2015, the benefits attributable to ramp meter operation was estimated as saving motorists 991,774 vehicle-hours annually, having a monetized value of $21,920,000 per year, or $1,826,000 per month. With an estimated operations and maintenance cost of $16,000 per month, the resulting benefit cost ratio (based solely on annual O&M costs and discounting an annualized capital cost) is 114:1. Researchers do not believe that the actual benefit cost ratio is this high, particularly since we are not accounting for capital expenses and longer term maintenance needs were likely not being met, but based on the estimated delay savings the benefits are greater than 1.0.

Summary of Findings

This study applied the ramp metering installation criteria developed in TxDOT research product 0-5294-P1 to 10 ramp locations along IH-69/US-59 (Southwest Freeway) in the Houston District. The study also examined current maintenance logs to identify main concerns and potential solutions. Following is a summary of findings based on the information gathered and analyzed for this study.

- Based on traffic and safety considerations for installing ramp meters, eight out of 10 ramp locations studied for this report can benefit from a well-designed ramp metering strategy, including two ramps not currently metered.
- Equipment knockdown is the most common maintenance issue accounting for approximately 50% maintenance log records for ramp meters. Communication and detection failures, as well as missing equipment were also noted as maintenance issues in the maintenance logs.
- Field visits indicated that current metering algorithm and/or detection may not be working as intended since only two out of the eight ramp meters along US 59 NB were found to be active in the AM peak period. It is possible that there was not sufficient demand on the mainlanes to activate the meters; however without being able to retrieve this information from the controller, it will be difficult to ensure intended operations. Thus there is need for upgrade of controllers and central monitoring of ramp metering operations to optimize the system maintenance and ensure proper operations.
- Currently, there is no mechanism in place to assess the continual benefits or impacts of ramp metering operations. It is recommended that a plan be developed for data collection and assessment of ramp metering operations.
- The benefit cost ratios for ramp metering operations in the U.S. can range from 7 to more than 50 to 1. In Houston, a very simplistic analysis indicated a benefit cost ratio of 114:1. Even if this naïvely calculated ratio is 10 times the real ratio, the benefits are still positive for ramp metering deployment and operation.

Recommendations

- The pilot study on IH-69 Southwest Freeway indicated that a majority of tested entry ramps would meet guidelines for installation (and/or ongoing) ramp meter operation. Based on an assumption that confirming these results would be similar on other corridors, researchers recommend continued use of ramp metering in the Houston District as viable, proactive means of the application of ITS for operational benefits, including more reliable trips.
- The District should conduct studies of other corridors, including those not currently metered, to determine if meters should be used at more locations than currently in operation.
- To provide optimal operations and enable effective monitoring of system operation, there is a need to update and replace existing ramp meter controllers with state-of-the-art controllers capable of advanced system algorithm deployment as well as logging and retrieving operational data from a central remote location (Houston TranStar). LoneStar does not currently have the capability to control ramp meters from a central location. However, a ramp metering module does exist in Florida's Sunguide TMC software suite to which TxDOT has access through a sharing agreement. This software includes firmware for Model 170 field controllers as well as centrally controlled operational capability. Further investigation of the use of the Sunguide ramp metering module should be pursued.
- It would be advisable to have the ability to operate ramp meters in a centrally integrated system-wide strategy for freeway traffic management.

- Develop operational and maintenance manuals for the ramp metering operations, and expand the ability to TAMS to track ramp metering issues with more detail.
- Evaluate the benefits of ramp metering on a periodic basis and reassess the need for ramp metering based on measured benefits for local traffic and safety conditions and crash experience.
- Investigate whether knockdowns are at higher rates for two-post installations, one-post on the right, or one-post on the left installations. It may be possible to identify if one of those configurations leads to less knockdown experience than others (we posit that one-post on the left may experience fewer knockdowns than configurations with an unprotected post on the right).
- To better understand the causes of knockdowns of unprotected signal posts, install cameras at certain ramp meter locations (where knockdowns are more frequent) to understand if knockdowns are a result of vandalism or errant vehicles hitting the equipment in a pattern. Use appropriate strategies to rectify specific problem. If at all possible, to prevent knockdowns place the signal equipment behind barriers.

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APPENDIX A – TRAFFIC VOLUME DATA

APPENDIX B – RAMP METER INSTALLATION WORKSHEETS