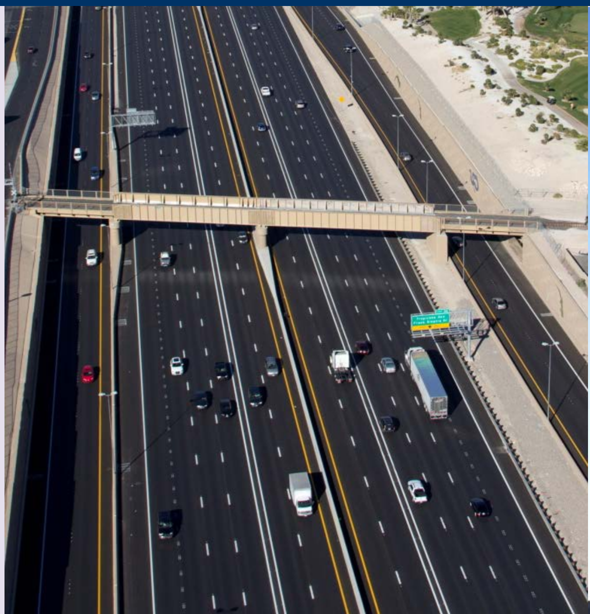
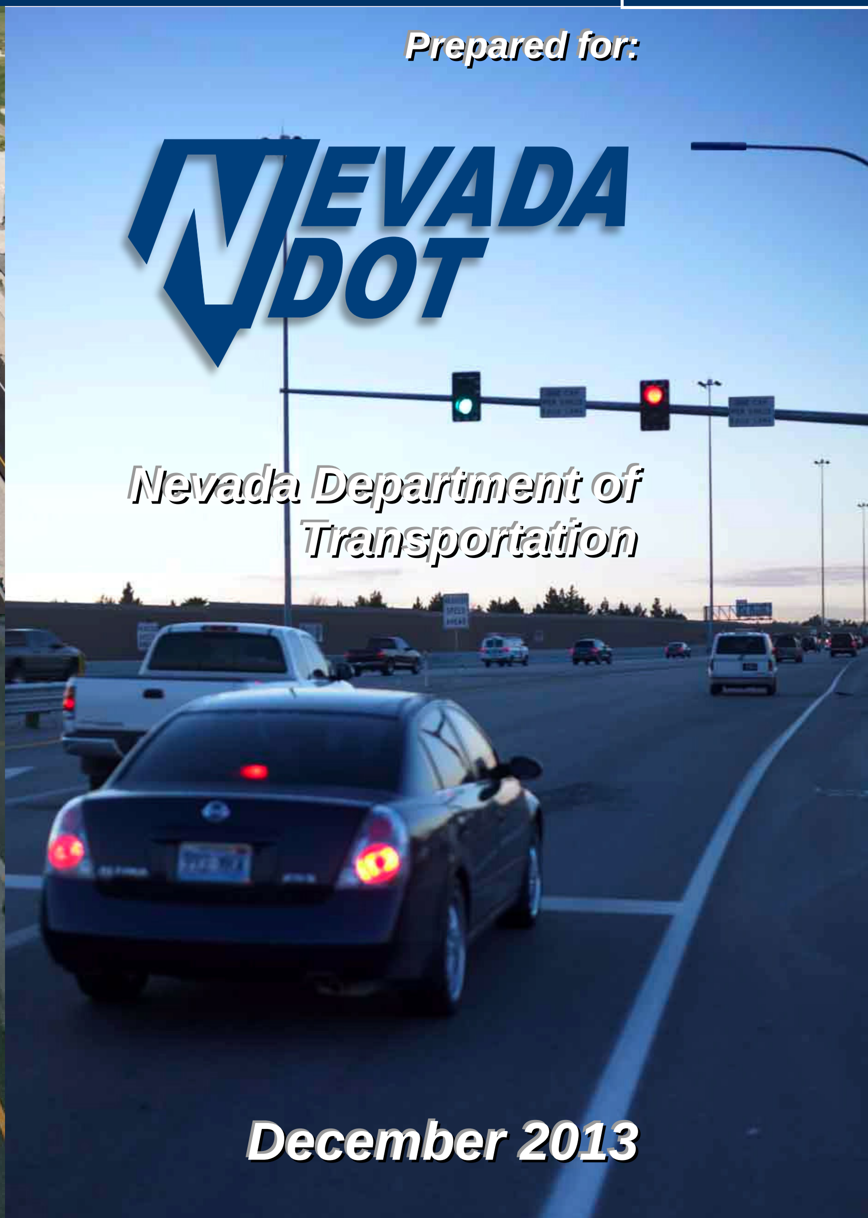
Managed Lanes and Ramp Metering Manual

Part 4: Ramp Metering Performance Measurement Plan





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Part 4: Ramp Metering Performance Measurement Plan presents guidance on how to effectively and consistently monitor, evaluate, and report the operations of ramp meters deployed throughout Nevada. Relevant background information and definitions are addressed in *Part 1: Introduction and Policies.*

1.0. PURPOSE

Ramp metering performance measurement is the monitoring, evaluation, and reporting of data to measure the performance of ramp meters and identify if specific goals are achieved. Through performance measurement, NDOT and stakeholder agencies can make changes to ramp metering operations to improve freeway, ramp, and arterial conditions, while generating greater public acceptance of ramp meters and improving public perception of the operating agencies. Performance measurement could also improve intra-agency and inter-agency support, and potentially provide funding for ramp metering facility investments by establishing the benefits of ramp metering and by confirming ramp metering as an effective means to obtain operational improvements. Ramp metering performance measurement can be used to:

- Track changes in ramp metering system performance over time,
- Identify ramp meter systems or corridors with poor performance,
- Identify the degree to which the ramp metering facilities are meeting goals and objectives established for those facilities,
- Identify potential causes and associated solutions,
- Identify specific areas of a freeway management program or system that requires improvement/enhancements, and
- Provide performance information to decision-makers and the public.

Performance measurement leads to the following:

- **Operational Improvements.** Performance measurement helps identify the extent and precise location of traffic and safety problems so operational improvements can be made. This process also may support the identification of hardware or software failures, which can help resolve problems earlier and minimize ramp meter facility down time.
- **Increased Visibility of Benefits.** Performance measurement provides a clearer picture of freeway performance, and whether or not ramp metering is promoting overall program goals and objectives. By publicizing the results of performance monitoring and evaluation, ramp metering benefits can become more widely known. This, in turn, contributes to the increased likelihood that the public will accept and support these facilities.
- **Appropriate Resource Allocation.** Performance measurement can also lead to informed decisions related to resource allocation by NDOT and partner agencies. For example, if a ramp meter is providing greater benefits than another freeway management or traffic management program, decision makers can allocate more resources to expanding the use of ramp meters in that area. Conversely, if metering is not as effective as expected, performance measurement can help identify the deficiencies and provide information that may lead to improved results.

2.0. APPROACH TO PERFORMANCE MEASUREMENT

Performance measurement is a continuous process that occurs throughout the life cycle of ramp meters. Evaluation is an integral part of a periodic review process that analyzes the effectiveness of individual meters as well as the overall system. Any performance measurement approach must be routinely reviewed and revised to reflect any changes to ramp meter status and implementation.

Several questions must be answered as part of the initial steps to developing an effective approach to performance measurement. The questions include:

- How will the performance information be used?
- What are the goals and objectives of the ramp metering program?
- What impacts will be measured?
- How will impacts be measured?
- What types of data will be collected?
- Where will data collection occur?
- Who will be responsible for collecting data?
- How will the results be reported?
- Who will be responsible for publicizing the reports?

Understanding the overall ramp metering program goals is critical when selecting the most appropriate performance measures.[1] The evaluator must confirm that the performance measurement process is directly linked to the program goals in order to ensure that the results of ramp metering evaluations are meaningful and valuable. For each goal, not only must the appropriate performance measures be identified, but the desired threshold level of change must be clearly defined to determine if a particular ramp meter or the larger system has met the defined goal. Section 3.0 discusses the performance measures for the ramp metering program.

2.1. Performance Evaluation

Performance evaluation is the process of analyzing collected data to provide feedback and results related to the performance of individual meters or the entire system. The type of analysis is defined by the objectives of the evaluation and type of feedback that is desired. Ramp metering evaluations are performed prior to implementation, conducted as “before” and “after” snapshot views of performance, or implemented as a continuous evaluation process. The evaluation efforts may also be narrowly focused to analyze one specific performance impact, or may be more broadly defined to capture the comprehensive region-wide benefits of ramp metering. Furthermore, analysis may be focused on particular impacts and benefits related specifically to ramp metering, or may be utilized as part of a broader evaluation designed to analyze the impacts and benefits of a selected combination of traffic management strategies. The basic types of analysis that can be used to evaluate the impacts and effectiveness of ramp metering are described in the following sections.

[1] Ramp metering program goals are defined in Part 1: Policy Manual.

2.1.1. System Impact Analysis

System impact analysis is often used to identify the impact that ramp metering has on one or more performance measure. Analysis typically involves the comparison of conditions "before" ramp meter installation with conditions "after" ramp meter installation by measuring field data combined with modeling (described further in the sections below). For instance, a system impact analysis may be done to determine the extent by which a ramp meter has improved a particular system deficiency, such as higher than expected crash rates in a merge area.

2.1.1.1. Before and After Analysis

Before and after analysis is a comparison of conditions "before" ramp meter installation with conditions "after" ramp meter installation. To accomplish this, performance data is collected before the ramp meters are installed, and the same data is collected after the ramp meters are activated. Since before and after analysis is based on "actual" field measured data, it provides an assessment of "actual" impact as opposed to "estimated" impact.

2.1.1.2. Modeling

Modeling provides the "estimated" impacts of ramp metering. Modeling is useful when estimating more system-wide impacts related to ramp metering and can be used to evaluate different control strategies. Modeling can also be used to analyze operations and impacts prior to implementation, which could be useful in determining if ramp metering is an appropriate ramp management strategy.

The following is a summary of modeling tool categories that are available to evaluate ramp metering.[2]

- **Sketch Planning Tools.** Sketch planning tools can estimate general order-of-magnitude impacts of ramp metering on travel demand and operations.
- **Analytical/Deterministic Tools.** Analytical/deterministic tools can estimate the impacts of ramp metering on traffic flow parameters, such as capacity, density, speed, and queuing.
- **Microsimulation.** Microsimulation can estimate ramp metering impacts and different control strategies on the overall freeway/arterial network, as well as on more isolated sections, such as entrance ramp/freeway merge areas.

Travel demand modeling is not an applicable tool when evaluating ramp metering impacts. Travel demand models are large-scale traffic analysis tools and are not intended for evaluating transportation system management (TSM) and intelligent transportation system (ITS) strategies, such as ramp metering. They have limited capability to estimate operational impacts from such systems, which is the reason why this type of modeling is not included above.

2.1.2. Benefit/Cost Analysis

A benefit/cost analysis is similar to a system impact analysis in that both provide assessments of the impacts related to the implementation of ramp metering. However, a system impact analysis

[2] The Federal Highway Administration's (FHWA) Traffic Analysis Toolbox Volume 1 and Volume 2 provide information on specific tools available for each category, and guidance on selecting the most appropriate evaluation tool.

focuses on particular performance measure(s), whereas a benefit/cost analysis is broader and attempts to more fully describe the comprehensive, multimodal impacts of ramp metering, including both positive impacts (such as reduced travel time on the mainline facility) and negative impacts (such as increased emissions associated with queues on the ramp). In short, a benefit/cost analysis evaluates the overarching and observed impacts of a ramp metering facility against the cost of implementing and operating the facility.

Benefit/cost analysis identifies the investment value of one strategy by comparing this value with other potential strategies. This comparison is often the justification for funding prioritization of future applications. In addition to this and similar to the system impact analysis, the information generated by a benefit/cost analysis is used to communicate the relative benefits of a ramp meter or larger system to decision makers and the traveling public.

A benefit/cost analysis also can compare conditions both with and without the application of the strategy. This comparison may represent a snapshot view or may be based on long-term trends, all of which depend on the needs of the particular study. Due to its more comprehensive nature, a benefit/cost analysis often leverages analysis tools and models more substantially to generate estimates that provide a full range of possible impacts.

As discussed, a benefit/cost analysis intends to provide a comprehensive quantitative analysis of the benefits and costs of ramp metering; however, there are many impacts that are too difficult or impossible to quantify, such as traveler perceptions. No benefit/cost analysis can fully encompass all of the possible impacts of an individual ramp meter or the larger system. Rather, this approach provides a partial view of the overall picture that can be evaluated when assessing the success of ramp metering.

Lastly, an evaluator can design a benefit/cost analysis to focus specifically on impacts and benefits of ramp metering, or utilize this approach to conduct a broader evaluation designed to analyze the impacts and benefits of a selected combination of traffic management strategies.

2.1.3. Ongoing System Monitoring and Analysis

Ongoing monitoring and analysis is typically described as the use of automated data sources, such as loop detector data, radar or other detectors, closed circuit television cameras (CCTVs), and automatic vehicle location systems to obtain direct, real-time feedback on the performance of individual ramp metering facilities. These automated data sources may be deployed as part of a specific ramp metering facility or as part of a general freeway management system. Through this process, system operators are able to identify the means to maximize the effectiveness of ramp metering operations and more actively manage the entire system. However, in order to achieve the full benefit of this analysis, ongoing system monitoring and analysis must be established as early in the ramp metering implementation process as possible.

Furthermore, reliable access to accurate data sources is a prerequisite to executing a successful monitoring and analysis program. Once established, the data collected through ongoing monitoring efforts must also be appropriately archived so that further analysis may be performed to identify trends related to how the impacts of ramp metering may change over time or vary under differing traffic conditions. Archiving this data also helps to lower the cost of performance monitoring efforts over time, while concurrently providing accurate information for managing and operating ramp meters.

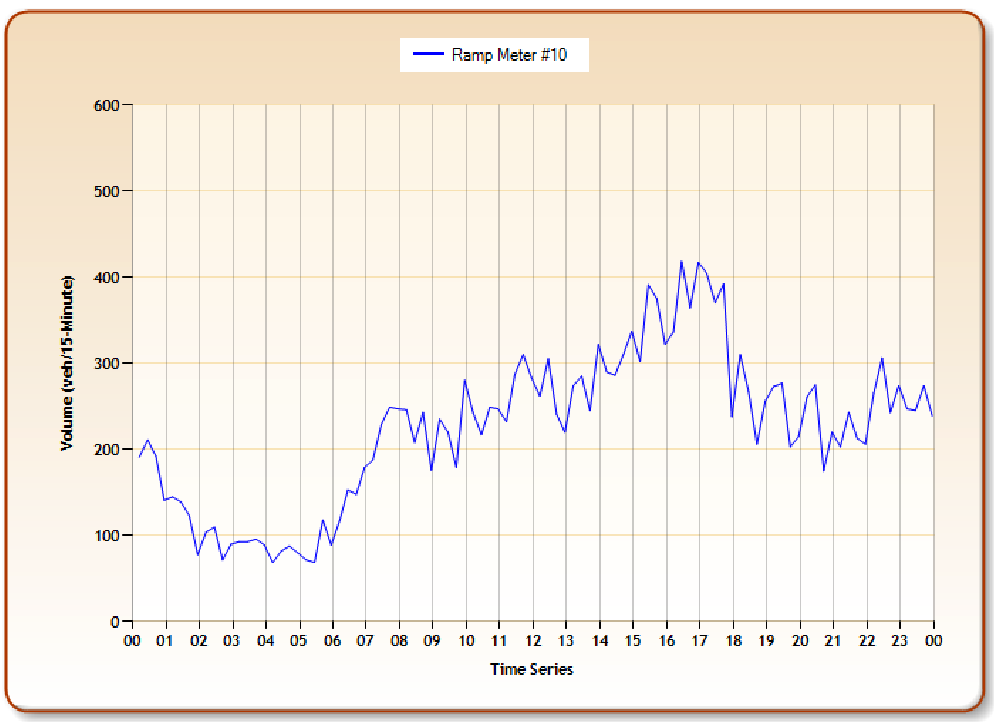
While this approach is intended to provide real-time feedback to system operators, it is also important to note that the data generated may be used for other evaluation efforts. For example, automated system data can be used in benefit/cost analysis, and historical volume and speed data can be used to extrapolate impacts observed during a limited data collection window to other time periods and traffic conditions.

2.1.3.1. Ongoing System Monitoring and Analysis by FAST

FAST has established an ongoing system monitoring program for the ramp meters in Las Vegas, which are equipped with detectors and CCTVs as part of FAST's Freeway Management System (FMS). FAST collects volume, speed, and occupancy data along various freeway mainline segments through flow detectors placed approximately every one-third mile along the segment. Volume data on each entrance ramp is also collected through detectors on the ramp. Data from the mainline and ramp detectors is sent to the FAST Traffic Management Center (TMC) every 60 seconds, which is then aggregated to 15-minute data sets.

The data collected through the ongoing monitoring efforts are archived in the FAST's database system. This data is available directly from FAST through their web-based interactive dashboard (located at *www.rtcsouthernnevada.com/mpo/fast/dashboard.cfm*), which allows the evaluator to extract and review several types of data/plot points. Figure 2-1 illustrates an example data plot obtained from the interactive dashboard for ramp meter volumes on a particular entrance ramp on a selected day.

Figure 2-1: Example Data Plot from the RTC Dashboard



FAST monitors a number of measures as part of their ongoing system monitoring efforts. These measures allow FAST to assess the operational capabilities of each ramp meter and the overall ramp metering system. These measures are defined as follows.[3]

- **Average cycle length.** Average cycle length for the ramp meter measured from the beginning of red display to beginning of next red display.
- **Average ramp meter service flow rate.** The hourly service flow rate computed by dividing 3,600 seconds by the average cycle length.
- **Average total flow rate.** The average of the total number of vehicles serviced during the hours of operation, including the number of vehicles that used the ramp during flushing and start-up time after each flush.
- **Freeway speed.** The speed of freeway traffic every 15 minutes during the time period at which the ramp meter is operational. This is obtained from freeway detector data.
- **Ramp meter efficiency.** A ratio of the average ramp meter service flow rate to the average total flow rate. A value close to unity indicates that majority of the ramp traffic is under the ramp meter control. A value close to zero indicates that most of the demand is serviced when the ramp meter is inactive.

There are also additional measures that FAST is not currently monitoring but considering to monitor in the future. These are listed below.

- **Average number of flushes.** Average number of times during the operation period that the ramp meter was operating in flush mode.
- **Average time to first flush.** Average of the difference in time (in minutes) from the ramp meter start time to the time when the first flush occurs.
- **Mean flush duration.** Average time (in seconds) that the ramp meter was operating in flush mode, computed by averaging the difference in time from when the ramp meter began operating in flush mode to when the ramp meter ended flush mode.
- **Average maximum flush duration.** Average time (in seconds) of the largest time duration that the ramp meter was operating in flush mode.
- **Mean time to next flush.** Average time (in minutes) that elapses between successive flushing events.

2.2. Defining Geographic Scope

The study area selected can have significant implications on the analysis requirements, evaluation techniques, resource requirements, and the final results. These implications are discussed in this section to assist in identifying the most appropriate study area suitable to particular needs.

Ramp metering facilities can have impacts far beyond their local area of implementation. Depending on travel pattern changes, impacts may be observed at arterial intersections located away from an interchange, freeway bottleneck locations far downstream from the entrance ramp,

[3] For the purpose of the following definitions, “flushing” is defined as “temporarily turning off the ramp meter signal until the queue on the ramp has dissipated.”

or even on alternative modes of transportation, such as transit. Failure to define the study area broadly enough may result in not capturing critical impacts, leading to an overstatement or understatement of reported benefits. On the other hand, defining the study area too broadly may result in the inefficient use of resources by diverting time and energy towards analyzing inconsequential impacts. Therefore, it is important to identify an appropriate study area prior to evaluation to ensure the proper and complete assessment of potential metering impacts. There are no firmly established guidelines for identifying the appropriate study area; however, the decision is usually based on the following:

- **Purpose of the study.** Is the analysis being done to identify the extent by which ramp metering mitigates a specific deficiency in a specific location, or does the analysis intend to provide a comprehensive evaluation of region-wide benefits and costs?
- **The number of ramp meters under evaluation.** Is the analysis focused on a single ramp meter, a limited number of ramp meters, or multiple ramp meters?
- **Knowledge of local traffic conditions.** Has local personnel maintained a close familiarity with the traffic conditions, and how have personnel been involved with decisions regarding the extent of the study area?

Furthermore, factors such as the particular performance measures being evaluated, the proposed analysis tools, and the evaluation resources available must be considered when determining the most appropriate study area. Similarly, the identified study area may influence the possible performance measures, the appropriate analysis tool, and the evaluation resources required. Study areas are often generalized into three categories: localized, corridor, or region-wide. These categories are discussed below with examples of when each is to be applied. However, not all performance evaluation efforts will fit neatly into these study area definitions. For example, some evaluations may demand the use of multiple study area definitions based on the performance measures being evaluated or the availability of data.

2.2.1. Localized Study Area

A localized study area focuses on the impacts observed on facilities immediately adjacent to the ramp meter and is often the most appropriate analysis for limited-scale deployments or for performance evaluations centered on a narrowly defined set of performance measures. For example, when conducting an evaluation that focuses on analyzing a ramp meter’s effectiveness at decreasing the number of collisions occurring within a specific merge area, the study area would likely include only a short distance (e.g., a quarter of a mile) upstream of the merge area to a short distance (e.g., a quarter of a mile) downstream of the merge area.

2.2.2. Corridor Study Area

Expanding the study area to the corridor level is appropriate when multiple ramps are involved, or when the deployment is anticipated to impact any of the selected performance measures beyond a localized area. The extent of this study area is based on local street patterns and knowledge of local travel demand to determine the mainline, ramp, and arterials to be included.

2.2.3. Region-wide Study Area

A region-wide study area is most appropriate when a comprehensive or general accounting of all possible impacts is required, or when the deployments are scattered across a large area. Region-wide analyses can be the most costly analysis to conduct due to significant data requirements.

3.0. PERFORMANCE MEASURES

Performance measures provide the basis for evaluating ramp metering performance and for identifying the location and its impact on severity of traffic problems, such as congestion and high collision rates. In essence, performance measures are used to measure how ramp meters perform in connection with the entire transportation system and within the parameters of the program's overall vision and adopted policies. Performance measures also provide managers and users with access to real-time and archived system performance data that ultimately can inform decision-making and educational processes related directly to ramp metering.

Agencies have often instituted performance measures and associated performance measurement plans for a variety of reasons, including as a means to:

- Provide better information about the transportation system to the public and decision makers;
- Improve management's access to relevant performance data; and
- Generally improve agency efficiency and effectiveness, particularly where demands on the transportation agency have increased but the availability of associated resources has decreased.

3.1. General Categories of Performance Measures

This section describes several performance measure categories that directly relate to ramp metering.

3.1.1. Safety

Travel safety is often measured through statistically documenting differences in the number of crashes. Crashes may be segmented by severity (e.g., fatal, injury, or property damage only) or by type (e.g., rear-end or side-swipe). Safety data is obtained from crash records retained by NDOT.

Evaluators need to use caution when developing an approach and analyzing crash data. Crashes are randomly occurring events and may be based on limited sample sizes, particularly in the case of less frequently occurring crashes, such as those involving fatalities. Thus, a limited number of crashes may cause an unsubstantiated spike in the crash rate over short periods of time or in particular locations, which may lead to misinterpreting safety data directly related to the implementation of a specific ramp meter or the larger ramp metering system. Therefore, longer-term historical data must be used to validate crash rates. Additionally, it is recommended that evaluators consider consolidating some of the crash segmentations to ensure an adequate sample size is represented. It is often more appropriate to evaluate the crash rate (e.g., number of crashes per mile traveled) instead of the actual number of observed crashes to help control for changes in travel demand.

3.1.2. Mobility

Travel mobility impacts are typically measured as a change in travel time or delay. Mobility related performance measures intend to capture the user's travel experience. Therefore, these measures are most effective when captured on a per trip basis, such as the change in travel time for a door-to-door trip. Additionally, use of aggregate system measures, such as total system person hours of travel (PHT), may not accurately capture user benefits. Likewise, spot measurements of speed may not accurately reflect the individual's overall travel experience.

3.1.3. Travel Time Reliability

Performance measures related to travel time reliability are important to evaluating ramp metering improvements. Typical performance measures for travel time reliability are as follows.

- **95th percentile travel time.** As per FHWA's definition, 95th percentile travel time estimates how bad the delay will be on specific routes during the heaviest traffic day. The travel time on the worst weekday of the month marks the 95th percentile travel time.
- **Travel time index (TTI).** TTI is a comparison of peak and free-flow travel conditions. TTI is calculated by dividing average peak period travel time by free-flow-speed travel time. Values closer to 1.0 imply less congested conditions.
- **Buffer index (BI).** BI indicates the amount of extra "buffer" needed to be on time at the destination, 95 percent of the time. BI is calculated by dividing the difference between 95th percentile travel time and the average travel time by the average travel time.
- **Planning time index (PTI).** PTI represents how much total time a traveler should allow to ensure on-time arrival. PTI is calculated by dividing 95th percentile travel time by the free-flow-speed travel time.
- **Congested hours.** This is the average number of hours during specified time periods (typically weekdays between 6 AM to 10 PM) during which the evaluated segments are congested. This measure is to be reported for two separate conditions: 1) average number of hours when speeds are less than 35 mph, and 2) average number of hours when speeds are less than 45 mph.
- **Speed standard deviation.** This is the standard deviation of the observed speeds.
- **Inter-quartile speed range.** This range is the difference between the 75th and 25th percentile speeds.

Each of these travel time reliability measures is intended to capture the impact of reducing travel time variability and making travel times more predictable. More predictable travel times allow travelers to better plan their travel schedules and avoid unexpected delays. Ramp metering systems have been shown to reduce travel time variability.

3.1.4. Environmental

Environmental performance measures are typically measured as changes in vehicle emissions and fuel consumption. However, there is often a challenge in identifying effective environmental performance measures that can be successfully evaluated within the defined framework and the available resources. For example, implementing a ramp meter can reduce emissions and fuel consumption on the freeway mainline but increase these factors at the queue location. For this reason, the data collection and analysis methodology must account for this situation when applying the measure.

3.1.5. Throughput

Throughput related performance measures include the following:

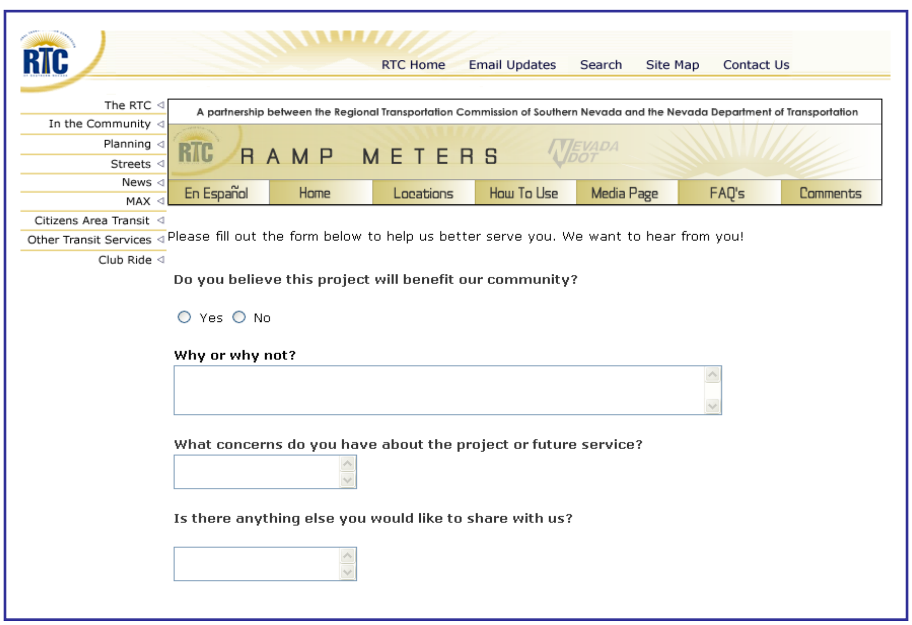
- Traffic volume,
- Person volume,
- Level of service (LOS),
- Facility speed,
- Volume to capacity ratio (V/C), and
- Queuing measures (length and frequency).

The particular performance measure(s) selected under this category greatly influences the format of the data that needs to be collected. In general, measures targeted toward assessing vehicle occupancy rates (i.e., person-based measures) are more difficult to collect than vehicle-based measures. However, person-based measures can provide a much more accurate picture of changes in traveler behavior. For the majority of smaller scale ramp metering evaluations, vehicle occupancy is not anticipated to change significantly. This allows for vehicle-based measures to be used without a significant loss of accuracy.

3.1.6. Public Opinion

Depending on the purpose of the study, measuring and documenting the perceptions of the traveling public regarding the benefits of ramp metering and system performance can be extremely important. Public opinion is often used to support the findings from the data collection in the field, as well as to identify areas where perceptions differ from reality. Public opinion data can be collected through conducting focus groups, telephone surveys, intercept surveys, or panel survey groups. While this type of data collection often demands a significant use of resources, the information gained through these methods can be invaluable in shaping public information campaigns. Figure 3-1 provides an example of a survey that was available on RTC's website during a particular ramp meter deployment project in Las Vegas.

Figure 3-1: Example Public Opinion Survey



3.2. Data Needs

Depending on the selected performance measures, specific types of data are needed to evaluate the impacts of ramp metering. In general, traffic data is to be collected at metered ramps and along the metered corridors both before and after ramp meters are turned on and become operational. Ideally, data is to be collected for each day of the week that a ramp meter(s) is being operated, and analysis is to include an evaluation of daily stratification as well as aggregation over all weekdays.

Both qualitative data (e.g., observations and agency and public feedback) and quantitative data (e.g., speeds, crashes, and queue length) are necessary when analyzing ramp metering performance and to ensure that all ramp meters and/or the larger system are operating as intended.

Since the results of data collection are used to make operational and program-level decisions, the collected data must be of superior quality. High quality data leads to better conclusions and is more valuable to agency decision makers. Improving data collection efforts are to be continually investigated as funding and policy permits. As long as the objectives of data collection are fully satisfied, the most time efficient and least costly efforts are to be implemented when collecting data. Data collection is to begin with an analysis of the archived data, followed by a determination of what data still needs to be collected.

3.2.1. Types of Data

Data needs are all dependent on the types of analysis that will be conducted. The following types of data are necessary when assessing ramp meter performance.

3.2.1.1. Traffic Volume

Traffic volume is defined as the number of vehicles observed or predicted to pass over a given point or section of a lane or roadway during a given time. Volume is typically used to track historical trends and to predict the future occurrence of congestion on specific freeway segments. In terms of measuring ramp meter performance, analysis of traffic volumes at upstream and downstream locations along the mainline and at on-ramps in the corridor can provide useful insights regarding the efficiency of the freeway and the overall changing traffic patterns in the corridor.

3.2.1.2. Mainline Vehicle Speed

Mainline vehicle speed is frequently used to describe traffic operations because it is a measurement most drivers experience directly and can easily understand. Speed measurements are typically taken for individual vehicles at specific locations and are averaged to characterize the general traffic flow as a whole. Measured speeds can be compared to optimum values when estimating how a freeway is operating when ramp meters are operational.

3.2.1.3. Travel Time

Travel time is the time it takes a vehicle to travel a certain distance, usually the length of the metered corridor. Travel time data is usually collected before and after the deployment of a ramp meter(s) within a freeway corridor. The difference in travel times before and after deployment is then compared to determine the impact of the ramp meter(s).

Travel time data for the freeway and individual entrance ramps can be obtained using a number of methods. The simplest and most commonly used method is referred to as the "floating car" technique, which uses a probe vehicle to conduct a series of trips along a stretch of freeway or a specific entrance ramp to measure travel times. Travel time can also be estimated or calculated based on other traffic measurements, such as speed or volume and lane occupancy.

3.2.1.4. Crash Records

Of specific interest when evaluating ramp metering performance are the type of crashes that have been recorded as “rear-end,” “lane change,” or “sideswipe” crashes. In many cases, ramp metering has the potential to decrease the number of rear-end collisions by reducing or eliminating stop-and-go driving behavior on both the mainline and merge areas. Similarly, the staggered release of metered vehicles creates a smoother flow of vehicles merging with freeway traffic, which may result in a reduced number of sideswipe or lane change crashes at the entrance ramp/freeway merge area and at the back of a mainline queue. A comparison of crash records before and after the installation of a ramp meter(s) can help determine if there are any significant reductions in crash rates on the mainline, at entrance ramps, or in the merge areas.

3.2.1.5. Ramp Queues and Driver Behavior

To a large extent, the success of ramp metering depends on the ability to create a smooth flow of traffic onto the freeway, while adequately serving demand on the entrance ramp. Part of monitoring a ramp meter is monitoring the queues that form at entrance ramps as a result of ramp metering operations. When demand exceeds the metering flow rate and storage at the entrance ramp cannot contain the excess demand, traffic may back up to the adjacent arterial, potentially causing traffic and safety problems. Ramp metering approaches must consider not only whether to manage but how to manage ramp queues. Before and after analysis of ramp queues can indicate whether or not a ramp meter is negatively affecting operations on the upstream arterial.

Whenever new traffic control devices are installed (such as a ramp meter), it is also critical to monitor driver behavior to assess how the drivers are responding to the traffic control device and related signs and pavement markings. When ramp meters are deployed, drivers may ignore the ramp meter. In either case, this may confuse other drivers, which, in turn, may result in similar driver behavior. Ignoring the ramp meter may also defeat the purpose of the ramp meter to create a smooth flow of traffic merging onto the freeway.

Ramp queuing and driver behavior assessments are best conducted either manually through observations by personnel stationed in the field or remotely by viewing images from CCTV cameras. If it is observed that queues back up to the arterial and impact arterial traffic operations, operators can adjust metering rates or the parameters that are used in ramp meter algorithms in an effort to resolve any queue-related issues. Similarly, if drivers are not obeying the ramp meter, metering rates may be adjusted to reduce driver frustration, or ramp meter compliance may need to be actively enforced.

3.3. Performance Measures and Data Needs for Specific Locations

Determining the location of data collection is essential to assessing the full impact of a ramp meter(s). Solely focusing on just the individual ramp meter often limits the evaluator from only capturing a portion of the effects that the ramp meter(s) has on overall traffic flow. For instance, motorists may divert from using a newly metered entrance ramp to other upstream and downstream entrance ramps because they do not want to wait at the ramp meter. To offset a potential for skewed data, the evaluators must account for all locations that are most likely to be impacted by ramp metering. These locations, which are discussed below, include freeways, entrance ramps, adjacent arterials, and freeway/entrance ramp merge areas.

3.3.1. Freeway Performance

Conditions on the metered segments of area freeways are to be monitored in order to determine what impacts ramp metering may have on vehicle speeds, throughput, and crashes. Table 3-1 summarizes potential performance measures that may be used and the necessary associated data for measuring freeway performance.

In addition to the typical freeway performance measures previously described in Section 3.1, FAST has recently developed two new performance measures for evaluating freeway performance: delay volume (DV) and average vehicle delay (AVD). DV quantifies congestion with temporal, spatial, and congestion intensity values. AVD measures the average delay per vehicle with traffic volume as a weighting factor by accounting for traffic volume variations between freeway segments. FAST has developed these performance measures as part of the US 95 ramp metering evaluation study. Details on this study are provided in Section 5.0.

3.3.2. Entrance Ramp Performance

Entrance ramp performance and conditions are monitored to determine if queue storage at a ramp meter is adequate, and if ramp metering operations are resulting in excessive delay or improper driver behavior. Table 3-2 summarizes potential performance measures that may be used and the necessary associated data for measuring entrance ramp performance.

3.3.3. Ramp/Freeway Merge Area Performance

Ramp metering has the potential to significantly improve traffic operations at and immediately upstream of entrance ramp merge areas. This is because ramp metering restricts excessive demand from entering the freeway and breaks up platoons. Ramp metering also allows vehicles to enter a freeway at regulated intervals, releasing vehicles in a controlled, smooth manner. Table 3-3 summarizes potential performance measures that may be used and the necessary associated data for measuring entrance ramp/freeway merge area performance.

3.3.4. Arterial Performance

When monitoring conditions at an entrance ramp, conditions at the ramp/arterial intersection must also be monitored. If a ramp meter(s) does not release vehicles fast enough, queues may build at the ramp meter and may back up into the ramp/arterial intersection. This adversely impacts operations on the arterial. Table 3-4 summarizes potential performance measures that may be used and the necessary associated data for measuring arterial performance. Arterial performance measures are also intended to capture the impacts of drivers diverting from the freeway to avoid ramp metering.

Table 3-1: Freeway Performance Measures and Data Needs

Performance Measure	Analysis Data Needed	Data Collection Methods and Tools
Crash Rate	Number of crashes	Crash records
	Vehicles miles traveled	Traffic volume counts
Average Travel Time	Observed travel times	Travel time runs or speeds from multiple detection sites
Traveler Delay	Observed travel times and free-flow travel times	Travel time runs or speeds from multiple detection sites
Travel Time Reliability Measures (95th Percentile Travel Time, TTI, BI, PTI, Congested Hours, Speed Standard Deviation, Inter-Quartile Speed Range)	Observed travel times, free-flow travel times, observed speeds	Travel time runs or speeds from multiple detection sites
Traffic Volume	Observed traffic volumes	Traffic volume counts
Facility Speed	Spot speed measurements	Travel time runs or automated speed collection
LOS or V/C	Observed traffic volumes	Traffic volume counts
	Facility capacity	Estimates from FHWA's Highway Capacity Manual or traffic volume counts
Delay Volume	Observed speeds and volumes	Traffic speed and volume data from field detectors
Average Vehicle Delay	Observed speeds and volumes	Traffic speed and volume data from field detectors
Fuel Consumption	Vehicle speeds, volumes, and acceleration profiles	Travel time runs and traffic volume counts by vehicle class
Vehicle Emissions	Vehicle speeds, volumes, and acceleration profiles	Travel time runs and traffic volume counts by vehicle class

Source: Adapted from FHWA's Ramp Management and Control Handbook.

Table 3-2: Ramp Performance Measures and Data Needs

Performance Measure	Analysis Data Needed	Data Collection Methods and Tools
Crash Rate	Number of crashes	Crash records
	Vehicles miles traveled	Traffic volume counts
Ramp Delay	Seconds of ramp delay	Ramp queue observations
Ramp Delay Standard Deviation	Seconds of ramp delay	Ramp queue observations
Traffic Volume	Observed ramp volumes	Ramp volume counts
Queue Spillover	Percent of time ramp queue impacts on adjacent arterial	Observation of ramp queue lengths
Fuel Consumption	Vehicle speeds and acceleration profiles	Travel time runs and ramp queue counts by vehicle class
Vehicle Emissions	Observed emissions	Hot spot detection
	Vehicle speeds and acceleration profiles	Travel time runs and ramp queue counts by vehicle class

Source: Adapted from FHWA's Ramp Management and Control Handbook.

Table 3-3: Merge Area Performance Measures and Data Needs

Performance Measure	Analysis Data Needed	Data Collection Methods and Tools
Crash Rate	Number of crashes	Crash records
	Vehicles miles traveled	Traffic volume counts
Number of Conflicts	Observation of conflicting movements	Observation of conflicts
Traffic Volume	Observed traffic volumes	Traffic volume counts
Facility Speed	Spot speed measurements	Automated speed collection
Fuel Consumption	Vehicle speeds and acceleration profiles	Travel time runs
Vehicle Emissions	Observed emissions	Hot spot detection

Source: Adapted from FHWA's Ramp Management and Control Handbook.

Table 3-4: Arterial Performance Measures and Data Needs

Performance Measure	Analysis Data Needed	Data Collection Methods and Tools
Crash Rate	Number of crashes	Crash records
	Vehicles miles traveled	Traffic volume counts
Average Travel Time	Observed travel times and speeds	Travel time runs or speeds from multiple detection sites
Traveler Delay	Observed travel times and free-flow travel times	Travel time runs or speeds from multiple detection sites
Travel Time Reliability Measures (95^{th} Percentile Travel Time, TTI, BI, PTI)	Observed travel times, free-flow travel times, observed speeds	Travel time runs or speeds from multiple detection sites
Traffic Volume	Observed traffic volumes	Traffic volume counts
Facility Speed	Spot speed measurements	Travel time runs or automated speed collection
Arterial LOS or V/C	Observed traffic volumes	Traffic volume counts
	Facility capacity	Estimates from FHWA's Highway Capacity Manual or traffic volume counts
Intersection LOS	Observed traffic volumes	Traffic volume counts
	Signal timing settings	Signal timing settings from local agencies
Queue Spillover	Percent of time ramp queue impacts on adjacent arterial	Observation of ramp queue lengths
Fuel Consumption	Vehicle speeds, volumes, and acceleration profiles	Travel time runs and traffic volume counts by vehicle class
Vehicle Emissions	Vehicle speeds, volumes, and acceleration profiles	Travel time runs and traffic volume counts by vehicle class

Source: Adapted from FHWA's Ramp Management and Control Handbook.

3.4. Recommended Performance Measures

Building upon the information in the preceding sections, a set of performance measures is selected for evaluating ramp meters. Table 3-5 summarizes these recommended performance measures. Additional performance measures may be reported to meet local and regional needs.

Table 3-5: Recommended Performance Measures

Location	Performance Measures
Freeway Mainline	Crash Rate
	95th Percentile Travel Time
	Congested Hours
	LOS
	Traveler Delay
Ramp	Ramp Delay
	Queue Spillover
Freeway/Ramp Merge Area	Crash Rate
	Speeds
Arterial	Arterial LOS
	Intersection LOS

4.0. PERFORMANCE REPORTING

Performance reporting is what allows NDOT to not just monitor performance but use the relevant information to improve strategies and refine goals and objectives related to ramp metering. Reporting and outreach efforts are key to building support for ramp metering by showing the benefits of the ramp metering system in part and in whole. This section discusses how to report ramp metering performance and to whom it is to be reported.

In general, performance reporting and outreach seek to build understanding of ramp metering benefits. Agencies responsible for the implementation of ramp meters must actively market the benefits of these facilities and seek to inform the public, local decision makers, and the media of project progress and the benefits observed to date. Agencies must also undertake efforts to inform internal agency personnel of the benefits ramp metering provides and the proposed timelines associated with implementation. This offers a beneficial mechanism to promote ramp metering and disseminate information about ramp management to outside groups.

4.1. Reporting Frequency

After a ramp meter(s) is deployed, tested, and initially operated, each meter must be monitored and managed to determine if and how the operational strategies employed are to be adjusted to ensure optimal performance. System operation is analyzed on a continual basis, with more formal evaluations conducted and reported several times within the first year and at least annually thereafter.

System operation is to be observed in the field and confirmed in the operations center. If problems are reported, adjustments, maintenance, or other responsive action are then performed. Likewise, problems reported by other agencies and the public are to be investigated, addressed, and corrected.

4.1.1. Initial Observations and Monitoring

During the first weeks that a ramp meter(s) is operational, staff is to monitor conditions to determine if and how the new metering operations are to be adjusted to improve traffic flow. Any required improvements are to be done as soon as possible. One specific area to monitor is driver response to a new ramp meter(s). Often times reminders to drivers (usually through the media) on how to react to a ramp meter(s) can be effective at improving driver response.

Related, all calls and letters from the public concerning the new ramp meter(s) must be investigated thoroughly and corrective action taken, if appropriate. If it is not possible to make changes to address public concerns, the respondent is to be contacted and the situation explained. The objective is to make all contacts positive and informative. Efforts made to better inform the public often lead to a more accurate and positive information exchange among other members of the public.

4.1.2. Three-Month Observation and Monitoring

Three months after initiating operations, a formal evaluation is required to determine if the ramp meter(s) is performing as expected. The results of this evaluation are recorded, documented, and reported to decision makers, the public, and those responsible for making adjustments to the facilities. Any required adjustments are to be performed as soon as possible. After the three-month report, ongoing monitoring through an automated system (e.g., FAST dashboard) would be adequate until the annual report discussed below.

4.1.3. Annual Observations and Monitoring

One year after initiating operation and every year thereafter, ramp meter operations and performance are to be formally evaluated, documented, and reported to determine if the ramp meter(s) is providing expected benefits. Data is collected on an annual basis and compared against the data collected before the ramp meter was installed. As the ramp meter(s) becomes more mature, data collected for the current year can be compared to previous year data to determine if annual adjustments have been beneficial, as well as to determine changing trends in traffic conditions and traffic patterns.

4.2. Target Audiences

Evaluators must be aware that ramp meter performance results are ultimately reported to local leaders, motorists, the media, and external agencies to strengthen support for the expansion of the ramp metering program. Continual support from these groups will help to successfully implement ramp metering now and in the future. Information on ramp meter performance is to be formatted and tailored to the specific needs and concerns of each group.

Performance results are not only valuable to the groups noted above, but also for decision makers, special interest groups, and the general public. In an effort to communicate needed information to each of these varied groups, the challenge becomes how to conduct accurate and objective evaluations of a ramp meter(s) that centers on key criteria, so that the results are meaningful and understood by all groups.

4.2.1. The Public

Public support and understanding of ramp metering and the larger ramp metering program are critical to ensuring that the ramp metering program is successfully meeting their objectives. Public opposition to ramp metering poses a serious challenge that can significantly delay and hinder implementation and operation efforts. To reduce the possibility of misunderstandings that could lead to public opposition, evaluators must take all the steps necessary to educate the public of ramp metering benefits before and after a ramp meter(s) becomes operational.

Reporting ramp meter performance can help offset some drivers' initial impression that ramp meters do not provide sufficient benefits to the traveling public. Initially, some motorists may focus on the few, but more noticeable, negative impacts of ramp metering, such as ramp queues. Yet, by actively promoting the benefits of ramp metering based on performance monitoring and evaluation, the potential for adverse public opinion can be mitigated. One option to respond to negative public opinion is through frequently disseminating information on the benefits of ramp metering through various techniques (e.g., public service announcements, leaflets, and radio spots) that promote public understanding.

4.2.2. Upper Management

Ramp meter performance reporting can be valuable in conveying to upper management the importance and benefits of ramp metering. Similar to the general public, upper management support is often vital to the success of a ramp metering program. Without upper management support, the program may not receive adequate funding or resources needed to continue operation or to implement planned and needed expansion. It is this performance information that becomes instrumental when upper management and agencies develop directives that support the ramp metering program and allocate funding to implement the program or individual ramp meters. Through ramp meter performance results, upper management is able to observe programmatic and individual ramp meter improvements. This, in turn, can make the case for funding allocations to maintain and expand the existing ramp metering network. To ensure success, performance results must demonstrate how well ramp metering contributes to the goals and objectives of the agency, the region, and the overall freeway management program.

4.2.3. Local Leaders and Elected Officials

Local leaders (specifically elected and appointed officials) can be valuable advocates for or powerful opponents against ramp metering. It is important to determine if local leaders are predisposed to either support or oppose metering. Based on these leanings, effective outreach programs can be developed to target both supporters and opponents.

Reaching out to local leaders who support the program helps in mobilizing their advocacy for current and proposed ramp metering efforts. It is equally important to reach out to opponents (or potential opponents) in an attempt to understand their concerns. Some of these concerns may be addressed in the design or operation of the ramp meter(s). Others may be the product of misinformation that can be minimized by providing accurate information that addresses those concerns.

4.2.4. NDOT and RTC Staff

Ramp performance information is necessary for NDOT and RTC staff and managers to identify where improvements to ramp meters can be made. With this information, issues related to ramp metering operations can more easily and readily be identified, assessed, and resolved. NDOT and RTC staff may use this information to inform decision making concerning other elements of their ITS program. For instance, through performance measurement, NDOT staff may find that ramp metering is more effective than other ITS strategies and, consequently, propose the expansion and quicker implementation of ramp metering in certain areas or region- wide.

4.2.5. Media

The media can be a valuable voice in widely disseminating information on the benefits of ramp meters for the public. A good relationship with the media may pave the way for the media to act as the advocate for the ramp metering program.

Information released to the public, local agencies, and the media must be accurate and factual to reduce any chance that the released information may be called into question at a later date. This also reduces the potential “surprise factor” that, when left unchecked, can lead to public frustration and contempt for proposed strategies.

4.3. Reporting Methods and Techniques

The most important consideration in reporting performance evaluation results is presenting the findings in a manner appropriate to their intended audience. Because reporting can be communicated in various formats and to a number of different audiences, evaluators must consider, early in the evaluation process, the means and methods of reporting. The report’s format, in addition to the intended audience, is what often guides the selection of performance measures, the development of data collection plans, and the identification of analysis techniques and tools.

Results that are reported to non-technical decision-makers or the public must limit or completely avoid the use of technical jargon and must not assume any prerequisite knowledge of operational concepts. Instead, these types of reports are to present results and findings as clearly and concisely as possible that focuses on the performance measures most applicable to the target audience. Conversely, reporting evaluation findings to a more technical audience must provide sufficient detail on the evaluation methodology and empirical evidence to support the findings. For these reasons, evaluators may want to consider developing more than one evaluation report to meet the needs of diverse audiences.

Final report format often varies depending on the particular needs of the evaluation. It may be formatted as a formal document intended for wide distribution, or an informal report used for internal agency use only. Performance evaluation findings and results may not even be written in a traditional report format, but instead may be communicated through use of presentations, web sites, press releases, or other media.

Lastly, monitoring and managing initial operations must also include reporting software and hardware installation and the control parameter settings used to control ramp meters. Documentation is to include system errors, how these errors were resolved, and any system updates that were incorporated to prevent the errors from occurring in the future. In the initial phases of a ramp metering program, documentation will allow the evaluators to keep an up-to-date record of activities that may be used to address future hardware and software issues. Documentation is to be carried beyond the initial operation of ramp meters and viewed as a life-cycle activity that needs to be continually conducted in operating and maintaining these systems.

4.3.1. Formal Reports

Of the various reporting methods discussed, formal reports are the most comprehensive and often provide the most detail regarding ramp meter performance or overall system evaluation. As such, formal reports are typically used to report performance results to a technical audience that demands as much detail as there is available. This audience may include the following:

- Upper management and agency decision makers,
- Transportation management system operators,
- Educators, and
- Researchers.

Although formal reports are the most comprehensive and detailed approach, attention must be focused on presenting the results and findings in an easy-to-understand format, similar to the other reporting methods discussed below. Therefore, it is beneficial to use tables, charts, and illustrations to communicate the results accurately and efficiently.

At a minimum, formal ramp meter performance reports are to contain discussions of the following:

- Purpose of the report,
- Systems that were evaluated or geographic scope,

- Data collection methods,
- Performance measures,
- Aspects of the system that were evaluated, and
- Findings.

4.3.2. Fact Sheets, Summaries, and Other Documents

Similar to formal reports, information contained in facts sheets and summaries must report performance findings in an accessible and efficient manner. Unlike formal reports, fact sheets and summaries are useful for reporting performance findings to non-technical audiences, such as local-elected officials and the general public. For this reason, fact sheets and summaries are to focus on the impacts of a ramp meter(s) or the overall program, without delving into specific details on how the impacts where derived. Detailed discussion on methodology or how the evaluation was conducted is likely to either confuse readers or be ignored altogether.

4.3.3. Media Releases

Media releases, in either electronic or hardcopy format, can express the benefits of ramp meters prior to and during construction. To accomplish this, the local media is to be notified of program goals, objectives, and benefits well in advance of when a ramp meter(s) is expected to be turned on. This will help form a working relationship with the media that will be needed to continue to publicize the benefits of ramp meters.

Although the media can aid in acquiring public support, the media can also be obstructive if not handled properly. If the benefits of ramp metering are oversold or unrealistic, the credibility of the implementing agency can be questioned.

5.0. CASE STUDY: EVALUATION OF US 95 RAMP METERING

Using archived data, FAST performed a before and after analysis to quantify the benefits of ramp meters along US 95 between Rancho Drive and Craig Road. “Before” and “after” scenarios were defined as “without” and “with” ramp metering, respectively. The study, titled *Ramp Meters Evaluation: Using ITS Archived Data*, was published in the Journal of Transportation Engineering. The following is the abstract of this before and after analysis. The entire study may be requested from FAST.

5.1. Ramp Meters Evaluation: Using ITS Archived Data

In December 2009, ramp meters along US 95 in Las Vegas between Rancho Drive and Craig Road were activated. A study was performed to quantify the benefits of ramp meters on the freeway mainline using archived ITS data. Traditional performance measures such as average travel speed, speed standard deviation, inter-quartile speed range, Travel Time Index (TTI), and Buffer Index (BI) were employed to conduct the evaluation. In addition, two new performance measures—Delay Volume (DV) and Average Vehicle Delay (AVD)—developed by the Freeway and Arterial System of the Transportation Division of the Regional Transportation Commission of Southern Nevada were used to enhance the evaluation. Specifically, DV quantifies the congestion with temporal, spatial, and congestion intensity values, and AVD measures the average delay per vehicle with traffic volume as a weighting factor. Comparing both the freeway and ramp performance with and without ramp meters clearly demonstrates that ramp meters are very effective in mitigating the recurring heavy congestion for southbound US 95 during weekday peak periods. The improvement is comparatively little on the more lightly congested northbound section of US 95. The evaluation results also demonstrate that the DV and AVD metrics are useful in evaluating operational strategies such as ramp metering. Finally, informative results are achieved regarding the influence of ramp meters on the bottleneck and the comparative effects metering has on the general purpose and High Occupancy Vehicle (HOV) lanes.

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