TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM

Project Summary Report 2121-S
Project 0-2121: Design and Operations Criteria for Ramp Metering
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PROJECT SUMMARY REPORT

Designing Freeway On-Ramps for Metering

Use of ramp meters in Texas began in the 1960s. During the following years, the Texas Department of Transportation (TxDOT) installed ramp meters in several cities. These meters were later removed due to extensive freeway reconstruction. Texas cities have continued to experience a steady increase in traffic demand, and, as a result, most large metropolitan areas are again facing daily traffic congestion on their freeways. In many cases, reconstruction is not a viable alternative. Therefore, TxDOT has reintroduced ramp metering as a component of freeway traffic management systems. This time, however, ramp demands are much higher than those faced by the earlier ramp meters. In fact, it is not uncommon for many ramps to now experience demands in the range of 1200 to 1400 vehicles per hour (VPH). In a significant number of cases, ramp demand is even higher. Furthermore, engineers did not design the existing ramps in Texas with ramp-metering application in mind, especially for the level of demand being experienced now. TxDOT does not have guidelines for designing freeway entrance ramps with explicit consideration of ramp metering. TxDOT initiated this project to address this need.

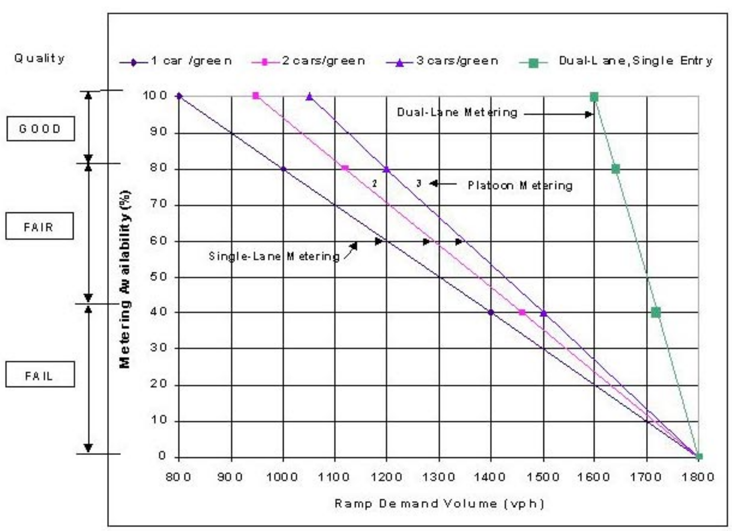

Figure 1. Quality of ramp-metering strategies for a range of traffic demands

What We Did . . .

First, the research team performed an in-depth study of current ramp metering design and operations practice in Texas and in other states. The purpose of this study was to acquire an understanding of all key elements related to ramp metering in Texas. Then the researchers developed spreadsheet-based analytical tools and simulation models for studying all key design variables. The researchers also utilized hardware-in-loop simulation to verify the results of these models. These tasks led to the development of design criteria for ramp metering in Texas as summarized in this report.

What We Found . . .

We begin with a description of ramp-metering objectives and conclude this report with a summary of research findings.

Objectives of Ramp Metering

Engineers install ramp meters to achieve one or more of the following three objectives:

1. Keep freeway demand below its operational capacity by controlling the number of vehicles that enter the freeway.

2. Reduce freeway demand by encouraging traffic diversion. This objective is achieved by introducing controlled delay to vehicles wishing to enter the freeway.
3. Make the freeway merging operations smooth by breaking up platoons of vehicles released from an upstream traffic signal, usually a diamond interchange.

Ramp Metering Practice in Texas

Current TxDOT ramp-metering practice is to prevent ramp queues from spilling back into the upstream traffic signal. In addition, TxDOT desires that no vehicle experience more than two minutes of delay while waiting for service at the ramp meter. These objectives are achieved by detecting and flushing large queues before they reach the upstream signal. A queue detector (referred to as the primary queue detector) is placed some distance downstream of the upstream traffic signal. When the back of the queue reaches the primary queue detector, the controller shuts off the metering operation until the queue clears. Other essential components of ramp meters are

- advance warning signs plus a flashing beacon, to inform drivers that the meter is in operation;
- demand detectors, which inform the controller when a vehicle arrives at the meter, at which point the controller displays user-programmed green, yellow, and red signal indications; and
- signal heads located on both sides of the entrance ramp.

Dual-lane meters have two demand detectors, one in each approach lane. Several other detectors can be used to provide a wide range of control. These include freeway detectors, an intermediate queue detector, and a merge detector.

Most ramp meters in Texas use the single-lane, one-car-per-green metering strategy. Two ramps located in Houston are the only exceptions. One of these ramps provides dual-lane metering, and the other provides bulk metering (three cars per green). Field and simulation studies show that a meter does not work well when the demand is significantly higher than its capacity. In addition, bulk metering does not significantly increase the capacity of a single lane meter. Dual-lane metering provides the maximum metering capacity; however, most existing ramps in Texas do not have room for providing two lanes. Figure 1 shows operational efficiencies of the various metering strategies.

Operational Considerations

Even when long-term (5 minutes or more) ramp demand is less than the meter capacity, short-term ramp demand may be much higher due to the platoons of vehicles released at saturation flow rates from the upstream signal during each signal cycle. Ramp area upstream of the meter must have a sufficiently large buffer (storage space) to store these vehicles. If sufficient storage is not provided, the meter may stay in the flush mode most of the time (as frequently as each cycle of the upstream signal), thereby defeating one objective of ramp metering. Thus, if a meter is to provide the expected benefits, entrance ramps should be designed to provide sufficient storage space and with metering capacity larger than the traffic demand. In addition, a ramp should be designed to provide sufficient distance for a vehicle stopped at the meter to accelerate and achieve a safe merge speed. Furthermore, sufficient distance should be provided for vehicles being discharged from the upstream traffic signal to safely stop and join the queue at the meter.

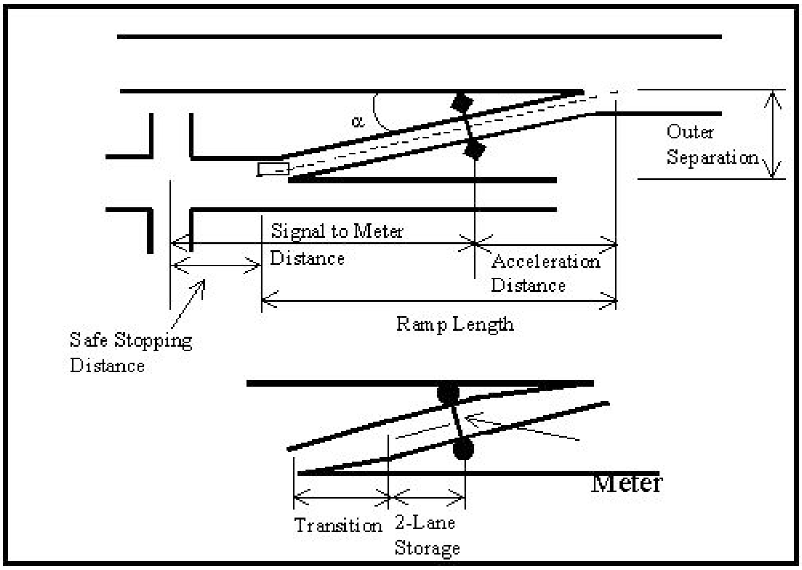

Figure 2. Distance requirement and geometric constraints

Ramp Design Criteria and Constraints

Figure 2 illustrates the geometric distance requirements described above. In addition, this figure shows that ramp length is a function of outer separation and ramp angle (α). Additional factors constrain the location of meters. These factors include ramp width and minimum clearances from curb or edge of shoulder to ramp signal poles. Ramp widths range from 22 feet

(6.7 meters) to 32 feet (9.7 meters) for single- and dual-lane ramps with shoulders. The minimum and desired widths for dual-lane ramps with curbs are 26 feet (7.9 meters) and 28 feet (8.5 meters), respectively. Furthermore, dual-lane meters require a single-lane to dual-lane transition length of 175 feet (53.3 meters) and a minimum dual-lane queue storage-space of 100 feet (30.5 meters) for at least four cars per lane. Ramp length, meter location, and resulting storage and acceleration distances illustrated in Figure 2 can be computed using trigonometry.

Significant Findings

Figure 3 shows the stopping plus queue storage distance (distance from centerline of intersection to ramp-meter) requirements for expected peak-hour demand. These calculations assume a minimum stopping distance of 250 feet (75 meters). As shown in Figure 3, the optimum distance for high-demand ramps is about 800 feet (250 meters). Figure 4 shows acceleration length from meter to merge point for three ramp grades and a range of freeway merge speeds based on AASHTO criteria. Our analysis further shows that an outer separation of at least 50 feet (15.25 meters) is needed to provide sufficient storage space and acceleration distance.

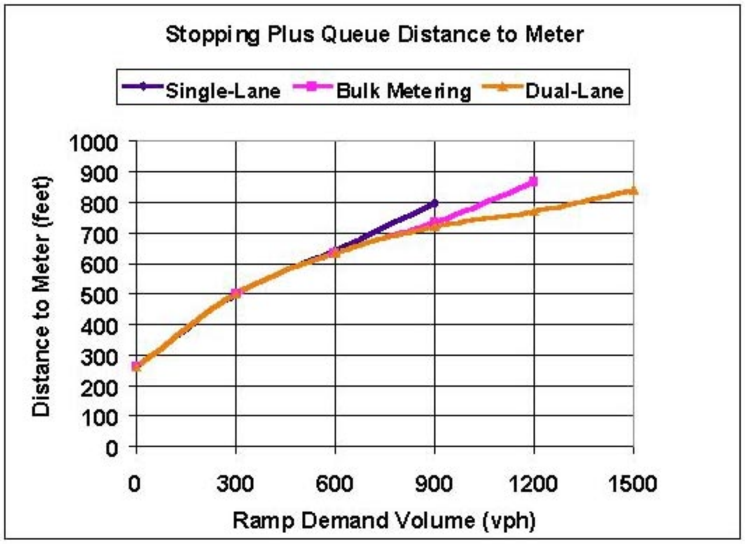

Figure 3. Optimum distance from center of upstream signalized intersection to ramp meter for various traffic demands levels

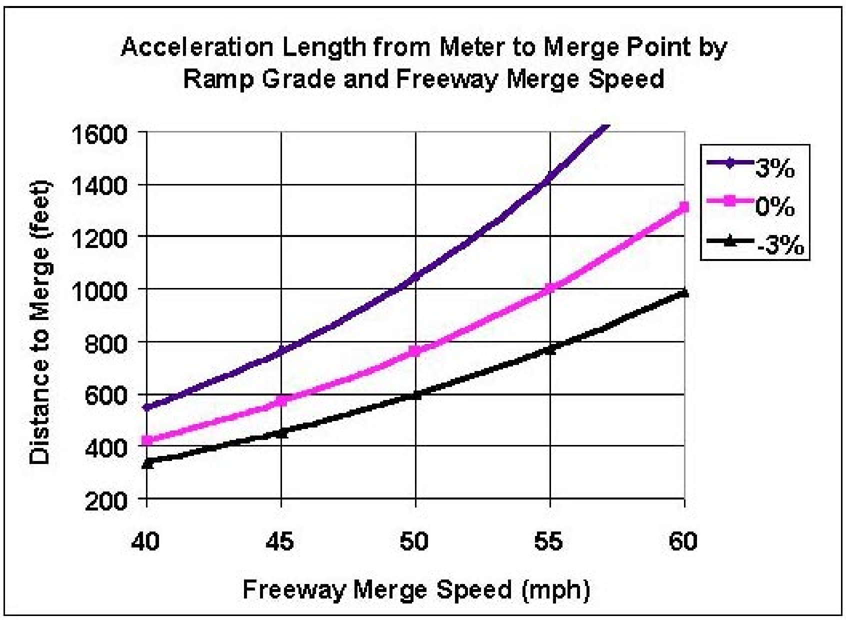

Figure 4. Distance from meter to merge point for three ramp grades

The Researchers Recommend . . .

An urban freeway entrance ramp should be designed for a metering strategy appropriate for handling the expected peak hour ramp demand. In addition, the researchers recommend the following:

1. provide a minimum stopping distance of 250 feet (75 meters) from the center of upstream signal to the back of the expected queue storage area;

2. provide an additional minimum storage length of 450 feet (175 meters) along the ramp to the meter; and

3. provide sufficient meter-to-merge acceleration distance for the ramp grade and freeway speed.

For More Details . . .

The research is documented in Report 2121-2, *Ramp Metering Design and Operations Guidelines for Texas*

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To obtain copies of the report, contact Dolores Hott, Texas Transportation Institute, Information & Technology Exchange Center, (979) 845-4853, e-mail d-hott@tamu.edu. See our on-line catalog at http://tti.tamu.edu

TxDOT Implementation Status
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TxDOT may want to use more ramp meters in the future to help with increasing traffic demands. This research will provide TxDOT with improved ramp metering design and implementation guidelines. These guidelines can be used for implementing ramp metering on existing ramps, upgrading existing ramps, and designing new ramps for ramp metering if needed.

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