



Ramp Metering: A Proven, Cost-Effective Operational Strategy

A Primer | October 2014



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LIST OF ABBREVIATIONS AND SYMBOLS

ATDM	Active Transportation and Demand Management
Caltrans	California Department of Transportation
CARMA	Corridor Adaptive Ramp Metering Algorithm
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
HCM	<i>Highway Capacity Manual</i>
HOV	high-occupancy vehicle
ITS	Intelligent Transportation Systems
MnDOT	Minnesota Department of Transportation
ODOT	Oregon Department of Transportation
SWARM	System-Wide Adaptive Ramp Metering
SZM	Stratified Zone Metering
TOPS-BC	Tool for Operations Benefit/Cost
TRB	Transportation Research Board
TSM&O	Transportation Systems Management and Operations
WSDOT	Washington State Department of Transportation

1. OVERVIEW OF RAMP METERING

Due to the growth of metropolitan areas and tightening of fiscal belts, the need for effective and financially viable freeway management tools is unprecedented. This primer poses ramp metering as a potential tool to address commonly occurring congestion and safety issues. Despite initial opposition and skepticism from various stakeholders, ramp metering has been deployed, sustained, and even expanded in many regions. This primer incorporates recent research on challenges agencies experience during their attempts to deploy or expand ramp metering in their regions.

While geometric limitations of existing ramps are a common challenge, agency support and project costs also pose difficulties for several agencies. Recent case studies provide insights into how these common challenges could be addressed as well as lessons learned. This primer emphasizes organizational capability, public outreach, and geometric limitations as key considerations when deploying or expanding ramp metering.

“Our region first installed ramp metering in our state’s largest urban area in the 1980s and we have steadily expanded the system since then. Other, smaller cities in our state have seen the benefits and are planning ramp meter systems.”—*Pete Briglia, former WSDOT and TRB Freeway Operations Committee Chair*

1.1 What Is Ramp Metering?

Ramp meters are traffic signals installed on freeway on-ramps to control the frequency at which vehicles enter the flow of traffic on the freeway. Ramp metering reduces overall freeway congestion by managing the amount of traffic entering the freeway and by breaking up platoons that make it difficult to merge onto the freeway. As seen in Figure 1, vehicles traveling from an adjacent arterial onto the ramp form a queue behind the stop line. The vehicles are then individually released onto the mainline, often at a rate that is dependent on the mainline traffic volume and speed at that time. The configuration in the

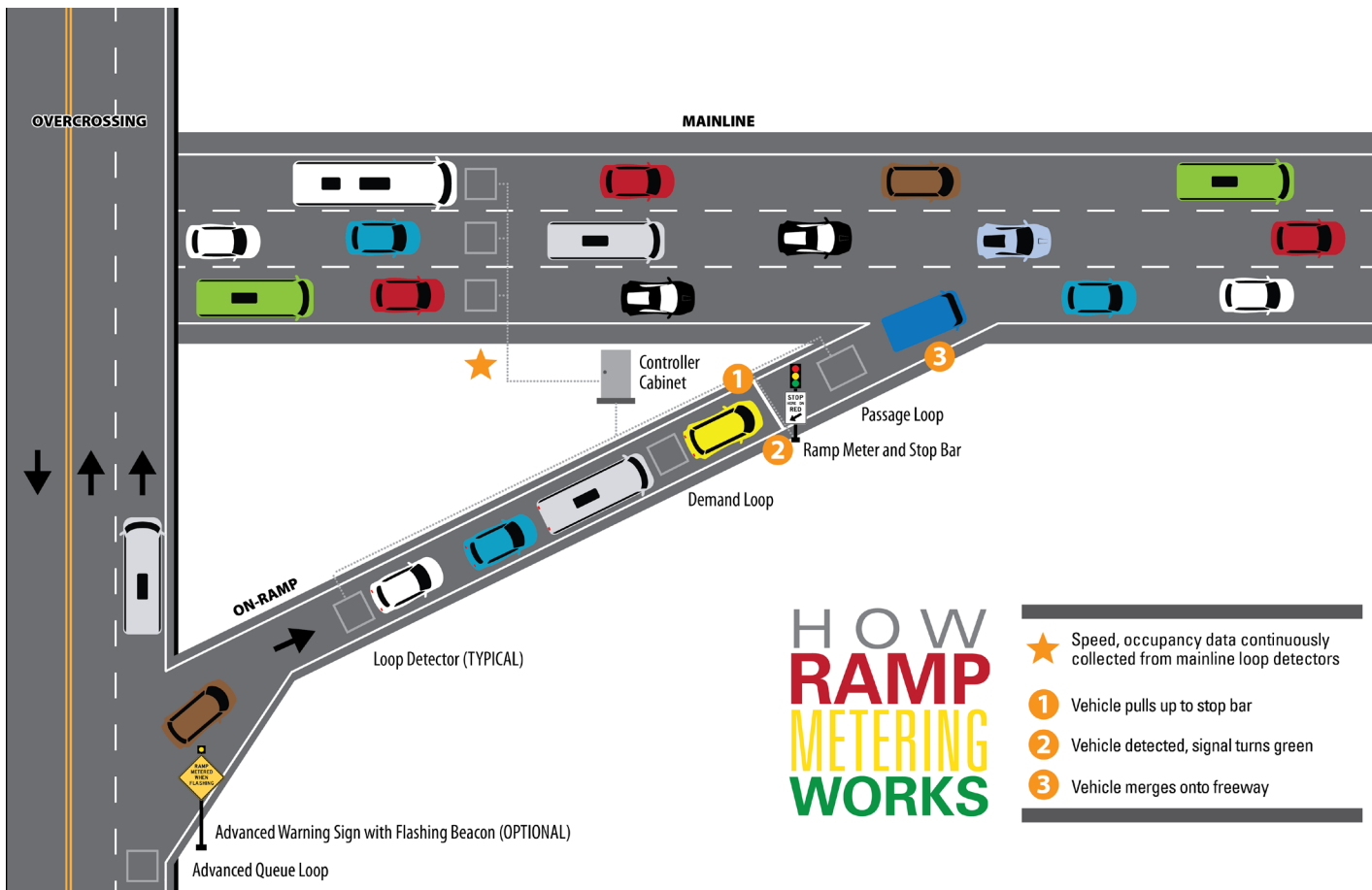


Figure 1: Ramp metering configuration

diagram is the most common; however, some agencies have altered this design to accommodate transit and high-occupancy vehicle (HOV) policies or existing geometric limitations.

1.2 Ramp Metering and Transportation Systems Management and Operations

Ramp metering is one of many strategies in the realm of freeway management and operations that agencies use to operate the existing freeway network at full potential. Successful operation of ramp metering systems leads toward integration with other activities that actively manage the freeway network. Transportation Systems Management and Operations (TSM&O) is an integrated program, with strategies such as ramp metering, road weather management, and incident management (Figure 2), that requires continuous and active management by agencies to ultimately provide optimized system performance to existing freeway infrastructure. The end result is a program that will improve mobility, reliability, safety, and environmental impacts while preserving freeway capacity at a significantly lower cost than traditional capacity improvements. Ramp metering can also support regional congestion management processes.

1.3 Ramp Metering Goals and Objectives

An agency's goals and objectives for ramp metering should be consistent with regional transportation goals and objectives, which will vary from region to region. Often these goals and objectives are driven by the needs and areas of opportunity for a region. For instance, one region may want to improve safety and another may prioritize increasing mainline speed. Alternatively, some regions may want to encourage HOV and transit use. Some common priorities among agencies are safety, mobility, quality of life, environmental effects, and motorist perceptions and satisfaction. With a set of objectives in place, agency decisions, such as what kind of system or algorithm should be used, will be appropriately focused.

1.4 History of Ramp Metering

Ramp metering was first deployed in the 1960s on the Eisenhower Expressway in Chicago. In the subsequent years, ramp meters were deployed in major metro areas such as Detroit, Los Angeles, and

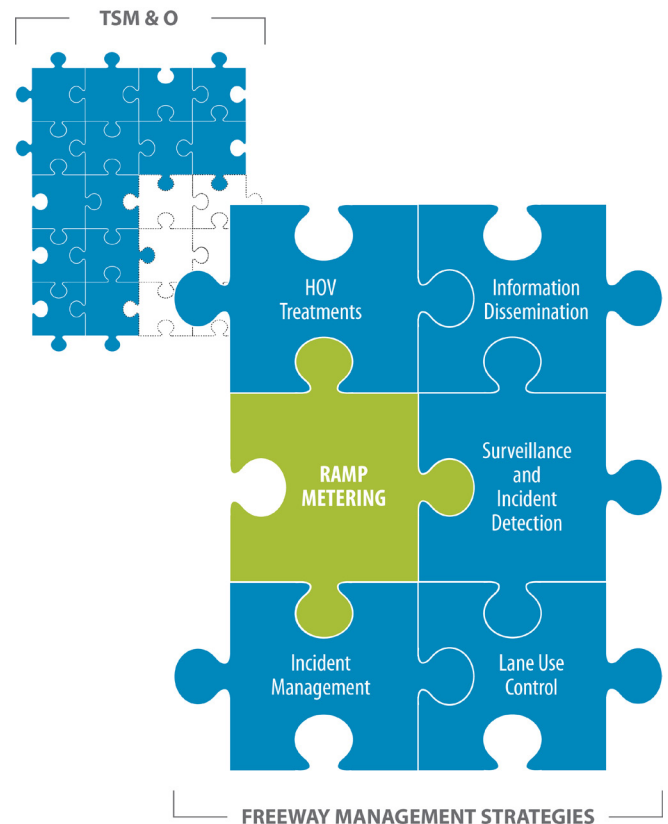


Figure 2: Ramp metering within freeway management and TSM&O

Minneapolis/St. Paul as experiments in increasing driver speeds during peak travel periods while reducing travel times and the frequency of freeway crashes. As ramp metering strategies and techniques advanced, more metro areas across the U.S., as well as Europe and Australia, began implementing ramp metering systems.

The uniqueness of the cities furthered the advancement and refinement of ramp metering as a traffic management strategy. The different agency needs and priorities resulted in various strategies, such as preferential treatment for HOVs and transit through the designation of bypass lanes, special ramp treatments like metering multiple lanes (including ramp shoulders), and metering two or three vehicles per green. As displayed on Figure 3, ramp metering has been deployed in varying degrees of sophistication and scale across the U.S.



Ramp Metering in the Top U.S. Metropolitan Areas^{1,2}

Ramp Meter Penetration

- No ramp metering
- 1–100 ramp meters
- 101–300 ramp meters
- More than 300 ramp meters

Ramp Meter Control

Local or Fixed-Time Control: Meters are either fixed/pre-timed to meet historical trends or are responsive/actuated to meet local, real-time conditions in the vicinity of the ramp.

System Control: Meters are responsive/actuated to system-wide conditions (i.e., optimizing flow along an entire facility, corridor, or system wide).

Note: 1. According to the 2010 United States Census, metro areas have a population greater than one million people.
2. Ramp metering information is current as of 2014.

Figure 3: Ramp metering in the top U.S. metropolitan areas

1.5 Benefits of Ramp Metering

When agencies implement effective ramp metering programs using strategies suitable to the region, they often realize significant, long-term benefits. While the magnitude of the benefits may vary depending on the level of congestion and configuration, common benefits persist across many regions. The widespread benefits of ramp metering, relative to its costs, make it one of the most cost-effective freeway management strategies.

Mobility, Reliability, and Efficiency

Ramp metering reduces mainline congestion and overall delay, while increasing mobility through the freeway network and traffic throughput. Travel times, even when considering time in queue on the ramp, are generally reduced when ramp metering is implemented. Travel time reliability has become an important measure of ramp metering effectiveness. Many regions have experienced increased travel time reliability (reduced variations in day-to-day travel times) due to ramp metering.

Safety

Ramp meters help break up platoons of vehicles that are entering the freeway and competing for the same limited gaps in traffic. By allowing for smooth merging maneuvers, collisions on the freeway can be avoided. Many regions have reported significant reductions in crash rates after starting ramp metering.

Effective ramp queue management can prevent queues from spilling onto the adjacent arterial and clogging up the city street network with stopped vehicles that are waiting to enter the freeway.

Reduced Environmental Impacts

Ramp meters smooth the flow of traffic entering the freeway so vehicles can merge with mainline traffic with minimal disruption to traffic flow. Eliminating prolonged periods of stop-and-go conditions due to congestion can reduce vehicle emissions and fuel consumption on the freeway. It can be argued that emissions and fuel consumption increase at the ramp meter, which is why the environmental analysis must be sensitive to actual ramp operations and fuel estimation methodologies, especially with the prevalence of electric and hybrid vehicles on the roadway.

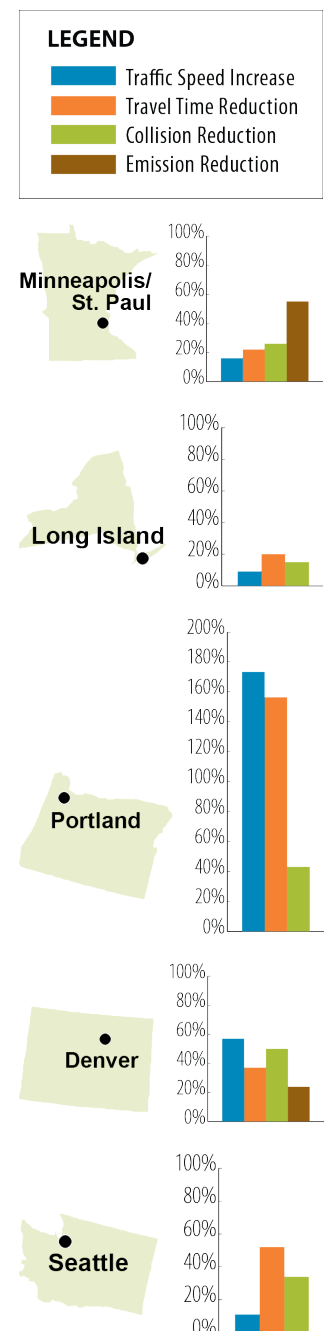


Figure 4: Select regional benefits of ramp metering

Source: FHWA Ramp Management and Control Handbook

Select environmental impacts:

- Minneapolis identified a net annual savings of 1,160 tons of emissions.*
- Other simulation analysis shows ramp metering to be effective in reducing CO emissions by 1,195 tons per year

*emission values calculated based on a simplified approach on average changes in speed.

Though it is typically difficult to measure, many regions have attributed reductions in carbon emissions and fuel consumption to ramp metering implementation.

Benefit Versus Cost

A benefit/cost analysis is a comprehensive analysis to evaluate and compare the cost effectiveness of ramp metering implementation and operation against the “no ramp meter” condition. The measured benefits of implementing ramp metering systems can outweigh the associated costs by a ratio of 15 to 1, as concluded in the Twin Cities Ramp Meter Evaluation. A 15 to 1 benefit/cost ratio is excellent for transportation improvements.

1.6 Why Ramp Meters Are Effective

Without ramp meters in operation, multiple vehicles merge in tightly packed platoons, causing drivers on the mainline to slow down or even stop in order to allow vehicles to enter. The cascading slower speeds, both on the mainline and on the ramp, quickly lead to congestion and sometimes stop-and-go conditions. Ramp meters can break up the platoons by controlling the rate at which vehicles enter the mainline from the ramp, as shown on Figure 5. This allows vehicles to merge smoothly onto the mainline and reduces the need for vehicles on the mainline to reduce speed. In addition to breaking up platoons, ramp meters help manage entrance demand at a level that is near the capacity of the freeway, which prevents traffic flow breakdowns. Ramp meters are shown to reduce peak hour lane occupancies (i.e., freeway density) and quicken recovery from mainline breakdown back to or below the critical occupancy threshold, as shown on Figure 6. Typical results include reductions in travel time, reductions in crash rates, and increased traffic speed.

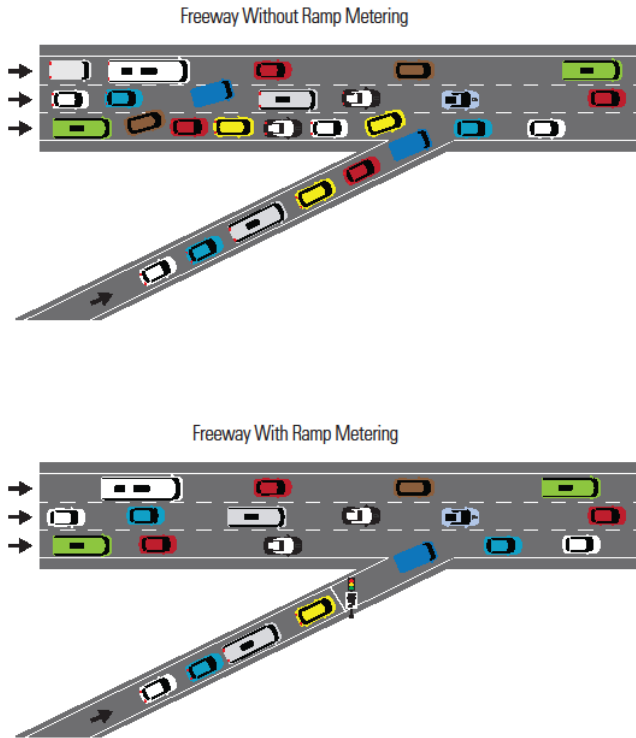


Figure 5: Comparison of mainline conditions with and without ramp metering—provided by WSDOT

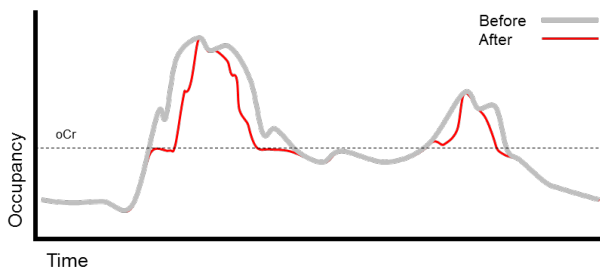


Figure 6: Duration of occupancy at shutdown capacity before and after ramp metering

1.7 Ramp Metering Analysis Tools

The technology utilized by ramp meters has evolved to offer increased scalability, efficiency, and customization. Through developed simulations and databases, agencies can model the effects of ramp metering on their existing freeway operations. These exercises can aid in the decision-making and planning process when planning for ramp metering deployment or expansion.

Simulation models can aid in determining what control algorithm would be most appropriate to manage freeway congestion based on user-defined inputs on system conditions. Computer-based simulations can estimate a set of traffic measures, such as travel time speed, for a given freeway corridor. The simulations can use new operational strategies like adaptive ramp metering coded directly into the software so that realistic environments can be evaluated for a proactive approach to congestion management.

Optimal ramp meter operations require robust data collection and analysis. Data regarding traffic volumes, travel times, and other appropriate performance measures should be collected, modeled, and analyzed both before and after ramp meters are installed. Volume data is collected in the form of video or loop detection along the ramp and on the freeway mainline upstream and downstream of the ramp.

An integrated database, that contains data such as roadway inventory, detector data, traffic counts, crash records, and incident records, can streamline the process to evaluate the effectiveness of various ramp metering strategies or algorithms. The evaluation database not only reduces the effort to collect all these data sets independently, but can be used with enhanced data sets and could provide the data needed to support visualization of various ramp metering scenarios.

1.8 Ramp Metering Control Approaches

Depending on the existing infrastructure, constraints, or objectives of the ramp metering program, an agency may select various ramp metering approaches. Table 1 provides details on various levels of control, including appropriate situations to use each approach. The following is a high-level overview of commonly used control approaches for ramp metering:

Table 1: Summary of ramp metering approaches

	PRE-TIMED	TRAFFIC RESPONSIVE
LOCAL	<ul style="list-style-type: none"> • Appropriate for localized problems. • Detection in the field is not needed. • Requires periodic manual updates. • Not effective for non-static conditions. • Higher operations costs compared to traffic responsive systems. 	<ul style="list-style-type: none"> • Appropriate for localized problems. • Detection in the field is needed. • Higher capital and maintenance costs compared to pre-timed systems. • Yields greater benefits because it responds to conditions in the field.
SYSTEM-WIDE	<ul style="list-style-type: none"> • Appropriate for widespread problems. • Detection in the field is not needed. • Rarely used compared to system-wide, traffic responsive systems. 	<ul style="list-style-type: none"> • Appropriate for widespread problems. • Detection in the field is needed. • Most useful for corridor, system-wide applications. • Greatest capital and maintenance costs, but yields most benefits.

Single or Multi-Lane Metering—Single lane metering allows only one vehicle to enter the freeway during each signal cycle. Multi-lane metering requires two or more lanes to be provided on the ramp and a signal head dedicated to each lane. After the stop bar, the lanes are required to merge into a single lane before merging onto the freeway.

Single or Dual Release Metering—One vehicle per green (or single release metering), operates with a shorter green time than with a two vehicles per green (or dual release) approach. Dual release allows for two vehicles to enter the freeway each cycle but requires a longer green time. The dual release metering approach usually increases ramp capacity under metering.

Freeway-to-Freeway Connections—Ramp metering on freeway-to-freeway ramps is less common due to the high travel speeds and the perceived increased potential for vehicle collisions because of vehicle queues where drivers may not expect them. Geometric constraints also exist such as limited sight distance along a curved roadway and limited provisions to provide the required storage for queued vehicles on ramps. Freeway-to-freeway metering, if possible, can significantly improve the ability to manage traffic on a freeway because a greater share of entering traffic is controlled by meters.

Bypass Lanes—Bypass lanes allow a specific class of vehicle (usually an HOV, a bus, or, in some locations, a truck) to avoid delay at ramp meters and have the right of way to merge directly on to the freeway.

Bypass lanes may have a single detection loop, actuations of which could incrementally increase the length of the ramp meter cycle each time a vehicle is detected.

1.9 Ramp Metering Components

Ramp metering requires some essential components and equipment in order to operate safely and effectively. Configuration, communication, and safety are objectives agencies should consider when placing signal heads, detectors, and signs. The following are key components in most ramp metering setups:

Signal Heads—The signal heads used for ramp metering are either two-section or three-section heads. Two section heads have green and red indications. Three section heads include the yellow indication and may be more familiar to most drivers.

Detectors—Detectors are necessary to monitor condition on the ramp and mainline. For instance, the signal should only turn green when a vehicle is detected at the stop bar. Queue detectors can also be used to monitor and manage queue length when placed upstream of the stop bar. Detectors can also monitor demand on the mainline and merge points to aid in determining the metering rate. Detection equipment on the ramps themselves (such as stopbar located demand detectors) should be connected directly to the ramp controller cabinet.

Signage—Signs should be placed at the start of the ramp and near the signal head. The sign content can provide instruction to vehicles when they enter the ramp and at the signal. Upstream signs with lights or adaptive screens can also indicate whether the ramp is being metered at a given time. Proper signage will facilitate clear communication and compliance with the established system.

1.10 Ramp Metering Algorithms

There are a wide range of ramp metering control strategies and algorithms. The three primary types of control strategies are fixed time, local control, and system-wide control. Fixed time metering is the simplest approach in terms of implementation because it has no reliance on traffic detection or communication with a Traffic Management Center. However, it is also the most rigid since it cannot make adjustments to the metering rate based on changing real-time mainline or ramp conditions. Both system-wide and local traffic responsive control rely on loop detectors or other forms of traffic surveillance to select metering rates. A local control strategy will select metering rates based on traffic conditions present on the ramp and at

adjacent mainline locations to remedy isolated congestion or safety-related problems. Local control cannot factor in conditions at adjacent ramps or throughout the freeway mainline. Local control is often used as a back-up strategy when system-wide algorithms are offline or communications are inoperable. System-wide control is responsive to both local and corridor-wide real-time traffic conditions. When calculating a metering rate, system-wide control takes into account traffic conditions upstream and downstream from an individual ramp along a specific freeway segment or along an entire corridor. System-wide control provides more options in optimizing mainline capacity and reducing the amount of overall system delay by using multiple ramps to control traffic at any given bottleneck or congested location. Descriptions of example algorithms are included in Table 2.

Table 2: Description of example algorithms

ALGORITHM	CONTROL TYPE	DESCRIPTION	USED BY
ALINEA	Local	Metering rates are determined based on occupancy data collected from mainline loop detectors located downstream from the meter. The goal is to maximize the mainline throughput by maintaining occupancy values below the target threshold.	Other Algorithms
Corridor Adaptive Ramp Metering Program (CARMA)	System	Metering rates determined based on mainline speeds and prevailing local controller conditions which are then optimized over each freeway direction. The concept is based on the assumption that a ramp can allow maximum vehicles when the speed is high and should allow no vehicles when the speed is near optimal.	Kansas City, MO
Heuristic Ramp Metering Coordination (HERO)	System	This algorithm uses the ALINEA algorithm as the foundation for managing local conditions. When ramp queues meet threshold conditions, the control algorithm is activated and assigns restrictive metering rates to upstream ramps in order to balance downstream conditions.	Melbourne, AUS
Fuzzy Logic	System	This algorithm incorporates ramp queues and makes them integral to managing and controlling the freeway system. This algorithm controls multiple ramps, uses more comprehensive mainline and ramp inputs, and uses different heuristics which allow for the most flexibility on determining metering rates for changing local conditions.	Seattle, WA Miami, FL
Stratified Zone Metering (SZM)	System	This algorithm operates on density measurements and requires detection upstream of the ramp merge, at mainline exit ramps, and on the mainline to sustain the overall objective of the total volume exiting a zone exceeding the volume entering. SZM attempts to rebalance the increase in mainline density by making other meter rates in the active zone more restrictive. Ramp queue wait times are managed by a separate algorithm function.	Minneapolis, MN
System-Wide Adaptive Ramp Metering (SWARM)	System	Metering rates are calculated based on the current density, the required density, and the number of vehicles that should be removed or added to the freeway zone between each ramp. Additional upstream ramps are called to action when a single ramp has exceeded its capacity to balance the zone density. SWARM provides advantages to mixed ramp controls, so that some ramps can be operated locally, manually, or with a different algorithm and SWARM will adapt to distribute wait times equally among ramps.	Orange County, CA Portland, OR

2. RAMP METERING CHALLENGES

Though ramp metering has proved a successful strategy in many cities, agencies continue to face barriers and other opposition in their attempts to deploy or expand their ramp metering systems. In a survey of the top metro areas, the barriers cited by agencies displayed common themes, such as lack of support—whether financial or political—and existing infrastructure that was not compatible with ramp metering.

Figure 7 shows the most common barriers to development from the survey.

Typically, regions with existing ramp metering systems will see areas of opportunity where ramp metering could be further deployed to improve freeway operations.

Of the regions that already have ramp meters in operation, many cited barriers to expanding their current system. The most prevalent barrier was the geometric limitations of the existing ramps (58 percent), with capital costs (42 percent) and operations and maintenance costs (26 percent) also frequently cited. The ability to maintain the system infrastructure and the technical skills of the existing staff were seen as barriers in 16 percent of the regions. Public opposition and local agency opposition was cited by 11 percent of regions as barriers to expansion.

2.1 Geometry of Existing Infrastructure

Some agencies have stated that ramp metering is not possible in their region due to the configuration and structure of their ramps. Because ramp metering requires space for vehicles to merge into mainline traffic and to wait in a queue, not all ramp configurations are suitable for ramp metering. Key geometric issues that should be considered when investigating ramp metering include inadequate acceleration length, mainline weaving problems due to closely spaced ramps, and limited sight distances on a horizontal or crest vertical curve. Ramp metering can reduce the impact of geometric conditions that cause problems under high speed or high volume ramp conditions and heavy mainline volumes because the ramp speeds are likely to be lower and there is less disruption from vehicle platoons vying for limited mainline gaps.



Figure 7: Identified barriers to ramp metering deployment

Thinking about expansion?

Agencies considering expansion or further development of their ramp metering program should first assess the current state of the program. In particular, the agencies should evaluate current performance metrics in order to target areas of opportunity and set expectations for improvement. The impact of the proposed expansion should be reported and shared with relevant stakeholders.

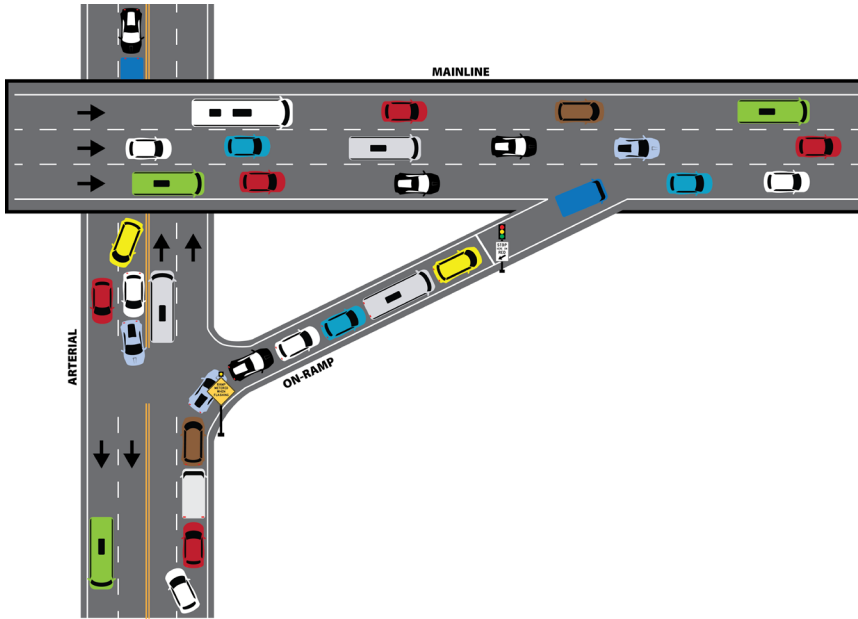


Figure 8: Example of challenging geometries for ramp metering

For instance, if an on-ramp lane merges too abruptly, the short distance past the stop bar may create unsafe conditions leaving inadequate space for vehicles to accelerate to a safe speed in comparison to the mainline. Figure 8 illustrates common geometrics that pose challenges to ramp meter implementation. In addition, narrow configurations may not have adequate shoulder space for an HOV bypass lane, a transit bypass lane, or an enforcement zone where compliance can be monitored.

2.2 Costs and Funding

Despite the benefits of ramp metering, there are monetary costs for deploying

and maintaining ramp metering systems. Without sufficient and well-timed funding, ramp metering deployment may be unsuccessful and not realize its full benefits. When agencies attempt to procure funding for ramp metering programs from local, state, or federal governments, they are often competing with other initiatives that may have greater priority or support. As exhibited in recent survey results, most agencies desire expansion of their ramp metering system following the initial deployment, which would require additional funds.

2.3 Public Opposition

The support of the public is often critical in the deployment and expansion of ramp metering. Many agencies encountered public opposition that significantly deterred or completely halted efforts to deploy ramp meters. Often this opposition is rooted in misconceptions about ramp metering and its effectiveness. The public may also raise concerns about equity, claiming that ramp metering asymmetrically favors those who live outside the city center.

2.4 Heavy Ramp Volume

As a ramp meter regulates the flow of vehicles entering the mainline, cars form a queue on the ramp behind the signal. If the meter's release rate is less than the rate at which vehicles approach the ramp, the queue will lengthen. If too long, a queue could spill onto arterials resulting in inefficient arterial operations. Ramps that are shorter in length or have

less storage space are at a higher risk of arterial backup than long ramps with similar demand.

2.5 Local Agency Opposition

Deploying or expanding ramp metering systems often impacts a variety of stakeholders including arterial agencies and local businesses. These groups may have a negative perception of ramp metering and may have the resources to halt efforts to deploy or expand ramp metering. Local agencies are often concerned that the ramp queues will negatively affect their transportation systems. Local agencies, like the public, may also be concerned about equity issues. Conversely, such groups would be valuable allies in building support for ramp metering and ensuring smooth operations.

2.6 Lack of Agency Support

Sometimes there may be a lack of support from the agency with responsibility for freeway operations. There could be many reasons for this lack of support. Sometimes it is because key people in the agency do not understand ramp metering. They may not be aware of the benefits of ramp metering and the high benefit/cost ratio that ramp metering projects show. It may also be because there is a concern over long term maintenance and operations costs. Agency staffing may also be an issue, either there is not sufficient staff or there is not staff with the needs skills and knowledge to implement or operate ramp metering. Consistent and clear communication and information can often increase agency support.

Lessons learned

- Agencies should consider suitability and feasibility prior to deploying ramp metering
- Public should be involved in ramp metering planning and development process
- Ramp metering requires continuous monitoring, even following deployment

3. KEYS FOR SUCCESSFUL RAMP METERING DEPLOYMENT OR EXPANSION

Whether an agency is expanding its already robust system or deploying ramp meters for the first time, there are key components of the planning and implementation process that it should keep in mind.

3.1 Is Ramp Metering Right for You?

The agency attempting to start new projects or deploy new systems should have an understanding of the high-level regional and agency goals, both short-term and long-term. New projects, including ramp metering deployment, should contribute to and complement existing initiatives and adhere to high-level objectives.

Ramp metering should be deployed with purpose to address existing operational issues (Figure 9). The primary issue ramp metering can mitigate is recurring mainline congestion; however, the agency may also want to increase safety at merge points and on the mainline and control mainline access during construction activities, special events, or traffic incidents. All of these issues have the potential to be aided through ramp metering and are valid reasons to pursue this strategy. However, if these issues are not present in the region or corridor, ramp metering is not an applicable strategy and should not be pursued.

Once the agency determines that its issues are relevant to ramp metering, it must determine if ramp metering is a feasible strategy to pursue. It can conduct feasibility studies to allocate resources efficiently and determine where ramp meters would be effective. Through evaluating outcomes from feasibility studies, it can discern whether or not a ramp meter is warranted at a particular location and get a preliminary glimpse into the potential effectiveness and magnitude of benefits.

Benefit/cost analysis is an additional tool that assigns a dollar value to the expected costs and benefits of ramp metering, which can determine and communicate the value of the project. Because the agency may



Figure 9: Ramp metering deployment decision process flow

face operations, maintenance, and capital costs as barriers, a benefit/cost analysis that yields a high ratio or positive net present value will provide leverage when seeking or appropriating funds. This type of analysis can be applied to a variety of constraints and scenarios, making it scalable to numerous regions that want to investigate ramp metering. Furthermore, this technique can be used for initial deployment and to measure the incremental benefit of expanding or improving a ramp metering system for ongoing performance reporting.

The agency should also assess its organizational capabilities and evaluate whether it is mature enough to undertake ramp metering deployment. Ramp metering deployment requires the operating agency to perform a multitude of tasks. Agency assessment can often identify strengths and areas that need strengthening. Agency assessment will prioritize areas of improvement by evaluating the internal capability to successfully implement ramp metering according to various organizational dimensions. The TSM&O capability maturity model is an assessment tool that identifies six dimensions of capability in which the agency can determine its level of maturity.

If the results from these various exercises indicate ramp metering is both appropriate and feasible, then the agency should take the next step in moving toward ramp metering deployment, which includes making sure that ramp metering projects are in the agency transportation plan and program.

3.2 Getting Ready for Ramp Metering

A systems engineering approach should be taken on all ramp metering projects, as required by FHWA Final Rule 23 CFR 940 for federally funded ITS projects to conform to the National ITS Architecture and standards. Going through the systems engineering process in the project development stage can guide the agency through the procurement, construction, fabrication, and systems acceptance phases of a project. An agency can tailor and scale the “V” systems engineering model, the FHWA preferred model for ITS projects, to fit the complexity of a project. One of the primary benefits in following these processes is early stakeholder involvement, the coordination with regional ITS architectures, and identification of interface points. Although systems engineering may require more effort at the beginning than would be conducted otherwise, the end result is a ramp metering system that is highly functional, efficient, has a reduced risk of failure, and one that can evolve with a minimum level of redesign and cost.

What is in 23 CFR 940? Systems Engineering Analysis

- Identification of portions of regional or statewide ITS architecture implemented
- Identification of participating agencies and other stakeholders
- Operational concept
- Agreements required for implementation
- System functional requirements
- Interface requirements
- Identification of ITS standards
- Sequence of projects required for implementation

Challenges addressed

- Lack of agency support
- Public opposition
- Equity imbalance
- Lack of backing materials to promote expansion

SPOTLIGHT

FDOT's steps for training and operational readiness

- Management and Operations Staff Training
- Operator Training
- Field Technician Training
- Actions required to be operationally ready for turn-on:
 - Develop or finalize operational strategies
 - Assessment of operational readiness
 - Performance monitoring
- Recommended outreach activities needed prior to turn-on:
 - Public & media communication
 - Leadership outreach

SPOTLIGHT

WSDOT public outreach

The detailed public involvement plan started three to five years prior to ramp meter activation and continued through one year after turn-on, with multiple objectives like increasing driver education and acceptance of the system, address enforcement issues, and allowance for design changes prior to construction stemming from driver knowledge of neighborhood issues.

To define project costs and a timeline, the agency should identify staffing and training needs and create specific procedures for testing, installing, and maintaining software systems and field devices if these procedures are not already established through previous ramp metering deployments. These procedures are key concepts in the systems engineering process.

Traffic data collection prior to and after ramp meter installation measures the benefits of the implemented ramp metering strategies. A consistent approach to collecting, modeling, and analyzing traffic volumes, travel times, and other performance measures should be established early in the project development process.

Agencies, such as FDOT, are finding success with established procedures to guide management through the ramp metering implementation process.

Gain public and agency support

Because negative perceptions held by the public and other local agencies can hinder ramp metering deployment or expansion, the agency should devote efforts to outreach and collaboration.

To familiarize the public with ramp metering and to encourage their support, the agency should conduct outreach that proactively disseminates information to the public and clearly communicates the benefits of ramp metering. These efforts may include gathering public feedback, answering questions from the public, conducting focus groups and open houses, and issuing statements to local media. In order to reach a broader local population, the agency should maintain FAQs and other important information on a website and distribute this information via brochure or flyer. Providing clear information and addressing questions adds transparency to the planning process, which the public will generally favor. The agency could address stakeholder misconceptions of actual or perceived operations and maintenance costs by a thorough evaluation of costs associated with operating and maintaining ramp metering systems.

Local officials and interest groups can be instrumental in gaining widespread support. The agency should reach out to local officials to communicate the benefits of ramp metering and collaborate to address potential and existing issues.

Inter-agency cooperation is essential for early and on-going coordination. Inter-agency support can be won by assembling and providing supporting information that justifies the need for ramp meter

deployment or expansion. The agency can develop agreements among each other to address known concerns, which can be a mutually beneficial relationship. For instance, a key element of successfully ramp metering is driver compliance. Transportation agencies should work with enforcement agencies to develop a cohesive enforcement plan.

Identify costs and funding sources

The agency can utilize FHWA tools, such as the USDOT Knowledge Resources website, to identify capital costs related to the installation of new systems. FHWA tools can also be used to identify and estimate corresponding benefits to be used in funding and programming decisions. The agency can strengthen its case for deploying ramp metering by itemizing specific costs, thus increasing transparency.

Providing benefit and cost information can help strengthen the case for ramp meter expansion by showcasing the benefits and providing leverage for requesting funds.

In order to secure funding, the agency must communicate the high priority of ramp metering to authorities. In agency budgeting processes, provisions for ramp meter installation should be included in future construction planning efforts.

Understand traffic conditions and volumes on ramps, mainline, and arterials

Successful ramp metering requires an understanding not only of the ramp conditions but also the conditions and volumes of the mainline and surrounding arterials. Thus, the agency should monitor the ramp, mainline, and arterial conditions to inform ramp metering policies, procedures, and strategies.

When evaluating mainline conditions, the agency should identify segments of freeway that show congestion forming near particular ramp locations. Metering these ramps can balance mainline volumes within the segment and reduce overall congestion. The impact of queue spillover on the local road network is potentially disruptive for arterial traffic flow and poses problematic merging and turning situations. The agency should collaborate with the arterial signals operators to enhance safety and effectiveness of ramp meters through signal timing, arterial striping, and ramp metering rates to manage queue backup.

Benefit/cost analysis web resources

FHWA Operations Benefit/Cost Analysis Desk Reference web site: provides guidance, tools, and information for conducting benefit/cost analysis for a wide range of TSM&O strategies and projects (ops.fhwa.dot.gov/publications/fhwahop13004/)

U.S. Department of Transportation Research & Innovative Technology Administration ITS Joint Programs Office Knowledge Resources web site: users can browse benefits and costs from various projects (www.itsknowledge.resources.its.dot.gov/)

Challenges addressed

- Long ramp queues
- Arterial backups
- Violation rates

Consider queue lengths and delay

Upon observation of system-wide traffic conditions, and the collection and analysis of traffic volumes at each ramp, an agency can determine whether or not they need to implement queue management strategies at single or multiple ramp locations.

The queue length on the ramp will be impacted by both the mainline and arterial traffic conditions. While queue management is a key consideration for optimizing freeway operations, the amount of time spent in a ramp meter queue generally adds to negative public perception. Queue management is closely related to the geometric limitations of the existing ramps, so both should be considered when exploring options. Two approaches to address queue length are increasing queue storage through lengthening the ramp or widening the ramp through adding pavements or restriping, or reducing the queue length through the techniques mentioned below.

Ramp metering technology has developed various methods of queue detection and corresponding solutions handled either by being hard-wired into the controller or with the software as a function of the control algorithm. It is important to deploy a system that provides operators with information about the length of queue wait times. If adding additional storage capacity at a ramp is not feasible, the agency could consider adjusting the metering control scheme to increase ramp metering capacity.

Strategies to increase ramp metering capacity include dual-lane or dual-release metering, implementing the use of the ramp shoulder as a metered lane during peak periods or restriping the shoulder lane to allow for an optimal acceleration lane taper (see Figure 10 for a typical sign). These are lower-cost options for controlling the queue.

Because queue length is a crucial aspect of ramp metering operations that is relevant to many stakeholders, the agency should create policies on maximum queue wait time and be able to communicate and justify these policies publicly.

3.3 Operating Ramp Metering Effectively

Monitor performance

After deploying or expanding a ramp metering system, the agency should assess various dimensions of the system's performance. It should establish which metrics to measure, appropriate benchmarks for those measures, and monitoring and reporting procedures.

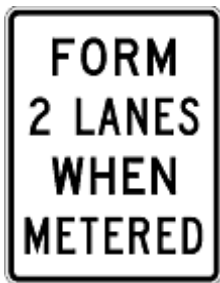


Figure 10: Typical sign used to convert single lane on-ramp into dual-lane queue storage or allow conditional use of the shoulder

Performance monitoring can be used to identify areas of improvement and make small tweaks to the algorithm and overall system after the initial ramp metering deployment. Performance monitoring can also aid the agency in building inter-agency and public support for ramp metering. Creating public relations materials or reaching out to media regarding performance can increase the favorability of ramp metering with citizens, local businesses, and local governments. Providing agency transparency on the effect ramp meters are having on the freeway network is a successful strategy to overcoming opposition and determining target areas for improvement.

Analyze costs and benefits

Measuring the costs and benefits of a proposed ramp metering system is a practiced strategy for accelerating ramp metering deployment. The agency could face scrutiny regarding the proposed benefits of ramp metering in its region. A benefit/cost analysis can make the case for ramp metering more convincing. FHWA has developed resources to assist in this analysis. The Intelligent Transportation Systems (ITS) Benefits database documents findings from evaluations of a variety of ITS deployments on system performance, categorizes benefits by ITS goal areas (such as customer satisfaction, mobility, safety), and provides a comprehensive summary of benefits that can help the agency in making informed planning and investment decisions. A companion to the Benefits database is the Costs database, a national resource of costs estimates for ITS deployments. The Tool for Operations Benefit/Cost (TOPS-BC) spreadsheet is designed to assist agencies in conducting benefit/cost analysis and to provide additional structure to critical decision-support actions and analysis of selected key TSM&O strategies. Another useful resource for analyzing impacts from ATDM strategies is the recent update to Chapter 35 of the Highway Capacity Manual (HCM), which describes methods to analyze freeway mainline effects of ATDM strategies, such as ramp metering.

There are numerous costs associated with ramp metering, including capital and maintenance costs associated with hardware and installation, user costs, and other costs stemming from congestion, environmental pollutants, and safety. A sound evaluation of the benefits



Figure 11: Dimensions of performance monitoring

and associated costs of ramp metering can make a compelling case to relevant stakeholders that ramp metering would benefit a given area.

Monitor and manage ramp queues

Following the activation of ramp meters, the agency should give particular attention to the length and behavior of the ramp queues. As discussed, excessive ramp queues that back up onto arterials are hazardous from both an operational and public relations standpoint. A common criticism of ramp metering from the public is the time drivers must spend in queues, so maintaining support for ramp metering can be contingent on managing queues. In addition, drivers are more likely to

comply with ramp meters when the queue is reasonable. The agency should establish policies and methods for regularly monitoring the ramp queues, as traffic conditions can change over time and throughout the day.

Through its data collection and analysis processes, the agency should make adjustments to algorithm parameters as needed. To accommodate various ramp dimensions, it may change the configuration of the ramp. This could include forming two-lanes during metering, lengthening the storage lane, and adding a full-time lane. The release policy could also be increased to two cars per green, which would allow cars into the mainline at a higher rate.

CHALLENGES:	MITIGATION STRATEGIES:
01 Existing Ramp Geometry	<ul style="list-style-type: none"> - Conduct feasibility studies to test new technology - Implement alternate metering approach - Develop capital investment plan to improve geometry of key ramps
02 Cost/Funding	<ul style="list-style-type: none"> - Conduct benefit/cost analysis - Conduct feasibility studies
03 Public Opposition	<ul style="list-style-type: none"> - Develop and conduct public outreach and involvement plans
04 Heavy Ramp Volume	<ul style="list-style-type: none"> - Implement ramp queue management techniques - Implement alternate metering approach
05 Local Agency Opposition	<ul style="list-style-type: none"> - Present results of benefit/cost analysis to improve communication - Measure and present performance metrics
06 Lack of Agency Support	<ul style="list-style-type: none"> - Communicate internally often and clearly early-on in planning process - Show and illustrate the benefits - Show that strategy is cost effective

Figure 12: Ramp metering deployment challenges and mitigation strategies

Figure 12 distills the keys presented above into mitigation strategies for common barriers to ramp metering.

4. GOING ABOVE AND BEYOND

After deploying a basic ramp metering system, the operation of the system may benefit further from increased sophistication. The extent to which an agency can and should develop its ramp metering program can vary greatly. The need for these enhancements can also vary greatly, from agency policy preferences to managing excess volume. One of the key attitudes that agencies with successful ramp metering programs embrace is the desire for continued improvement in ramp metering operations. Through ongoing performance monitoring and internal agency assessment, enhanced ramp metering strategies can be identified and planned for in future regional planning efforts.

Operational enhancements can include policies that extend the use of ramp meter operation outside the peak hours and for special events and construction activities, special ramp treatments, adaptive ramp metering, and integrated freeway and arterial corridor management strategies.

Special ramp treatments include strategies that can improve traffic conditions, improve safety at the merge point, and provide driver incentives for specific modes of travel. For instance, to encourage carpooling and transit use, some ramps have HOV bypass lanes that allow HOV and transit vehicles to avoid delay by bypassing the ramp queue and merging onto the freeway.

Adaptive ramp metering is one application out of the suite of Active Transportation and Demand Management (ATDM) concepts that aims to control the rate of vehicles entering the freeway utilizing advanced technologies. Part of the ATDM (and TSM&O) philosophy includes monitoring the transportation system and taking steps to continuously improve its operation. In other words, it is important to actively manage each ramp metering system. Exploration of basic ramp metering approaches to meet freeway management goals and objectives is beneficial prior to implementing more advanced technologies and concepts.

Agencies can also focus on developing the systems aspect of ramp metering. For instance, adaptive ramp metering employs algorithms that change release rates based on the level of congestion on the mainline. This technique is effective for recurring and non-recurring congestion, since it can respond to mainline traffic conditions and on/off mainline flow in real time.

SPOTLIGHT

WSDOT: Automated turn on/off

In November of 2012, WSDOT automated the on/off operation of the Seattle area ramp meters through an added function to the Fuzzy Logic algorithm that looks at traffic conditions local and downstream of the ramp. All meters have the ability to be automated and most of them are. The few that are not automated are still in manual because of presence of construction activity.

ODOT: Adaptive ramp metering

Oregon Department of Transportation (ODOT) switched its ramp meters from pre-timed operation to the SWARM algorithm in 2005 to provide increased efficiency and effectiveness of a traffic-responsive ramp metering algorithm. About 150 ramps in the Portland metropolitan area are under adaptive control during the morning and evening peak periods.

(See Table 2 for algorithm descriptions)

Another enhancement to a ramp meter system may be the integration of the arterial signal system as part of a system-wide corridor management strategy. When operating independently of the ramp meter signals, the arterial signals may release too many cars onto the ramp, causing backup onto the arterial. If the two systems are integrated, backup could be reduced leading to safer and more efficient conditions.

These approaches tend to require high organizational capability and are not necessarily suitable for all ramp metering locations. As stated above, even agencies that already have ramp meters should assess both suitability and feasibility prior to expanding and improving their programs.

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