



# **Guidelines for Applying Peak-Period Ramp Closure for Interstate Highways**

**Research Product 0-4764-P1**

**Research Project 0-4764**

**Performed in cooperation with the  
Texas Department of Transportation  
and the  
Federal Highway Administration**

**by the**

**Center for Transportation Infrastructure Systems  
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# **Guidelines for Applying Peak-Period Ramp Closure for Interstate Highways**

**By**

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**Product Number 0-4764-P1  
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Development and Evaluation of Peak-Period Ramp  
Closure Strategies**

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El Paso, TX 79968-0516**

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# 1. INTRODUCTION

In spite of the advent of Intelligent Transportation Systems (ITS) technologies, and improved practices for traffic operation, freeway traffic management continues to be one of the most challenging tasks that traffic engineers encounter in maintaining satisfactory mobility of highway networks. Such difficulties and challenges arise from the continuing growth of passenger and goods movements along major transportation corridors, as well as evolving and intensified urban activities in metropolitan areas in the U.S.

Among all freeway management strategies, controlling freeway inflow/outflow has been a widely used approach. This type of technique, as defined by the latest Freeway Management and Operation Handbook (FHWA, 2003), includes ramp metering, entrance ramp closure, and exit ramp closure. Ramp metering is perhaps the most widely applied and fully tested technique among the three. The use of ramp metering aims to prevent freeway main line traffic from breaking down, and maintains reasonable throughput and levels of service when the main line traffic is onset to its capacity.

Most of the related technical documents suggest that engineers use entrance and exit ramp closures under very restrictive circumstances or only in situations where ramp metering is ineffective, because of the possibility of under-utilizing freeway capacity, over-flooding alternate routes, and public concern when ramp closure is not applied carefully. The discussions of typical situations in which ramp closure is

recommended appear in several technical documents, including Freeway Management and Operation Handbook (FHWA, 1997, 2003), Traffic Operations Manual (TxDOT, 1998), and Intelligent Transportation Systems (ITS) Design Manual (Wisconsin DOT, 2000), etc. Typical situations in which ramp closure is considered include:

- (1) The entrance ramp does not provide sufficient storage length to prevent queues of vehicles waiting to enter the freeway from interfering with surface street traffic.
- (2) Traffic demand on the freeway immediately upstream is at capacity, and an alternate route with adequate capacity is available. Even if the upstream traffic demand is less than downstream capacity, the rate at which traffic could be allowed to enter the freeway might be so low that it would not be possible to control the entrance of ramp traffic without a large number of violations.

## **1.1. Purpose of This Guidebook**

The purpose of this guidebook is to provide general recommendations for applying peak-hour ramp closure as a viable freeway management strategy. Central to the discussion is the review of various traffic operation strategies in conjunction with ramp closure, together with the recommendations for implementation, including traffic engineering, geometric consideration, and benefit evaluations.

This guidebook is prepared with the following objectives:

- To characterize conditions that warrant the application of ramp closure.
- To develop recommendations for integrated traffic operation strategies using conventional traffic engineering approaches and/or ITS technologies (if available) from traffic management and safety improvement perspectives.
- To develop an evaluation plan for continual improvement of ramp closure implementation.

## 1.2. Existing Guidelines for Peak-Period Ramp Closure

Every roadway improvement planning, real-time operation, and evaluation of traffic impact studies on highways across the nation requires supervision from the Federal Highway Administration (FHWA). The FHWA classifies ramp closure strategies as either temporary or permanent.<sup>1</sup> Recently, the closing of access ramps has been implemented to improve traffic conditions on highway main lanes and arterials in the surrounding areas. A ramp closure may also be caused by work zones in the area. According to the FHWA, ramp closure is an extreme strategy as it restrains traffic behavior that has been established over a significant period of time.<sup>2</sup> Some cases consider closing on-ramps to impede vehicle access to incorporate traffic on a highway. Other cases might consider closing exit ramps to monitor traffic on both arterials and highway.

Parallel to this effort, the FHWA pooled-fund study – development of “Ramp Management and Control Handbook”- briefly discusses the ramp closure as one type of ramp control strategy. The specific decision-making process, as illustrated in Figure 1-1, examines the ramp closure based on three categories: eventrelated, time of day, or recurrence. The peak-hour ramp closure, focal study subject of this effort, is categorized as a “time of day” type of closure. At the time of production of this guidebook, the research group of the Ramp Management and Control Handbook has not provided any specific recommendation for analyzing the benefit/impact of peak-hour ramp closure.

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<sup>1</sup> [http://tmcdfs.ops.fhwa.dot.gov/cfprojects/uploaded\\_files/CH%202-Final%20AOutline-v.1.1%20clean.doc](http://tmcdfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/CH%202-Final%20AOutline-v.1.1%20clean.doc)  
U.S. Department of Transportation Federal Highway Administration. TMC Pooled-Fund Study (PFS)

<sup>2</sup> Freeway Management Handbook. Chapter 7. Website:  
[http://ops.fhwa.dot.gov/Travel/traffic/freeway\\_management\\_handbook/chapter7\\_01.htm](http://ops.fhwa.dot.gov/Travel/traffic/freeway_management_handbook/chapter7_01.htm), U.S. Department of Transportation Federal Highway Administration. TMC Pooled-Fund Study.

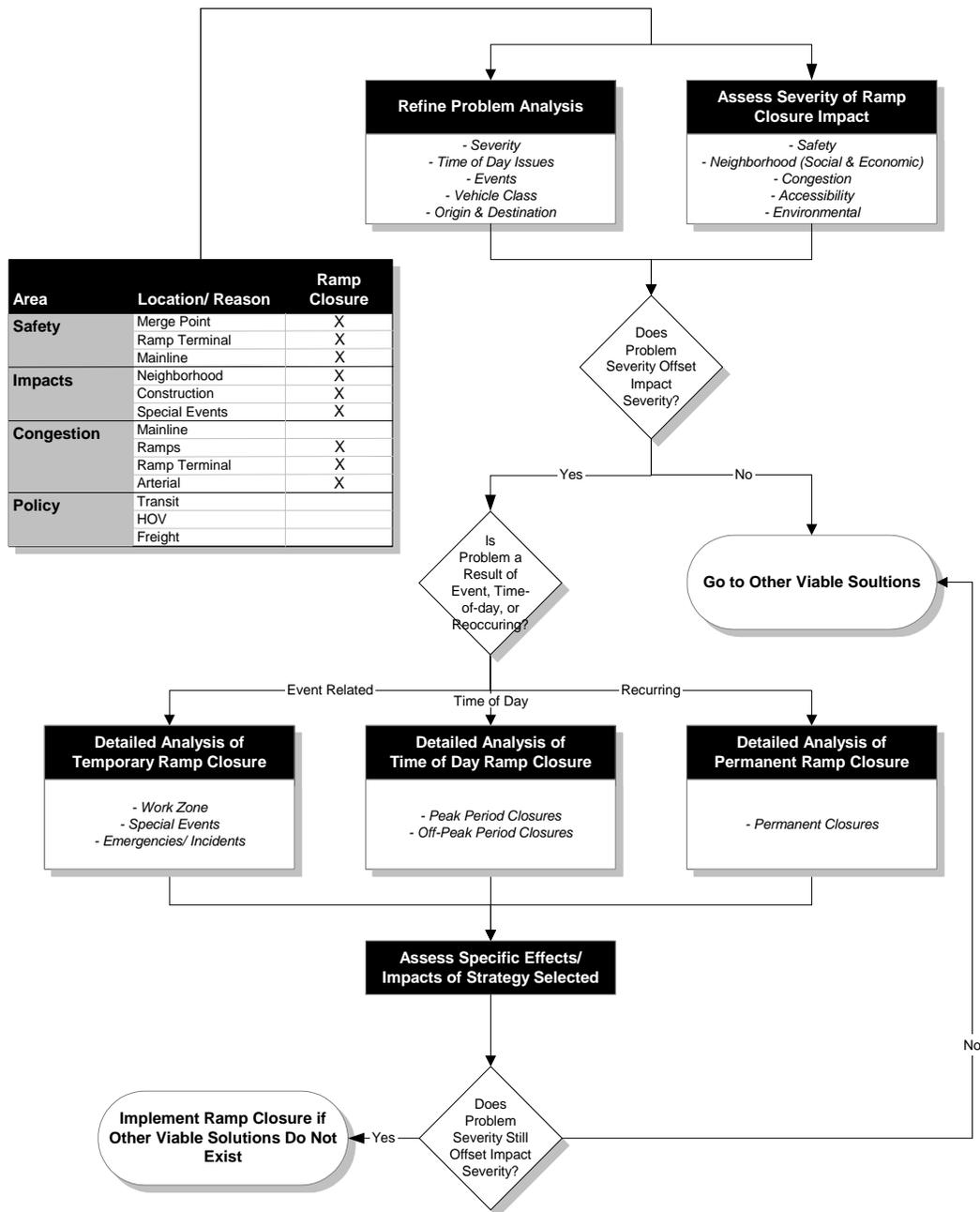


Figure 1-1 Ramp Closure Decision Tree (Ramp Management and Control Handbook, draft, 2004)

The FHWA emphasizes evaluation of closure for the traffic impact analysis. Common knowledge calls for a special inspection of traffic demand present on

such ramps on a daily basis. Closing a ramp can eliminate the need for complex traffic control that addresses both traffic entering the facility and traffic already on the facility<sup>3</sup>, reducing motorist delay and improving safety. The FHWA also encourages traffic analysts to include public information as well as public involvement prior to implementation.<sup>4</sup> Although the FHWA defines a ramp closure as the simplest form of controlling traffic on-ramps, the administration advises resorting to this technique as a last alternative. This might be because few research findings have been made available.

The ramp closure implementation is accomplished by means of either automatic or manually placed vertical or horizontal gates. Special attention must be paid to the benefit impact for each individual scenario. As previously mentioned, duration of the ramp closure must be considered. The FHWA classifies closure of a ramp to be permanent as the best approach in order to avoid driver confusion.<sup>5</sup> Thus, temporary closure must implement additional signs to alert upstream traffic to current conditions of the ramp.

Although no specific guidelines have been provided, special attention must be paid to the reduction of driver confusion prior to implementation. At this point, the administration may provide recommendations for the methodology applied to the ramp closure operation. In general, the FHWA concerns main issues abutting from this control system regarding processes that are used to analyze and select ramps to be closed, strategies employed to mitigate impacts, record of negative and positive impacts, specific challenges encountered in planning, and significant lessons learned for future reference.<sup>6</sup> Prior to any implementation of ramp closure, either classification (permanent or temporary), daily operations should be documented and related back to practices presented in a manual for each specific

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<sup>3</sup> <http://ops.fhwa.dot.gov/wz/resources/publications/FullClosure/CrossCutting/its.htm>

<sup>4</sup> Turner-Fairbank Highway Research Center website: <http://www.tfhrc.gov/pubrds/04may/01.htm>.

<sup>5</sup> [http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded\\_files/CH%205-Final%20Aoutline-v.1.2%20clean.doc](http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/CH%205-Final%20Aoutline-v.1.2%20clean.doc)  
U.S. DOT FHWA. TMC Pooled-Fund Study (PFS).

<sup>6</sup> [http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded\\_files/CH%205-Final%20Aoutline-v.1.2%20clean.doc](http://tmcpfs.ops.fhwa.dot.gov/cfprojects/uploaded_files/CH%205-Final%20Aoutline-v.1.2%20clean.doc)  
U.S. DOT FHWA. TMC Pooled-Fund Study (PFS).

case. Items that should be documented include conditions such as closure and opening procedures if closure is temporary, and monitoring traffic in the vicinity of the closure.

## 2. ENGINEERING ANALYSIS FOR PEAK-PERIOD RAMP CLOSURE

### 2.1. Ramp Closure Planning and Operation Procedure Overview

The engineering analysis procedure reflects several important considerations that focus on characterizing the feasibility of ramp closure, and on developing an integrated traffic management plan in conjunction with ramp closure, in order to maximize the benefit of ramp closure, while minimizing or mitigating potential impacts on the network.

Figure 3-2-1 describes the general framework for conducting the feasibility study and implementation of a peak-period ramp closure. First, an application and an entrance ramp that is considered the candidate location for applying ramp closure are identified. The pattern and intensity of traffic congestion must be characterized according to defined performance indicators. Basic qualification procedures are then applied to determine whether the ramp satisfies basic requirements. The qualification criteria will be primarily the freeway geometric features such as ramp spacing, main-lane and ramp traffic volumes, ramp storage, availability of alternate routes, etc.

Next, the feasibility of ramp metering should be studied. According to the FHWA guidelines, it is recommended that the ramp metering strategy be considered prior to adopting permanent or temporary closure of a ramp. If ramp metering is found to be desirable, then ramp metering is recommended; otherwise, benefit and impact analysis for a ramp closure option is recommended

In the ramp closure benefit and impact analysis procedure, two categories of criteria including "Freeway Level-of-Service Analysis," "Regional Surface Traffic Impacts," "Level of Closure Information Provision", and "Safety Impact (freeways and arterials)" will be used to evaluate the feasibility and operational characteristics of ramp closure. Moreover, four categories of operational strategies are recommended for evaluation based on the above criteria to determine the optimal configuration of the integrated operational strategies. The four categories of operational strategies are "Closure Time and Duration," "Closure Information Provision Strategies," "ITS Strategies," and "Freeways/Arterials Control Integration." It should be noted that proper integration of possible network operational strategies provides the crucial opportunity needed to make ramp closure work. Simply executing the ramp closure without implementing a package of comprehensive and integrated traffic management strategies will reduce the likelihood of making the ramp closure a successful freeway operation strategy.

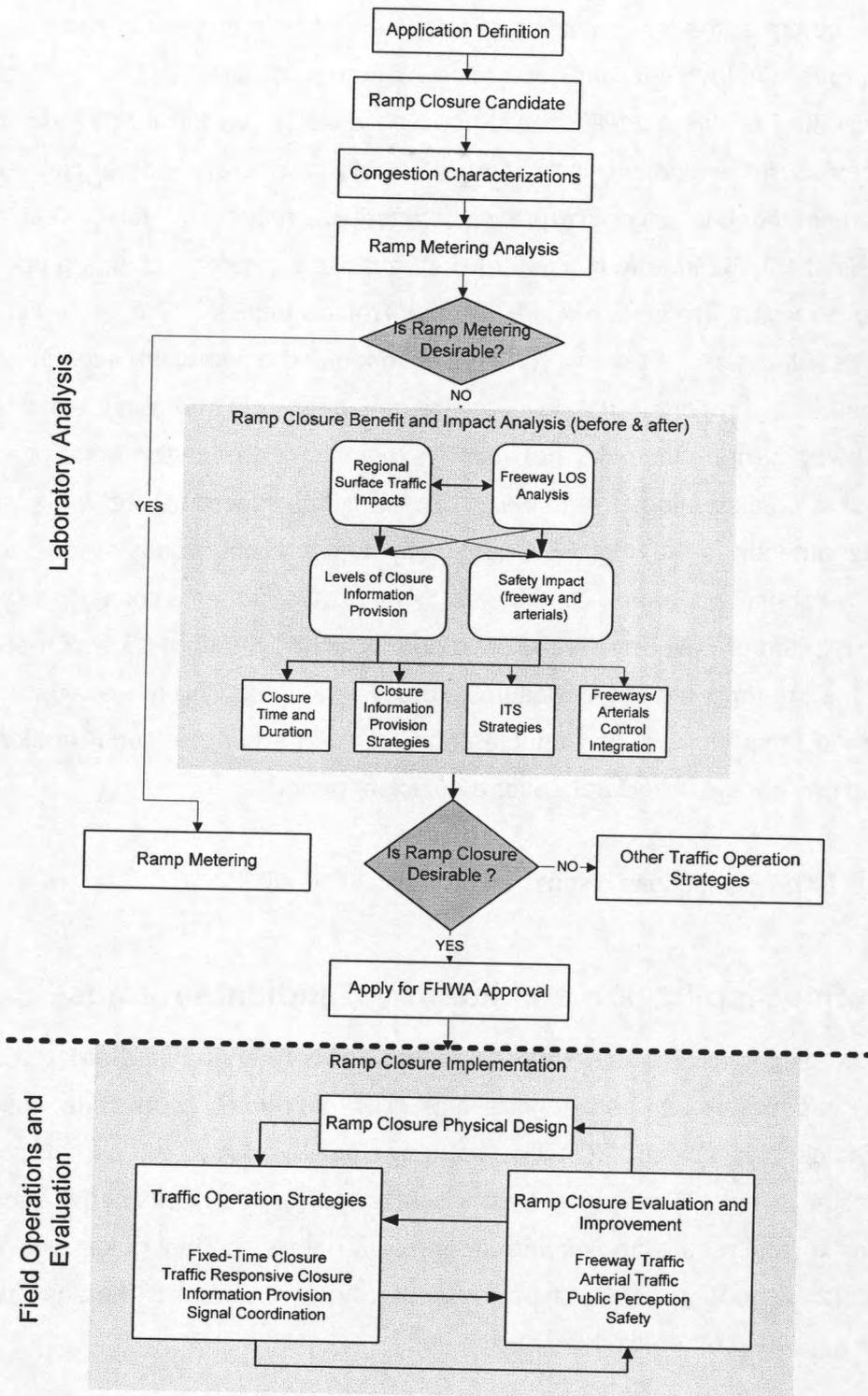


Figure 2-1 Engineering Analysis Procedure for Peak-Period Ramp Closure

The before-and-after evaluation of ramp closure help engineers identify issues and improve deployment and operation of ramp closure. The evaluation plan presented in this guideline encompasses a set of performance indicators to be included in evaluation, procedures for before-and-after data collections, and recommendations for interpreting evaluation results. Here, this guidebook preliminarily defines four types of performance indicators for this purpose. They are “Freeway Traffic Impacts,” “Arterial Traffic Impacts,” “Public Perception,” and “Safety Impacts.” Prevedouros (1999) conducted a two-week experiment of ramp closure, and reported that drivers were generally surprised about the closure. The freeway performance did not reach expectation even after a variety of control device configurations were tried. There is an important and well-documented phenomenon in that motorists constantly adjust driving behavior for a time-period in response to traffic conditions. Any traffic patterns observed before the equilibrium of driver-system interaction is reached may not be well representative of the true impacts of the closure strategy. In conducting the evaluation of peak-period ramp closure, one should consider such a behavior equilibration process, and one should collect data over a sufficient period.

The following sections discuss these steps in details.

## **2.2. Define Application and Identify Candidate Ramps**

According to the Ramp Management and Control Handbook (draft), the application of ramp closure can be categorized as (1) event related (work zone, special event, emergencies/incident), (2) time of day (peak-period closures, off-peak period closure), and (3) recurring (permanent closure). All these applications require similar analyses with varying degree of details. This guidebook addresses primarily the “time of day” type of closure; however, most of the analysis can also be applied to other two type of closures.

## **2.3. Traffic Analysis Tools**

The tools that can be used for analyzing the traffic on both freeways and arterials include, but are not limited to, Highway Capacity Manual (HCM), microscopic simulation models, and simulation and assignment models. These tools have their respective strengths and limitations, and an engineer needs to understand these features in order to select suitable tools.

### **2.3.1. Analytical Approach - Highway Capacity Manual**

The HCM is a national standard primarily for highway planning and design purposes. Aided by the supplementary software (Highway Capacity Software, published by McTran, University of Florida), the HCM approach can be a simple and straightforward approach to analyzing the highway level-of-service (LOS).

Generally, the HCM is composed of the following parts and sections [1]:

Part I: Overview (Chapters 1-6) This part introduces the reader to basic capacity and LOS concepts. It describes the various types of applications, and includes broad-level decision-making tools and guidelines. It also includes a glossary of terms that are used throughout the remainder of the document.

Part II: Concepts (Chapters 7-14) This part includes a discussion of basic capacity parameters for each facility type. It also recommends default values that might be appropriately used in the absence of actual field data, and example service volume tables for use in general planning applications. A detailed discussion is also included of the accuracy and precision that can be expected from each of the analysis procedures described in HCM2000.

Part III: Applications (Chapters 15-27) This part contains the step-by-step procedures recommended for use in evaluating each of the different facility types, including both uninterrupted and interrupted flow facilities.

Part IV: Corridor and Area-wide Analyses (Chapters 28-30) This part includes material that is entirely new to the Highway Capacity Manual. It presents methods for aggregating the results of analyses conducted under Part III into facility, corridor, and/or area-wide assessments. A single level-of-service estimate is not provided in these cases; rather, a number of key performance measures are estimated, the values of which are summarized in a “report card” type of format. This analysis approach is intended to address the emerging need of all transportation professionals to consider system-wide performance characteristics on a more holistic basis. As it is the first attempt to undertake this type of complex analysis, HCM2000 is not yet comprehensive with respect to all elements of the transportation system, and it must also make some initial simplifying assumptions in some cases. Nevertheless, the procedures described in this part constitute a significant advancement in the state of practice.

Part V: Simulation and Other Models (Chapter 31). This final part also includes material that is entirely new to the Highway Capacity Manual. It suggests appropriate applications of simulation models, provides some numerical examples, and includes an extensive reference list.

Chapters that may be needed for analyzing the ramp closure traffic impact include:

- Chapter 20 Two-Lane Highways
- Chapter 21 Multilane Highways
- Chapter 22 Freeway Facilities
- Chapter 23 Basic Freeway Segments
- Chapter 24 Freeway Weaving
- Chapter 25 Ramps and Ramp Junctions
- Chapter 26 Interchange Ramp Terminals

The HCM approach is conceptually highway-element-oriented. Namely, highway facilities are analyzed individually based on facility type and then different methodologies and models are applied to study the performance of highway

facilities under various traffic flow conditions. For example, to analyze the ramp closure, a highway segment in the vicinity of the candidate closed ramp needs to be separated into basic segment, weaving area, ramp junction, etc. Model inputs need to be estimated and then analysis output can be generated. Such an approach implicitly falls short in predicting the interactions between consecutive highway elements, particularly under congested traffic conditions. The HCM2000 provides an aggregated procedure for analyzing the entire highway corridor (in chapters 28-30), but the procedure may not be as robust and straightforward as using a simulation-based approach.

### **2.3.2. *Microscopic Simulation Approach – CORSIM***

The Microscopic simulation approach has been increasingly used for operations analysis purposes. Such an approach is generally sensitive to highway geometric and traffic control configurations. The distinct advantage of simulation is that it captures interactions among vehicles, and between vehicles and highway geometrics and traffic controls, for the entire corridor of interest. The challenge of such an approach is that it needs to be calibrated against local traffic conditions/driver behavior before being used for further analysis.

The Traffic Software Integrated System (TSIS) [2] is a collection of software tools for use by traffic engineers and researchers. Originally built as a simple shell around CORSIM, TSIS has evolved into a sophisticated toolkit. Though used by the FHWA for conducting research, these tools are sold to the public.

CORridor SIMulation (CORSIM) [2] is the comprehensive microscopic traffic simulation model within TSIS. It is applicable to simulation traffic on surface streets, freeways, and integrated networks with a complete selection of control devices (i.e., stop/yield signs, traffic signals, and ramp metering).

CORSIM simulates traffic and traffic control systems using commonly accepted vehicle and driver behavior models. CORSIM combines two of the most widely used traffic simulation models, NETSIM for surface streets, and FRESIM for

freeways. The latest version of CORSIM (Ver. 5.1, released in 2003) has expanded the capabilities of NETSIM and FRESIM in modeling ramp metering, HOV, and vehicle-type-specific turn percentage, which makes it possible for CORSIM to be integrated with other traffic simulation and assignment model like DYNASMART-P and RouteSim to provide hybrid simulation capability.

The advantage of the microscopic simulation approach is that it can simulate vehicle-vehicle, vehicle-roadway, and vehicle-control interaction dynamics in a rather realistic fashion (abnormal driving behavior and traffic flow patterns still exist in each different model under different circumstances). The common disadvantage is that simulation results greatly depend on model inputs, and model inputs in many cases are difficult to estimate accurately, thus making the simulation likely to deviate from actual condition. This issue could be particularly prominent in the traffic analysis for ramp closure. To simulate traffic conditions under the ramp closure scenario, those vehicles which used to traverse through the to-be-closed ramp will be re-routed. Drivers could choose to get on the freeway at upstream or downstream ramps, or even take a very different route without going through highway. Such re-routing (flow re-distribution) affects the entry volumes of ramps/main-lanes, and thus affects the analysis results. Unfortunately, such re-routing is extremely difficult to predict based on simple equation or formula because it is driven by a driver's route choice behavior, and such behavior and resulting traffic is difficult to capture without a more sophisticated model.

There are two possible approaches to address this issue in a meaningful manner. The first is a Monte-Carlo based approach. This approach calls for an extensive number of simulation scenarios (in the order of 20-50, depending on the size of the study corridor) to assign the closed-ramp traffic in a random fashion to other adjacent upstream-ramps, downstream-ramps, and/or main-lanes. The distribution of the closed-ramp traffic could be uniformly random, or in many cases, weighted by engineering judgment. If an engineer has evidence to believe that

more traffic will enter the highway via upstream ramps, these ramps may receive more traffic than downstream ramps.

After creating these flow re-distribution scenarios in the simulation model, the engineer can examine the speed, density, and flow distributions of each highway segment/ramp of interest across all scenarios. If these indicators for a highway segment exhibit a small variation, it means that the traffic pattern and level of service at this segment is insensitive to various flow re-distribution scenarios. One has a higher degree of confidence that the actual level of the service should reside in the range predicted by the simulation model. On the other hand, if a segment exhibits high variation in performance indicators, one needs to examine this segment carefully, and investigate possible mitigation strategies to prevent the occurrence of the worst-case scenarios. An example application of such an approach applied is documented in [3].

Another feasible approach for addressing this issue is the use of a dynamic traffic simulation and assignment model, which intrinsically take into account the traffic flow re-distribution. Such an approach overcomes the limitation of typical microscopic simulation approaches in that it not only simulates traffic, but also captures a driver's possible re-routing behavior due to ramp closure. The principle of such a mechanism is called dynamic/time-dependent user equilibrium. With this approach, an engineer can make a much more accurate estimation of re-distribution of closed-ramp traffic to other highway segments. A representative model of this kind is called DYNASMART-P which is currently under development by the FHWA [4-8]. The next section briefly describes the capabilities and features of DYNASMART-P.

### ***2.3.3. Simulation and Traffic Assignment Approach - DYNASMART-P***

DYNASMART-P is a state-of-the-art dynamic network analysis and evaluation tool conceived and developed at The University of Texas at Austin. The Federal Highway Administration (FHWA) has partially sponsored its development, with Oak Ridge National Laboratory acting as project manager. DYNASMART-P models

the evolution of traffic flows in a traffic network that result from the travel decisions of individual travelers seeking to fulfill a chain of activities at different destinations over a given planning horizon. It overcomes many of the known limitations of static tools used in current practice. These limitations pertain to the types of alternative measures that may be represented and evaluated, and the policy questions that planning agencies are increasingly asked to address. DYNASMART-P allows consideration of an expanded set of such measures compared to both conventional static assignment models and traffic simulation tools. This capability is primarily due to (1) richer representation of traveler behavior decisions than static assignment models, (2) explicit description of traffic processes and their time-varying properties, and (3) more complete representation of the network elements, including signalization and other operational controls.

#### 2.3.3.1. DYNASMART-P Model Features

The modeling features chosen for the implementation of DYNASMART-P achieve a balance between representational detail, computational efficiency, and input data requirements. These features include:

- Micro-simulation of individual trip-maker decisions, particularly route, departure time and mode, including user responses to varying types of information, as well as higher-order activity participation and sequencing decisions.
- Efficient hybrid traffic simulation approach, which moves individual particles (vehicles) according to robust macroscopic traffic flow relations.
- Ability to load individual trips and trip chains with several intervening stops of associated durations.
- Representation of multiple user classes in terms of (1) operational performance (e.g., trucks, buses, passenger cars), (2) information availability and type, and (3) user behavioral rules and responses to information.
- Representation of traffic processes at signalized junctions, under a variety of operational controls.

- Iterative algorithms for computing consistent flow patterns and user decisions (such as time-varying user equilibrium) where applicable.

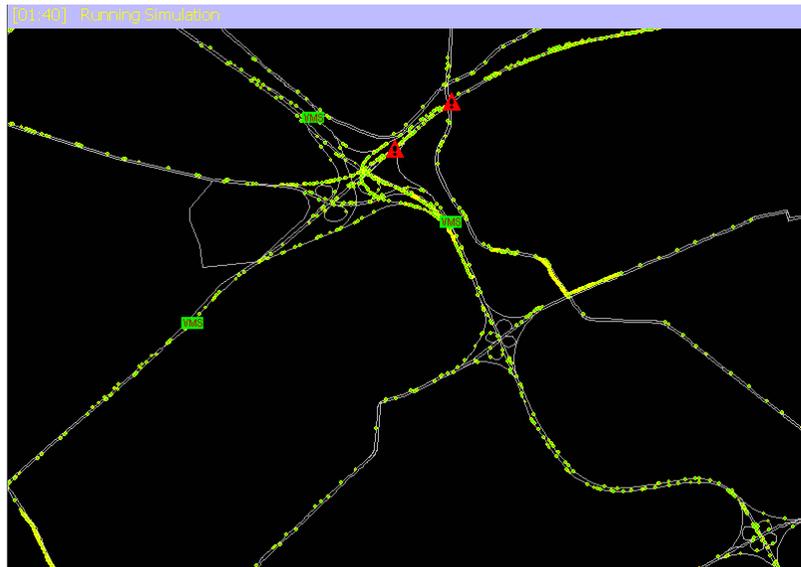
#### 2.3.3.2. Additional Applications of DYNASMART-P

A partial list of the strategic and operational network planning decisions that can be evaluated with the aid of DYNASMART-P includes:

- High-occupancy facilities and special-use lanes and/or facilities (HOV/HOT lanes) in conjunction with variable pricing schemes.
- Evaluation and design of operational strategies, including signal control strategies, coordination schemes along arterials, and path-based coordination schemes (possibly in conjunction with DTA tools).
- Developing ATMS strategies, including Variable Message Sign (VMS) location and information supply strategies, adaptive coordinated ramp metering, and incident management schemes. These are particularly useful for supporting operational planning decisions in conjunction with planned reconstruction activities.
- Congestion pricing schemes that vary with location, time, and prevailing network state.
- In addition to the general applications, DYNASMART-P is also ideally suited for generating traffic assignment in activity-based micro-simulation approaches to travel demand forecasting.



**Figure 2-2 DYNASMART-P Network Visualization**



**Figure 2-3 DYNASMART-P Vehicle Simulation Visualization**

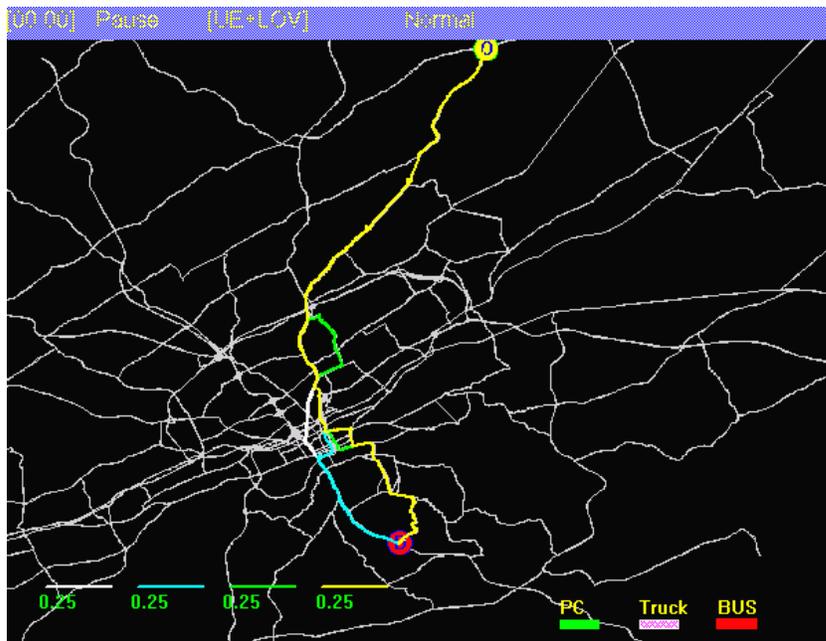


Figure 2-4 Diversion Policy Generation in DYNASMART-P

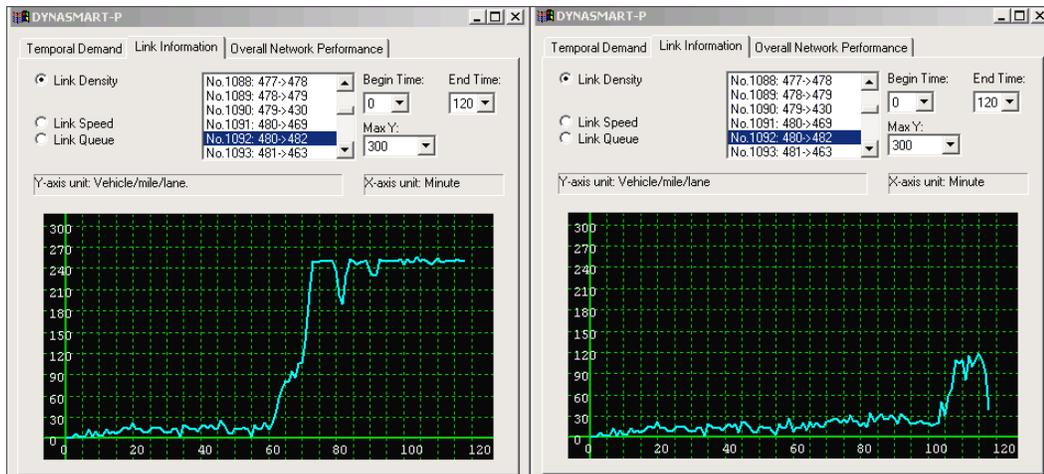


Figure 2-5 DYNASMART-P Link Statistics Comparison between Scenarios

#### 2.3.3.3. Additional Planned Evaluations of DYNASMART-P

A partial list of ongoing deployments planned for the evaluation of DYNASMART-P includes:

- ITS benefits evaluation and deployment planning in several networks (Orange County, California; Austin and Fort Worth, Texas; San Juan, Puerto Rico; Taichung, Taiwan; Beirut, Lebanon)
- HOV/HOT lanes in selected Texas networks
- Traffic management strategies evaluation in work zone areas
- Integrated corridor management in the Fort Worth network
- Strategic evaluation of airport access options for Austin and Dallas/Fort Worth networks
- Air quality conformity analysis, Sacramento network (in collaboration with University of California-Davis)
- Capacity addition in selected links for various networks

**Table 2-1 Comparison of Ramp Closure Modeling Approaches**

|                        | HCM/HCS2000   | Microscopic Simulation   | Simulation/Assignment Model   |
|------------------------|---|--|---|
| Modeling spatial scope | freeway corridor, candidate closed ramp and adjacent arterials/intersections  | freeway corridor, candidate closed ramp and adjacent arterials/intersections                   | A larger area encompasses freeway corridor, candidate closed ramp and adjacent arterials/intersections                          |
| Data requirement       | Traffic volumes, speeds highway geometrics, arterial signal timing plan (optional)  | Traffic volumes, speeds, highway geometrics (detailed), arterial signal timing plan (optional) | Traffic volumes, highway geometrics (detailed), arterial signal timing plan, time-dependent origin/destination data             |
| Time requirement       | 160-250 man-hours*  | 150-350 man-hours  | 250-500 man-hours   |
| Advantage              | Simple and straightforward  | Comprehensive, capture of traffic dynamics at different time period                            | Comprehensive, capture of traffic dynamics on both freeways, arterials at different time period, capture of re-routing behavior |
| Limitation             | Difficult to capture traffic dynamics at different time periods, seems to over-predict speeds at weaving areas, needs additional flow re-distribution procedure to estimate the after-closure scenarios | Needs additional flow re-distribution procedure to estimate the after-closure scenarios        | Relatively data-intensive, potentially time-consuming for inexperienced users   |
| Situations to use      | Under very restricted time and resource limitation, lesser analysis accuracy requirement  | Moderate accuracy requirement and reasonably available man-power and resources                 | High accuracy requirement, and available man-power and resources  |

\*Estimation based on a case study in [3], including initial training for an engineer unfamiliar with this approach

The general advantage of the simulation assignment approach is that it does not require an additional procedure (random closed-ramp traffic distribution) to estimate the possible flow re-distribution to other ramps. The disadvantage is that it requires more data than the other two approaches, particularly for a network that is large in size, and the time-dependent origin/destination matrices. For an inexperienced user, it can take two as much time as using the HCM approach. Given and pros and cons of these approaches, one should choose the most appropriate approaching depending on accuracy requirement and available work force and resources.

## **2.4. Ramp Metering Feasibility Analysis**

All the existing guidelines suggest that ramp metering should be considered prior to considering implementing the ramp closure. In most cases, it is preferable to meter a series of ramps in a freeway section in a coordinated fashion based on criteria that consider the entire freeway section [9]. Considerations such as avoidance of unacceptable spillback from the ramps, limiting ramp waiting time to a value that is acceptable to the motoring community, and surface street congestion resulting from the diverted traffic need to be carefully evaluated. For these reasons, implementing ramp metering at the to-be-closed ramp alone requires additional caution. Situations may exist such that the local ramp meter may not necessarily help improve freeway volume and alleviate congestion. These same situations may also cause excessive delays and queues at the metered ramp and cause various traffic and safety concerns and user disapproval.

It is recommended that the feasibility of ramp metering be evaluated in the simulation environment. Most simulation models (CORSIM, VISSIM, Paramics, etc.) have the capabilities to simulate the effectiveness of ramp metering.

There are a number of factors that may prevent ramp metering from being an effective control scenario, including (1) proximity to arterial intersection, (2) potential spillover, (3) insufficient of storage, (4) lack of acceleration lane, and (5) undesirable congestions at the diverted arterials/intersections. These factors need

to be carefully examined during the analysis. The newly published Highway Management and Operations Handbook [9] provides detailed information about the planning, design, and implementation of ramp-metering. An engineer is encouraged to consult that handbook for further detailed information.



## 3. IMPLEMENTATION CONSIDERATIONS

### 3.1. Crashworthiness

Conducting crash testing on new gate design is a costly and cumbersome process. Therefore this guidebook recommends the usage of gates which have been already crash tested and approved by the FHWA. Examples of such gates are the gates used by Wyoming and Minnesota. For example, the gates used by Minnesota and Chicago are in traffic conditions similar to those of the recommended sites in El Paso and Austin. These gates are placed on ramps exiting/entering high-speed freeway sections. A survey list from interviewed DOT engineers of companies manufacturing such gates includes:

- B&B Electrical – used in Chicago
- Thomtech Engineering Design – Minnesota
- Winter Alpine Engineering Corporation – Wyoming
- Safetran Systems – South Dakota
- Hy-Security Gate systems – South Dakota

### 3.2. Life-Cycle Cost Estimates

The cost of the gate alone is expected to be around \$ 10,000 without labor. Minnesota DOT experienced two accidents in the year of 2002, and the gate arm

was damaged. The cost of integrating the gate with the ITS facility is expected to be around \$60,000 -100,000, varying depending on the scope and level of integration.

### **3.3. Public Awareness**

One of the key steps in the ramp planning and operation closure process is to keep the public well aware of the planning and operation status. Once the candidate closure ramp is ready to be implemented, sufficient publicity has to be provided through mass media. The local press should be involved in the process. Since the local press plays an important role in molding public opinion, significant effort and care should be invested in convincing the local press of the benefits of the system. Local legislative and law-making/enforcing bodies could also be involved in the process. This is desirable because the success of the ramp closure will depend on reducing the number of violators. Publicity also ensures that people who are directly affected by the closure of the ramp are made aware of information like the time of the day during which the ramps are closed and hence can plan their routes accordingly. The public should be made aware of the tangible system benefits that will be obtained from closing the ramps. Care should be taken when making the public aware of the system benefits. If the benefits of the closure are exaggerated when presented to the public, it will lead to disillusionment when the system is in place, leading to negative public perception.

### **3.4. Integrating ITS Technologies**

The ramp closure should also be coordinated with the traffic signals and other ITS devices used for freeway management in the vicinity of the closed ramp. If any ramp metering is done on the other ramps in the vicinity of the closed ramp then care should be taken to ensure that the metered flow volume is high. The ramp meters on the entrances in the immediate vicinity of the closed ramp, must be shut down completely. This is so because, due to the closure of the ramp, the ramp volumes on the other ramps in the vicinity will increase. Excessive metering on the ramps might lead to queue formation on the other ramps thus increasing the delay.

Queues formed can extend to the arterials and the frontage roads, thus leading to significant deterioration of the system performance. The ramp volume on the closed ramp will divert to alternate routes, thus changing the traffic flow pattern on the surface streets. This will result in an increase/decrease in the volumes of various movements in the arterials or the surface streets. Thus the actual green times of the various movements will change and additional green times will have to be provided wherever necessary. The possible paths/route taken by vehicles which would have used the closed ramps must be identified by a simple O-D trip analysis or by using Dynamic Traffic Assignment. The green times must be increased on all such movements. The green times on all possible routes leading to the closed ramp must be decreased.

The information about closure must be displayed on all Dynamic Message Signs in the vicinity of the ramp. Dynamic Message Signs must be placed on all inbound arterials. These signs must be placed at a distance of 1000 feet from the ramp. Dynamic Message Signs must be activated 2-5 minutes before the ramp closure. Warning signs combined with yellow flashing beacons must be placed on all inbound arterials. The beacons must be activated 45-90 seconds before the ramp closure and must be placed at a distance of 100-500 feet from the ramp. Warning signs should contain information about possible fines for all violators. The numbers recommended are obtained by a synthesis of all the studies conducted for ramp closure.

Cameras should be placed on all gates. This facilitates monitoring of the traffic conditions in the vicinity of the ramp. These cameras also aid in identifying errant drivers. They provide video evidence against motorists who crashed into the gates, and discourage these motorists from suing the DOT.



## 4. SYSTEM PERFORMANCE ASSESSMENT AND MONITORING

**A**lthough peak-hour ramp closure is not a usual freeway traffic control practice, it has been shown by this analysis to be a potentially effective strategy when other ramp control strategies like ramp metering are not feasible. Because only limited prior experience has been documented, it is important to perform a thorough before-and-after-closure assessment with particular emphasis on the direct/indirect benefit/cost and safety impact on freeways/arterials. This chapter discusses a general procedure recommended for short-term and long-term performance monitoring and assessment so that the effectiveness of peak-hour ramp closure operation can be constantly maintained.

Three-stage planning and operations tasks are defined for the peak-hour ramp closure implementation. They are discussed as follows.

- **Pre-implementation planning**

Before the peak-hour ramp closure is implemented, efforts need to be made to undertake the following tasks, which include:

(1) Defining performance indicators

Performance indicators can be classified into three groups:

a. Freeway LOS performance

This group of indicators includes average speed, average density, and average flow rate. For the study site, the scope of the assessed highway segment includes the entire freeway segment of interest.

b. Arterial LOS performance

This group of indicators includes average link speed, density, and flow rate, as well as intersection delays at adjacent intersections and arterials that diverted traffic may impact.

c. Safety impact

The Number of accidents on both freeway main lanes and adjacent arterials needs to be collected. The number of gate collisions and close-calls also needs to be collected, documented, and analyzed.

(2) Setting up data collection plan

Data collection will primarily utilize the existing traffic detection system. Data from detectors deployed on both main lanes and on/off ramps on the freeway segment of interest will be collected. Additional supplementary data can be sought through video surveillance or probe vehicles. For example, probe vehicles equipped with a GPS system can be dispatched during the time of interest in order to collect actual speed and travel time information. A video camera to continuously monitor the gate operation during the short-term testing phase is recommended. This is to aid the understanding of the motorists' reaction and behavior before, during, and after the closure.

(3) Collecting traffic and accident data on both freeways and arterials

Once the data collection scope and mechanism are defined, the data collection is recommended to begin at least 1-2 weeks before the scheduled start of ramp closure and continue to the scheduled ending date.

- (4) Inter-connecting traffic control devices and coordinating with other agencies (optional)

If the gate is connected with other control devices (e.g. nearby flashers, dynamic message signs, changeable message signs, and/or intersection signals, etc.), the necessary connections need to be completed at this stage. If the ramp terminal is very close to an arterial/freeway intersection, it is recommended that the signal phasing at that intersection be set to “All Red” phase beginning 5-10 seconds before the gate closure is set in motion until the completion of the gate closure. To ensure that the gate and signals are properly synchronized, an inter-connection between them is recommended. There are several different ways for timing synchronization. Both the DOT and the City need to agree on an inter-connection approach at the pre-implementation planning stage.

- (6) Plan and deploy traffic control devices (i.e., where, when and how to deployed permanent or temporary traffic control devices)

In addition to the gate/intersection signal synchronization, other necessary traffic control devices need to be planned and deployed at this stage. The deployment of traffic control devices follows the recommended traffic control plan, which is briefly described as follows. It is noted that actual deployment of the traffic control plan may vary depending on other practical considerations at the time of deployment.

Flashers with warning messages (and perhaps a lane assignment message with an arrow, such as “Use frontage road when ramp is closed”) are recommended for installation at the entrance of the Paisano ramp. It is

also recommended that at least one additional flasher with warning messages be installed at 150-200 feet<sup>7</sup> before the stop line of each inbound approach. All four flashers are activated at 5-10 seconds prior to the gate closure until the completion of gate closure.

Portable changeable message signs are placed at major inbound approaches at least 500-1000 ft upstream of the intersection. The signs display messages indicating the time of the day of closure. The message signs are recommended to be deployed at least 2 weeks prior to the date of ramp closure deployment.

Ramp closure information (starting date, time of day, etc.) can be displayed on the dynamic message signs along freeway during peak hours, provided the ramp closure information does not preempt other incident/traffic/amber alert type of information. It is recommended that such messages are to be displayed 2 weeks prior to the deployment until a defined date.

The same information can also be displayed on the TMC website (if available) following the same defined time period as used by the dynamic message signs.

#### (7) Notifying the public of the upcoming ramp closure

Public notification mechanisms are recommended to disseminate the ramp closure information to the public prior to the closure. A press release can be sent to major newspapers and/or TV stations to increase public awareness of the ramp closure event.

Also, as shown in Figure 4-1, the pre-implementation planning is recommended to start 1-2 months prior to the deployment – depending on

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<sup>7</sup> Based on 2.5-5.0 second of reaction time at the speed of 30 mph before motorists approach the intersection

the scope of work – to ensure that most likely scenarios and outcomes are anticipated and control measures are provided.

- **Short-term monitoring and evaluation**

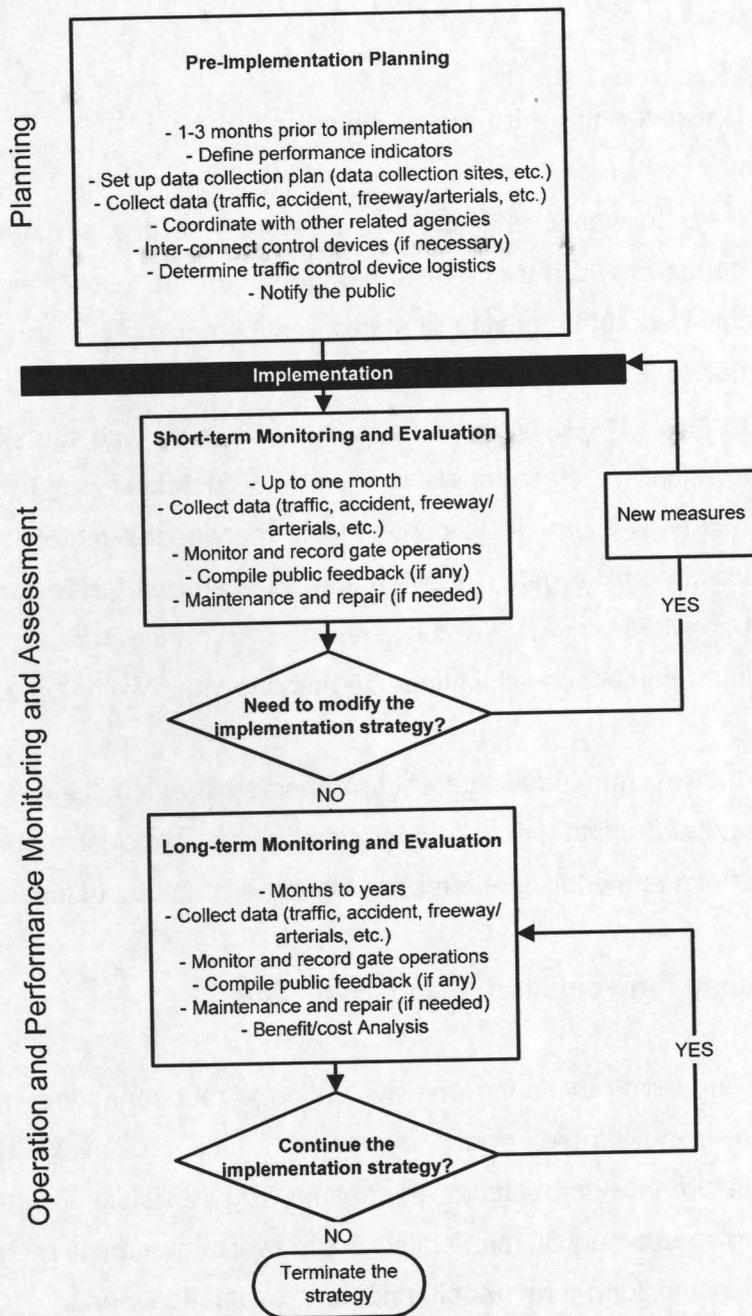
Days to weeks after the closure deployment is perhaps the most critical period in which traffic disturbances on arterials are likely to occur. During this period, motorists will start to encounter the closure on-site (if they are not aware of the closure prior to the closure) and try to adjust to different routes. Traffic patterns on both the freeway and the vicinity of the ramp terminal on the arterials are likely to fluctuate during this period. Effort needs to be made to continuously monitor the motorists' behavior in the vicinity of the gate, to determine if hazardous traffic conditions or driving behaviors arise. At the end of this period, assessment and further improvement decisions may be made to improve the operation.

It is recommended that such a short-term evaluation be performed at the end of the first month of operations so that conclusive observations can be drawn and additional remedial measures can be put in place.

- **Long-term monitoring and evaluation**

Long-term monitoring and evaluation is recommended in order to capture the equilibrated traffic dynamics. As previously discussed, traffic disturbance or motorist adaptations require a significant period to settle down to an equilibrium state. Six to twelve months is recommended as the minimal long-term monitoring and evaluation period. Over this period, TxDOT engineers can more realistically estimate (1) the cost of maintenance or repair of the gate, (2) the increase or decrease in the number of incidents compared to pre-implementation conditions, (3) traffic

condition changes on both freeways and adjacent arterials, (4) public perceptions/opinion.



**Figure 4-1 Framework for Implementation Planning, Performance Monitoring, and Assessment (Short-term and Long-term)**

## 5. CONCLUDING REMARKS

**T**hrough a related study [3], the peak-hour ramp closure has been found to be a low-cost and effective strategy for both freeway main-lane flow control and managing queue-jumping applications.

Ramp metering has been shown not to be effective or feasible when the traffic flow in the downstream of the metered ramp exceeds the capacity. Metering the ramp does not improve the traffic flow conditions. It also imposes excessive queue on the ramp. In the study case, due to the short length of the ramp, the queue spills back to the upstream intersection for a significant period of time. Closing the ramp, equivalent to zero metering rate, is more effective in preventing intersection spillbacks and serves to minimize the violations.

Establishing a suite of traffic control and impact mitigation strategies is the key for a successful implementation of peak-hour ramp closure. These strategies include:

- Synchronizing the adjacent intersection signal to ALL RED in conjunction with the transition to gate closure to prevent collisions at the onset of closure

- Information provision/advance warning is crucial to prevent last-minute diversion and/or confusion at the gate. It also facilitates better traffic diversion further upstream of the closed ramp. Mobile CMS or DMS are recommended for use, particularly during the short-term evaluation period, to promote public awareness of the peak-hour closure.
- Continuous performance assessment and improvement is recommended to ensure consistent and satisfactory operating performance of both the freeways and arterials.

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