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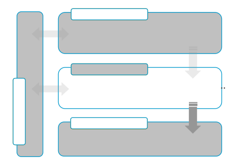
6 DEVELOPING AND SELECTING STRATEGIES AND PLANS



Decision Making

6.1 Chapter Overview

Chapter 6 outlines the next step in the decision-making process for implementing ramp management strategies. This chapter builds upon the high-level discussion of ramp management strategies presented in Chapter 5, by discussing the various issues that agencies should take into consideration when developing and selecting appropriate ramp management strategies. The discussion presented in this chapter feeds directly into Chapter 7 (Implementing Strategies and Plans) and Chapter 8 (Operation and Maintenance of Strategies and Plans), which collectively represent the next logical steps: implementing and managing the ramp management strategies selected in this chapter.

As presented in Chapter 5, several ramp management strategies are available. The key, therefore, is to determine which strategy best addresses a particular problem or situation. Depending on the problem or situation, one or more of the ramp management strategies presented in Chapter 5 may be suitable, but certain strategies may be more beneficial than others. This chapter addresses ramp management strategies with respect to the situations or problems they best address, and the impacts that are likely to result when they are implemented.

Chapter Organization

When developing or selecting a ramp management strategy, individuals responsible for making this decision need to address a series of questions before they determine that one strategy is more suitable than another. These questions include:

- How do I determine that the freeway or corridor will benefit from ramp management strategies?
- What ramp management strategies are best suited for the conditions found?
- How do I implement selected ramp management strategies?
- How do the day-to-day operational procedures of ramp management strategies differ? Can operational procedures be supported?
- How do I ensure that the ramp management strategies continue to be effective once implemented?
- Do I have access to adequate technical expertise to design, implement, operate, and maintain the needed ramp management strategies?
- Can I make an accurate estimate of the financial and personnel resources needed to design, implement, operate, and maintain the ramp management strategies? Do I have the required resources?

To help answer these questions and to guide readers through the process of developing and selecting ramp management strategies, several objectives were established for this chapter. These objectives are outlined below.

Chapter 6 Objectives:

Objective 1:	Determine the need for ramp management strategies, including ramp closure, ramp metering, and special-use and ramp terminal strategies.
Objective 2:	Understand the potential impacts of ramp management strategies on the freeway and adjacent arterials.
Objective 3:	Understand the recommended decision-making process for each ramp management strategy and the benefits of using a structured process.
Objective 4:	Become familiar with the tools available for comparing and selecting ramp management strategies, and the level (i.e., high-level or detailed) at which each is best applied.

6.2 High-Level Screening of Ramp Management Strategies

Ramp management strategies are used to address several traffic-related impacts or problems. Most ramp management strategies address problems related to safety, mobility, or a combination of the two. Other strategies are focused on reducing the impacts associated with certain vehicle classes (e.g., construction vehicles, trucks, etc.) as well as special event traffic. Lastly, ramp management strategies can promote local, regional, or state policies. For instance, strategies may be implemented on ramps to promote the use of transit, encourage carpooling, or provide quicker response for emergency vehicles.

Several ramp management strategies exist, so the process of selecting and developing a strategy that best addresses an existing problem or situation may be a difficult task. As such, it is recommended that the list of acceptable strategies be narrowed before beginning a detailed analysis. In other words, practitioners should begin the process of selecting ramp management strategies by focusing their efforts on narrowing the list of available strategies to those that may be best applied based on existing situations or problems. This will help expedite the selection process and will lead to considerable time savings. After the list of ramp management strategies is narrowed, the impacts of each strategy should be analyzed to make sure that strategies do not result in new problems or shift existing problems from one location to another. Last, but not least, the indicators or warrants that justify a ramp management program and strategies should be analyzed, and the strategies that best satisfy observed indicators should be selected.

Figure 6-1 illustrates a process that may be used to narrow down the list of available ramp management strategies to those that meet an agency's goals, objectives, and policies and can be applied to remedy specific problems and/or situations. After applicable strategies are selected, practitioners may proceed to the section(s) where these strategies are discussed, to determine which of the applicable strategies are most appropriate for the situation or problem at hand. Each major step in the process, as illustrated in Figure 6-1, is described in chronological order in Sections 6.2.1 through 6.2.4.

6.2.1 Assess Transportation Management Policies, Goals, and Objectives

The process of selecting ramp management strategies should begin by revisiting an agency's or region's transportation management program policies, goals, and objectives. Further clarification and understanding of program goals and objectives will help practitioners identify the ramp management strategies that best fit within an agency's transportation management program. A solid understanding of these goals and objectives will also act as the foundation from which strategies can be selected and applied to address existing situations and/or problems.

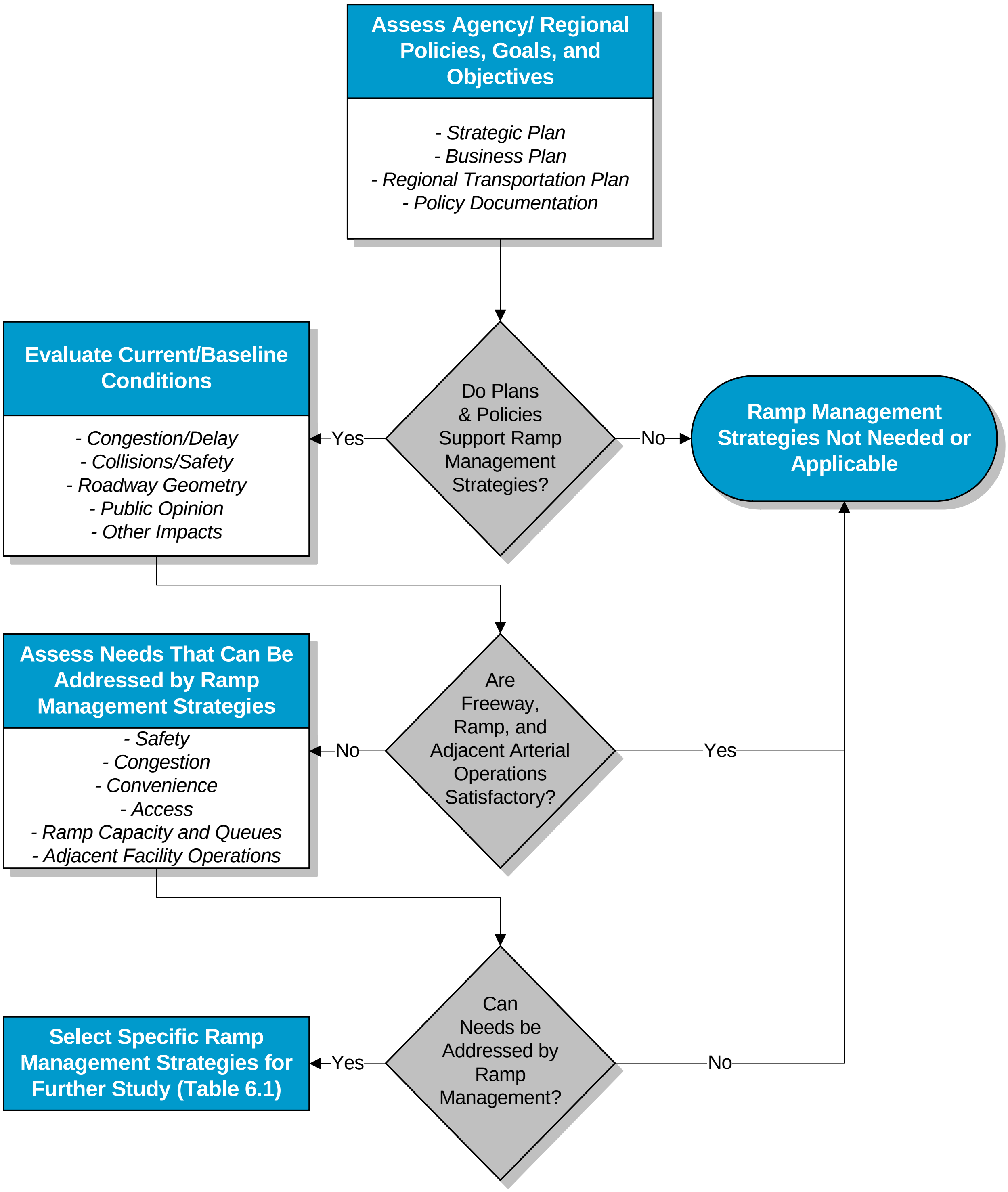


Figure 6-1: High-Level Screening for Ramp Management Strategies

Only the ramp management strategies that support transportation management system policies, goals, and objectives should be considered for implementation. Additionally, ramp management strategies should be viewed as elements of a transportation management program and be applied with other traffic management strategies, where possible, to accomplish transportation management program goals and objectives. This will "promote the efficient and effective movement of people and goods, to improve the safety of the traveling public, and to improve the environment by reducing both the duration and extent of recurring and nonrecurring congestion on the freeway system".[1] For example, a ramp metering program may benefit from adjustments to signal timing and additional lanes on the ramp, as these improvements prevent queues that form at ramp meters from backing up into the adjacent ramp/arterial intersection.

"Only the ramp management strategies that support transportation management system policies, goals, and objectives should be considered for implementation."

Typically, ramp management strategies are used to reduce congestion, reduce collisions, and improve travel time reliability. As a result, improvements to travel speed, travel time, delay, and crash rates are commonly observed.

Although ramp management strategies typically address safety and mobility problems, they may also be used to support local, regional, and state policies. For instance, High-Occupancy Vehicle (HOV) strategies implemented along a ramp can support goals and objectives related to improving transit operations and encouraging multi-occupant modes of transportation (i.e., transit, carpools, and vanpools). HOV strategies give preferential treatment to multi-occupant vehicles, allowing these vehicles to bypass queues that result from vehicles stopped on the ramp or freeway facility.

Revisiting program policies, goals, and objectives is just the first step in the process of identifying, developing, and selecting ramp management strategies. Other considerations, including indicators and impacts of ramp management strategies, must also be taken into account. The latter is discussed in the next section.

6.2.2 Evaluate Current/Baseline Conditions

After revisiting program policies, goals, and objectives and gaining a better understanding for how ramp management strategies fit into the transportation management program, agencies should evaluate current or future-year baseline conditions to determine what problems exist and whether ramp management strategies are appropriate. The fact that a ramp management strategy is feasible and fits into an agency's transportation management program does not necessarily make it appropriate to implement. It is certainly possible that existing conditions do not warrant ramp management strategies or that conditions cannot be adequately addressed through their implementation. Therefore, it is critical that agencies analyze conditions on the ramp, near the ramp freeway merge point, and along adjacent arterials before selecting a ramp management strategy, so the nature of the problem(s) can be more accurately assessed. A more accurate assessment of existing problems will also help determine which strategies are most appropriate if it is deemed that ramp management is appropriate. For instance, ramp management strategies can unintentionally "push" problems from one location to another, despite being implemented properly. Evaluating existing or baseline conditions before strategies are selected will help ensure that the strategies selected are the most appropriate given local conditions and observed problems.

Ramp management strategies should also be considered when performing long-term transportation planning or other long-term transportation investment decisions. For example, a corridor study of a freeway corridor may base the analysis and transportation investment decisions on a 20-year forecast of traffic volumes. This forecast is often referred to as the baseline conditions, with which alternative transportation investments are considered and compared. Understanding the baseline traffic conditions, such as locations of traffic congestion and delays, is important in this step so that ramp management strategies can be considered using the remainder of the decision-making process described in this chapter.

6.2.3 Assess Needs that Can be Addressed by Ramp Management Strategies

Practitioners who consider implementing ramp management strategies should analyze traffic operations on the freeway mainline, ramps, and adjacent arterials. This was done in the previous step of evaluating current or baseline conditions. The next step is to match the identified needs (or problems) with conditions that ramp management strategies are known to help mitigate. If these conditions, referred to as indicators in this handbook, are present in the current or baseline conditions, then ramp management strategies are likely warranted for further study. These indicators, which may warrant ramp management strategies, are discussed in the following subsections.

Safety

High collision rates on freeways or in the vicinity of freeway/ramp merge/weave areas may warrant the implementation of strategies to improve traveler safety. Of particular importance are crashes linked to ramp operations, including rear-end collisions upstream of ramps and at the merge, diverge, and weave areas of ramps. High collision rates at these locations may indicate that freeway operations are being jeopardized by vehicles either entering or exiting the freeway facility. For instance, turbulence from vehicle platoons entering the freeway may cause an unexpected decrease in vehicle speeds at freeway/ramp merge areas, resulting in an increased likelihood of rear-end collisions immediately upstream of the merge area and side-swipe and lane-change collisions at the ramp/freeway merge point. Similarly, vehicles that attempt to exit the freeway facility onto ramps where traffic is queued onto the freeway facility may be forced to stop short of the ramp and wait for queues to clear while waiting on the freeway. This results in a bottleneck situation at the exit ramp, which subsequently creates congestion on the freeway and leads to reductions in safety, especially for traffic in the right lane(s) where vehicles are stopped.

Analysis of recent collision rates, by total collisions and by collision type, should include the entire length of freeway for which ramp management strategies are considered. Results from this analysis can be used to conclude whether collisions are more prevalent at a single ramp or longer section of freeway. Based on this information, the scope of the ramp management program is made more apparent.

Congestion

Collisions or other incidents are some of the principal causes of freeway congestion. Other causes include vehicle queuing on ramps that spill back onto the freeway, bottlenecks, geometric deficiencies including those that limit motorists' ability to smoothly enter the freeway facility, and increases in demand (i.e., entering demand exceeds existing capacity). It is critical that the causes of congestion are known and understood before selecting a ramp management strategy. In some cases, ramp management strategies may not be applicable or less favored when considered side by side with other types of improvements. Specific methods that can be used to pinpoint congestion problems are discussed in the following sections.

Level of Service

Freeway Level of Service (LOS) and freeway speed are good indicators of whether or not ramp metering or other strategies are needed. Low freeway speeds suggest a problem and may in part be due to the fact that traffic from one or more ramps is entering the freeway in platoons. Freeways with LOS D or worse are good candidates for ramp metering or other ramp management strategies. For more information regarding LOS and their respective values, please refer to the Transportation Research Board's Highway Capacity Manual (HCM).[2]

Similar to freeways, ramps with a poor LOS may also be candidates for ramp management strategies. Ramp LOS may be affected by a number of problems, one of which is congestion at the freeway/ramp merge point that occurs as a result of vehicle platoons entering the mainline. Another reason is the lack of available capacity to handle ramp traffic volumes.

Queue Jumping

Bottlenecks often result in a type of driving behavior known as queue jumping. Queue jumping occurs where drivers exit the freeway and re-enter the freeway at a downstream entrance ramp, to avoid freeway queues that result from recurring bottlenecks. Queue jumping is unfair to motorists who remain on the freeway and often moves congestion from one location to another downstream location. In the design phase, it is important to strategically identify entrance ramps that may be subject to queue jumping and design the ramp management strategy accordingly. One way to address queue jumping is to meter the downstream entrance ramp.

Convenience

Ramp management strategies may be used to make traveling more convenient. Ramp management strategies help reduce congestion and travel times, which helps improve motorists' overall driving experience by reducing the amount of delay they experience in traveling to their destination. This also reduces the stress motorists may experience when delayed in traffic. Strategies implemented at ramps may improve conditions so much that motorists may elect to change their driving behavior as once congested links in the network are now uncongested.

Transit and Emergency Vehicle Access

Congested ramps may prevent transit vehicles from arriving at stops as scheduled. Significant delays in transit operations cause rider frustration and may lead to reduced use of transit agency services and investments. This in turn adds to congestion problems as riders seek other less efficient means of transportation. Similarly, congestion on or near ramps may delay emergency vehicle response to and from incidents. As a result, injured persons receive proper treatment in a less timely fashion. In either case, ramp management strategies such as priority treatments and HOV designations may improve transit and emergency vehicle access to ramps and freeways so the public can be better served. In most cases, policies will need to be in place prior to the deployment of these types of treatments.

Ramp Capacity and Queues

Ramp capacity and queues should be taken into account before ramp management strategies are selected. In the case of ramp meters, ramps must have adequate capacity and queue storage for ramp metering to be successful. In Minneapolis, the storage requirement for any given ramp is calculated by taking 10 percent of the pre-metered peak hour volume. Therefore, 70 vehicles is an adequate storage for a ramp with a peak hour volume of 700 vehicles per hour (veh/h). If there is adequate capacity and storage on the ramp, practitioners must then look at queues that form at meters and choose how they wish to manage them. If queues affect operations on the adjacent arterial, it may be an indicator that ramp terminal treatments (e.g., channelization, widening, signal timing, etc.) may be needed to offset impacts that result from metering operations. When possible, efforts should be made to hold traffic to the ramp without having traffic back up onto adjacent arterials. Traffic that backs up onto local arterials may disrupt traffic operations on the arterial and other streets that feed into it.

Adjacent Facility Operations

Facilities adjacent to ramps (i.e., freeways and arterials) should be examined to determine if problems occur at these locations and if operations on the nearby ramps contribute to the problem. Operations on adjacent facilities may be affected by traffic that backs up on the ramp and spills either onto the freeway mainline or adjacent arterials. Therefore, ramp management strategies are typically applied at the ramp terminal to eliminate or minimize the effects of traffic queues at these locations. Possible solutions may include adjusting signal timing, adding capacity to the ramp or adjacent arterial, or adding or modifying pavement markings.

6.2.4 Select Specific Ramp Management Strategies for Further Study

The selection of appropriate ramp management strategies begins with an assessment of the needs that can be addressed through ramp management. Ramp management strategies and approaches may be used to improve existing conditions, reduce the impact of special events adjacent to or near ramp facilities, or give priority to specific vehicle classes (e.g., transit, emergency, construction vehicle, or a combination of the three). If needs such as these exist, further consideration can be given to the implementation of ramp management strategies and approaches.

However, these needs alone do not justify the use of ramp management strategies. Agencies must also take into consideration the fact that although ramp management strategies may provide additional benefits, existing conditions on the freeway, ramp, or arterial may be satisfactory. Considering this, it may be to the public's benefit to instead use funds to improve conditions deemed unsatisfactory. Additionally, agencies considering ramp management strategies may not have the policies in place to support ramp strategy implementation. However, if it appears that operations or conditions on the ramp or nearby freeway or arterial facilities are unsatisfactory and policies are in place, ramp management strategies may be needed and applicable.

Figure 6-1 illustrates the process described above and directs readers to consider certain ramp management strategies based on the specific type of problem (i.e., safety, potential impacts, congestion or policy) that exists. The last step in this diagram (Select Specific Ramp Management Strategies for Further Study) acts as the starting point for considering specific ramp management strategy implementation. The process is shown in the high-level screening matrix in Table 6-1. The ramp management strategies that may be used to address various problems at different locations are indicated by a check mark within the matrix. For example, ramp metering, ramp closure, and special-use treatments may be appropriate for addressing safety-related problems at merge points.

6.3 Selecting Ramp Metering Strategies

Selecting ramp metering strategies is a multi-step process that requires several decisions to be made before strategies can be selected. However, before decisions are made and strategies selected, it is recommended that practitioners be well versed on ramp metering concepts and terminology (see Chapter 5). Practitioners should be aware of the different metering strategies that are available, the geographic limits for which strategies may be applied, the methods for controlling traffic flow at ramp meters, and all other aspects inherent to ramp metering. This will ease the decision-making process and lead to considerable time savings.

As presented in the high-level screening box within Table 6-1, ramp metering strategies may be used to address certain types of safety and congestion-related problems. Ramp metering can also be an effective strategy to offset certain neighborhood-related impacts and impacts that occur as a result of special events or construction activities. Despite these uses, however, ramp metering may not always be an appropriate solution for all conditions. Agencies should consider the effects ramp metering will have on safety and mobility once implemented.

If Table 6-1 indicates that ramp metering may be used to address existing problems or needs, further analysis of ramp metering can be conducted to determine if ramp metering should be selected. A decision tree outlining the steps agencies can follow to analyze and select a ramp metering strategy is shown in Figure 6-2 and Figure 6-3. The remaining discussion in this section describes each step in the decision tree.

Table 6-1: High-Level Screening Matrix

Need/Problem	Location/Reason	Ramp Management Strategies: Ramp Metering	Ramp Closure	Special-Use Treatments	Ramp Terminal Treatments
Safety	Merge Point	✓	✓	✓	
	Ramp Terminal		✓		✓
	Freeway Mainline	✓	✓		
Impacts	Neighborhood	✓	✓	✓	✓
	Construction	✓	✓	✓	✓
	Special Events	✓	✓	✓	✓
Congestion	Freeway Mainline	✓	✓		
	Ramps		✓		✓
	Ramp Terminal		✓		✓
	Arterial		✓		✓
Policy	Transit			✓	
	HOV			✓	
	Freight			✓	

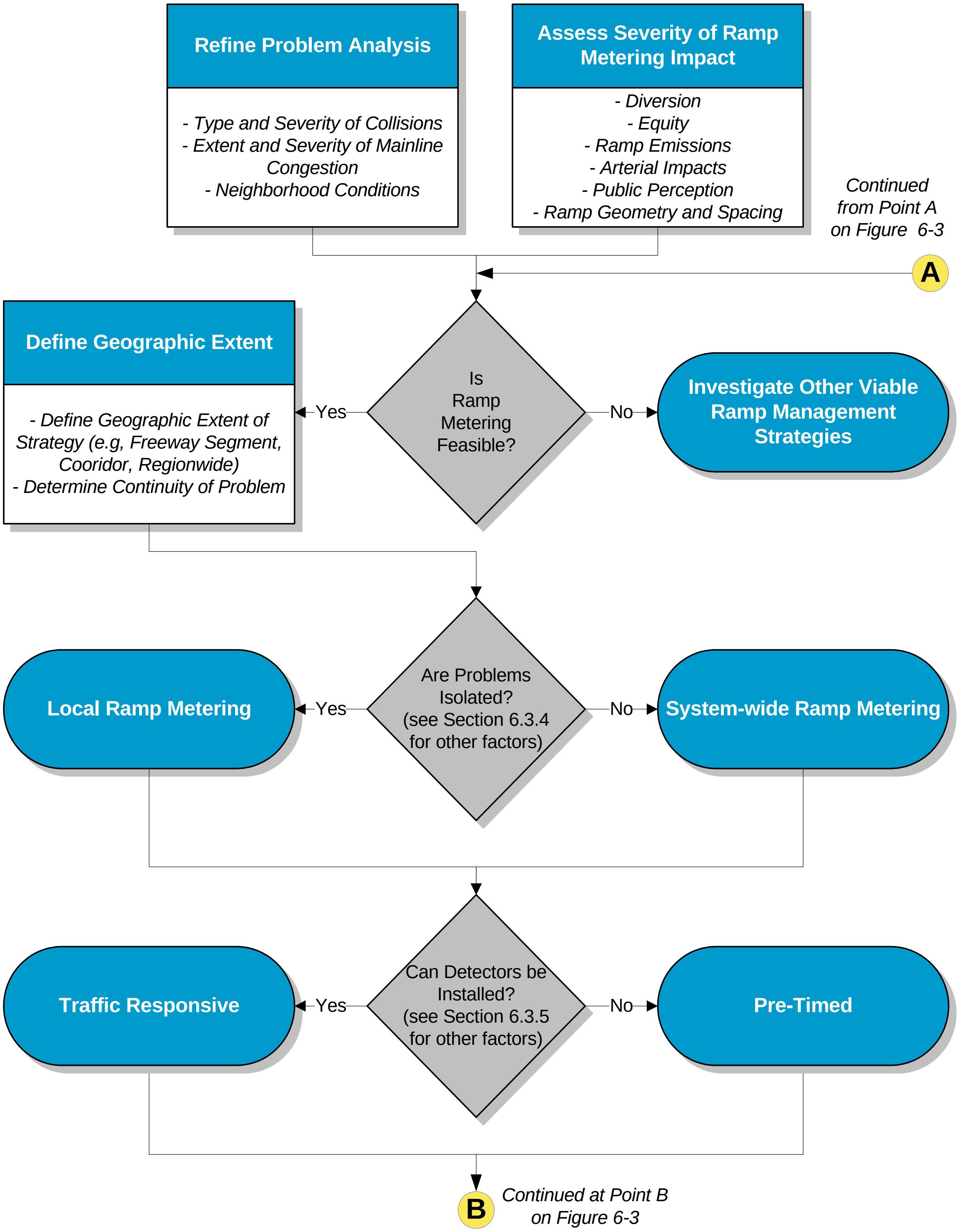


Figure 6-2: Ramp Meter Selection Decision Tree (1 of 2)

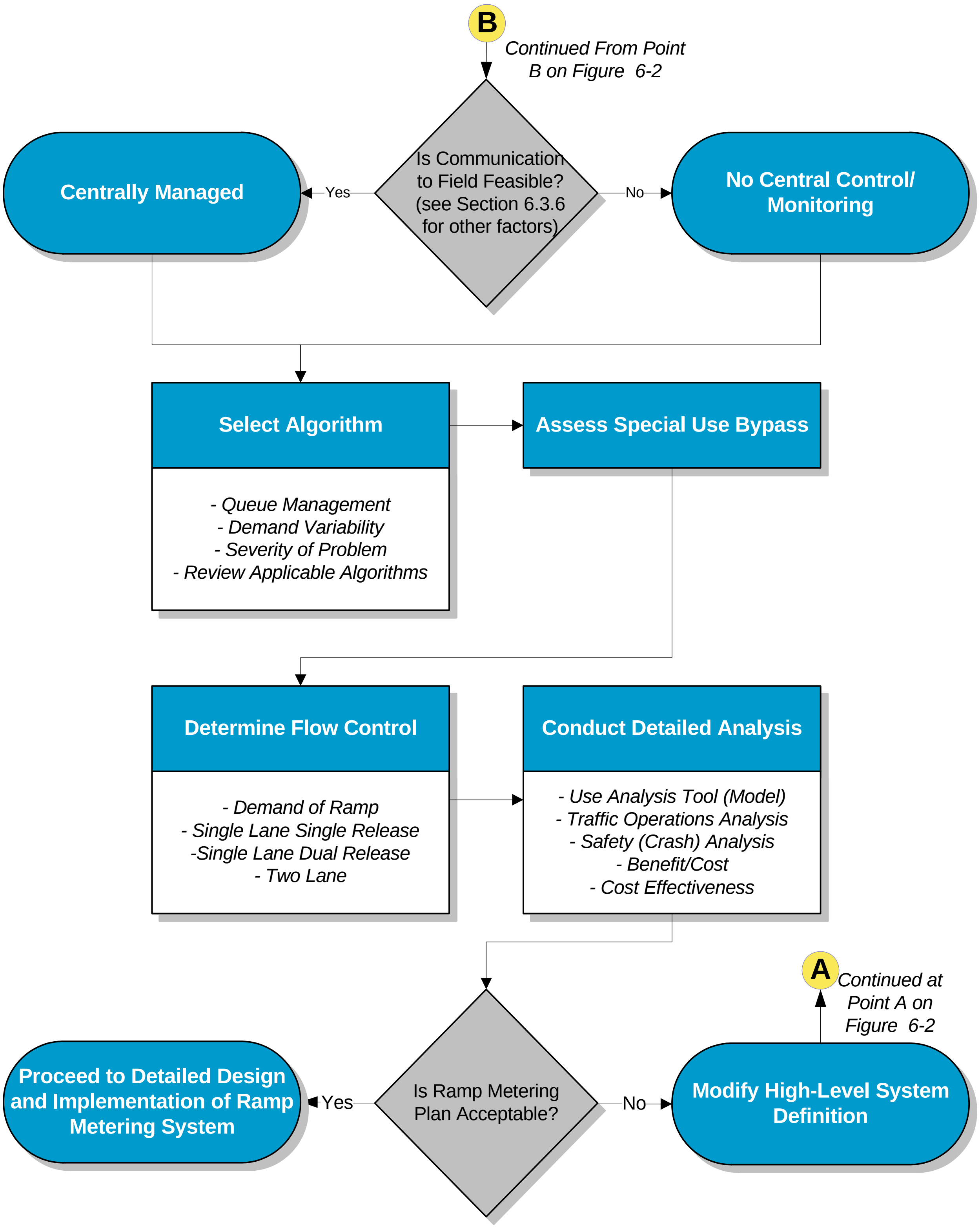


Figure 6-3: Ramp Meter Selection Decision Tree (2 of 2)

6.3.1 Refine Problem Analysis and Assess Severity of Ramp Metering Impact

The selection of ramp metering as a strategy to address freeway-related problems requires a high-level analysis of existing conditions and a thorough assessment of the impacts of metering. Depending on the results of this high-level analysis, ramp metering may or may not be feasible or offer the greatest potential for cost-effective improvement compared to other ramp management strategies. Metering may also result in adverse effects, such as excessive ramp queuing, that may offset expected benefits. As such, ramp metering may or may not be an appropriate strategy to address existing problems or situations.

Refine Problem Analysis

After determining that ramp metering may successfully address existing/baseline problems, the next step in determining the viability of ramp metering is to refine the current understanding of the problem that was previously performed at a high-level (as shown in Figure 6-1). Practitioners should refine the problems to be addressed, including the severity of collisions, congestion problems, and conditions on neighboring surface streets and arterials. An in-depth analysis of existing problems will help develop a solid understanding of the environment in which problems are occurring, allowing practitioners the flexibility to see the “whole picture” not just the most apparent problems that lie at the surface. Practitioners who refine problems before they begin the process of selecting strategies will be comforted by the fact that they have all the information needed to determine if ramp metering is a viable solution to identified problems.

When taking a closer look at existing/baseline problems, practitioners should consider the geographic extent of the problem(s) encountered. This will help determine the extent to which ramp meters should be deployed (i.e., should ramp meters be installed at one, several, or all ramps in a region?), so resources can be expended effectively. In addition, the type and severity of collisions may give some indication as to which specific metering approaches may best rectify the existing safety problem. This information will help practitioners develop and select strategies appropriate to the problems observed.

Assess Severity of Ramp Metering Impact

Practitioners should estimate the impacts that ramp metering will have on the problems identified in the previous step (e.g., congestion, safety, queuing, adjacent arterial and neighborhood conditions, etc.). This evaluation is done at a high-level (or sketch-planning level) at this stage, because the actual ramp metering system has not yet been defined. The purpose at this stage is to merely determine whether ramp metering is feasible. Sketch-planning models such as the ITS Deployment Analysis System (IDAS) can be used to estimate the impacts of ramp metering. If impacts of ramp metering offset the problems being addressed, ramp metering may be appropriate.

Impacts commonly assessed include:

- Change in collision rates.
- Change in freeway flow (volume, speed, travel time).
- Change in arterial flow (volume, progression, speed, travel time).
- Change in ramp volumes.
- Change in ramp queues.
- Travel time reliability/predictability.
- Travel time impacts on long versus short trips.
- Air quality analysis including air quality at individual ramps.
- Environmental justice.
- Public attitude/acceptance.

These impacts may be considered for ongoing performance monitoring, as described in Section 8.4.1.

Traffic analysis models are normally used before implementation to predict the impacts of the strategies on existing traffic patterns and operations. Additionally, "before and after" studies can extend beyond operation to include an assessment of public attitude and acceptance. Through both modeling and in-field measurement and evaluation, the impact of the selected ramp management strategies can be assessed. Chapter 9 covers the application of proper traffic analysis models.

Along with assessing whether ramp metering will help solve the problems identified in the previous step, it is also important to estimate the potential negative impacts of ramp metering. Potential negative impacts could include traffic diversion, equity issues, vehicle emissions on ramps, adjacent arterial impacts, and public perception issues. The following paragraphs discuss each of these potential negative impacts.

Diversion
Implementation of ramp meters may result in a portion of the existing traffic diverting from freeways to arterials. At locations where ramp meters are installed, motorists may elect to bypass queues that form at ramp meters in lieu of arterials that parallel a freeway facility. This is especially true for motorists who take short trips, in which case wait times at meters may exceed the additional travel time spent on slower-speed arterials.

Traffic diversion may or may not be a problem depending on the availability of routes able to carry diverted traffic. If a sufficient number of routes are available, diversion may be a benefit because it makes more efficient use of existing capacity. However, if available routes cannot support traffic diversion, operations on nearby arterials may be negatively affected. This may also cause jurisdictional disputes and conflicts, because ramp and arterial facilities are typically managed by different agencies and one agency's operations may negatively impact another's. In Portland, Oregon, the relationship between ramp meters and diversion was studied. The results are outlined in the following case study.[3]

Case Study: Ramp Metering Diversion (Portland, Oregon)

After ramp meters were installed on I-5 in Portland, traffic volumes on adjacent streets were closely monitored to determine if volumes had increased by more than 25 percent (a pre-determined threshold that was agreed upon by the state and local city officials). If volumes had exceeded this 25 percent threshold, the deployed ramp meters had to be either removed or adjusted to cut the increased volumes to below 25 percent. Observations after ramp meters were installed indicated that the effect of ramp meters on arterial traffic volumes was “not substantial”. In other words, there was little indication that motorists diverted from using ramps to travel on adjacent nearby surface streets.

Equity

The goal of most ramp meter programs is to improve the overall throughput and safety of the freeway facility. However, equity arguments against ramp meter implementations have suggested that ramp meters favor suburban motorists who make longer trips versus those who live within metered zones and make shorter trips. This argument is based on the assumption that the suburban motorist lives outside a metered zone and is not delayed by ramp meters when entering a freeway and traveling through a metered zone. As such, the possibility exists that the motorists who live closer to a downtown area may have proportionally unfair commutes when comparing travel time against travel distance.

Detroit, Atlanta and Seattle have employed different techniques in an effort to minimize the issue of equity. In Detroit and Atlanta, ramp meters were initially operated for the outbound direction to eliminate the city-suburban equity problem. After a period of time operating in this mode, the effectiveness of the system was demonstrated and used to justify the use of meters in both directions. The Seattle system approached the equity issue by implementing more restrictive metering rates farther away from the downtown area.

Emissions on Ramps

Ramp meters smooth the flow of traffic entering freeways so vehicles can merge with freeway traffic with minimal effect on traffic flow. Reductions in vehicle emissions and fuel consumption on the freeway can be attributed to ramp metering, but the reductions are partially offset by increases in emissions and fuel consumption from vehicles waiting on ramps. At metered ramps, vehicles are subject to delays that result in higher emissions than under free-flow ramp conditions.

Arterial Impacts

During periods of high demand, there may not be enough capacity on the ramp to hold traffic waiting at ramp meters. Queues may form that spill into the ramp/arterial intersection, causing unexpected delays on the adjacent arterial. This will obviously affect traffic on the arterial. However, the institutional relationships that govern operations at the ramp/arterial intersection may be affected as well. The mixed jurisdiction over the freeway and arterial may make it more difficult to coordinate ramp meter operations with arterial operations and signal systems.

Public Perception

Without public support, ramp metering may fail or not be implemented at all. Public opposition toward ramp metering usually stems from the fact that delays occur as a result of ramp metering and its associated benefits may not be obvious. For example, a portion of the public may perceive ramp metering as an approach that does not work. This perception can be altered though persistent public communication and involvement. Agencies must be proactive in disseminating information to the public as well as demonstrating the many benefits metering has to offer.

Ramp Geometry and Spacing

Ramp geometry and spacing also affect traffic operations on or near freeway ramps. Ramps with inadequate acceleration or merge distances and major weaves are problems closely tied to ramp geometry and spacing. Others include ramp-to-ramp spacing and sight distances.

- Closely Spaced Ramps - Ramps located less than one mile apart may be a factor in collisions and delay on the freeway. In many instances, ramps that are too closely spaced do not offer the merging distances needed for vehicles to safely enter and exit the freeway at freeway speeds. The lack of available merging distance is made worse because significant speed differences often occur in the merging zones of upstream entrance ramps and downstream exit ramps. Closely spaced ramps are more often a problem in older downtown locations versus newer, suburban locations.
- Inadequate Acceleration Distance - The distance from the ramp meter to the ramp/freeway merge point must be a length sufficient to allow all types of vehicles to adequately accelerate to freeway speeds. If acceleration distances are inadequate, safety along the ramp, freeway or at the freeway/ramp merge point may be jeopardized. First, vehicles entering the freeway at speeds lower than those observed on the mainline may force vehicles approaching the freeway/ramp merge point to slow down or change lanes to allow vehicles from the ramp to enter safely. As a result, rear-end, lane-change, and side-swipe collisions are more likely to occur at locations immediately upstream of the freeway/ramp merge point. In severe cases, slow-moving vehicles entering from a ramp may be forced to wait for gaps in mainline traffic at the freeway/ramp merge point before entering the freeway facility. Severe slowing or stopping to merge may contribute to increases in side-swipe collisions at the freeway/ramp merge point as well as rear-end collisions on the ramp.
- Sight Distance - Sight distances on ramps are often limited by the curvature of the ramp or vegetation located alongside the ramp. Metered ramps with limited sight distance will require advance warning signs posted at strategic points along the ramp to alert motorists that they will need to stop at the ramp meter when it is operating.
- Merge/Weave Operations - Traffic congestion and safety problems (e.g., rear-end and side-wipe collisions) that occur at ramp/freeway merge points may be direct results of platoons entering the freeway from ramps. In these situations, ramp metering can be implemented to break up platoons so vehicles may merge with mainline traffic individually at freeway speeds. Congestion and safety problems may also occur at merge points when ramps are spaced closely together.

6.3.2 Analyze Feasibility of Ramp Metering

Practitioners can use their understanding of existing situations or problems and estimated impacts to determine if the benefits of ramp metering will offset the negative impacts likely to occur after implementation. Practitioners should also compare ramp geometry and spacing issues to determine if it is even possible to implement ramp metering. If ramp geometry and spacing issues are satisfactory and metering benefits are shown to offset impacts, practitioners should continue to analyze ramp metering by comparing it against other appropriate strategies, to come to a final decision on the best strategy or strategies to implement. The analysis should include an assessment of how the ramp metering system is proposed to operate. If ramp metering is not feasible, then the practitioner should investigate other viable ramp management strategies.

6.3.3 Define Geographic Extent

If ramp metering is deemed feasible in the previous step, then practitioners should define the geographic extent of the metering system envisioned. The geographic extent should be based on the problems encountered. Entire freeway corridors are typically considered for ramp metering, but situations may exist where local ramp metering at specific points along a freeway may be more practical. Results of the analysis performed in the previous step should be used in making this determination. Considerations for selecting the geographic extent include:

- Extent of recurring congestion (bottlenecks).
- Extent of safety problems.
- Jurisdictional boundaries.
- Limiting diversions.
- Political/institutional boundaries or issues.

Practitioners should also determine if the problems within the geographic extent are confined to a few spot problems, or if problems extend throughout most of the geographic area defined. Some ramps within the corridor may be considered to operate without ramp metering control, such as during the following conditions:

- Add-Lanes – Ramp meters may not be needed when ramps connect with the freeway at locations where new lanes are added. The added lane may eliminate the immediate need for vehicles leaving the ramp to merge with freeway traffic. However, there may also be reasons to meter these ramps, including the overall volume of traffic entering the freeway and the downstream characteristics of the freeway. Each case should be considered based on the local conditions.
- Inadequate Storage – Ramps with inadequate storage may need to operate without ramp meter control, since meters may cause traffic queues to back up into adjacent ramp/arterial intersections. Practitioners should first consider ways to reduce the demand on the ramp or to accommodate the expected queues. If no practical alternative can be found, the ramp may need to be left unmetered. Care must be given to this decision, because one unmetered ramp in the midst of a metered system may attract more traffic than desired.

- Driver Diversion – Ramps may need to operate without ramp meters if metering results in drivers diverting to nearby arterials that cannot handle the additional volume.
- Political/Institutional Issues – Ramps may need to operate without ramp meters if political or institutional support is not strong enough to acquire the needed funds to implement, operate, and maintain them.

Upon selection of the geographic extent and location of ramp meters, the practitioner should then decide on the ramp metering approach (local or system-wide), as discussed in the next section.

6.3.4 Local versus System-Wide Metering

Following the determination of geographic extent, the practitioner responsible for deploying ramp meters must decide whether meters will operate independently of each other or as an integrated system. This decision is based on several factors, including an assessment of where problems are occurring. The following subsections provide guidance on how to select between local and system-wide ramp metering. The discussion in this section builds off the basic description of these two approaches provided in Chapter 5.

Local Ramp Metering

Sometimes a single ramp or a series of ramps is metered based strictly on conditions adjacent to that ramp, with no consideration given to upstream or downstream conditions. This approach is known as local ramp metering. Local ramp metering is not recommended when congestion extends to some distance upstream of a bottleneck, but some conditions exist where it is appropriate. When considering local ramp metering, certain factors must apply. Typically, local ramp metering is employed when one or more of the following conditions exist:

- Collision experience at the ramp/freeway merge point is the primary problem being addressed.
- Traffic congestion at a spot location can be reduced through metering if no widespread congestion problems occur within the corridor.
- Traffic congestion is predominantly a recurring problem and if there is no history of major incidents or major route diversions.
- Several ramps in a freeway section are to be metered but are separated by a significant distance, or are separated by a number of unmetered entrance ramps or several exit ramps, which results in independent operation of the ramps.

Conversely, local ramp metering should not be used when:

- Safety or congestion problems are continuous or exist at many places within the corridor.
- Problems at a bottleneck are severe enough that metering a single ramp cannot result in acceptable traffic conditions.
- Traffic diversion or redistribution causes freeway congestion at upstream or downstream ramps, or on the freeway mainline sections associated with those ramps.

System-Wide Ramp Metering

System-wide metering addresses more complex problems than local ramp metering. It is normally preferable to meter ramps in a coordinated fashion, thus system-wide metering is often the choice. System-wide ramp metering may be the preferable option where:

- Collision problems are not clustered at isolated locations, but rather extend along a facility or throughout a corridor.
- Multiple bottlenecks/locations of recurring congestion on the freeway are observed.
- Optimization of freeway throughput requires coordinated rates for several ramp meters.
- The situation requires the improved ability to address non-recurring congestion problems.
- Flexibility to address changing conditions over time more rapidly is needed.

When multiple corridors are metered, consideration should be given to metering freeway-to-freeway ramps. Freeway-to-freeway metering aims to improve traffic conditions downstream of major merges. Guidelines for the selection of appropriate sites for freeway-to-freeway metering are listed below.[4]

- Consider locations where recurrent congestion is a problem or where route diversion should be encouraged.
- Consider route diversion only where suitable alternative routes exist.
- Avoid metering twice within a short distance.
- Avoid metering single lane freeway-to-freeway ramps that feed traffic into an add-lane.
- Do not install meters on any freeway-to-freeway ramp unless analysis ensures that mainline flow will be improved so that freeway-to-freeway ramps users are rewarded.
- Install meters on freeway-to-freeway ramps where more than one ramp merges together before feeding onto the mainline, and congestion on the ramp occurs regularly (4 or more times a week during the peak period).
- If traffic queues that impede mainline traffic develop on the upstream mainline because of a freeway-to-freeway ramp meter, then the metering rate should be increased to minimize the queues on the upstream mainline, or additional storage capacity should be provided.
- Freeway-to-freeway ramp meters should be monitored and be controllable by the appropriate traffic management center.
- Whenever possible, install meters at locations on roadways that are level or have a slight downgrade, so that heavy vehicles can easily accelerate. Also, install meters where the sight distance is adequate for drivers approaching the meter to see the queue in time to safely stop.

The considerations differ slightly for high-speed versus lower-speed system merges.

At this point in the process, the practitioner should select a general metering approach of either local or system-wide metering. Once this has been done, then the next logical step is to choose between pre-timed or traffic-responsive metering control, as discussed in the next section.

6.3.5 Pre-Timed Versus Traffic Responsive Metering

In Chapter 5, pre-timed and traffic responsive metering approaches are described, and the advantages and disadvantages of each are outlined. As stated in Chapter 5, pre-timed and traffic responsive metering differ in several aspects, including the methods by which metering rates are determined, flexibility in responding to real-time conditions (especially non-recurring congestion), and implementation costs. Based on each of these criteria, practitioners can gain a sense for which metering approach may be best suited to their needs and unique situations. However, the selection of a pre-timed or traffic responsive metering approach may be based on other factors, most notably of which is the ability to install traffic detectors on the freeway adjacent to the ramp merge area. If traffic detectors cannot be installed, traffic responsive metering cannot be used and therefore pre-timed metering must be selected. For example, it may not be possible to install detectors for budgetary purposes because the system will only be temporary (e.g., work zone project), or there may not be time or funding available to install detectors.

Cost is another factor that may affect the decision of whether pre-timed or traffic responsive metering should be selected. At first glance, it may appear as though traffic responsive metering will have a higher cost, due to the fact that there are more components to install (e.g., loop detectors and communications equipment) and traffic responsive systems have greater complexity. However, these higher capital and maintenance costs are typically offset by operating costs that are lower than the day-to-day monitoring and set-up tasks required with pre-timed meters. The assumption sometimes is that pre-timed meters require little operator oversight because metering rates are fixed. This, however, is not the case. Operators must periodically gauge whether or not pre-timed meters are operating as desired. This requires operators to frequently recalculate or adjust pre-timed metering rates to optimize performance, whereas traffic responsive systems complete this task automatically.

After selecting between pre-timed and traffic responsive metering control, the next logical step is to select the means of communication and control of the ramp meters. This is described in the next section.

6.3.6 Communications and Control

Ideally, all ramp meter controllers would communicate to a central location. However, sometimes communication is not feasible because of the area in which ramps are to be metered or the temporary nature of the ramp metering project (e.g., a special event or work zone). Communications may also be too expensive or take too long to implement for the initial operation of the system. In cases where communication is feasible and cost effective, a centrally managed system should be selected so the operation of the metering system can be monitored and controlled from a central location. This will allow a central algorithm to be used and operators to monitor metering operations and make adjustments to metering parameters in real-time from a central location.

After selecting the means of communications and control, the next logical step is to select the most appropriate ramp metering algorithm. This is described in the next section.

6.3.7 Select Algorithm

Algorithms are used for traffic-responsive systems. Therefore, if meters will be pre-timed, practitioners do not need select appropriate algorithms. Selection of the appropriate metering algorithm depends on answers to several questions, such as "Are problems isolated?" and "Can detectors be installed?". Some of these questions have been discussed previously. Another decision factor includes limiting ramp queues, especially to avoid queue spillback onto adjacent arterials. Based on the answers to these questions, the selection of appropriate algorithms can be narrowed to just a few possibilities. For instance, if problems are isolated and not widespread, one should look at selecting a local traffic-responsive algorithm, versus a system-wide algorithm like the SWARM algorithm. Other factors to consider when selecting metering rates or algorithms include:

- Variability of demand – how much does demand vary over the metering period, from day to day, and from season to season? The more variability, the more flexible and robust the algorithm should be and the more it should take into account direct field measures from detectors.
- Severity and extent of congestion – the more severe the congestion problem and the more congestion extends upstream from the bottleneck, the greater the need for an algorithm that takes into account conditions throughout the corridor.
- Severity and types of safety problems addressed – if freeway mainline rear-end and side-swipe collisions occur throughout the corridor, the greater the need for an algorithm that takes into account conditions throughout the corridor.
- The need to coordinate the arterial street signals with ramp meters to minimize queuing.
- Data requirements to support ramp metering – the type of metering will affect the type and amount of data collected for analyzing the strategy and used as input into an algorithm.
- Freeway and arterial management efforts to support metering.
- The likely extent of ramp queues – the need to manage ramp queues effectively.
- Complexity of algorithm – whether the required technical expertise is available to the agency.
- Previous success of algorithm – whether or not the algorithm has a proven track record of working in other areas with similar issues and conditions. This includes the amount of maintenance required in previous implementations.

Answers to these questions will help further narrow the list of available algorithms to those that are applicable. Refer to Chapter 5 for a description of specific algorithms. The purpose of this discussion is not to provide all the details about a particular algorithm, but rather to provide sufficient detail from which specific algorithms may be chosen. This will reduce the time needed to investigate options and to select an algorithm that is best suited for the agency's specific conditions.

Upon selection of the appropriate metering algorithm, the practitioner will have defined the extent and type of metering system most appropriate for the problems identified and conditions in the field. The next step is to consider whether special-use bypass lanes are appropriate, which is discussed in the next section.

6.3.8 Assess Special-Use Bypass

Agencies considering ramp metering should evaluate the potential for and benefits of special-use (such as HOV) bypass lanes at ramps considered for metering. HOV bypass lanes provide a travel time incentive for multi-occupant vehicles (e.g., transit, carpools, and vanpools). The occupancy requirements of HOV lanes may be adjusted higher in order to lower HOV volumes. A policy decision could be made that every metered ramp must include a special-use bypass or that only specific ramps that meet specific thresholds may include bypasses. Considerations include wait times (ability to reduce target delay), the need to minimize overall queues (will the bypass help reduce queue lengths?), and location of the ramp in special-use corridors.

6.3.9 Determine Flow Control

The method by which vehicles are permitted to enter a freeway facility from a ramp meter location is referred to as the ramp meter flow control. Under normal conditions a single-lane, uncontrolled ramp may have a throughput capacity of 1800 to 2200 veh/h.[5] When flow controls are implemented on the same ramp, the capacity of the ramp is reduced and excess demand above capacity is queued on the ramp.

Chapter 5 provides an in-depth discussion of the available flow controls that may be employed at ramp meter locations. Readers unfamiliar with the types of flow controls should read Chapter 5 before reading further. This section provides a brief overview of the available flow controls presented in Chapter 5 and provides additional discussion and criteria that can be used to select appropriate flow controls.

Three types of controls can be used in conjunction with ramp meters. These controls are described below:

- Single Entry – Permits vehicles to enter the freeway facility one by one, as vehicles are detected.
- Tandem or Two Abreast – Permits two or more vehicles to enter the freeway facility per cycle, side by side in adjacent lanes depending on the number of lanes at the meter (one vehicle per lane per cycle).
- Platoon – Permits two or more vehicles to enter the freeway facility per ramp meter signal cycle, in each lane that is metered (multiple vehicles per lane per cycle).

Selection of appropriate flow controls depends on answers to the following questions:

1) What is the demand on the ramp without a meter?
2) What is the available storage on the ramp?
3) What is the extent of diversion expected after meters are deployed?
4) Does the ramp have enough lateral clearance to accommodate more than one lane?

The demand on the ramp is used to determine the frequency at which vehicles must be released so queues do not back up and flow onto the ramp/arterial intersection. Table 6-2 provides some guidance for initially determining what flow control options may be appropriate for ramps given the pre-metering demand on those ramps.

Table 6-2: Flow Control Options for Ramp Demand Levels

Pre-Metering Ramp Demand (veh/h)	Flow Control Scheme	Number of Lanes
< 1,000	Single Entry	1
900 – 1,200	Platoon	1
1,200 – 1,800	Tandem	2

Note that there are overlapping demand levels for the various flow control schemes presented in Table 6-2. Depending on the likely diversion away from the ramp in question, higher ramp demand could be considered for the flow control schemes shown. Also note that additional ramp lanes could be added, but the reason for additional lanes should be more related to providing additional storage than providing for higher demand. The ramp merge point or even an add-lane on the freeway could not carry much over 1,800 veh/h. Finally, it is possible to combine platoon metering with tandem (or multiple lane) metering.

Storage on the ramp is used to hold traffic waiting at the meter. Practitioners should make every effort to contain vehicles on the ramp so queues do not spill onto and affect operations at the ramp/arterial intersection. If there is little or no available storage on the ramp during peak periods, strategies may need to be implemented to increase storage. Storage on the ramp may be increased by adding additional lanes, either by widening the ramp or restriping lanes. At locations where storage on the ramp cannot be increased, storage lanes may be added to adjacent arterials to hold traffic destined for the freeway via the ramp.

Traffic diversion from freeways onto adjacent arterials is a potential by-product of ramp metering that needs to be carefully considered when analyzing flow controls. Traffic that diverts onto arterials may raise neighborhood issues such as increased traffic, reduced safety, and increased noise levels. Diversion of traffic onto arterials is likely to increase with increases in wait times at ramp meters. Therefore, practitioners should consider ways to reduce wait times at ramp meters so motorists will not view arterial travel more favorably then freeway travel. However, for short trips, vehicles that divert to other roadways may be more of a benefit than a drawback if available roadway capacity will be more fully utilized. This helps to improve traffic flow on the freeway mainline by reducing demand.

Upon selection of the appropriate flow control scheme, the entire ramp metering system will have been defined at a high-level. The practitioner is then ready to conduct a more detailed analysis, as discussed in the next section, to help decision makers make a "go/no-go" decision on whether to proceed with design and implementation of the selected metering system.

6.3.10 Conduct Detailed Analysis

Now that a specific ramp metering plan has been selected, it is important to conduct a detailed traffic operations analysis (to assess the benefits and negative impacts), a safety (crash) analysis, a cost analysis (capital, operating, and maintenance costs), and a benefit/cost or cost-effectiveness analysis to determine if it is worth implementing this particular strategy. The traffic operations analysis undertaken at this point should be more thorough than the one completed earlier in the refine problem analysis step. At this stage, all impacts should be identified and understood to a degree that a decision can be made on whether ramp meters should be implemented. If the impacts of ramp metering are offset by the severity of the problem, metering may be considered. The tools discussed in Section 6.7 may be used to better gauge the expected benefits and impacts of metering. These tools can also be used to determine if the benefits ramp meters will offset their costs.

6.3.11 Implementation Decision

This is the final step in the ramp meter decision process, where a final "go/no-go" decision is made to pursue the ramp metering plan. This decision is typically made by upper management or other decision makers and not by the practitioner(s) performing the detailed analysis. However, the detailed analysis should feed into the final decision. In addition to the detailed analysis, the decision makers could also consider the political impacts, risks of public rejection, funding considerations, or other potential risks to the plan. In the end, decision makers will decide on one of the following outcomes:

- Embrace the proposed ramp metering plan, in which case the next step is to pursue the detailed design and implementation of the plan.
- Modify the plan by feeding back to the beginning of the process and considering an alternate geographic extent or entire system altogether.
- Reject ramp metering altogether and pursue other viable ramp management strategies.

Section 6.7 discusses tools that can be used to support making a decision as to whether or not to implement ramp meters. Practitioners should embrace these tools and use them to assess the likely impacts of ramp metering. If all or some impacts are not acceptable, practitioners may wish to modify decisions made in previous steps, mitigate impacts, or investigate other ramp management strategies.

6.4 Selecting Ramp Closure Strategies

Ramp closure may be a viable solution for safety and congestion problems and to mitigate impacts associated with neighborhood impacts, construction activities, and special events. Ramps should be considered for closure only when closing them does not present a more severe problem than currently exists. If existing conditions are more severe than the impacts associated with closing the ramp, operations should be analyzed to determine if ramps should be closed by time-of-day, permanently, or temporarily when events occur. Regardless of which type of closure is selected, the selected strategy should be analyzed in greater depth to determine the specific effects or impacts of the strategy selected. If the benefits of the selected strategy offset the impacts of the problem and no other options are available, ramps may be considered for closure. However, if the benefits of the selected strategy do not offset the problem, other ramp management strategies should be analyzed to resolve the problem. A decision tree outlining the steps agencies can follow to analyze and select a ramp closure strategy is shown in Figure 6-4. Before following the steps provided in Figure 6-4, the type and location of the selected problems should be analyzed to determine if ramp closure is a potential solution. Table 6-3 provides a matrix that maps the three different types of ramp closures to specific needs or problems.

6.4.1 Refine Problem Analysis and Assess Severity of Ramp Closure Impact

To determine if ramp closure is practical, a high-level assessment should be first made to determine if the benefits of ramp closure offset its negative impacts. This assessment should include the following actions:

- Refine the problems to be addressed, including the severity of collision and congestion problems and conditions on surrounding surface streets and arterials. Refer to Section 6.3.1 for a more detailed description on performing a refined problem analysis.
- Determine if there are any special vehicle classes that have critical access needs that may prevent ramps from being closed, or vehicle classes that are a significant cause of the observed problems on or near the ramp.
- Assess the positive and negative impacts that are likely to arise from closing the ramp (i.e., neighborhood, safety, congestion and mobility impacts). To perform a high-level assessment, a sketch-planning tool or macroscopic traffic analysis model may be used to assess changes in congestion, safety, traffic diversion, or other impacts.

If the negative impacts of ramp closure are less than the existing safety/congestion problem, the next step is to conduct an operational analysis to determine the extent to which ramp closure should be considered. If the high-level problem assessment indicates that ramp closure impacts outweigh existing impacts and the benefits of this strategy do not offset them, then other viable ramp management strategies should be considered.

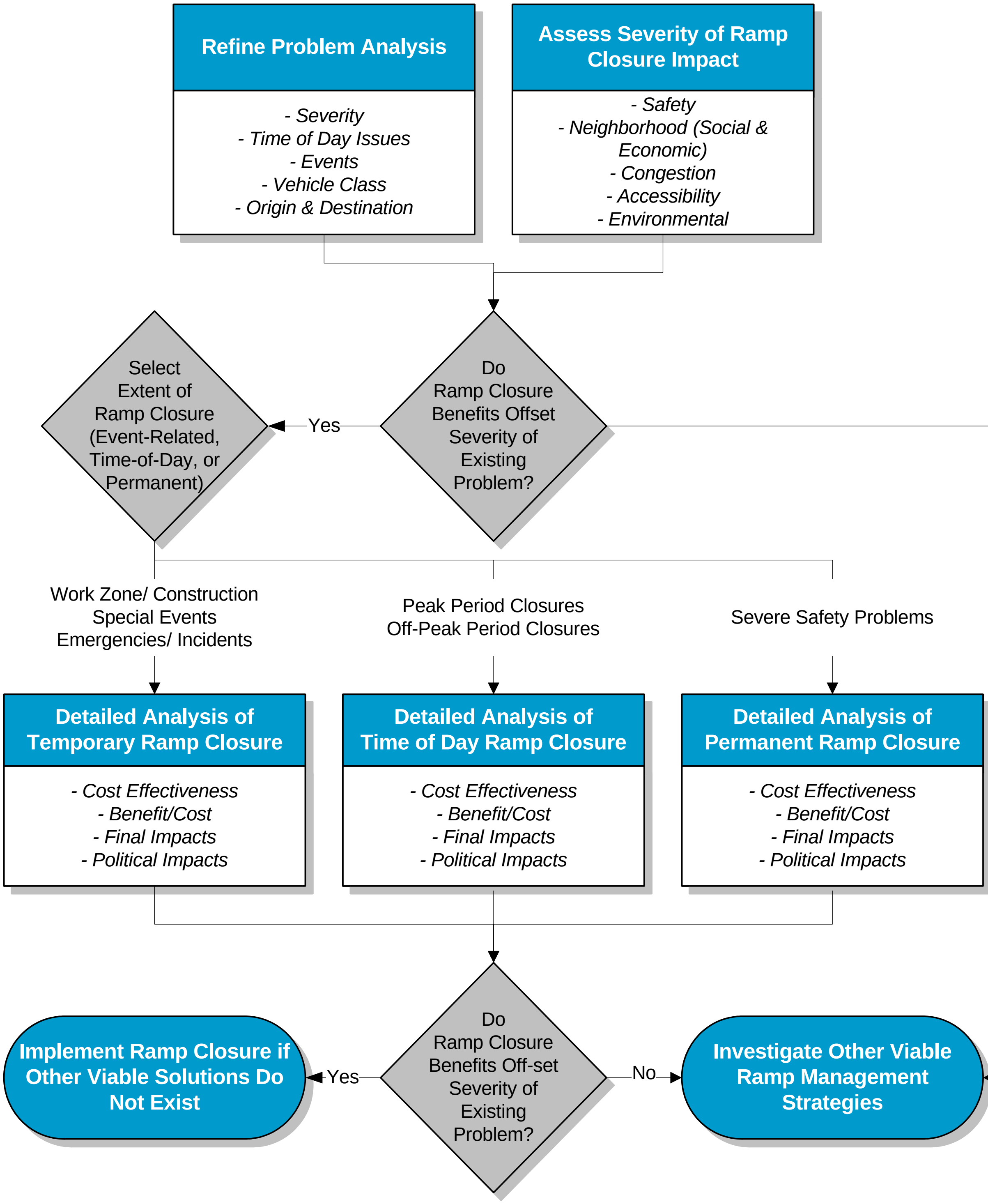


Figure 6-4: Ramp Closure Decision Tree

Table 6-3: Ramp Closure High-Level Screening Matrix

Need/Problem	Location/Reason	Type of Closure
Safety	Merge Point	Time-of-Day, Permanent
	Ramp Terminal	Time-of-Day, Permanent
	Freeway Mainline	Time-of-Day, Permanent
Impacts	Neighborhood	Time-of-Day, Permanent
	Construction	Temporary
	Special Events	Temporary
Congestion	Freeway Mainline	Time-of-Day
	Ramps	Time-of-Day
	Ramp Terminal	Time-of-Day
	Arterial	Time-of-Day
Policy	Transit	Time-of-Day, Permanent
	HOV	Time-of-Day, Permanent
	Freight	Time-of-Day, Permanent

6.4.2 Ramp Closure Extent

Depending on the type of ramp closure being considered, practitioners need to take into account other considerations that may negatively affect the viability of ramp closure strategies. First, the impacts of diverted traffic need to be assessed to determine if there is enough capacity on alternate routes to service diverted traffic. If not, practitioners need to determine if capacity improvements or operational enhancements can be implemented on these routes to provide the needed capacity. Similarly, practitioners need to consider if there are any special circumstances that prevent a ramp from being closed. For instance, it may not be feasible to close a freeway exit ramp, even if there is a safety problem, if the stretch of freeway immediately downstream of the ramp is susceptible to recurring severe incidents and there is no other exit ramp nearby to provide additional routing. The ramp in this case must remain open so motorists can exit the freeway and re-enter it at a location downstream of the location where incidents occur. The impacts to businesses and event venues near closed ramps should also be considered. Public education campaigns may mitigate the impact of ramp closure on local businesses.

In situations where ramp closure is deemed practical and beneficial, the extent of ramp closure needs to be determined so as not to close ramps when situations do not warrant it. Depending on when problems occur, ramp closure may be:

- Temporary (event-related).
- Permanent.
- Based on time of day.

Each of these closures is discussed in greater detail below.

Detailed Analysis of Temporary Ramp Closure

Ramps may be closed on a temporary or event-related basis to improve safety or mobility during special events or when construction activities are scheduled. Special event closures intentionally divert traffic from entrance or exit ramps and arterial streets that cannot handle the traffic volumes associated with the special event to ramps and arterials that can. Special event-related ramp closures should be part of an overall special event Traffic Management Plan.

Besides special events, temporary ramp closures may be implemented to provide a safer incident scene for responders and victims when collisions occur on or near ramps.

Ramps may also be closed on a temporary basis to facilitate construction or maintenance work zones. For instance, ramps adjacent to construction zones may experience high traffic volumes that must enter the freeway on a substandard taper because of the location of the work zone. The safety impacts of keeping an entrance ramp open in such a situation may well offset the impacts of closing the ramp. When impacts are severe, ramps adjacent to construction zones may be temporarily closed. Ramps may be closed to all vehicles, or all vehicles except construction vehicles. Additionally, ramps may be closed at certain times of day (most likely at night when traffic volumes are minimal), during certain phases of a construction project or for the entire length of the construction project. Construction or maintenance-related ramp closures should be part of the overall work zone/construction Traffic Management Plan.

Case Study: Wisconsin DOT Temporary Ramp Closure Procedure for Construction Activities.

The Wisconsin DOT has developed an approach for temporarily closing entrance and exit ramps when needed to support freeway mainline construction activities. The intent of this approach is to reduce the demand through the work zone (i.e., reach an acceptable freeway queue length and delay) in an overall effort to improve safety. The approach begins by analyzing peak-period entrance ramp closures to determine if closures during the peak period are capable of reducing freeway mainline volumes. If queue lengths and vehicle delays are acceptable, then the peak period entrance ramp closure is implemented. If queue lengths and delays are not acceptable, then full-time ramp closures are analyzed to see if additional volume reductions are sufficient. If reductions from full entrance ramp closures are still not acceptable and a downstream high volume exit exists, then this process is repeated for exit ramps. In severe cases, when entrance and/or exit ramp closures do not produce acceptable queue lengths and delay times, staff may consider implementing freeway-to-freeway ramp closures. However, this is only permissible when the impacts of closures are analyzed and deemed acceptable.

Detailed Analysis of Time-of-Day Ramp Closure

Time-of-day ramp closure is often used when the impacts are limited to certain hours of the day. Impacts could be severe enough that closing the ramp is only acceptable when ramp volumes are relatively low (leading to off-peak closures) or because ramp volumes are high enough to create problems when volumes are very high (leading to peak closures).

Under rare circumstances, ramp closure may be used during peak hours of the day when traffic conditions and ramp geometrics combine to cause severe safety or congestion problems, when these problems do not arise during other times, and/or when no other options are available to correct the problems and there is a compelling reason to allow the ramp to be open during the other hours of the day. A case study of Toronto's experience with time-of-day closure is highlighted below.[6]

Case Study: Toronto's Time-of-Day Ramp Closure

In the early 1970s, the City of Toronto implemented time-of-day ramp closures at two entrance ramps in response to a high rate of crashes and congestion observed at these locations. Both ramps were located adjacent to Toronto's Gardiner Expressway, a downtown urban expressway with a speed limit of 90 km/h (55mi/h).

The westbound ramp from Lake Shore Boulevard (at Jameson Avenue) had several geometric deficiencies, including a short acceleration lane and steep downgrade. The ramp also ended in a large concrete bridge abutment, which was believed to contribute to the safety problem at this location. To remedy the severe safety problem, the westbound ramp from Lake Shore Boulevard was closed from 4:00 to 6:00 PM, Monday through Friday. This helped to stabilize traffic flow entering the expressway from the westbound on-ramp.

The other time-of-day ramp closure in Toronto is on the eastbound on-ramp from Lake Shore Boulevard (at Jameson Avenue). Similar to its westbound counterpart, the problems here were in part directly related to the influx of vehicles entering the mainline from the on-ramp. However, unlike the geometric deficiencies observed at the westbound on-ramp, problems here were primarily related to the lack of capacity on the mainline and the mainline's inability to accept heavy traffic volumes originating from the ramp. From the hours of 7:00 to 9:00 AM, approximately 1,400 vehicles were entering the mainline via the eastbound on-ramp. This fact, combined with the fact that the mainline was already operating at capacity, prompted officials to close the ramp. By doing so, it was anticipated that turbulence and congestion on the mainline would be reduced and existing capacity on Lake Shore Boulevard would be more efficiently used. The results showed that traffic flow on the mainline did improve because of the eastbound on-ramp closure.

Ramp closure can be used for either on- or off-ramps, and is typically used at locations with high collision rates, or in response to severe local or neighborhood traffic-related problems.

Detailed Analysis of Permanent Ramp Closure

Permanent ramp closures should only be considered for severe safety problems that cannot be addressed by other ramp management strategies. For example, permanent ramp closures may be a viable option for ramps where a severe safety problem exists, either on the ramp itself or on the freeway mainline at the ramp merge area, and where ramp metering is not a viable option due to inadequate queue storage on the ramp. However, before the decision is made to permanently close a ramp, consideration should be given to public reaction, impacts on neighborhood traffic patterns, and impacts on surrounding businesses and land use.

6.4.3 Conduct Detailed Analysis

This step is similar to the high-level feasibility and impact analysis completed earlier. However, this analysis is carried out to a greater level of detail. It is important to conduct a detailed traffic operations analysis as well as a safety (crash) analysis, cost analysis (capital, operating, and maintenance costs), and then a benefit/cost or cost effectiveness analysis. This will help identify and understand all the impacts associated with ramp closure, which in turn will ease the decision-making process when determining whether or not to close a ramp.

If the impacts of ramp closure are offset by the severity of the problem, closures may be considered. Before implementing a closure, however, other ramp management strategies should be considered. If no other strategies can offset the severity of the observed problems, ramp closure may be implemented. On the other hand, if ramp closure benefits cannot offset the severity of the problem, closure should not be considered and other viable solutions should be considered.

6.4.4 Implementation Decision

This is the final step in the ramp closure decision process where a final “go/no-go” decision is made to pursue the ramp closure. If the results of detailed analysis indicate that ramp closure is a viable solution to the identified problem, closure may be implemented. If ramp closure does not help to offset the severity of existing problems, then other viable strategies should be considered.

Specific implementation issues are discussed in Chapter 7. Among the most important ramp closure issues is how to physically close the ramp (barricades, cones, etc.). The safety of personnel closing the ramp and the cost required to implement and maintain ramp closures should be primary concerns in deciding on the method to implement ramp closures.

6.5 Selecting Special-Use Ramp Treatments

In addition to ramp metering and/or ramp closure, special circumstances may arise in which additional measures are needed to manage traffic on or near freeway ramps. Special-use ramp management strategies can be used in conjunction with, or independently of, other ramp management strategies to help mitigate traffic-related problems occurring on or near ramps. Selecting a particular strategy depends on the type of problem (i.e., whether on not the problem is related to safety, neighborhood impacts, congestion, or policy). For this purpose, Table 6-4 provides a high-level screening matrix that maps specific special-use ramp treatments to specific problems based on their type and location. This table allows a practitioner to select specific special-use ramp treatments for further study based on the specific problems that exist, or are forecast to exist, in their region.

As Table 6-4 shows, the reader is referred to Figures 6-5 through 6-9 depending on the type and location of the problem(s). These figures present decision trees for further analyzing and selecting specific special-use treatments:

- Figure 6-5 – selecting special-use treatments that target safety impacts at merge points.
- Figure 6-6 – selecting special-use treatments that target neighborhood impacts.
- Figure 6-7 – selecting special-use treatments that target construction impacts.
- Figure 6-8 – selecting special-use treatments that target special event-related impacts.
- Figure 6-9 – selecting special-use treatments that target policies.

Table 6-4: Special-Use Treatments High-Level Screening Matrix

Need/Problem	Location/Reason	Special-Use Treatments
Safety	Merge Point	Figure 6-5
	Ramp Terminal	NA*
	Freeway Mainline	NA*
Impacts	Neighborhood	Figure 6-6
	Construction	Figure 6-7
	Special Events	Figure 6-8
Congestion	Freeway Mainline	NA*
	Ramps	NA*
	Ramp Terminal	NA*
	Arterial	NA*
Policy	Transit	Figure 6-9
	HOV	Figure 6-9
	Freight	Figure 6-9

*NA – Not Applicable

Applying each of these decision trees to select appropriate special-use ramp treatments is explained in the remainder of Section 6.5.

6.5.1 Special-Use Treatments for Safety Problems

Poor geometry on or near the ramp can contribute to safety problems, especially in the ramp/freeway merge area. If geometric problems do exist, the first step would be to try to fix these problems. In some cases this may be too expensive or not physically possible, thus special-use treatments such as truck restrictions should be considered.

Special-use treatments that address safety problems typically focus on efforts that restrict certain classes of vehicles such as trucks, construction vehicles, or other slow-moving vehicles from ramps. For example, if the acceleration lane taper on a freeway merge is not sufficient, slow-moving vehicles and/or trucks may not be able to accelerate to freeway speeds in time to merge smoothly. When this situation is exacerbated by poor sight distance on the mainline or a severe uphill grade on the ramp, a safety problem will likely result that can potentially be addressed through truck restrictions. Also, if the geometrics on the ramp, such as a sharp curve with insufficient superelevation, make it difficult for trucks, over-height, or wide loads to negotiate the ramp safely, restrictions should also be considered.

The decision-making process for addressing safety problems at a freeway/ramp merge area through special-use treatments is illustrated in Figure 6-5. The first two steps in determining whether truck restrictions or other special-use treatments can be used to address safety problems on a ramp are: 1) refine the problem analysis to better understand existing problems and 2) assess the severity of special-use impact. These two steps should be completed simultaneously, because inputs from each are needed before additional decisions can be made.

Safety problems on or near ramps should be analyzed to determine when problems occur, if problems are attributed to geometric deficiencies, and if vehicle mix, speeds, and/or volumes contribute to the problem. For example, if roadway geometry is not a contributing factor to the safety problem, then truck restrictions will not help and therefore are not appropriate. Truck restrictions in this case will not provide justifiable benefits and will only push problems to other local ramps.

On the other hand, if roadway geometry contributes to the problem, truck restrictions on the ramp may improve safety at the merge point or at the location on the ramp with the geometry deficiency. The extent to which trucks should be restricted depends on further analysis of the safety problem and whether or not the problem exists all day or if it occurs only at certain times within the day. Depending on the results of this analysis and based on whether or not geometrics contribute to the problem, truck restrictions may be implemented at certain times of the day rather than on a permanent basis. In either case, a final analysis of truck restrictions should be completed to determine if it is beneficial to implement a restriction based on cost effectiveness or benefit/cost analyses, potential political impacts, and budgetary considerations. Once a detailed analysis is complete, decision makers can use the results of this analysis to determine whether to proceed with truck restrictions or to analyze other viable ramp management strategies.

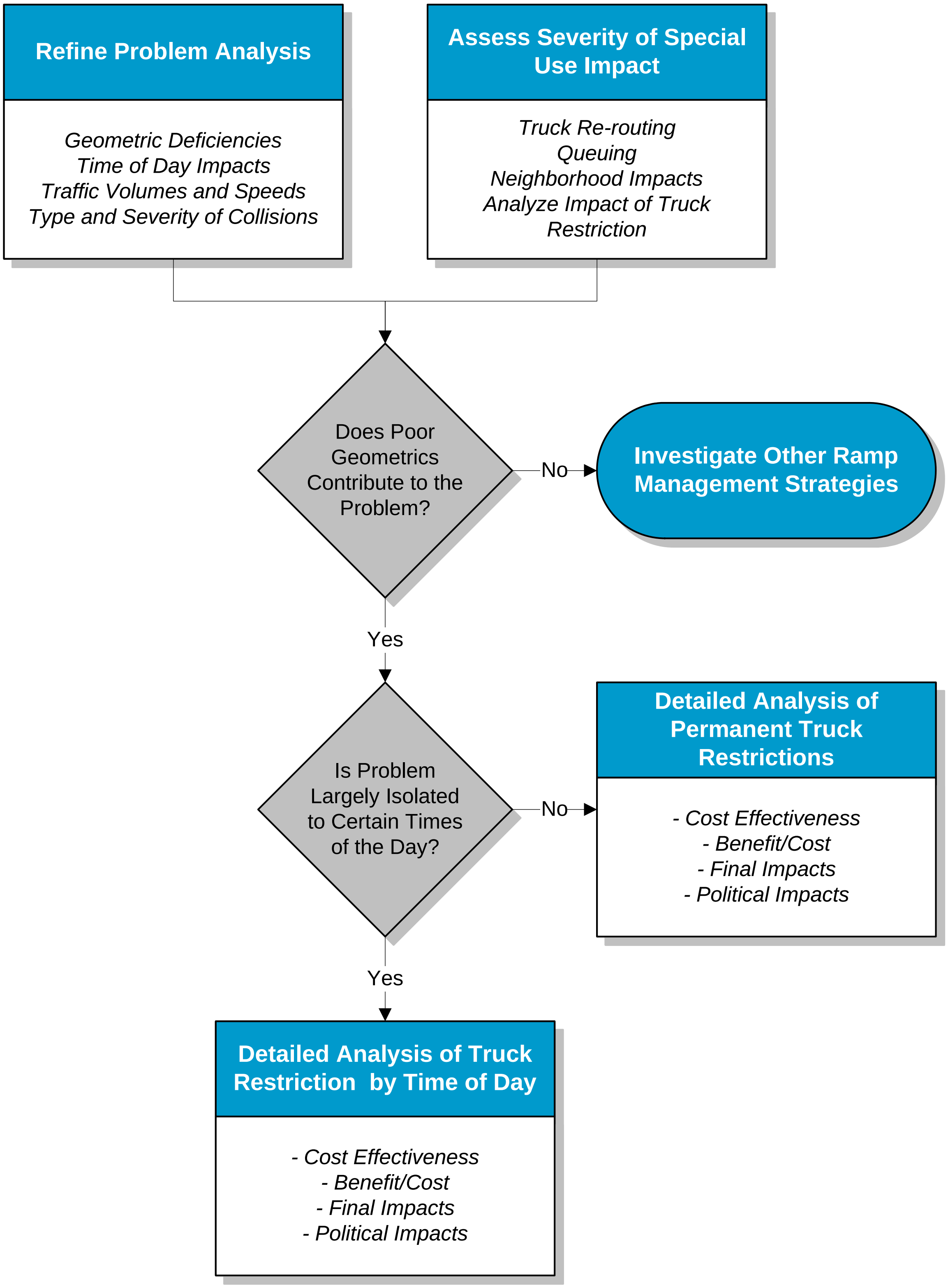


Figure 6-5: Decision Tree for Special-Use Treatments that Target Safety Impacts at Merge Points

6.5.2 Special-Use Treatments for Neighborhood Impacts

High truck volumes on ramps that lead to nearby arterials may contribute to problems in nearby neighborhoods if the arterial streets are not designed for truck traffic or if land use patterns are inconsistent with heavy truck traffic (e.g., residential neighborhoods). Large volumes of trucks that access a freeway from neighborhood streets or that leave the freeway and travel on a neighborhood street may create problems if the arterial is not designed to accommodate trucks, or if land use patterns create conflicts with heavy truck traffic.

Special-use ramp treatments for neighborhood impacts are similar to those for improving safety. Treatments for neighborhood impacts take into account deficiencies in the geometry of the ramp or downstream arterial, and traffic volumes and speeds on ramps and nearby arterials. Based on the analysis of geometry, traffic volumes, and traffic speeds, applications such as truck restrictions may be implemented to mitigate, to the extent possible, the problem affecting the neighborhood.

The decision tree showing special-use treatments for neighborhood impacts is illustrated in Figure 6-6. The first step in determining special-use treatments that address neighborhood impacts is to refine the understanding of the problems affecting the neighborhood. This analysis should identify the following:

- Geometric deficiencies.
- Existing traffic compositions and patterns.
- Target traffic levels and speeds (i.e., Level of Service requirements set by local agencies).
- Truck impacts.
- Safety/crash analysis.
- Neighborhood survey of perceived impacts.

Based on the results of the problem analysis, the practitioner must first determine if target traffic levels and speeds are achieved by restricting trucks. If target levels and speeds can be achieved then the practitioner can perform a more detailed analysis of truck restrictions. If target traffic levels and speeds cannot be achieved through truck restriction alone, the practitioner must determine if the ramp's geometry contributes to the problem. If the answer to this question is yes, then truck restrictions combined with other strategies may be analyzed. However if geometry does not contribute to the problem, then the practitioner should investigate other viable ramp management strategies.

Detailed analysis should focus on the cost effectiveness of the full set of impacts (traffic and political) of the strategy being analyzed.

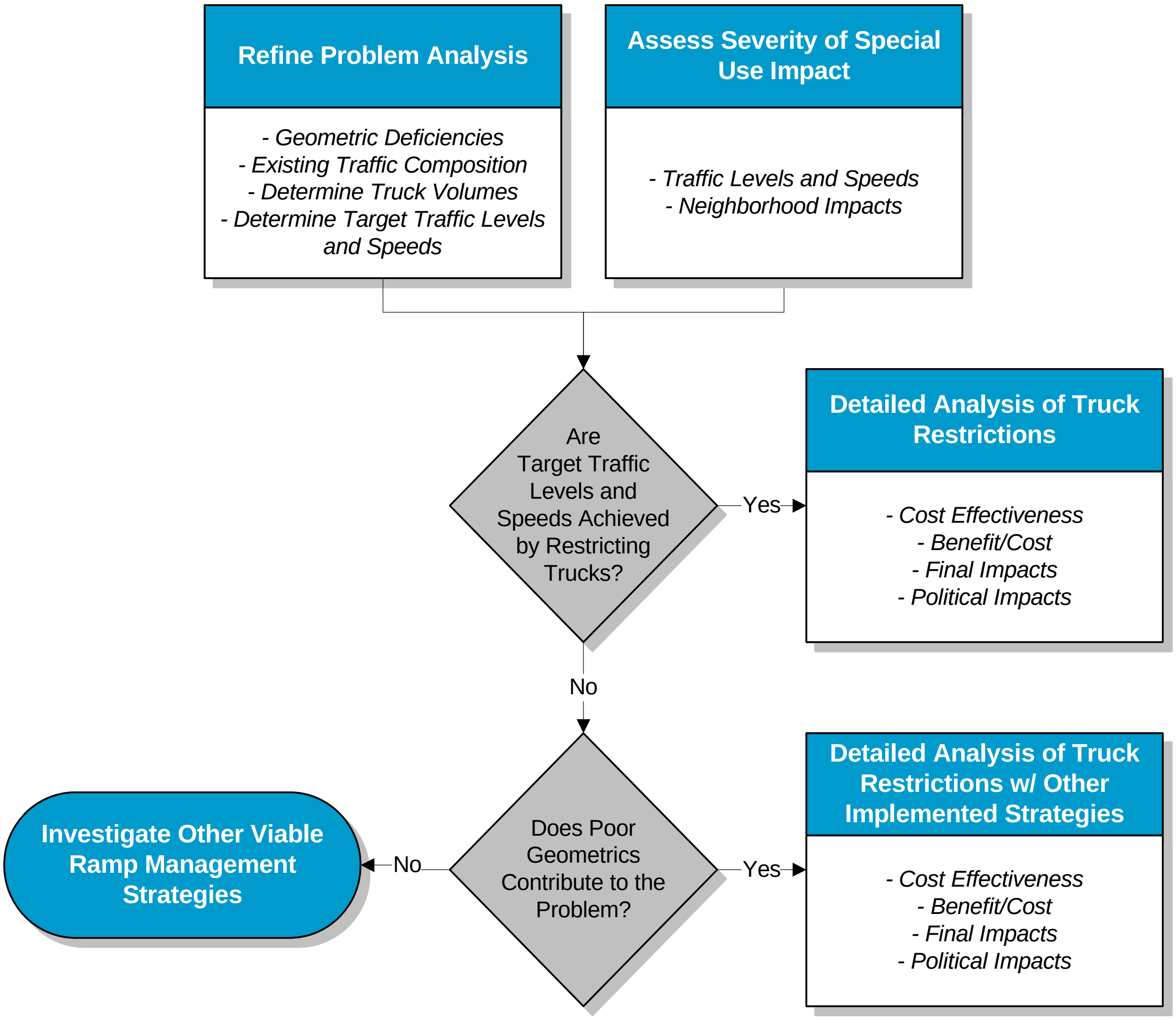


Figure 6-6: Decision Tree for Special-Use Treatments that Target Neighborhood Impacts

6.5.3 Special-Use Treatments for Construction Impacts

Special-use treatments, including full closures and truck restrictions, may be implemented at freeway ramps to improve safety and to minimize the impacts that construction vehicles, personnel, and equipment have on ramp traffic and vice versa. The special-use treatments for construction impacts decision tree is illustrated in Figure 6-7. Practitioners looking to implement special-use treatments for construction impacts should begin with a refined analysis of problems on the ramp and surrounding areas, including geometric deficiencies, type and location of crashes, traffic volumes and speeds, and other problems affecting construction or traffic on the ramp.

Based on the results of the first step (Refining Problem Analysis), the second step in implementing special-use treatments for construction is to assess whether or not the impact of construction activities on normal ramp operations will be severe (e.g., a high mix of slow-moving construction vehicles causing significant differences in speeds, frequent occurrences of construction vehicles entering and exiting the roadway, presence of construction workers working near the roadway).

If construction impacts are severe, then the feasibility of ramp closure should be considered. If full ramp closure (closed to all vehicles) is feasible, the ramp(s) should be closed during the appropriate phases (when construction impacts are most severe) of the construction project. However, if full ramp closure is not feasible, then vehicle restrictions should be considered. For example, restrictions may be enacted that simply allow only construction vehicles to use the ramp, thereby reducing the likelihood of safety problems from occurring if other vehicles were present. Alternatively, restrictions to all heavy trucks could be implemented when the ramp geometry is inadequate and this poor geometry contributes to the problem.

If the construction impacts on a ramp(s) are not deemed severe and the ramp geometry is adequate, the practitioner responsible for ramp management should review the work zone traffic control plan to see if ramp management strategies are included in the plan. If ramp management strategies are included in the plan, then the practitioner should perform a detailed analysis of the ramp management strategies included in the plan. If ramp management strategies are not included in this Plan, the practitioner should assess whether demand on the ramp needs to be further reduced. It is also recommended that practitioners determine if further reductions in demand are needed after the detailed analysis of the ramp management strategies listed in the Traffic Control Plan. If further reductions in demand are needed then practitioners should conduct a detailed analysis of vehicle class restrictions and priority treatments. If priority treatments currently exist within the region, similar treatments could be considered at the analyzed ramp locations. Otherwise, special-use treatments should not be implemented until vehicle priority policies are implemented, in use, and practical at the analyzed ramp locations. If demand on the ramp does not need to be further reduced, practitioners should consider other Viable Ramp Management Strategies to reduce the impacts of construction on ramp traffic.

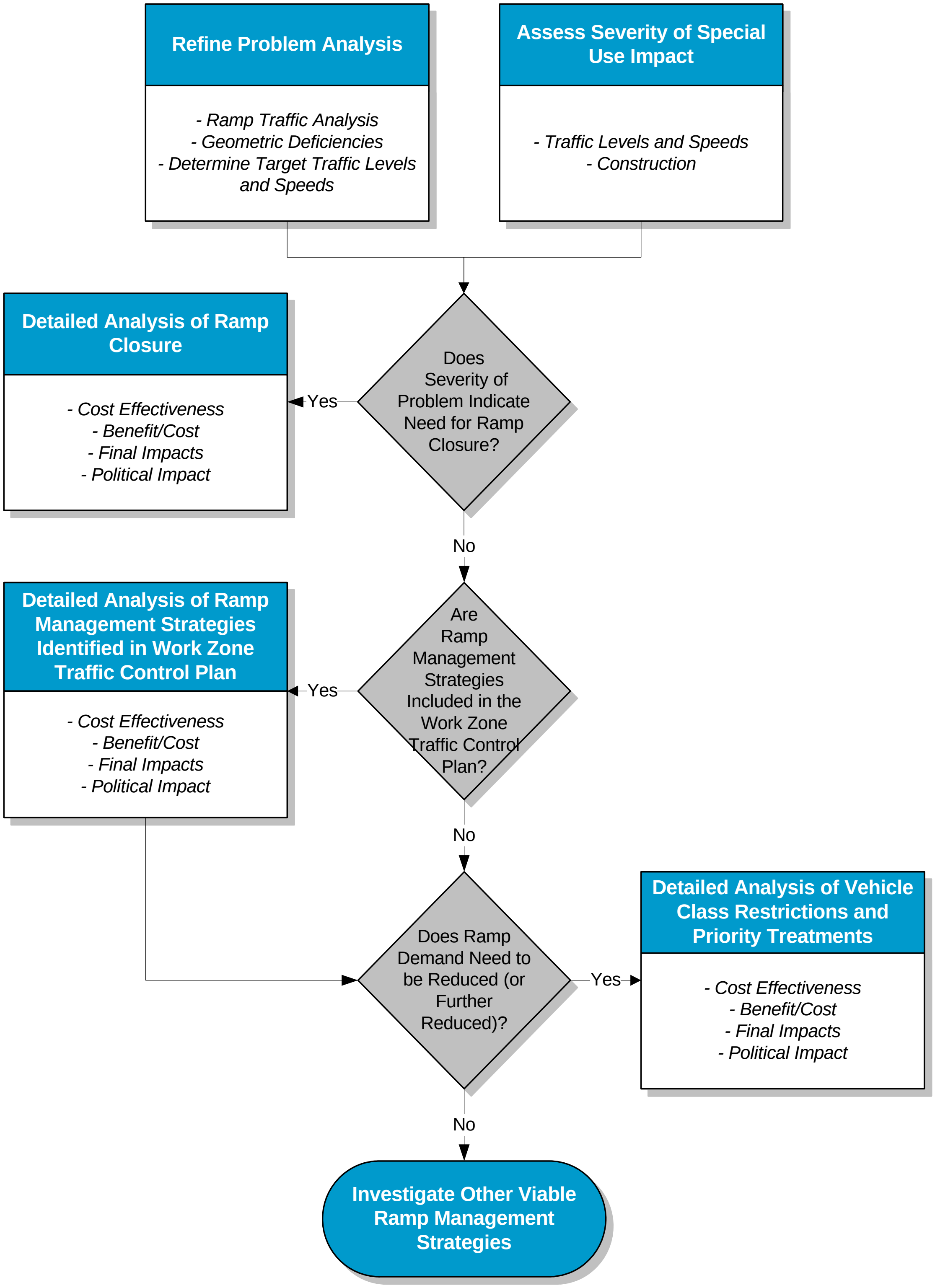


Figure 6-7: Decision Tree for Special-Use Treatments that Target Construction Impacts

6.5.4 Special-Use Treatments for Special Events

When special events occur, ramp capacities may be temporarily exceeded, resulting in safety, congestion, and mobility problems on ramps and immediately upstream of the ramp. Due to the high volumes of traffic during a special event, queues may form at the ramp/arterial intersection. These queues may extend the entire length of the exit ramp and may spill onto the freeway. This may increase the risk of rear-end and side-swipe collisions. Additionally, traffic congestion on the ramp may prohibit the quick, efficient movement of emergency vehicles responding to incidents at the special event venue or at other nearby locations. When the impacts of special event traffic are severe, practitioners may consider full ramp closure as a means of diverting traffic to ramps with greater capacity. The special-use treatments for special events decision diagram is illustrated in Figure 6-8.

The first step in deciding whether or not to implement special-use treatments to mitigate the impacts of special events is to better understand the problems that currently exist. The refined analysis should seek to understand the following:

- Local traffic conditions.
- Special event congestion.
- Special event collision history.
- Queue and delay impacts.
- Impacts that may occur downstream of the analyzed ramp.
- Availability of alternate routes.
- Need for emergency vehicle access.

If there is a special event Traffic Management Plan, much of the information mentioned above should be found in this Plan. Based on the analysis of existing problems, one can begin to assess whether or not special-use treatments are needed for special events and what these treatments may be. Regardless of the treatments selected, they must be compatible with and integrated into the special event Traffic Management Plan.

First, as mentioned above, the severity of the problem will dictate whether a full ramp closure is needed or not. If full closure is indicated, emergency vehicle access needs to be considered. If the ramp is the most direct or quickest route for emergency vehicles to access the venue or to travel through the neighborhood surrounding the venue, the ramp closure should allow for emergency vehicles access. In either case, a detailed analysis of the impacts of the closure should be undertaken before a final decision is made. The analysis should consider cost effectiveness, the assessment of traffic impacts, and the assessment of political implications.

If the severity of the problem does not require ramp closure but is significant enough to trigger the need for mitigation, the special event Traffic Management Plan should be reviewed to determine if HOV or transit policies were approved, incentives are encouraged, or HOV/transit trips constitute a major component of transportation to and from the special event venue. If so, implementing HOV or transit incentives on ramps near special event venues, such as HOV or transit-only lanes, should be considered through a detailed analysis of the cost effectiveness, benefit/cost, and additional impacts. If not, HOV or transit incentives should not be considered, yet other viable ramp management strategies could be considered.

Similar to HOV and transit, the needs of delivery vehicles and patrons destined for the special event are issues that must be taken into consideration when making decisions regarding ramp closure. Delivery vehicles must have access to transport goods to and from the special event. Therefore, special-use ramps may need to be designated for delivery vehicles only, if traffic patterns prevent delivery vehicles from arriving and departing the special event venue in a timely manner. Similarly, if the large queues of vehicles that form on entrance or exit ramps spill over onto freeways or adjacent arterials, entrance and exit ramps may need to be closed in order to divert traffic to ramps with greater capacities upstream and downstream of ramps where problems exist.

If a special-use treatment is implemented, the need for delivery vehicle access on the ramp should be considered. If delivery vehicles need access to the ramp to deliver special event goods and the ramp can safely handle this traffic under the special event Traffic Management Plan, delivery vehicle access and/or priority on the ramp in question should be considered.

6.5.5 Special-Use Treatments for Policy

Some special-use treatments, such as full-time or time-of-day priority for transit, HOV, or commercial vehicles (trucks) are only applicable in situations where agency or regional policies are in place to support them. Without such policies, these special-use treatments will fail to gather the support needed for successful implementation. If policies are in place to support one or more special-use treatments, the high-level analysis of problems should be refined. The refined analysis should seek to understand the following:

- Special class demand (i.e., vehicle and/or passenger demand for transit, HOV, or other special class vehicles).
- Downstream attractors/upstream generators (i.e., where the special class trips start and end).
- Traffic volumes and operations (i.e., overall traffic volumes and traffic operations, using measures such as average speed, delay, queues, etc.).

Based on the above analysis, a decision to implement a special-use strategy on the ramp can be made. The criteria for making this decision will vary based on the beliefs of individuals responsible for making this decision, however public input may be a contributing factor. The special-use treatments for policy decision diagram is illustrated in Figure 6-9.

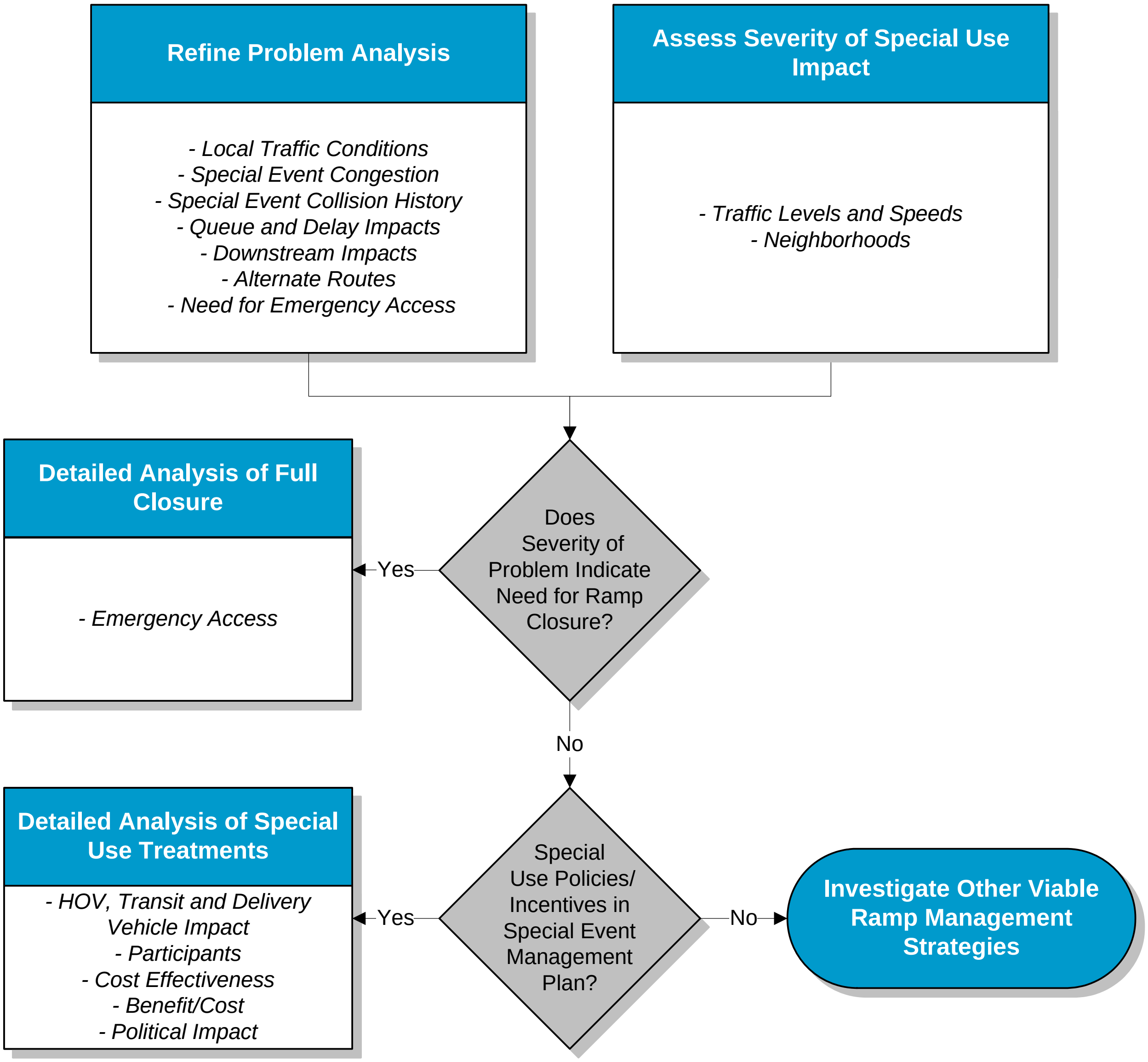


Figure 6-8: Decision Tree for Special-Use Treatments that Target Special Event Related Impacts

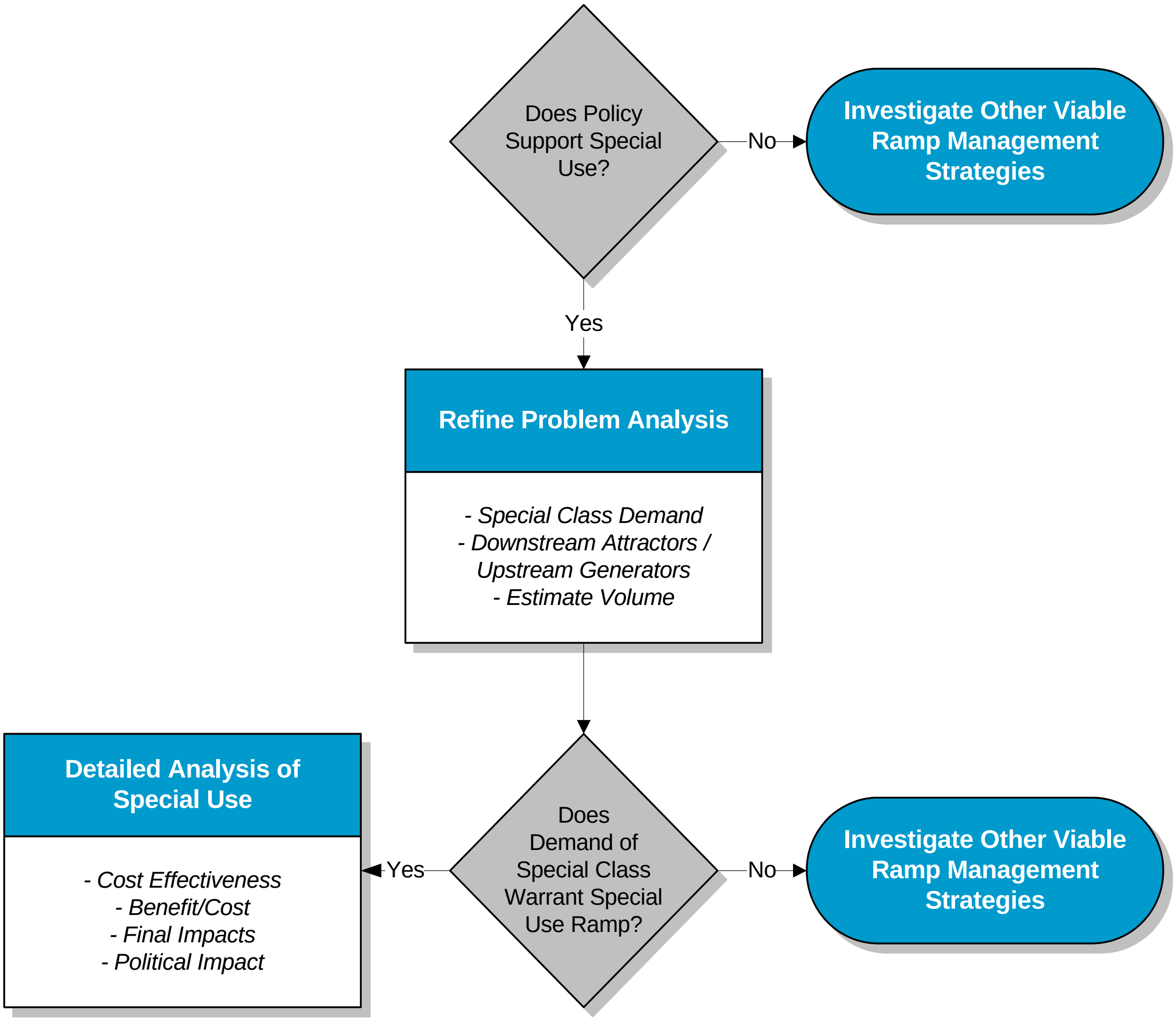


Figure 6-9: Decision Tree for Special-Use Treatments that Target Policies

6.6 Selecting Ramp Terminal Treatments

Improvements at ramp/arterial terminals can reduce the occurrence of unacceptable traffic queues, number of collisions, vehicle delay, and other impacts at or downstream of the ramp/arterial intersection. The specific ramp/arterial improvement depends on the type and location of the problem. Using the matrix in Table 6-5, the type and location of the selected problems are mapped to ramp terminal treatments.

Table 6-5: Ramp Terminal Treatments High-Level Screening Matrix

Need/Problem	Location/Reason	Ramp Terminal Treatments
Safety	Merge Point	
	Ramp Terminal	✓
	Freeway Mainline	
Impacts	Neighborhood	✓
	Construction	✓
	Special Events	✓
Congestion	Freeway Mainline	
	Ramps	✓
	Ramp Terminal	✓
	Arterial	✓
Policy	Transit	
	HOV	
	Freight	

These strategies may be stand-alone improvements or a coordinated effort with the other ramp management strategies described in this chapter. The need for ramp terminal strategies will depend on conditions that occur on the ramp.

These strategies and all the strategies discussed in this chapter must support agency policies, goals, and objectives. Conflicting goals may need to be prioritized and compromises considered. Examples of two conflicting goals are: 1) managing freeway traffic to minimize delay, and 2) managing queues at ramp meters so they do not affect arterial operations. The ramp terminal treatment decision tree is illustrated in Figure 6-10.

Refine Problem Analysis

- Ramp & Arterial Traffic Analysis
- Special Event Congestion and Traffic Flow
- Historical Collision Analysis
- Geometric Deficiencies
- Determine if There are Target Traffic Levels and Speeds
- Upstream and Downstream Trip Generators

Impacts	Location to Implement Strategy	- Widening	- Channelization	- Signal Timing	- Turn Restrictions	- Geometrics (Tapers, Sight Distance, etc.)	- Warnings (Signing, Pavement Marking, etc.)	- Lane Assignment
Congestion (Queuing & Delay)	On-Ramp	X	X	X				
	Off-Ramp	X	X	X				
	Arterial	X	X	X	X			
Safety - Collisions	On-Ramp	X	X	X		X	X	
	Off-Ramp	X	X	X		X	X	X
	Arterial	X	X	X		X	X	X
Downstream Arterial Impacts	Off-Ramp		X	X	X		X	X
	Arterial		X	X			X	X

Figure 6-10: Ramp Terminal Treatment Decision Tree

6.6.1 Ramp Widening

Ramps may need to be widened to improve safety and traffic flow on the ramp or the arterial, or to support other ramp management strategies. Implementation of ramp meters, for instance, may require that entrance ramps be widened to increase capacity and/or provide additional storage on the ramp. Likewise, ramps that give priority treatment to HOVs may need to be widened to provide a separate lane adjacent to the general-purpose lane so that HOV vehicles can bypass queues at the meters. Exit ramps may need to be widened if additional storage or turn lanes are needed at the ramp terminal intersection. However, it may not be possible to widen a ramp, if there is a lack of right-of-way or other restriction present. For instance, it may not be possible to widen a ramp if there is not enough room after the ramp is widened to perform maintenance activities or adequately position maintenance equipment (e.g., bucket trucks) near the ramp. Practitioners need to carefully analyze the possibilities of widening ramps before they make the decision to widen.

6.6.2 Channelization

Channelization helps delineate and separate traffic movements, thus reducing driver confusion and improving overall roadway safety. Channelization in the form of new turn or storage lanes may extend on the adjacent arterial to separate through traffic from traffic destined for the ramp. This helps hold traffic destined for the ramp without impeding the movement of through traffic.

6.6.3 Signal Timing

Traffic signals at the ramp/arterial intersection may be retimed to reduce queuing on the ramp and to prevent queues from backing up into the intersection (entrance ramps), onto the freeway facility (exit ramps), or onto the arterial (entrance ramps). Where possible, agencies involved should coordinate ramp meters with arterial management systems to optimize flow at intersections. Agencies may need to enter into agreements to specify the manner in which traffic signal systems will be operated.

At entrance ramps, signal timing may be adjusted to hold traffic destined for the ramp on arterials so vehicles do not stop within the intersection when queues form. This ensures that through traffic is not affected by ramp metering operations and jurisdictional issues do not arise. However, practitioners should make sure that approaches or lanes that lead to the ramp have sufficient capacity or storage to hold ramp-bound traffic.

At exit ramps, signal timing may be adjusted to permit all vehicles waiting on the ramp to clear the intersection. This will minimize the length of queues that form between green phases, so that queues do not back up onto the freeway facility.

Signal timing at the interchange may also be modified to support traffic management on the arterial downstream from the ramp interchange. In some cases, traffic from the interchange can overwhelm the ability of the arterial downstream to handle traffic. Queues may form in areas not well suited to accommodate backups, such as closely-spaced intersections.

In these cases, ramp terminal signal timing may be set to limit, or "gate", the traffic destined downstream of the interchange.

6.6.4 Turn Restrictions

Turn restrictions at ramp terminals may be considered as a method to restrict volumes on the arterial downstream of the interchange, similar to the signal "gating" strategy discussed previously. Turn restrictions can either be permanent, during the signal's red interval (no right turn on red), or by time of day, depending on the severity of the downstream arterial problem and times that the problem exists.

6.6.5 Improvement to Geometry

Poor geometry is a leading cause of many collisions on or near freeway ramps. Improving the geometry of ramps will smooth the flow of traffic entering the freeway facility, and will reduce potential vehicle conflicts that result from motorists taking corrective measures because of geometric deficiencies. Examples of geometric improvements that may be included are improvements to sight distance and reduction in horizontal and vertical curves in the roadway. When making improvements to ramp geometry, special consideration should be given to the hours when improvements will be made, so as to reduce impacts to traffic using the ramp during construction. It is possible that delays caused by construction on or near the ramp may impede traffic flow, which may result in queues that back up onto the adjacent surface street (in the case of entrance ramps) or freeway (in the case of exit ramps). If possible, construction should be completed at night or during off-peak hours to mitigate these negative impacts.

6.6.6 Signing and Pavement Marking

A certain level of signing and pavement marking is needed to support any of the ramp strategies discussed. Signing and pavement marking improvements are generally used to inform drivers of downstream conditions or to provide guidance to drivers approaching or on a ramp. Pavement markings are implemented to delineate traffic and help facilitate vehicle movements.

6.7 Tools to Support Selection of Ramp Management Strategies

Several traffic analysis tools are available to practitioners responsible for developing and selecting ramp management strategies. Because several tools are available, practitioners must select the appropriate tools needed to perform required analyses. In other words, is the analysis going to be conducted at a high-level or at a more detailed level? The answer to this question will help identify the appropriate tool or tools needed. Data collection activities that will be relied upon during high-level and detailed analysis include:

- Crash records.
- Observations.
- Traffic counts.

The extent and depth to which the data collected through these activities will be used will increase as the analysis becomes more detailed.

6.7.1 High-Level Analyses

Throughout this chapter, one of the first steps undertaken in the decision-making process is to refine the problem analysis. This is a high-level analysis undertaken to gain more insight into the problem, to support selection of a particular strategy or set of strategies from among all the potential ramp management strategies. The high-level analyses rely heavily on observations of existing conditions and data, and on high-level analysis tools. Each section of this chapter describes the high-level analyses appropriate for the subject decisions.

Tools to support the high-level analyses described in this chapter include:

- Sketch-planning tools.
- Analytical/deterministic tools (HCM-based).

A more detailed discussion of these tools can be found in Chapter 9, Section 9.4.

6.7.2 Detailed Analyses

Throughout this chapter, nearly the last step in the decision-making process is to perform a detailed analysis of the selected ramp management strategy. These analyses are described in each decision-making section. Most of them include a determination of cost effectiveness, benefits and costs, and final impacts. These detailed analyses require more powerful tools that often take more time to use and more data than the high-level tools. For example, the impacts of implementing complex ramp management strategies often require the use of simulation models. The models provide an estimate of the traffic operations impacts, and those impacts are then used to determine cost effectiveness (i.e., benefit/cost ratio). The output of the models also helps provide input to decision makers to judge what the likely political impacts will be.

Tools to support the detailed analyses described in this chapter include:

- Macroscopic simulation models.
- Microscopic simulation models.
- Mesoscopic simulation models.

A more detailed discussion of these can be found in Chapter 9, Section 9.4. Additional information can be obtained from FHWA's *Traffic Analysis Tools Primer, Volumes 1 and 2*.[7,8]

6.8 Chapter Summary

Practitioners can choose from four primary categories of ramp management strategies to improve traffic flow on ramps. As is the case with most new projects, a fifth strategy also exists, which is to take no action. Determining whether ramp management strategies are needed and/or which strategy or combination of strategies is "best" for addressing existing problems or conditions are decisions that may be difficult to make. This is due in part to similarities between ramp management strategies. For instance, both ramp metering and ramp closure can be applied to resolve safety-related problems at the ramp/freeway merge point. The selection of the best strategy in cases like these requires a complete and thorough analysis and comparison of each strategy's impacts as well as their benefits. For instance, even though strategies may address similar problems, the associated impacts of deploying one strategy versus another may be substantially different. In some cases, it may not even be feasible to implement strategies based on the results of this analysis.

Selecting the "best" ramp management strategy or combination of strategies should begin with a cross-comparison of existing problems and conditions with problems and conditions that each ramp management strategy can address. Based on the results of this comparison, practitioners can focus their efforts on the applicable strategies that are capable of addressing existing problems or conditions. From here, practitioners can perform detailed analyses of the applicable ramp management strategies, to identify strategies or combinations of strategies that work best for the agency and the problems or conditions being addressed. Chapter 7 provides additional details on how to successfully implement the strategies that have been selected through guidance provided in this chapter. Chapter 8 discusses procedures on how to best operate and maintain the implemented strategies, so as to maximize return on investment.

REFERENCES

[1] *Freeway Management Handbook*. Publication FHWA-SA-97-064. Federal Highway Administration (FHWA), U.S. Department of Transportation. August 1997. Available: http://plan2op.fhwa.dot.gov/pdfs/Pdf2/Edl07243.pdf

[2] Highway Capacity Manual (HCM) 2000. Transportation Research Board, Washington, D.C. 2000.

[3] Piotrowicz, G. and J. Robinson. *Ramp Metering Status in North America; 1995 Update.* Publication DOT-T-95-17. Federal Highway Administration (FHWA), U.S. Department of Transportation. June 1995. Available: http://www.odot.state.or.us/its/PDFs/BenefitsofITS/rampmeteringstatus1995.pdf

[4] Jacobson, E.L., and J. Landsman. *Results of the On-line Implementation and Testing of a Fuzzy Logic Ramp Metering Algorithm*. Presented at the 79th Annual Meeting of the Transportation Research Board. Washington D.C. January 2000.

[5] Chaudhary, N.A. and C.J. Messer. *Ramp Metering Technology and Practice: Task 1 and 2 Summary*. Publication FHWA/TX-00/2121-1. Texas Department of Transportation. May 2000. Available: http://tti.tamu.edu/documents/2121-1.pdf

[6] E-mail from Bruze Zagvania, Manager, Urban Traffic Control Systems. City of Toronto Transportation Services Division. April 14, 2004.

[7] *Volume 1: Traffic Analysis Tools Primer*: Publication FHWA-HRT-04-038. Federal Highway Administration (FHWA), U.S. Department of Transportation. June 2004. Available: http://ops.fhwa.dot.gov/trafficanalysistools/tat_vol1/index.htm

[8] *Volume 2: Decision Support Methodology for Selecting Traffic Analysis Tools.* Publication FHWA-HRT-04-039. Federal Highway Administration (FHWA), U.S. Department of Transportation. June 2004. Available: http://ops.fhwa.dot.gov/trafficanalysistools/tat_vol2/index.htm