A Toolbox for Reducing Queues at Freeway Off-Ramps

Prepared for

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METRIC CONVERSION TABLE

Approximate Conversions to SI Units

SYMBOL	WHEN YOU KNOW	MULTIPLY BY LENGTH	TO FIND	SYMBOL
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

Approximate Conversions to SI Units

SYMBOL	WHEN YOU KNOW	MULTIPLY BY LENGTH	TO FIND	SYMBOL
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi

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16. Abstract
Interstate highways are one of the most important components of the transportation infrastructure in America. Since the completion of the majority of the interstates in 1975, there have been a series of changes in transportation and urban developments throughout the country. The rapid growth of population and economic activities in many states have caused queues on the freeways off-ramps to spill back onto the freeway mainline. The problem of queue spillback onto the freeway mainline may be encountered at different locations at different stages of severity. This problem creates a potentially hazardous condition where high-speed traffic on the freeway suddenly comes up on traffic stopped and queued from the off-ramp. There are many potential treatments for reducing queues at freeway off-ramps to minimize potential fatal crashes and major freeway congestions. The objective of this project is to study the problem of queues at freeway off-ramps in order to provide transportation practitioners and agencies with a set of potential treatments for its alleviation. This set of potential treatments or countermeasures is presented in the form of a toolbox, targeting the off-ramp queue spillback problem from different perspectives: freeway operations, arterial operations and off-ramp operations. This toolbox was based on comprehensive literature review, surveys of FDOT districts, interviews with FDOT District Traffic Operation Engineers, opinions from transportation experts, and case studies.

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EXECUTIVE SUMMARY

There have been tremendous changes in American transportation and urban developments since the interstate system was initially designed and constructed. Rapid growth of population and economic activities in many states have caused queues on the freeways off-ramps to spill back onto the freeway mainline. The problem of queue spillback onto the freeway mainline is present at different locations at different stages of severity throughout Florida. This creates a potentially hazardous condition where high-speed traffic on the freeway suddenly comes up on traffic stopped and queued from the off-ramp. This leads to a potential for increased high-speed rear-end collisions on the mainline and also an increased probability of sideswipe crashes, as vehicles suddenly change lanes to avoid hitting the back of the queue. In many cases, the problems of off-ramp queues backed up to the freeway mainline are due to heavy peak-hour demand, limited off-ramp storage and service capacity, inefficient operation at the off-ramp terminal intersection, and congestion on the artery near the freeway off-ramp. Typically, all that can be done to alert motorists is to use dynamic message signs indicating upcoming congestion.

Transportation practitioners and researchers have focused major efforts on the development of countermeasures for freeway management and arterial management. However, studies on the countermeasures to reduce queues at freeway off-ramps are limited. Currently, more attention and effort are being made to emphasize the integration of both freeway systems and arterial systems, and cooperation between state and local transportation agencies.

There are many potential treatments for reducing queues at freeway off-ramps to minimize potential fatal crashes and major freeway congestion. The objective of this project is to study the problem of queues at freeway off-ramps in order to provide transportation practitioners and agencies with a set of potential treatments for alleviation of these problems. These treatments may vary from one location to another. Some treatments such as major geometric improvements at off-ramps, terminal intersections or arteries are primarily long-term countermeasures. Some treatments such as signal timing adjustments at off-ramps and along arteries are considered short-term countermeasures. This set of potential treatments or countermeasures is presented in the form of a toolbox.

To achieve the proposed objectives, the project was divided into seven major tasks:

- Task 1: Assessment of the current state of the practice
- Task 2: Preliminary countermeasure list
- Task 3: Initial site selection
- Task 4: Before studies
- Task 5: Implementation
- Task 6: After studies
- Task 7: Evaluation

Based on interviews with traffic operation engineers and their staff, this study found that, in general, signal timing and geometric improvements are the most common countermeasures used by FDOT districts and the Florida Turnpike Enterprise. For rural and small urban areas, signal timing adjustments and minor geometric improvements at congested off-ramp terminal intersections are the major successful countermeasures to reduce off-ramp queues. For mid-size urban areas or large urban areas, many different countermeasures such as basic signal timing improvements and major interchange rebuilding could be used to effectively reduce queues at freeway off-ramps depending on specific causes. For large metropolitan areas, the available right-of-way is very limited and expensive. The added capacity from signal timing and minor geometric improvements can be consumed very quickly due to large traffic demand. Therefore, the countermeasures to alleviate traffic congestion focus more on the shift of some traffic demand to public transit systems, deployment of ramp meter systems, provision of traveler information such as 511 systems to inform travelers of traffic congestion, effective monitoring and response to traffic congestion through traffic management centers, prompt response to incidents to reduce congestion duration, and major geometric improvement along the interstate highway and arterials to create sustainable extra capacity.

This study also found that inadequate capacity at off-ramp terminal intersections due to rapid demand growth and/or outdated traffic signal timing plans, limitation of off-ramp storage capacity, lane blockages on the arterial, congestion problems along the arterial, and close distance between the off-ramp terminal and its immediate downstream intersections are the major causes for the spillback of queue from off-ramps to freeway mainlines.

Four case studies were conducted for this project to examine the effectiveness of some proposed countermeasures. The case studies were conducted at the I-75 & Fowler Avenue interchange, the I-75 & Big Bend Road interchange in Tampa, the I-95 & Eau Gallie Boulevard interchange in Melbourne, and the I-75 & Bee Ridge Road interchange in Sarasota. Signal timing and minor geometric improvements are the major countermeasures used. The case studies verify the benefits of these specific countermeasures. In the case studies, microscopic traffic simulation proved to be an effective tool to provide thorough before-and-after-analysis. It provided valuable performance measure data such as delays and queue lengths of many intersections for before-and-after analysis and comparisons, which are otherwise very difficult and expensive to collect.

The most common and effective short-term countermeasures include, but are not limited to:

- Signal timing improvements at the off-ramp terminal intersections
- Signal retiming along the arterial near the off-ramp terminal intersection
- Reassignment of lane usage at the off-ramp terminal intersection or freeway diverge gore area
- Adding lanes to the off-ramp, lengthen the off-ramp turning lanes
- Lengthening turning lanes at downstream intersections to reduce lane blockage
- Adopting access management policy
- Applying ramp metering to control freeway volumes
- Implementing TDM strategies to reduce freeway demand
- Applying ATIS technologies to provide traveler information

- Utilizing ATMS to effectively monitor traffic congestion to take immediate action

The most common and effective long-term countermeasures include, but are not limited to:

- Major geometric improvements at the off-ramp terminal intersection
- Adding lanes on the congested off-ramp to increase departure and storage capacities
- Adding lanes on the arterial to reduce arterial congestion
- Constructing additional interchange near the congested one

This study points out countermeasures to reduce queues at freeway off-ramps based on a comprehensive literature review, surveys of FDOT districts, interviews with FDOT District Traffic Operation Engineers, opinions from transportation experts, and case studies. In general, this toolbox is a source of countermeasures targeting the off-ramp queue spillback problem from different perspectives: freeway operations, arterial operations, and off-ramp operations.

With the growth of traffic demand in many states, it is anticipated that the problem of spillback of off-ramp queues to freeway mainlines will become more and more serious. The toolbox of countermeasures developed in this study valuable for assessing the potential countermeasures to alleviate the off-ramp congestion problems. Further study may focus on the benefit and cost analysis for all proposed countermeasures to reduce queues at freeway off-ramps. It will provide transportation professionals with further information to determine needed countermeasures and required costs.

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1 INTRODUCTION

Interstate highways are the backbone of the American highway network. The construction of the majority of the interstate system was completed in 1975. There have been tremendous changes in American transportation and urban developments since the interstate system was initially designed and constructed. With rapid growth of populations and economic activities in many states, there are several freeway interchanges where queues on the off-ramps spill back onto the freeway mainline. This creates a potentially hazardous condition where high-speed traffic on the freeway suddenly comes up on traffic stopped and queued from the off-ramp. This leads to a potential for increased high-speed rear-end collisions on the mainline and also an increased probability for sideswipe crashes, as vehicles suddenly change lanes to avoid hitting the back of the queue. In many cases, the problems of off-ramp queues backed up to the freeway mainline are due to heavy peak-hour demand, limited off-ramp storage and service capacity, inefficient operation at the off-ramp terminal intersection, and congestion on the artery near the freeway off-ramp. Typically, all that can be done is to alert motorists via dynamic message signs of upcoming congestion.

In the past, transportation practitioners and researchers focused major efforts on the developments of countermeasures for freeway management and arterial management. As to ramp management, ramp metering at freeway on-ramps has been studied and implemented in some states to control the volumes entering the freeway to minimize freeway congestion. However, studies on the countermeasures to reduce queues at freeway off-ramps are limited. Currently, more and more attention and efforts are being made to emphasize the integration of both freeway systems and arterial systems and cooperation between state and local transportation agencies.

There are many potential treatments for reducing queues at freeway off-ramps to minimize potential fatal crashes and major freeway congestions. These treatments may vary from one location to another. Some treatments include major geometric improvements at off-ramps, terminal intersections or arteries and are long-term countermeasures. Some treatments which may include signal timing adjustments at off-ramps and along arteries are considered short-term countermeasures. The intent of this project is to present countermeasures based on an assessment of the current state of the practice through literature review, survey, personal interviews simulation, and case studies.

1.1 OBJECTIVES OF THE PROJECT

The main objective of this project is to study the problem of queues at freeway off-ramps to provide transportation practitioners and agencies with a set of potential treatments for its alleviation. This set of potential treatments or countermeasures is presented in the form of a toolbox.

Secondary objectives supporting the main project objective are to understand the main causes of queue congestion at freeway off-ramps, assess the best practices for reducing freeway off-ramp queues in Florida, and address qualitatively the advantages, cautions and disadvantages of the different treatments to cope with the queuing problems at congested off-ramps.

1.2 MAJOR PROJECT TASKS

The project was divided into seven major tasks aimed to accomplish the proposed objectives. The tasks constituted the methodological guide to the project team throughout the progress of the project. Tasks 1 through 3 are related to information gathering, tasks 4 through 6 comprise the analytical part, and task 7 is deals with the documentation of the findings. A more detailed description of each task is provided below.

- Task 1: Assessment of the current state of the practice. This task assessed what agencies have done in the past and pertinent research completed to date in this area. Interviews with each of the District offices were carried out to determine what countermeasures they have each tried and been successful with.

- Task 2: Preliminary countermeasure list. Based on the results of the literature review, survey and personal interviews with the FDOT Districts and the Turnpike Enterprise, a preliminary listing of countermeasures was developed for consideration and testing.

- Task 3: Initial site selection. Based on input from the District offices and the Department's knowledge of where congested off-ramps existed, four locations were determined that appeared to be suitable for different countermeasure treatment. One of the determining criteria was the availability of existing data for each of the interchanges.

- Task 4: Before studies. Upon determination of the test intersections, relevant data were gathered that included: existing operational data including traffic volumes signal timing, signal spacing, spacing of adjacent major access points and speeds. Data on queue lengths also were gathered, when possible.

- Task 5: Implementation. The recommended treatments for the selected locations were implemented at the test locations. Recommended signalization changes were installed by either local agency staff or contractors to the agency or the Department.

- Task 6: After study. After the recommended treatments had been implemented, operational data were collected for comparison against the before data gathered in Task 4.

- Task 7: Evaluation. This task compiled the data from the previous tasks into this final report documenting the findings of this research effort. The final report contains the toolbox of suggested countermeasures, including a description of criteria and contra-indicators for each of the proposed types of treatments. The toolbox is organized in a manner that will allow the user to quickly determine which treatments may be applicable for a particular intersection, and determine whether those changes would be long-term or short-term, thus helping to determine the relative costs of alternative treatments. The operational benefits observed in the before and after studies are documented for each of the applied countermeasures.

1.3 FUNDAMENTAL RESEARCH APPROACHES

The off-ramp queue spillback problem can be explained by the concept of supply and demand. Basically, the number of vehicles entering the off-ramp section from the freeway is higher than the number of vehicles being discharged from the off-ramp into its corresponding arterial road. When this extra demand exceeds the storage capacity of the freeway off-ramp, the queue at the freeway off-ramp will start to grow back to the freeway mainline.

The basic concepts for management of a queuing system at a freeway off-ramp are to reduce input demand from the freeway, increase output capacity from the off-ramp, and improve storage capacity of the off-ramp. Based on these basic concepts, there are three major fundamental approaches used in this study to reduce queues at freeway off-ramps, as shown in Figure 1. The first approach is to reduce travel demand and improve freeway operations; the second is to improve off-ramp departure capacity and alleviate arterial congestion; and the third approach is to improve the off-ramp and freeway storage capacities for queues.

The major countermeasures for each fundamental approach of this study also are listed in Figure 1. Detailed descriptions of the major countermeasures and their associated specific countermeasures will be presented in later chapters. Each fundamental approach will be explained first, followed by the major countermeasures. Under each major countermeasure, specific countermeasures will be illustrated. These countermeasures can be used individually or combined to minimize the queuing problem at off-ramps and improve traffic safety and congestion.

1.4 ORGANIZATION OF THE REPORT

This report is organized by chapters; each chapter comprises one or more tasks. Chapter 1 presents an introduction to the project. Chapter 2 provides a literature review on interchange type characteristics and countermeasures dealing with the problem of queues on freeway off-ramps. Chapter 3 presents the assessment of the state-of-the-practice in Florida for which a series of surveys and personal interviews were carried out with traffic operations engineers of the FDOT Districts and the Turnpike Enterprise. The preliminary countermeasure list based on the literature review and assessment of current state-of-the-practice in Florida is presented in Chapter 4. Chapter 5 focuses on case studies, including site selection, data collection, and the analysis of the conditions before and after the implementation of the countermeasures. Chapter 6 contains the main outcome of this project, which is the list of countermeasures in the form of a toolbox. Finally, Chapter 7 provides concluding remarks and insights regarding the treatments to tackle the problem of queues at freeways off-ramps.

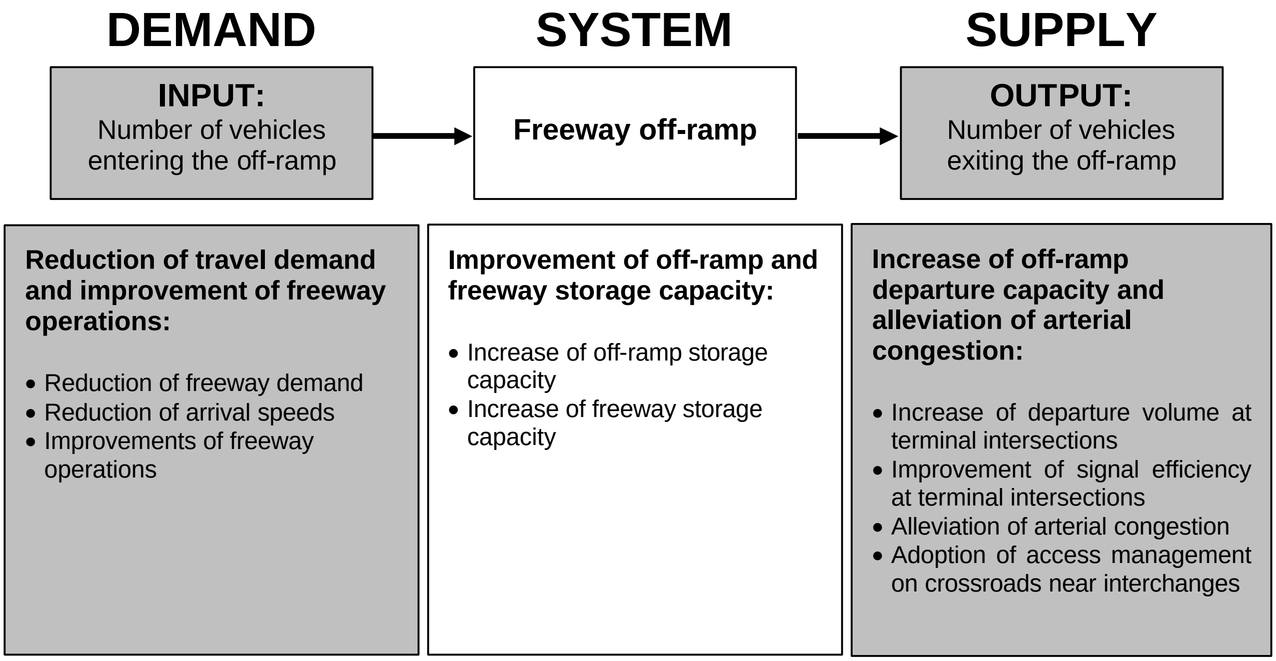


Figure 1: Fundamental approach and countermeasures to reduce queues at freeway off-ramp

2 LITERATURE REVIEW

2.1 OVERVIEW

The purpose of the literature review was to obtain knowledge of the most common countermeasures used to reduce queues at off-ramps through approaches from freeways, off-ramps, and arterial sections of transportation systems. The outcome of the review was used for the development of a toolbox of countermeasures in later chapters. It was used by the research team to develop a questionnaire the helped the research team in the assessment of the state of the practice in Florida in a subsequent stage of the project.

The literature review consisted of a study of the different interchange types and their characteristics, followed by a review of the countermeasures tried, aimed at alleviating the off-ramp queueing problem. The findings of the literature review were divided into the three areas or fundamental approaches to the queuing problem as described in Chapter 1: freeway, off-ramp, and arterial roads.

2.2 CHARACTERISTICS OF FREEWAY INTERCHANGE TYPES

This section provides a description of the different types of geometries for freeway interchanges based on the available literature. The review of the characteristics for different types of interchanges provided an insight of potential causes of queueing problems and the countermeasures to alleviate these problems. This description involves general characteristics, alternative configurations, and advantages and disadvantages for each particular class of interchange. Information related to this subject can be found in references [1] through [7]. The general interchange classifications widely accepted by the agencies and different entities in the transportation field are diamonds, cloverleaf, partial cloverleaf, trumpets, directional and semi-directional interchanges. A more detailed analysis on this subject was carried out at early stages of this project and is reported in Hagen et al. [8]. Alternative configurations for each interchange type are presented in appendix A.

2.2.1 Diamond Interchange

This type of interchange is the most frequently encountered across the country, according to Garber et al. [9]. The diamond interchange consists of four one-way diagonal ramps two on-ramps, and two off-ramps. Each off-ramp typically provides left and right turn movements at the crossroad, as can be observed in Figure 2. In general, right turns are free while left turns are made across conflicting traffic on the crossroad. The on-ramp entrance requires left and right movements for the vehicles traveling on the surface street.

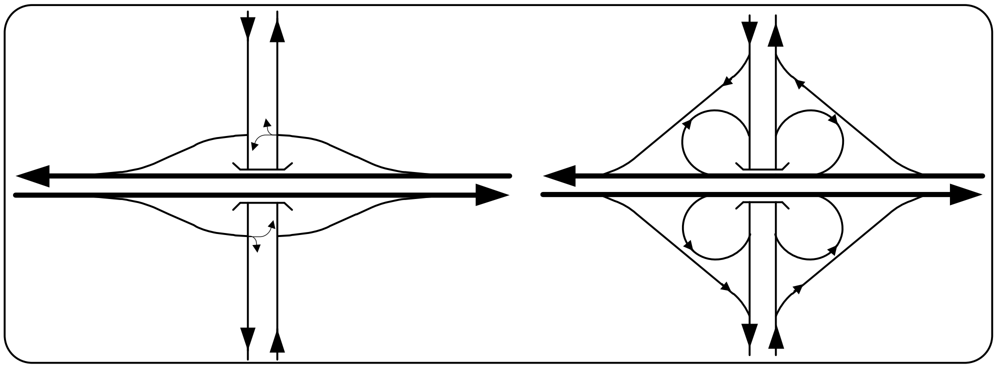


Figure 2: Diamond interchange (left), full cloverleaf interchange (right)

2.2.1.1 Advantages

Compared to other interchanges diamonds require less right-of-way and are the least expensive. Others advantages are that they easily allow future modifications to provide greater ramp capacity, allow traffic entering and exiting the mainline at relatively high speeds, and allow easy accommodation of pedestrian crossings when the crossroad is a minor road.

2.2.1.2 Disadvantages

Traffic is subject to stopped delay operations rather than free flow. In suburban and urban areas, signalization is generally required at the crossroad intersections. Diamonds require right-of-way in all four quadrants of the interchange; therefore, they are not suitable when the interchange area presents adverse topographical conditions. The overall capacity of this type of interchange is limited by the capacity of the intersection at the ramp terminal. In general, diamonds encounter difficulties in handling significant left-turn volumes, causing backups on both the crossroad and the ramps. There are also potential risks for wrong-way entry onto the ramps.

2.2.2 Cloverleaf Interchanges

This type of interchange uses loop ramps in the four quadrants to handle traffic, providing continuous movement from freeway to highway and vice versa. A full cloverleaf is the minimum type interchange that suffices for a freeway-to-freeway interchange. Left-turn movements are made through loop-shaped ramps, requiring a 270-degree turn before heading onto the desired direction. Representation of this geometry is presented in Figure 2

2.2.2.1 Advantages

The main advantage of this design is the elimination of the vehicular stops providing free-flow operation for exit and entry ramps. As a direct consequence of its free-flow operation, this geometry eliminates the need for traffic lights. It is adaptable to any grade crossing of roadways because its traveling directions are subject to merging movements at the terminals.

2.2.2.2 Disadvantages

Full cloverleafs require large amounts of right-of-way due to the size of the ramps and wide structures. For this reason, these interchanges are typically more expensive than diamond interchanges. The loops in cloverleafs result in a greater travel distance for left-turning vehicles compared to diamonds; the 270-degree turn generally decreases the speeds on the ramps. Exit and entrance terminals are located before and after the crossroad structure; therefore, additional signage is often required to guide motorists. The main operational disadvantage of this type of interchange is the weaving movements that take place between on-ramp loops and off-ramp loops serving the same mainline. To account for this effect, weaving sections between loop ramps must be made long enough to provide for safe weaving.

2.2.3 Partial Cloverleaf Interchange

Also referred to as parclos, these interchanges have loops in one, two, or three quadrants, depending on the available right of way. They can be combined with diagonal-type ramps, providing design flexibility to overcome topographical restrictions that can be encountered in the field. Figure 3 shows one of the possible configurations of partial cloverleafs in which the loops are serving different traffic streams.

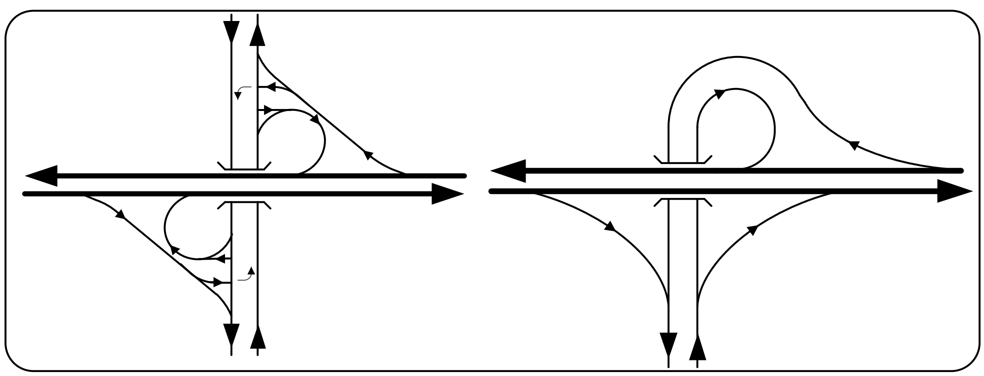


Figure 3: 2-Quadrant parclo A (left), trumpet type A (right)

2.2.3.1 Advantages

Partial cloverleafs provide service where one or more quadrants present right-of-way or topographic problems. This geometry can handle unbalanced turning volumes by arranging the ramps in such a way that the least impediment is provided to the most demanded directions by mean of loop ramps. This practice allows improved capacity, operations, and safety.

2.2.3.2 Disadvantages

Partial cloverleafs suffer the same disadvantages as the full cloverleaf regarding loop ramps and weaving areas. In addition, parclos result in at least one 90-degree intersection, thus requiring the vehicles to stop whether at a stop, sign or a signal control.

2.2.4 Trumpet Interchanges

This design is used when three intersecting traffic legs are present. In some cases, two of the three intersecting legs can be in direct alignment, forming a through road. In cases where the angle of the third intersecting leg is not acute, the interchange can be referred to as T-shaped interchange; otherwise, it may adopt a Y-shaped form. In Figure 3, one of the configurations for T-shaped interchanges is shown.

2.2.4.1 Advantages

These interchanges have great capabilities for handling unbalanced traffic volumes. This can be done by arranging the ramps in such a way that the most direct alignment is assigned to the heavier traffic volume. When future expansion to the unused quadrant is not practical or likely, a trumpet design may be considered.

2.2.4.2 Disadvantages

Trumpet interchanges are typically limited to intermediate traffic volumes that can be accommodated by single lane ramps. When an intersection is too close to the merging area with the local road, there can be weaving problems.

2.2.5 Directional Interchange

This is the most effective interchange to handle high traffic volumes. The directional interchange is mainly characterized by providing free-flow movement in all directions with a small deviation from the direction of travel (direct connections), as opposed to loop ramps, which require large deviation from the original trajectory. This interchange type is said to be fully-directional when all the left-turn movements are provided by direct connections, as can be observed in Figure 4. Usually these interchange types require four-level structures.

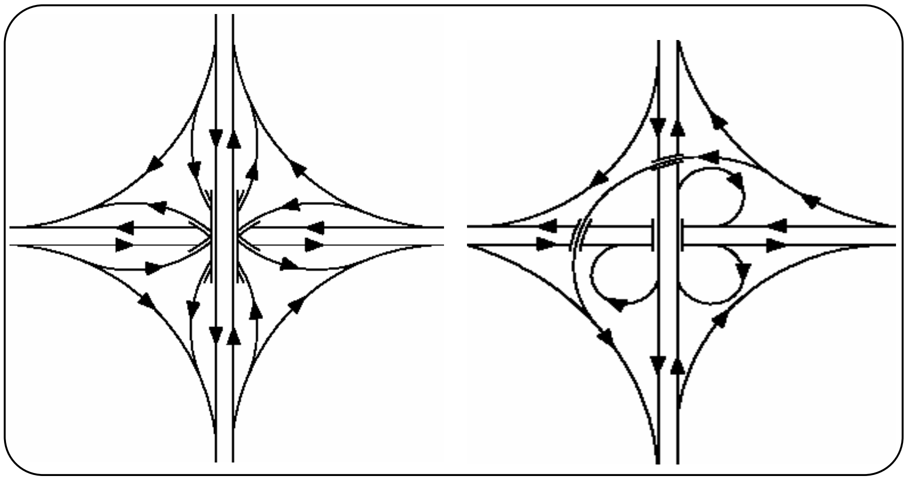


Figure 4: Fully directional interchange (left), semi-directional interchange (right)

2.2.5.1 Advantages

The advantages of using directional interchanges are shorter travel distances, higher speed, no weaving (fully-directional), increased level of service, more operational efficiency, and improved capacity. In fact, these interchanges have the highest capacity of all the interchange geometries.

2.2.5.2 Disadvantages

Sometimes left-hand exits may cause difficulties to drivers who are conditioned to expect regular right turn off-ramps. For this reason, left turn off-ramps should be avoided. These interchanges require large amounts of right-of-way and they are the most expensive of all, due to the multiple-level structures required. Because of their high costs, fully-directional interchanges are typically used only for system connections (freeway to freeway).

2.2.6 Semi-Directional Interchanges

This interchange type is very similar to directional interchanges but, in this case, one or more left-turn movements are handled by loop ramps or by non-direct connections. This means that left-turn movements may have a ramp requiring a significant deviation from the original travel direction but not as great as required by loop ramps. One of the possible configurations for this interchange type is shown in Figure 4.

2.2.6.1 Advantages

The advantages of using semi-directional interchanges are the same as for directional interchanges: shorter travel distances, higher speed, reduced weaving, increased level of service, more operational efficiency, and improved capacity. In this design, loops can be used; thus, it is adaptable to a wider range of geographical and right-of-way conditions than fully-directional interchanges.

2.2.6.2 Disadvantages

These interchange types offer the same disadvantages of the directional interchange in terms of cost, right-of-way, and unusual left-turn ramps. In addition, they may not eliminate weaving effects at all due to the presence of loop ramps.

2.3 COUNTERMEASURES FOR REDUCING QUEUES AT FREEWAY OFF-RAMPS

The countermeasures for reducing queues at freeway off-ramps obtained from the literature review are presented in this section. These countermeasures were classified with respect to freeway operations, arterial operations, and off-ramp operations approaches

2.3.1 Improvement of Freeway Operations

The countermeasures covered by this approach are related to demand reduction, or demand re-routing. This can be done by suggesting the drivers take certain actions to improve the operation of the freeway. In some cases, these actions may be enforced to attain a target performance on the operations. By reducing the demand on a particular off-ramp, the queue growth onto the freeway may be delayed or controlled.

2.3.1.1 Apply Variable Message Signs

One approach is to provide information to motorists via variable message signs (VMS). Detailed information on VMS can be found in Daganzo [10], Chateerjee [11], Wardman [12], and Hagen [13]. Wardman [12] for instance, the driver responses to VMS were investigated in terms of route choices. The study concluded that delay time is highly valued by motorists. This means that, if provided with information regarding possible delays due to downstream off-ramp excessive queues, some motorists will try to find alternate routes to avoid the severe congestion. Details on traffic diverting strategies are given in references [14] through [18]. These studies show the importance of using VMS to improve the performance of freeways and off-ramps

2.3.1.2 Use Ramp Metering

Ramp metering is the use of traffic signals at freeway on-ramps to control the rate of vehicles entering the freeway. The metering rate is set to reduce or optimize freeway flow and minimize congestion. The metering rate can be fixed or responsive to local or system-wide conditions. Further documentation on this topic is given by Daganzo [10], Lei [19], Smaragdis [20], and

Carvell [21]. In Lei [19], the author develops an analytical framework for ramp metering under which various ramp control strategies can be viewed as ramifications of the same most-efficient control logic with different threshold values, control methods, and equity considerations. The author utilizes off-ramp queues as a tool to determine the control logic for the upstream ramp meters.

2.3.1.3 Apply High Occupancy Vehicle (HOV) Lanes

Another approach to reduce demand and improve freeway flow was the use of HOV lanes. Dahlgren [22], describes where are High Occupancy Tolls (HOT) and HOV lanes should be located to provide the best possible benefit. According to Dahlgren [22], proper utilization of HOT reduces freeway congestion, increases utilization of HOV lanes, and generates revenue. In Dahlgren [23], the author challenges the idea of HOV lanes being always effective and determines the circumstances in which it is better to use normal lanes instead. Additional information regarding HOV lanes can be encountered in Daganzo [10].

2.3.1.4 Adopt Transportation Demand Management strategies (TDM)

Transportation Demand Management (TDM) techniques are defined as the activities in which the movement of traffic is controlled by altering the designated use of road space, Meyer [24] .The topic of TDM has been well studied and documented in the literature. Carpooling is an example of such activities. Carpooling behavior and optimal congestion pricing in a multilane highway with or without HOV lanes is studied in Hai [25]. This paper shows that a uniform toll for all vehicles (independent of their number of occupants) should be charged to achieve the best traffic flow in the absence of HOV lanes. However, in the presence of HOV lanes, the best flow is achieved by differentiating the toll per vehicle across segregated lanes. Telecommuting and pricing schemes are other examples of TDM. Congestion pricing appeared to be an effective countermeasure to reduce freeway demand, but is not popular due to technical and political reasons. An example of congestion pricing is given in “I-35W/Crosstown Concept Study”, Minnesota Department of Transportation [28]. In Safirova [26] and Hitoshi [27], the concept of telecommuting is defined under the TDM umbrella and its benefits are accounted. Due to the extremely high utilization of mass transportation services in Tokyo, Japan (i.e., long waiting times to get into a bus),Hitoshi [27] discusses the positive impact that telecommuting has on mass transit congestion. According to the authors’ estimates on the number of people that will be telecommuting by the year 2010, Tokyo will see a 6.9 - 10.9 percent reduction in congestion.

2.3.1.5 Use Variable Speed Limit Signs

Variable speed sign (VSS) is another countermeasure studied in the literature to alleviate congestion. Smulders [29], proposed a control policy that optimizes the throughput of the freeway section and succeeds in postponing congestion. In Allessandri [30], an optimal control problem is stated for variable speed signaling in order to improve traffic behavior near congestion. These studies proved the efficiency of VSS in decreasing traffic congestion. Further details related to VSS are given in Davey [31] and Lin [32].

2.3.1.6 Apply Dynamic Off-Ramp Management

The dynamic off-ramp management strategy was suggested in some of the literature Daganzo [10] and Prevedourous [33]. The paper indicated that it is suitable for freeways that carry an unusually high demand for some off-ramps over a relatively short period of time e.g., a special event such as a football game in a nearby stadium. In this case, the exit queues at preferred ramps may back up, forming a queue that entraps non-special-event traffic and causing great system-wide congestion. This strategy suggests temporally closing the off-ramp, diverting the traffic to less-congested ramps located downstream. The off-ramp closure could be in the form of advice or mandatory.

2.3.1.7 Use of 511 Calling System and/or Highway Advisory Radio (HAR)

The Federal Communications Commission designated 511 as the single traffic information telephone number for use by states and local jurisdictions on July 21, 2000. Travelers can dial 511 to access current information for specific routes and roadway segments, including anticipated travel delays, traffic accidents, roadway blockages and lane closures. HAR is another way to communicate travel information to motorists. Further details are provided in Florida Department of Transportation "Florida Statewide 511Conceptual Plan Design" [34] and US Department of Transportation , "511 Traveler Information" [35]. Details on traffic diverting strategies are given in references [15], through [18].

2.3.1.8 Provide Frontage Road along the Bottleneck Section of the Freeway

An interesting approach to reduce traffic demand and improve congestion in freeways was the use of frontage roads. Kockelman et al. [36], conducted a study to assess frontage road design policies and the operational issues associated with such policies. The study concluded that frontage roads may improve the operation of the mainlines in intensely developed areas, depending on interchange design, spacing, and traffic loads [36].

2.3.1.9 Apply Major Geometric Improvements

One of the countermeasures that significantly affects the performance of the operations at congested freeway off-ramps is geometric improvement. Building another off-ramp or interchange near a congested off-ramp is the most effective way to reduce large exiting traffic volumes. This is, in general, a long-term countermeasure due to its high implementation cost. In certain urban areas, the implementation cost of this kind of countermeasures is more expensive than usual due to the development in the interchange areas and thus high costs for right-of-way.

2.3.2 Improvement of Arterial Operations

The objective of this approach is to increase the flow rate of vehicles entering the artery from the off-ramp. This can be achieved through improving signal operational efficiency at the off-ramp terminal, alleviation of arterial congestion, and applying access management on the crossroads near freeway interchanges.

2.3.2.1 Increase the Green Time for a Congested Off-Ramp

In many cases, the amount of green time given to motorists at the off-ramp terminal intersection is not enough, due to outdated timing plans and an increase in off-ramp volumes. The most direct countermeasure is to properly increase the amount of green time for motorists to clear the off-ramp; therefore increasing the off-ramp discharge capacity should reduce the occurrence of queue spillback into the freeway. Related information is provided in Lin et al. [14], Lin et al. [15], Cassidy et al. [40] and Morales [41].

2.3.2.2 Use Volume-Density's Gap Reduction Feature

The queue problem at off-ramps sometimes is due to unexpected early signal gap-outs from slow-moving vehicles such as heavy trucks, trailer and construction vehicles if the passage time (extension time) is not set long enough to extend the green time. The off-ramp queue may continue to spill back to the freeway mainline throughout the entire peak hour period because of just one or two such unexpected signal gap-outs in the early stage of the period. This type of queue problem may be mistaken as a major capacity problem. However, the problem can be easily minimized or eliminated by applying volume-density features at the terminal signals Engelbrecth et al. [42].

2.3.2.3 Use Monitoring Cameras to Improve Responsiveness

Any incident on or near an interchange can easily cause off-ramp and arterial congestion. The key to minimize this type of traffic congestion is a prompt response to the incident by the appropriate agencies. Arterial signal timing plans also should be properly adjusted. For arterial management, closed-circuit television cameras play an important role in monitoring traffic flow, detecting incidents and providing direct visual feedback to any action taken for traffic management [43].

2.3.2.4 Provide Better Signal Coordination on the Arterial

Inefficient traffic signal operations on an arterial increase the probability of queues from off-ramps reaching freeways. Heavy traffic congestion on an arterial road can prevent the discharge of vehicles from an off-ramp. A logical solution to this problem is to optimize signal timings on the local arterial connecting to the off-ramps. According to Morales [41], traffic signal improvements rank as one of the most cost-effective strategies in urban areas. To achieve the biggest benefits from signal modifications in terms of traffic flow, adjacent signals must be coordinated in order to prevent queues from forming. A control technique to improve signal coordination was developed in Kosonen [44]. With this approach, signals operate individually as agents and negotiate with other signals about the control strategy. The decision making of the agents is based on fuzzy inference that allows a combination of various aspects like safety and flow. In Abu-Lebdeh [45], the author presents the formulation and solution of a new algorithm for queue management and coordination of traffic signals along oversaturated arterials. The results show that the algorithm can produce dynamic and responsive control so that traffic progression is attained and all undesirable conditions (i.e., queue spillback) are avoided. A practical example of signal coordination is provided in Lin et al. [46].

2.3.2.5 Reduce Queues of Turning Lanes on the Arterial near Off-Ramps

Excess queues from left-turn or right-turn lanes at downstream signalized intersections on an arterial near freeway interchanges are another possible cause of arterial congestion, which cause the queue problem at off-ramps. Different signal timing strategies such as traffic signal coordination, lead-lag left-turn operation for a coordinated signal, shorter cycle length, and longer left-turn green time can be applied to minimize the effect of queue blockage problem. Further details are found in Courage et al. [47] and Lin [48].

2.3.2.6 Remove Signals on the Arterial near Interchanges

Another way to improve traffic operations in arterial sections is to remove unnecessary traffic signals. According to Morales [41], traffic signals should be removed if they are no longer warranted due to changed traffic volumes. Removal of a traffic signal requires detailed studies in order to determine its impact on traffic flow and safety. Another reason to remove a traffic signal is when it is too close to the off-ramp terminal intersection. Signalized intersections close to ramp terminals may cause heavy volumes of weaving traffic, complex traffic signal operations, accidents, congestion, and traffic backing up the ramps on to the mainline [49]. However, this countermeasure is not popular to the general public or the affected land owners.

2.3.2.7 Adopt of Access Management on Crossroads near Interchanges

The adoption of access management is especially important to limit direct access to major arteries, and regulate the signal spacing as well as median openings on crossroads near interchanges. It can help provide an efficient and safe roadway transportation system. According to the FDOT Access Management and Site Circulation Regulations, the minimum distance to the first connection from the terminus of the off-ramp shall be at least 660 feet (1/8 mile). This distance may be long enough to minimize potential weaving problems from the off-ramp to the left-turn bay of the first median opening or signalized intersection. By implementing access management regulations especially in the vicinity of interchange ramps, the ramp terminal intersection can discharge vehicles onto the artery in a safe and efficient manner. This should help to reduce the possibility of queues spilling back onto the mainline of the freeway. Related information on this countermeasure can be found in Williams et al.[49], Rules of the Department of Transportation [50], and in the Access Management Manual [51].

2.3.3 Improvement of off-ramp operations

The third fundamental approach to alleviate the off-ramp queue problem is to increase the storage capacity either on the off-ramp or its associated freeway segment or deceleration lane. The storage capacity at the off-ramp can be increased in general by the lengthening of existing turn lanes or addition of extra lanes.

2.3.3.1 Increase of Off-Ramp and Freeway Storage Capacities

When an off-ramp queue spills back to a freeway mainline, it is common to see motorists who are waiting to enter the off-ramp naturally use the shoulder as a temporary storage lane to avoid directly stopping or slowly moving on the outside lane of a freeway when most upstream vehicles are traveling with relatively high speeds. It is necessary to mention that the use of shoulder lanes as travel lanes to improve freeway congestion has been evaluated with positive results. The Freeway Management and Operations Handbook [37] indicates that significant increases in capacity (up to 30 percent) are possible. Further information on related countermeasures can be found in Carvell et al. [21], Butorac et al.[38], and in UK Highway Agency [39].

2.3.3.2 Reassign Lane Usage on the Freeway at the Diverge Gore

In some cases, the off-ramp has two or three receiving lanes but the freeway has only one or two exclusive exit lanes. One way to ensure the off-ramp capacity is fully utilized is to examine whether the resources (lanes) at the off-ramp are efficiently utilized. Proper lane usage assignment will increase the freeway exit capacity [10]. At the same time, it is important to satisfy lane balance requirements as indicated by AASHTO [1].

2.3.3.3 Add turn lanes at the of-ramp terminal intersection

When the capacity on an arterial allows the discharge of more vehicles, then it may be possible to increase the capacity at the ramp terminals by constructing additional lanes or extending the existing turning lanes [10]. The former has a greater impact than the latter because it utilizes the green time more efficiently.

3 ASSESSMENT OF CURRENT PRACTICE IN FLORIDA

3.1 OVERVIEW

The assessment of current practice in Florida is mainly through the survey and interviews with FDOT Districts and the Florida Turnpike Enterprise. A comprehensive survey was designed and conducted among the seven FDOT Districts and the Turnpike Enterprise in 2005 in order to understand the causes of queues spilling back into the mainline and the countermeasures used in solving these problems.In-depth personal interviews with traffic operations engineers and their staff were followed to obtain specific off-ramp problems, their associated successful countermeasures, and the philosophy of each FDOT District for reducing queues at off-ramps. The results from the survey were also used for the site selection for case studies. The interviews also provided critical information that aided the research team in building the toolbox

3.2 METHODOLOGY

To assess the current practice in Florida to reduce queues at freeway off-ramps, a survey and personal interview were conducted for each FDOT District and the Florida Turnpike Enterprise. The potential countermeasures listed in the survey questionnaire were mainly based on the results of the previous literature review. In the survey questionnaire, each District was asked to provide additional successful countermeasures if they were not on the list of countermeasures. Based on the results of surveys, an in-depth personal interview was scheduled and conducted with each FDOT District Traffic Operation Engineer and his/her staff. This personal interview provided an excellent opportunity to verify the survey results, clarify specific questions, understand the characteristics of each District, comprehend problematic interchanges, and obtain successful countermeasures and the philosophy behind them. Based on the comprehensive literature review, detailed survey, and in-depth personal interviews with FDOT Districts and the Florida Turnpike Enterprise, a thorough list of potential countermeasures was obtained and used for the development of a toolbox for reducing queues at freeway off-ramps.

3.3 SURVEY OF SEVEN FDOT DISTRICTS AND FLORIDA TURNPIKE ENTERPRISE

The purpose of the survey among the different FDOT Districts and the Turnpike was twofold: to understand the characteristics of the current and past problematic freeway off-ramps in terms of queues backing up into the freeway, and to assess the effectiveness of the countermeasures used to alleviate the specific problems. The survey also helped to identify the locations with congested off-ramps in each FDOT District. These problematic off-ramps were potential candidates for case studies; final site selection for case studies also was dependent on data availability. Detailed case studies are presented in Chapter 4.

The survey was composed of 14 questions, categorized into four main areas: general description of the freeway system, location and description of the main problematic interchanges, countermeasures used, and data collected. A sample of the survey questionnaire is provided in Appendix A. Emphasis was placed on obtaining information about the causes of off-ramp queues backing up into freeways and about the countermeasures that were successfully tried and yielded positive results. The survey questionnaire is provided in Appendix B.

3.4 SURVEY RESULTS AND ANALYSIS

Table 1 shows the major causes of queue spillbacks in ranked order. The ranking is based on the number of times that each cause was selected by the Districts. Figure 5 shows the number of times that each major cause of spillback was selected in the survey by the FDOT districts. The graph shows that capacity problems and lane blockages due to arterial traffic rank as the major contributors for off-ramp traffic extending to freeways. The surveys with the Districts responses are presented in appendix C.

Table 1: Causes for Queue Spillback

Ranked ID	Major Causes of Queue Spillback
1	Capacity problems at the off-ramp terminal intersection
2	Not enough storage space at the off-ramps
3	Lane blockage problem of downstream intersections on the local artery
4	Inadequate signal spacing on the artery near the freeway off-ramp
5	Not enough green time allocated to off-ramps at the terminal intersections
6	Inefficient operation of off-ramp lane assignments at the terminal intersections
7	Frequent signal pre-emption at the off-ramp terminal intersection
8	Other

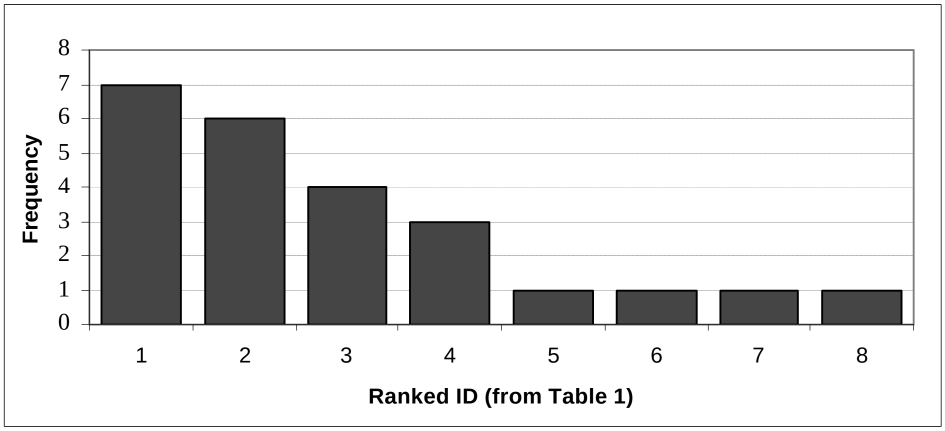


Figure 5: Frequency of Causes of Queue Backed Up to Freeways

The survey asked each District to select which of them have been used successfully in terms of decreasing the occurrence of queue spillbacks. Figure 6 shows the results, which indicate that geometric improvements (i.e., adding lanes) and signal timing improvements are among the best solutions tried so far. The complete list of countermeasures provided in the survey is shown in Table 2.

Table 2: List of Countermeasures

Index	Countermeasures
1	Increase capacity through reconstruction at off-ramp terminal intersections
2	Increase capacity through lengthening storage lane lengths for off-ramp approaches
3	Adjust signal timing plans on arterial signals adjacent to the freeway off-ramps
4	Lengthen left/right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps
5	Increase green time on the off-ramp approach at off-ramp terminal intersection
6	Retime signals on the local artery to provide better signal coordination
7	Install variable message signs (VMS) on the freeway to warn the upstream traffic about downstream congestion
8	Provide signal coordination in a way that the progression of traffic flow is from the off-ramp approach to artery
9	Disseminate real-time traffic conditions through website, Highway Advisory Radio (HAR), or/and 511 to motorists
10	Increase capacity through lane reassignment at off-ramp terminal intersections
11	Build additional lanes on the freeway leading exiting traffic to the off-ramp
12	Allow right turn on red from the off-ramp approach at the terminal intersection
13	Apply Transportation Demand Management (TDM) strategies such as bus, carpool,
14	Use toll roads to ease traffic demand, so it reduces traffic volume at off-ramps
15	Use freeway or off-ramp monitoring (CCTV) cameras for a congested off-ramp and take proper action to reduce the queue
16	Use VMS to divert traffic into alternative routes during a freeway incident
17	Increase efficiency through lane reassignments at the freeway diverge gore

Index	Countermeasures
18	Use detectors to monitor off-ramp queues. Preempt the off-ramp terminal intersection if the queue reaches a critical location
19	Use HOV lane to encourage carpooling to reduce traffic demand on freeways
20	Use upstream on-ramp metering to slow down the increase of traffic demand
21	Reduce posted speed limit for freeway bottleneck sections near the congested off-ramps
22	Use changeable posted speed limit signs instead for the above Countermeasure11
23	Devote some freeway shoulder lanes to queues backed up from the off-ramp
24	Build frontage road along the freeway bottleneck section to reduce demand
25	Build another off-ramp near the off-ramp with severe queue problem

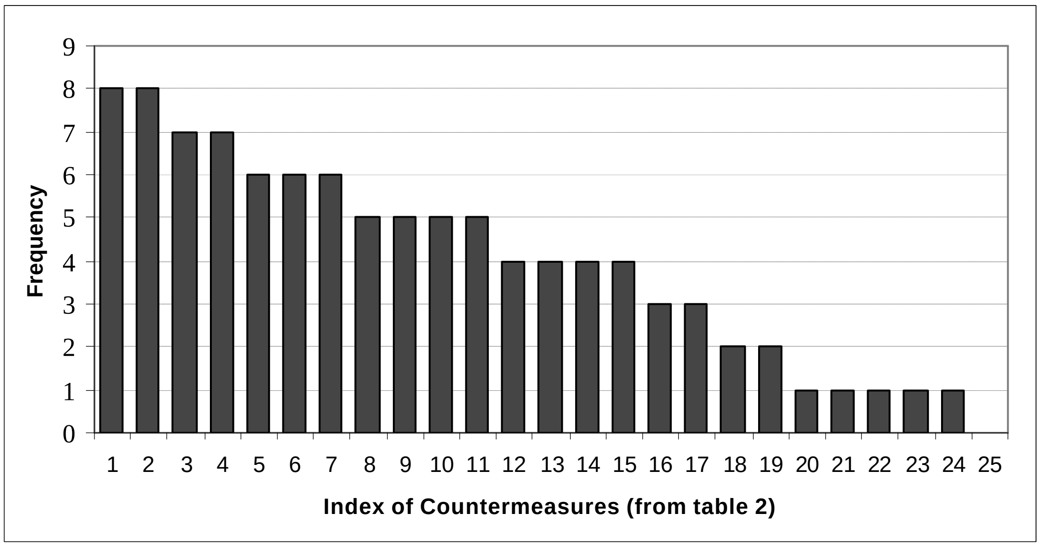


Figure 6: Frequency of Selection of Countermeasures

The survey also asked each District to list the three most successful short-term and long-term countermeasures. Table 3 and Table 4 list the resulting countermeasures in ranked order. The ranking is based on the number of times that each countermeasure was selected by Districts. Figure 7 and Figure 8 show the results of ranking based on the frequency and reach the same conclusion, that geometric and signal timing improvements are the best solutions so far. The most successful short-term countermeasure is signal timing improvement, while geometric improvement is the most successful long-term countermeasure.

Table 3: Short Term Countermeasures

Index	Short-Term Countermeasures
1	Signal timing at arterial section
2	Signal timing at off-ramp terminal intersection
3	Add lanes to ramp
4	Re-design the Intersection
5	Redesign lane assignments
6	CCTV monitoring
7	Pre-emption of the exit ramps
8	Extend the deceleration lanes (freeway)
9	Mobile ITS applications

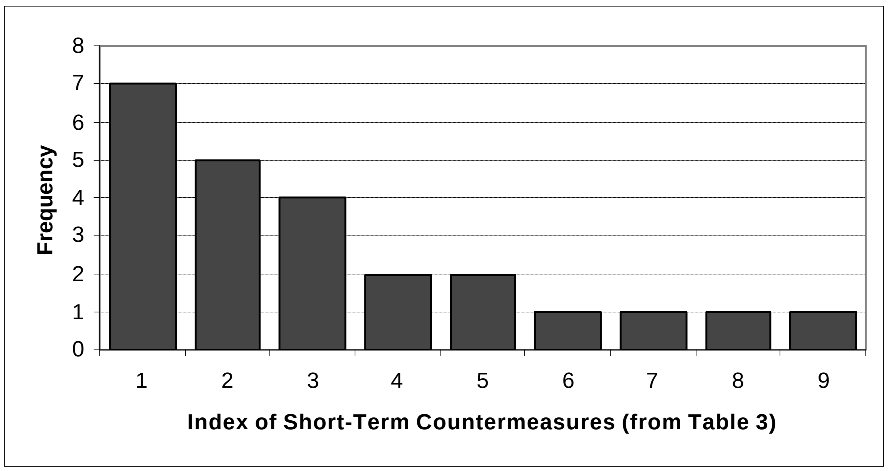


Figure 7: Frequency of the Selection of Short-Term Countermeasures

Table 4: Long-Term Countermeasures

Index	Long-Term Countermeasures
1	Add lanes to off-ramp
2	Add lanes to arterial
3	Rebuild Interchange
4	ITS deployment
5	Retrofit single point interchange
6	Signal removal
7	Use separators at terminals
8	Build an additional interchange

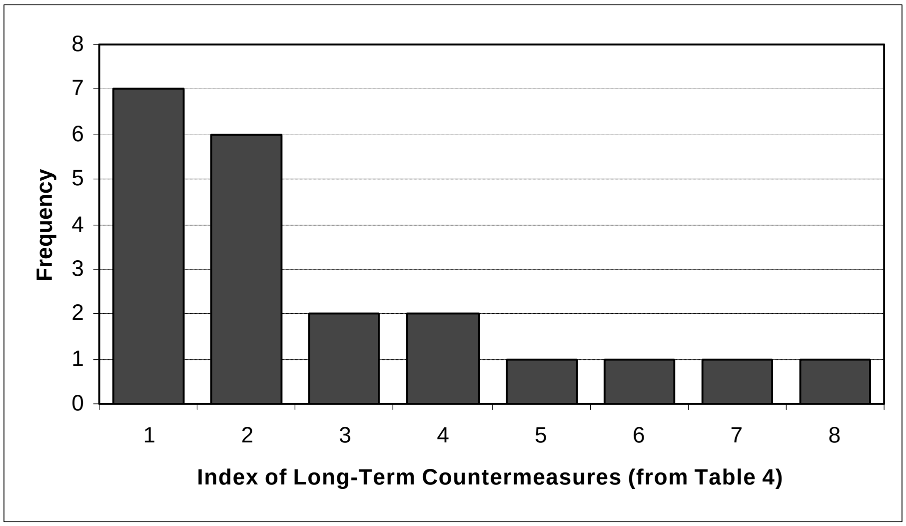


Figure 8: Frequency of the Selection of Long Term Countermeasures

3.5 IN-DEPTH PERSONAL INTERVIEWS WITH FDOT DISTRICT TRAFFIC OPERATION ENGINEERS

Interviews with the District Traffic Operations Engineers (DTOE) from FDOT districts were conducted to discuss in detail the survey results. FDOT District Three was unable to schedule the interview due to response to hurricane damages in the district. The interviews resulted in a much deeper discussion of the subject and a better understanding of the characteristics of the problematic interchanges, the causes of congestion, and the countermeasures to reduce queues at freeway off-ramps. This section provides a general description of the main subjects discussed in the interview with each district. A map of each district is provided below in Figure 9.

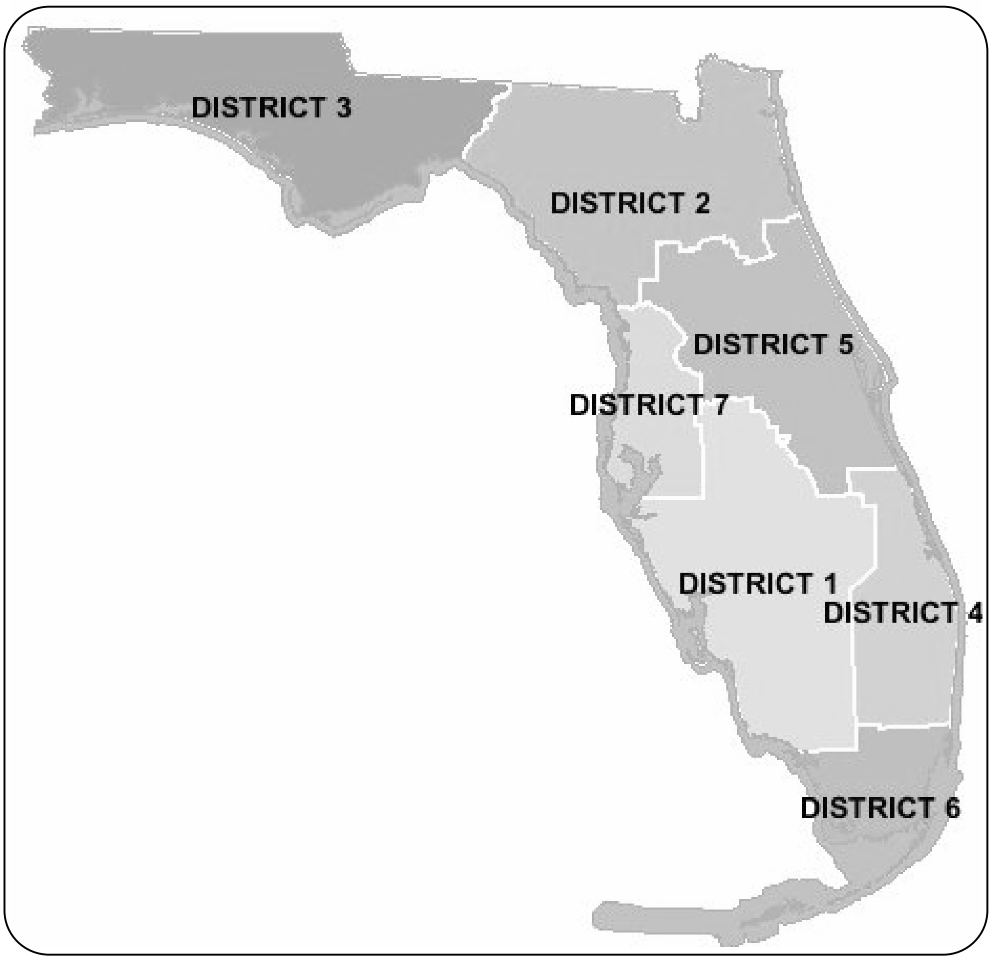


Figure 9: Map of FDOT districts

3.5.1 District 1

This district serves a total of 12 counties, as it can be observed in Figure 10. Most of the interchanges in this district are located in rural areas. The district has less than 50 total interchanges. Less than 10 percent of these interchanges have suffered from off-ramp queues extending into the intersecting freeway. The main problems reported by District 1 are capacity constraints in both the off-ramp and its terminal intersection due to recent significant increases in traffic volumes.

Figure 10: Map of FDOT District 1

One of the potential causes for excessive demand on particular off-ramps could be the limited use of VMS to provide travelers with information on traffic conditions in downstream freeway sections. Another cause of spillback is that there are traffic signals on the arterial that are too close to the off-ramp terminal intersection. This causes queues on the arterial to block the discharge of vehicles from the off-ramps. Signal timing improvements are the major strategies successfully implemented in District 1 to reduce off-ramp congestion. Minor geometric improvements at the off-ramp terminal intersection are used when funding is available.

An additional countermeasure under consideration by this district was the removal of any median opening or unwarranted traffic signal on arterials that are too close to the congested off-ramp terminal.

3.5.2 District 2

This district has a total of 18 counties. A map of this county is provided in Figure 11. The interchanges in this district are located in both rural and urban areas. The district has between 75 and 100 total interchanges. Between 10 and 25 percent of these interchanges suffer from off-ramp queues extending into the intersecting freeway on a recurring basis.

The main contributors for off-ramp queue spill backs onto the freeway are reportedly capacity-related problems in both the off-ramp and its terminal intersection, and lane blockages on the local artery. The lane blockage problems on arteries reduce the departure flow from off-ramps. This may be caused by traffic signals on the arterial roads being too close to the off-ramp terminal intersection.

Figure 11: Map of FDOT District 2

One unique countermeasure from this district consisted of encouraging lane-changes upstream of the back of the queue from the off-ramp, and banning last minute lane changes to "cut in" the queue. They implemented this by painting double solid white lines and thus preventing lane changes to or from the right-most lane approaching an off-ramp queue. This action was enforced with full support from the Florida Highway Patrol. The objective of this countermeasure was to effectively improve freeway congestion and manage off-ramp queues

Another particular countermeasure to alleviate queueing problems at the freeway off-ramps was the construction of quadruple right-turn lanes at an off-ramp to handle the off-ramp traffic with major destinations of trips located on the right side of the artery downstream of the off-ramp. This countermeasure is particularly useful when a large number of vehicles will make turns at several immediate downstream intersections. These kinds of designs provide a good channellization of traffic at the off-ramp to avoid significant uneven lane utilization, weaving, and queue problems

3.5.3 District 3

This district, has a total of 16 counties. Most of the interchanges in this district are located in rural areas. The district has less than 50 total interchanges. Less than 10 percent of these interchanges have suffered from off-ramp queues extending into the intersecting freeway. A map of this district is shown in Figure 12.

Figure 12: Map of FDOT District 3

3.5.4 District 4

This district comprises 5 counties as observed in Figure 13. Most of the interchanges in this district are located in urban areas. The district has more than 100 total interchanges. Less than 10 percent of these interchanges suffer from off-ramp queues extending into the intersecting freeway on a recurring basis.

In this district the main cause of off-ramp queues backing up to the freeway is the existence of railroad crossing sections in the adjacent area of the intersection of the off-ramp and the local road. This situation causes the need for more storage capacity to accommodate the waiting vehicles at the railroad crossing. The railway is located on the west of the I-95 interchanges. Moreover, in recent years, there have been some significant developments on the west side of Yamato Rd in Boca Raton which, in addition to the previously explained situation, constitute the major problem at this location. Another cause of extensive queues is the frequent occurrence of signal pre-emption at the off-ramp terminal intersection from emergency vehicles.

Figure 13: Map of FDOT District 4

The major countermeasures for this district include signal timing improvement, adding off-ramp capacity and implementing TDM and ITS technologies. One special proposed countermeasure by the District was to have the capability to allocate capacity in real time based the status of the roadway system. In this way, the District will be able to coordinate signals more appropriately. This is an ITS long-term solution due to the infrastructure it implies.

3.5.5 District 5

This district is composed of 9 counties. The interchanges in this district are located in both rural and urban areas. The district has more than 100 total interchanges. Less than 10 percent of these interchanges suffer from off-ramp queues extending into the intersecting freeway. A map of the counties forming this district is presented in Figure 14.

The types of the problematic interchanges in this district are typically diamond. Over the years, the increase in population has exceeded the capacity of these interchanges, which were designed to accommodate lighter traffic volumes. Another contributor to freeway spillbacks is the occurrence of queues on the arterial roads blocking the discharge of vehicles from the off-ramps. This may be caused by traffic signals on the arterial roads being too close to the off-ramp terminal intersection.

Figure 14: Map of FDOT District 5

In this District, the 511 traveler information system is well accepted by the public mainly because it is accurate, fast, and voice-activated. As an example of this, in the week that this interview took place, over 28,000 calls were made to 511, with an average call length of 48 seconds. It was mentioned that the average maximum delay time that motorists are willing to accept before deciding to use an alternate route is 10 to 12 minutes. Also, the District uses a high technology video monitoring system that covers all central Florida. The video data gathered are used by the Regional Traffic Manager to communicate information to motorists through VMS. Over 700 detectors are installed all over the District; most of them on I-4 near the Orlando area. The data collected daily are stored in a data warehousing system.

Ramp metering is not used on any of the on-ramps upstream of the respective problematic interchanges because it shows no overall benefit for th District. For example, due to the geometry of the interchange connecting I-4 with SR-436 and its demand-capacity ratio, metering the on-ramp would actually create an extensive queue that would block the off-ramp vehicles turning onto the arterial (SR-436). FDOT District 5 believes that, for ramp metering to be an effective countermeasure, it needs to be established as a system and not just for some isolated situations. In addition to not using ramp metering in the District's interchanges, the use of HOV lanes is another countermeasure that is not used because there are not enough lanes on the existing interstate highways and the use of HOV lanes will not be effective.

Another topic discussed briefly was I-Florida, currently an ongoing project. Some of the expected results from I-Florida are dynamic congestion pricing (charging different rates depending on traffic volumes and conditions) and forecasting real-time traffic using weather conditions, since it is known that weather has an impact on travel times and route selection.

3.5.6 District 6

This district has a total of 2 counties. The interchanges in this district are located in both rural and urban areas. The district has between 50 and 75 total interchanges. Between 10 and 25 percent of these interchanges suffer from off-ramp queues extending into the intersecting freeway. A map of this district is shown in Figure 15.

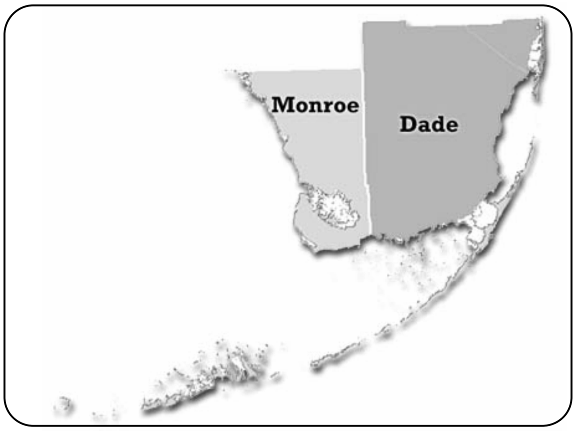


Figure 15: Map of FDOT District 6

District 6 utilizes the most variety of countermeasures. It is the only District that is in the process of implementing ramp metering in Florida. The District believes that improving or rebuilding a single interchange will not have a major impact in congestion. Only large-scale construction projects will help to ease the traffic congestion on off-ramps, interstate highways and local arterials for a significant period of time. Ramp metering, signal timing improvements, and major geometric improvements are the successful countermeasures in District 6. Currently, the District is aiming at travel demand management strategies, encouraging the use of the available modes of public transit like the tri-rail and bus service. District 6 also focuses on providing traveler information through VMS and 511 systems. Effective traffic monitoring and prompt incident response are another two major methods.

District 6 has a significant number of CCTV monitoring cameras and data collection stations located near congested freeway off-ramps. These data are stored in a database for future traffic analysis. Among the uses of this database are forecasting traffic demand for future roadway needs, identifying freeway bottleneck locations, using them for the 511 system and sharing traffic data with other agencies.

3.5.7 District 7

This district has a total of 5 counties, as shown in Figure 16. The interchanges in this District are located in both rural and urban areas. The district has between 75 and 100 total interchanges. Less than 10 percent of these interchanges suffer from off-ramp queues extending into the intersecting freeway.

Figure 16: Map of FDOT District 7

The main reported cause of freeway off-ramp queues backing up to the freeway in this District is the high occurrence of queues in the arterial roads blocking the discharge of vehicles from the off-ramps. This may be caused by traffic signals in the arterial roads being too close to the off-ramp terminal intersection, or improper coordination of traffic signals.

This District is expecting the deployment of ITS projects to take place in order to have more efficient ways to tackle the congestion problems by monitoring traffic conditions. This will benefit the implementation of countermeasures aiming to alleviate the congestion at freeway off-ramps. Currently, there are less than 10 CCTV monitoring cameras installed in this District near congested freeway off-ramps. In addition, less than 10 traffic data collection stations are located near congested freeway off-ramps. This number may significantly increase with the completion of the Hillsborough County Traffic Monitoring Center (TMC) which will network with other TMC's within the District as the Tampa Bay SunGuide Center. The type of traffic data collected automatically through the devices installed on specific freeway segments in this district are traffic volume, vehicle occupancy, vehicle classification, and speed.

Signal timing improvement is the short-term countermeasure successfully implemented at many locations of District 7. A comprehensive study [52] on the interchanges along the I-75 corridor suggested a set of geometric improvements at off ramps or terminal intersections in District 7. Some of these improvements are under consideration, and some have been approved. These are medium-to-long-term projects that will help to ease the off-ramp queue spill back problem.

3.5.8 Turnpike Enterprise

Most of the interchanges are located in urban areas. The Turnpike has between 50 and 75 total interchanges. It goes through most of the FDOT districts as observed in Figure 17. Between 10 and 25 percent of these interchanges suffer from off-ramp queues extending into the intersecting freeway

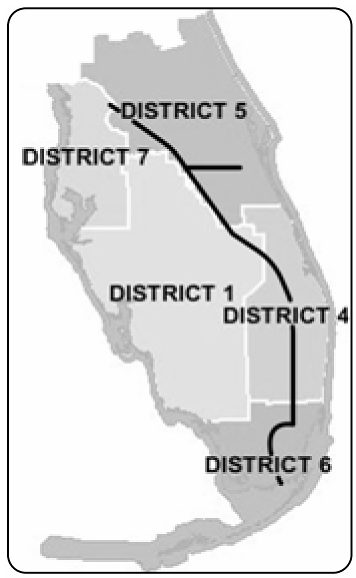


Figure 17: Map of Florida's Turnpike

The most commonly encountered interchange type along the Florida's Turnpike is the trumpet interchange. This kind of geometry has a section in which both on-ramps and off-ramps travel side by side. This section is bounded by the arterial street where the traffic discharged. This feature allows tolling entering and exiting vehicles at a single point. For this reason this geometry is the most suitable for toll booth placement.

In general, the intersection with the off-ramp terminal is in the form of a "T" junction. After passing the toll booth, exiting vehicles can go either left or right at the intersection, causing weaving movements. The problem becomes serious if the length of the segment between the toll booth and the intersection is not long enough to allow lane change maneuvers. The queue often starts to spill back onto the main line during peak hours when there are schools or malls near the off-ramp.

To avoid rebuilding interchange , the Turnpike plans to build extra on-ramps or off-ramps where needed. At certain locations, the construction of an on-ramp improves the congested off-ramp given that the traffic flows are reduced and more green time can be provided to the exiting vehicles. The new ramps will improve the direction with the greatest congestion. To make its operation more efficient, the new ramp will collect the toll electronically by mean of the SunPass system.

3.6 CURRENT PRACTICE IN FLORIDA

This section summarizes the main countermeasures implemented by transportation practitioners throughout Florida. For each District, a brief summary is provided, comprising information regarding its size, major cause of queue spillback, and the countermeasures implemented or under consideration by the District.

3.6.1 District 1

The major causes indicated are capacity problems in both the off-ramp and its terminal intersection. To reduce the occurrence of off-ramp traffic spilling back into the freeway, the district has implemented the following countermeasures:

- Increasing the green time on the off-ramp approach at the off-ramp terminal intersection
- Adjusting the signal timing plans on arterial signals adjacent to the freeway off-ramps
- Retiming signals on the local artery to provide better signal coordination
- Providing signal coordination in a way that the progression of traffic flow is from the off-ramp approach to the artery
- Using detectors to monitor off-ramp queues automatically in order to preempt the off-ramp terminal intersection if the queue reaches a critical section
- Allowing right turns on red from the off-ramp approach at the terminal intersection.
- Lengthening left-turn and/or right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps
- Increasing capacity through reconstruction at off-ramp terminal intersections
- Increasing capacity through lengthening storage lane lengths for off-ramp approaches

The top two short-term countermeasures are improving signal timing in both the ramp and the arterial. The top three long-term countermeasures are adding lanes to a problematic off-ramp, rebuilding the interchanges, and efficient ITS deployment.

3.6.2 District 2

The major causes of off-ramp spillback in District 2 are capacity problems in both the off-ramp and its terminal intersection and lane blockage on the local artery. To alleviate the problem of freeway off-ramp queues backing up to the mainline, District 2 has implemented the following countermeasures:

- Increasing the green time on the off-ramp approach at the off-ramp terminal intersection

- Adjusting signal timing plans on arterial signals adjacent to the freeway off-ramps
- Retiming signals on the local artery to provide better signal coordination
- Providing signal coordination in a way that the progression of traffic flow is from the off-ramp approach to the artery
- Encouraging motorists to slow down or divert to alternate routes by using VMS
- Using VMS to divert traffic into alternative routes during a freeway incident
- Lengthening left-turn and/or right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps
- Increasing capacity through reconstruction at off-ramp terminal intersections
- Increasing capacity through lengthening storage lane lengths for off-ramp approaches
- Prohibiting lane changing to or from the right-most lane approaching an off-ramp queue area by painting double solid white lines

The top two short-term countermeasures are increasing green time, improving the signal timing (progression) downstream of a ramp. The top three long-term countermeasures are adding lanes to a problematic off-ramp, retrofitting with a single point interchange, and adding lanes to a minor road usually under an overpass by cutting into the sloped embankment.

3.6.3 District 3

No information on the current state of the practice could be properly assessed due to the hurricane response situation experienced by the District.

3.6.4 District 4

The major causes indicated are not enough off-ramp storage, inadequate signal system integration, and excessive signal preemptions. The countermeasures implemented by District 4 to cope with this problem are:

- Increasing green time on the off-ramp approach at off-ramp terminal intersection
- Allowing right turn on red from the off-ramp approach at the terminal intersection
- Applying TDM strategies such as bus, carpool, vanpool, telecommuting, and flexible work schedule
- Using HOV lanes to encourage carpooling to reduce traffic demand on freeways
- Using toll roads to ease traffic demand in order to reduces traffic volume at off-ramps
- Reduce arrival rates by installing VMS on the freeway to warn the upstream traffic about downstream congestion
- Disseminating traveler information by the use of highway advisory radio (HAR) and/or the 511 system.
- Lengthening left-turn and/or right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps
- Increasing capacity through lane reassignment at off-ramp terminal intersections
- Increasing capacity through reconstruction at off-ramp terminal intersections
- Increasing capacity through lengthening storage lane lengths for off-ramp approaches
- Increasing efficiency through lane reassignments at the freeway diverge gore

- Building additional lanes on the freeway leading exiting traffic to the off-ramp

The top two short-term countermeasures are improving the signal timing and using CCTV monitoring. The top two long-term countermeasures are widening off-ramps and increasing arterial capacity.

3.6.5 District 5

The major causes for off-ramp congestion are not enough off-ramp storage and lane blockages on the arterial roads. The countermeasures used by District 5 to reduce the queues at freeway off-ramps are listed below:

- Adjusting signal timing plans on arterial signals adjacent to the freeway off-ramps
- Retiming signals on the local artery to provide better signal coordination
- Using detectors to monitor off-ramp queues automatically to preempt the off-ramp terminal intersection if the queue reaches the critical location
- Applying TDM strategies such as bus, carpool, vanpool, telecommuting, and flexible work schedules
- Using toll roads to ease traffic demand to reduce traffic volume at off-ramps
- Reducing posted speed limit for freeway bottleneck sections near the congested off-ramps, hence reducing arrival rates of traffic at the off-ramps
- Using changeable posted speed limit signs
- Encouraging motorists to slow down or divert to alternate routes by using VMS
- Using VMS to divert traffic into alternative routes during a freeway incident
- Disseminating traveler information by the use of highway advisory radio (HAR), and/or the 511 system
- Lengthening left-turn and/or right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps
- Increasing capacity through lane reassignment at off-ramp terminal intersections
- Increasing capacity through reconstruction at off-ramp terminal intersections
- Increasing capacity through lengthening storage lane lengths for off-ramp approaches
- Building additional lanes on the freeway leading exiting traffic to the off-ramp

The top three short-term countermeasures identified are pre-emption of the off-ramps, improving signal timings at the intersections of arterial with off-ramps, and extending the deceleration lanes. The top three long-term countermeasures identified are signal removal, adding capacity through construction, and using separators at the terminals.

3.6.6 District 6

The major causes of off-ramp spillback are capacity problems at the off-ramp terminal intersection and lane blockage on the arterial roads. The countermeasure used regularly to alleviate the problem of off-ramp queues spilling back onto the freeway are listed below:

- Adjusting signal timing plans on arterial signals adjacent to the freeway off-ramps

- Retiming signals on the local artery to provide better signal coordination
- Upstream on-ramp metering to slow down the increase of traffic demand.
- Applying TDM strategies such as bus, carpool, vanpool, telecommuting, and flexible work schedule
- Using HOV lanes to encourage carpooling to reduce traffic demand on freeways
- Using toll roads to ease traffic demand to reduce traffic volume at off-ramps
- Reduce arrival rates is installing VMS on the freeway to warn the upstream traffic about downstream congestion
- Disseminating traveler information by the use of highway advisory radio (HAR), and/or the 511 system.
- Lengthening left-turn and/or right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps
- Increasing capacity through lane reassignment at off-ramp terminal intersections
- Increasing capacity through reconstruction at off-ramp terminal intersections
- Increasing capacity through lengthening storage lane lengths for off-ramp approaches
- Building additional lanes on the freeway leading exiting traffic to the off-ramp
- Removing traffic signals

The top two short-term countermeasures identified are improving the signal timing and changing lane assignments at ramp terminals. The top long-term countermeasure identified was reconstruction of ramps.

3.6.7 District 7

The major identified causes for off-ramp spillback are capacity problems in both the off-ramp and its terminal intersection, inadequate signal spacing in the arterial near the off-ramp intersection, and too many traffic signals. To reduce the occurrence of off-ramp traffic spilling back into the freeway, the District has implemented the following types of countermeasures:

- Increasing green time on the off-ramp approach at off-ramp terminal intersection
- Adjusting signal timing plans on arterial signals adjacent to the freeway off-ramps
- Providing signal coordination in a way that the progression of traffic flow is from the off-ramp approach to the artery
- Allowing right turn on red from the off-ramp approach at the terminal intersections
- Applying TDM strategies such as bus, carpool, vanpool, telecommuting, and flexible work schedules
- Using toll roads to ease traffic demand in order to reduce traffic volume at off-ramps
- Reduce arrival rates by installing VMS on the freeway to warn the upstream traffic about downstream congestion
- Disseminating traveler information by the use of highway advisory radio (HAR) and/or the 511 system
- Lengthening left-turn and/or right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps
- Increasing capacity through lane reassignment at off-ramp terminal intersections
- Increasing capacity through reconstruction at off-ramp terminal intersections

- Increasing capacity through lengthening storage lane lengths for off-ramp approaches
- Building additional lanes on the freeway leading exiting traffic to the off-ramp
- Building frontage roads along the freeway bottleneck section to reduce demand
- Extending the merge section in the arterial to make it a through lane

The top three short-term countermeasures identified are adjusting signal timings at ramps to favor the ramp, adjusting timings of adjacent signals, and reallocating lane utilization at the ramp signal. The top three long-term countermeasures identified are adding lanes on the artery at the ramp, adding lanes on the ramp, and building additional interchanges.

3.6.8 Turnpike Enterprise

The major causes of off-ramp congestion identified are capacity problems in both the off-ramp and its terminal intersection and lane blockage on the arterial roads. The countermeasures used by the Florida Turnpike Enterprise to reduce the queues at freeway off-ramps are listed below:

- Increasing green time on the off-ramp approach at off-ramp terminal intersection
- Adjusting signal timing plans on arterial signals adjacent to the freeway off-ramps
- Retiming signals on the local artery to provide better signal coordination
- Providing signal coordination in a way that the progression of traffic flow is from the off-ramp approach to artery
- Allowing right turn on red from the off-ramp approach at the terminal intersection
- Installing VMS on the freeway to warn the upstream traffic about downstream congestion (including off-ramp queue backed up), encouraging motorists to slow down or divert to alternate routes
- Using VMS to divert traffic to alternate routes during a freeway incident
- Disseminating traveler information by the use of highway advisory radio (HAR), and/or the 511 system.
- Lengthening left-turn and/or right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps
- Increasing capacity through lane reassignment at off-ramp terminal intersections
- Increasing capacity through reconstruction at off-ramp terminal intersections
- Increasing capacity through lengthening storage lane lengths for off-ramp approaches
- Devoting some freeway shoulder lanes to queues backed up from the off-ramp

The top three short-term countermeasures are increasing queue storage, use of mobile ITS applications (particular countermeasure applied by the Florida Turnpike Enterprise), and signal timing improvements. The top three long-term countermeasures are increasing the capacity of interchanges, major geometric improvements, and use of ITS technologies.

4 COUNTERMEASURES LIST

Based on the literature review, the survey results and the personal interviews with FDOT districts and the Florida Turnpikes Enterprise, a potential countermeasures list was developed. The countermeasures list was divided according to the basic approaches to the problem of reducing queues at freeway off-ramps. The first approach is to reduce travel demand and improve freeway operations. The second one is to improve off-ramp departure capacity and alleviate arterial congestion. The last approach is to improve the off-ramp and freeway storage capacities for queues.

Table 5: Countermeasures Based on the Reduction of Travel Demand and Improvement of Freeway Operations

Reduction of travel demand and improvement of freeway operation
Reduction of freeway demand
• Use ramp metering strategy of upstream on-ramps
• Use and enforce high occupancy vehicle (HOV) lanes
• Install VMS on a freeway or an artery to inform motorists of the traffic congestion on freeways
• Provide 511 calling system and/or highway advisory radio (HAR)
• Apply Transportation Demand Management (TDM) strategies
• Use pricing to reduce demand
• Divert traffic from a bottleneck section or an incident location
• Build frontage road along the bottlenecked section of the freeway
• Build another off-ramp or interchange to reduce large exiting traffic volumes
Reduction of arrival speeds
• Reduce posted speed limit using static signs
• Reduce posted speed limit using variable speed limit signs
Improvement of freeway operations
• Apply dynamic off-ramp management
• Apply lane-changing restriction and implement lane assignment upstream of the off-ramp

Table 6: Countermeasures Based on an Increase in Off-Ramp Departure Capacity and Improvement of Arterial Operations

Increase in Off-Ramp Departure Capacity and Improvement of Arterial Operations
Increase in departure capacity at off-ramp terminal intersections
• Install a traffic signal at terminal intersection
• Increase the green time for a congested off-ramp
• Reassign the lane usage at an off-ramp terminal intersection
• Build additional lanes at the off-ramp to increase discharge rate
• Construct triple or quadruple right-turn lanes
• Apply split diamond interchanges
• Reconstruct the off-ramp terminal intersection to increase the capacity and efficiency
• Modify trumpet interchange by adding an extra ramp
Improvement of signal efficiency at off-ramp terminal intersections
• Use monitoring camera to effectively monitor the congested off-ramp and take proper actions to reduce the off-ramp queue
• Apply multiple cycling or short cycle length
• Pre-empt signals if an off-ramp queue reaches a designated point on the off-ramp
• Allow right-turn on red from the off-ramp at the terminal signalized intersection
• Use volume-density’s gap reduction feature
• Provide free right turns from the off-ramps to arteries with tapers or exclusive lanes
Alleviation of arterial congestion
• Use monitoring cameras to effectively manage congestion and respond to incidents
• Provide better signal coordination on the arterial
• Reduce queues of downstream turning lanes on the arterial near off-ramps
• Provide adequate turn lanes at downstream intersections or median opening on the arteries near interchanges
• Provide signal coordination from the off-ramp to the artery if it is more effective
• Remove signals on the arterial near interchanges
• Reduce response time to an arterial incident
• Properly manage school zones, work zones, and special events on arteries
• Add lanes on arteries near interchanges
• Add lanes to minor roads
Adoption of access management on crossroads near interchanges
• Ensure adequate signal spacing, median openings and connection on the roadways connected to freeway interchanges
• Adopt access management regulations on limited access interchange areas

Table 7: Countermeasures Based on the Improvement of Off-Ramp and Freeway Storage Capacity

Improvement of Off-Ramp and Freeway Storage Capacity
Increase of off-ramp storage capacity
• Lengthen existing turn lanes at off-ramp terminal intersections
• Add extra lanes at off-ramps
Increase of freeway storage capacity
• Dynamically use shoulder as a queue storage lane for a short recurring bottleneck
• Construct deceleration or exclusive exit lane(s) before a congested off-ramp
• Reassign lane usage on the freeway at the diverge gore

5 CASE STUDIES

5.1 OVERVIEW

This section is composed of Task 3-Initial Site Selection for Case Studies, Tasks 4-Before Studies, Task 5- Implementation, and Task 6- After Study. Some case studies in Task 5 involved the implementation of major geometric improvements that could not be completed within the time frame of this project. In those case studies, traffic microsimulation was used as a tool to conduct the before-and-after studies to ensure the consistency of the performance data collection for both, before and after studies. Four locations were selected for case studies to examine the application of some countermeasures. For each case study, the information regarding the location, problem description, before-and-after, data collection, analysis and countermeasure used is provided in the following sections.

5.2 SITE SELECTION FOR CASE STUDIES

The first step for a site selection was to determine which interchanges were the most congested in Florida. This issue was addressed as part of the survey carried out for assessing the state of the practice. Each District was asked to list the top three interchanges in terms of off-ramp congestion. This list is presented in Table 8. Maps of the problematic locations can be found in Appendix D. Each interchange was analyzed and considered from its geometry, problem causes and information availability. The availability of operational data also played an important role in selecting the definitive locations. The top problematic interchanges for each District are presented below:

Table 8: Top Congested Interchanges by District

Zone	Main Problematic Interchanges
District 1	I-75 & Fruitville Road, I-75 & Bee Ridge Road , and I-75 & Daniels Parkway
District 2	I-295 & US-17 and I-295 & SR-21
District 4	I-95 & Yamato Road and I-95 & Hollywood Road
District 5	I-4 & SR-434 ,I-4 & 436, ,and I-95 & SR-518
District 6	I-95 & Ives Dairy Road, SR-826 (Palmetto Exp.) & Bird Road, SR-826 (Palmetto Exp.) & Red Road, and SR-826 (Palmetto Exp.) & 67th Avenue
District 7	I-75 & Fowler Avenue, I-75 & SR-54, I-75 & Martin Luther King Boulevard, I-75 & SR-60, and I-75 & Big Bend Road
Turnpike	Turnpike & Commercial Boulevard, Turnpike & PGA Boulevard, and Turnpike & Hollywood Boulevard

A previous work, Garber et al. [9], showed that, in the United States, 62 percent of the interchanges are diamonds. Approximately the same proportion holds for the problematic interchanges presented in Table 8, according to a study carried out by the research team, Lin et al. [8]. Among the top congested interchanges across Florida, approximately 60 percent are diamonds. Moreover, the other prevailing interchange type among this list is the parclo geometry which also has diagonal off-ramps as the diamond interchange. A more detailed description of the problematic interchanges by shape and by ramp types in Florida can be encountered in Lin et al. [8]. In Florida, the majority of the causes for the spillback of the off-ramp queue to the freeway were capacity-related problems and downstream blockage on the arterial. The similarity among the problematic interchanges across the state of Florida limits the application of a variety of countermeasures. This implied that a subset of countermeasures is common to 60 percent or more of the congested scenarios. However, each case study still presents some particular features.

There was a tradeoff between diversity of interchange geometric configurations, information availability, and the possibility of actual implementation during the project timeframe. It was decided to include free-flow ramps as in the case study of I-75 & Fowler Avenue. The possibility of implementation was the determining criterion in the cases of I-75 & Big Bend Road and I-75 & Bee Ridge Road. The information availability on before conditions determined the selection of the I-95 and Eau-Gallie Blvd as one of the case studies. The selected locations along with the congested direction, ramp type and method of analysis are presented in Table 9.

Table 9: Selected Locations for Case Studies and Analysis Method

Location	Problem Direction	Ramp Type	Analysis Method
I-75 & Fowler Avenue	NB off-ramp –A.M.	Semi-direct	Simulation
I-95 & Eau Gallie Blvd	SB off-ramp-A.M.	Diagonal*	Simulation
I-75 & Big Bend Road	SB off-ramp-A.M.	Loop*	Simulation-Implementation
I-75 & Bee Ridge	NB off-ramp-P.M	Diagonal*	Implementation

* denote ramps with signalized intersections

5.3 METHODOLOGY TO CONDUCT CASE STUDIES

The following methodological approach to conduct the case studies covered Tasks 4-Before Studies, Task 5- Implementation, and Task 6- After Study. When proposed implementation was not possible within the project timeframe, such as major geometric improvements, microscopic simulation was used as the analysis tool. Each location constituted a case study for which the following analysis approach was adopted:

- Description of the case study: Qualitative assessment of the problem; the symptoms of the problems and their possible causes are explained.

- Methods for data collection and performance evaluation: It describes the analysis method used for each particular case study as well as the information needed.

- Before conditions analysis: This describes the conditions prior to the implementation of the countermeasure providing, performance measures such as queue length and delay when feasible.

- Proposed countermeasure: This is a description of the countermeasure to be used to overcome the queue spillback problem encountered. It includes reasons for which the selected countermeasure is suitable for the particular problem being treated.

- After conditions analysis: This section presents the performance measures after the implementation of the countermeasure.

- Conclusions: Additional insights are provided in this section for each case study. It also provides closing statements summarizing the most important features of the implemented countermeasure.

5.4 CASE STUDY 1: I-75 & FOWLER AVENUE INTERCHANGE

5.4.1 Description of the case study

The I-75 and Fowler Avenue interchange is located in Tampa Hillsborough County, Florida. The approximate coordinates for this interchange are Latitude 28.054115, and Longitude -82.353784 (decimal degrees). This interchange does not operate efficiently because there are major queuing problems on the northbound off-ramp of I-75 during the morning peak hour. The problem is mainly observed in the off-ramp vehicles from I-75 northbound heading westbound on Fowler Avenue. The off-ramp onto Fowler Avenue consists of a two-lane ramp leaving I-75, which then gets divided into two single-lane ramps, one of which heads in the eastbound direction and the other heads westward. Each ramp has an exclusive lane when they merge onto Fowler Avenue. In the case of the westbound section of the off-ramp, it merges onto Fowler Avenue close to its intersection with Morris Bridge Road. In addition, there are vehicles coming out of the I-75 southbound off-ramp merging westward onto Fowler Avenue's westbound traffic as shown in Figure 18. During the morning peak hour, the heavy westbound I-75 northbound off-ramp traffic, heading to Fowler Avenue and the close distance between the off-ramp merging point and the Morris Bridge Road intersection have contributed to the formation of a long queue on the off-ramp that at times backs up onto I-75. At the intersection, the cycle times have reached their maximum reasonable values and there is not much that can be done in timing to cope with the problem. During the congested period, some drivers coming out of the off-ramp attempt to merge into the through lanes or left turn lane on Fowler Avenue constituting an additional source of delay. The Morris Bridge over the Hillsborough River is located immediately just west of the intersection. This feature imposes constraints to the widening of the street, as can be observed in Figure 18. In the same figure, the lane distribution is also presented.

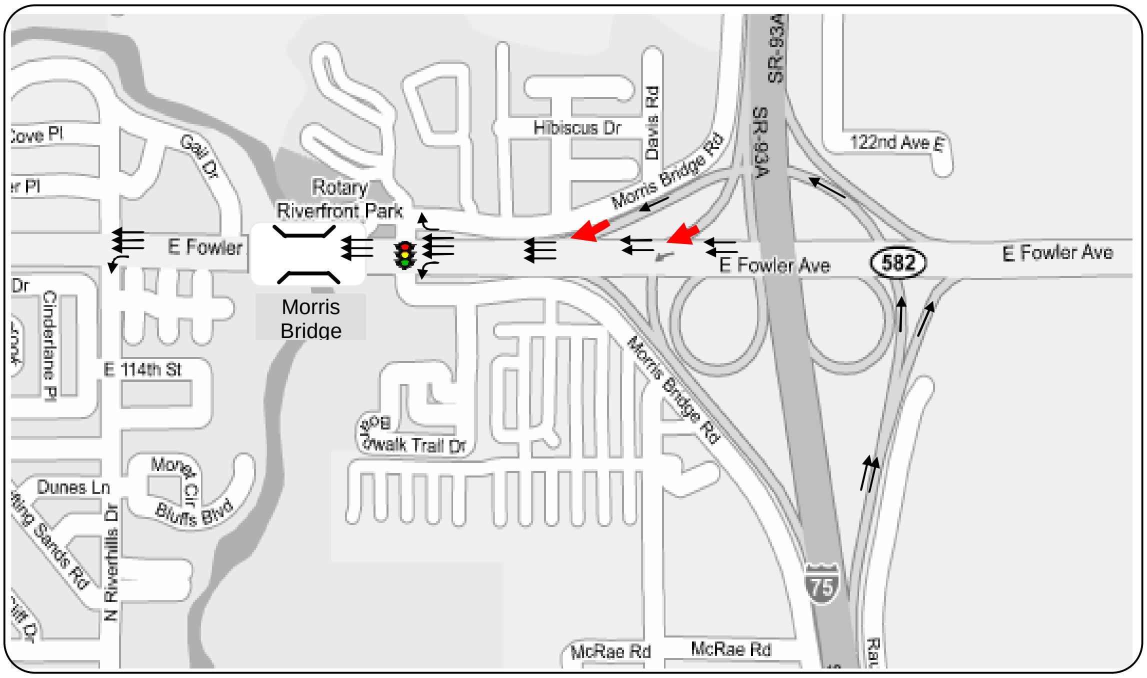


Figure 18: Existing Conditions of the I-75 & Fowler Avenue Interchange

5.4.2 Methods for data collection and performance evaluation

The proposed countermeasure for this case study involves major geometric improvements. The implementation of the countermeasure may take several years to get completed leaving the data collection for after implementation conditions out of the time frame for this project. To overcome this issue, microscopic traffic simulation was chosen as the analysis tool for this particular case. To keep the consistency between before and after conditions data, both situations were analyzed using the simulation approach.

The system under study is comprised of the I-75 & Fowler Avenue interchange, 1.3 miles of Interstate I-75, a section of Morris Bridge Rd, and 1.7 miles of Fowler Avenue. The measures of effectiveness selected for evaluating the performance of the countermeasures are average delay, average queue and 95th percentile of queue. The simulation model was calibrated to reflect the observed behavior and queue length on the surrounding area of the interchange object of study

For the model building phase, it was necessary to collect information related to the timing plan for the traffic signals in the area of interest. District 7 provided all the necessary information on this subject. The traffic volumes needed for the model were extracted from a report, FDOT District seven [52], and by field observations. The adjusted traffic volumes based on 2005 peak season traffic used in the simulation model are shown in Figure 19. Snapshots of the simulation model showing before and after conditions can be observed in Appendix E.

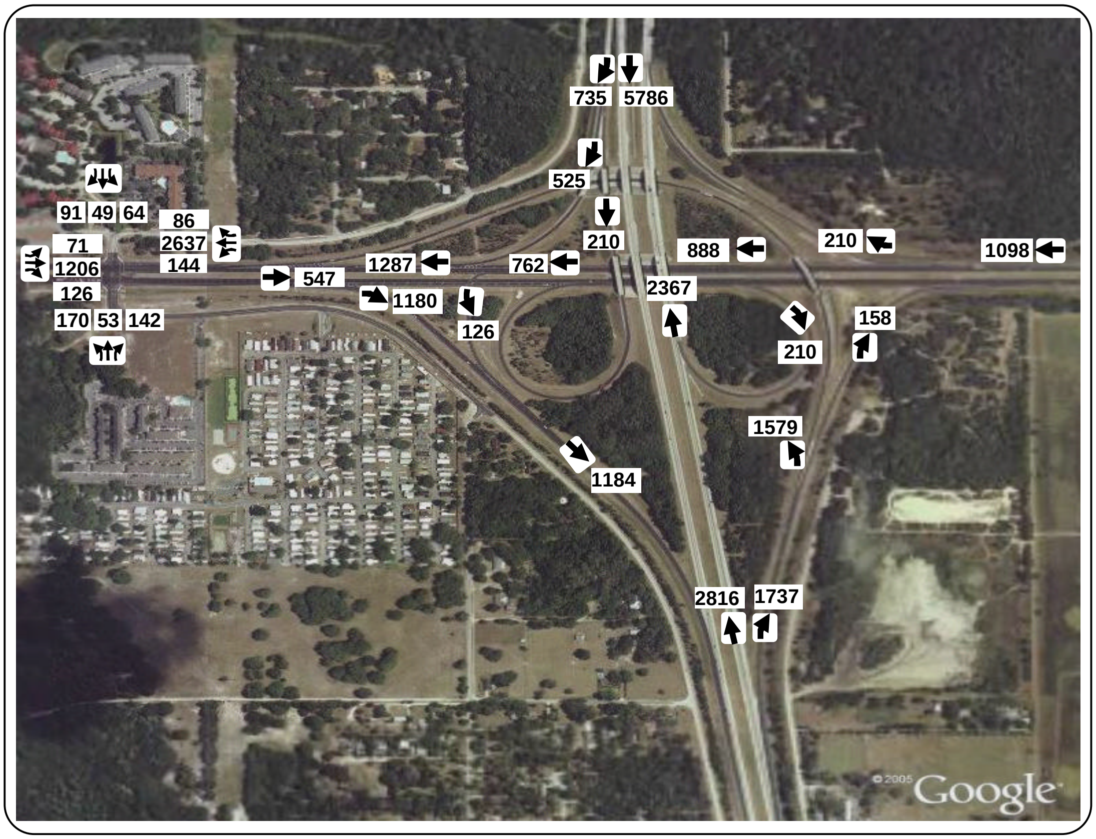


Figure 19: Traffic Volumes Used in the Simulation Model

5.4.3 Before conditions

A total of 20 runs of the model were made for both before and after conditions to account for the variance of the performance measures. The distribution of the delay along the ramp is shown in Figure 20. It is observed that there are two nodes, 43 and 24, experiencing relatively high delays with respect to the rest of the off-ramp sections. Node 43 corresponds to the ramp terminal, and Node 24 is a diverge gore area. The origin of the delay problem is in Node 43, and it propagates back up to node 24 where it increases significantly again. When the congestion on the westbound roadway of the off-ramp ramp reaches Node 24, vehicles from both traffic flows heading eastbound and westbound join the queue, increasing the delay on this section of the off-ramp.

The total delay on the ramp is 178.6 seconds on average, and its 95 percent confidence interval ranges from 162.5 sec to 194.7 sec. The frequency histogram for the total delay is presented in Figure 21.

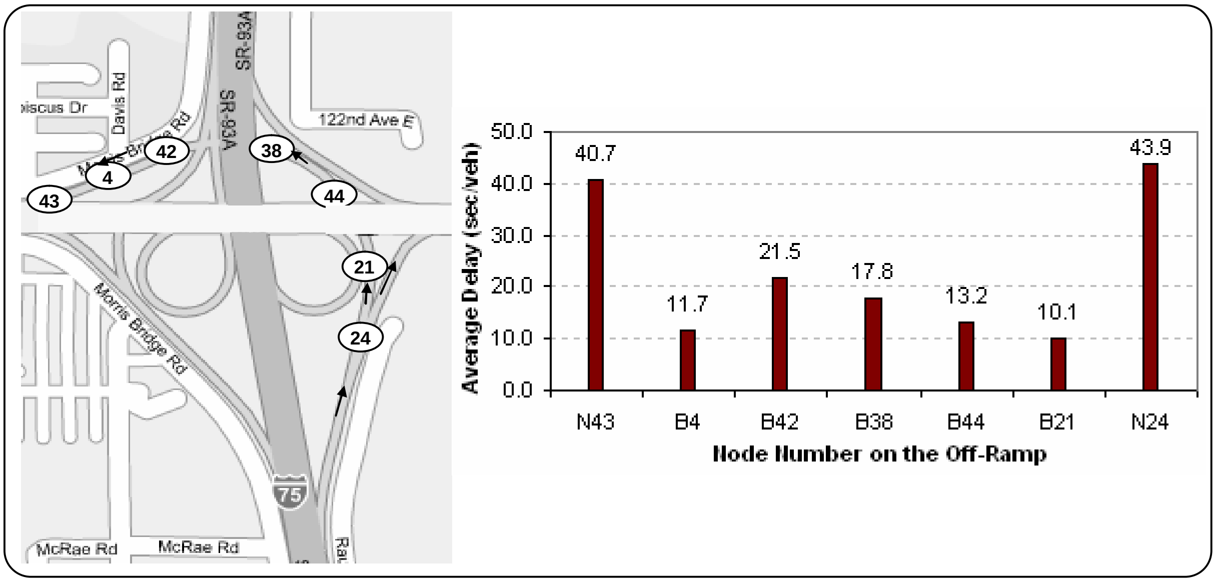


Figure 20: Distribution of the Delay on the I-75 Northbound Off-Ramp before Implementing the Countermeasure

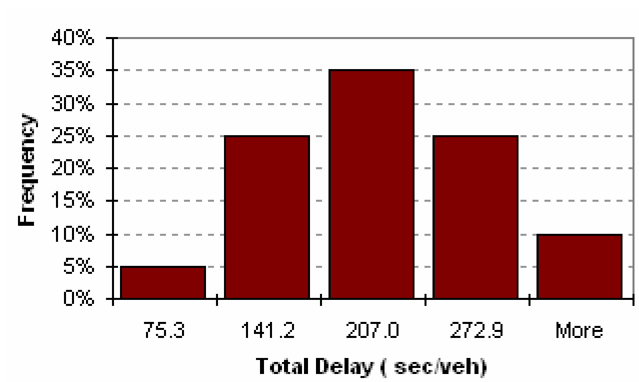


Figure 21: Frequency Distribution of the Total Delay on the I-75 Northbound Off-Ramp before Implementing the Countermeasure.

The average queue has a 95 percent confidence interval varying from 4394 ft to 5301 ft, with a mean of 4847 ft. The average storage utilization is about the 71 percent of the ramp capacity. It can be observed in Figure 22 that high queue length values in the simulation model are reflecting the queue length and driver behavior observed in the field.

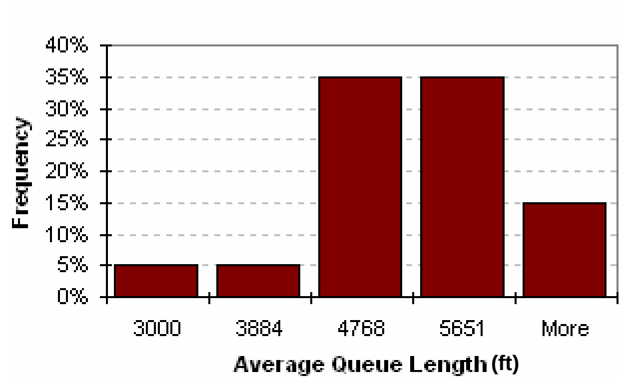


Figure 22: Frequency Distribution of Average Queue Length for the I-75 Northbound Off-Ramp before Implementing the Countermeasure.

The 95th percentile of the queue ranged from 2691 to 7457 throughout all the simulations and the median was 5623. In the median of the 95th percentile values the capacity utilization is about 83 percent.

5.4.4 Implementation of countermeasures

The proposed countermeasure from FDOT District 7 to overcome the queue problems at the I-75 northbound off-ramp fits into the category of geometric improvement. The proposed improvement consists of adding a 1576 ft lane at the northbound off-ramp terminal as shown in Figure 23. These two lanes will continue to the intersection with Morris Bridge Road where the rightmost lane will become a shared right-through lane. The new lane will also be extended 1400 feet past Morris Bridge to North River Hills Drive, where it will become an exclusive right-turn lane. It is observed that the westbound section of Fowler Avenue is constrained to a 3-lane roadway by the Morris Bridge; after the implementation of the countermeasure it will become a 4-lane section as depicted in Figure 23.

5.4.5 After conditions

Although the proposed geometric modification will be in place in the future, the improvement is assumed completed for analysis purposes. After implementing the proposed countermeasure in the simulation model, it is observed that the distribution of the delay along the ramp turns to a more uniform pattern when compared to the current conditions (see Figure 20). The delay values along the ramp are shown in Figure 24. The total delay has mean of 28.6 seconds and varies from 29.9 to 27.2 with a 95 percent of confidence. The frequency histogram for the total delay for the improved conditions is presented in Figure 25.

Figure 23: Proposed Improvements for I-75 & Fowler Avenue Interchange

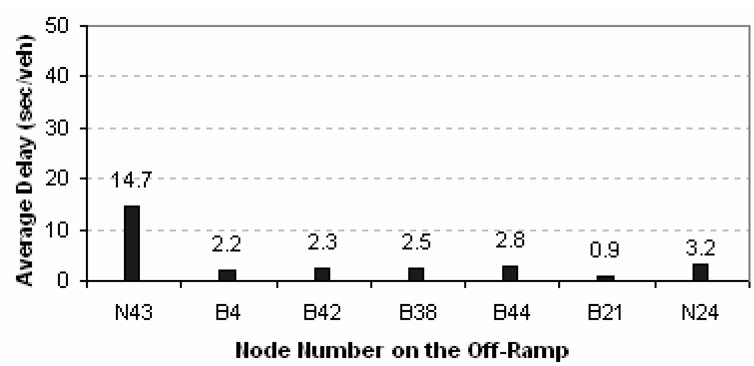


Figure 24: Distribution of the Delay on the I-75 Northbound Off-Ramp after Implementing the Countermeasure

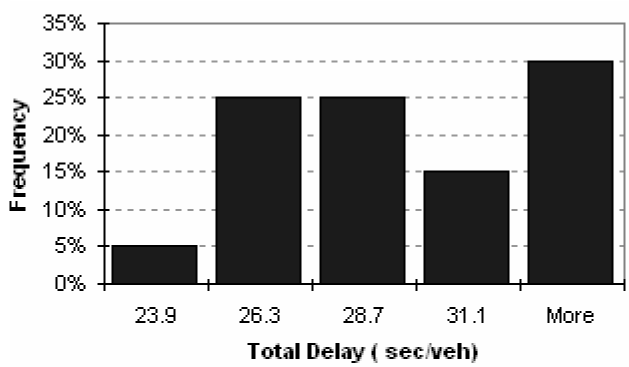


Figure 25: Frequency Distribution for the Total Delay on the Off-Ramp after Implementing the Countermeasure.

The average queue length has a mean of 33 ft at Node 43, which is a significant reduction of the queuing problems at this off-ramp. The frequency distribution of the average queue is shown in Figure 26.

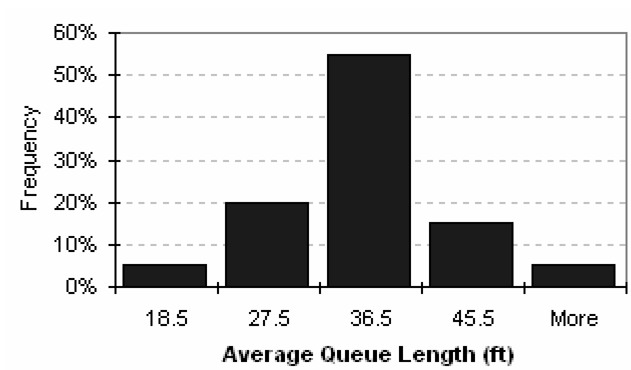


Figure 26: Frequency Distribution of the Average Queue for the I-75 Northbound Off-Ramp after Implementing the Countermeasure

5.4.6 Before-and-after Analysis

It is observed in Figure 27 that the average queue on the off-ramp for the before study has a high value and it is close to the ramp length, while in the improved conditions this value was significantly reduced. The 95th percentile of the queue is hovering around the ramp length which means that is not surprising to observe spillbacks of the off-ramp queue onto I-75.

The total delay in the ramp was reduced not only in magnitude but also in variability which makes the travel time estimates more reliable. A plot of the total delay versus run number for both, before and after conditions is presented in Figure 28.

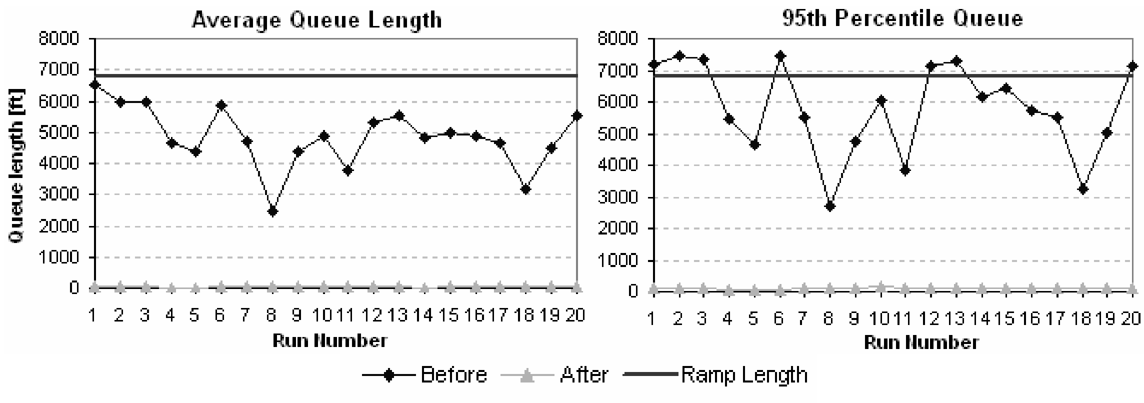


Figure 27: Average Queue versus Run Number (left) and 95th Percentile Queue Versus Run Number (right)

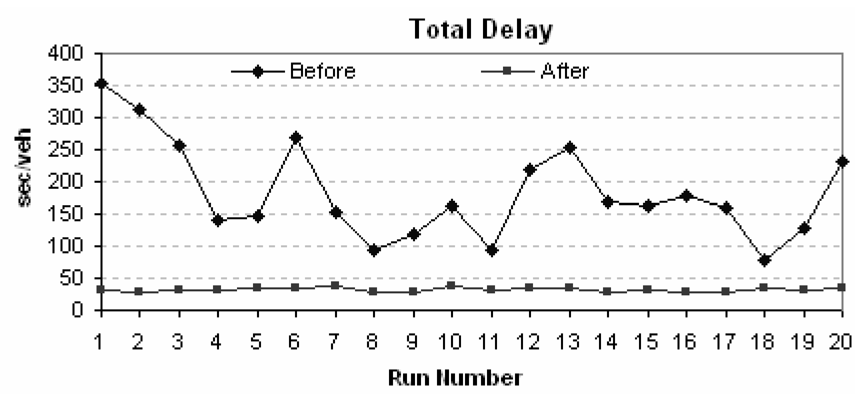


Figure 28: Plot of Total Delay versus Run Number for Before and After Conditions

A comparison of the before and after implementation performance measures based on traffic simulation is presented on Table 10. It can be noticed how the proposed countermeasure helps in reducing the queue in problems significantly on I-75 northbound to westbound off-ramp.

Table 10: Summary of Performance Measures for before and after Conditions

Average Delay (sec/veh)		**Average Queue Length (ft)**		**95th Percentile Queue (ft)**	
Before	After	Before	After	Before	After
178.6	28.6	4847	33	5801	103

5.4.7 Results and findings

The I-75 northbound to westbound off-ramp is a semi-directional ramp of 6792 ft in length. This off-ramp carries the traffic heading west ending at Fowler Avenue 500 ft from the intersection with Morris Bridge Rd. Although this off-ramp has its own lane when merging onto Fowler Avenue, the proximity to the intersection reduces its operational capabilities during congested periods. The problem is mainly observed in the morning, from 7:00 to 8:00 A.M. when the demand reaches its daily peak value. Observations in the field revealed that during this period showed that a slow moving line is formed from the intersection throughout the ramp and sometimes is backed up onto the freeway. Another contributor to the problem, but in less proportion, is the delay at the ramp terminal caused by some drivers attempting to merge into the through lanes and left lanes on Fowler Avenue.

The key element to solve this problem is to efficiently clear a considerable amount of off-ramp traffic on every signal cycle. A significant issue is that the discharge capacity of the off-ramp is limited at its terminal section to one lane. This characteristic, in addition to the proximity to the intersection and high arrival rates, makes the performance of the off-ramp very sensitive to behavioral-related events such as improper lane changing or unusual conditions such as several trucks in a row. A secondary objective could be to increase the storage capacity to prevent the queue spillback onto the freeway.

The proposed countermeasure to overcome this problem is to add one more lane at the ramp terminal, more precisely at the last 1976 ft from the merging point continuing along the ramp. In this way, the discharge capacity of the off-ramp can reach a more desirable operational performance. This measure by itself does not alleviate the problem, because more vehicles are being released at the intersection affecting its performance. The new lane needs to be prolonged beyond the intersection to facilitate a proper discharging of the off-ramp traffic, and safer lane changing and thus improving the operational performance of the interchange. The proposed countermeasure was implemented in a traffic micosimulation model, and the results showed a drastic reduction in the queued vehicles on the off-ramp as well as travel delay and queue spillbacks onto the freeway

5.5 CASE STUDY 2: I-95 & EAU GALLIE BOULEVARD INTERCHANGE

5.5.1 Description of the Case Study

The I-95 & Eau Gallie Boulevard interchange is located in Melbourne, Brevard County, Florida. The approximate coordinates for this interchange are Latitude 28.120581, Longitude -80.705963 (decimal degrees).This interchange is experiencing serious queueing problems on its southbound off-ramp during the morning peak hour. Over the years, the increasing vehicle flow has exceeded the capacity of this interchange. The vehicles exiting Interstate 95 southbound are mainly heading east onto Eau Gallie Boulevard, and this is possible only by performing a left turn movement at the intersection. The I-95 and Eau Gallie Boulevard interchange geometry belongs to the category of diamond interchanges and, as such, it encounters problems handling heavy left turn volumes.

This interchange has a singe-lane southbound off-ramp that is divided into right and left single turning lanes near the terminal intersection. In addition, the approximately 580 ft of spacing between the two I-95 terminals rank it as compressed diamond interchange. This last feature implies that the timing plan for all the ramps has a significant impact on the operational performance of the interchange, especially when unbalanced turning movements are present.

At 1650 ft from the I-95 interchange on the east side is John Rodes Boulevard which is a signalized intersection. This intersection handles relatively high traffic volumes during the peak hour under consideration. This intersection also plays an important role in clearing the interchange area on Eau Gallie Boulevard to allow a proper discharge of the vehicles on the off-ramps onto the surface street. Jones Road is located 550 ft from the I-95 interchange on the west side; it is controlled by stop signs but does not represent a major cause of congestion due to the low traffic volumes in that direction. The lane distribution of for this interchange is presented in Figure 29.

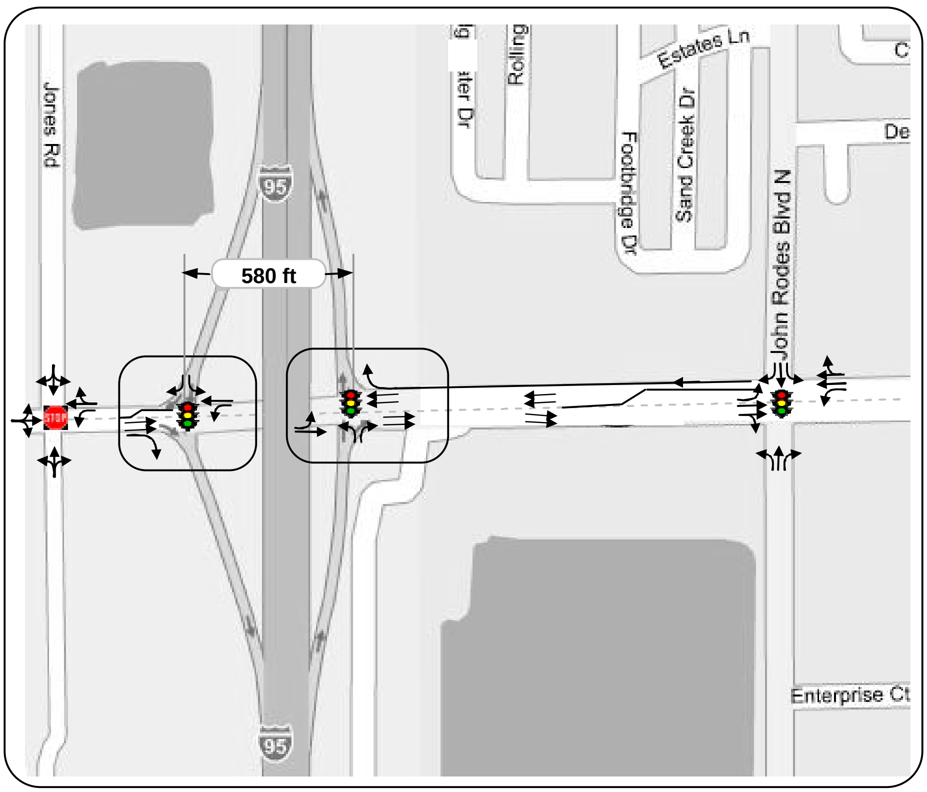


Figure 29: Existing Conditions of the I-95 & Eau Gallie Boulevard Interchange

5.5.2 Methods for Data Collection and Performance Evaluation

The operational information of the before conditions is based on a study conducted by FDOT District 5 [53]. According to observations in the study, the southbound off-ramp was found to operate inefficiently, and serious spillback problems of the queue were also reported. The countermeasure for this case study involves geometric improvements; therefore, its implementation might take several years. For this reason, it will not be feasible to collect information on real performance of the proposed improvements within the schedule of this case study. To overcome this disadvantage, microscopic traffic simulation was also chosen as the analysis tool for this study. To keep the consistency between before and after conditions, both situations were analyzed using the simulation approach.

The system under consideration is composed of 1.35 miles of Interstate 95, Jones Road and John Rodes Boulevard and the corresponding on-ramps and off-ramps of the interchange. For the model building phase, it was necessary to collect information related to the timing plan and volumes for the interchange area. Brevard County provided all the necessary information on this subject. Information related to the countermeasure was obtained from FDOT District 5 [53]. The volumes used to carry out the simulation are shown in Figure 30. The simulation model was properly calibrated to reflect field observations on traffic conditions. Snapshots of the simulation model showing before and after conditions are provided in Appendix E.

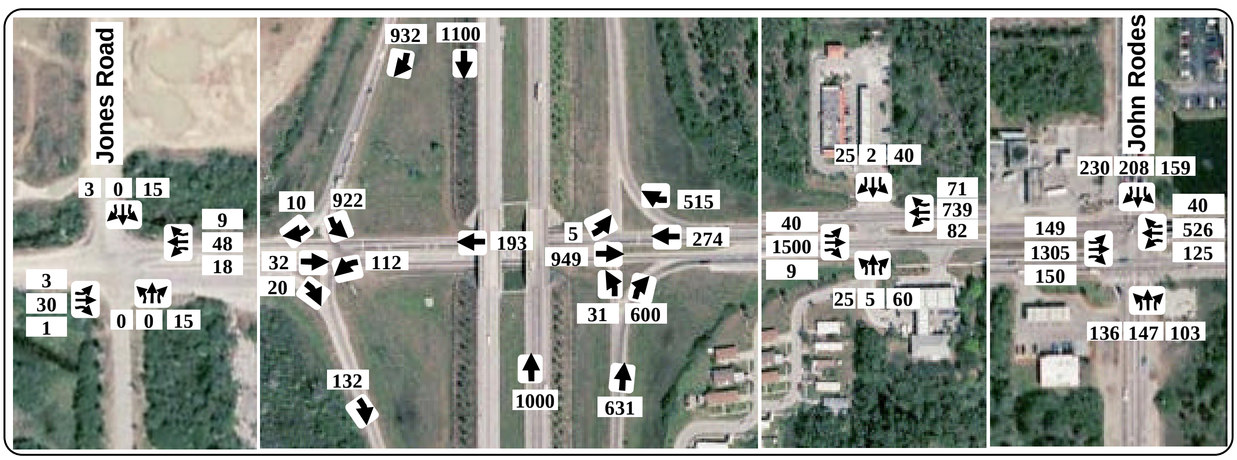


Figure 30: Traffic Volumes Used in the Simulation Model

5.5.3 Before Conditions

The distribution of the delay along the off-ramp is shown in Figure 31. It is observed that during congested periods, the delay on the ramp is concentrated at the diverge point. Node 18 represents the delay on Interstate 95 and is caused by a serious spillback of the queue onto the freeway.

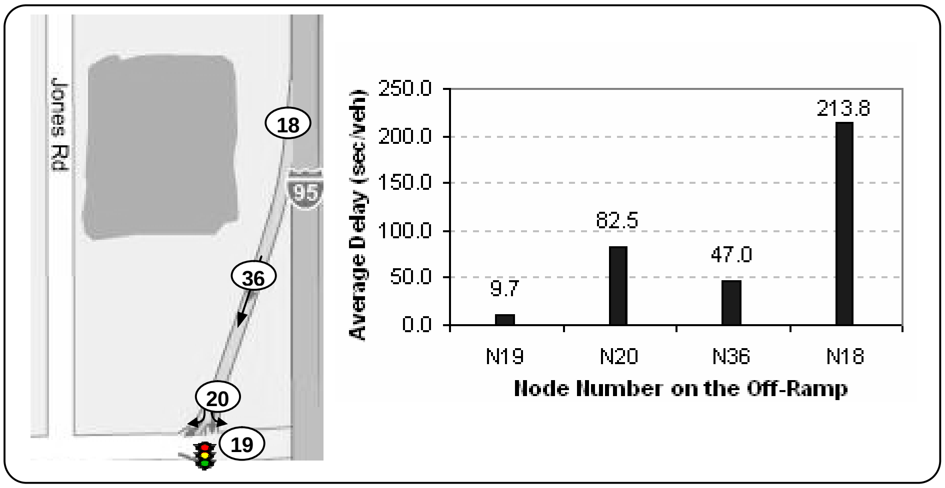


Figure 31: Distribution of the Delay on the I-95 Southbound Off-Ramp before Implementing the Countermeasure

The total delay for traffic on the studied off-ramp has a mean 353.1 sec/veh with a standard deviation of 77.3 sec/veh ranging between 317 and 389 sec/veh with a 95 percent confidence. The frequency distribution of the total delay is shown in Figure 32.

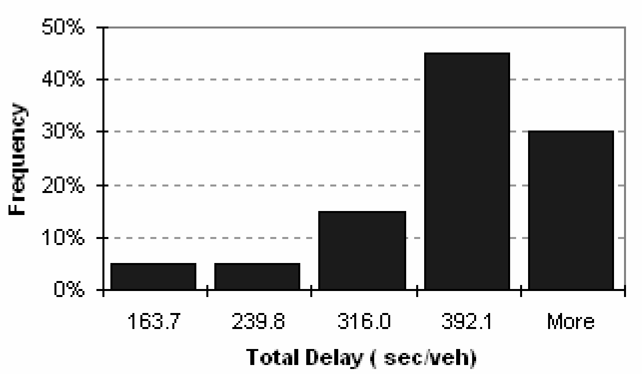


Figure 32: Frequency Distribution of the Total Delay on the Off-Ramp before Implementing the Countermeasure

It is observed that the average queue tends to be very long. This can be observed by the skew in distribution of the average queue in Figure 33. The true average queue ranges between 2835 ft and 2471ft and has a mean of 2653 ft. The 95th percentile queue is 3960 ft. Given that the off-ramp length is only1139 ft, this confirms that there is a serious spillback problem at this off-ramp.

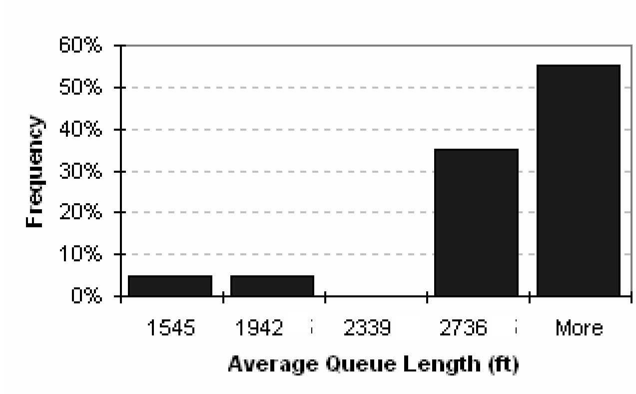


Figure 33: Frequency Distribution of the Average Queue Length for the I-95 SB Off-Ramp before Implementing The Countermeasure.

5.5.4 Implementation of Countermeasures

The southbound off-ramp has a length of 1139 ft, which can store approximately 46 passenger vehicles. The maximum allowable split (green + yellow + all red) for the left turn movement on the off-ramp is 72 seconds, with a volume to capacity ratio of 1.1. The improvement consists in providing an additional left turn lane starting 736 ft from the intersection with Eau Gallie Boulevard as shown in Figure 34.

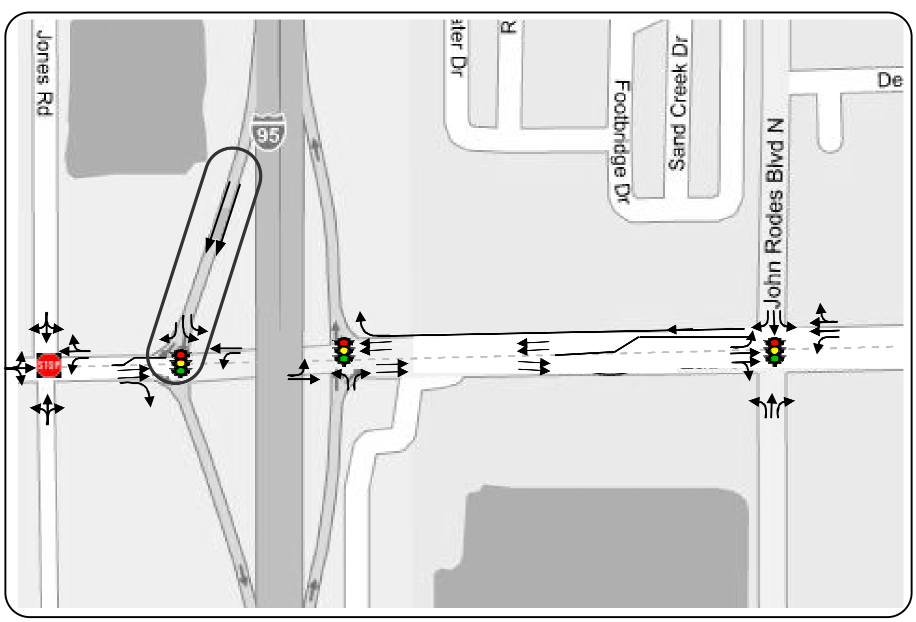


Figure 34: Proposed Improvements for Eau Gallie Boulevard Interchange

This improvement will increase the capacity for handling left turn traffic at the intersection. It is necessary to note that signal timing improvement along with geometric improvement can effectively reduce further the queues at this off-ramp. As a secondary objective, the proposed countermeasure will increase the storage capacity of the ramp by 65 percent which is equivalent to 30 more passenger vehicles. The signal timing improvement consists of increasing the maximum allowable split from 72 seconds to 82 seconds, preserving the same cycle length of 130 seconds.

5.5.5 After Conditions

After implementing the countermeasures, the total delay was reduced and the delay along the ramp was redistributed to the nodes closest to the off-ramp terminal as shown in Figure 35. The implemented countermeasures showed a significant reduction of the delay at the freeway indicating the alleviation of the queue spillback problem.

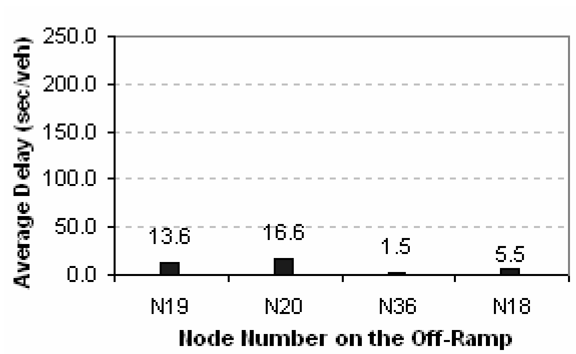


Figure 35: Distribution of the Delay on the I-95 North Bound Off-Ramp after Implementing the Countermeasure

The frequency distribution of the total delay is shown in Figure 36. In the improved conditions the mean total delay is 37.2 sec/veh, its standard deviation 4.3 sec/veh and its 95 percent confidence interval varies from 39.3 sec/veh to 35.1 sec/veh.

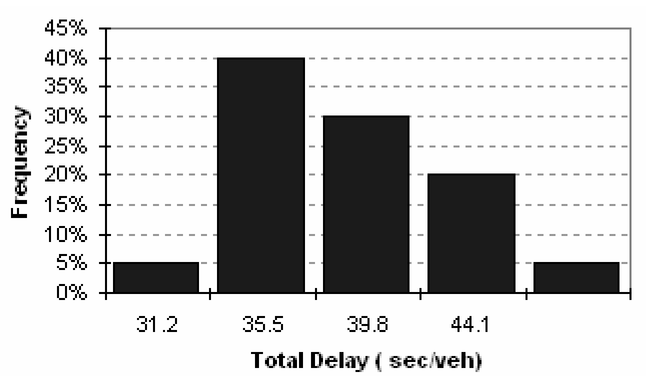


Figure 36: Frequency Distribution for the Total Delay on the Off-Ramp after Implementing the Countermeasure

The variability on the average queue length was reduced from 1125 ft to 235 ft. The distribution of the average queue has also changed, as it can be observed in Figure 37.

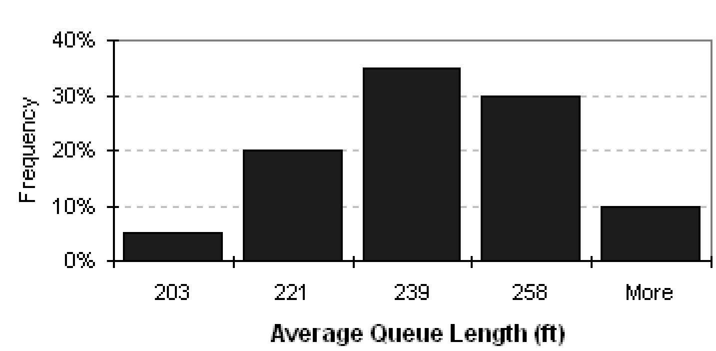


Figure 37: Frequency Distribution of the Average Queue for the I-95 NB Off-Ramp after Implementing the Countermeasure

The 95th percentile queue length was reduced from 3960 ft to 359 ft. The storage capacity of the off-ramp was increased to 75 passenger vehicles. The improvement provides a good operational performance.

5.5.6 Before-and-after Analysis

A comparison between before and after performance measures on the queue lengths across all the simulation runs is shown in Figure 38.

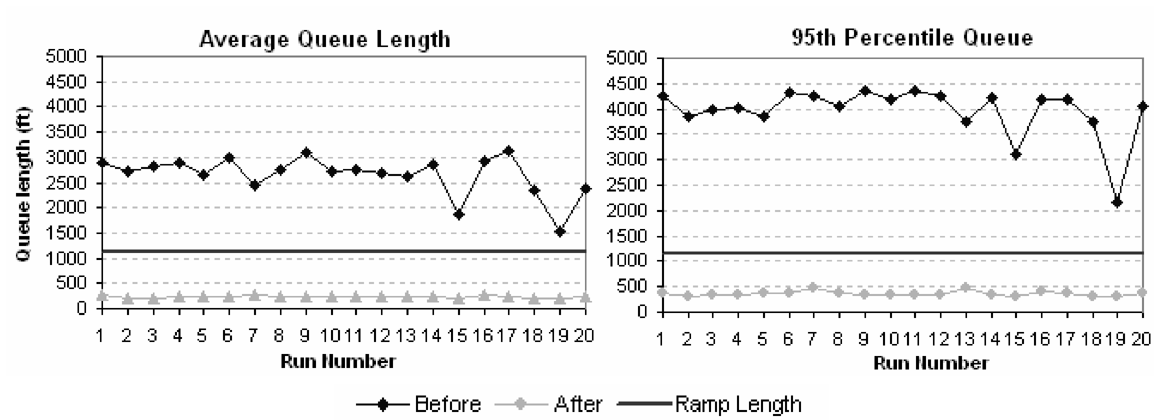


Figure 38: Average Queue versus Run Number (left) and 95th Percentile Queue versus Run Number (right)

The total delay in the off-ramp was reduced in both value and variance which makes the travel time more reliable and therefore enhances the performance of the interchange. A plot of the total delay versus run number for both, before and after conditions is presented in Figure 39.

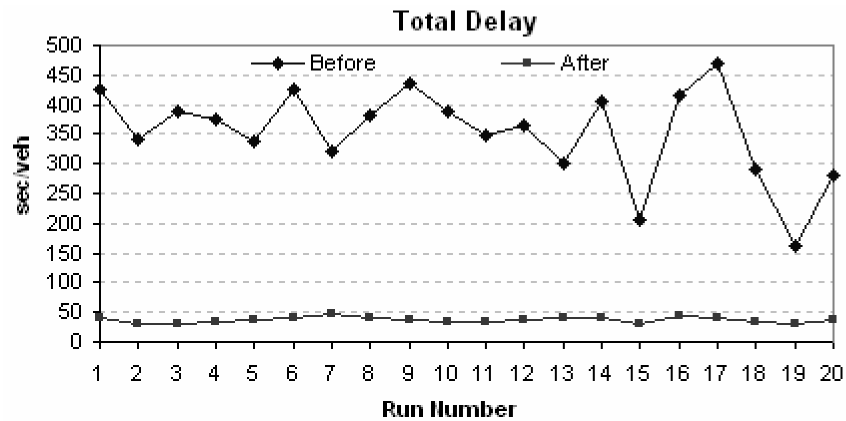


Figure 39: Plot of Total Delay versus Run Number for Before and after Conditions

The overall performance measures for before and after conditions are presented in Table 11. It can be noticed how the proposed countermeasure helps in reducing the queue and vehicle delay in problems significantly on the I-95 northbound off-ramp.

Table 11: Summary of Performance Measures for before and after Conditions

Average Delay (sec/veh)		**Average Queue Length (ft)**		**95th Percentile Queue (ft)**	
Before	After	Before	After	Before	After
353.	37.2	2653	235	3960	359

5.5.7 Results and Findings

The I-95 and Eau Gallie Boulevard interchange is a compressed diamond interchange, intended to serve low to moderate traffic volumes. The land development in the surrounding area of the interchange, mainly to the east, has caused the exiting traffic of I-95 in that direction to increase. This increase in the eastward traffic has brought along operational problems to the southbound off-ramp of the interchange due to the difficulties of diamond interchanges in serving moderate to large left turn volumes. In addition, due to the off-ramp length, its storage capacity is easily exceeded. The peak period traffic is not a problem for I-95 northbound traffic heading east because this movement is served by a free right turn lane and the traffic volumes are not as high as in the southbound direction.

The proposed countermeasure for this case has two parts, geometric improvement and signal timing adjustment. The geometric improvement seeks to increase the discharge capacity and storage capacity for left turn traffic by adding one more lane for this movement. The new lane will start 736 ft from the ramp terminal. The maximum allowable split (green + yellow + all red) for the left turn movement on the off-ramp was modified from 72 seconds to 82 seconds which helped to increase the discharge rate of the off-ramp. The proposed countermeasures were implemented in a traffic microsimulation model showing effective results in preventing the queue spillback onto the freeway and increasing the operational capabilities of the interchange.

5.6 CASE STUDY 3: I-75 & BIG BEND ROAD INTERCHANGE

5.6.1 Description of the Case Study

The I-75 & Big Bend Road interchange is located in Hillsborough County, Florida. The approximate coordinates for this interchange are Latitude 27.791792, Longitude -82.356670 (decimal degrees). This interchange presents problems of queue spillback on the southbound off-ramp of I-75 during both the morning and afternoon peak-hour traffic. This case study focuses on the morning peak condition.

This interchange is a parclo AB interchange type; its southbound off-ramp is a single lane loop that ends at the intersection with Big Bend Road. As the ramp approaches the intersection, the traffic is separated into a free right turn lane and a left turn lane with protected movement. This ramp is starting to develop queuing problems during the morning peak hour. The Eisenhower Middle School is located 1500 ft to the west of the I-75 southbound off-ramp terminal, increasing the morning hour traffic traveling in the westbound direction on Big Bend Road. The school entrance is a roadway that intersects Big Bend Road, forming a T-type junction followed by the intersection with Old Big Bend Road, just 130 ft to the west. These two closely spaced intersections are the access to the school as observed in Figure 40.

The signal phasing of the intersection between Big Bend Road and the Eisenhower Middle School entrance has a long cycle time which interrupts the westbound traffic on Big Bend Road for more than 2 minutes. For this reason, the westbound traffic on Big Bend Road is backed up blocking the left turning vehicles on the I-75 southbound off-ramp. The problem not only affects the off-ramp terminal but the upstream intersections on Big Bend Road. On several occasions, the off-ramp had green indications and vehicles were not able to proceed to the intersection. When this happened the queue grew considerably reaching the deceleration lane on the freeway. At times, the queue reached the freeway's mainline.

5.6.2 Methods for Data Collection and Performance Evaluation

The necessary information for building the simulation models was provided by Hillsborough County and by vehicle counts in the field. Although the proposed countermeasure was successfully implemented by Hillsborough County, simulation models were built to show a detailed analysis of the before and after conditions.

The system under study comprises the I-75 & Big Bend Road interchange, 1.2 miles of the Interstate I-75, a section of the Big Bend Road at the west of the interchange covering the Eisenhower Middle School entrance roadway. The measures of effectiveness selected for evaluating the performance of the countermeasures are: verage delay, average queue and 95th percentile of queue. The simulation model was calibrated to reflect this behavior observed in the field. The adjusted traffic volumes based on 2005 peak season traffic used in the simulation model are shown in Figure 41. Appendix E presents snapshots of the simulation model showing before and after conditions.

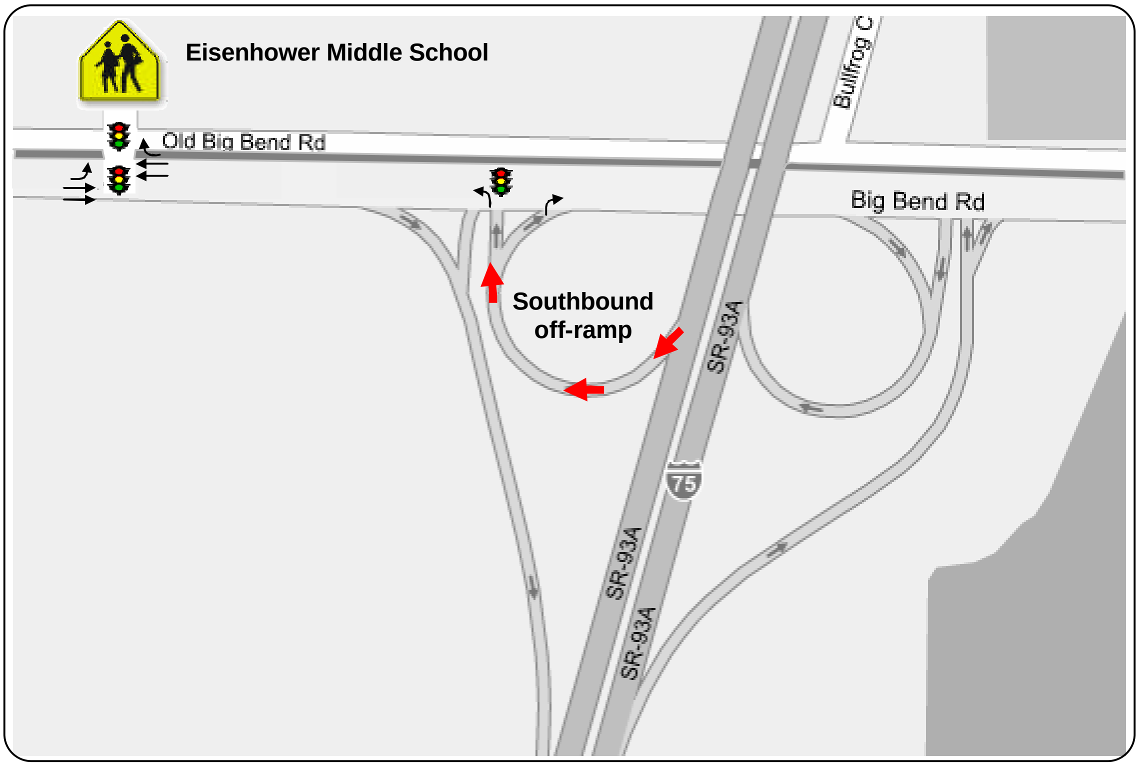


Figure 40: Existing Conditions of the I-75 & Big Bend Road Interchange

5.6.3 Before Conditions

The distribution of the delay along the studied off-ramp is shown in Figure 42. It is observed that the queue on the off-ramp induces a delay on the freeway traffic. In this figure, nodes 29 and 9 correspond to freeway nodes. The total delay on the ramp was 150 sec/veh, and it ranged from 97.4 sec/veh to 202.15 sec/veh 95 percent of the time.

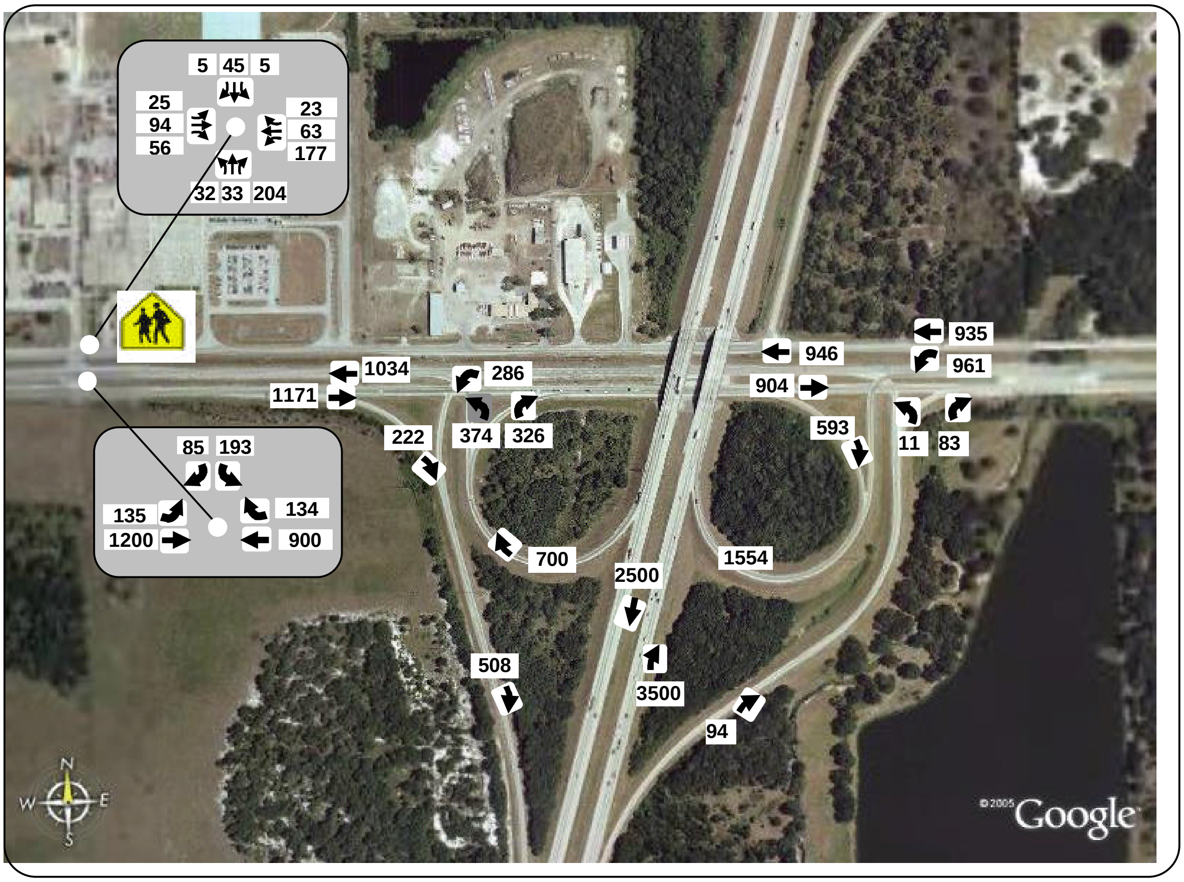


Figure 41: Traffic Volumes Used in the Simulation Model

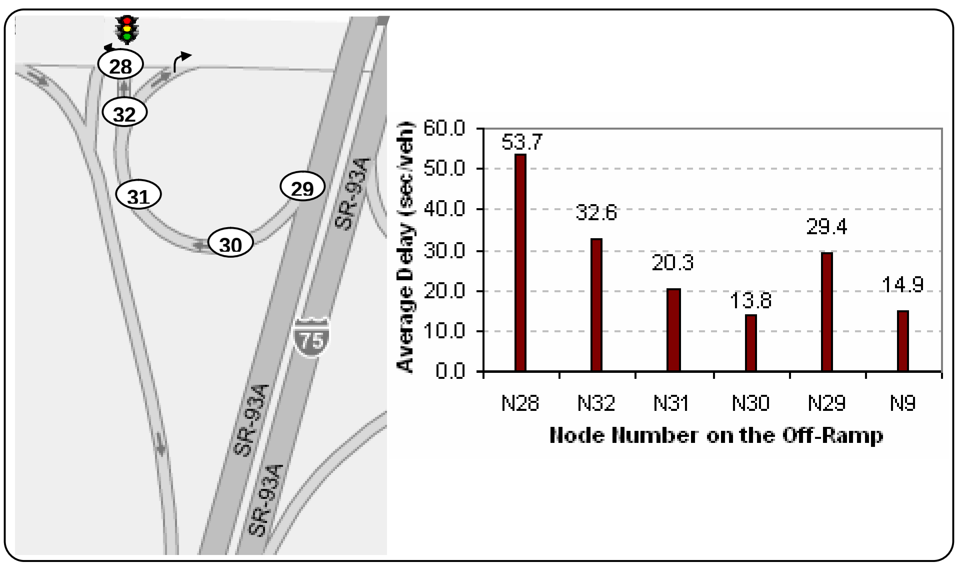


Figure 42: Distribution of the Delay on the I-75 Southbound Off-Ramp before Implementing the Countermeasure

The frequency distribution of the total delay is presented in Figure 43, where it is observed that low values of delay happen in only 5 percent of the runs. In the remaining runs, the delay is relatively high. This situation induces uncertainty in the travel time on the ramp, which reflects the behavior observed in the field.

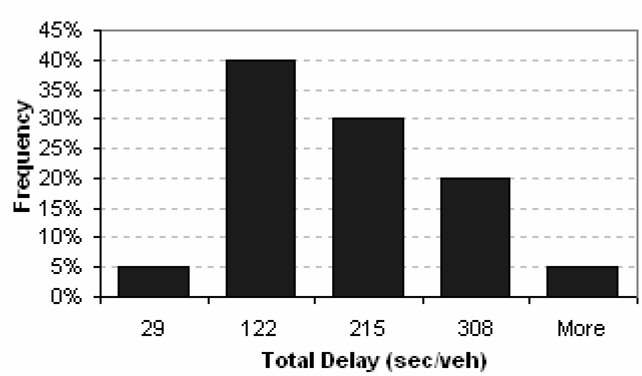


Figure 43: Frequency Distribution of the Total Delay on the I-75 Southbound Off-Ramp before Implementing the Countermeasure

In Figure 44, it is noted that the queue length exceeds the ramp length, which is 1340 ft, in 70 percent of the runs. The deceleration lane is 2192 ft long; thus, a total of 3532 ft is available to store the queued vehicles adding both sections.

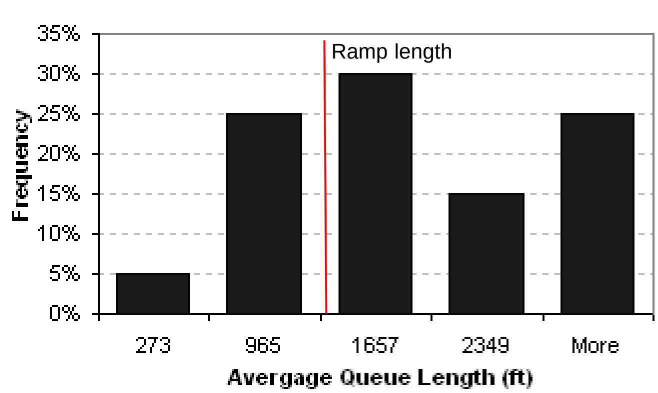


Figure 44: Frequency Distribution of Average Queue Length for the Off-Ramp before Implementing the Countermeasure

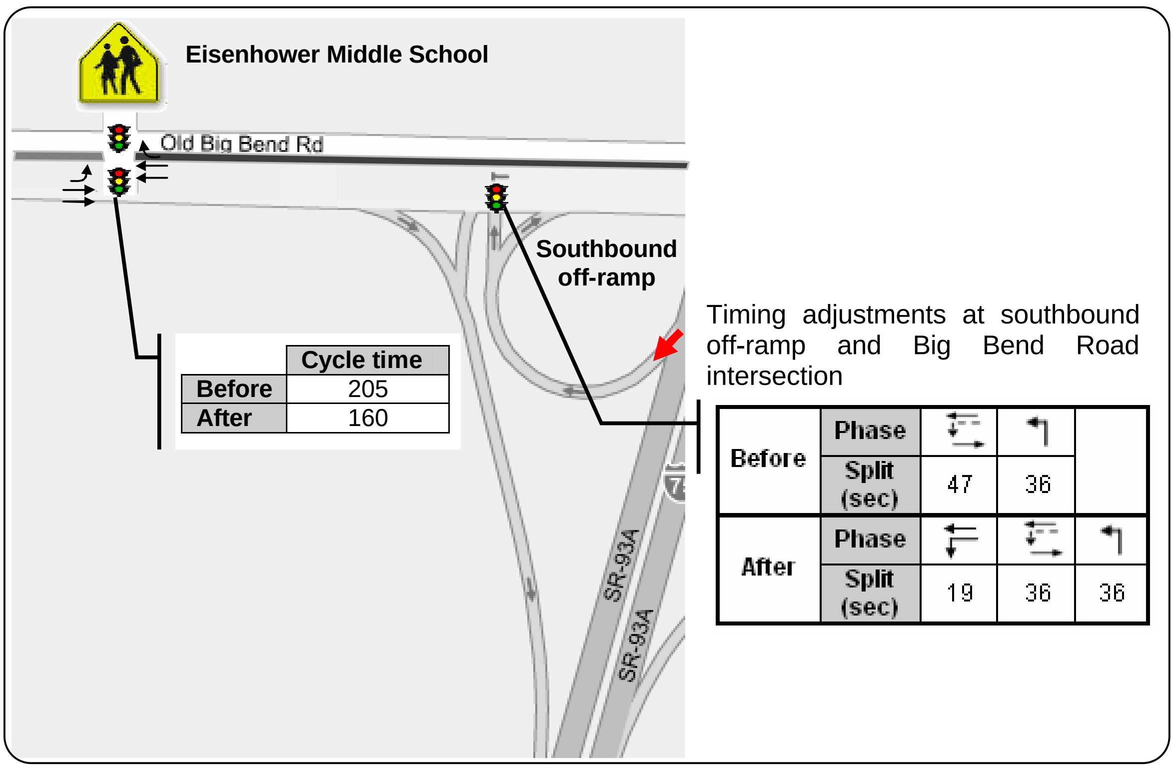
The 95th percentile queue was 1994 ft on average, implying that, under extreme events, the queue length will exceed the ramp length but not the deceleration lane length.

5.6.4 Implementation of Countermeasures

The countermeasure to cope with the queuing problem was proposed by the Hillsborough County Traffic Service Division and was successfully implemented in the field. The countermeasure was devised to overcome both the off-ramp queue spillback and the Big Bend Road westbound traffic back up. The improvement consisted in an adjustment of the timing on southbound off-ramp terminal intersection and in the school entrance intersection.

The time adjustment consisted in reducing the cycle time at the school entrance intersection and thus making some room at the back of the queue of the westbound traffic for the incoming off-ramp vehicles at Big Bend Road. The timing modifications at the off-ramp terminal traffic signal included providing a new protected phase for the westbound vehicles from the Big Bend Road to the south bound on-ramp (left turn) and increase the maximum allowable split for the westbound through movement.

The green time on the intersection of the off-ramp and Big Bend Road was increased from 83 seconds to 91 seconds while the green time of the school entrance intersection was reduced from 205 to 160, as presented in Figure 45.



	Cycle time
Before	205
After	160

Before	Phase			
	Split (sec)	47	36	
After	Phase			
	Split (sec)	19	36	36

Figure 45: Proposed Improvements for the I-75 & Big Bend Road Interchange

5.6.5 After Conditions

The distribution of the delay along the ramp was reduced significantly with the implementation of the countermeasure. This means that the ramp is discharging vehicles in a more efficient way and consequently reducing the delay on the freeway. In the improved conditions the queue does not affects the operational performance and safety on the freeway. This can be noted in Figure 46.

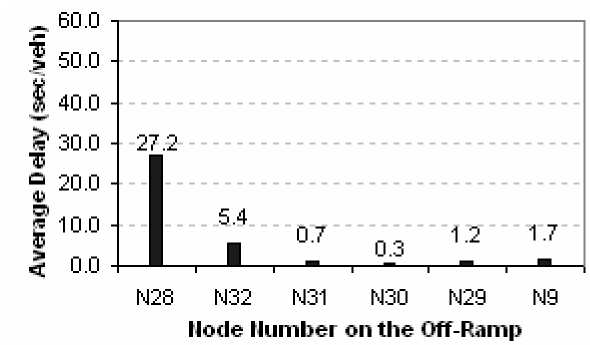


Figure 46: Distribution of the Delay on the Off-Ramp after Implementing the Countermeasure.

The total delay on the ramp was significantly reduced by applying the proposed countermeasure. The total delay on the ramp was decreased from 150 to 35 sec/veh ranging from 33.5 sec/veh to 36.3 sec/veh. An additional benefit was the reduction of the variability on the time to traverse the ramp. The frequency distribution of the total delay is presented in Figure 47.

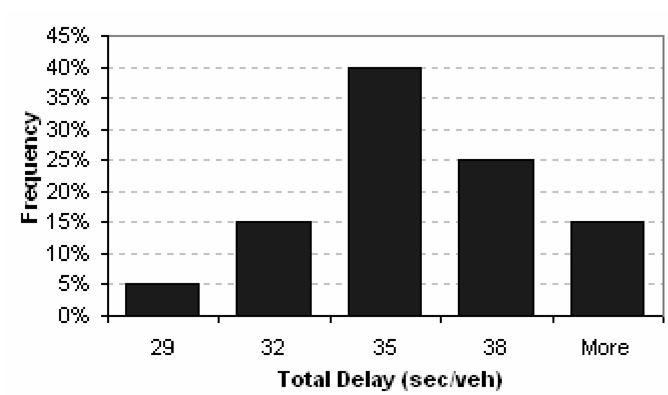


Figure 47: Frequency Distribution for the Total Delay on the Off-Ramp after Implementing the Countermeasure

The average queue length also reflects the improved conditions, as observed in Figure 48. The queue length under the improved conditions showed a mean of 295 ft and its 95 percent confidence interval ranged from 288 ft to 302 ft.

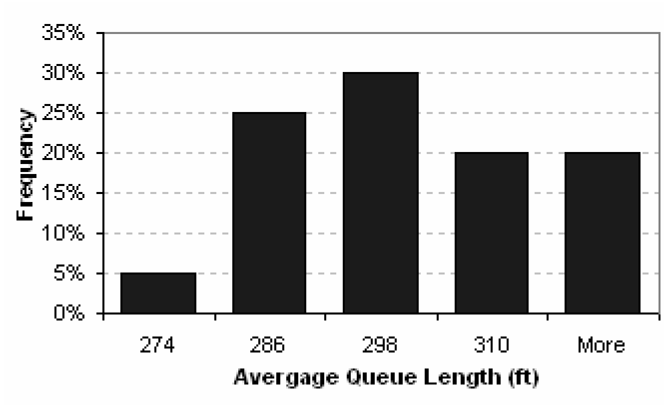


Figure 48: Frequency Distribution of the Average Queue for the Off-Ramp after Implementing the Countermeasure

The 95th percentile queue was 388 ft, and the mean queue length does not exceed the off-ramp length.

5.6.6 Before-and-after Analysis

In Figure 49, it is observed that the average queue and the 95th percentile queue at times exceeded the off-ramp length (solid line) and the deceleration lane length (dashed line) for before conditions. Under the improved conditions, the queue length was contained on the off-ramp.

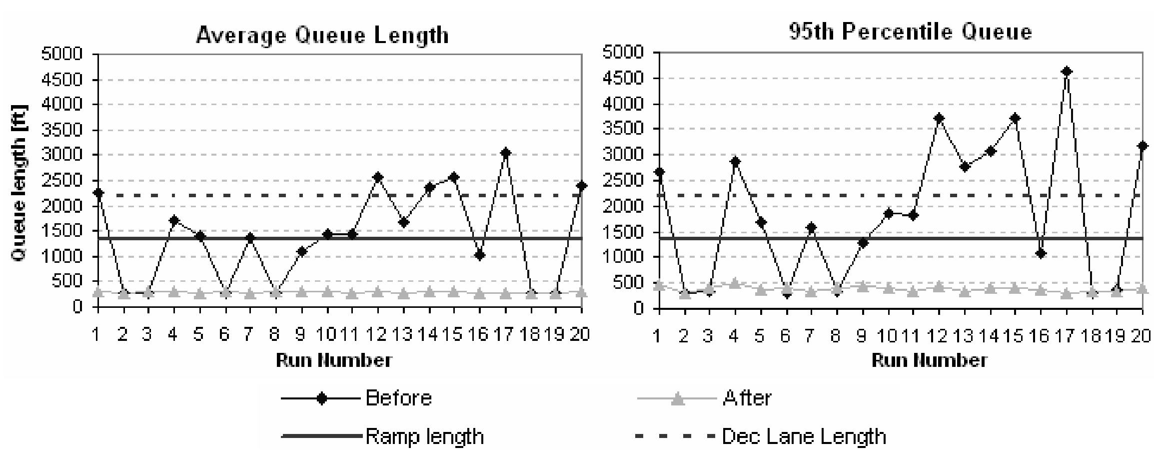


Figure 49: Average Queue versus Run Number (left) and 95th Percentile Queue versus Run Number (right)

Similarly, the total delay was plotted versus run number for before and after countermeasure implementation as shown in Figure 50. It shows how the total delay was reduced not only in magnitude but also in variability.

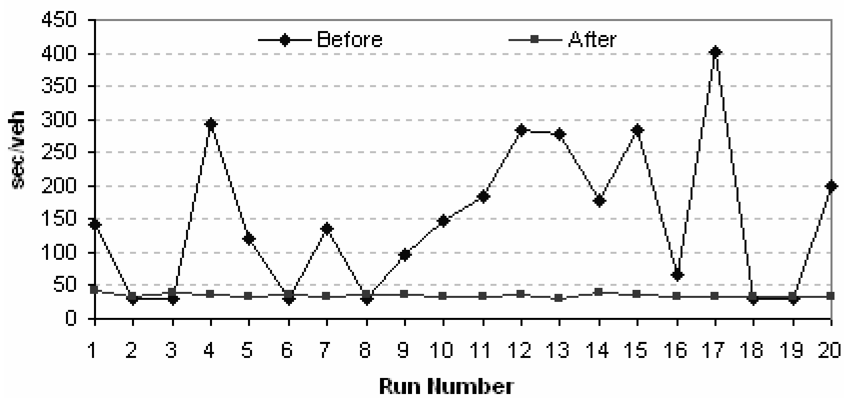


Figure 50: Plot of total delay versus run number for before and after conditions

The overall performance measures are presented for before and after implementation conditions in Table 12. It indicates that the countermeasure implemented had a significant effect on improving the travel time through the off-ramp and reducing the queue length.

Table 12: Summary of Performance Measures for before and after Conditions

Average Delay (sec/veh)		**Average Queue Length (ft)**		**95th Percentile Queue (ft)**	
Before	After	Before	After	Before	After
150	35	1400	295	1994	388

5.6.7 Results and Findings

The I-75 & Big Bend Road interchange area was experiencing two kinds of traffic back up problems. One of them was the backup of the westbound traffic on Big Bend Road at the southbound off-ramp terminal intersection. The other was the backup of the vehicles exiting the I-75 southbound off-ramp at times backs onto the freeway.

The development on the areas adjacent to the interchange has brought problems such as closely spaced intersections. In this case, the presence of a middle school requires reduced speed zones, which, in addition to the signal timing plan operated at the school entrance during the morning peak hour, affect the traffic patterns during the morning period. Due to the interchange geometry, the southbound off-ramp has little storage capacity. When the signal at Big Bend Road failed in clearing left turn vehicles on the off-ramp, the queue rapidly grew up to the diverge gore and from there kept increasing its length faster because it blocked the right turn vehicles. Once right turn traffic on the off-ramp was blocked, off-ramp queue grew significantly. There were few chances for the queue to return to normal operation, based on field observations.

Although the off-ramp queue length was sensitive to whether the right turn traffic was blocked and queue spillback problems were observed, the situation has not reached the point that requires geometric modifications. The countermeasure consisted of a new phase for the westbound left turn traffic on Big Bend Road heading to the southbound on-ramp. This new phase was intended to alleviate the backup problem on Big Bend Road. The reduction in the cycle time in the downstream intersection, at Eisenhower School, was made to significantly prevent excessive accumulation of vehicles and thus providing some room at the back of the queue for the off-ramp traffic. In this way, when the off-ramp vehicles get a green light, they will be able to proceed in the westbound direction on Big Bend Road. The countermeasure was implemented in the field and was also simulated for a better understanding of the problem. The countermeasure successfully eliminated the risk of queue spillback while keeping the operational performance of the interchange at desirable levels during morning peak hour.

5.7 CASE STUDY 4: I-75 & BEE RIDGE ROAD INTERCHANGE

5.7.1 Description of the Case Study

The I-75 & Bee Ridge Road interchange is located in Sarasota County, Florida, under the jurisdiction of FDOT District 1. The approximate coordinates for this interchange are latitude 27.298819, longitude-82.448058 (decimal degrees). This interchange is experiencing queuing problems on the northbound off-ramp of I-75 during the A.M. peak hour

The I-75 & Bee Ridge Road interchange is a modified diamond interchange. The additional feature with respect to conventional diamonds is the presence of a loop-shaped on-ramp for the eastbound traffic on Bee Ridge Road. The remaining ramps are typical of diamond interchanges. The northbound off-ramp has one left turn lane for the vehicles exiting the I-75 heading west on the Bee Ridge Road. The traffic volume on this inbound direction increases during the A.M. peak hour causing congestion on the off-ramp. At times, above-average arrival patterns during a green phase created residual queues that added more vehicles to the subsequent cycles. The unexpected gap out of the traffic signal from heavy vehicles was believed to be part of the reason for traffic congestion at this off-ramp. The southbound off ramp currently has two right-turn lanes for the I-75 exiting vehicles heading west, as shown in Figure 51.

5.7.2 Methods for Data Collection and Performance Evaluation

The treatment for this ramp consisted on a modification of the signal timing settings to include the volume-density feature of gap reduction. The implementation of the countermeasure and the field data collection were facilitated by Sarasota County. In this case study traffic data and queue length were used in the analysis. The video images for the period from 6:45 to 8:45 A.M. were recorded by a CCTV monitoring camera van. The equipment setting at the site is shown in Figure 52

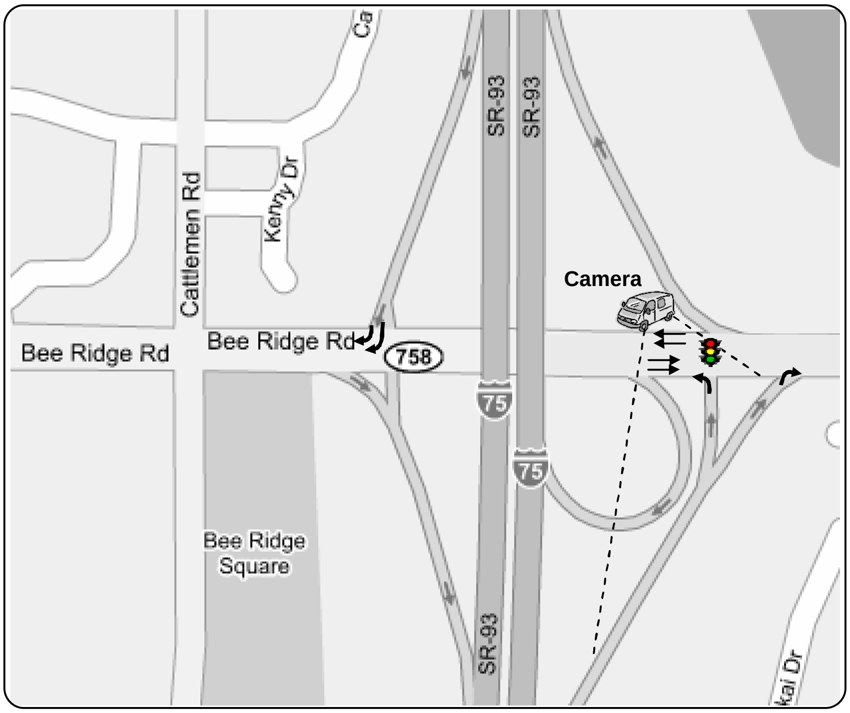


Figure 51: Existing Conditions of the I-75 & Bee Ridge Road Interchange

Figure 52: Camera Van Used to Record before and after Study Traffic Information

5.7.3 Before Conditions

Based on the recorded tape, the traffic volumes for the studied period are presented in Figure 53. It is observed that the vehicular flow is greater in the westbound direction. The count of the off-ramp corresponds to vehicles exiting the northbound direction of I-75 and heading west onto Bee Ridge Road. During the selected period of the A.M. peak hour, 36 percent of the traffic signal cycles the queue could not be cleared, thus carrying over vehicles into the subsequent cycle.

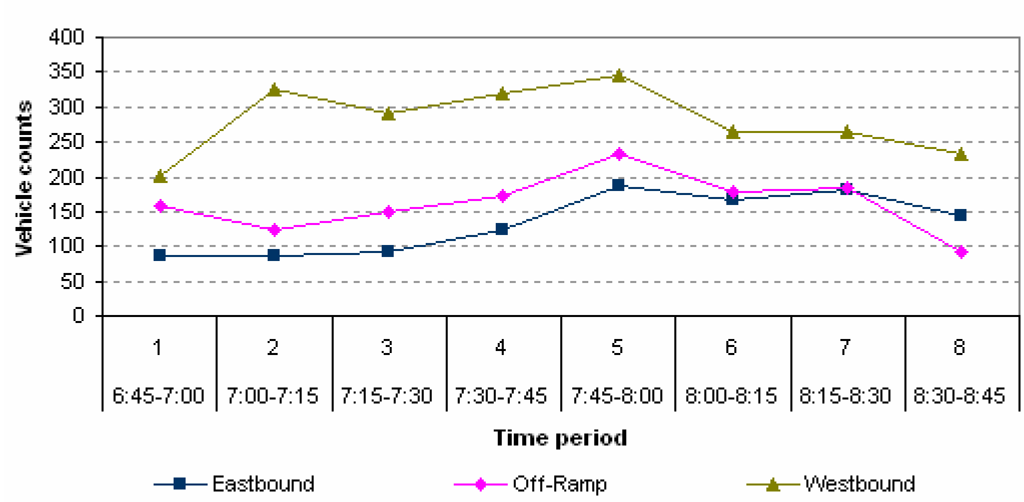


Figure 53: Traffic Volumes at the I-75 Northbound Off-Ramp Terminal and Bee Ridge Road before the Countermeasure Implementation.

5.7.4 Implementation of Countermeasures

The proposed countermeasure implemented by Sarasota County consisted in a modification of the parameters of the traffic signal controller to take advantage of the volume-density feature to prevent unexpected signal gap out due to heavy or slow moving vehicles.

There are two major features in the volume-density control: the added initial and the gap reduction. These types of features have the ability to alter the timing patterns to enhance the performance of the intersection. For this case study, only the gap reduction feature was implemented. Gap reduction timing is generally used with setback detectors on high speed approaches to control the duration of allowable gap. With setback detectors, longer passage time for vehicles from the detector to the intersection is needed during the early stage of green to ensure safety. However, it will cause inefficient operation when vehicles pick up speed. The use of the gap reduction feature can reduce the chance of signal gap out due to a short signal passage time setting. In this case study, the time before reduction, the initial gap, and the minimum gap were set to 22, 5 and 3 seconds respectively.

5.7.5 After Conditions

The percentage of cycles in which the queue could not be cleared was 22 percent. Within the observed timeframe, the most congested periods were 5, 6 and 7 (after conditions). These periods can be compared with the periods 4, 5, and 6 since they range from 7:30 to 8:15 A.M., as can be observed in Figure 53 and Figure 54. The volumes are very similar in both cases, but in the after conditions the signal operation did show some improvement.

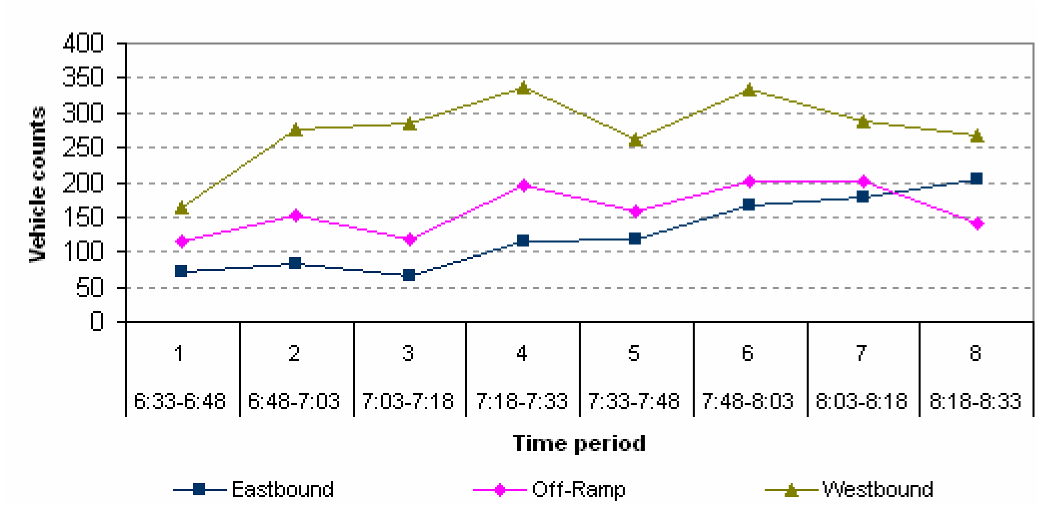


Figure 54: Traffic Volumes at the I-75 Northbound Off-Ramp Terminal and Bee Ridge Road after the Countermeasure Implementation

5.7.6 Before-and-after Analysis

The percentage of period in which the queue could not be cleared was reduced from 36 percent to 22 percent. Although the observed queue lengths were similar for both situations, in the after conditions the queue can be cleared more effectively thus reducing its probability of spillback onto the freeway.

5.7.7 Results and Findings

Timing improvement is one of the most cost-effective countermeasures to cope with queuing problems at signalized intersections. In this case study, the use of the additional gap reduction feature of the controller improved the effectiveness of the traffic signal to clear the off-ramp queue The volume-density control strategy can be used at off-ramps to prevent unexpected signal gap out due to heavy or slow-moving vehicles. An appropriate setting of this feature can postpone the need to construct additional road capacity.

6 TOOLBOX FOR REDUCING QUEUES AT FREEWAY OFF-RAMPS

6.1 OVERVIEW

There are several possible treatments for reducing queues at freeway off-ramps to minimize potential fatal crashes and reduce major freeway congestion. These treatments vary from one location to another and may have different implementation times. Moreover, the treatments may be targeting different problem causes at a different degree of effectiveness. Three main areas for improvements were identified: reduce input demand from the freeway, increase output capacity from the off-ramp, and improve storage capacity of the off-ramp. Based on these concepts, three major fundamental approaches were used in this study to devise a toolbox for reducing queues at freeway off-ramps. The organization of the toolbox is depicted in Figure 55. The first approach is to reduce travel demand and improve freeway operations. The second one is to improve off-ramp departure capacity and alleviate arterial congestion. The last is to improve the off-ramp and freeway storage capacities for queues.

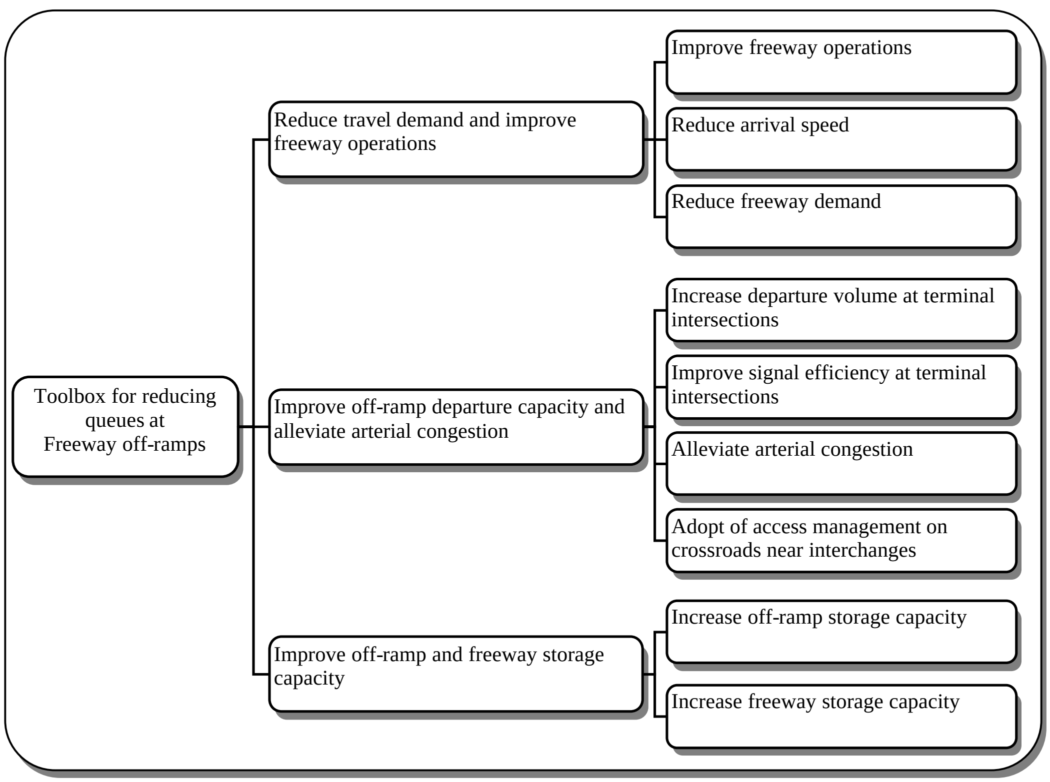


Figure 55: Organization of the Toolbox for Reducing Queues at Freeway Off-Ramps

6.2 REDUCTION OF TRAVEL DEMAND AND IMPROVEMENT OF FREEWAY OPERATION

The first approach is to reduce the flow rate of vehicles entering the off-ramp from the freeway. It can be achieved through reduction of freeway demand, reduction of arrival speeds of vehicles entering the off-ramp, and improvement of freeway operations by dynamic off-ramp management and/or lane-changing restriction upstream of the off-ramp. The organization of the countermeasures presented in this section is shown in Figure 56.

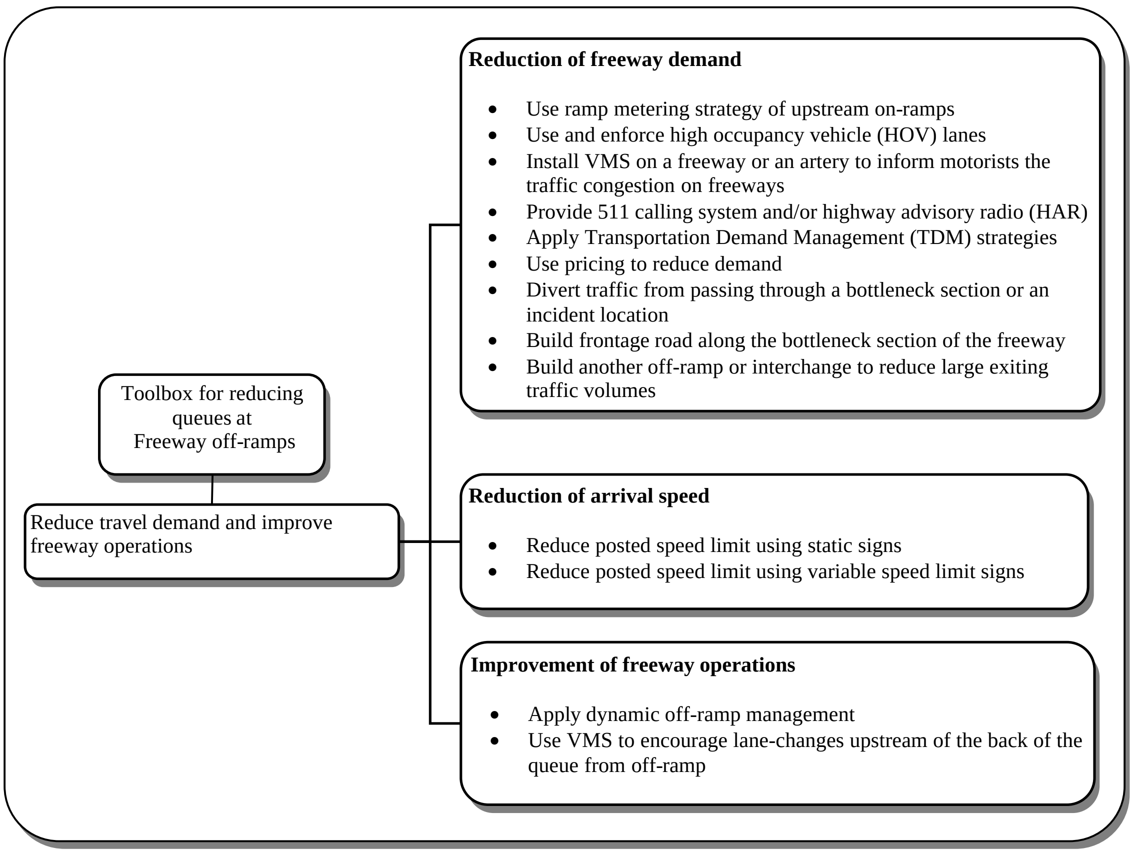


Figure 56: Countermeasures Based on Travel Demand Reduction and Freeway Operations Improvements

6.2.1 Reduction of Freeway Demand

The traffic volume at an off-ramp is directly proportional to the freeway traffic volume up to a certain extent. If the freeway, demand upstream of an off-ramp can be reduced, it is very likely the traffic volume at the off-ramp will also be reduced, which can minimize the queuing problem at the freeway off-ramp. The following countermeasures are specifically used for reducing freeway demand.

6.2.1.1 Use ramp metering strategy of upstream on-ramps

Ramp metering is the use of traffic signals at freeway on-ramps to control the rate of vehicles entering the freeway as can be observed in Figure 57. The metering rate is set to reduce or optimize freeway flow, and minimize congestion. The metering rate can be fixed, or responsive to local or system-wide conditions. Existing ramps must have enough capacity to accommodate increased ramp queues without causing excessive spillover onto the surface street network. If ramps do not already have this capacity, construction costs can be high.

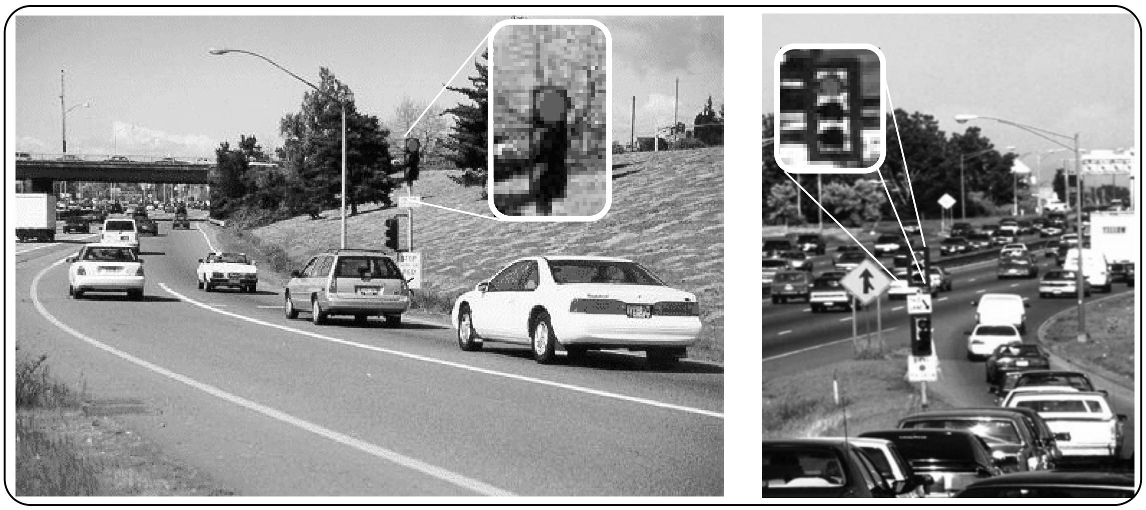


Figure 57: Examples of ramp metering

6.2.1.2 Use and enforce high occupancy vehicle (HOV) lanes

High occupancy vehicle lanes are reserved for carpools, vanpools, buses and motorcycles during designated time periods. Other than motorcyclists, motorists must carpool with at least one other person in order to use the HOV lane. These lanes are also known as carpool, commuter and express lanes. HOV lanes move more people because of their higher auto occupancies. Also, these lanes are designed to help move more people through congested areas by helping motorists bypass traffic. In this way, HOV lanes allow motorists to travel faster while also freeing up congestion in regular lanes. Examples of HOV lanes can be observed in Figure 58.

Figure 58: Examples of high occupancy vehicle lanes

6.2.1.3 Install VMS on a freeway or an artery to inform motorists of traffic congestion on freeways

VMS are traffic control devices used to provide motorists en-route traveler information. The information is most often displayed in real-time and can be controlled either from a remote centralized location or locally at the site. VMS are designed to affect motorist behavior to improve traffic flow and operations. Traveler information displayed on VMS may be generated as a result of a planned or unplanned event, which is programmed or scheduled by operations personnel. The general objective of providing the information is to allow motorists to avoid an incident or prepare for unavoidable conditions or to give travel directions. The specific objective of placing a VMS in a freeway section is to alert motorists of traffic congestion downstream and encourage possible diversion in order to decrease the traffic volume to the congested section. The specific objective of placing a VMS in an arterial section connecting to a freeway is to alert motorists about traffic congestion on the freeway and encourage the use of alternate routes in order to minimize entering volume to the already congested freeway section. Some examples of variable message signs are presented below in Figure 59

Figure 59 Examples of Variable Message Signs

6.2.1.4 Provide 511 calling system and/or highway advisory radio (HAR)

511 is now considered to be America's traveler information number. The Federal Communications Commission designated 511 as the single traffic information telephone number for use by states and local jurisdictions on July 21, 2000. Travelers can dial 511 to access current information for specific routes and roadway segments, including anticipated travel delays, traffic accidents, roadway blockages and lane closures. HAR is another way to communicate travel information to motorists. These radio messages report driving conditions, major incidents, and roadway conditions. HAR is designed to affect motorist behavior to improve traffic flow and operations. The goal is to alert motorists about downstream traffic congestion or incidents on the freeway, and encourage the appropriate response. Highway signage typically used for this countermeasure is shown in Figure 60.

Figure 60: Examples of 511 Calling System and Highway Advisory Radio

6.2.1.5 Apply Transportation Demand Management (TDM) strategies

Travel Demand Management (TDM) emphasizes reducing the demand for single occupant vehicle travel through techniques such as bus, carpool, vanpool, telecommuting, flexible work schedule, and teleconferencing. Bus, carpool, and vanpool are common TDM strategies to reduce traffic demand on a roadway network. Telecommuting, compressed work weeks, and flexible work hours are employment-based techniques to reduce the number of work trips per week or to transfer trips to reduce peak hour congestion. Telecommuting, or alternative work location, allows workers to perform job duties at home or another location, communicating with the main work center by internet, fax, or telephone as necessary. The addition of new and lower cost technologies, such as DSL lines for faster internet communications and less expensive internet access will continue to encourage telecommuting as a TDM strategy. Teleconferencing is generally defined as meetings held by telephone or via video hookup to replace the need for traveling to meet in person. It is also a popular TDM strategy. Some examples of travel demand management strategies are presented in Figure 61.

6.2.1.6 Use pricing to reduce demand

In addition to TDM strategies, congestion pricing seems to be an effective countermeasure to reduce freeway demand, but is not popular due to some technical and political reasons. However, congestion pricing is getting more attention and discussion because traffic congestion is worsening in many metropolitan areas. It is suggested by numerous studies that value pricing should be considered for new lanes built in high-traffic areas. For example, travelers will curtail non-essential travel during peak hours or use alternative modes or routes due to higher rush hour tolls. Thus, value pricing promotes more efficient highway use and therefore less congestion at the off-ramps. The technique of Open Road Tolling (without stopping to pay toll) will make toll roads more efficient and popular. An example of this strategy is shown in Figure 62.

6.2.1.7 Divert traffic from passing through a bottleneck section or an incident location

Transportation agencies can use VMS or HAR as a tool to minimize traffic entering congested sections. Transportation professionals may use VMS in freeways and arterial roads connecting to a freeway to inform motorists about downstream freeway traffic congestion and provide alternative routes, as shown in Figure 63.

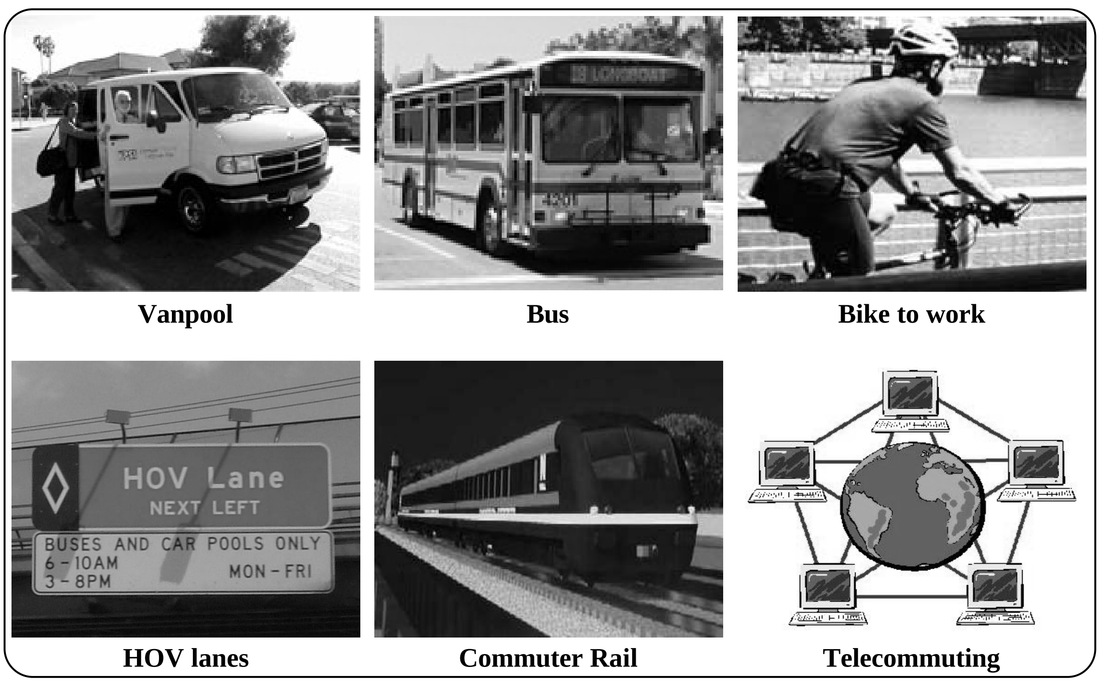


Figure 61: Examples of Transportation Demand Management

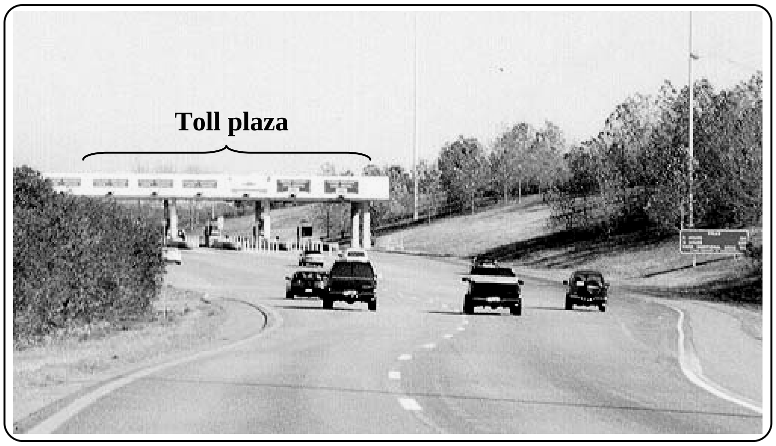


Figure 62: East Mainline Toll Plaza of Lee Roy Selmon Crosstown Expressway in Tampa

Figure 63: Use of VMS to Encourage Traffic Diversion to Alternate Routes

6.2.1.8 Build frontage road along the bottleneck section of the freeway

Frontage roads are roadways that are constructed generally parallel to a freeway or other highway. Freeway frontage roads normally have at-grade intersections with the arterial streets, which are generally perpendicular to the freeway and are grade-separated from the freeway main lanes. Under fully developed conditions, the at-grade intersections of frontage roads and arterials are typically signalized. Ramps provide connections between the frontage roads and the freeway. Traffic traveling from an arterial street to the freeway first turns from the arterial onto the frontage road and then travels along the frontage road to a freeway entrance ramp. Traffic traveling from the freeway to an arterial street leaves the freeway by means of an exit ramp that connects to the frontage road and then travels along the frontage road to its intersection with the arterial street. The frontage road can reduce freeway traffic and prevent off-ramp queue spillback onto the freeway. Examples of frontage roads are presented in Figure 64.

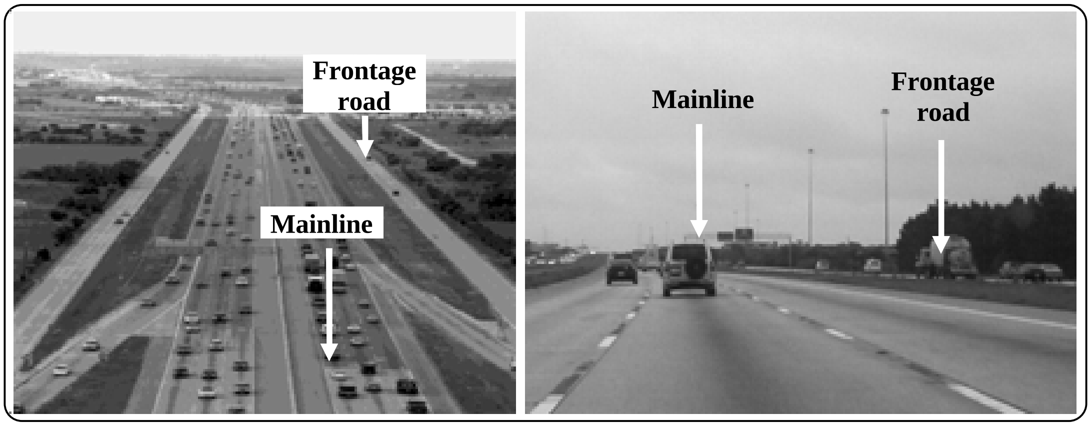


Figure 64: Typical Frontage Roads

6.2.1.9 Build another off-ramp or interchange to reduce large exiting traffic volumes

It sometimes becomes necessary to build another off-ramp or interchange to reduce large exiting traffic volumes for major sport, recreation, theme park and shopping destinations. This is generally a long-term countermeasure. An instance of this countermeasure is presented in Figure 65.

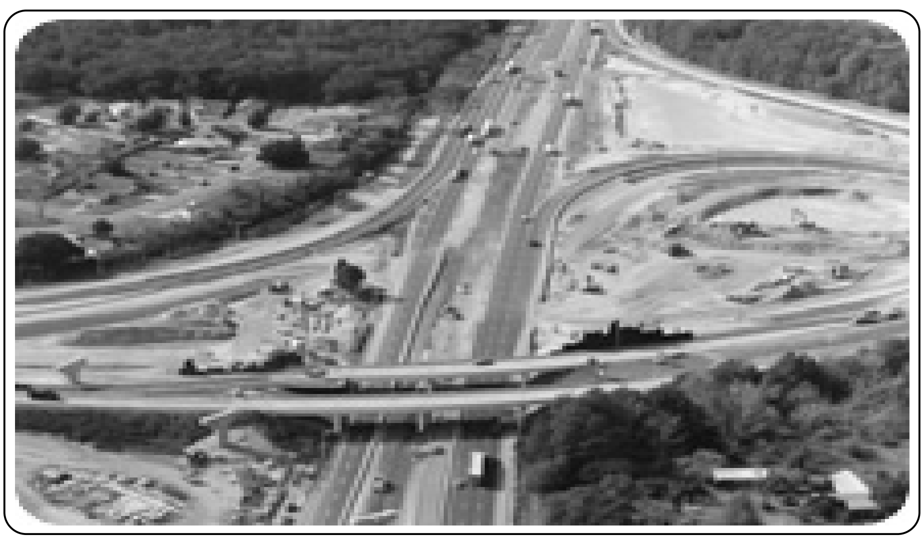


Figure 65: Construction of an Off-Ramp

6.2.2 Reduction of Arrival Speeds

The reduction of travel speeds on a freeway before a congested off-ramp is likely to reduce the possibility of the accumulated queues at the off-ramp spilling onto the freeway mainline. This is because the reduction of travel speed on the freeway will decrease the flow rate entering the off-ramp. It can not only reduce the potential for high-speed rear-end crashes but also minimize the chance of freeway congestion due to off-ramp queue problems. The reduction of arrival speeds on the freeway before the congested ramp can be achieved by properly reducing the posted speed limit through either permanent static speed limit signs or dynamic speed limit signs, coupled with aggressive enforcement. The dynamic speed limit sign is recommended due to its dynamic capability to post the appropriate speed limit according to real-time information.

6.2.2.1 Reduce Posted Speed Limit Using Static Signs

Static speed limit signs, as in Figure 66, can be used for segments of freeways with congestion during most of the day if the funding for a dynamic speed limit system is not available.

Figure 66: Static Speed Limit Signs for Congested Segments of a Freeway

6.2.2.2 Reduce Posted Speed Limit Using Variable Speed Limit Signs

Variable speed limit signs can be used to warn drivers about downstream congestion based on real-time traffic conditions, and lower their travel speeds if conditions warrant. The speed limit can be adjusted automatically based on an algorithm set up for downstream freeway congestion and off-ramp queue conditions or manually based on the roadway detector information and traffic monitoring through CCTV cameras. Variable speed limits can be an effective tool to manage speeds on interstate highways. Reducing the speed limit prior to a congested off-ramp will decrease the occurrence of freeway accidents due to excess off-ramp demand spillback onto the freeway. It will also minimize or prevent the queue at an off-ramp from spilling onto the freeway mainline. Some examples of the application of this countermeasure are provided in Figure 67.

Figure 67: Variable Speed Limit Sign for Speed Management on Freeways

6.2.3 Improvement of Freeway Operations

Improvements to freeway operations can also help reduce the queuing problems at off-ramps. Two specific countermeasures will be addressed here. The first one is to apply dynamic off-ramp management to better utilize downstream off-ramps, upstream off-ramps or both. The purpose of this countermeasure attempts to spread out the off-ramp volumes in order to minimize the problem off-ramp. The second countermeasure is to encourage lane-changes upstream of the back of the queue from an off-ramp, and ban last minute lane changes to “cut in” a queue. This countermeasure attempts to prevent queue problems from the off-ramp from impacting more than one lane of a freeway. It has the potential to improve traffic safety and reduce congestion.

6.2.3.1 Apply Dynamic Off-Ramp Management

This countermeasure could be applied as a direct control without advice to improve usage of downstream off-ramp or by using VMS’s to improve utilization of upstream off-ramps. This countermeasure is suitable for freeways that carry an unusual high demand for some off-ramps over a relatively short period of time; e.g., a special event such as soccer game in a nearby stadium as in Figure 68. In this case, the exit queues at preferred ramps may back up, forming a queue that entraps non-special event traffic, and causing great system-wide congestion. If some neighboring off-ramps are not sufficiently used, congestion can be mitigated by selectively closing the congested ones (e.g., a few minutes at a time) and diverting traffic to those less used. This strategy could be very advantageous for the system as a whole.

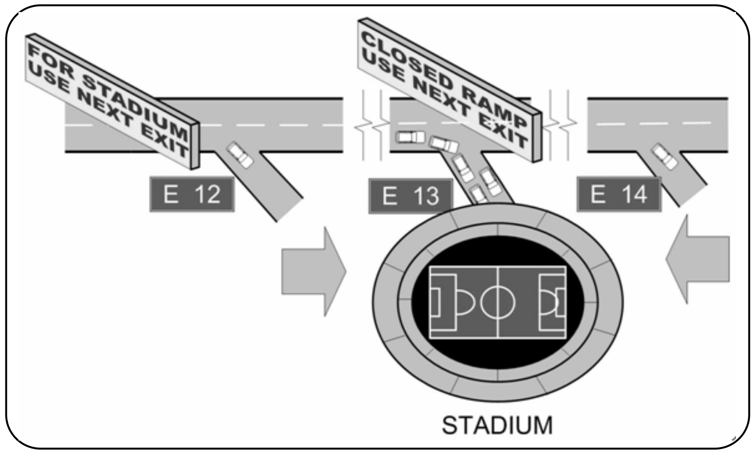


Figure 68: An Example of Dynamic Off-Ramp Management

Direct control to improve usage of downstream off-ramps can also be achieved by denying access to the preferred off-ramp once the off-ramp queue has emerged onto the freeway. With access denied, the queued vehicles on the freeway will be forced to drive further downstream and use the next off-ramp. The closed off-ramp will be reopened when the preferred off-ramp is nearly empty. However, temporary closure of an off-ramp due to queuing problems may not be accepted by the motoring public and transportation agencies. Safety on the closure of off-ramps is another concern.

The second countermeasure is to use VMS to direct traffic to upstream off-ramps to reduce the burden on the congested downstream off-ramp. The message may need to be forceful. To improve the reliability of the control, one can show the expected delay on the downstream congested ramp if possible.

6.2.3.2 Apply Lane-Changing Restriction and Implement Lane Assignment Upstream of the Off-Ramp

It is common for some motorists who desire to exit a freeway to conduct a last-minute lane change before an off-ramp to cut in front of slow-moving queues on the outside through lane in order to avoid delay. Frequently, these vehicles need to slow down significantly to find gaps to cut into a moving queue, which then forms another moving queue in the second outside lane, and causes upstream freeway congestion. An effective way to prevent this from happening is to use VMS to encourage lane-changes upstream of the back of the moving queue from the off-ramp and ban the last-minute lane change.

Enforcement of lane-changing restrictions and implementation of lane assignment upstream of the off-ramp are essential for this countermeasure to minimize the off-ramp queue problem. To start the implementation of this countermeasure full support from the Highway Patrol is needed. Figure 69 shows an example of how this countermeasure might be implemented by using solid double lines on the pavement signing near the off-ramp.

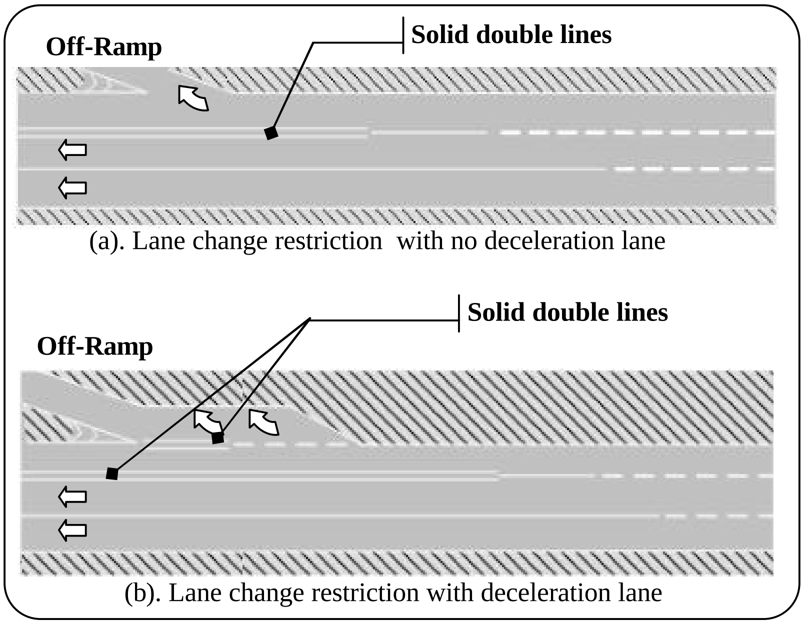


Figure 69: Example of Lane Change Restriction

6.3 INCREASE IN OFF-RAMP DEPARTURE CAPACITY AND IMPROVEMENT OF ARTERIAL OPERATIONS

The objective of the second fundamental approach is to increase the flow rate of vehicles entering the artery from the off-ramp. This can be achieved through increase in departure volume at off-ramp terminal intersections, improvement of signal operational efficiency at the off-ramp terminal intersections, alleviation of arterial congestion, and adoption of access management on crossroads near freeway interchanges. Proper spacing of signals and median openings are important. The above major countermeasures and their associated specific countermeasures addressed in this section are presented in Figure 70.

6.3.1 Increase in Departure Volume at Off-Ramp Terminal Intersections

The increase in departure volume at off-ramp terminal intersections is the most direct countermeasure to reduce queues at off-ramps. It can be achieved through the increase of effective green over cycle length (g/C) ratio, increase of saturation flow rate, or both. The specific countermeasures based on this major countermeasure include signalization at off-ramp terminal intersections, increase of the portion of green time for off-ramps, lane reassignments at the off-ramp terminal intersections, geometric improvements at off ramps or their terminal intersections, and application of split diamond interchanges. Among them, signal timing adjustments and possible lane reassignment are short-term cost-effective countermeasures; the rest of them are expected to be mid-term or long-term countermeasures.

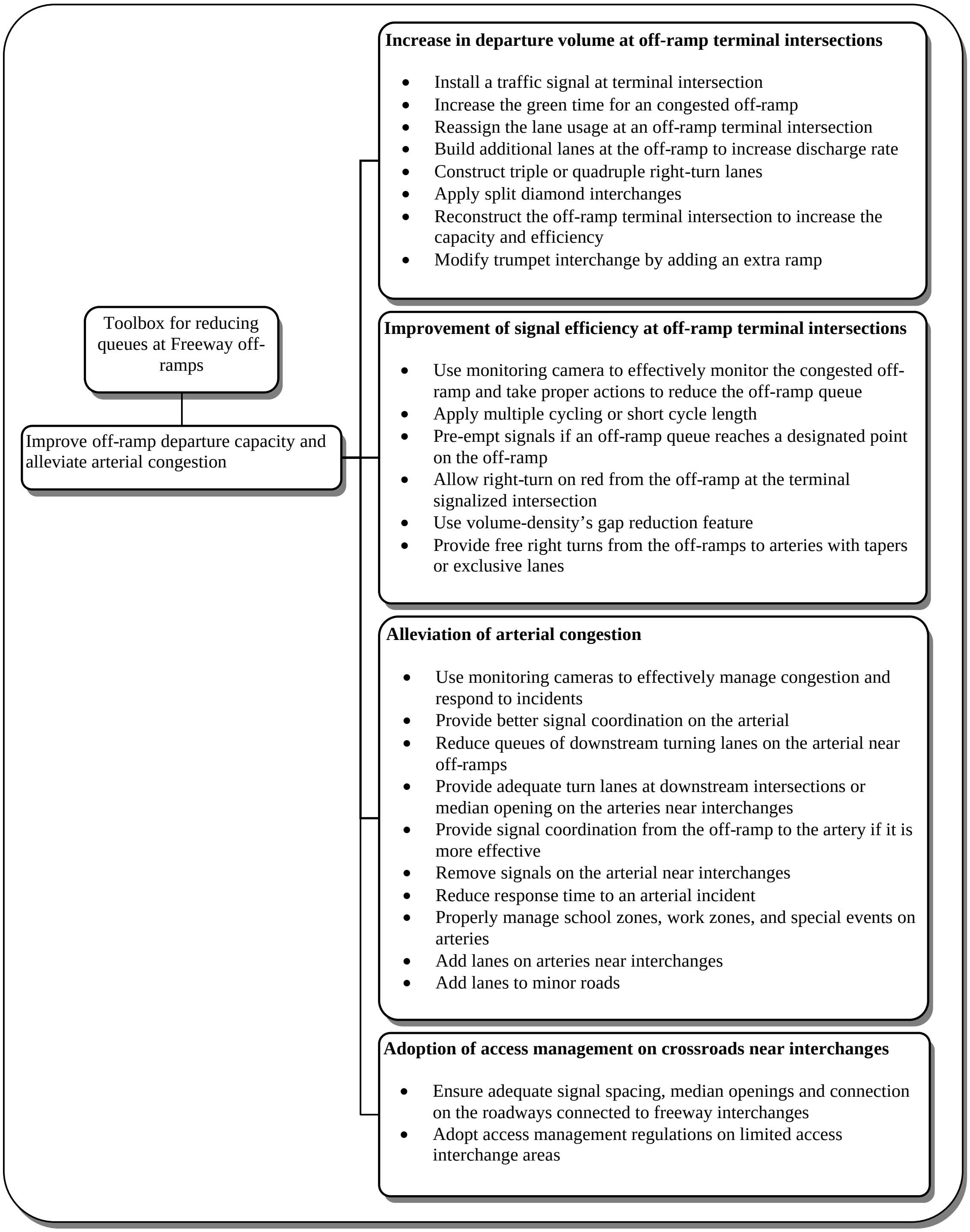


Figure 70: Countermeasures Based on Improvement of Off-Ramp Departure Capacity and Alleviation of Arterial Congestion

6.3.1.1 Install a Traffic Signal at Terminal Intersection

One of the possible causes for traffic congestion on freeways is that traffic cannot depart from a freeway off-ramp fast enough due to an unsignalized terminal intersection. The growing queue thenspills back to the highway and causes traffic congestion. A possible solution is to install a traffic signal at the freeway off-ramp and its intersected arterial as shown in Figure 71.

Figure 71: An Off-Ramp Signalized Terminal Intersection

6.3.1.2 Increase the green time for an congested off-ramp

In many cases, the amount of green time given to motorists at the off-ramp terminal intersection is not enough due to old timing plans and an increase in off-ramp volumes. The most direct countermeasure is to properly increase the amount of green time for motorists to clear the off-ramp; therefore increasing the queue discharge and minimizing the occurrence of queue spillback into the freeway, as shown in Figure 72.

Figure 72: Increase of Green Time to Reduce Queues at a Freeway Off-Ramp

6.3.1.3 Reassign the lane usage at an off-ramp terminal intersection

Inefficient lane assignments at off-ramp terminal intersections can be the cause of a large queue of vehicles. For example, if the demand of left-turning vehicles at the off-ramp terminal intersection exceeds the capacity of the left-turning lane(s), then a possible solution would be to add more capacity by reassigning other lane(s) to allow for left turns, as shown in Figure 73. This solution provides a tool for maximizing the utilization of lanes at the off-ramp terminal intersection without construction.

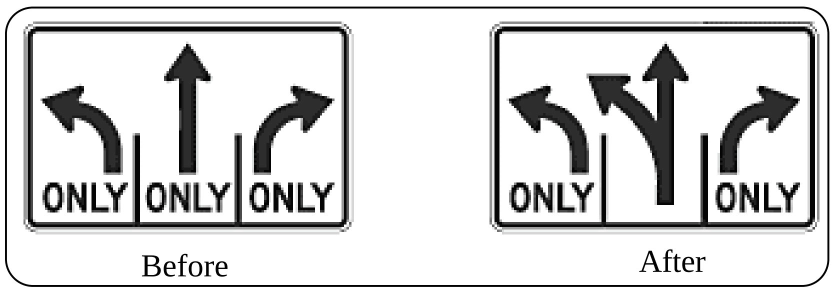


Figure 73: An Example of Reassignment of Lane Usage at Off-Ramp Intersections

6.3.1.4 Build additional lanes at the off-ramp to increase discharge rate

If the demand of vehicles entering an off-ramp exceeds its capacity, then these vehicles will spill back into the freeway. When other signal timing strategies are no longer effective, the situation may be resolved by building additional lanes on the off-ramp; therefore increasing its capacity to meet the traffic demand. For example, an additional right-turn lane was built and one of the left-turn lanes was lengthened for the northbound off-ramp at University Parkway in Sarasota, Florida as shown in Figure 74 , to reduce the queue spillback to I-75.

Figure 74: Northbound I-75 Off-Ramp at University Parkway in Sarasota, Florida

6.3.1.5 Construct triple or quadruple right-turn lanes

In some areas, major business and employment centers may be located close to freeway interchanges. Figure 75 shows an example of construction of quadruple right-turn lanes at the off-ramp to handle the off-ramp traffic with some major destinations of trips located on the right side of the artery downstream of the off-ramp. In this example from I-295 in Jacksonville, a large number of vehicles will make turns at the first two downstream intersections. This design provides a good channellization of traffic at the off-ramp to avoid significant uneven lane utilization, weaving, and queue problems.

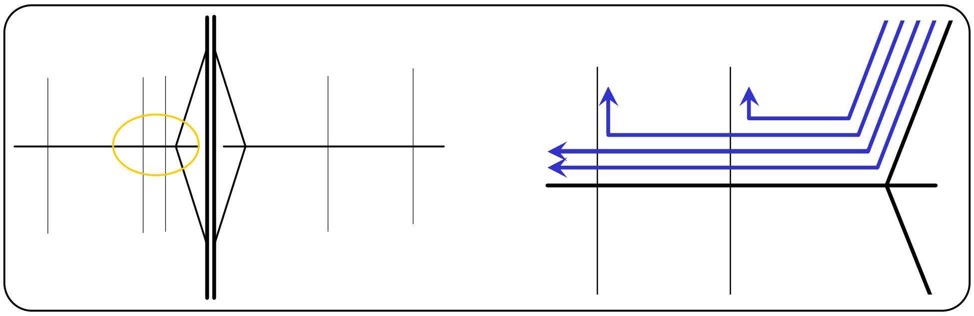


Figure 75: Quadruple Right-Turn Lanes at an Off-Ramp Terminal Intersection

6.3.1.6 Apply split diamond interchanges

In some situations, a freeway interchange can be built at locations with one-way pair streets as shown in Figure 76. It not only provides the function of serving traffic from a freeway to local arteries but also separates left-turn and right-turn traffic. This type of interchange can reduce the signal cycle length and the complexity of signal phasing at downstream signals, and thus it can minimize off-ramp queue problems.

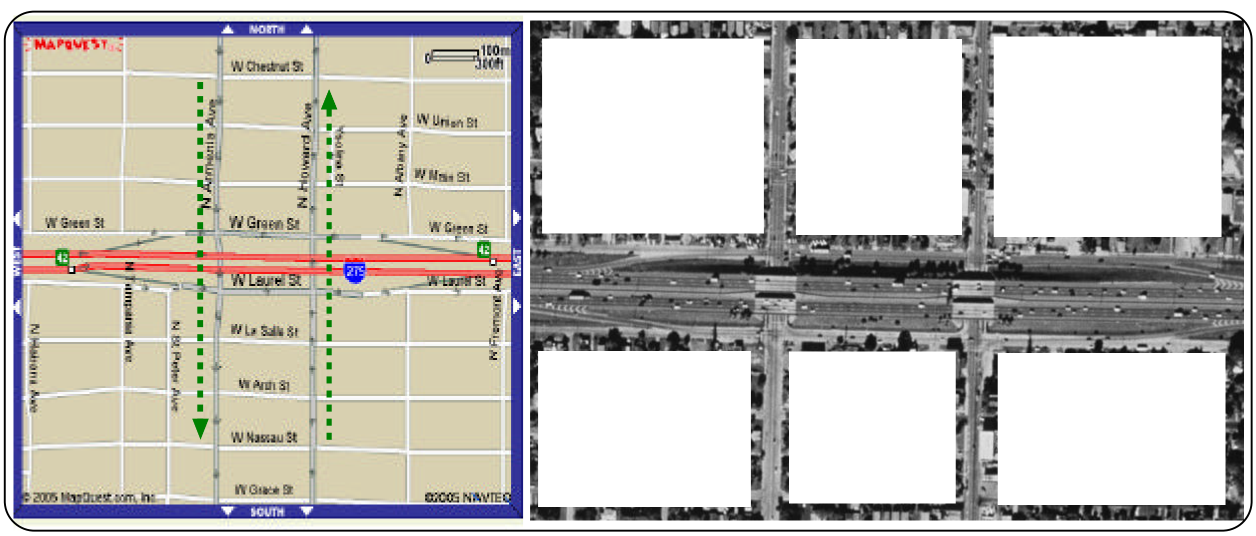


Figure 76: A Split Diamond Interchange on I-275 in Tampa, Florida

6.3.1.7 Reconstruct the Off-Ramp Terminal Intersection to Increase the Capacity and Efficiency

When both volumes at an off-ramp and its intersecting artery are extremely heavy during some periods of time, and signal timing adjustments at the off-ramp, lane reassignment at the off-ramp, signal retiming on the artery, and other signal improvements cannot resolve the traffic problem, reconstruction of the off-ramp terminal intersection, as shown in Figure 77, should be considered. Generally, this is a long-term countermeasure.

6.3.1.8 Modify Trumpet Interchange by Adding an Extra Ramp

The trumpet interchange as shown in Figure 78 is convenient for toll booth placement. However, as traffic volumes continue to increase, traffic congestion becomes unavoidable. Sometimes it is necessary to build an extra on-ramp for electronic toll collection exclusively (dotted line shown in Figure 78) . These kinds of countermeasures may help to reduce queueing problems at a major ramp with a toll plaza.

Figure 77: Reconstruction of an Off-Ramp Terminal Signalized Intersection

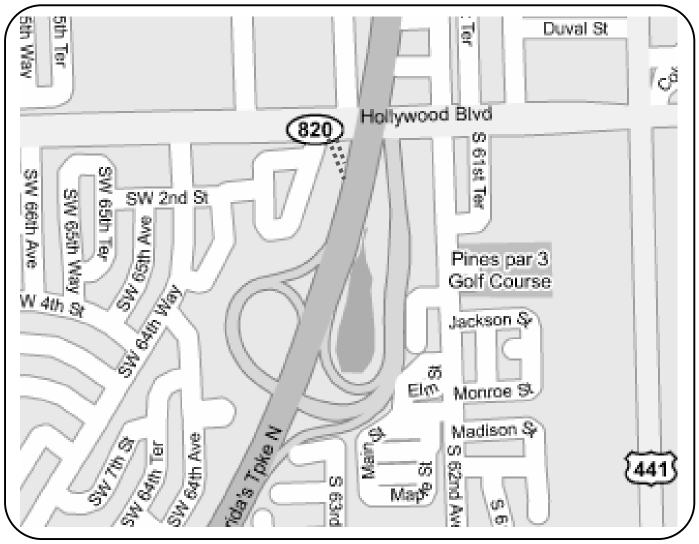


Figure 78: Proposed Improvement of a Trumpet Interchange by Florida Turnpike

6.3.2 Improvement of Signal Efficiency at Off-Ramp Terminal Intersections

The improvement of traffic signal efficiency is a major cost-effective short-term countermeasure to reduce queues at freeway off-ramps. These improvements may include but are not limited to effective monitoring with CCTV cameras, multiple cycling, use of signal pre-emption to clear off-ramp queues, use of volume-density controller features to prevent unexpected signal gap out at off-ramps due to slow-moving vehicles, allowance of right turn on red at off-ramp terminal intersections, and provision of free right turns from the off-ramp to arteries. Specific countermeasures are addressed as follows.

6.3.2.1 Use Monitoring Camera to Effectively Monitor the Congested Off-Ramp and Take Proper Actions to Reduce the Off-Ramp Queue

This is a popular countermeasure to utilize CCTV cameras to monitor off-ramp queues and arterial traffic conditions at traffic management centers, as shown in Figure 79. The TMC operators, supervisors and managers can take proper actions including signal timing adjustments to reduce the off-ramp queue problems based on overall off-ramp and arterial traffic conditions. Signal efficiency can be improved through effective monitoring.

Sun Guide Traffic Management Center, Miami   Dallas Traffic Management Center

Figure 79: Congestion Monitoring at Traffic Management Centers

6.3.2.2 Apply Multiple Cycling or Short Cycle Length

In some cases, a coordinated cycle length of an artery is long due to some critical intersections in the coordination system. If there is capacity available with volume/capacity (v/c) ratio is 0.85 or less at the off-ramp terminal intersection, a multiple-cycling technique may be used to try to minimize the queuing on the off-ramp.

The multiple-cycling technique is to use the same amount of time of a full cycle length of a coordination system to run multiple cycles at a specific signalized intersection in order to reduce motorist's waiting time or queue length on the side streets. At the same time, the traffic flow on the coordination system still can maintain certain degree of progression at the signalized intersection with a multiple cycling. For example, if the cycle length of a coordination system is 180 seconds, the cycle length for triple cycling is only 60 seconds.

By using a shorter cycle length for the off-ramp, the queuing and delays for the ramp may be dramatically reduced. This is because the queue accumulated during the shorter red time is less than that of longer red time. However, it is important to evaluate the effects of this type of operation at adjacent signalized intersections along the artery such as progression bandwidth. Figure 80 shows the effect of triple cycling at a ramp junction.

If the off-ramp terminal intersection is congested (v/c near 1.0), the application of multiple-cycling technique cannot resolve the queue problems due to more time wasted for signal changes during a full cycle length.

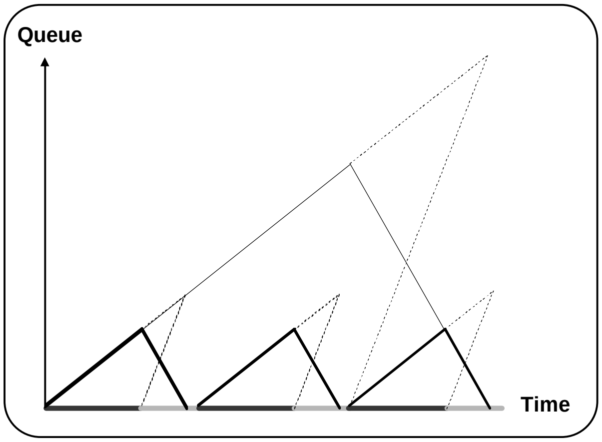


Figure 80: Multiple-Cycling Technique to Reduce Accumulated Queues

6.3.2.3 Pre-empt Signals If an Off-Ramp Queue Reaches a Designated Point on the Off-Ramp

Signal pre-emption can also be used to clear off-ramp queue. The traffic signal will turn green to clear off-ramp queues when a queue detector (box) as shown in Figure 81 detects the off-ramp queue reaching a certain critical point to avoid spillback to a freeway.

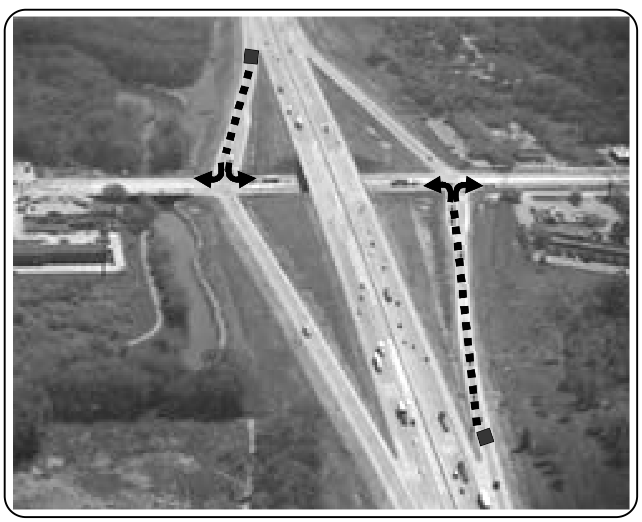


Figure 81: Use of Signal Pre-Emption to Reduce Off-Ramp Queues

6.3.2.4 Allow Right-Turn on Red from the Off-Ramp at the Terminal Signalized Intersection

When there is a problem of queue spillback from a freeway off-ramp to the freeway mainline, transportation professionals can allow right turns on red at the off-ramp terminal signalized intersections if no major safety concern exists at the terminal intersection. A No Turn on Red blank-out sign, as shown in Figure 82, may be used to prohibit right-turn on red only during specific time periods, thus allowing motorists to make right turns during most of time to increase intersection capacity. It will decrease the amount of vehicles queued waiting for the traffic light to turn green.

Figure 82: Use of No Turn on Red Blank-out Sign to Increase Intersection Capacity

6.3.2.5 Use Volume-Density's Gap Reduction Feature

The queue problem at off-ramps sometimes is due to unexpected early signal gap out from slow-moving vehicles. The off-ramp queue may continue to spill back to the freeway mainline throughout the whole peak hour period because of just one or two such unexpected signal gap outs in the early stage of the period. This type of queue problem may be mistaken as a major capacity problem. However, the problem can be easily minimized or eliminated by applying volume-density features at the terminal signals.

The signals at off-ramps are likely to gap out due to slow-moving vehicles such as heavy trucks, trailer and construction vehicles if the passage time (extension time) is not set long enough to extend the green time. However, long passage time is not efficient for signal operation. The best way to accommodate long passage time for slow-moving vehicles and short passage time for efficient signal operations is to use volume-density controller features which are addition of initial and gap reduction, as shown in Figure 83. The feature of addition of initial will allow the minimum green time to increase based on the number of vehicles passing the passage detector up to the maximum initial setting. The value of maximum initial setting is input by traffic engineers which is the estimated time to clear all vehicles stored between the stop bar and the passage detector. This feature will ensure the minimum green time is long enough to clear all vehicles stored before the passage detector. The feature of gap reduction will allow a long passage time in the early stage of a green period (vehicles moving from stop), gradually reduced to a minimum passage time (vehicles moving at certain speeds) at later stages of the green period. This feature can minimize the signal gap out due to slow-moving vehicles and at the same time maintain efficient signal operation.

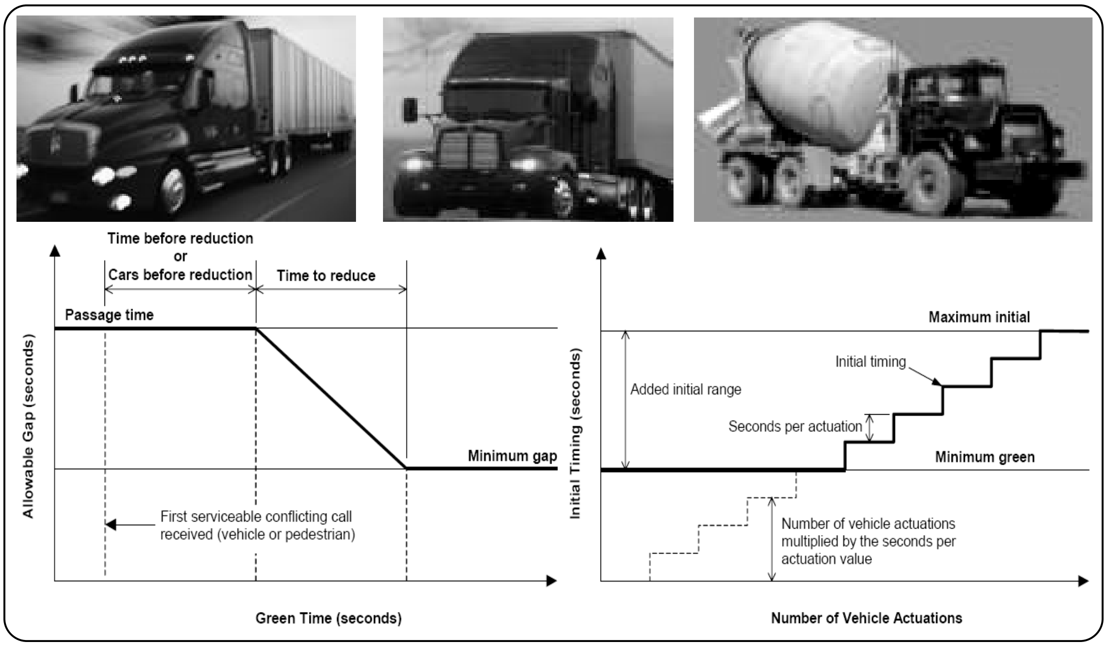


Figure 83: Use of Volume-Density Controller Features to Reduce Queue Problem

6.3.2.6 Provide Free Right Turns From the Off-Ramps to Arteries with Tapers or Exclusive Lanes

If there are no downstream weaving problems or safety concerns, it is effective to provide free right turns from the off-ramps to intersected arteries with proper tapers or exclusive lanes as shown in Figure 31 to reduce queue accumulated at off-ramps. The photo on the right shows an exclusive right-turn lane from the off-ramp that extends to the artery and becomes one of the through lanes on the artery. The exclusive lane allows vehicles to maintain their speeds without merging onto the artery, and reduces the traffic congestion at the off-ramp terminal intersection.

6.3.3 Alleviation of Arterial Congestion

In many cases, the queue problems at freeway off-ramps are not the off-ramps themselves but the arteries with which they intersect. The vehicles from the off-ramps cannot move effectively to the arteries because of the traffic congestion occurring on the arteries. The congestion may come from road construction or maintenance, traffic accidents, signal pre-emption, poor signal coordination, left-turn or right-turn queues at downstream intersections blocking through lanes, weaving problems on arteries, and roadway capacity problems.

Figure 84: Use of Free Right Turns to Reduce Off-Ramp Queues

In the past, state transportation agencies focused more on freeway management while local transportation agencies concentrated mainly on arterial management. The integration of both freeway and arterial management has become more and more important in today's traffic environment. It requires more communication, coordination and corporation among different jurisdictions in order to resolve more complicated and challenging transportation problems.

If the off-ramp queue problems come from arterial congestion, the alleviation of arterial congestion becomes the key to resolving the off-ramp queue issues. There are several major countermeasures to minimize arterial congestion, including effective monitoring of arterial congestion; provision of better signal coordination; reduction of downstream queue problems at turn lanes of arteries; lengthening of turn lanes; removal of signal on the arterial near congested interchanges; quick response to arterial incidents; proper arterial school zone, work zone, and special event management; and increased capacity of arteries by adding lanes on arteries or minor streets.

6.3.3.1 Use Monitoring Cameras to Effectively Manage Congestion and Respond To Incidents

For arterial management, CCTV cameras also play a very important role in monitoring traffic flow, detecting incidents and providing direct visual feedback to any action taken for traffic management. The regional Advanced Traffic Management System shown in Figure 85 is designed to enhance mobility on arterial roadways in Seminole County, Florida by incorporating the latest technological advancements. This Center is utilized jointly by the Traffic Engineering Division and 911 Operations personnel.

Figure 85: Regional Advanced Traffic Management System to Enhance Mobility on Arterial Roadways in Seminole County, Florida

6.3.3.2 Provide Better Signal Coordination on the Arterial

Traffic signal coordination on major arteries is essential for mobility in urban areas as shown in Figure 86. Signal retiming is one of the most cost-effective short-term countermeasures to minimize arterial congestion. If volume over capacity ratio is less than one, excess queues on arteries can generally be minimized by better signal coordination. The value of signal coordination to reduce traffic congestion on arteries should not be underestimated.

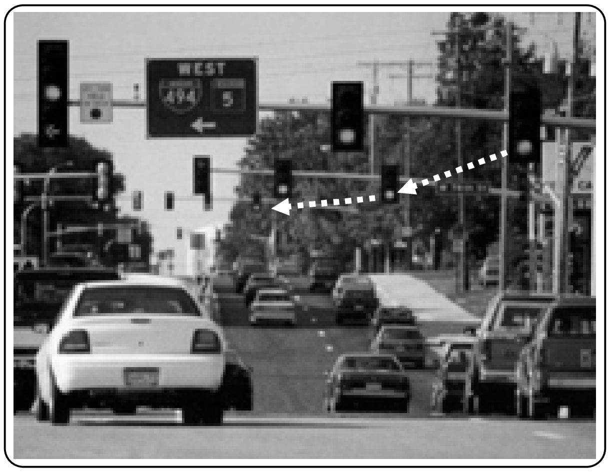


Figure 86: Alleviation of Arterial Congestion through Traffic Signal Coordination

6.3.3.3 Reduce Queues of Downstream Turning Lanes on the Arterial near Off-Ramps

Excess queues from inside through lane and left-turn lanes as shown in Figure 87 at downstream signalized intersections near freeway interchanges are another possible cause of arterial congestion, which cause the queue problem at off-ramps. Different signal timing strategies such as traffic signal coordination, lead-lag left-turn operation for a coordinated signal, shorter cycle length, and longer left-turn green time, can be applied to minimize the effect of queue blockage problems. If funding is available, the increase of left-turn storage length is a direct way to reduce queue blockage problems on arteries.

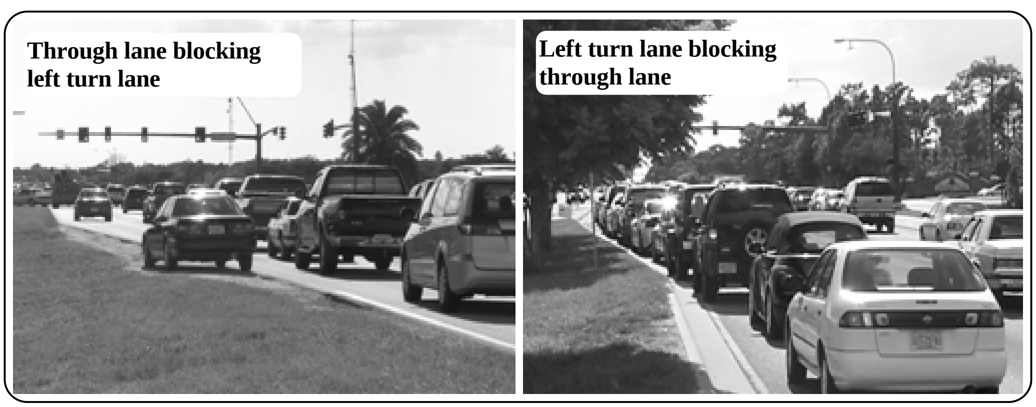


Figure 87: Reduction of Queue Blockage Problems to Reduce Arterial Congestion

6.3.3.4 Provide Adequate Turn Lanes at Downstream Intersections or Median Opening on the Arteries near Interchanges

Adequate lengths of left-turn and right-turn lanes on an artery near freeway interchanges are especially important to avoid queue blockage and minimize traffic congestion. Figure 88 shows an adequate left-turn lane on SR 70 just west of I-75 in Bradenton, Florida.

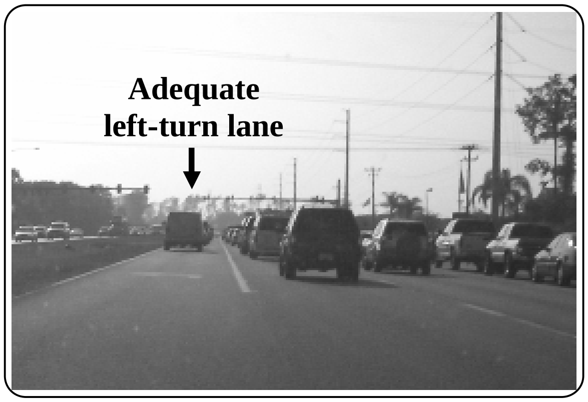
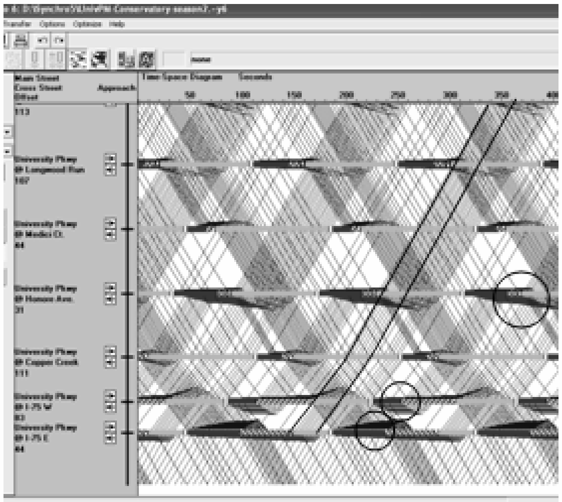


Figure 88: An Adequate Left-turn Lane on SR 70 Just West of I-75

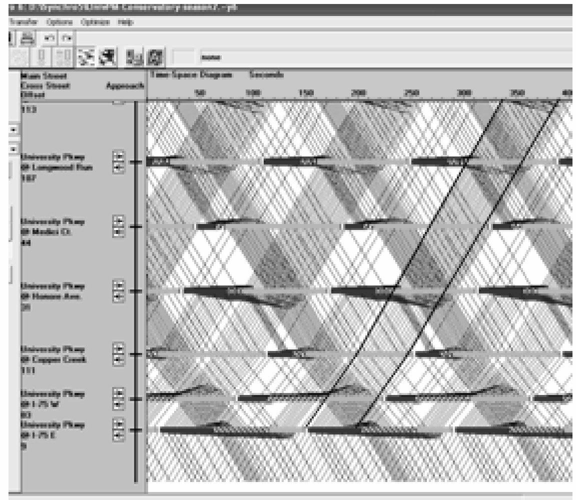
6.3.3.5 Provide Signal Coordination from the Off-Ramp to the Artery If It Is More Effective

The progressed movements of a traffic signal coordination plan usually are the through movements of an artery because the artery has more lanes and carries more traffic than the side streets. In some cases or during some periods of time, the traffic volume from an off-ramp is heavier than that from an artery. If the available capacity on the artery downstream is better utilized by the progression from the off-ramp, traffic engineers may consider providing traffic signal progression from the off-ramp.

Figure 89 shows a comparison of time-space flow diagrams between coordination for the arterial through movement and coordination for the off-ramp movement for University Parkway in the vicinity of I-75 in Sarasota County, Florida. The traffic volume from the off-ramp is larger than that from the westbound through movement on University Parkway. The diagram on the left side is the signal coordination from westbound University Parkway, indicating queues backed up at several intersections. The diagram on the right side is the signal coordination from the northbound off-ramp, indicating excellent westbound progression with minimum queues on the University Parkway. To reduce off-ramp queue problems, traffic engineers should consider signal coordination from the off-ramp to the artery if it is more effective.



Coordination from the arterial movement



Coordination from the off-ramp

Figure 89: Comparison of Two Time-Space Flow Diagrams

6.3.3.6 Remove Signals on the Arterial near Interchanges

In some situations, the traffic problem at the signalized intersection immediately downstream on the artery from the off-ramp terminal intersection is the major bottleneck of the artery. If a study shows that the signal is no longer warranted, removal of the unwarranted signal may be another option to reduce the traffic congestion near the off-ramp terminal intersection. Proper reallocation of the traffic flow is needed after the removal of the traffic signal. In general, this countermeasure is difficult to implement due to public opposition.

6.3.3.7 Reduce Response Time to an Arterial Incident

Any incident on or near an interchange can easily cause off-ramp and arterial congestion as shown in Figure 90. The key to minimize this type of traffic congestion is to promptly respond to the incident by the appropriate responsible agencies. Arterial signal timing plans should also be properly adjusted.

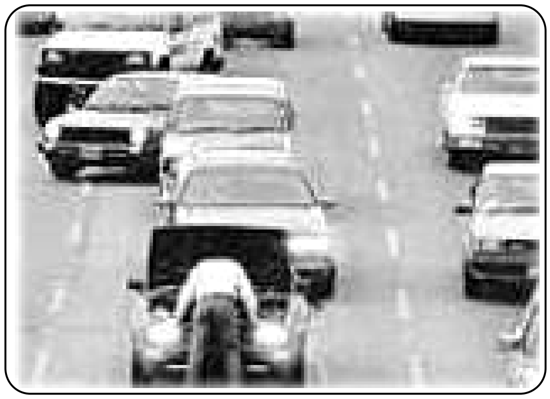


Figure 90: Arterial congestion due to an incident

6.3.3.8 Properly Manage School Zones, Work Zones, and Special Events on Arteries

Arterial congestion is sometimes caused by school zones, work zones, and special events. However, the traffic congestion can be minimized if proper actions are taken in advance such as signal timing modification, and setup of a detour route for traffic diversion. Figure 91 shows how traffic signal progression is used to improve traffic congestion at a school zone. The progression speed in the time-space flow diagram was designed based on 45 mph on the artery excluding the school zone and 15 mph for the segment of the school zone.

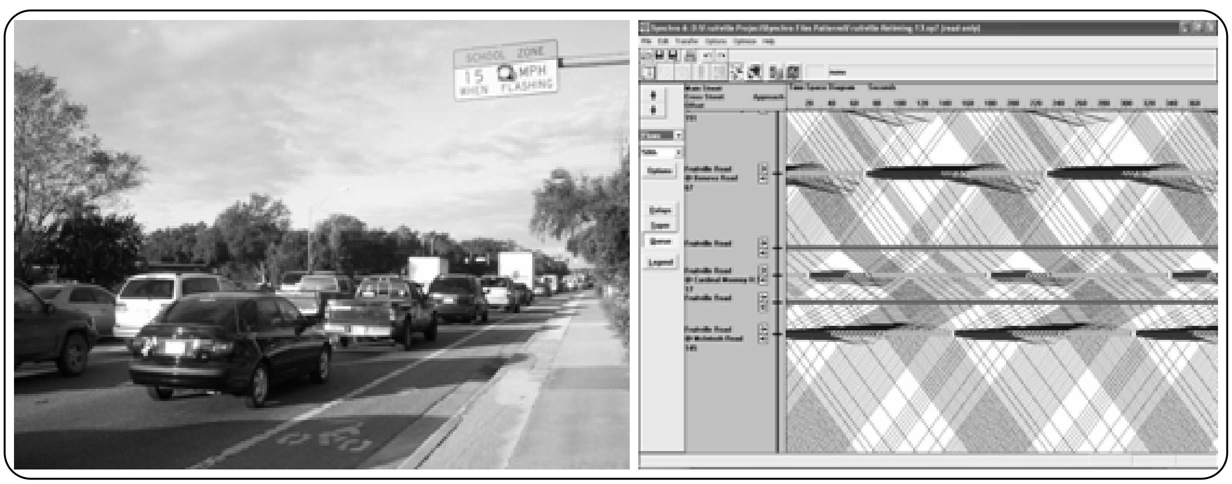


Figure 91: Use of Traffic Signal Progression to Improve School Zone Congestion

6.3.3.9 Add Lanes on Arteries near Interchanges

Addition of extra lanes on an artery near interchanges is a significant geometric improvement to increase arterial capacity. One of major disadvantages of a diamond interchange is that it is difficult to handle significant left-turn volumes from an artery to a freeway on-ramp. Therefore, addition of an exclusive left-turn lane on the artery near an interchange, as shown in Figure 92, can drastically alleviate the queue blockage problem on the artery, and increase arterial capacity. Dual left-turn lanes from the artery to the on-ramp at the signalized intersection are also recommended where left-turning volumes are heavy. By improving the arterial efficiency which allows for a redistribution of green time, they can provide off-ramps longer green time, and thus reduce queue blockage.

Figure 92: Addition of an Long Exclusive Left-Turn Lane near an Interchange

6.3.3.10 Add Lanes to Minor Roads

Besides adding lanes on arterial, addition of lanes or construction of sufficient capacity on minor roads, as shown in Figure 93, can reduce the green time required for traffic on minor roads; therefore, it can increase the proportion of green time for the artery. Addition of lanes to minor roads is an effective geometric improvement to increase the capacity on the artery especially near interchanges. It generally costs less and has a minor impact on traffic on the artery.

Figure 93: Addition of Lanes on Minor Roads to Reduce Arterial Congestion

6.3.4 Adoption of Access Management on Crossroads near Interchanges

Access management is the systematic control of the location, spacing, design and operation of median openings, driveways, and street connections. With fewer new arterial roadways being built, the need for effective systems management is greater than ever before. Different types of roadway serve different functions, as shown in Figure 94. It is important to design and manage the roadways according to the primary functions of that roadway. The adoption of access management policies and the use of access management techniques can increase roadway capacity, manage congestion, and reduce crashes. It is especially important to adopt access management to limit direct access to major arteries, and regulate the signal spacing as well as median openings on crossroads near interchanges to ensure efficient and safe roadway transportation systems. Specific countermeasures are addressed below.

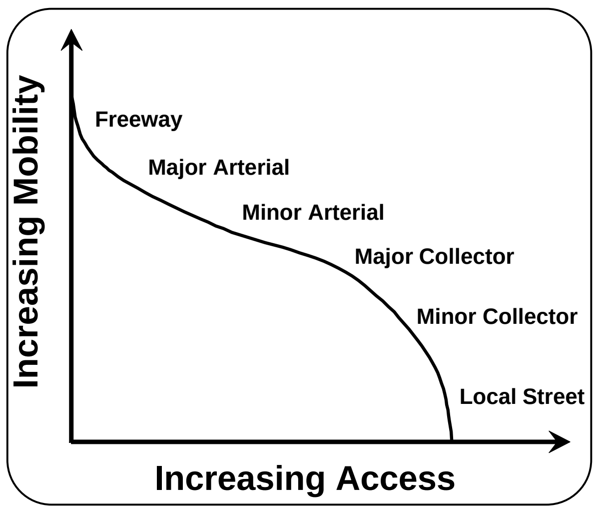


Figure 94: Classification Based On Mobility and Accessibility

6.3.4.1 Ensure Adequate Signal Spacing, Median Openings and Connection on the Roadways Connected To Freeway Interchanges

The lack of an access management plan or policy will have a number of negative impacts to the roadway system and public safety. These impacts include a reduction in overall traffic safety, increased traffic congestion, slower travel speeds, longer delays, increase of neighborhood cut-through traffic, more vehicle and pedestrian conflicts, and less pleasing visual settings and developments along the corridor. Transportation agencies should adopt access management standards or policies to ensure adequate signal spacing, median openings, and connections for their roadway networks especially near interchanges. The minimum standards for controlled access facilities based on the access class in the State of Florida are shown in Figure 95, and the FDOT Interim Standards are shown in Figure 96. The Interim Standards can be applied to a roadway where the access classification is not yet adopted.

6.3.4.2 Adopt access management regulations on limited access interchange areas

According to the FDOT Access Management and Site Circulation Regulations, "Connections and median openings on arterial and collector roadways located up to 1,320 feet (1/4 mile) from an interchange area or up to the first intersection, whichever distance is less, shall be regulated to protect the safety and operational efficiency of the limited access facility and the interchange area". The minimum distance to the first connection from the terminus of the off-ramp shall be at least 660 feet (1/8 mile) as shown in Figure 97(a). The minimum distance to the first full median opening shall meet FDOT connection spacing standards. This distance should be long enough to minimize potential weaving problems from the off-ramp to the left-turn bay of the first median opening or signalized intersection as shown in Figure 97(b). By implementing access management regulations in the vicinity of interchange ramps, the ramp terminal intersection can discharge vehicles onto the artery in a safe and efficient manner. This should help to minimize the possibility of queues spilling back onto the mainline of the freeway.

CONTROLLED ACCESS FACILITIES

ACCESS CLASS	FACILITY DESIGN FEATURES (MEDIAN TREATMENT AND ACCESS ROADS)	MINIMUM CONNECTION SPACING (FEET)	MINIMUM MEDIAN OPENING SPACING DIRECTIONAL (FEET)	MINIMUM MEDIAN OPENING SPACING FULL (MILE)	MINIMUM SIGNAL SPACING (MILE)
2	Restrictive with Service Roads	1320/660	1320'	0.5	0.5
3	Restrictive	660/440	1320'	0.5	0.5
4	Non-Restrictive	660/440	N/A	N/A	0.5
5	Restrictive	440/245	660'	0.5/0.25	0.5/0.25
6	Non-Restrictive	440/245	N/A	N/A	0.25
7	Both	125	330'	0.125	0.25

(Greater than 45 MPH/ Less than or = 45 MPH)

NOTE: * Section 14-97.003 and 14-97.004, FAC, contain supplementary and more detailed instrictions for the use of these standards.

Figure 95 Minimum Standards for Controlled Assess Facilities in Florida

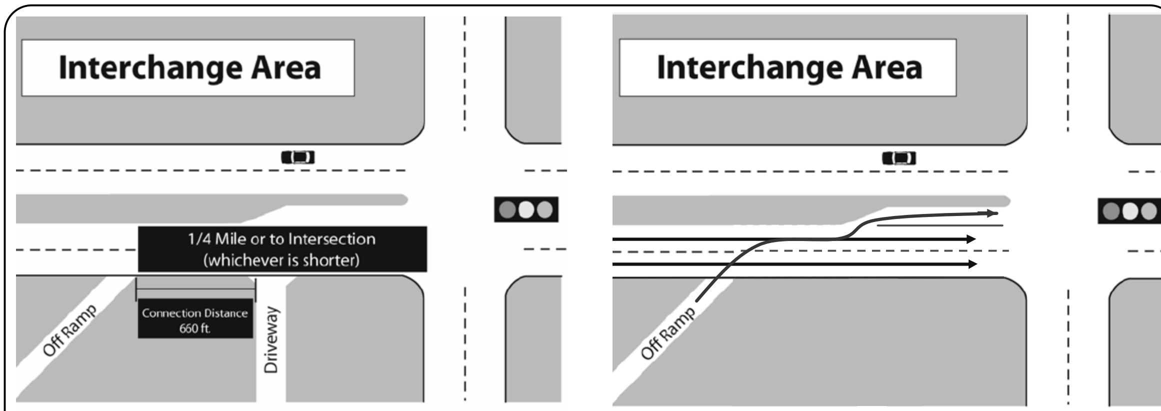
INTERIM STANDARDS

Posted Speed	Minimum Connection Spacing	Minimum Median Opening (Full)	Minimum Median Opening (Directional)	Minimum Signal Spacing
(MPH)	(Feet)	(Miles)	(Feet)	(Miles)
35 or less Special Case	125	0.125	330	0.25
35 or less	245	0.25	660	0.25
36 - 45	440	0.25	660	0.25
Over 45	660	0.50	1320	0.25

Figure 96 FDOT Interim Standards for Roadway without Classifications

6.3.4.3 Adopt access management regulations on limited access interchange areas

According to the FDOT Access Management and Site Circulation Regulations, "Connections and median openings on arterial and collector roadways located up to 1,320 feet (1/4 mile) from an interchange area or up to the first intersection, whichever distance is less, shall be regulated to protect the safety and operational efficiency of the limited access facility and the interchange area". The minimum distance to the first connection from the terminus of the off-ramp shall be at least 660 feet (1/8 mile) as shown in Figure 97 (a). The minimum distance to the first full median opening shall meet FDOT connection spacing standards. This distance should be long enough to minimize potential weaving problems from the off-ramp to the left-turn bay of the first median opening or signalized intersection as shown in Figure 97 (b). By implementing access management regulations in the vicinity of interchange ramps, the ramp terminal intersection can discharge vehicles onto the artery in a safe and efficient manner. This should help to minimize the possibility of queues spilling back onto the mainline of the freeway.



(a) Limited access interchange areas (b) Provision of adequate weaving distance

Figure 97: Example of access management applications

6.4 IMPROVEMENT OF OFF-RAMP AND FREEWAY STORAGE CAPACITY

The third fundamental approach to minimize the off-ramp queue problem is to increase the storage capacity either on the off-ramp or its associated freeway. The storage capacity at the off-ramp can be increased through lengthening of existing turn lanes, and addition of extra lanes at the off-ramp. The storage capacity at the freeway can be increased through dynamic use of a shoulder lane for a short recurring bottleneck during peak hours supplemented by a reasonable freeway speed limit, construction of a turn bay or an additional lane for deceleration before the off-ramp, which can provide extra storage space for off-ramp queues, and reassignment of lane usage on the freeway at the diverge gore. These strategies are presented in Figure 98.

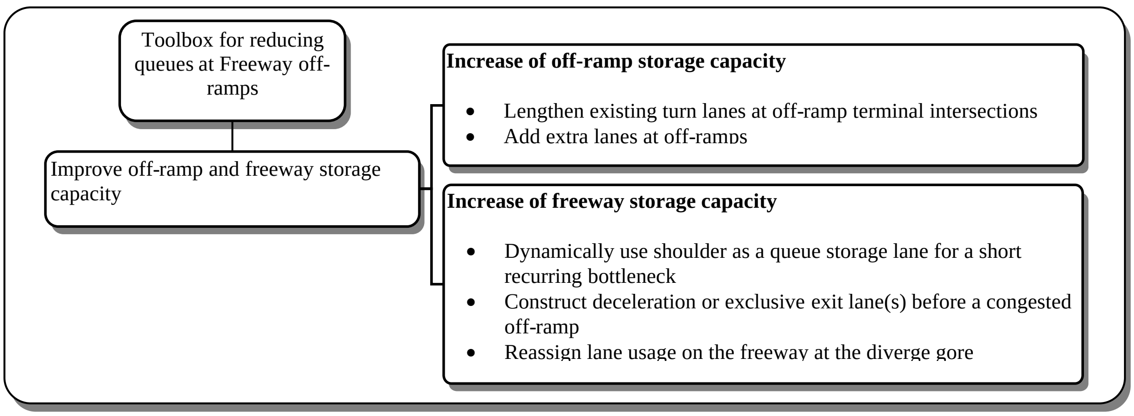


Figure 98: Countermeasures Based on Improve Off-Ramp and Freeway Storage Capacity

6.4.1 Increase of Off-Ramp Storage Capacity

The lack of storage capacity for vehicles queued at freeway off-ramps is one of the major causes of traffic spillback to the freeway mainline. The capacity of queue storage for many old interchanges has become inadequate to handle today's increasing traffic demand. There are two major countermeasures to resolve the queue storage problem at off-ramps. One is to lengthen existing left-turn and/or right-turn lanes at off-ramp terminal intersections, depending on the traffic volume and right-of-way constraints. The other one is to add extra lane(s) at the congested off-ramp. The extra lane(s) will not only improve storage capacity for vehicles waiting at off-ramps, but also increase the departure capacity at the off-ramp terminal intersection. These two geometric improvements generally can alleviate queue problems at off-ramps for a longer period of time than most other countermeasures.

6.4.1.1 Lengthen Existing Turn Lanes at Off-Ramp Terminal Intersections

This countermeasure consists of lengthening existing turn lanes at off-ramp terminal intersections to accommodate not only the existing queue during peak periods, but also the future queue of a projected design year. The length of the subject turn lane needs to be properly designed based on traffic volume and right-of-way constraints.

6.4.1.2 Add Extra Lanes at Off-Ramps

If the off-ramp encounters both storage capacity problems at the ramp and departure capacity problems at its terminal intersection, the addition of extra lanes at the off-ramp terminal intersection may be an effective countermeasure to serve both purposes. Figure 99 shows where a right-turn lane was added and one left-turn lane was lengthened to resolve off-ramp queue problems.

Figure 99: Addition of Extra Lanes to Resolve Off-Ramp Queue Problems

6.4.2 Increase of Freeway Storage Capacity

Although the purpose of freeways is not for the storage of off-ramp queues, in some situations the outside lane will unavoidably become a storage lane for spilled off-ramp queues. This creates a very dangerous potential for high-speed rear-end crashes. There are several countermeasures that can be used to minimize this problem through the increase of freeway storage capacity. The first countermeasure is to temporarily allow motorists to use the shoulder as a storage lane when other countermeasures are not effective or available. The second countermeasure is to construct deceleration or exclusive exit lane(s) before a congested off-ramp. This is effective especially for heavy exiting volumes at the off-ramp. The third countermeasure is to reassign lane usage on the freeway at the diverge gore for the off-ramp with two lanes. This countermeasure will increase the volume exiting the freeway, reduce the queue spill back to the freeway mainline, and indirectly provide extra storage capacity.

6.4.2.1 Dynamically Use Shoulder as a Queue Storage Lane for a Short Recurring Bottleneck

When the off-ramp queue spills back to a freeway mainline, it is common to see motorists who are waiting to enter the off-ramp naturally use the shoulder as a temporary storage lane to avoid directly stopping or slowly moving on the outside lane of a freeway when most upstream vehicles are traveling with relatively high speeds. If other countermeasures are not effective or available, the allowance of using the shoulder as a temporary storage lane for a short recurring bottleneck during peak hours is a cost-effective option to consider. In some occasions, shoulder may have been temporarily used as a detour route during crashes, construction or freeway maintenance. It may be justifiable to improve (widen and stripe) the shoulder near the off-ramp as an exclusive exit lane or for temporary storage of queues spilled from the off-ramp to minimize the potential of fatal crashes. This is a cost-effective improvement without the expense of constructing an extra lane. A proper message through VMS upstream of the exit ramp should be used to inform motorists about the temporary usage of shoulder and its schedule. Proper speed limits upstream of the freeway should be posted. This countermeasure can help to alleviate severe freeway congestion and improve motorists' safety

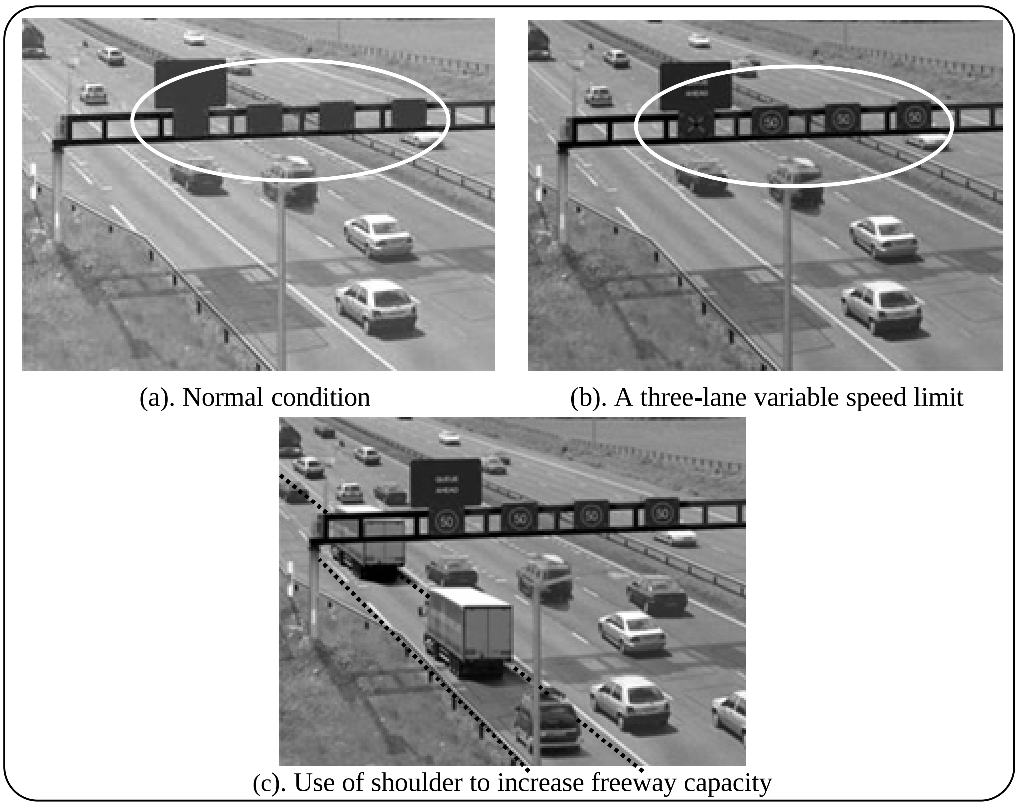
It is necessary to mention that the use of shoulder lanes as travel lanes to improve freeway congestion has been evaluated with positive results. These capacity increases however, have often been achieved with some increase in crash rates. Thus, the design of such lanes must clearly take into consideration the safety aspects of the particular freeway section. Even though such treatments should be considered temporary, an FHWA staff study found that in cities with populations over one million, almost 32 percent of the urban freeway mileage could experience reduced congestion though such low-cost measures. Figure 100 shows a shoulder of I-35 in Minneapolis, that is used as a bus lane.

Figure 100: Shoulder Bus Lane on I-35 in Minneapolis, Minnesota

Active traffic management at off-ramp 3A-7 on the M42 Motorway in the United Kingdom [39] is shown on Figure 101. When traffic flows are normal without incidents, there is no need for signal intervention to control speeds or lane availability as shown in Figure 101(a). As traffic flows increase, or in response to an incident, clear instructions will be given via the overhead VMS signs, shoulder lane sign, and variable speed limit signs as shown in Figure 101(b). The controlled use of the hard shoulder will be used to provide additional capacity during periods of congestion and in case of incidents as shown in Figure 101(c).

6.4.2.2 Construct Deceleration or Exclusive Exit Lane(S) before a Congested Off-Ramp

As mentioned earlier, the main concern from the spillback of vehicles into freeways resulting from congested off-ramps is when freeway vehicles traveling at high speeds collide with vehicles at very low (or zero) speed that are waiting to enter the off-ramp. If funding is available, a logical solution is to construct deceleration lane(s) or exclusive lanes before the existing off-ramp so that the excess off-ramp demand is removed from the freeway. This countermeasure is suitable for locations with heavy exiting traffic. Other than improving traffic safety, this solution also improves the overall highway system by allowing vehicles to maintain their speeds for longer periods. Figure 102 shows a exclusive exit lanes provided to reduce the queue from off-ramp spillback to the freeway on I-75 in the Tampa Bay area, and I-95 in the Ft. Lauderdale area, respectively.

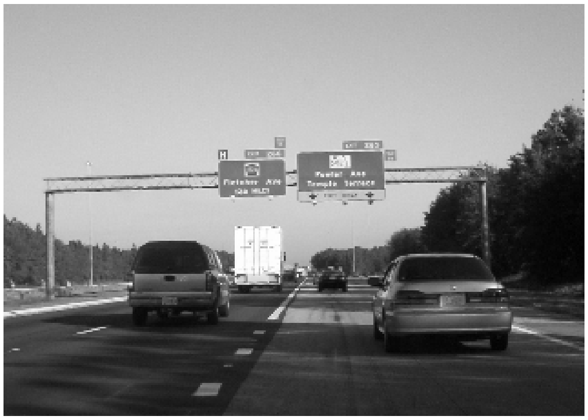


(a). Normal condition

(b). A three-lane variable speed limit

(c). Use of shoulder to increase freeway capacity

Figure 101: Active Traffic Management at Off-Ramp 3A-7 on M42 Motorway in UK



Two exclusive exit lanes on northbound i-75 before SR 582 (Fowler Ave) in Tampa, Florida

Provision of an exclusive exit lane on southbound I-95 before SR 842(Broward Blvd) in Broward County, Florida

Figure 102: Examples of Exclusive Exit Lanes

6.4.2.3 Reassign Lane Usage on the Freeway at the Diverge Gore

In some cases, the off-ramp has two or three receiving lanes but the freeway has only one or two exclusive exit lanes. One way to ensure the off-ramp capacity is fully utilized is to examine whether the resources (lanes) at the off-ramp are efficiently utilized. Proper lane usage assignment will increase the freeway exit capacity. For example, if outside lane on a freeway is an exclusive exit lane leading to a two-lane off ramp, transportation professionals can reassign the second outside lane on the freeway to a shared through and right-turn (exit) lane as shown in Figure 103. Where traffic leaving the freeway at an exit ramp exceeds the design capacity of a single lane, it is necessary to provide a two-lane exit ramp. To satisfy lane balance requirements and not reduce the basic number of through lanes, it is usually necessary to add an auxiliary lane upstream from the exit as indicated by AASHTO [1].

The vehicles on the shared lane can either continue on the freeway or enter the off-ramp. This countermeasure will increase the exit capacity from the freeway to the off-ramp. It is especially effective when the off-ramp terminal intersection has enough departure capacity to handle extra demand. This lane reassignment at the freeway diverge gore enables better lane utilization of the off-ramp, so it can reduce the chance of off-ramp queue spill to the freeway mainline.

Lane Assignment at a Freeway Diverge Gore Area

Lane Channellization at a Freeway Diverge Gore Area

Figure 103: Examples of lane reassignment on the freeway at the diverge gore

7 CONCLUSIONS AND RECOMMENDATIONS

With rapid growth of population and economic activities in many states, there are several freeway interchanges where queues on the off-ramps spill back onto the freeway mainline. It creates a potentially extremely hazardous condition of high-speed rear-end collisions on the mainline and also causes possible severe traffic congestion on the freeway. This work provides valuable countermeasures to reduce queues at freeway off-ramps based on comprehensive literature review, surveys of FDOT districts, interviews with FDOT District Traffic Operation Engineers, opinions from transportation experts, and case studies. In general, this toolbox is a source of countermeasures targeting the off-ramp queue spillback problem from different perspectives: freeway operations, arterial operations, and off-ramp operations. On the other hand, the countermeasures provided can be used in several ways, depending on the particular needs of the user. Additional countermeasure lists are presented in Appendix F.

The problem of queue spillback onto the freeway mainline is present at different locations at different stages of severity. This study found that inadequate capacity at the off-ramp terminal intersection due to rapid demand growth and/or outdated traffic signal timing plans, limitation of off-ramp storage capacity, lane blockages on the arterial, congestion problems along the arterial, and close distance between the off-ramp terminal and its immediate downstream intersections are the major causes for the spillback of queue from off-ramps to freeway mainlines.

The most common and effective short-term countermeasures include, but are not limited to:

- Signal timing improvement at the off-ramp terminal intersections
- Signal retiming along the arterial near the off-ramp terminal intersection
- Reassignment of lane usage at the off-ramp terminal intersection or freeway diverge gore area
- Adding lanes to the off-ramp, lengthen the off-ramp turning lanes
- Lengthening turning lanes at downstream intersections to reduce lane blockage
- Adopting access management policy
- Applying ramp metering to control freeway volumes
- Implementing TDM strategies to reduce freeway demand
- Applying ATIS technologies to provide traveler information
- Utilizing ATMS to effectively monitor traffic congestion to take immediate actions.

The most common and effective long-term countermeasures include, but are not limited to:

- Major geometric improvements at the off-ramp terminal intersection
- Adding lanes on the congested off-ramp to increase departure and storage capacities
- Adding lanes on the arterial to reduce arterial congestion
- Constructing additional interchange near the congested one

From the survey and in-depth interview with traffic operation engineers and their staff of the seven FDOT districts and the Florida Turnpike Enterprise, this study also provides the following findings and observations. In general, signal timing and geometric improvements are the most common countermeasures across all of FDOT districts and the Florida Turnpike Enterprise. For rural and small urban areas, signal timing adjustments and minor geometric improvements at the congested off-ramp terminal intersections are the major successful countermeasures to reduce off-ramp queues. For mid-size urban areas or large urban areas, many different countermeasures mentioned earlier, ranging from basic signal timing improvements to major interchange rebuilding, could be used to effectively reduce queues at freeway off-ramps depending on specific causes. For large metropolitan areas, the available right-of-way is very limited and expensive. The added capacity from signal timing and minor geometric improvements can be consumed very quickly due to large traffic demand. Therefore, the countermeasures to alleviate traffic congestion focus more on the shift of some traffic demand to public transit systems, deployment of ramp meter systems, provision of traveler information such as 511 systems to inform traffic congestion, effective monitoring and response to traffic congestion through traffic management centers, prompt response to incidents to reduce congestion duration, and major geometric improvements along the interstate highway and arterials to create sustainable extra capacity.

Four case studies were conducted to examine the effectiveness of some proposed countermeasures: I-75 & Fowler Avenue interchange and I-75 & Big Bend Road interchange in Tampa, I-95 & Eau Gallie Boulevard interchange in Melbourne, and I-75 & Bee Ridge Road interchange in Sarasota. Signal timing and geometric improvements are the major countermeasures used in these case studies. The results from all case studies verify the benefits of specific countermeasures used in each case study. In the case studies, microscopic traffic simulation proved to be an effective tool to provide thorough before-and-after-analysis. It provided valuable performance measure data such as delays and queue lengths of many intersections for before-and-after analysis and comparisons, which are otherwise very difficult and expensive to collect.

The key findings attained with the project are summarized below:

- The problem of spilled queues from an off-ramp to a freeway mainline is serious and needs to be addressed. The development of countermeasures to reduce queues at off-ramp is required to minimize both safety and congestion problems.

- The countermeasures developed in this work follow three major fundamental approaches, including 1) reduce travel demand and improve freeway operations, 2) improve off-ramp departure capacity and alleviate arterial congestion, and 3) improve the off-ramp and freeway storage capacities for queues.

- Three major countermeasures are used to achieve the reduction in travel demand and improvement of freeway operations: 1) reduction of traffic demand entering the off-ramp, 2) reduction of arrival speeds of vehicles entering the off-ramp, and 3) improvement of freeway operations by dynamic off-ramp management and/or lane-changing restriction upstream of the off-ramp.

- Four major countermeasures are employed to achieve the increase in off-ramp departure capacity and improvement of arterial operations: 1) increase of departure volume at off-ramp terminal intersections, 2) improvement of signal operational efficiency at the off-ramp terminal intersections, 3) alleviation of arterial congestion, and 4) adoption of access management on crossroads near freeway interchanges.

- Three major countermeasures are used to achieve the improvement of off-ramp and freeway storage capacities: 1) dynamic use of a shoulder lane for a short recurring bottleneck during peak hours supplementing with a reasonable freeway speed limit, 2) construction of a turn bay or an additional lane for deceleration before the off-ramp, which can provide extra storage space for off-ramp queue, and 3) reassignment of lane usage on the freeway at the diverge core.

- Many successful or recommended specific countermeasures under each major countermeasure are illustrated with photos and diagrams. These specific countermeasures can be applied individually or combined based on the actual conditions and available funding to reduce serious queuing problems at a specific freeway off-ramp.

With the growth of traffic demand in many states, it is anticipated the problem on the spillback of off-ramp queues to freeway mainlines will become more and more serious. The toolbox of countermeasures developed in this study is a valuable tool to assess the potential countermeasures to alleviate the off-ramp congestion problems. Further study may focus on the benefit and cost analysis for all proposed countermeasures to reduce queues at freeway off-ramps. It will provide transportation professionals with further information to determine needed countermeasures and required cost

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[48] Lin Pei-Sung, "The Effects of Left-turn Lane Queue Lengths on Intersection Delay", ITE 2004 Annual Meeting and Exhibit, Compendium of Technical Papers, *Institute of Transportation Engineers*, Washington D.C., August 2004.

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[51] Transportation Research Board, "Access Management Manual", Washington, D.C., 2003.

[52] FDOT District seven "Corridor Studies.I-75 Interchange Operational Study". September 2004.

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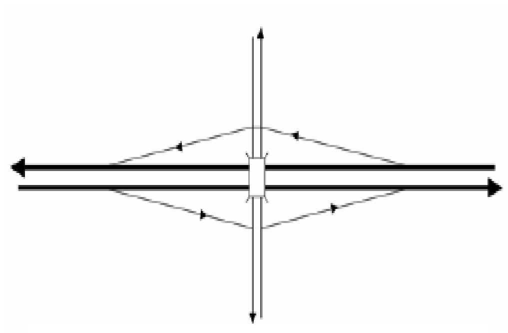
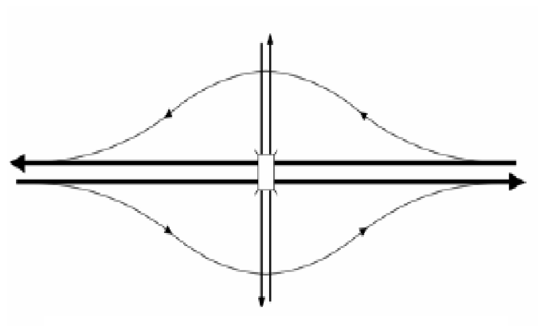
APPENDIX A

ALTERNATIVE INTERCHANGE CONFIGURATIONS

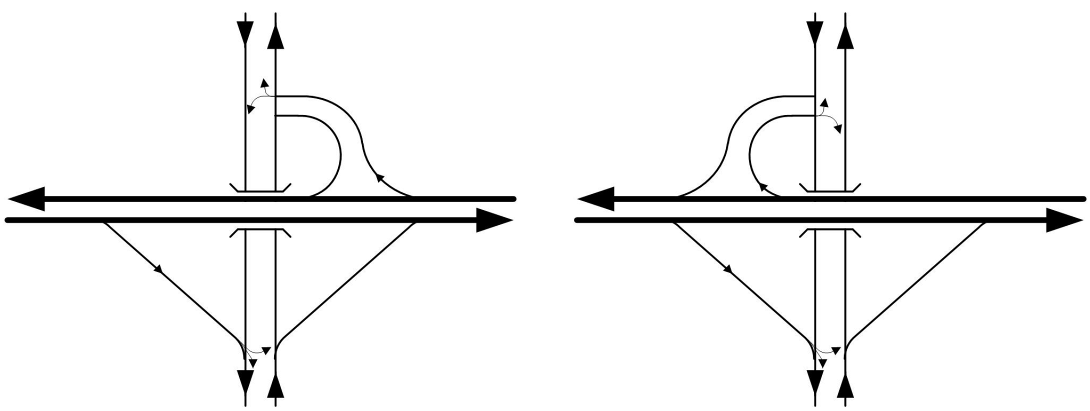
Diamond interchanges



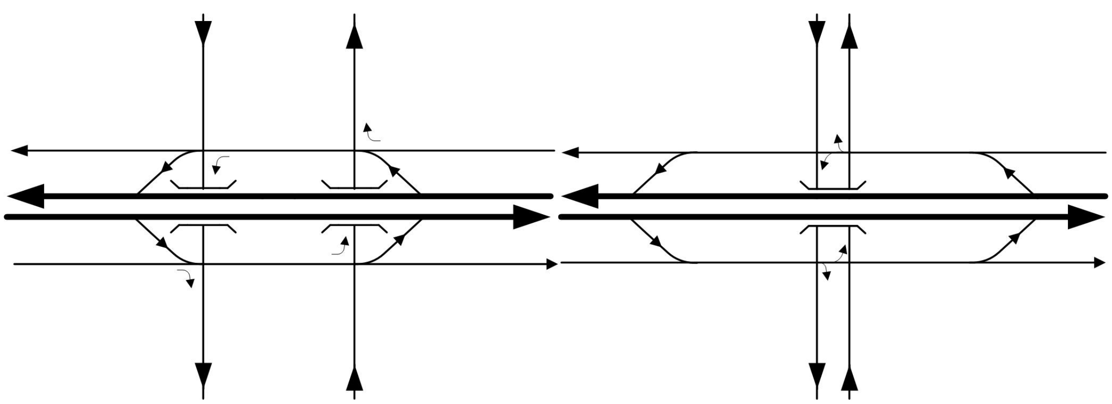
Compressed diamond



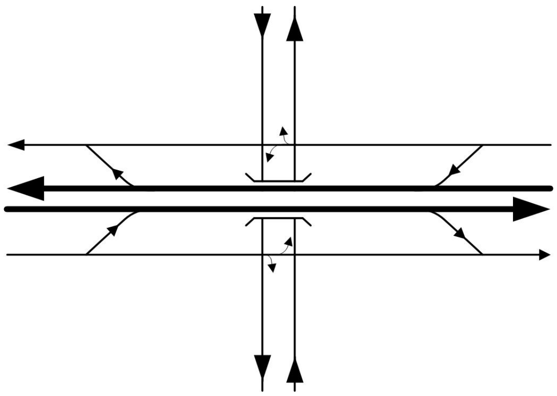
Conventional (spread) diamond



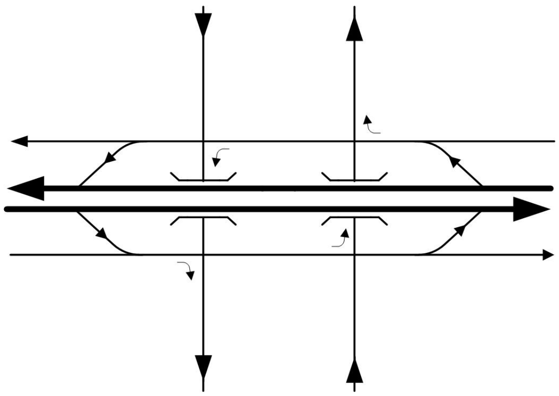
Modified diamond configurations



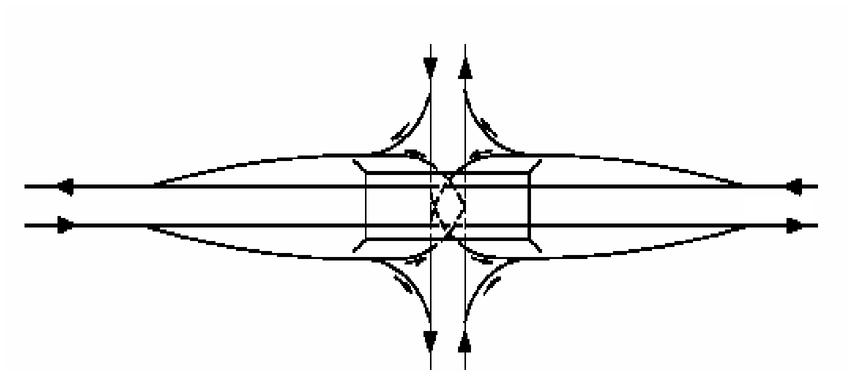
Split diamond configurations



Reverse diamond

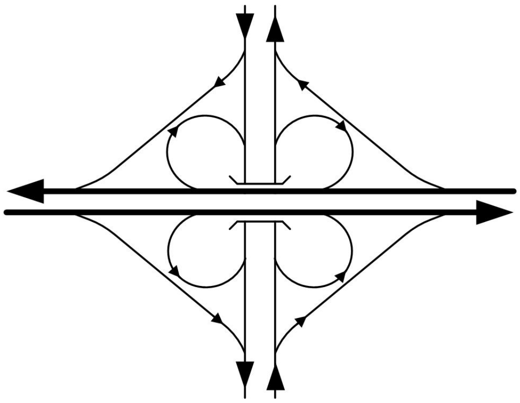


Split diamond

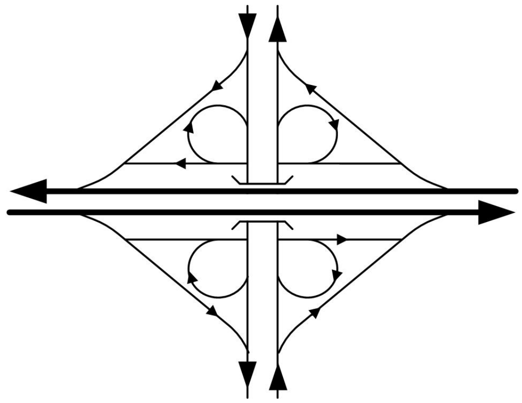


Single point urban diamond interchange

Full cloverleaf interchanges

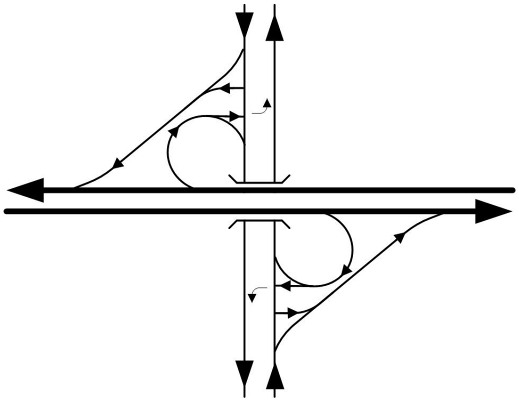


Full cloverleaf

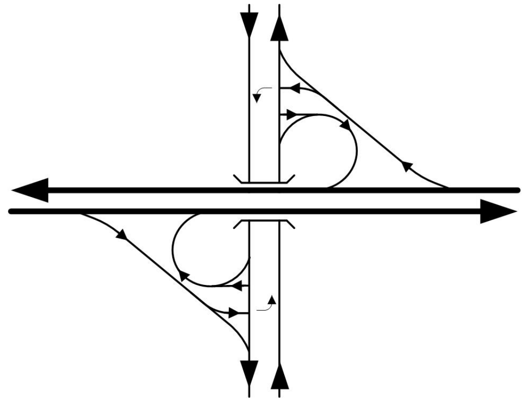


Full cloverleaf with frontage roads

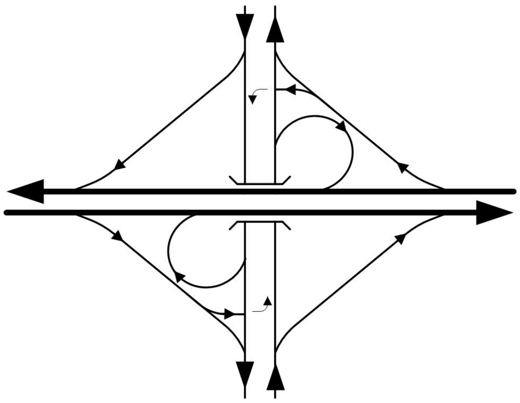
Partial cloverleaf interchanges



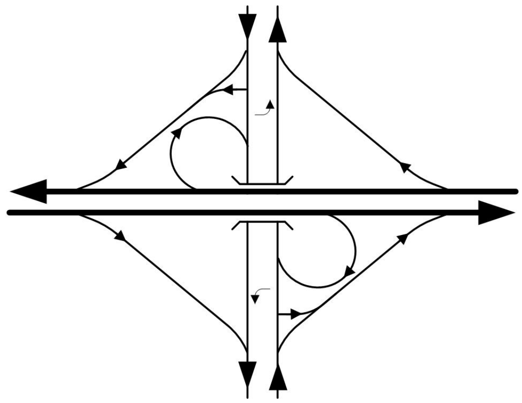
2- Quadrant parclo A



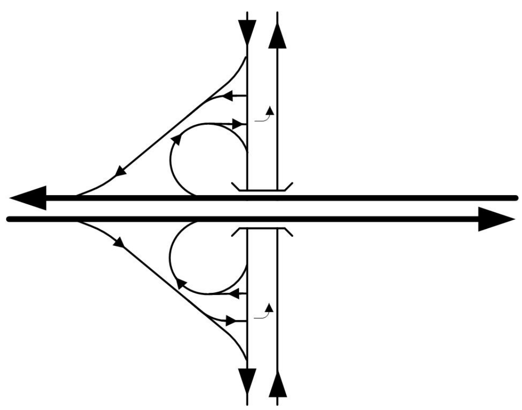
2- Quadrant parclo B



4-Quadrant partial cloverleaf A

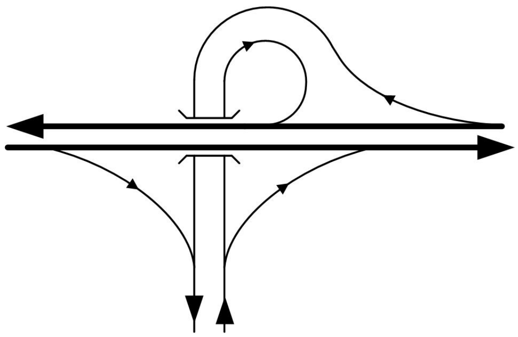


4-Quadrant partial cloverleaf B

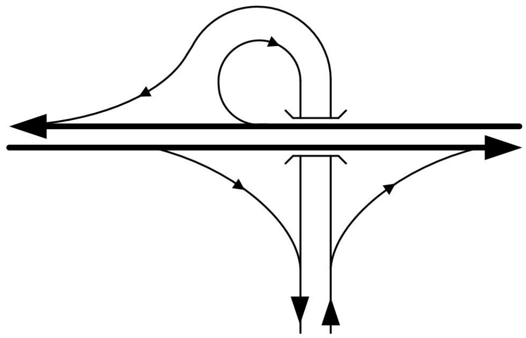


2-Quadrant partial cloverleaf AB

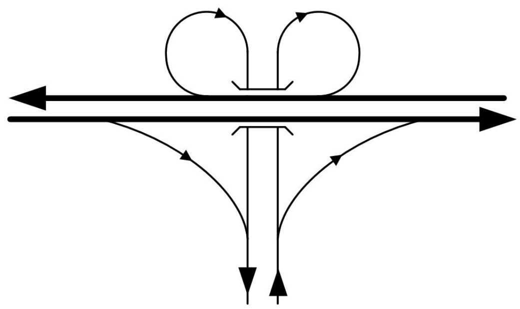
Trumpet interchanges



Trumpet type A

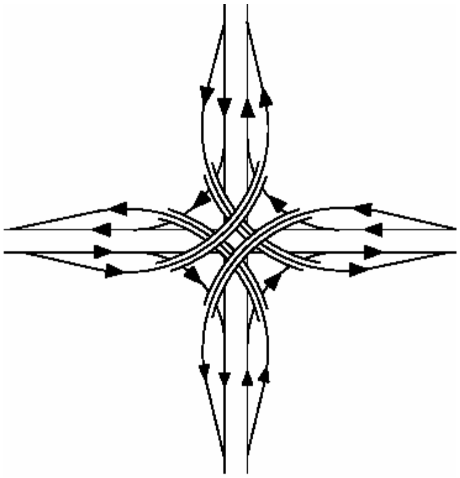


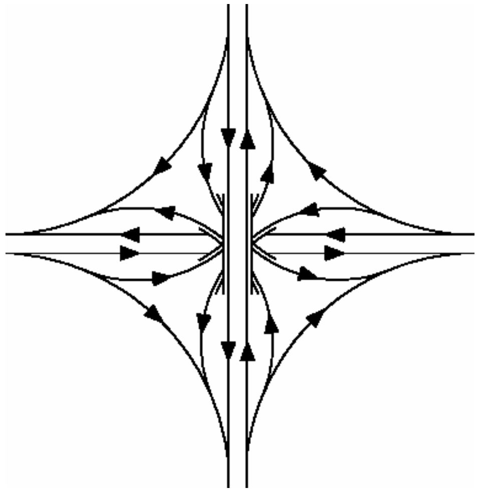
Trumpet type B



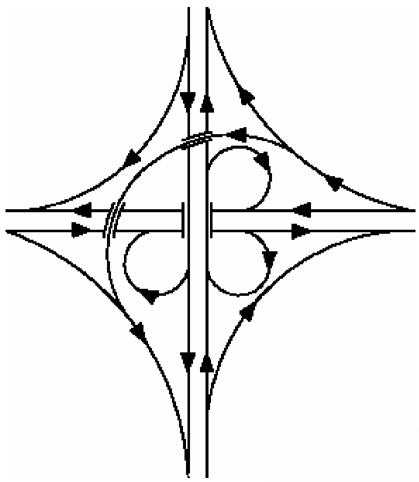
Trumpet type A

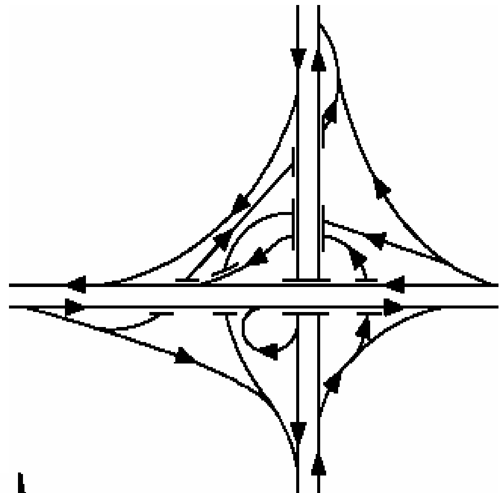
Fully directional interchanges

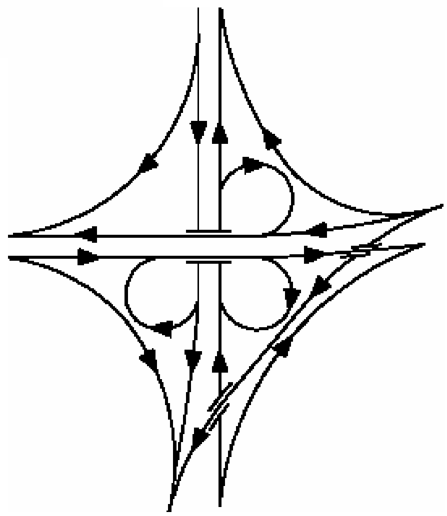




Semi-directional interchanges







APPENDIX B

SURVEY QUESTIONNAIRE

Questionnaire for Countermeasures to Reduce Freeway Off-Ramp Queues

--- Assessment of the Current State of Practice ---

Prepared
by
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FAX: (813) 974-5168
Email: lin@cutr.usf.edu

Agency:	FDOT	**District Number:**	
Name:		**Title:**	
Phone number:		**Fax Number:**	
e-mail address:			

Throughout Florida, there are several freeway interchanges where queue on the off-ramps spill back onto the freeway mainline, which causes serious freeway congestions and potential hazards. The research team from the Center for Urban Transportation Research (CUTR) at the University of South Florida is currently working on a FDOT research project on the development of a toolbox for reducing queues at freeway off-ramps. The objective of the interview questionnaire below is to assess the current state of the practice from each FDOT district on how to effectively reduce queues at freeway off-ramps. Your knowledge, experience and support on this subject are very beneficial for the development of this toolbox. The research team will contact you to schedule a telephone interview with you and your staff soon on the following questionnaires. It will only take about 40 to 60 minutes. We greatly appreciate your time and efforts.

1. **How many freeway interchanges do you have in your district?**

☐1) Less than or equal to 50
☐2) More than 50 but less than or equal to75
☐3) More than 75 but less than or equal to100
☐4) More than 100 freeway interchanges

2. **Most of freeway interchanges in your FDOT district are located at ALL AREAS LISTED**

☐1) Rural area
☐2) Urban and suburban areas
☐3) Approximately half in urban and half in rural areas

3. What percentage of freeway interchanges have ever had freeway off-ramp queue backed to freeway mainline in your district?

☐1) 10% or less
☐2) 10%-25%
☐3) 26%-50%
☐4) More than 50%

4. How serious are freeway off-ramp queue problems in your district?

☐1) Serious in most major urban and their suburban areas
☐2) Serious in major urban areas
☐3) Minor in major urban areas
☐4) Not a concern

5. When do freeway off-ramp queue problems occur?

☐1) Only during AM or PM peak hours
☐2) During both AM and PM peak hours
☐3) Most of daytime
☐4) All the time except late at night

6. Please list the top 3 interchange locations and directions with off-ramp queues backed up to freeway in your district?

1) _____

2) _____

3) _____

7. In general, what are the major causes of freeway off-ramp queue backed up to the freeway in your district?

☐ 1) Capacity problems at the off-ramp terminal intersection
☐ 2) Lane blockage problem of downstream intersections on the local artery
☐ 3) Inefficient signal coordination of local arteries adjacent to the freeway off-ramps
☐ 4) Not enough green time allocated to off-ramps at the terminal intersections
☐ 5) Inefficient operation of off-ramp lane assignments at the terminal intersections
☐ 6) Not enough storage space at the off-ramps
☐ 7) Slow, heavy vehicles at off-ramp causing signal to gap out earlier than expected
☐ 8) Frequent signal pre-emption at the off-ramp terminal intersection
☐ 9) Prohibition of No-Turn on Red at the off-ramp terminal intersection
☐ 10) Inadequate signal spacing on the artery near the freeway off-ramp
☐ 11) Other _____

8. Please closely review the following countermeasures to reduce off-ramp queue problems. Select those that have been tried with success in your district.

Signal Timing Improvements

- ☐ 1) Increase green time on the off-ramp approach at off-ramp terminal intersection
- ☐ 2) Adjust signal timing plans on arterial signals adjacent to the freeway off-ramps
- ☐ 3) Retime signals on the local artery to provide better signal coordination
- ☐ 4) Provide signal coordination in a way that the progression of traffic flow is from the off-ramp approach to artery
- ☐ 5) Use detectors to monitor off-ramp queues automatically. Preempt the off-ramp terminal intersection if the queue reaches the critical location
- ☐ 6) Allow right turn on red from the off-ramp approach at the terminal intersection

Ramp Metering

- ☐ 7) Use upstream on-ramp metering to slow down the increase of traffic demand

Transportation Demand Management

- ☐ 8) Apply Transportation Demand Management (TDM) strategies such as bus, carpool, vanpool, telecommuting, and flexible work schedule
- ☐ 9) Use HOV lane to encourage carpooling to reduce traffic demand on freeways
- ☐ 10) Use toll roads to ease traffic demand, so it reduces traffic volume at off-ramps

Reduction of Arrival Rates

- ☐ 11) Reduce posted speed limit for freeway bottleneck sections near the congested off-ramps, hence reducing arrival rates of traffic at the off-ramps
- ☐ 12) Use changeable posted speed limit signs instead for the above Countermeasure11
- ☐ 13) Install variable message signs (VMS) on the freeway to warn the upstream traffic about downstream congestion (including off-ramp queue backed up) and encourage motorists to slow down or divert to alternate routes
- ☐ 14) Use VMS to divert traffic into alternative routes during a freeway incident

Traveler Information Dissemination

- ☐ 15) Disseminate real-time traffic conditions through website, Highway Advisory Radio (HAR), or/and 511 to motorists

Geometrical Improvement

- ☐ 16) Lengthen left-turn, or/and right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps
- ☐ 17) Increase capacity through lane reassignment at off-ramp terminal intersections
- ☐ 18) Increase capacity through reconstruction at off-ramp terminal intersections
- ☐ 19) Increase capacity through lengthening storage lane lengths for off-ramp approaches
- ☐ 20) Devote some freeway shoulder lanes to queues backed up from the off-ramp
- ☐ 21) Increase efficiency through lane reassignments at the freeway diverge gore
- ☐ 22) Build additional lanes on the freeway leading exiting traffic to the off-ramp
- ☐ 23) Build frontage road along the freeway bottleneck section to reduce demand
- ☐ 24) Build another off-ramp near the off-ramp with severe queue problem

Effective Monitoring

☐ 25) Use freeway or off-ramp monitoring (CCTV) cameras to effectively monitor the congested off-ramp and take proper action to reduce the off-ramp queue

9. Please provide additional successful countermeasures in your district if they are not covered in your answers to the Question 8.

_____

10. From your answers to Questions 8 and 9, please provide us with your top 3 short-term and top 3 long-term countermeasures to effectively reduce queues at freeway off-ramps.

Your top 3 short-term countermeasures:

1) _____

2) _____

3) _____

Your top 3 long-term countermeasures:

1) _____

2) _____

3) _____

11. How many CCTV monitoring cameras were installed in your district near congested freeway off-ramps?

☐ 1) Less than 10
☐ 2) 10-25
☐ 3) 25-50
☐ 4) More than 50 CCTV cameras

12. How many traffic data collection stations were located in your district near congested freeway off-ramps?

☐ 1) Less than 10
☐ 2) 10-25
☐ 3) 25-50
☐ 4) More than 50 traffic data collection stations

13. Currently, what kinds of traffic information do you collect automatically through the devices installed on specific freeway segments in your district?

☐ 1) Traffic volume data
☐ 2) Vehicle occupancy data
☐ 3) Vehicle classification data

☐ 4) Speed data
☐ 5) Travel time data
☐ 6) Queue length data
☐ 7) Others: _____

14. How does your district utilize the collected traffic data?

☐ 1) Stored in the database for future traffic analysis
☐ 2) Forecast traffic demand for future roadway needs
☐ 3) Identify freeway bottleneck locations to resolve problems
☐ 4) Disseminate traffic conditions and travel time information to motorists
☐ 5) Use them for 511
☐ 6) Share traffic data with other agencies
☐ 7) Others: _____

THANK YOU!!!

APPENDIX C

SURVEY RESULTS

Following are the survey responses from each of the Florida districts and the Turnpike.

District 1

1. **How many freeway interchanges do you have in your district?**
   ☒1) Less than or equal to 50
   ☐2) More than 50 but less than or equal to75
   ☐3) More than 75 but less than or equal to100
   ☐4) More than 100 freeway interchanges

2. **Most of freeway interchanges in your FDOT district are located at ALL AREAS LISTED**
   ☒1) Rural area
   ☐2) Urban and suburban areas
   ☐3) Approximately half in urban and half in rural areas

3. **What percentage of freeway interchanges have ever had freeway off-ramp queue backed to freeway mainline in your district?**
   ☒1) 10% or less
   ☐2) 10%-25%
   ☐3) 26%-50%
   ☐4) More than 50%

4. **How serious are freeway off-ramp queue problems in your district?**
   ☐1) Serious in most major urban and their suburban areas
   ☒2) Serious in major urban areas
   ☐3) Minor in major urban areas
   ☐4) Not a concern

5. **When do freeway off-ramp queue problems occur?**
   ☐1) Only during AM or PM peak hours
   ☒2) During both AM and PM peak hours
   ☐3) Most of daytime
   ☐4) All the time except late at night

6. **Please list the top 3 interchange locations and directions with off-ramp queues backed up to freeway in your district?**
   1) Fruitville Road

   2) Bee Ridge Road

   3) Daniels Parkway

7. In general, what are the major causes of freeway off-ramp queue backed up to the freeway in your district?

☒ 1) Capacity problems at the off-ramp terminal intersection
☐ 2) Lane blockage problem of downstream intersections on the local artery
☐ 3) Inefficient signal coordination of local arteries adjacent to the freeway off-ramps
☐ 4) Not enough green time allocated to off-ramps at the terminal intersections
☐ 5) Inefficient operation of off-ramp lane assignments at the terminal intersections
☒ 6) Not enough storage space at the off-ramps
☐ 7) Slow, heavy vehicles at off-ramp causing signal to gap out earlier than expected
☐ 8) Frequent signal pre-emption at the off-ramp terminal intersection
☐ 9) Prohibition of No-Turn on Red at the off-ramp terminal intersection
☐ 10) Inadequate signal spacing on the artery near the freeway off-ramp
☐ 11) Other _____

8. Please closely review the following countermeasures to reduce off-ramp queue problems. Select those that have been tried with success in your district.

Signal Timing Improvements

☒ 1) Increase green time on the off-ramp approach at off-ramp terminal intersection
☒ 2) Adjust signal timing plans on arterial signals adjacent to the freeway off-ramps
☒ 3) Retime signals on the local artery to provide better signal coordination
☒ 4) Provide signal coordination in a way that the progression of traffic flow is from the off-ramp approach to artery
☒ 5) Use detectors to monitor off-ramp queues automatically. Preempt the off-ramp terminal intersection if the queue reaches the critical location
☒ 6) Allow right turn on red from the off-ramp approach at the terminal intersection

Ramp Metering

☐ 7) Use upstream on-ramp metering to slow down the increase of traffic demand

Transportation Demand Management

☐ 8) Apply Transportation Demand Management (TDM) strategies such as bus, carpool, vanpool, telecommuting, and flexible work schedule
☐ 9) Use HOV lane to encourage carpooling to reduce traffic demand on freeways
☐ 10) Use toll roads to ease traffic demand, so it reduces traffic volume at off-ramps

Reduction of Arrival Rates

☐ 11) Reduce posted speed limit for freeway bottleneck sections near the congested off-ramps, hence reducing arrival rates of traffic at the off-ramps
☐ 12) Use changeable posted speed limit signs instead for the above Countermeasure11
☐ 13) Install variable message signs (VMS) on the freeway to warn the upstream traffic about downstream congestion (including off-ramp queue backed up) and encourage motorists to slow down or divert to alternate routes
☐ 14) Use VMS to divert traffic into alternative routes during a freeway incident

Traveler Information Dissemination

- ☐ 15) Disseminate real-time traffic conditions through website, Highway Advisory Radio (HAR), or/and 511 to motorists

Geometrical Improvement

- ☒ 16) Lengthen left-turn, or/and right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps
- ☐ 17) Increase capacity through lane reassignment at off-ramp terminal intersections
- ☒ 18) Increase capacity through reconstruction at off-ramp terminal intersections
- ☒ 19) Increase capacity through lengthening storage lane lengths for off-ramp approaches
- ☐ 20) Devote some freeway shoulder lanes to queues backed up from the off-ramp
- ☐ 21) Increase efficiency through lane reassignments at the freeway diverge gore
- ☐ 22) Build additional lanes on the freeway leading exiting traffic to the off-ramp
- ☐ 23) Build frontage road along the freeway bottleneck section to reduce demand
- ☐ 24) Build another off-ramp near the off-ramp with severe queue problem

Effective Monitoring

- ☐ 25) Use freeway or off-ramp monitoring (CCTV) cameras to effectively monitor the congested off-ramp and take proper action to reduce the off-ramp queue

9. Please provide additional successful countermeasures in your district if they are not covered in your answers to the Question 8.

1. Preemp the ramp
2. Remove signals (in the arterial roads) that aretoo close to the off-ramp terminal intersection

10. From your answers to Questions 8 and 9, please provide us with your top 3 short-term and top 3 long-term countermeasures to effectively reduce queues at freeway off-ramps.

Your top 3 short-term countermeasures:
1) Improve signal timing at off-ramp terminal intersections

2) Improve signal timing in the arterials connected to the off-ramps to provide better traffic flow.

3) _____

Your top 3 long-term countermeasures:
1) Add lanes to improve capacity

2) Rebuild interchanges

3) ITS deployment (VMS, Traffic Monitoring Cameras, etc.)

11. How many CCTV monitoring cameras were installed in your district near congested freeway off-ramps?

☒ 1) Less than 10
☐ 2) 10-25
☐ 3) 25-50
☐ 4) More than 50 CCTV cameras

12. How many traffic data collection stations were located in your district near congested freeway off-ramps?

☒ 1) Less than 10
☐ 2) 10-25
☐ 3) 25-50
☐ 4) More than 50 traffic data collection stations

13. Currently, what kinds of traffic information do you collect automatically through the devices installed on specific freeway segments in your district?

☒ 1) Traffic volume data
☐ 2) Vehicle occupancy data
☒ 3) Vehicle classification data
☐ 4) Speed data
☐ 5) Travel time data
☐ 6) Queue length data
☐ 7) Others: _____

14. How does your district utilize the collected traffic data?

☐ 1) Stored in the database for future traffic analysis
☒ 2) Forecast traffic demand for future roadway needs
☐ 3) Identify freeway bottleneck locations to resolve problems
☐ 4) Disseminate traffic conditions and travel time information to motorists
☐ 5) Use them for 511
☐ 6) Share traffic data with other agencies
☐ 7) Others: _____

District 2

1. **How many freeway interchanges do you have in your district?**
   - ☐ 1) Less than or equal to 50
   - ☐ 2) More than 50 but less than or equal to75
   - ☒ 3) More than 75 but less than or equal to100
   - ☐ 4) More than 100 freeway interchanges

2. **Most of freeway interchanges in your FDOT district are located at ALL AREAS LISTED**
   - ☐ 1) Rural area
   - ☐ 2) Urban and suburban areas
   - ☒ 3) Approximately half in urban and half in rural areas

3. **What percentage of freeway interchanges have ever had freeway off-ramp queue backed to freeway mainline in your district?**
   - ☐ 1) 10% or less
   - ☒ 2) 10%-25%
   - ☐ 3) 26%-50%
   - ☐ 4) More than 50%

4. **How serious are freeway off-ramp queue problems in your district?**
   - ☒ 1) Serious in most major urban and their suburban areas
   - ☐ 2) Serious in major urban areas
   - ☐ 3) Minor in major urban areas
   - ☐ 4) Not a concern

5. **When do freeway off-ramp queue problems occur?**
   - ☐ 1) Only during AM or PM peak hours
   - ☒ 2) During both AM and PM peak hours
   - ☐ 3) Most of daytime
   - ☐ 4) All the time except late at night

6. **Please list the top 3 interchange locations and directions with off-ramp queues backed up to freeway in your district?**

   1) I-295 Northbound , Us-17

   2) I-295 Northbound, SR-17

   3) I-295 Southbound ,Sr-21

7. **In general, what are the major causes of freeway off-ramp queue backed up to the freeway in your district?**
   - ☒ 1) Capacity problems at the off-ramp terminal intersection
   - ☒ 2) Lane blockage problem of downstream intersections on the local artery
   - ☐ 3) Inefficient signal coordination of local arteries adjacent to the freeway off-ramps

☐ 4) Not enough green time allocated to off-ramps at the terminal intersections
☐ 5) Inefficient operation of off-ramp lane assignments at the terminal intersections
☒ 6) Not enough storage space at the off-ramps
☐ 7) Slow, heavy vehicles at off-ramp causing signal to gap out earlier than expected
☐ 8) Frequent signal pre-emption at the off-ramp terminal intersection
☐ 9) Prohibition of No-Turn on Red at the off-ramp terminal intersection
☐ 10) Inadequate signal spacing on the artery near the freeway off-ramp
☐ 11) Other _____

8. Please closely review the following countermeasures to reduce off-ramp queue problems. Select those that have been tried with success in your district.

Signal Timing Improvements

☒ 1) Increase green time on the off-ramp approach at off-ramp terminal intersection
☒ 2) Adjust signal timing plans on arterial signals adjacent to the freeway off-ramps
☒ 3) Retime signals on the local artery to provide better signal coordination
☒ 4) Provide signal coordination in a way that the progression of traffic flow is from the off-ramp approach to artery
☐ 5) Use detectors to monitor off-ramp queues automatically. Preempt the off-ramp terminal intersection if the queue reaches the critical location
☐ 6) Allow right turn on red from the off-ramp approach at the terminal intersection

Ramp Metering

☐ 7) Use upstream on-ramp metering to slow down the increase of traffic demand

Transportation Demand Management

☐ 8) Apply Transportation Demand Management (TDM) strategies such as bus, carpool, vanpool, telecommuting, and flexible work schedule
☐ 9) Use HOV lane to encourage carpooling to reduce traffic demand on freeways
☐ 10) Use toll roads to ease traffic demand, so it reduces traffic volume at off-ramps

Reduction of Arrival Rates

☐ 11) Reduce posted speed limit for freeway bottleneck sections near the congested off-ramps, hence reducing arrival rates of traffic at the off-ramps
☐ 12) Use changeable posted speed limit signs instead for the above Countermeasure11
☒ 13) Install variable message signs (VMS) on the freeway to warn the upstream traffic about downstream congestion (including off-ramp queue backed up) and encourage motorists to slow down or divert to alternate routes
☒ 14) Use VMS to divert traffic into alternative routes during a freeway incident

Traveler Information Dissemination

☐ 15) Disseminate real-time traffic conditions through website, Highway Advisory Radio (HAR), or/and 511 to motorists

Geometrical Improvement

☒ 16) Lengthen left-turn, or/and right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps
☐ 17) Increase capacity through lane reassignment at off-ramp terminal intersections
☒ 18) Increase capacity through reconstruction at off-ramp terminal intersections
☒ 19) Increase capacity through lengthening storage lane lengths for off-ramp approaches
☐ 20) Devote some freeway shoulder lanes to queues backed up from the off-ramp
☐ 21) Increase efficiency through lane reassignments at the freeway diverge gore
☐ 22) Build additional lanes on the freeway leading exiting traffic to the off-ramp
☐ 23) Build frontage road along the freeway bottleneck section to reduce demand
☐ 24) Build another off-ramp near the off-ramp with severe queue problem

Effective Monitoring

☐ 25) Use freeway or off-ramp monitoring (CCTV) cameras to effectively monitor the congested off-ramp and take proper action to reduce the off-ramp queue

9. Please provide additional successful countermeasures in your district if they are not covered in your answers to the Question 8.

_____

10. From your answers to Questions 8 and 9, please provide us with your top 3 short-term and top 3 long-term countermeasures to effectively reduce queues at freeway off-ramps.

Your top 3 short-term countermeasures:
1) Increase ramp green time

2) Improve signal timing/progression downstream of ramp

3) Add lanes to off-ramp

Your top 3 long-term countermeasures:
1) Add lanes to off-ramp

2) Retrofit single point interchange

3) Add lanes to minor road (usually) under the overpass by cutting into sloped embankament

11. How many CCTV monitoring cameras were installed in your district near congested freeway off-ramps?

☐ 1) Less than 10
☒ 2) 10-25
☐ 3) 25-50
☐ 4) More than 50 CCTV cameras

12. How many traffic data collection stations were located in your district near congested freeway off-ramps?

☒ 1) Less than 10
☒ 2) 10-25
☐ 3) 25-50
☒ 4) More than 50 traffic data collection stations

13. Currently, what kinds of traffic information do you collect automatically through the devices installed on specific freeway segments in your district?

☐ 1) Traffic volume data
☐ 2) Vehicle occupancy data
☐ 3) Vehicle classification data
☐ 4) Speed data
☐ 5) Travel time data
☐ 6) Queue length data
☐ 7) Others: _____

14. How does your district utilize the collected traffic data?

☐ 1) Stored in the database for future traffic analysis
☐ 2) Forecast traffic demand for future roadway needs
☐ 3) Identify freeway bottleneck locations to resolve problems
☐ 4) Disseminate traffic conditions and travel time information to motorists
☐ 5) Use them for 511
☐ 6) Share traffic data with other agencies
☐ 7) Others: _____

<u>District 3</u>

1. How many freeway interchanges do you have in your district?

☒1) Less than or equal to 50
☐2) More than 50 but less than or equal to75
☐3) More than 75 but less than or equal to100
☐4) More than 100 freeway interchanges

2. Most of freeway interchanges in your FDOT district are located at ALL AREAS LISTED

☒1) Rural area
☐2) Urban and suburban areas
☐3) Approximately half in urban and half in rural areas

3. What percentage of freeway interchanges have ever had freeway off-ramp queue backed to freeway mainline in your district?

☒1) 10% or less
☐2) 10%-25%
☐3) 26%-50%
☐4) More than 50%

4. How serious are freeway off-ramp queue problems in your district?

☐1) Serious in most major urban and their suburban areas
☐2) Serious in major urban areas
☒3) Minor in major urban areas
☐4) Not a concern

5. When do freeway off-ramp queue problems occur?

☐1) Only during AM or PM peak hours
☒2) During both AM and PM peak hours
☐3) Most of daytime
☐4) All the time except late at night

6. Please list the top 3 interchange locations and directions with off-ramp queues backed up to freeway in your district?

1) <u>At This Time There Is A Lot Of Construction In The More Congested Area. It Would Be Unfair To List Them At This Time.</u>

2) ______

3) ______

7. In general, what are the major causes of freeway off-ramp queue backed up to the freeway in your district?

☒ 1) Capacity problems at the off-ramp terminal intersection
☐ 2) Lane blockage problem of downstream intersections on the local artery

- ☐ 3) Inefficient signal coordination of local arteries adjacent to the freeway off-ramps
- ☐ 4) Not enough green time allocated to off-ramps at the terminal intersections
- ☐ 5) Inefficient operation of off-ramp lane assignments at the terminal intersections
- ☐ 6) Not enough storage space at the off-ramps
- ☐ 7) Slow, heavy vehicles at off-ramp causing signal to gap out earlier than expected
- ☐ 8) Frequent signal pre-emption at the off-ramp terminal intersection
- ☐ 9) Prohibition of No-Turn on Red at the off-ramp terminal intersection
- ☐ 10) Inadequate signal spacing on the artery near the freeway off-ramp
- ☐ 11) Other _____

8. Please closely review the following countermeasures to reduce off-ramp queue problems. Select those that have been tried with success in your district.

Signal Timing Improvements

- ☒ 1) Increase green time on the off-ramp approach at off-ramp terminal intersection
- ☒ 2) Adjust signal timing plans on arterial signals adjacent to the freeway off-ramps
- ☒ 3) Retime signals on the local artery to provide better signal coordination
- ☒ 4) Provide signal coordination in a way that the progression of traffic flow is from the off-ramp approach to artery
- ☐ 5) Use detectors to monitor off-ramp queues automatically. Preempt the off-ramp terminal intersection if the queue reaches the critical location
- ☐ 6) Allow right turn on red from the off-ramp approach at the terminal intersection

Ramp Metering

- ☐ 7) Use upstream on-ramp metering to slow down the increase of traffic demand

Transportation Demand Management

- ☐ 8) Apply Transportation Demand Management (TDM) strategies such as bus, carpool, vanpool, telecommuting, and flexible work schedule
- ☐ 9) Use HOV lane to encourage carpooling to reduce traffic demand on freeways
- ☐ 10) Use toll roads to ease traffic demand, so it reduces traffic volume at off-ramps

Reduction of Arrival Rates

- ☐ 11) Reduce posted speed limit for freeway bottleneck sections near the congested off-ramps, hence reducing arrival rates of traffic at the off-ramps
- ☐ 12) Use changeable posted speed limit signs instead for the above Countermeasure11
- ☐ 13) Install variable message signs (VMS) on the freeway to warn the upstream traffic about downstream congestion (including off-ramp queue backed up) and encourage motorists to slow down or divert to alternate routes
- ☐ 14) Use VMS to divert traffic into alternative routes during a freeway incident

Traveler Information Dissemination

- ☐ 15) Disseminate real-time traffic conditions through website, Highway Advisory Radio (HAR), or/and 511 to motorists

Geometrical Improvement

☐ 16) Lengthen left-turn, or/and right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps

☐ 17) Increase capacity through lane reassignment at off-ramp terminal intersections

☒ 18) Increase capacity through reconstruction at off-ramp terminal intersections

☒ 19) Increase capacity through lengthening storage lane lengths for off-ramp approaches

☐ 20) Devote some freeway shoulder lanes to queues backed up from the off-ramp

☐ 21) Increase efficiency through lane reassignments at the freeway diverge gore

☒ 22) Build additional lanes on the freeway leading exiting traffic to the off-ramp

☐ 23) Build frontage road along the freeway bottleneck section to reduce demand

☐ 24) Build another off-ramp near the off-ramp with severe queue problem

Effective Monitoring

☐ 25) Use freeway or off-ramp monitoring (CCTV) cameras to effectively monitor the congested off-ramp and take proper action to reduce the off-ramp queue

9. Please provide additional successful countermeasures in your district if they are not covered in your answers to the Question 8.

Each location may have a different problem, thus a different solution is needed to resolve the problem.

10. From your answers to Questions 8 and 9, please provide us with your top 3 short-term and top 3 long-term countermeasures to effectively reduce queues at freeway off-ramps.

Your top 3 short-term countermeasures:

1) Additional lanes

2) Retime traffic signals & Redesign intersections

3) Better maintenance on traffic signals

Your top 3 long-term countermeasures:

1) More asphalt (more lanes in all approaches)

2) More asphalt (more lanes in all approaches)

3) More asphalt (more lanes in all approaches)

11. How many CCTV monitoring cameras were installed in your district near congested freeway off-ramps?

☒ 1) Less than 10

☐ 2) 10-25

☐ 3) 25-50

☐ 4) More than 50 CCTV cameras

12. How many traffic data collection stations were located in your district near congested freeway off-ramps?

☒ 1) Less than 10
☐ 2) 10-25
☐ 3) 25-50
☐ 4) More than 50 traffic data collection stations

13. Currently, what kinds of traffic information do you collect automatically through the devices installed on specific freeway segments in your district?

☐ 1) Traffic volume data
☐ 2) Vehicle occupancy data
☐ 3) Vehicle classification data
☐ 4) Speed data
☐ 5) Travel time data
☐ 6) Queue length data
☒ 7) Others: _____

14. How does your district utilize the collected traffic data?

☐ 1) Stored in the database for future traffic analysis
☐ 2) Forecast traffic demand for future roadway needs
☐ 3) Identify freeway bottleneck locations to resolve problems
☐ 4) Disseminate traffic conditions and travel time information to motorists
☐ 5) Use them for 511
☐ 6) Share traffic data with other agencies
☐ 7) Others: _____

District 4

1. **How many freeway interchanges do you have in your district?**
   - ☐ 1) Less than or equal to 50
   - ☐ 2) More than 50 but less than or equal to75
   - ☐ 3) More than 75 but less than or equal to100
   - ☒ 4) More than 100 freeway interchanges

2. **Most of freeway interchanges in your FDOT district are located at ALL AREAS LISTED**
   - ☐ 1) Rural area
   - ☒ 2) Urban and suburban areas
   - ☐ 3) Approximately half in urban and half in rural areas

3. **What percentage of freeway interchanges have ever had freeway off-ramp queue backed to freeway mainline in your district?**
   - ☒ 1) 10% or less
   - ☐ 2) 10%-25%
   - ☐ 3) 26%-50%
   - ☐ 4) More than 50%

4. **How serious are freeway off-ramp queue problems in your district?**
   - ☐ 1) Serious in most major urban and their suburban areas
   - ☐ 2) Serious in major urban areas
   - ☒ 3) Minor in major urban areas
   - ☐ 4) Not a concern

5. **When do freeway off-ramp queue problems occur?**
   - ☐ 1) Only during AM or PM peak hours
   - ☒ 2) During both AM and PM peak hours
   - ☐ 3) Most of daytime
   - ☐ 4) All the time except late at night

6. **Please list the top 3 interchange locations and directions with off-ramp queues backed up to freeway in your district?**

   1) I-95 ,Hollywood Blvd (SouthBound)

   2) Yamato Rd , Palm Beach County (Southbound)

   3) _____

7. **In general, what are the major causes of freeway off-ramp queue backed up to the freeway in your district?**
   - ☐ 1) Capacity problems at the off-ramp terminal intersection
   - ☐ 2) Lane blockage problem of downstream intersections on the local artery
   - ☐ 3) Inefficient signal coordination of local arteries adjacent to the freeway off-ramps

☒ 4) Not enough green time allocated to off-ramps at the terminal intersections
☐ 5) Inefficient operation of off-ramp lane assignments at the terminal intersections
☒ 6) Not enough storage space at the off-ramps
☐ 7) Slow, heavy vehicles at off-ramp causing signal to gap out earlier than expected
☒ 8) Frequent signal pre-emption at the off-ramp terminal intersection
☐ 9) Prohibition of No-Turn on Red at the off-ramp terminal intersection
☐ 10) Inadequate signal spacing on the artery near the freeway off-ramp
☐ 11) Other _____

8. Please closely review the following countermeasures to reduce off-ramp queue problems. Select those that have been tried with success in your district.

Signal Timing Improvements
☒ 1) Increase green time on the off-ramp approach at off-ramp terminal intersection
☐ 2) Adjust signal timing plans on arterial signals adjacent to the freeway off-ramps
☐ 3) Retime signals on the local artery to provide better signal coordination
☐ 4) Provide signal coordination in a way that the progression of traffic flow is from the off-ramp approach to artery
☐ 5) Use detectors to monitor off-ramp queues automatically. Preempt the off-ramp terminal intersection if the queue reaches the critical location
☒ 6) Allow right turn on red from the off-ramp approach at the terminal intersection

Ramp Metering
☐ 7) Use upstream on-ramp metering to slow down the increase of traffic demand

Transportation Demand Management
☒ 8) Apply Transportation Demand Management (TDM) strategies such as bus, carpool, vanpool, telecommuting, and flexible work schedule
☒ 9) Use HOV lane to encourage carpooling to reduce traffic demand on freeways
☒ 10) Use toll roads to ease traffic demand, so it reduces traffic volume at off-ramps

Reduction of Arrival Rates
☐ 11) Reduce posted speed limit for freeway bottleneck sections near the congested off-ramps, hence reducing arrival rates of traffic at the off-ramps
☐ 12) Use changeable posted speed limit signs instead for the above Countermeasure11
☒ 13) Install variable message signs (VMS) on the freeway to warn the upstream traffic about downstream congestion (including off-ramp queue backed up) and encourage motorists to slow down or divert to alternate routes
☐ 14) Use VMS to divert traffic into alternative routes during a freeway incident

Traveler Information Dissemination
☒ 15) Disseminate real-time traffic conditions through website, Highway Advisory Radio (HAR), or/and 511 to motorists

Geometrical Improvement

☒ 16) Lengthen left-turn, or/and right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps

☒ 17) Increase capacity through lane reassignment at off-ramp terminal intersections

☒ 18) Increase capacity through reconstruction at off-ramp terminal intersections

☒ 19) Increase capacity through lengthening storage lane lengths for off-ramp approaches

☐ 20) Devote some freeway shoulder lanes to queues backed up from the off-ramp

☒ 21) Increase efficiency through lane reassignments at the freeway diverge gore

☒ 22) Build additional lanes on the freeway leading exiting traffic to the off-ramp

☐ 23) Build frontage road along the freeway bottleneck section to reduce demand

☐ 24) Build another off-ramp near the off-ramp with severe queue problem

Effective Monitoring

☒ 25) Use freeway or off-ramp monitoring (CCTV) cameras to effectively monitor the congested off-ramp and take proper action to reduce the off-ramp queue

9. Please provide additional successful countermeasures in your district if they are not covered in your answers to the Question 8.

_____

10. From your answers to Questions 8 and 9, please provide us with your top 3 short-term and top 3 long-term countermeasures to effectively reduce queues at freeway off-ramps.

Your top 3 short-term countermeasures:

1) Add ramp capacity

2) Signal capacity

3) CCTV Monitoring (operated by the counties)

Your top 3 long-term countermeasures:

1) Widen ramps

2) Increase arterial capacity

3) _____

11. How many CCTV monitoring cameras were installed in your district near congested freeway off-ramps?

☐ 1) Less than 10

☒ 2) 10-25

☐ 3) 25-50

☐ 4) More than 50 CCTV cameras

12. How many traffic data collection stations were located in your district near congested freeway off-ramps?

☐ 1) Less than 10
☐ 2) 10-25
☒ 3) 25-50
☐ 4) More than 50 traffic data collection stations

13. Currently, what kinds of traffic information do you collect automatically through the devices installed on specific freeway segments in your district?

☒ 1) Traffic volume data
☐ 2) Vehicle occupancy data
☐ 3) Vehicle classification data
☒ 4) Speed data
☐ 5) Travel time data
☐ 6) Queue length data
☐ 7) Others: _____

14. How does your district utilize the collected traffic data?

☒ 1) Stored in the database for future traffic analysis
☒ 2) Forecast traffic demand for future roadway needs
☒ 3) Identify freeway bottleneck locations to resolve problems
☒ 4) Disseminate traffic conditions and travel time information to motorists
☒ 5) Use them for 511
☒ 6) Share traffic data with other agencies
☐ 7) Others: _____

District 5

1. **How many freeway interchanges do you have in your district?**
   ☐1) Less than or equal to 50
   ☐2) More than 50 but less than or equal to75
   ☐3) More than 75 but less than or equal to100
   ☒4) More than 100 freeway interchanges

2. **Most of freeway interchanges in your FDOT district are located at ALL AREAS LISTED**
   ☐1) Rural area
   ☐2) Urban and suburban areas
   ☒3) Approximately half in urban and half in rural areas

3. **What percentage of freeway interchanges have ever had freeway off-ramp queue backed to freeway mainline in your district?**
   ☒1) 10% or less
   ☐2) 10%-25%
   ☐3) 26%-50%
   ☐4) More than 50%

4. **How serious are freeway off-ramp queue problems in your district?**
   ☐1) Serious in most major urban and their suburban areas
   ☐2) Serious in major urban areas
   ☒3) Minor in major urban areas
   ☐4) Not a concern

5. **When do freeway off-ramp queue problems occur?**
   ☐1) Only during AM or PM peak hours
   ☒2) During both AM and PM peak hours
   ☐3) Most of daytime
   ☐4) All the time except late at night

6. **Please list the top 3 interchange locations and directions with off-ramp queues backed up to freeway in your district?**
   1) I-4, SR-434 Westbound Seminole County (AM, PM)

   2) I-4, Sr-436 Westbound

   3) I-95 , Sr-518 Southbound

7. **In general, what are the major causes of freeway off-ramp queue backed up to the freeway in your district?**

   ☒ 1) Capacity problems at the off-ramp terminal intersection
   ☒ 2) Lane blockage problem of downstream intersections on the local artery

☐ 3) Inefficient signal coordination of local arteries adjacent to the freeway off-ramps
☐ 4) Not enough green time allocated to off-ramps at the terminal intersections
☒ 5) Inefficient operation of off-ramp lane assignments at the terminal intersections
☒ 6) Not enough storage space at the off-ramps
☐ 7) Slow, heavy vehicles at off-ramp causing signal to gap out earlier than expected
☐ 8) Frequent signal pre-emption at the off-ramp terminal intersection
☐ 9) Prohibition of No-Turn on Red at the off-ramp terminal intersection
☒ 10) Inadequate signal spacing on the artery near the freeway off-ramp
☐ 11) Other _____

8. Please closely review the following countermeasures to reduce off-ramp queue problems. Select those that have been tried with success in your district.

Signal Timing Improvements

☐ 1) Increase green time on the off-ramp approach at off-ramp terminal intersection
☒ 2) Adjust signal timing plans on arterial signals adjacent to the freeway off-ramps
☒ 3) Retime signals on the local artery to provide better signal coordination
☐ 4) Provide signal coordination in a way that the progression of traffic flow is from the off-ramp approach to artery
☒ 5) Use detectors to monitor off-ramp queues automatically. Preempt the off-ramp terminal intersection if the queue reaches the critical location
☐ 6) Allow right turn on red from the off-ramp approach at the terminal intersection

Ramp Metering

☐ 7) Use upstream on-ramp metering to slow down the increase of traffic demand

Transportation Demand Management

☒ 8) Apply Transportation Demand Management (TDM) strategies such as bus, carpool, vanpool, telecommuting, and flexible work schedule
☐ 9) Use HOV lane to encourage carpooling to reduce traffic demand on freeways
☒ 10) Use toll roads to ease traffic demand, so it reduces traffic volume at off-ramps

Reduction of Arrival Rates

☒ 11) Reduce posted speed limit for freeway bottleneck sections near the congested off-ramps, hence reducing arrival rates of traffic at the off-ramps
☒ 12) Use changeable posted speed limit signs instead for the above Countermeasure11
☒ 13) Install variable message signs (VMS) on the freeway to warn the upstream traffic about downstream congestion (including off-ramp queue backed up) and encourage motorists to slow down or divert to alternate routes
☒ 14) Use VMS to divert traffic into alternative routes during a freeway incident

Traveler Information Dissemination

☒ 15) Disseminate real-time traffic conditions through website, Highway Advisory Radio (HAR), or/and 511 to motorists

Geometrical Improvement

☒ 16) Lengthen left-turn, or/and right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps
☒ 17) Increase capacity through lane reassignment at off-ramp terminal intersections
☒ 18) Increase capacity through reconstruction at off-ramp terminal intersections
☒ 19) Increase capacity through lengthening storage lane lengths for off-ramp approaches
☐ 20) Devote some freeway shoulder lanes to queues backed up from the off-ramp
☒ 21) Increase efficiency through lane reassignments at the freeway diverge gore
☒ 22) Build additional lanes on the freeway leading exiting traffic to the off-ramp
☐ 23) Build frontage road along the freeway bottleneck section to reduce demand
☐ 24) Build another off-ramp near the off-ramp with severe queue problem

Effective Monitoring

☒ 25) Use freeway or off-ramp monitoring (CCTV) cameras to effectively monitor the congested off-ramp and take proper action to reduce the off-ramp queue

9. Please provide additional successful countermeasures in your district if they are not covered in your answers to the Question 8.

Use physical separation to avoid weaving movements

10. From your answers to Questions 8 and 9, please provide us with your top 3 short-term and top 3 long-term countermeasures to effectively reduce queues at freeway off-ramps.

Your top 3 short-term countermeasures:

1) Preemmtion of the exit ramps

2) Modify timing in the intersection

3) Extend the decelaration lane

Your top 3 long-term countermeasures:

1) Signal removal

2) Addition of capacity

3) Use separators at terminals

11. How many CCTV monitoring cameras were installed in your district near congested freeway off-ramps?

☐ 1) Less than 10
☐ 2) 10-25
☐ 3) 25-50
☒ 4) More than 50 CCTV cameras

12. How many traffic data collection stations were located in your district near congested freeway off-ramps?

☐ 1) Less than 10
☐ 2) 10-25
☐ 3) 25-50
☒ 4) More than 50 traffic data collection stations

13. Currently, what kinds of traffic information do you collect automatically through the devices installed on specific freeway segments in your district?

☒ 1) Traffic volume data
☒ 2) Vehicle occupancy data
☒ 3) Vehicle classification data
☒ 4) Speed data
☒ 5) Travel time data
☐ 6) Queue length data
☐ 7) Others: _____

14. How does your district utilize the collected traffic data?

☒ 1) Stored in the database for future traffic analysis
☒ 2) Forecast traffic demand for future roadway needs
☐ 3) Identify freeway bottleneck locations to resolve problems
☒ 4) Disseminate traffic conditions and travel time information to motorists
☒ 5) Use them for 511
☒ 6) Share traffic data with other agencies
☐ 7) Others: _____

District 6

1. **How many freeway interchanges do you have in your district?**
   ☐ 1) Less than or equal to 50
   ☒ 2) More than 50 but less than or equal to75
   ☐ 3) More than 75 but less than or equal to100
   ☐ 4) More than 100 freeway interchanges

2. **Most of freeway interchanges in your FDOT district are located at ALL AREAS LISTED**
   ☐ 1) Rural area
   ☒ 2) Urban and suburban areas
   ☐ 3) Approximately half in urban and half in rural areas

3. **What percentage of freeway interchanges have ever had freeway off-ramp queue backed to freeway mainline in your district?**
   ☐ 1) 10% or less
   ☒ 2) 10%-25%
   ☐ 3) 26%-50%
   ☐ 4) More than 50%

4. **How serious are freeway off-ramp queue problems in your district?**
   ☐ 1) Serious in most major urban and their suburban areas
   ☒ 2) Serious in major urban areas
   ☐ 3) Minor in major urban areas
   ☐ 4) Not a concern

5. **When do freeway off-ramp queue problems occur?**
   ☒ 1) Only during AM or PM peak hours
   ☐ 2) During both AM and PM peak hours
   ☐ 3) Most of daytime
   ☐ 4) All the time except late at night

6. **Please list the top 3 interchange locations and directions with off-ramp queues backed up to freeway in your district?**
   1) I-95,Ives Dairy Rd (Southbound)

   2) SR-826 (Palmetto), Bird Rd (Southbound)

   3) Sr-826(Palmetto) , Red Road (Westboound)

7. **In general, what are the major causes of freeway off-ramp queue backed up to the freeway in your district?**
   ☒ 1) Capacity problems at the off-ramp terminal intersection
   ☒ 2) Lane blockage problem of downstream intersections on the local artery
   ☐ 3) Inefficient signal coordination of local arteries adjacent to the freeway off-ramps

☐ 4) Not enough green time allocated to off-ramps at the terminal intersections
☐ 5) Inefficient operation of off-ramp lane assignments at the terminal intersections
☐ 6) Not enough storage space at the off-ramps
☐ 7) Slow, heavy vehicles at off-ramp causing signal to gap out earlier than expected
☐ 8) Frequent signal pre-emption at the off-ramp terminal intersection
☐ 9) Prohibition of No-Turn on Red at the off-ramp terminal intersection
☒ 10) Inadequate signal spacing on the artery near the freeway off-ramp
☐ 11) Other _____

8. Please closely review the following countermeasures to reduce off-ramp queue problems. Select those that have been tried with success in your district.

Signal Timing Improvements
☐ 1) Increase green time on the off-ramp approach at off-ramp terminal intersection
☒ 2) Adjust signal timing plans on arterial signals adjacent to the freeway off-ramps
☒ 3) Retime signals on the local artery to provide better signal coordination
☐ 4) Provide signal coordination in a way that the progression of traffic flow is from the off-ramp approach to artery
☐ 5) Use detectors to monitor off-ramp queues automatically. Preempt the off-ramp terminal intersection if the queue reaches the critical location
☐ 6) Allow right turn on red from the off-ramp approach at the terminal intersection

Ramp Metering
☒ 7) Use upstream on-ramp metering to slow down the increase of traffic demand

Transportation Demand Management
☒ 8) Apply Transportation Demand Management (TDM) strategies such as bus, carpool, vanpool, telecommuting, and flexible work schedule
☒ 9) Use HOV lane to encourage carpooling to reduce traffic demand on freeways
☐ 10) Use toll roads to ease traffic demand, so it reduces traffic volume at off-ramps

Reduction of Arrival Rates
☐ 11) Reduce posted speed limit for freeway bottleneck sections near the congested off-ramps, hence reducing arrival rates of traffic at the off-ramps
☐ 12) Use changeable posted speed limit signs instead for the above Countermeasure11
☒ 13) Install variable message signs (VMS) on the freeway to warn the upstream traffic about downstream congestion (including off-ramp queue backed up) and encourage motorists to slow down or divert to alternate routes
☐ 14) Use VMS to divert traffic into alternative routes during a freeway incident

Traveler Information Dissemination
☒ 15) Disseminate real-time traffic conditions through website, Highway Advisory Radio (HAR), or/and 511 to motorists

Geometrical Improvement

☒ 16) Lengthen left-turn, or/and right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps
☒ 17) Increase capacity through lane reassignment at off-ramp terminal intersections
☒ 18) Increase capacity through reconstruction at off-ramp terminal intersections
☒ 19) Increase capacity through lengthening storage lane lengths for off-ramp approaches
☐ 20) Devote some freeway shoulder lanes to queues backed up from the off-ramp
☒ 21) Increase efficiency through lane reassignments at the freeway diverge gore
☒ 22) Build additional lanes on the freeway leading exiting traffic to the off-ramp
☐ 23) Build frontage road along the freeway bottleneck section to reduce demand
☐ 24) Build another off-ramp near the off-ramp with severe queue problem

Effective Monitoring

☒ 25) Use freeway or off-ramp monitoring (CCTV) cameras to effectively monitor the congested off-ramp and take proper action to reduce the off-ramp queue

9. Please provide additional successful countermeasures in your district if they are not covered in your answers to the Question 8.

Remove signals , change directions one way , increase capacity on arterial

10. From your answers to Questions 8 and 9, please provide us with your top 3 short-term and top 3 long-term countermeasures to effectively reduce queues at freeway off-ramps.

Your top 3 short-term countermeasures:

1) Change lane assignements at ramp terminals

2) Retiming signals

3) ___

Your top 3 long-term countermeasures:

1) _____

2) _____

3) _____

11. How many CCTV monitoring cameras were installed in your district near congested freeway off-ramps?

☐ 1) Less than 10
☐ 2) 10-25
☐ 3) 25-50
☒ 4) More than 50 CCTV cameras

12. How many traffic data collection stations were located in your district near congested freeway off-ramps?

☐ 1) Less than 10
☐ 2) 10-25
☐ 3) 25-50
☒ 4) More than 50 traffic data collection stations

13. Currently, what kinds of traffic information do you collect automatically through the devices installed on specific freeway segments in your district?

☒ 1) Traffic volume data
☒ 2) Vehicle occupancy data
☒ 3) Vehicle classification data
☒ 4) Speed data
☐ 5) Travel time data
☐ 6) Queue length data
☐ 7) Others: _____

14. How does your district utilize the collected traffic data?

☒ 1) Stored in the database for future traffic analysis
☒ 2) Forecast traffic demand for future roadway needs
☒ 3) Identify freeway bottleneck locations to resolve problems
☐ 4) Disseminate traffic conditions and travel time information to motorists
☒ 5) Use them for 511
☒ 6) Share traffic data with other agencies
☐ 7) Others: _____

District 7

1. **How many freeway interchanges do you have in your district?**
   - ☐ 1) Less than or equal to 50
   - ☐ 2) More than 50 but less than or equal to75
   - ☒ 3) More than 75 but less than or equal to100
   - ☐ 4) More than 100 freeway interchanges

2. **Most of freeway interchanges in your FDOT district are located at ALL AREAS LISTED**
   - ☐ 1) Rural area
   - ☒ 2) Urban and suburban areas
   - ☐ 3) Approximately half in urban and half in rural areas

3. **What percentage of freeway interchanges have ever had freeway off-ramp queue backed to freeway mainline in your district?**
   - ☒ 1) 10% or less
   - ☐ 2) 10%-25%
   - ☐ 3) 26%-50%
   - ☐ 4) More than 50%

4. **How serious are freeway off-ramp queue problems in your district?**
   - ☒ 1) Serious in most major urban and their suburban areas
   - ☐ 2) Serious in major urban areas
   - ☐ 3) Minor in major urban areas
   - ☐ 4) Not a concern

5. **When do freeway off-ramp queue problems occur?**
   - ☐ 1) Only during AM or PM peak hours
   - ☒ 2) During both AM and PM peak hours
   - ☐ 3) Most of daytime
   - ☐ 4) All the time except late at night

6. **Please list the top 3 interchange locations and directions with off-ramp queues backed up to freeway in your district?**

   1) I-75 , Fowler Ave, Northbound

   2) I-75 Martin Luther King Blvd Southbound

   3) I-75 Sr-54

7. **In general, what are the major causes of freeway off-ramp queue backed up to the freeway in your district?**
   - ☒ 1) Capacity problems at the off-ramp terminal intersection
   - ☐ 2) Lane blockage problem of downstream intersections on the local artery
   - ☐ 3) Inefficient signal coordination of local arteries adjacent to the freeway off-ramps

☐ 4) Not enough green time allocated to off-ramps at the terminal intersections
☐ 5) Inefficient operation of off-ramp lane assignments at the terminal intersections
☒ 6) Not enough storage space at the off-ramps
☐ 7) Slow, heavy vehicles at off-ramp causing signal to gap out earlier than expected
☐ 8) Frequent signal pre-emption at the off-ramp terminal intersection
☐ 9) Prohibition of No-Turn on Red at the off-ramp terminal intersection
☒ 10) Inadequate signal spacing on the artery near the freeway off-ramp
☒ 11) Other _____

8. Please closely review the following countermeasures to reduce off-ramp queue problems. Select those that have been tried with success in your district.

Signal Timing Improvements
☒ 1) Increase green time on the off-ramp approach at off-ramp terminal intersection
☒ 2) Adjust signal timing plans on arterial signals adjacent to the freeway off-ramps
☐ 3) Retime signals on the local artery to provide better signal coordination
☒ 4) Provide signal coordination in a way that the progression of traffic flow is from the off-ramp approach to artery
☐ 5) Use detectors to monitor off-ramp queues automatically. Preempt the off-ramp terminal intersection if the queue reaches the critical location
☒ 6) Allow right turn on red from the off-ramp approach at the terminal intersection

Ramp Metering
☐ 7) Use upstream on-ramp metering to slow down the increase of traffic demand

Transportation Demand Management
☒ 8) Apply Transportation Demand Management (TDM) strategies such as bus, carpool, vanpool, telecommuting, and flexible work schedule
☐ 9) Use HOV lane to encourage carpooling to reduce traffic demand on freeways
☒ 10) Use toll roads to ease traffic demand, so it reduces traffic volume at off-ramps

Reduction of Arrival Rates
☐ 11) Reduce posted speed limit for freeway bottleneck sections near the congested off-ramps, hence reducing arrival rates of traffic at the off-ramps
☐ 12) Use changeable posted speed limit signs instead for the above Countermeasure11
☒ 13) Install variable message signs (VMS) on the freeway to warn the upstream traffic about downstream congestion (including off-ramp queue backed up) and encourage motorists to slow down or divert to alternate routes
☐ 14) Use VMS to divert traffic into alternative routes during a freeway incident

Traveler Information Dissemination
☒ 15) Disseminate real-time traffic conditions through website, Highway Advisory Radio (HAR), or/and 511 to motorists

Geometrical Improvement

☒ 16) Lengthen left-turn, or/and right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps

☒ 17) Increase capacity through lane reassignment at off-ramp terminal intersections

☒ 18) Increase capacity through reconstruction at off-ramp terminal intersections

☒ 19) Increase capacity through lengthening storage lane lengths for off-ramp approaches

☐ 20) Devote some freeway shoulder lanes to queues backed up from the off-ramp

☐ 21) Increase efficiency through lane reassignments at the freeway diverge gore

☒ 22) Build additional lanes on the freeway leading exiting traffic to the off-ramp

☒ 23) Build frontage road along the freeway bottleneck section to reduce demand

☐ 24) Build another off-ramp near the off-ramp with severe queue problem

Effective Monitoring

☐ 25) Use freeway or off-ramp monitoring (CCTV) cameras to effectively monitor the congested off-ramp and take proper action to reduce the off-ramp queue

9. Please provide additional successful countermeasures in your district if they are not covered in your answers to the Question 8.

Extend the merge section on the artirial to make it a through lane

10. From your answers to Questions 8 and 9, please provide us with your top 3 short-term and top 3 long-term countermeasures to effectively reduce queues at freeway off-ramps.

Your top 3 short-term countermeasures:

1) Adjust timing to favor the ramp

2) Adjust timings at adjacent signals

3) Relocate lane utilization at ramp signal

Your top 3 long-term countermeasures:

1) Add lanes on the artery at the ramp

2) Add lanes on the ramp

3) Build an additonal interchange

11. How many CCTV monitoring cameras were installed in your district near congested freeway off-ramps?

☒ 1) Less than 10

☐ 2) 10-25

☐ 3) 25-50

☐ 4) More than 50 CCTV cameras

12. How many traffic data collection stations were located in your district near congested freeway off-ramps?

☒ 1) Less than 10
☐ 2) 10-25
☐ 3) 25-50
☐ 4) More than 50 traffic data collection stations

13. Currently, what kinds of traffic information do you collect automatically through the devices installed on specific freeway segments in your district?

☒ 1) Traffic volume data
☒ 2) Vehicle occupancy data
☒ 3) Vehicle classification data
☒ 4) Speed data
☐ 5) Travel time data
☐ 6) Queue length data
☐ 7) Others: _____

14. How does your district utilize the collected traffic data?

☐ 1) Stored in the database for future traffic analysis
☒ 2) Forecast traffic demand for future roadway needs
☐ 3) Identify freeway bottleneck locations to resolve problems
☐ 4) Disseminate traffic conditions and travel time information to motorists
☒ 5) Use them for 511
☐ 6) Share traffic data with other agencies
☐ 7) Others: _____

Turnpike

1. **How many freeway interchanges do you have in your district?**
   - ☐ 1) Less than or equal to 50
   - ☒ 2) More than 50 but less than or equal to75
   - ☐ 3) More than 75 but less than or equal to100
   - ☐ 4) More than 100 freeway interchanges

2. **Most of freeway interchanges in your FDOT district are located at ALL AREAS LISTED**
   - ☐ 1) Rural area
   - ☐ 2) Urban and suburban areas
   - ☐ 3) Approximately half in urban and half in rural areas

3. **What percentage of freeway interchanges have ever had freeway off-ramp queue backed to freeway mainline in your district?**
   - ☐ 1) 10% or less
   - ☒ 2) 10%-25%
   - ☐ 3) 26%-50%
   - ☐ 4) More than 50%

4. **How serious are freeway off-ramp queue problems in your district?**
   - ☒ 1) Serious in most major urban and their suburban areas
   - ☐ 2) Serious in major urban areas
   - ☐ 3) Minor in major urban areas
   - ☐ 4) Not a concern

5. **When do freeway off-ramp queue problems occur?**
   - ☐ 1) Only during AM or PM peak hours
   - ☒ 2) During both AM and PM peak hours
   - ☐ 3) Most of daytime
   - ☐ 4) All the time except late at night

6. **Please list the top 3 interchange locations and directions with off-ramp queues backed up to freeway in your district?**

   1) <u>Commercial Blvd</u>

   2) <u>Pga Blvd</u>

   3) <u>Hollywood Blvd</u>

7. **In general, what are the major causes of freeway off-ramp queue backed up to the freeway in your district?**
   - ☒ 1) Capacity problems at the off-ramp terminal intersection
   - ☒ 2) Lane blockage problem of downstream intersections on the local artery
   - ☐ 3) Inefficient signal coordination of local arteries adjacent to the freeway off-ramps

- [ ] 4) Not enough green time allocated to off-ramps at the terminal intersections
- [ ] 5) Inefficient operation of off-ramp lane assignments at the terminal intersections
- [x] 6) Not enough storage space at the off-ramps
- [ ] 7) Slow, heavy vehicles at off-ramp causing signal to gap out earlier than expected
- [ ] 8) Frequent signal pre-emption at the off-ramp terminal intersection
- [ ] 9) Prohibition of No-Turn on Red at the off-ramp terminal intersection
- [ ] 10) Inadequate signal spacing on the artery near the freeway off-ramp
- [x] 11) Other _____

8. Please closely review the following countermeasures to reduce off-ramp queue problems. Select those that have been tried with success in your district.

Signal Timing Improvements

- [x] 1) Increase green time on the off-ramp approach at off-ramp terminal intersection
- [x] 2) Adjust signal timing plans on arterial signals adjacent to the freeway off-ramps
- [x] 3) Retime signals on the local artery to provide better signal coordination
- [x] 4) Provide signal coordination in a way that the progression of traffic flow is from the off-ramp approach to artery
- [ ] 5) Use detectors to monitor off-ramp queues automatically. Preempt the off-ramp terminal intersection if the queue reaches the critical location
- [x] 6) Allow right turn on red from the off-ramp approach at the terminal intersection

Ramp Metering

- [ ] 7) Use upstream on-ramp metering to slow down the increase of traffic demand

Transportation Demand Management

- [ ] 8) Apply Transportation Demand Management (TDM) strategies such as bus, carpool, vanpool, telecommuting, and flexible work schedule
- [ ] 9) Use HOV lane to encourage carpooling to reduce traffic demand on freeways
- [ ] 10) Use toll roads to ease traffic demand, so it reduces traffic volume at off-ramps

Reduction of Arrival Rates

- [ ] 11) Reduce posted speed limit for freeway bottleneck sections near the congested off-ramps, hence reducing arrival rates of traffic at the off-ramps
- [ ] 12) Use changeable posted speed limit signs instead for the above Countermeasure11
- [x] 13) Install variable message signs (VMS) on the freeway to warn the upstream traffic about downstream congestion (including off-ramp queue backed up) and encourage motorists to slow down or divert to alternate routes
- [x] 14) Use VMS to divert traffic into alternative routes during a freeway incident

Traveler Information Dissemination

- [x] 15) Disseminate real-time traffic conditions through website, Highway Advisory Radio (HAR), or/and 511 to motorists

Geometrical Improvement

☒ 16) Lengthen left-turn, or/and right-turn lanes on the local artery to prevent through lane blockage on the artery adjacent to the freeway off-ramps
☒ 17) Increase capacity through lane reassignment at off-ramp terminal intersections
☒ 18) Increase capacity through reconstruction at off-ramp terminal intersections
☒ 19) Increase capacity through lengthening storage lane lengths for off-ramp approaches
☒ 20) Devote some freeway shoulder lanes to queues backed up from the off-ramp
☐ 21) Increase efficiency through lane reassignments at the freeway diverge gore
☐ 22) Build additional lanes on the freeway leading exiting traffic to the off-ramp
☐ 23) Build frontage road along the freeway bottleneck section to reduce demand
☐ 24) Build another off-ramp near the off-ramp with severe queue problem

Effective Monitoring

☒ 25) Use freeway or off-ramp monitoring (CCTV) cameras to effectively monitor the congested off-ramp and take proper action to reduce the off-ramp queue

9. Please provide additional successful countermeasures in your district if they are not covered in your answers to the Question 8.

______

10. From your answers to Questions 8 and 9, please provide us with your top 3 short-term and top 3 long-term countermeasures to effectively reduce queues at freeway off-ramps.

Your top 3 short-term countermeasures:

1) Increase queue storage

2) Mobile ITS appications

3) Signal improvements

Your top 3 long-term countermeasures:

1) Increase interchange capacity

2) Geometric improvements

3) ITS

11. How many CCTV monitoring cameras were installed in your district near congested freeway off-ramps?

☐ 1) Less than 10
☒ 2) 10-25
☐ 3) 25-50
☐ 4) More than 50 CCTV cameras

12. How many traffic data collection stations were located in your district near congested freeway off-ramps?

☒ 1) Less than 10
☐ 2) 10-25
☐ 3) 25-50
☐ 4) More than 50 traffic data collection stations

13. Currently, what kinds of traffic information do you collect automatically through the devices installed on specific freeway segments in your district?

☒ 1) Traffic volume data
☒ 2) Vehicle occupancy data
☒ 3) Vehicle classification data
☒ 4) Speed data
☒ 5) Travel time data
☐ 6) Queue length data
☐ 7) Others: _____

14. How does your district utilize the collected traffic data?

☒ 1) Stored in the database for future traffic analysis
☒ 2) Forecast traffic demand for future roadway needs
☒ 3) Identify freeway bottleneck locations to resolve problems
☒ 4) Disseminate traffic conditions and travel time information to motorists
☒ 5) Use them for 511
☒ 6) Share traffic data with other agencies
☐ 7) Others: _____

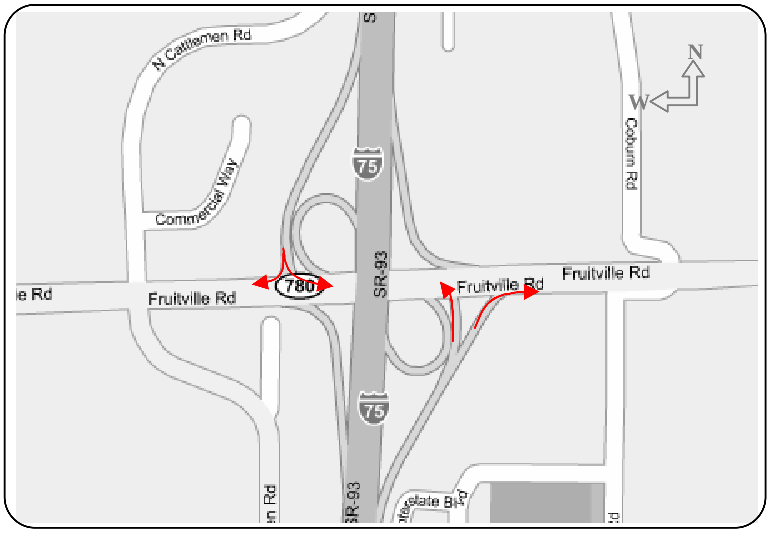
APPENDIX D

MAPS OF PROBLEMATIC INTERCHANGES LOCATIONS FOR EACH DISTRICT

Following are maps of the locations of the different problematic interchanges per district.

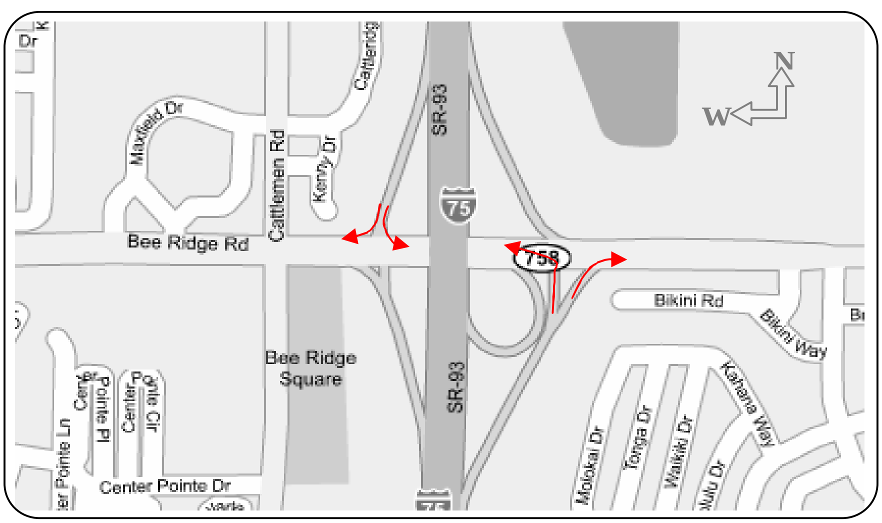
<u>District 1</u>

<u>Site: I-75, Fruitville</u>



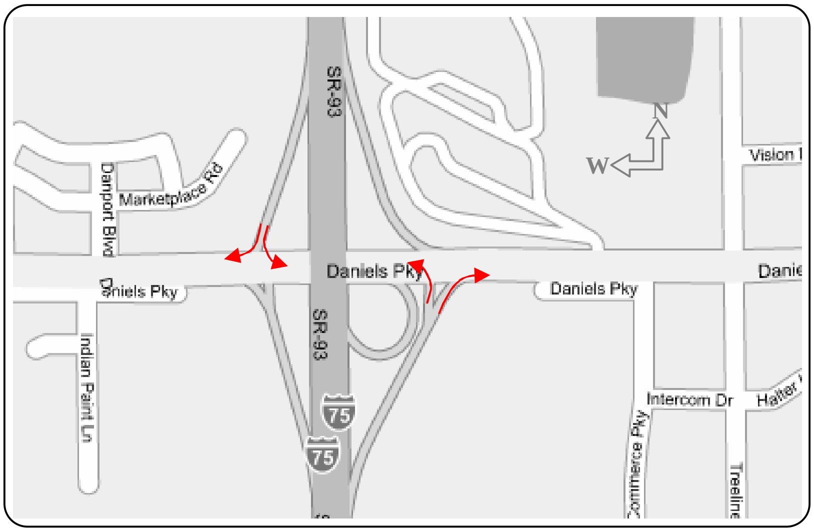
The exit ramps in both directions are subject to traffic control at the crossroads. This interchange was firstly conceived to handle rural traffic volumes; therefore, it encounters problems as the surrounding area becomes urban. Currently, this interchange presents congestion problems in both directions of the exit ramps of the I-75. This interchange design corresponds to a 4-Quadrant partial cloverleaf type A.

<u>Site: I-75, Bee Ridge Road</u>



The I-75 & Bee Ridge Road interchange is a modified diamond interchange. The additional feature with respect to conventional diamonds is the presence of a loop-shaped on-ramp for the eastbound traffic on Bee Ridge Road. The remaining ramps are typical of diamond interchanges. The northbound off-ramp has one left turn lane for the vehicles exiting the I-75 heading west on the Bee Ridge Road. The traffic volume on this inbound direction increases during the A.M. peak hour causing congestion on the off-ramp.

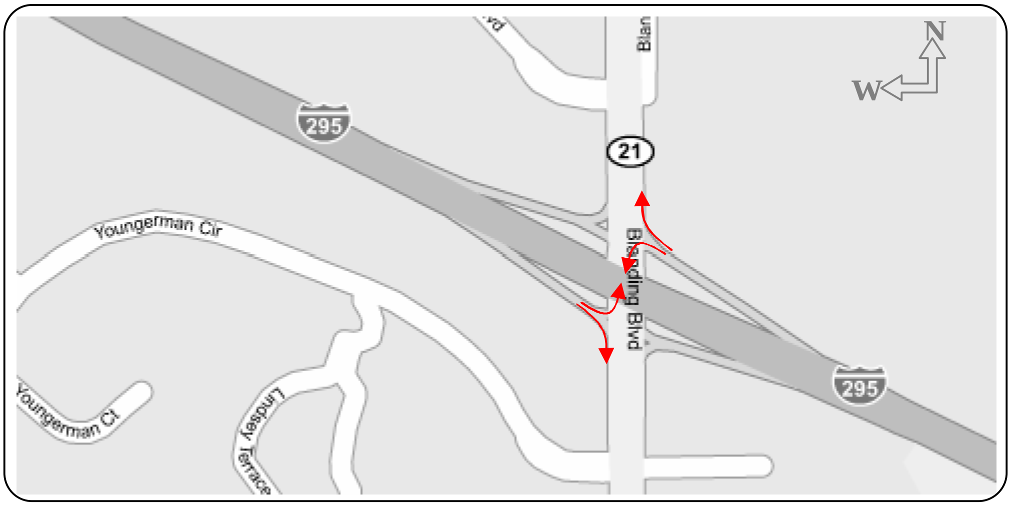
Site: I-75, Daniels Parkway



Currently, the southbound direction during A.M. peak hour is facing congestion problems. Only one lane is provided for each movement. Developments in the surrounding area have caused congestion on the off-ramps. According to its geometry, this design can be classified as diamond (modified) interchange because only has one loop.

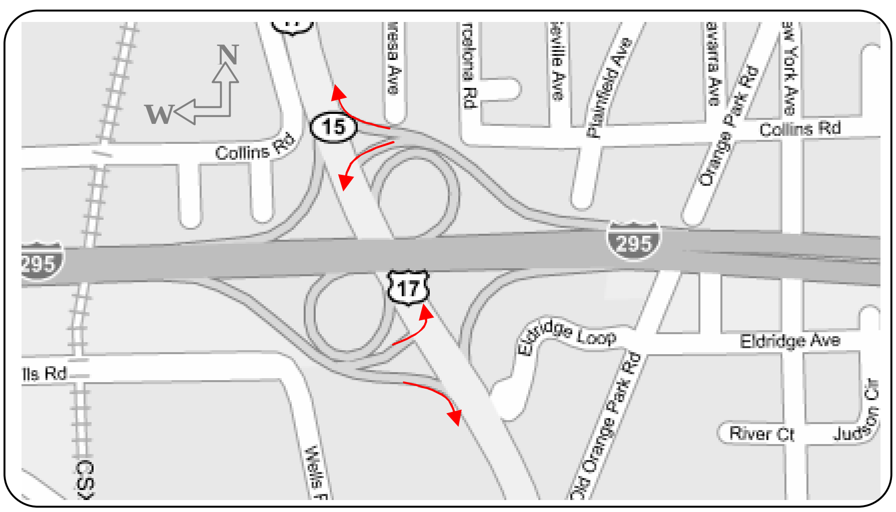
District 2

Site: I-295, Sr-21



This interchange presents problems at exit ramps in both directions, south bound and north bound. It only has only one lane for each movement at the south bound off-ramp which causes lane blockage problems. This interchange corresponds to a diamond type geometric design.

Site: I-295, US 17



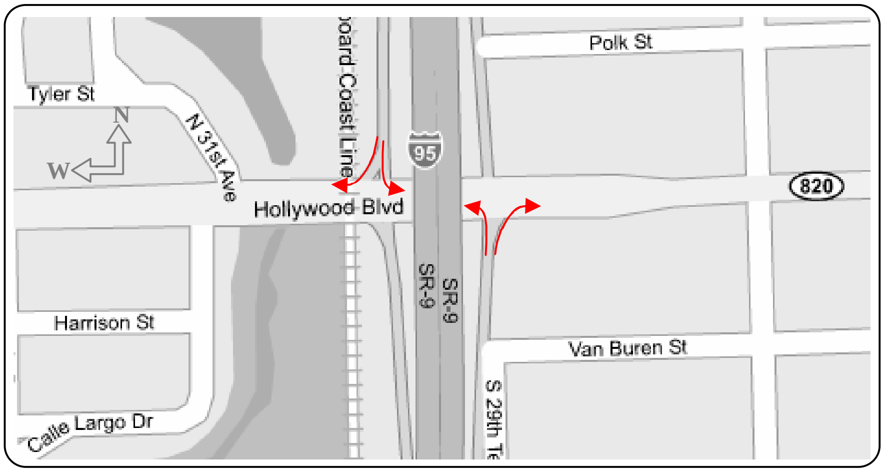
This interchange design corresponds to a partial cloverleaf type. The off-ramps have traffic signals at the terminal intersections suffering the same weakness of diamond interchanges with respect to unbalanced turning traffic volumes. This interchange is facing queuing problems mostly in the northbound (west in figure) direction of the I-295 freeway. One of the planned improvements is to add more left turn lanes.

District 3

This district was experiencing difficulties due to damages to transportation facilities caused by hurricanes. By the time this study took place, there was a significant construction work taking place and, therefore, the District was not considered to be under normal operating conditions.

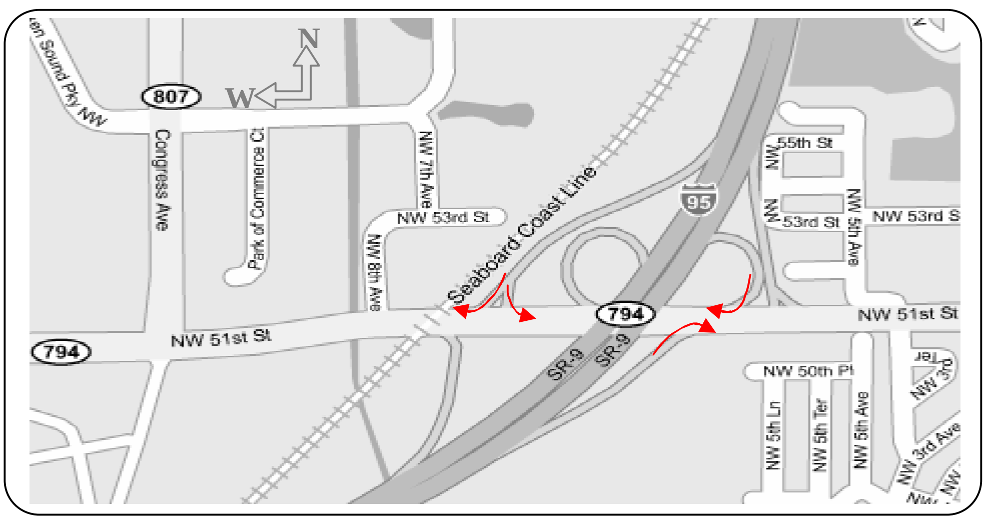
District 4

<u>Site: I-95 & Hollywood Blvd</u>



The railroad on the west of the interchange is the major cause of congestion. It is too close to the exit of the southbound direction of I-95. Preemption of the signals due to Tri-rail commuter trains contributes to the congestion at this interchange. The geometric design corresponds to a diamond interchange

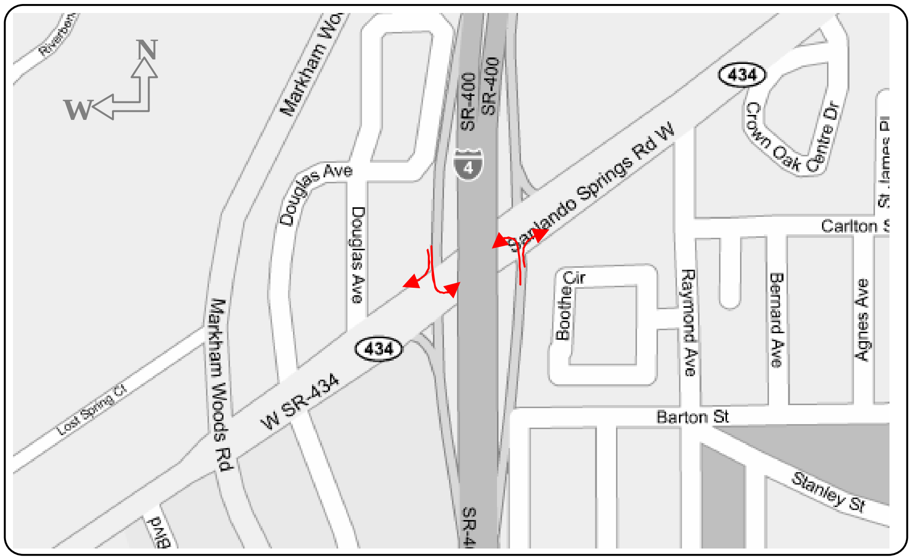
<u>Site: I-95 & Yamato Rd</u>



This interchange is facing the same problem as Hollywood Blvd due to the railroad crossing the arterial too close to the exit ramp. The problematic direction for this interchange is the southbound off-ramp of I-95. This interchange can be classified as a partial cloverleaf.

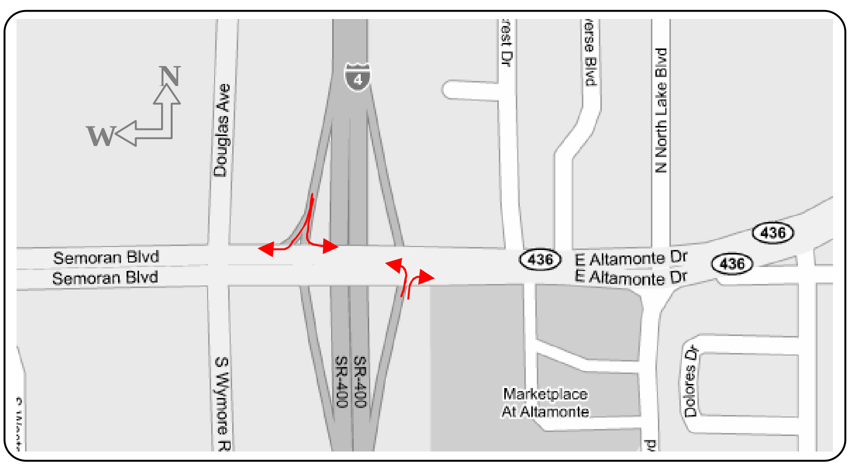
District 5

Site: I-4 & SR434



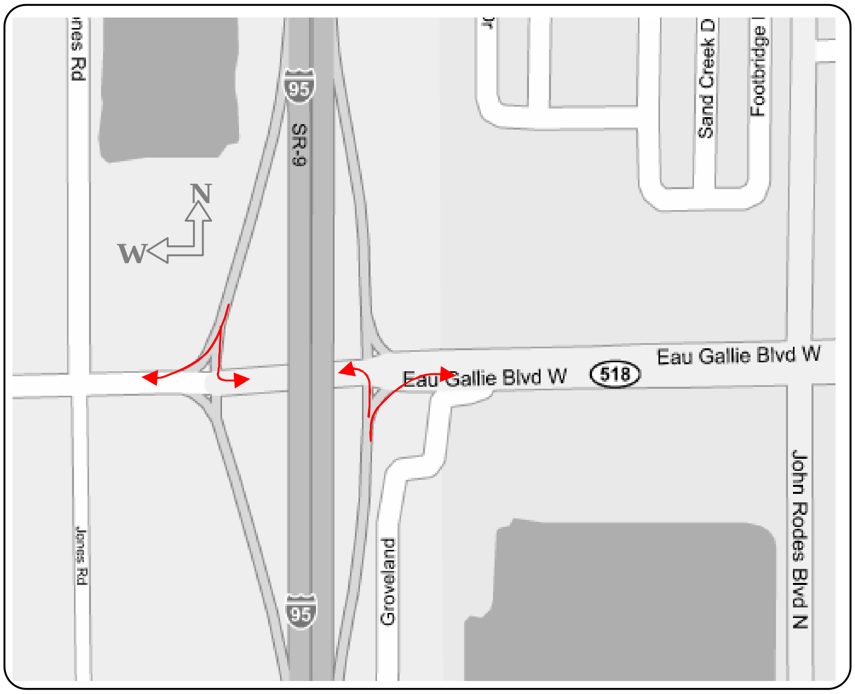
The exit ramp for the southbound traffic on the I-4 (for this segment) has only one left turn lane and one right turn lane. There is an intersection very close to the southbound exit ramp contributing to the congestion problem.

Site: I-4 & SR436



Traffic lights for both ramps are very close to the exit point, less than 300 ft, especially for the westbound exit ramp (southbound).Traffic on the arterial is too heavy to allow turning movements of the exiting vehicles. One of the improvements being proposed is to remove the signal and loop the traffic around the main streets to facilitate the turning movements of the exiting vehicles.

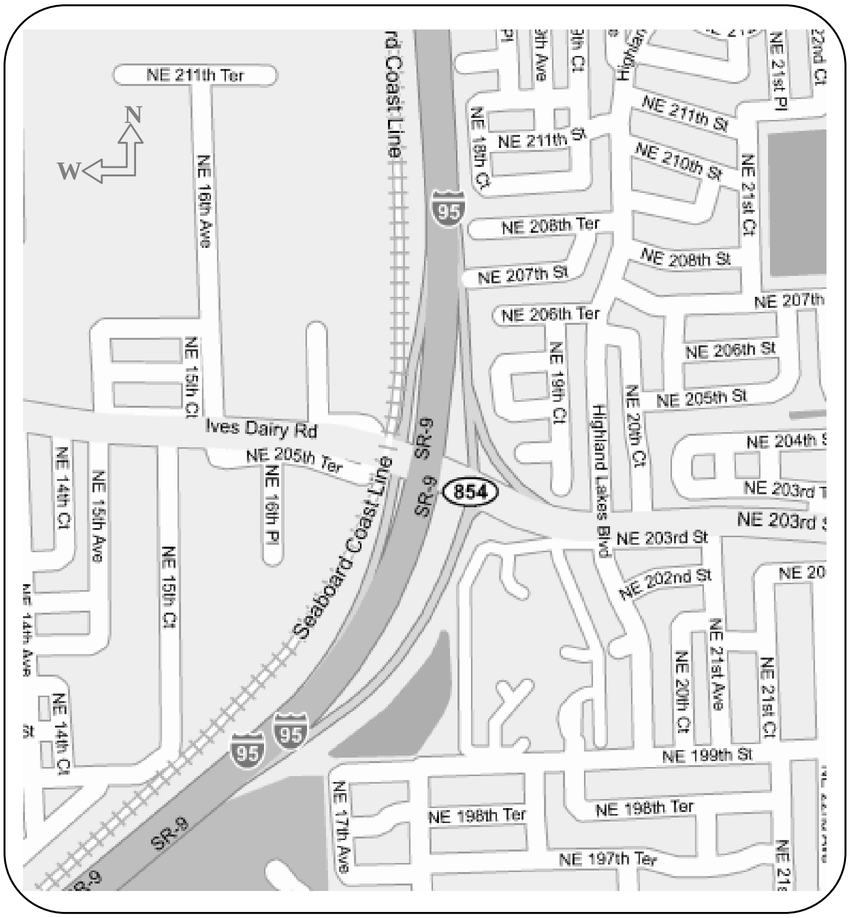
Site: I-95 & SR-518



The developments at the east area of the interchange have increased the traffic volumes heading in that direction. The problems are mainly observed on the off ramp serving the southbound direction of the interchange. Although Jones Road is close to the west approach of the interchange, this intersection is not contributing to congestion on the ramp because the traffic is greater on the eastbound direction. Currently, the eastbound direction is being served by a single left-turn lane, causing the queue to spill back onto the freeway. This is a commonly encountered situation in diamond interchanges.

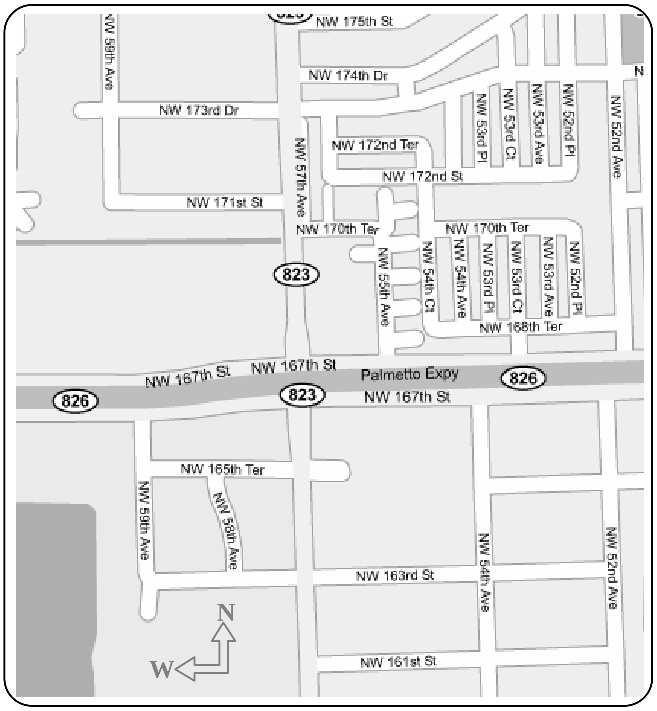
District 6

Site: I-95 and SR-854 (Ives Dairy Rd)

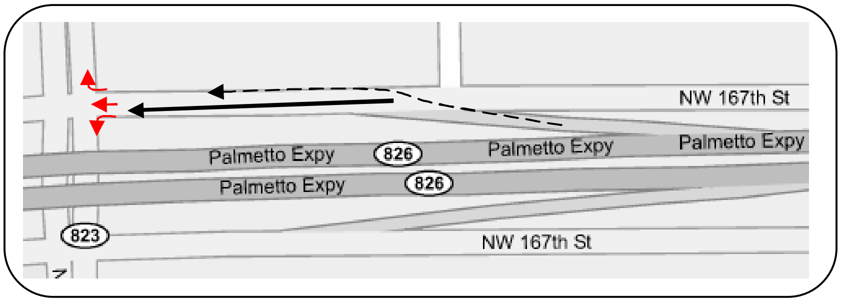


The southbound direction is experiencing problems in the afternoon peak period due to the exiting volumes from the I-95 and the proximity of the traffic light on the east direction. The geometry of this interchange follows a diamond pattern, which implies diagonal ramps with traffic signals at the intersection; the distance between them constitutes a critical factor for the performance of the facility. The surrounding area of this interchange is significantly developed, thus constraining the right-of- way for major reconstruction.

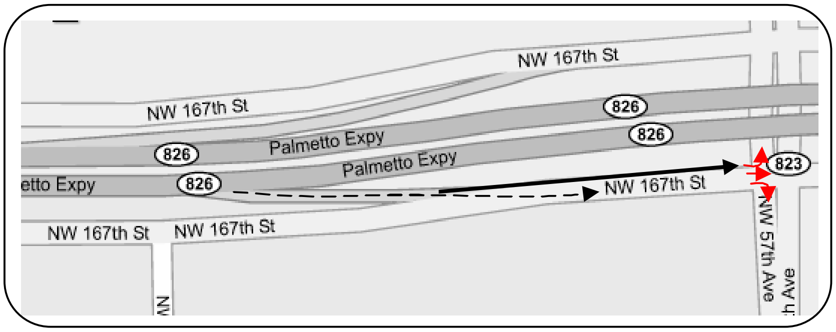
Site: Palmetto Expressway, SR-823 (NW 57Th Ave)



Detailed view WB

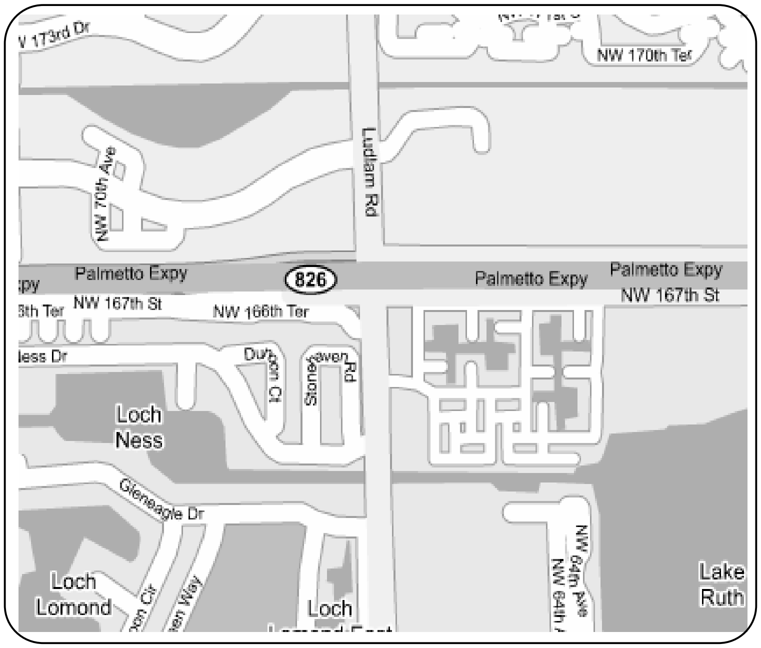


Detailed view EB

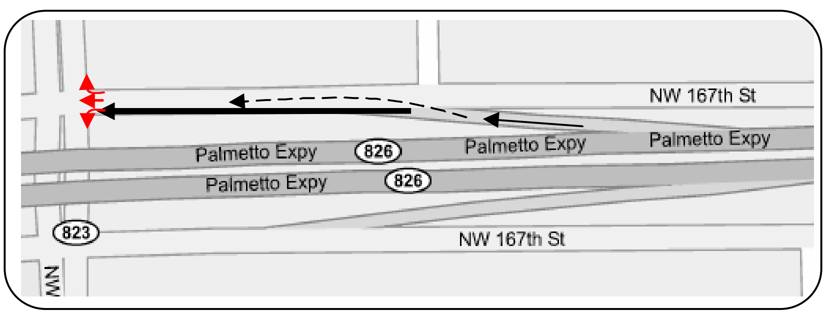


In both cases, the traffic of the frontage road, NW 167th St, obstructs the exiting vehicles heading to the through and right turn lanes on the NW 57th Ave intersection. The queuing problem is most frequently observed during the afternoon rush hour.

Site: Palmetto Expressway, Ludman Rd

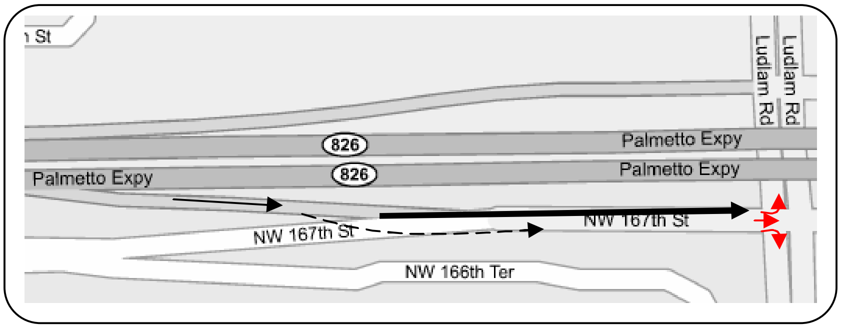


Detailed view WB



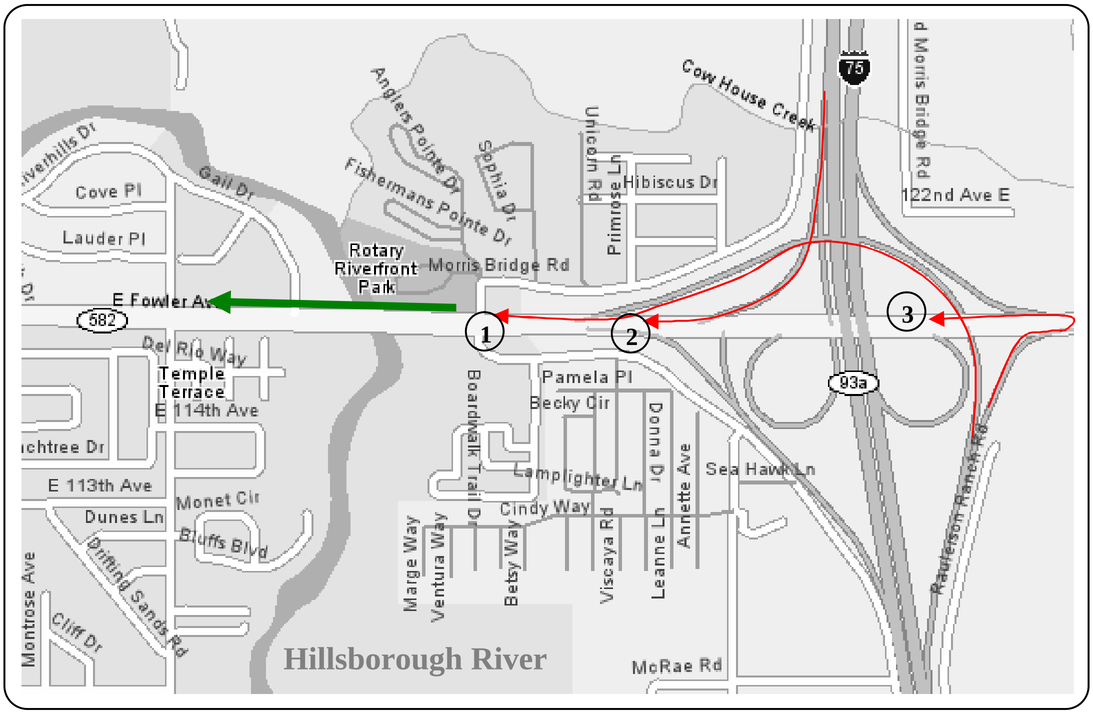
Vehicles exiting in the westbound direction are blocked by the queue of the traffic on the NW 167th St . The situation becomes more critical for the through and right movements of the exiting vehicles on the 823 Road because they have to go across the 167^{Th} Street to reach the intersection. The same situation occurs in the opposite direction.

Detailed view EB



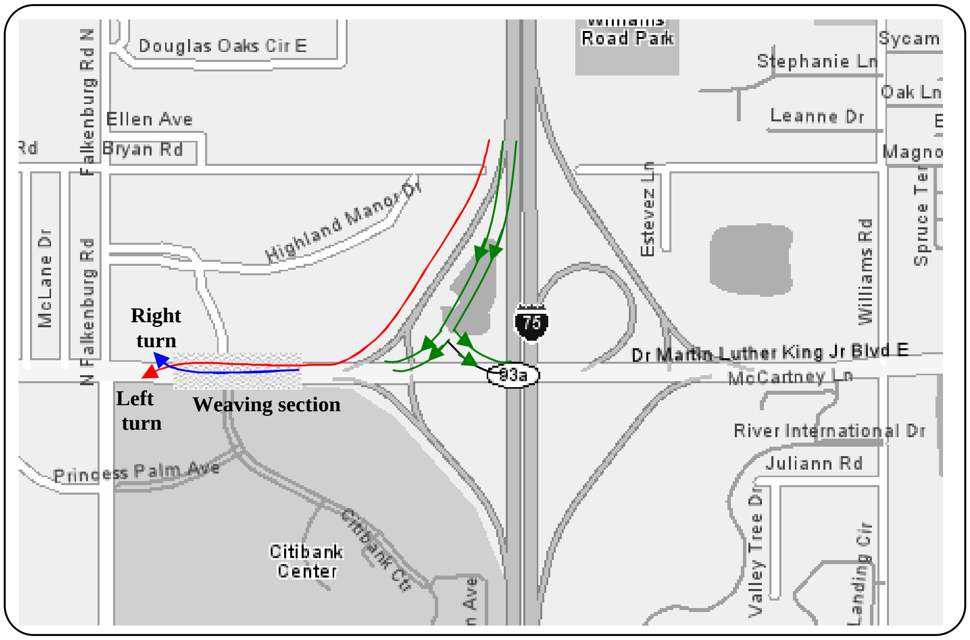
District 7

Site: I-75 North Bound, Fowler Ave.



This interchange can be classified as semi-directional. The northbound direction has shown a recurring queuing problem. The ramp has an exclusive lane when entering Fowler Avenue (1). There is a forced merge section due to the bridge over the Hillsborough River. There is also interference due to I-75 exiting vehicles (2). Some of the drivers take the eastbound exit ramp to enter Fowler Avenue and then make a U-turn to go westbound (3). Green time is already saturated, and the cycle time is too long. The side street queue also spills back; its delay at the intersection is about 3 to 5 cycles. The improvement planned by district 7 is to widen the bridge to expand the merging section westbound beyond the Hillsborough River. The time frame for the project is 4 to 5 years.

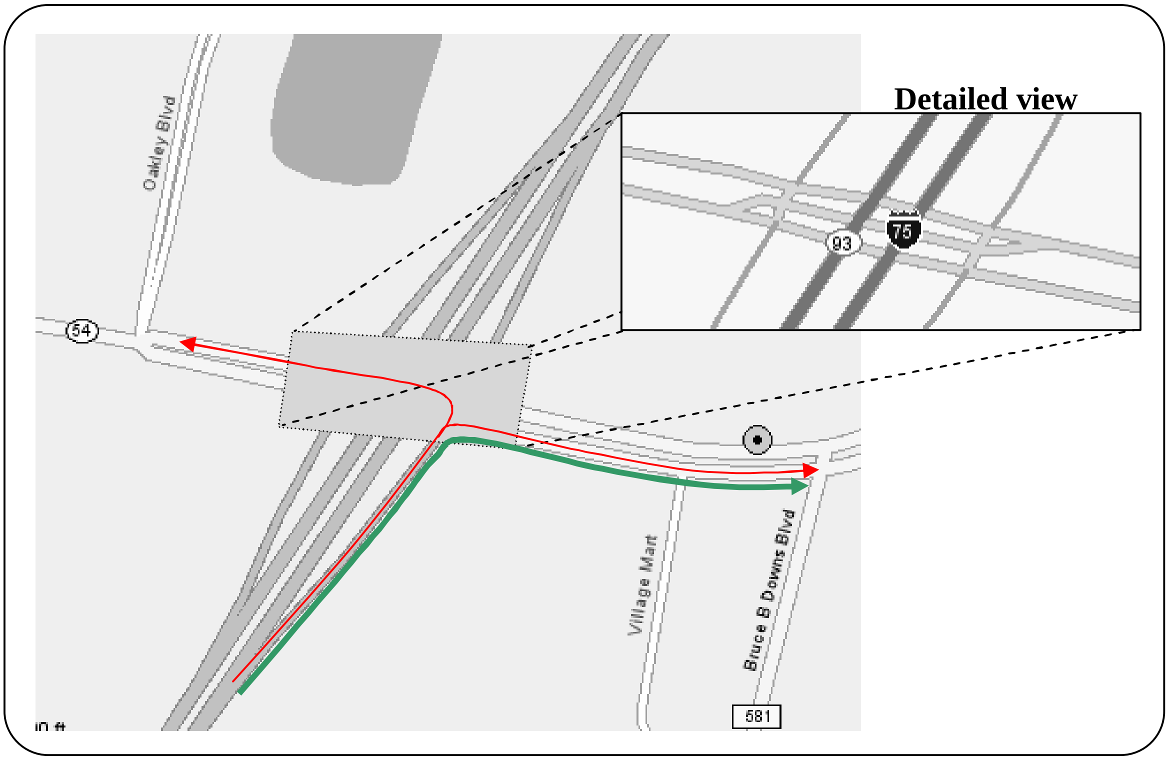
Site: I-75 South Bound, MLK Blvd



The southbound exit ramp has only one lane; the traffic is diverted into left-and-right-turn lanes at MLK. The section between the ramp terminal and Falkenburg Road intersection is congested due to the weaving effect caused by the traffic volume from the freeway approaching the left turn lanes and the arterial traffic, especially the right turners. This interchange can be classified as diamond (modified) because it has only one loop ramp.

The planned improvement is to add an additional lane to the exit ramp, rebuilding the exit ramp in such manner that the distance from the ramp terminal to the left turn lanes at Falkenburg is maximized. This improvement is planned to take place in the near future.

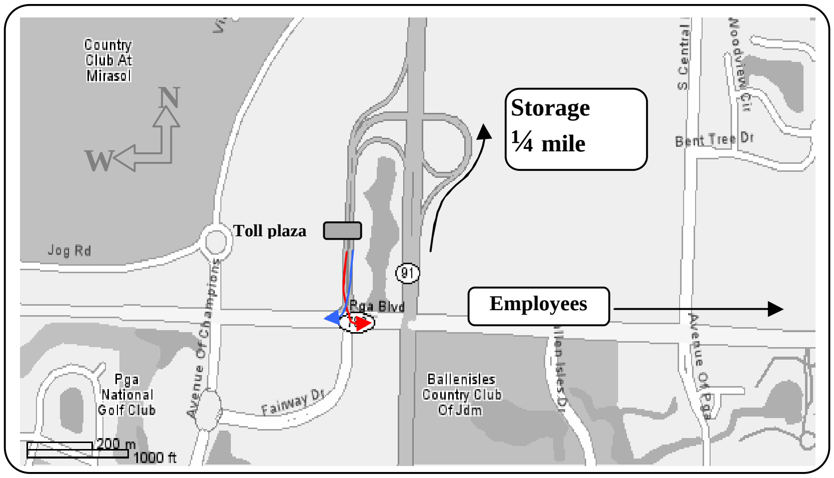
Site: I-75 SR-54



The PM peak hour northbound traffic exiting the freeway presents heavy right-and-left turn volumes affecting the intersection with Bruce B Downs Boulevard. The planned improvement is to widen the SR-54 such that right turn traffic has its own lane. According to its geometry, this interchange corresponds to a diamond type.

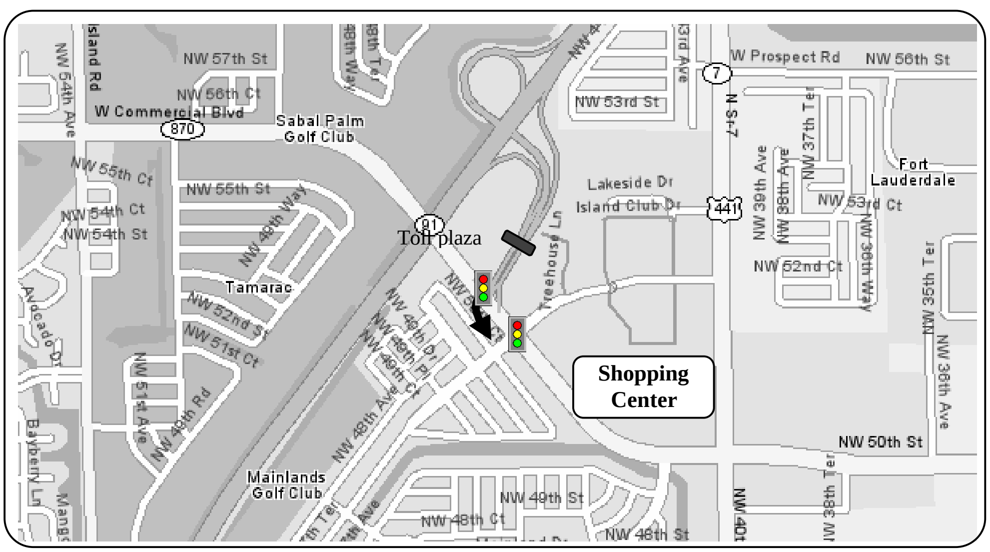
Turnpike

Site: Turnpike, PGA Blvd



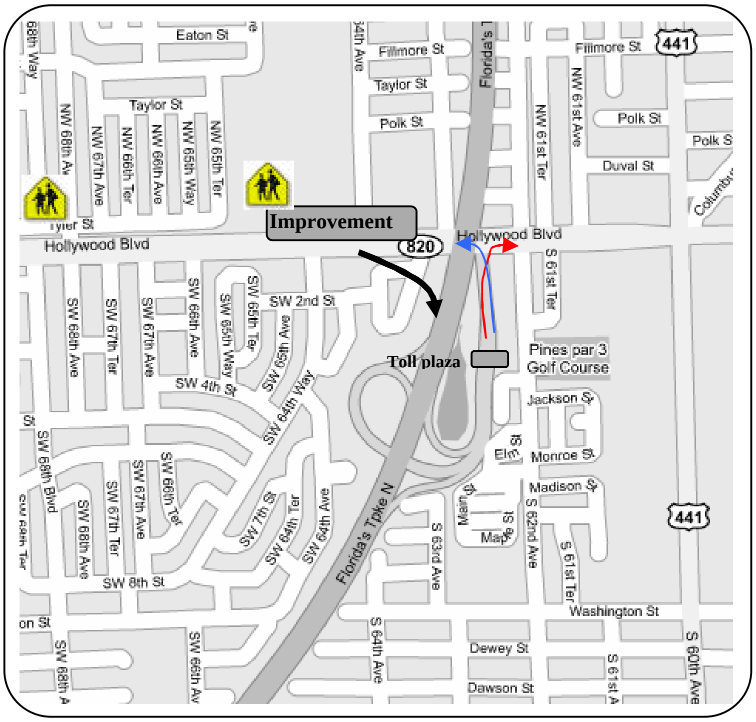
Most of the congestion is on the eastbound direction on PGA Blvd, due to the high number of employees traveling in that direction. There is also a capacity problem on the northbound exit ramp; the Turnpike is planning to build an additional storage lane because drivers have started to use the freeway shoulder as queue space which could cause damage to the pavement. There is also a problem at the toll plaza due to the weaving and merging effects together.

Site: Turnpike, Commercial Blvd



The toll plaza is too close to the intersection, increasing the interaction of left turn and right turn movements. There is a shopping center on the east of the interchange, so the major demand is on that direction. This is a reason for triple left turn bays, but there is another traffic light between the shopping center and the exit ramp, leading to a more critical situation. These two signals now operate out of one cabinet.

Site: Turnpike , Hollywood Blvd



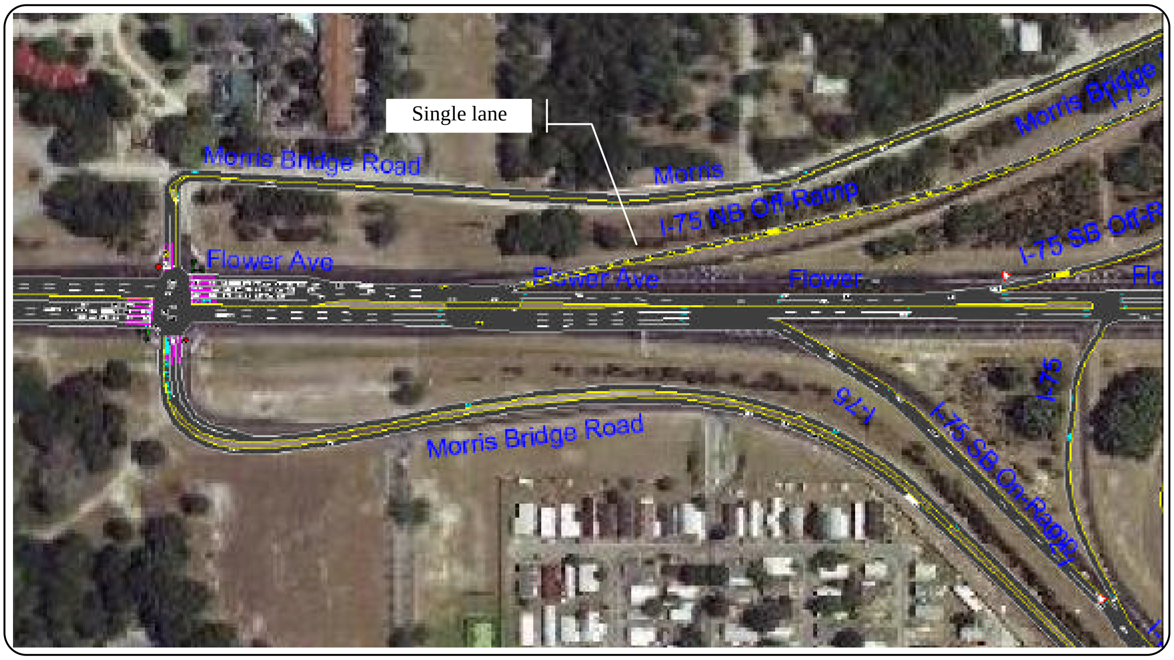
The congestion is due, in part, to the proximity of several schools at Hollywood Blvd. There is a lot of weaving in the approach of the intersection. One of the planned improvements is to implement triple left and dual right turns. The trumpet configuration seems to be appropriate for controlling purposes but, operationally, they have serious problems with weaving due to the closely spaced signal at 62nd Avenue.

APPENDIX E

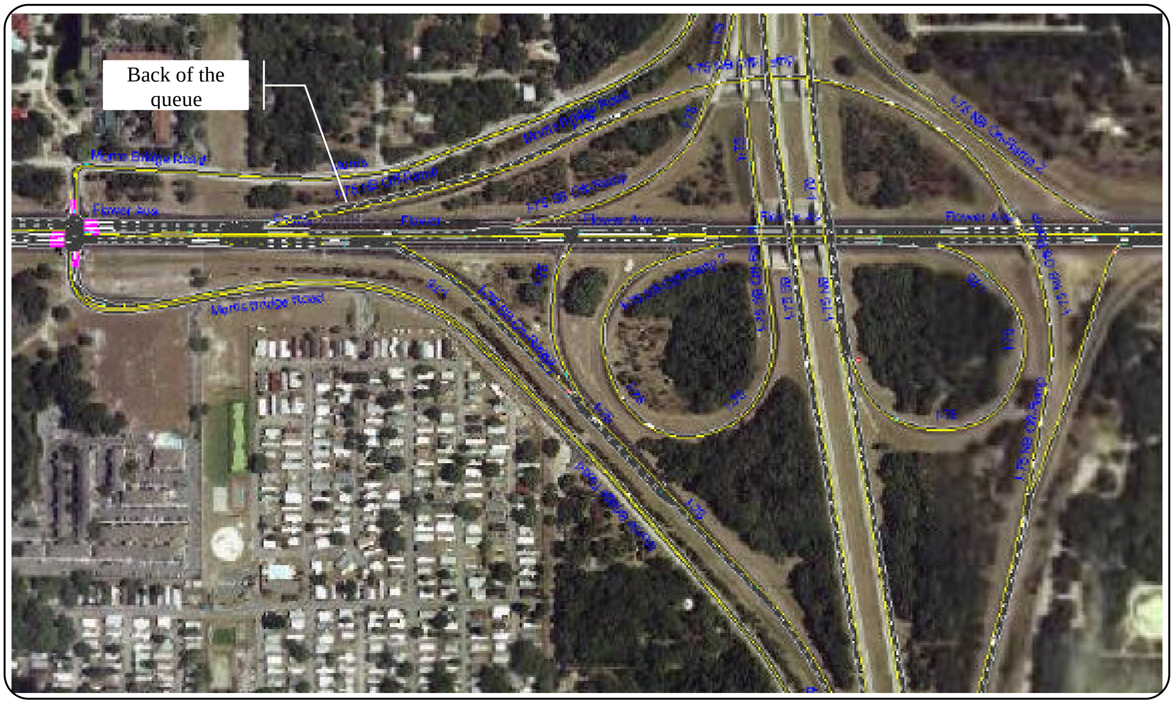
SIMULATION SNAPSHOTS

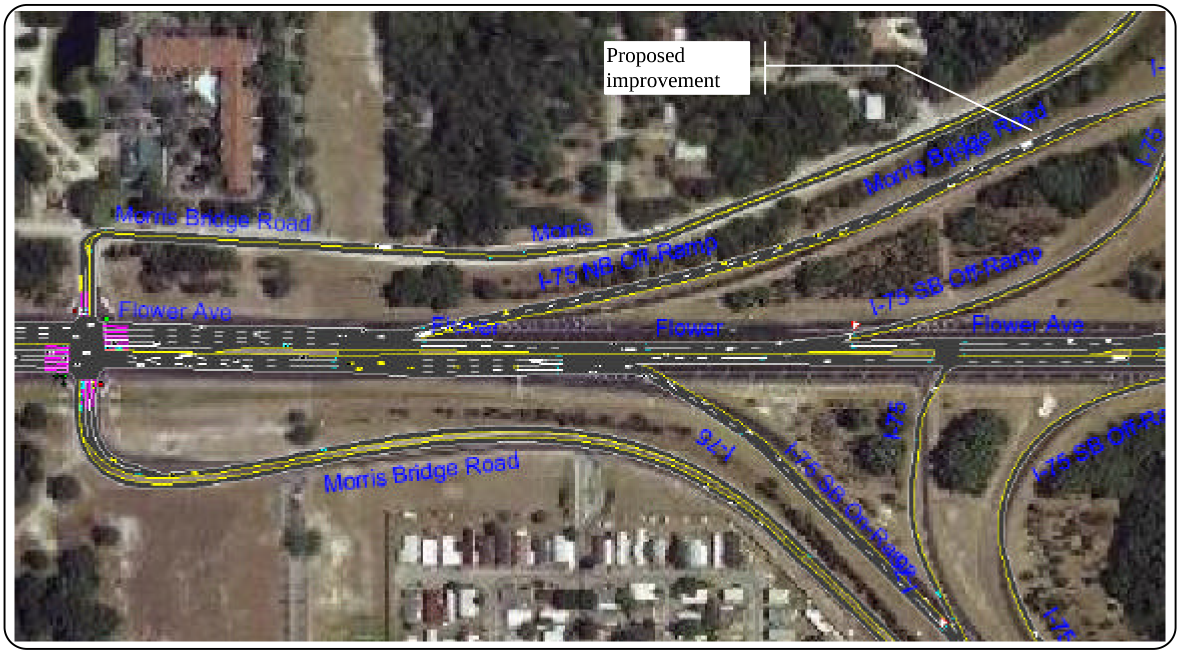
I-75 & Fowler Avenue

Before conditions



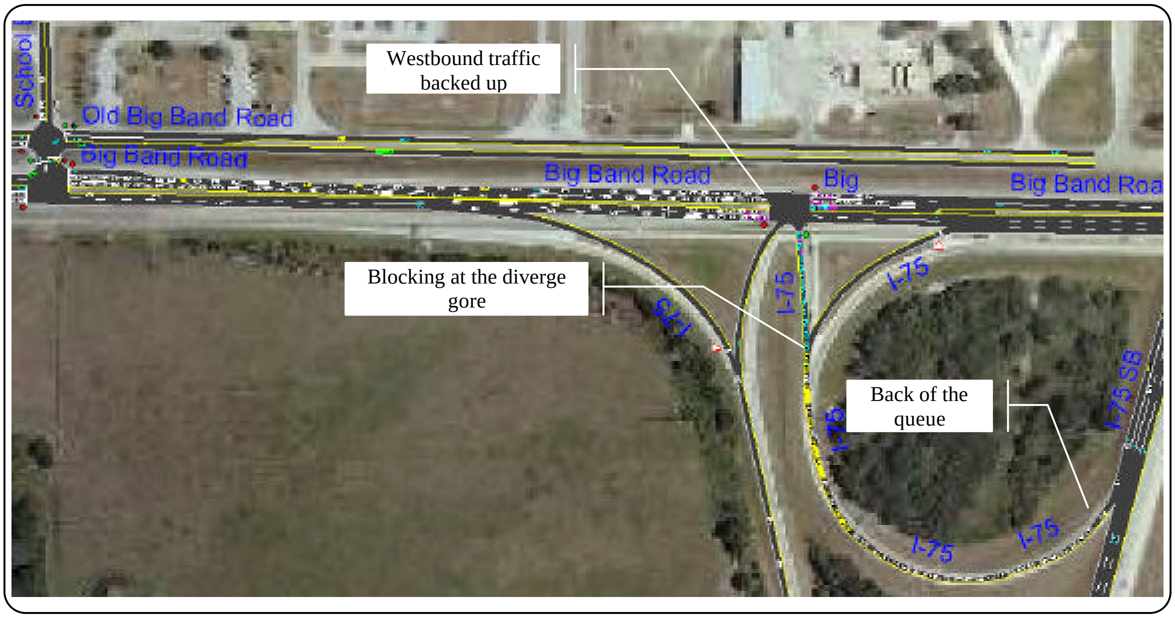
After conditions



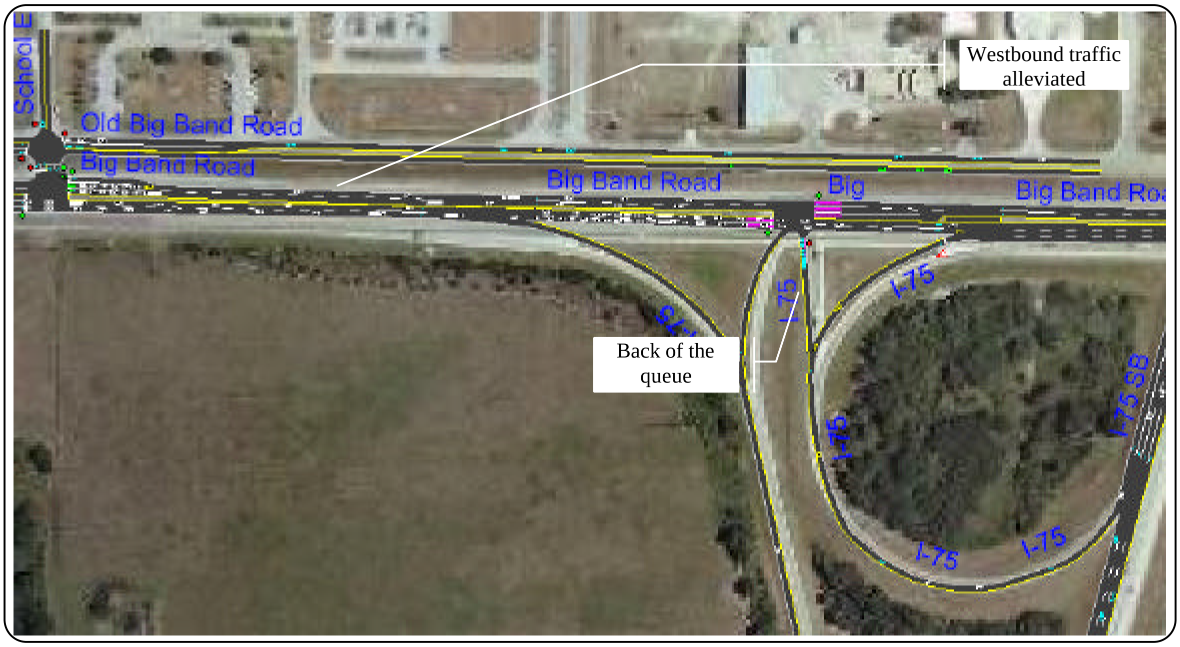


I-75 & Big Bend Road

Before conditions

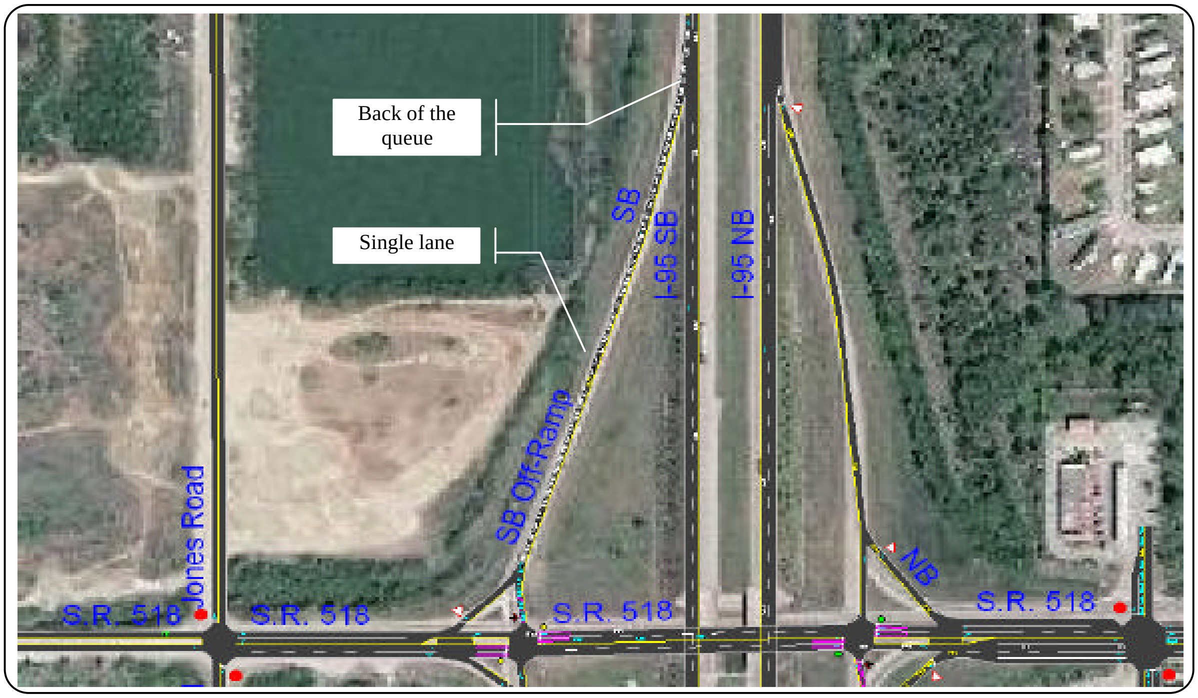


After conditions

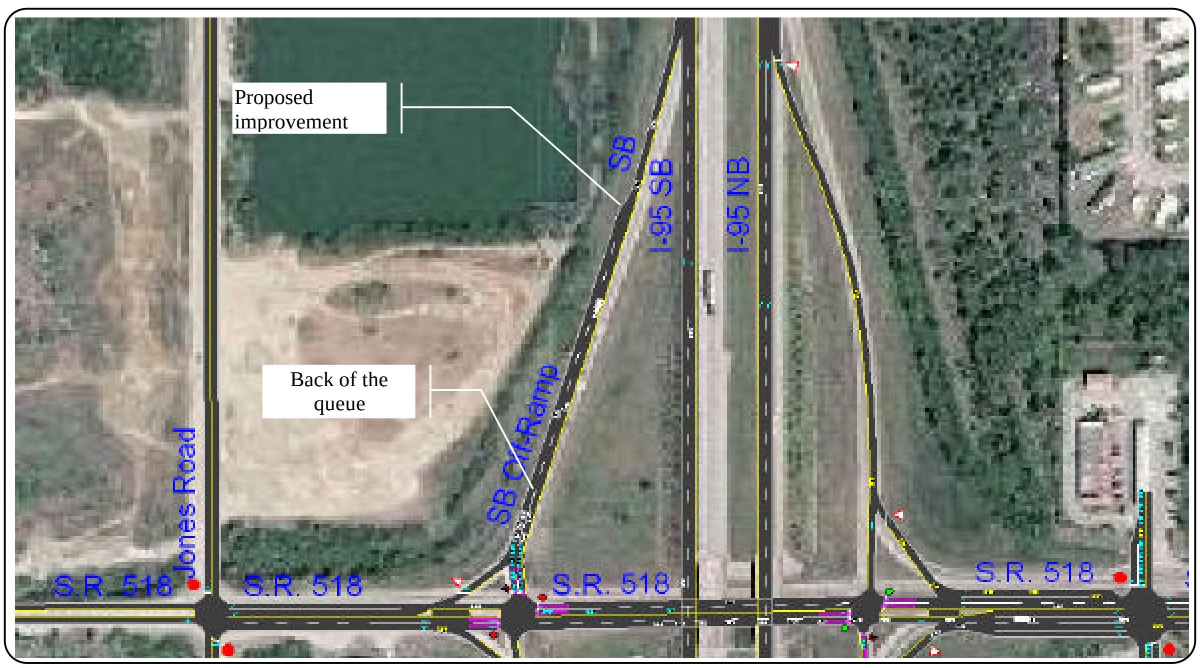


I-95 & Eau Gallie Boulevard

Before conditions



After conditions



APPENDIX F

ADDITIONAL COUNTERMEASURE TABLE

	Operational Effectiveness	Safety Effectiveness	Improved Conditions Term	Cost	Public Acceptance
Reduction of freeway demand					
Use ramp metering strategy of upstream on-ramps	Medium	High	Medium	High	Low
Use and enforce high occupancy vehicle (HOV) lanes	Medium	Medium	Medium	Medium	Low
Install VMS on a freeway or an artery to inform motorists the traffic congestion on freeways	Low	High	Short	Medium	Medium
Provide 511 calling system and/or highway advisory radio (HAR)	Medium	Medium	Short	Medium	Medium
Apply Transportation Demand Management (TDM) strategies	Medium	High	Long	Medium	Low
Use pricing to reduce demand	Medium	Medium	Medium	Medium	Low
Divert traffic from passing through a bottleneck section or an incident location	Medium	Medium	Short	Low	Medium
Build frontage road along the bottleneck section of the freeway	High	Medium	Medium	Medium	High
Build another off-ramp or interchange to reduce large exiting traffic volumes	High	Medium	Long	High	High
Reduction of arrival speeds					
Reduce Posted Speed Limit Using Static Signs	Medium	Medium	Short	Low	Medium
Reduce Posted Speed Limit Using Variable Speed Limit Signs	Medium	High	Short	Medium	Medium
Improvement of freeway operations					
Apply dynamic off-ramp management	High	Low	Medium	Medium	Low
Apply lane-changing restriction and implement lane assignment upstream of the off-ramp	Low	High	Short	Low	Medium
Increase in departure volume at off-ramp terminal intersections					
Install a traffic signal at terminal intersection	Medium	High	Medium	Medium	High
Increase the green time for an congested off-ramp	Medium	Medium	Short	Low	Medium
Reassign the lane usage at an off-ramp terminal intersection	Medium	Medium	Medium	Low	Medium
Build additional lanes at the off-ramp to increase discharge rate	High	High	Long	Medium	High
Construct triple or quadruple right-turn lanes	High	Medium	Long	Medium	Medium
Apply split diamond interchanges	High	High	Long	High	High
Reconstruct the off-ramp terminal intersection to increase the capacity and efficiency	High	High	Long	High	High
Modify trumpet interchange by adding an extra ramp	Medium	Medium	Long	Medium	High
Improvement of signal efficiency at off-ramp terminal intersections					
Use monitoring camera to effectively monitor the congested off-ramp and take proper actions to reduce the off-ramp queue	Low	Medium	Medium	Medium	Medium
Apply multiple cycling or short cycle length	Medium	Medium	Medium	Low	Medium
Pre-empt signals if an off-ramp queue reaches a designated point on the off-ramp	Medium	Medium	Medium	Low	Low

	Operational Effectiveness	Safety Effectiveness	Improved Conditions Term	Cost	Public Acceptance
Allow right-turn on red from the off-ramp at the terminal signalized intersection	Medium	Medium	Medium	Low	Medium
Use volume-density's gap reduction feature	Medium	Low	Short	Low	Medium
Provide free right turns from the off-ramps to arteries with tapers or exclusive lanes	Medium	Medium	Medium	Medium	High
Alleviation of arterial congestion					
Use monitoring cameras to effectively manage congestion and respond to incidents	Low	Medium	Medium	Medium	Medium
Provide better signal coordination on the arterial	Medium	Medium	Medium	Low	Medium
Reduce queues of downstream turning lanes on the arterial near off-ramps	Medium	High	Medium	Medium	Medium
Provide adequate turn lanes at downstream intersections or median opening on the arteries near interchanges	Medium	High	Medium	Low	High
Provide signal coordination from the off-ramp to the artery if it is more effective	Medium	Medium	Medium	Low	Medium
Remove signals on the arterial near interchanges	Medium	Low	Medium	Medium	Low
Reduce response time to an arterial incident	High	High	Medium	Medium	High
Properly manage school zones, work zones, and special events on arteries	High	Medium	Medium	Low	Medium
Add lanes on arteries near interchanges	High	High	Long	Medium	High
Add lanes to minor roads	High	High	Long	Medium	High
Adoption of access management on crossroads near interchanges					
Ensure adequate signal spacing, median openings and connection on the roadways connected to freeway interchanges	High	High	Long	High	Medium
Adopt access management regulations on limited access interchange areas	High	High	Long	High	Medium
Increase of off-ramp storage capacity					
Lengthen existing turn lanes at off-ramp terminal intersections	Medium	Medium	Short	Medium	High
Add extra lanes at off-ramps	High	Medium	Medium	Medium	High
Increase of freeway storage capacity					
Dynamically use shoulder as a queue storage lane for a short recurring bottleneck	Medium	Low	Medium	Low	Low
Construct deceleration or exclusive exit lane(s) before a congested off-ramp	Medium	High	Medium	Medium	High
Reassign lane usage on the freeway at the diverge gore	Medium	Medium	Medium	Low	Medium