Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-94/1232-3, Revision 1		

4. Title and Subtitle REVISION 1 TO THE TEXAS HIGHWAY OPERATIONS MANUAL	5. Report Date September 1994 6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No. Research Report 1232-3, Revision 1
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Study No. 0-1232
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Transfer Office P. O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Interim: September 1989 to August 1994 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.
Research Study Title: Urban Highway Operations Research and Implementation Program

16. Abstract

This is the first revision to the *Texas Highway Operations Manual* which was issued in August 1992. This revision provides a means of implementing the results of research tasks performed as part of this study and completed since the publication of the Manual.

The *Texas Highway Operations Manual* was developed for the Texas Department of Transportation to serve as a Department manual addressing highway operations. The information in the manual covers a wide range of operational issues related to the planning, design, construction, maintenance, and management of highways. Part I of the manual serves as an introduction to the manual and the concept of highway operations. Part II addresses operational considerations for project development, preliminary design, final design, and scheduled activities. Part III addresses systems management, data collection, operational analysis, incident management, control strategies, and information systems. Part IV contains the appendices, abbreviations and definitions, annotated bibliography, and index.

17. Key Words	18. Distribution Statement
Traffic Operations, Freeway Analysis, Highway Capacity, Freeways, Highway Systems, Traffic Management	No restrictions. This document is available to the public through NTIS: National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	118	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

This page intentionally left blank

TEXAS HIGHWAY OPERATIONS MANUAL

September 1994 Revision

Traffic Operations Division
Texas Department of Transportation

This is the first revision to the *Texas Highway Operations Manual* which was issued in August 1992. This revision provides a means of implementing the results of research tasks performed as part of this study and completed since the original publication of the Manual. The attached pages should be used to replace the pages in the original *Texas Highway Operations Manual*. The locations of changes are indicated by a vertical line in the outside margin as shown to the right. The following table summarizes the changes that have been on every one of the pages issued in this revision. Blank pages have not been included in the table. The type of changes include:

- Addition - New text, figure, or table has been added to the manual.
- Revision - The text, figure, or table in the original manual has been revised.
- Editorial - Spelling, grammar, cross-reference, or pagination has been changed.
- Layout - The layout of material on the page has been shifted, but there have been no changes in the text, figures, or tables on the page.
- None - There have been no changes on the page, but it is included in the revision because the other side of the page has been revised.

When there is more than one change on a page, and the descriptions of the revisions are different, an "a" and "b" are used to indicate the first and second changes, respectively.

Summary Table of Revisions to the Texas Highway Operations Manual

Page	Type of Change	Description of Change
inserts	revision	New inserts provided for cover and spine.
ivg	revision	Pen and ink changes to be made by user.
vii	addition	Section added to Table of Contents.
xi	editorial	Figure 10-1 added, number and page of Figure 10-2 corrected.
xiii	revision	Table title revised.
xiv	editorial	Page numbers corrected.
1-1	editorial	Segment title corrected.

Summary Table of Revisions to the Texas Highway Operations Manual (continued)

Page	Type of Change	Description of Change
1-15	revision	Description of ITS replaces previous descriptions of IVHS.
1-16	addition	Table 1-1 added to describe ITS user services.
1-16a		
1-19	revision	Cone of vision and assumptions in Figure 1-3 revised.
1-20	none	---
1-25	none	---
1-26	revision	Description of Figure 1-5 revised to match changes to figure.
1-27	revision	Figure 1-5 revised to show only one vertical curve instead of two.
1-28	addition	Text added for all revisions on the page.
3-1	revision	Page numbers changed and segment on C-D Roads added.
3-2	layout	Table of Contents continued from preceding page.
3-23	addition	Description of the use of interchange levels to accommodate trucks added.
3-24	none	---
3-25	addition	a-First paragraph on page added to describe advantages and disadvantage of directional interchanges. b-Text added to clarify use of benefit-cost analysis for directional interchanges.
3-26	layout	Text shifted due to addition of material on previous page.
3-27	none	---
3-28	addition	a-Text added to indicate cloverleafs require more ROW than fully directional interchanges. b-Text added describing driver expectation of left turn exit for cloverleaf interchanges.
3-29	revision	Some of the corners in the diamond interchange figure rounded.
3-30	none	---
3-31	addition	Disadvantage of C-D roads related to speed differentials added.
3-32	none	---
3-35	none	---
3-36	addition	Description of operational constraints of large vehicles added.
3-36a	addition	Segment on Collector-Distributor Roads added.

Summary Table of Revisions to the Texas Highway Operations Manual (continued)

Page	Type of Change	Description of Change
7-1	revision	Page number corrected.
7-2	revision	Page numbers corrected.
7-13	none	---
7-14	addition	a-Sentence added describing testing of conductive plastic loops. b-Two sentences added describing infrared detectors. c-The third disadvantage added; the fourth disadvantage revised. Text describing location for multilane applications added.
7-15	revision	a-Text relating to purchase of microwave and radar detectors deleted. b-Text relating to expense of image processing added.
7-16	layout	Text shifted due to addition of material on previous page.
7-19	addition	Description of a report added.
7-20	a-addition b-editorial	a-Line of sight description clarified. b-Sentence structure revised.
7-27	revision	a-Text "significant" and "incident detection algorithm" deleted. b-Text "caused by an incident" deleted.
7-28	addition	Two paragraphs on Detection Algorithms added.
7-29	addition	a-"Providing motorists with assistance if needed" and "police" added. b-Last sentence in paragraph added. c-"Private organizations" added. d-Text beginning with "They are also cost effective" added.
7-30	a-addition b-revision	a-Description of motorist assistance/courtesy patrols added. b-Description of motorist call systems revised.
7-31	layout	Text shifted due to addition of material on previous page.
8-1	editorial	New segment added and page numbers and heading revised.
8-2	editorial	New segment added and page numbers revised.
8-11	revision	Freeway lane capacity increased to 2,300 pcphpl.
8-12	none	---
8-19	a-editorial b-addition	a-Reference to Figure 8-4 added. b-List of bottleneck improvements added.

Summary Table of Revisions to the Texas Highway Operations Manual (continued)

Page	Type of Change	Description of Change
8-20	none	---
8-27	none	---
8-28	addition	Use of the 1965 *Highway Capacity Manual* clarified.
8-29	revision	Edition of the *Highway Capacity Manual* changed from 1965 to 1985.
8-30	none	---
8-31	addition	Segment on CORFLO added and description in Table 8.3 added.
8-32	addition	Material on CORFLO added and segment number revised.
8-33	a-addition b-editorial	a-Description for PASSER IV added. b-Capitalization of PASSER II corrected.
8-34	none	---
8-35	addition	Segment on PASSER IV added.
8-36	addition	Material on PASSER IV added to table and the segment number revised.
8-36a	addition	Description of PASSER IV added to table and the segment number revised.
8-37	revision	Use of the 1965 *Highway Capacity Manual* clarified.
8-38	none	---
9-1	editorial	Section on Management for Major Emergencies and the related segments added.
9-27	addition	Section on Management for Major Emergencies added along with segments on Planning for Major Emergencies, Emergency Response and Management, and Recovery from an Emergency.
9-28		
9-29		
9-30		
10-1	editorial	Page numbers in the Table of Contents corrected.
10-5	revision	Segment on Ramp Metering revised.
10-5a	addition	Figure 10-1 added.
10-5b	revision	Segment on Ramp Metering revised.

Summary Table of Revisions to the Texas Highway Operations Manual (continued)

Page	Type of Change	Description of Change
10-6	revision	The first three paragraphs of the Freeway Lane Control segment replaced with three new paragraphs. A new paragraph added at the end of the segment.
10-7		
10-8	revision	Description of enforcement and safety issues of separate HOV facilities revised.
10-11	addition	"Diamond interchanges" changed to "diamond interchange operation."
10-12	revision	Description of Dynamic Lane Assignment revised.
10-13	addition	Number of the figure revised and material on Dynamic Lane Assignment added at the end of the segment.
10-14	revision	Figure number changed.
10-15	layout	Text shifted due to addition of material on previous page.
10-16	layout	Text shifted due to addition of material on previous page.
11-1	addition	Jurisdictional Information segment added to the Table of Contents.
11-7	addition	Fourth and fifth bullets added and the last paragraph on the page added.
11-8	addition	Segment on Jurisdictional Information added.
11-9	a-revision b-addition	a-Description of static devices revised to clarify their use. b-List of reference materials expanded.
11-10	none	---
11-13	none	---
11-14	revision	Segment on Lane-Use Control Signals expanded.
11-14a		
14-1	none	---
14-2	addition	Heading at the top of the page added.
14-7	addition	Additional reference documents added to the Annotated Bibliography.
14-8		
14-9	addition	ITS America added to the list of organizations.
15-1	a-editorial b-addition	a-Position of "Cable" entry moved to left margin. b-"Communication" entry added to the index.
15-2	editorial	Overprinting of page numbers corrected for Collection.

This page intentionally left blank

ERRATA FOR TEXAS HIGHWAY OPERATIONS MANUAL

The user should make the following corrections to the *Texas Highway Operations Manual*:

Page	Line	Correction
i	---	Change "Maintenance and Operations Division" to "Traffic Operations Division."
iii	next to last	Change "Transportation Planning Division (D-10R)" to "Office of Research and Technology Transfer (RTT)."
1-7	next to last	Change "Transportation Planning Division (D-10R)" to "Office of Research and Technology Transfer (RTT)."
1-21	1	Add "weight" to list of vehicle characteristics.
1-31	16, 18	Change the number of Table 1-1 to Table 1-2.
1-32	12	Change "may lead to a failure of service" to "may lead to a failure to provide adequate service"
2-17	4	Delete the last word of the paragraph - "interchanges."
2-17	10	Change "Frontage" to "frontage."
2-17	17	Insert "during maintenance operations," following "such as."
3-40	2	Change "markings are worn" to "markings are worn or pavement is wet at night."
8-9	19	Change "represent" to "represents."
9-19	19	Change "Section 2, Segment 3.0" to "Section 6."

This page intentionally left blank

TABLE OF CONTENTS (Continued)

PART IV - SUPPORTING MATERIAL

This page intentionally left blank.

LIST OF FIGURES (Continued)

This page intentionally left blank.

LIST OF TABLES

LIST OF TABLES (Continued)

Begins on Page

CHAPTER 7. DATA COLLECTION

CHAPTER 8. TRAFFIC OPERATIONS ANALYSIS

CHAPTER 9. INCIDENT MANAGEMENT

CHAPTER 10. CONTROL STRATEGIES

no tables

CHAPTER 11. INFORMATION SYSTEMS

CHAPTER 1
INTRODUCTION TO OPERATIONS MANUAL

This page intentionally left blank.

3.0 Current Challenges

Although freeway and highway design has made tremendous advances in the last 40 years, these advances have not eliminated all the problems associated with such systems. The major challenges at the present time include the high levels of demand which have developed over recent years in urban areas and the difficulty of adding lanes to increase capacity. Other challenges include aging of highway infrastructure, reconstructing existing facilities while maintaining traffic flow, changing travel patterns, updating design standards, and providing for different vehicle characteristics.

4.0 Future Direction and ITS

The future in highway operations will involve more efficient management of the transportation system and may include the development of automated vehicles, computerized navigation, and other technological advances. Efforts are already underway in the United States and in Texas to develop the Intelligent Transportation Systems (ITS) concept. The term ITS applies to transportation systems that involve integrated applications of advanced surveillance, communications, and control process technologies, both on the highway and in the vehicle. ITS was originally known as Intelligent Vehicle Highway Systems (IVHS).

Originally, IVHS research and activities were concentrated in six areas: Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Advanced Public Transportation Systems (APTS), Commercial Vehicle Operations (CVO), Advanced Rural Transportation Systems (ARTS), and Advanced Vehicle Control Systems (AVCS). More recently, however, the emphasis of ITS has shifted to providing the user services shown in Table 1-1. These 28 services, while still evolving, collectively define near, mid, and long term capabilities that will likely comprise ITS. Although many of the initial applications of ITS were in urban areas, rural ITS applications are receiving increasing emphasis.

An important issue of evolving ITS technologies is the ability of different systems and elements to communicate with each other. Such compatibility is necessary for the large scale deployment of ITS. It is essential for private sector development of products and services. The Federal Highway Administration (FHWA) is sponsoring research to evaluate ITS system architecture and address issues such as: standards, communications protocols, assignment of functions (for example, centralized versus distributed), varying levels of user services, and increasing functionality over time.

continued

4.0 Future Direction and ITS (continued)

Table 1-1. ITS User Services

Broad Area	User Services	Description
Travel and Traffic Management	Pre-Trip Travel Information	Provides information for selecting the best departure times, transportation modes, and routes.
	En-Route Driver Information	Includes driver advisories and in-vehicle signing to improve convenience and safety.
	Route Guidance	Provides drivers with simple instructions on how to reach their destinations.
	Ride Matching and Reservation	Makes ride sharing more convenient.
	Traveler Services Information	Provides a reference directory, or "yellow pages," of service information.
	Incident Management	Helps officials quickly identify incidents and implement a response to minimize their effects on traffic.
	Travel Demand Management	Supports policies and regulations designed to mitigate the environmental and social impacts of traffic congestion.
	Traffic Control	Manages the movement of traffic on streets and highways.
Public Transportation Management	En-Route Transit Information	Provides information to travelers using public transportation after they begin their trips.
	Public Transportation Management	Automates operations, planning, and management functions of public transit systems.
	Personalized Public Transit	Offers more convenient service to customers by providing flexibility.
	Public Travel Security	Creates a secure environment for public transportation patrons and operators.
Electronic Payment Services	Electronic Payment Services	Allows travelers to pay for transportation services electronically with "smart cards."

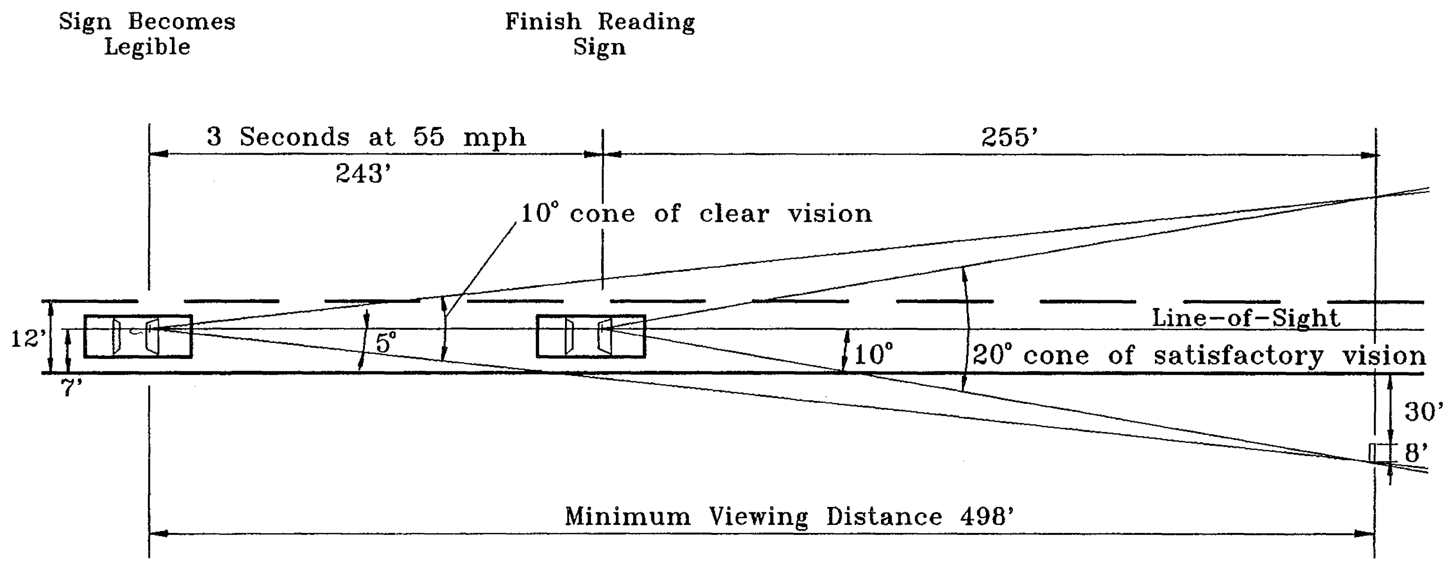
Table continued

4.0 Future Direction and ITS (continued)

Table 1-1. ITS User Services (continued)

Broad Area	User Services	Description
Commercial Vehicle Operations	Commercial Vehicle Electronic Clearance	Facilitates domestic and international border clearance, minimizing stops.
	Automated Roadside Safety Inspection	Facilitates roadside inspections.
	Commercial Vehicle Administrative Processes	Provides electronic purchasing of credentials and automated mileage and fuel reporting.
	On-Board Safety Monitoring	Senses the safety status of a commercial vehicle, cargo, and driver.
	Hazardous Material Incident Response	Provides immediate notification of an incident and immediate request for assistance.
	Commercial Fleet Management	Provides communications between drivers, dispatchers, and intermodal transportation providers.
Emergency Management	Emergency Notification and Personal Security	Provides immediate notification of an incident and an immediate request for assistance.
	Emergency Vehicle Management	Reduces the time it takes to respond to an incident once notified.
Advance Vehicle Safety Systems	Longitudinal Collision Avoidance	Helps prevent head-on and rear-end collisions between vehicles and other objects or pedestrians.
	Lateral Collision Avoidance	Helps prevent collisions when vehicles leave their lane of travel.
	Intersection Collision Avoidance	Helps prevent collisions at intersections.
	Vision Enhancement for Crash Avoidance	Improves the driver's ability to see the roadway and objects that are on or along the roadway.
	Safety Readiness	Provides warnings regarding the condition of the driver, the vehicle, and the roadway.
	Pre-Crash Restraint Deployment	Anticipates an imminent collision and activates passenger safety systems prior to collision.
	Automated Vehicle Operation	Provides fully automated, "hands off" operating environment.

This page intentionally left blank



Assumptions

Vehicle moving at 55 mph
Drivers line of sight is parallel to lane
Driver is 7 feet from edge of outside travel lane
Sign is 8 feet wide and 30 feet from travel lane
Time required to read sign is 3 seconds
Sign must be within the 10° cone of clear vision when the sign first becomes legible and reading begins
Sign must remain within 20° cone of satisfactory vision during reading

Not to Scale

Figure 1–3. Sign Location and Cone of Vision

1.0 Driver Characteristics (continued)

Visual capability decreases in nighttime driving conditions, primarily due to reduced lighting levels. Visual capability is further decreased by the inability of the human eye to quickly adjust from bright to dark conditions and to discern between low contrast objects. When the driver is exposed to a higher lighting level, the pupil contracts in adjusting to the light. As the lighting level is reduced, the pupil dilates to allow more light to enter the eye. The time needed for the pupil to contract is only about 0.3 seconds, while it takes about six seconds for the pupil to dilate. When the pupil has contracted, the driver cannot easily see objects in the areas away from the area of the bright light. The term glare is used to describe the presence of bright lights or bright light reflection which interfere with the driver's vision. Glare sources include vehicle headlights, street lighting, advertising, and adjacent site lighting. The engineer should strive to reduce glare sources to an acceptable level.

Driving performance is also impacted by the time required for a driver to react to various situations which may occur in the highway environment. This time period is known as the response time and includes the time needed for a driver to see an object, identify the object, decide how to react to the object, and to carry out the desired action. The response time increases with the number of choices, complexity of the judgement, and the driver's age, degree of fatigue, level of alcohol consumption, and physical deficiencies. Typical response times range from 0.5 to 4.0 seconds. The stopping sight distance and passing sight distance are used to represent response times in most geometric design elements. In some cases, the decision sight distance (Chapter 2, Section 3, Segment 4.3) should be used due to the operational maneuver distances required in normal driving.

Many older drivers possess diminished visual and response capabilities from that of the normal population. This is especially true in nighttime conditions. Additionally, older drivers are becoming an increasing proportion of the total driving population. The diminished capabilities of older drivers should be considered in the evaluation of highway operations, and countermeasures should be taken where appropriate.

Good operations will most likely occur when drivers have good visibility and the largest practical response time. However, perception conditions are seldom ideal due to driver and environmental variability. Therefore, information should be placed for maximum visual perception given the prevailing conditions. The engineer must strive to achieve a compromise between driver demands and the limitations of other design factors.

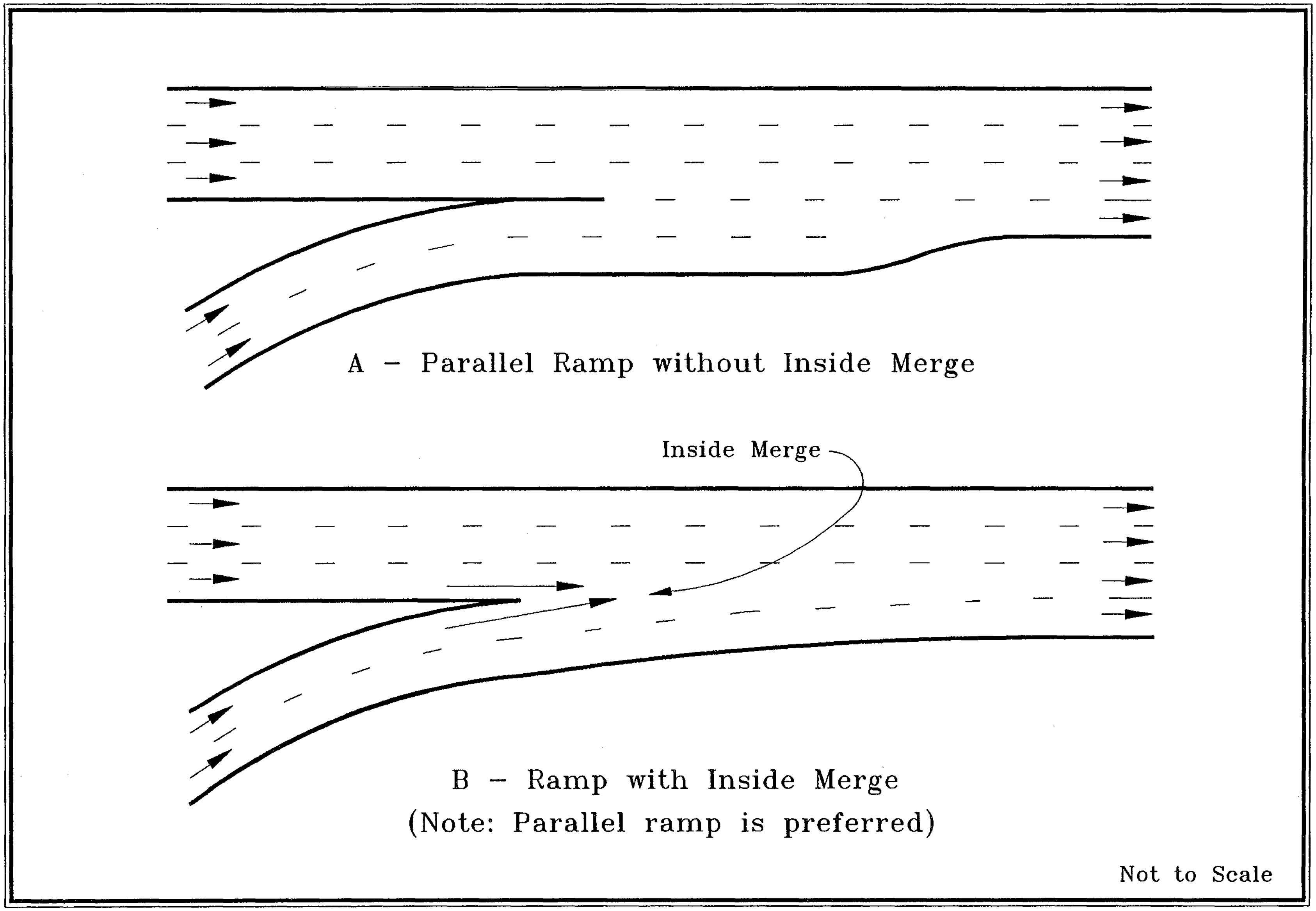


Figure 1–4. Inside Merge Illustration

1.4 Sight Distance

In a complex highway environment, the information processing demands of the driving task may overload the driver. Whenever possible, generous sight distance should be provided to reduce information processing demands. In addition, the part of the highway hidden from view should be the same as what the driver expects it to be from the portion of the highway visible to the driver.

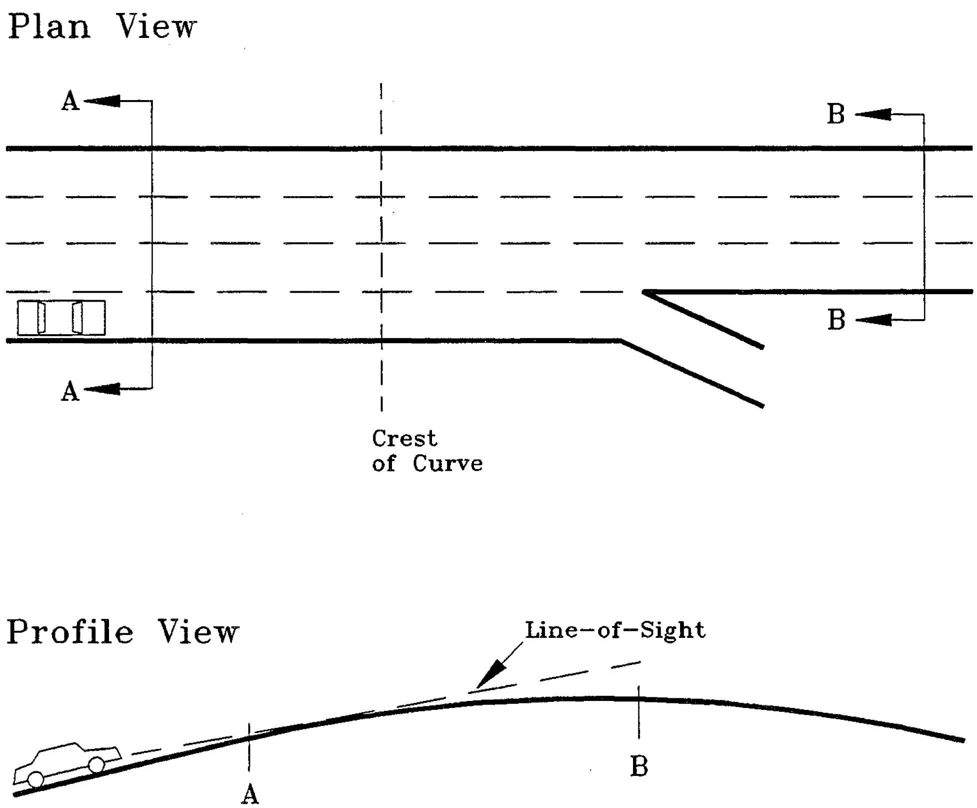
It is desirable to provide decision sight distance (Chapter 2, Section 2, Segment 4.3) at locations such as freeway entrances and exits, freeway-to-freeway connectors, lane drops, roadside rest stops, and inspection stations. The additional time provided by decision sight distance allows drivers to maneuver into the proper position for the desired action in a manner which has a minimal impact on highway operations. Decision sight distance may not be obtainable in all situations. In these cases, it may be appropriate to provide advance warning for the motorist.

In some cases a motorist may make an improper interpretation of the highway environment. This situation occurs when a portion of the highway is hidden from the driver's view and a change in alignment or operations occurs in the hidden area. Figure 1-5 illustrates one example of this situation. A driver approaching the vertical curve in the outside lane observes four lanes at the crest of the vertical curve. This observation leads to the expectation that all four lanes are continuous and that the driver can remain in the outside lane. However, beyond the vertical curve, the outside lane drops at an exit ramp. During periods of light traffic volumes, the driver should be able to change lanes with little impact on operations. However, during heavy volume periods, last minute lane changing may result in congestion.

1.5 Signing

Drivers will use signing to fill in their information gaps about the highway ahead. In order for the signing to have a positive impact on operations, the signing should fulfill an information need, be easily understood, and be consistent in application and use. Chapter 3, Section 3, Segment 7.0 and Chapter 4, Section 2, Segment 3.0 contain information about the proper use and design of guide signs.

Examples of signing which may confuse drivers include signs which conflict with the visible geometrics at the point where the driver reads the sign, inconsistent reference to destinations, variation in sign messages between different cities, signs which do not provide sufficient distance to allow proper maneuvering, signs which do not apply to the current highway environment, and signing for a successive exit located immediately after the current exit point.



There are 4 lanes visible to the driver at section A. The 3 lane section of highway at section B is not visible to the driver, leading the driver to think that the outside lane is continuous.

Not to Scale

Figure 1-5. Deceiving Sight Distance Example

1.6 Peak Period Impacts

The impacts of driver expectancy vary according to the level of traffic demand on the highway. At low volumes, drivers may be able to react to an unexpected condition in a manner which has minimal impact on the other vehicles in the traffic stream. Even in the cases where turbulence is created by the maneuvering vehicle or vehicles, the lack of heavy traffic demand allows a quick recovery to normal operating conditions.

However, during periods of heavy traffic volumes, a highway may be operating at or near capacity conditions. In this case, the turbulence created by a forced merge or lane change may cause a reduction in the speed of the vehicle stream, resulting in a breakdown of smooth traffic flow. Once the traffic flow breaks down, a return to normal traffic flow will not take place until the demand is reduced and congestion is cleared.

2.0 Driver Workload Capacity

Drivers have limited capabilities for assimilating and digesting information from the highway environment. Sources of information can be described as formal or informal. Although there is some disagreement on the definitions, formal information sources are intended to communicate specific information to users which is consistent from one application to another. They include signs, markings, signals, vehicle taillights, and road maps. Informal information sources communicate varying information, depending upon the source, situation, and driver interpretation. Informal sources include roadway geometry, roadside appurtenances, landmarks, personal directions, roadside advertisements, other vehicles, and prior knowledge. Research has shown that control devices are **not** the primary source of information to the familiar driver. Therefore, highway design and operations should focus on meeting driver information needs through informal sources and insuring that formal and informal information sources are compatible.

When the environment provides more information than the driver can effectively process, the driver sheds certain information in order to satisfy driving demands. Driver information needs are arranged in accordance with a hierarchy where the driving tasks related to control are at the top of the hierarchy. Control tasks include starting, stopping, speed control, and steering. The next level of information needs are guidance tasks which include maneuvering the vehicle on the road in response to roadway elements, traffic, environmental factors, and legal requirements. Navigation tasks such as direction finding, trip planning, and route following are at the bottom of the hierarchy. Information needs at the top of the hierarchy have the highest priority and these needs should be satisfied before tasks lower in the hierarchy can be addressed by the driver.

Information should be presented in accordance with this hierarchy. For example, critical directional signing should be located in an area which does not require complex control maneuvers. As an example, a driver negotiating a lane closure in a work zone will focus his or her attention on slowing down and changing lanes, and may miss directional information which is not as critical to the driving task at hand.

continued

CHAPTER 3
OPERATIONAL CONSIDERATIONS IN PRELIMINARY DESIGN

continued

CHAPTER 3
OPERATIONAL CONSIDERATIONS IN PRELIMINARY DESIGN (continued)

4.0 Weaving (continued)

Figures 3-10a, b, and c show weaving sections where both weaving movements are required to change lanes at least once. These arrangements may encounter operational difficulties under high volumes if acceptable gaps are limited. The weaving configuration in Figure 3-10a requires the non-weaving traffic to share the same lanes as the weaving traffic. This reduces the capacity for the weaving traffic. In Figure 3-10b, the non-weaving movements have the option to stay out of the lanes where weaving is taking place. The weaving section of Figure 3-10b is normally preferable to that in Figure 3-10a, if there is room for the additional lanes. The weaving section in Figure 3-10c is created by adding an auxiliary lane between an entrance and an exit ramp. In this case, creating a weaving section by adding the auxiliary lane may be preferable to not having a weaving section. In situations with a high exiting volume, a 2-lane exit ramp may be used.

5.0 Interchange Types

There are several geometric patterns of ramps for turning movements at interchanges. Their application at a particular site is determined by the number of intersection legs, the expected volumes of through and turning movements, topography, design controls, proper signing, and policy. The selection of a particular interchange design is also affected by how that interchange relates to other interchanges in the system and across the state. Signing and operations are major considerations in the design of interchanges. Each design should be tested to determine if it can be signed to provide a smooth flow of traffic. The need to simplify interchange design from the standpoint of signing and driver understanding can not be overstated.

Fully directional interchanges, 3-level diamond interchanges, and diamond interchanges are the most widely used interchanges in Texas. Cloverleaf interchanges are found on some of the earlier highways in the state, but are not normally used in new construction. Each of these interchange types and the operational concerns of each type are briefly discussed and illustrated in the following subsections.

5.1 Directional Interchange

Interchanges which provide a direct connection for the major turning movements are termed directional interchanges. When direct connections are provided for all turns, the interchange is a fully directional one. Fully directional interchanges provide the highest level of service. Figure 3-11 illustrates several different types of directional interchanges. The through lanes of a directional interchange typically should be located on the lower two levels. This may reduce the operational costs of the interchange by eliminating the need for large volumes of through vehicles to accelerate on a steep grade. For some directional interchanges, it may be appropriate to locate the through lanes for one highway at the highest level in order to eliminate height restrictions on a truck route.

continued

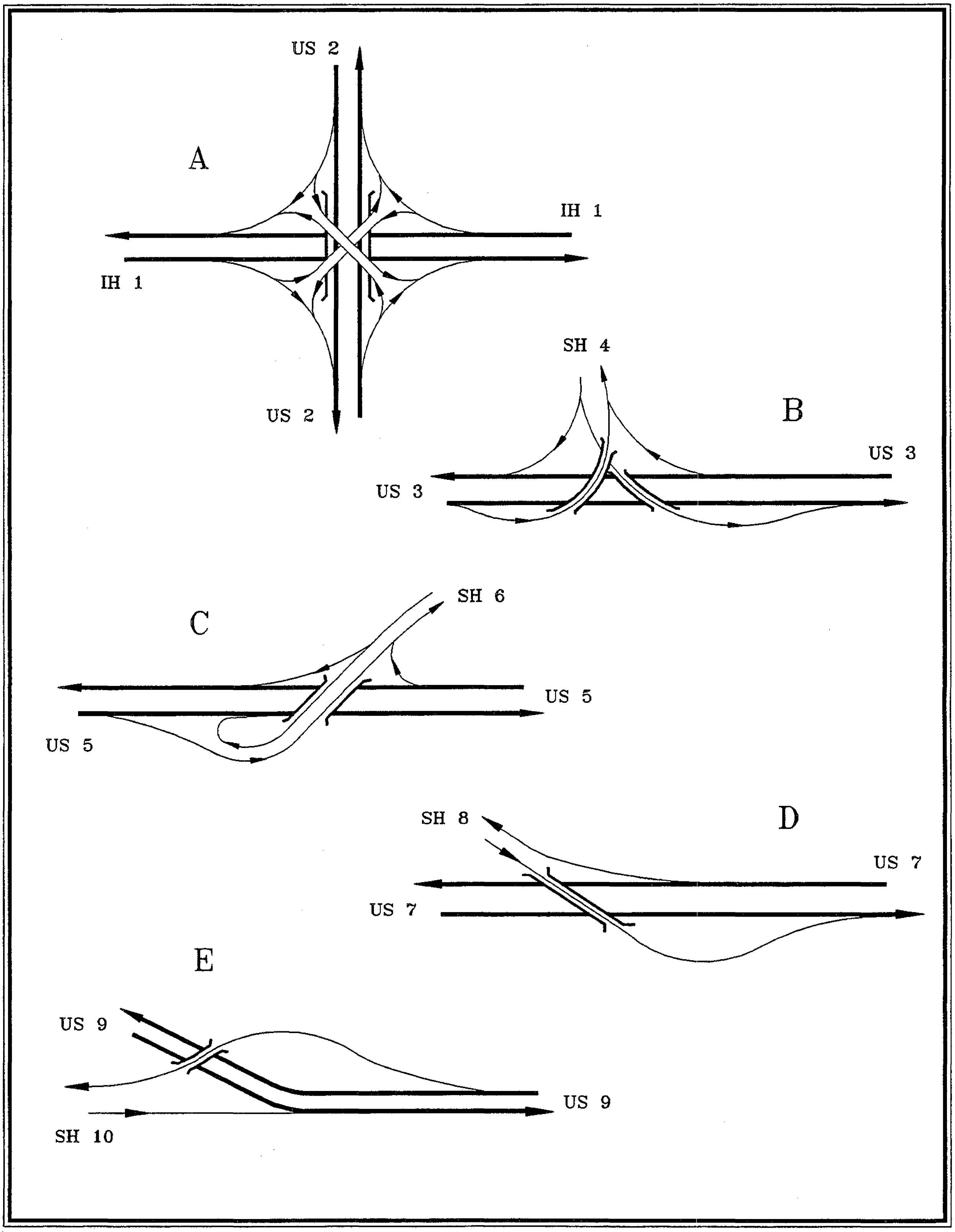


Figure 3-11. Typical Directional Interchanges

5.1 Directional Interchange (continued)

Some of the advantages of fully directional interchanges are that they require less right-of-way than cloverleaf interchanges, they can accommodate all movements, they are generally easier to sign than cloverleaf interchanges, they provide higher capacity, and they allow higher exiting and merging speeds. The major disadvantage of fully directional interchanges is that their higher cost, due to the number of structures, limits their use to interchanges of major routes.

Directional interchanges may utilize a single-exit or a two-exit design. The single-exit design illustrated in Figure 3-11a has several operational advantages. It is more consistent with driver expectancy, provides a single exit in advance of the separation structure, reduces weaving in the traffic stream, and simplifies providing interchange uniformity. A difficulty with the single-exit interchange design occurs under high-volume and high-speed conditions, at the fork following the single-exit from the freeway if the distance between the exit and fork is not adequate. There may also be some confusion at the second decision point, resulting in less than optimal operations. Signing may also be difficult to provide at the fork if minimum distances are used between diverge points.

Some designers prefer two exits on each approach of some directional interchanges with high-volume turning movements. Care should be exercised in these cases to insure that lane balance, weaving and signing requirements are properly satisfied. Signing is more difficult if both exits are served from the same lane. Signing may also be confusing because the left turn exit precedes the right turn exit, which is the reverse of typical driver expectation.

Generally, the provision of single exits is more costly because of the added roadway, longer bridges, and in some cases, additional separation structures. Also, many of the benefits produced by the use of single exits are of such nature that their value will not show positively in a benefit-cost analysis.

Figures 3-11b, 3-11c, 3-11d, and 3-11e illustrate three-leg directional interchanges. The three-leg interchange in Figure 3-11b is preferred to the loop ramp interchange shown in Figure 3-11c due to the lower speeds and limited capacity associated with loop ramps. The difference between Figures 3-11d and 3-11e is the primary route. In Figure 3-11d, the primary route curves to the right and minor route traffic must exit in order to continue straight ahead. In Figure 3-11e, the primary route continues along the tangent and the minor route must exit. The primary route should be determined on the basis of route continuity, not traffic volume.

5.2 Three-Level Diamond Interchange

The three-level diamond interchange may be used when two high volume roadways cross. Both routes should have a high volume of through traffic. This configuration provides uninterrupted through movement, but turning movements must maneuver through a series of intersections, which may be signalized or controlled with STOP or YIELD signs. A three-level diamond interchange is illustrated in the *Highway Design Division Operations and Procedures Manual*. This configuration may be used as an interim measure prior to the construction of a fully directional interchange if adequate right-of-way is available for future direct connections.

5.3 Diamond Interchange

The diamond interchange is the most common type of interchange found on a controlled access highway, and is especially prevalent in urban areas. The conventional diamond interchange derives its name from the shape of the access ramps, although the ramps may also take the form of a reverse diamond or X, where frontage roads exist. Figure 3-12 illustrates several different forms of diamond interchanges.

The conventional diamond form shown in Figures 3-12a and 3-12b is the most common application. The conventional diamond form has the advantages of having the exit ramp located near the cross street and the entrance ramp located to allow vehicles from the cross street quick access to the freeway. Its disadvantages include the possibility of exiting vehicles backing up onto the freeway when long queues form on the ramp or frontage road, and the requirement that most vehicles must go through the intersection to gain access to most frontage road property.

The reverse diamond or X interchange pattern shown in Figure 3-12c has application to locations with significant development on the frontage road. Its advantages are that access is provided to much of the property between interchanges, and queues will not typically back onto the freeway. Its disadvantages are that entering vehicles may have to accelerate on an upgrade, exiting maneuvers occur just beyond a crest vertical curve where weaving will also take place, and queues at the interchange may block access to the entrance ramp. Another disadvantage of the X interchange pattern is that it encourages frontage road traffic to bypass the frontage road traffic signal and weave with the freeway traffic. This may disrupt the through traffic and under utilize the frontage road between the entrance and exit ramps. This disadvantage becomes a concern when interchanges are closely spaced.

The diamond interchange illustrated in Figure 3-12d has superior operational characteristics with signalized intersections due to the greater separation between intersections. However, the additional right-of-way needed for this interchange may limit its use.

The diamond interchanges illustrated in Figures 3-12e and 3-12f are appropriate for use with one-way arterial streets.

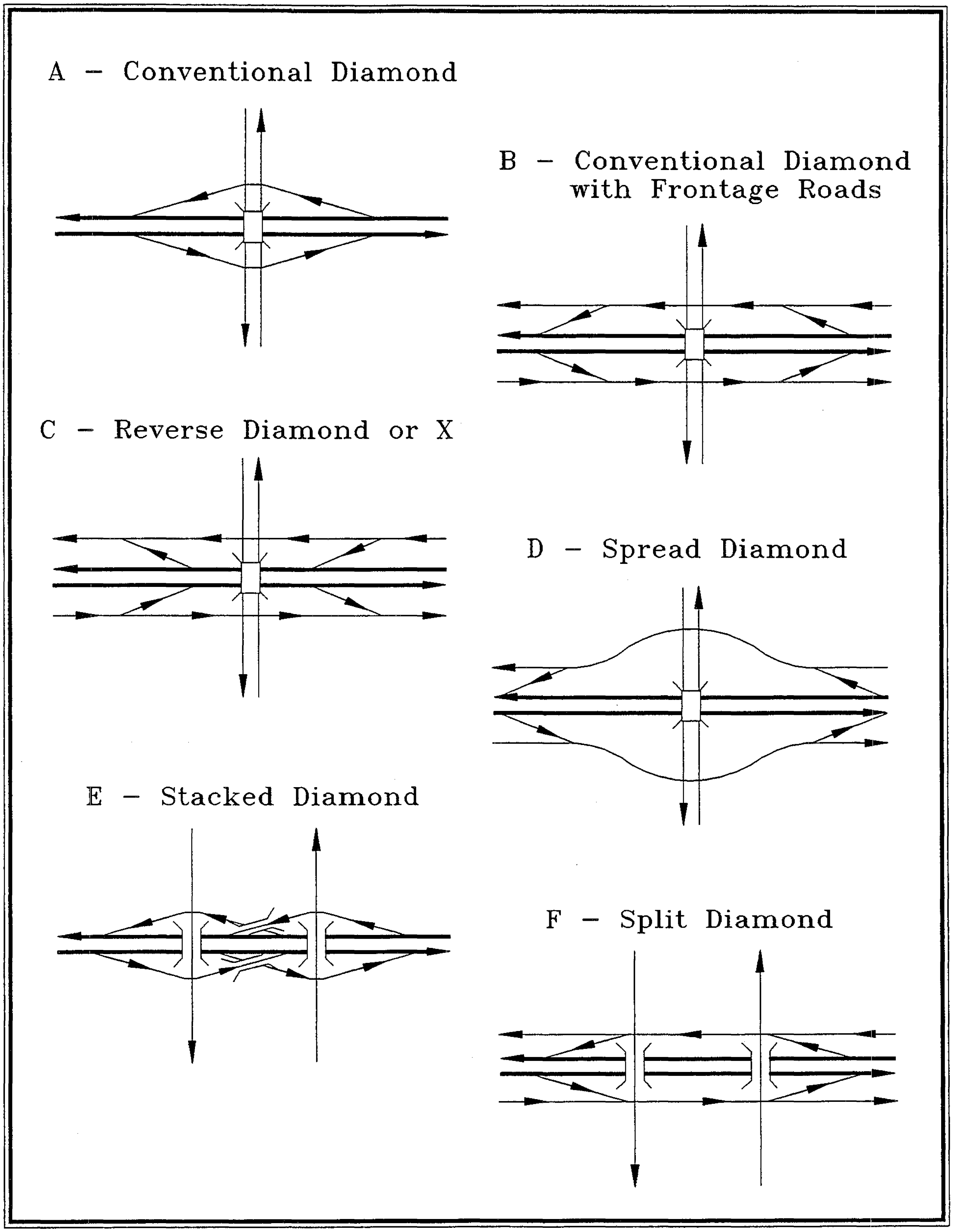


Figure 3-12. Typical Diamond Interchanges

5.4 Signalized Diamond Interchanges

Signalized diamond interchanges provide a majority of the access to freeways in urban areas. As a result, the traffic signal design and operation at a diamond interchange are critical to effective operation. Specific factors critical to design and operation include the number of approach lanes, the lane assignments, the distance between intersections, signal phasing, signal timing, and sight distance.

Generally, all lanes between the traffic signals should have a corresponding approach lane upstream of the traffic signal. Figure 3-13 illustrates a typical signalized diamond intersection with exclusive right turn lanes and U-turn lanes. The need for exclusive left and right turn lanes and U-turn lanes should be evaluated on the basis of future traffic volumes and future travel patterns. Whenever possible, adequate clearance and right-of-way should be provided for future implementation of such improvements. Lane assignments at diamond intersections also have significant implications on capacity and operations. Signal operation should be evaluated for all peak periods to insure that operations are acceptable.

Signal operation improves as the distance between the intersections of a diamond interchange increases. The desirable distance for signal operation is 300 to 400 feet. Distances less than 300 feet can be operated satisfactorily; however, there is less flexibility in the selection of traffic signal phasing. Even though the intersections of a diamond interchange may not be initially intended for signalized operation, consideration should be given to providing optimal intersection separation for future signalization.

5.5 Cloverleaf Interchanges

A full cloverleaf interchange has a loop ramp in each of four quadrants to accommodate the left turn movements. An interchange with less than four loop ramps is referred to as a partial cloverleaf. Cloverleaf interchanges require more right-of-way than diamond interchanges and fully directional interchanges and, therefore, are less common in urban areas. Figure 3-14 illustrates two examples of full and partial cloverleaf interchanges.

The advantage of the cloverleaf interchange is that it eliminates the need for a left turn grade separation structure and allows left turns to be made without the need for control at an intersection. Disadvantages of cloverleaf interchanges are the extra travel distance required for left turn traffic, the short weaving length available when two loops are in adjacent quadrants, the large reduction in speed for left turn movements, limited capacity of loop ramps, and the large right-of-way requirements. Locating the left turn maneuver beyond the cross street may be unexpected by some drivers. Another disadvantage includes the difficulty of providing 2-lane ramps when volumes warrant 2-lanes.

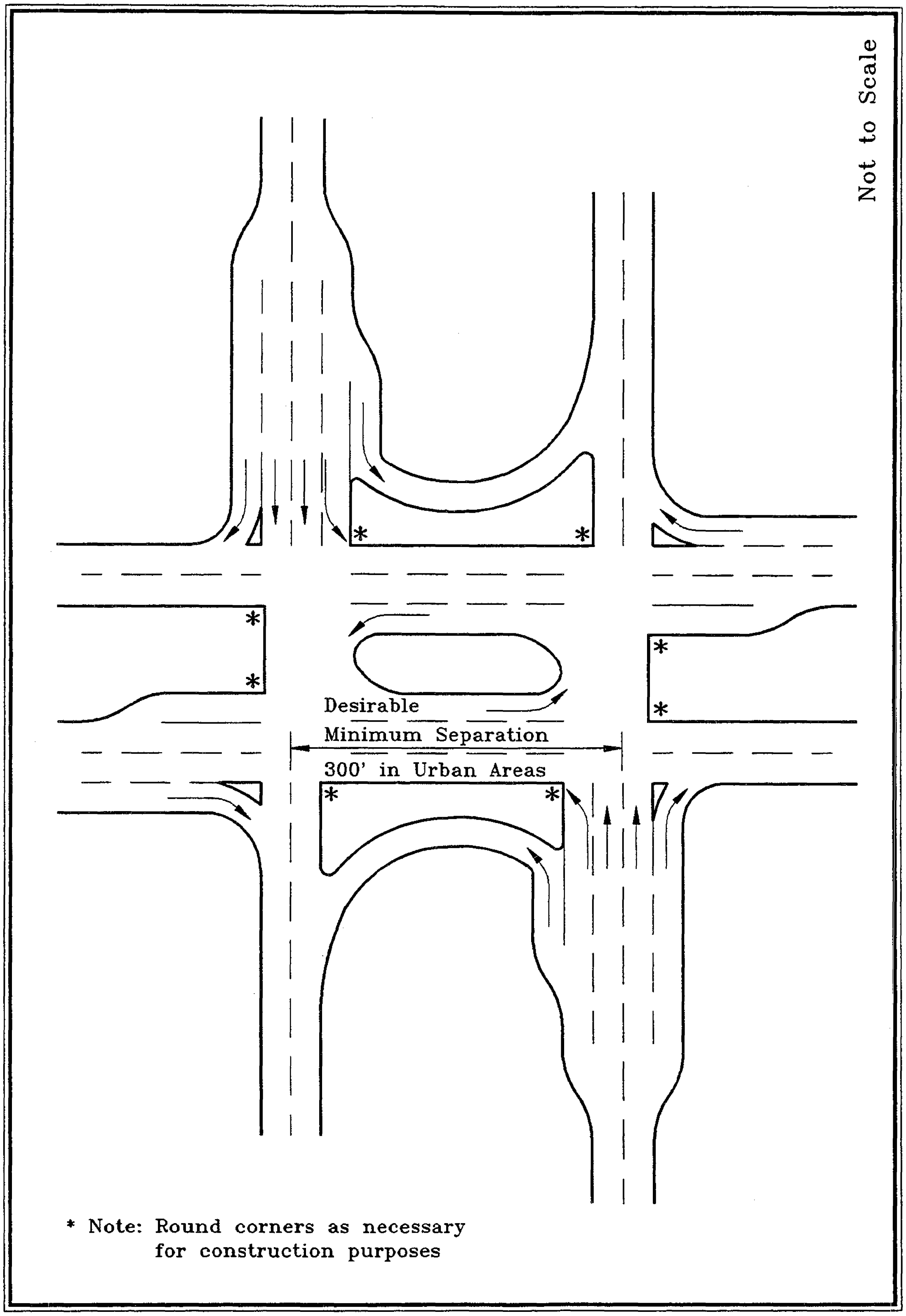
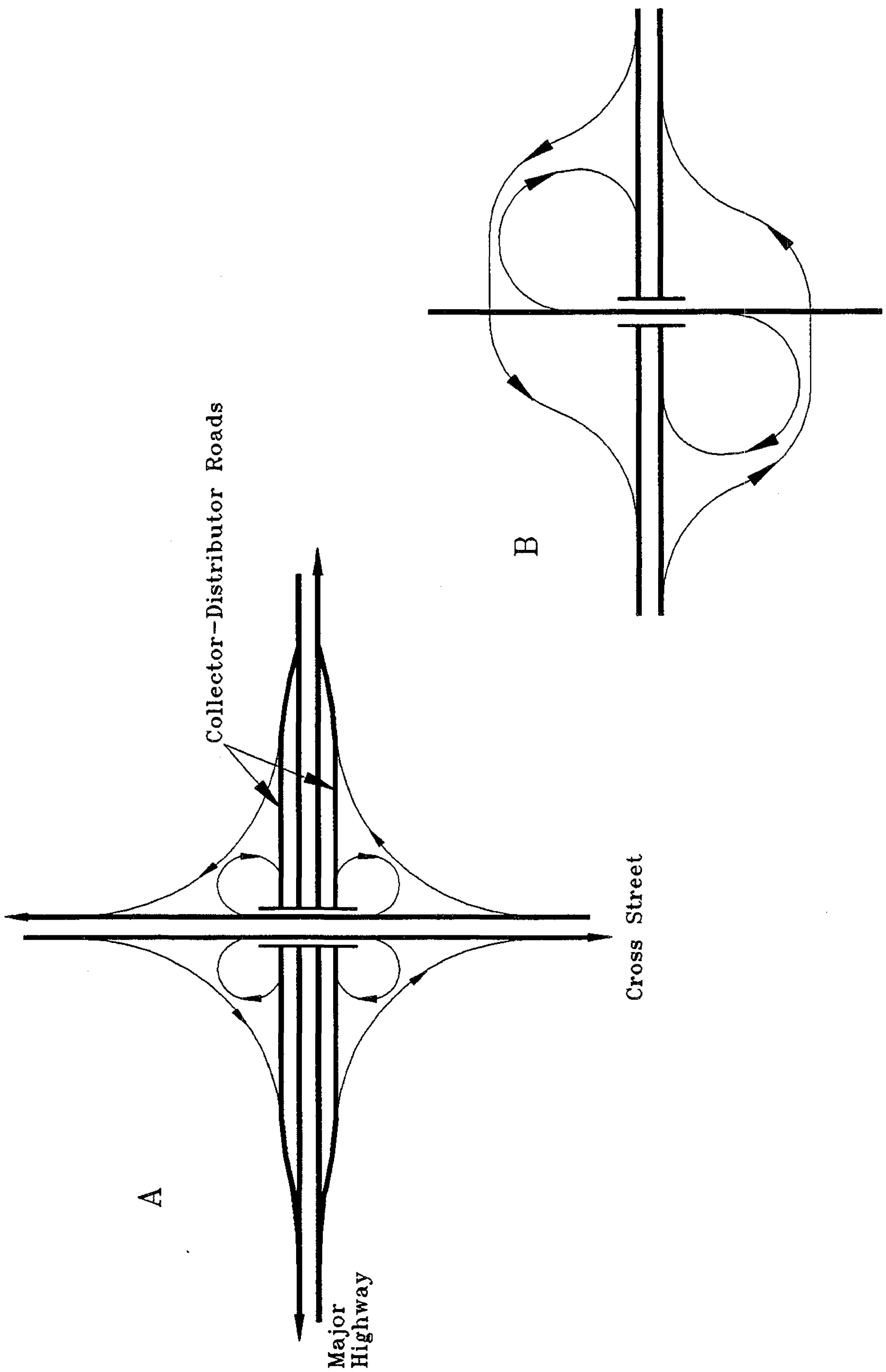


Figure 3-13. Typical Intersection for Diamond Interchange



Note: Avoid use of loop ramps whenever possible

Figure 3–14. Full and Partial Cloverleaf Interchanges

5.5 Cloverleaf Interchanges (continued)

The use of a separate collector-distributor road as shown in Figure 3-14a removes the weaving maneuvers from the freeway main lanes and places them on a lower speed roadway. If a collector-distributor road is not used, several other disadvantages include the double exit from and double entrance to the main lanes, the problems associated with signing a second exit, the speed differentials between the mainline traffic and the entering/exiting traffic, and the exit located after the crossing structure.

Figure 3-14b illustrates a partial cloverleaf with loop ramps that serve the two left turns from the cross street. This interchange is known as a Parclo-A interchange and may be an appropriate capacity enhancement for an existing diamond without frontage roads if adequate right-of-way exists. It may also be an appropriate conversion for an existing full cloverleaf that possesses operational problems if adequate capacity can be provided. The partial cloverleaf shown in Figure 3-14b has the advantages of no weaving problems and the loop ramp serving the lower speed arterial. The interchange has the appearance of a conventional diamond to freeway traffic, in that all exiting traffic uses the same ramp. The major limitation is the need to provide adequate arterial signing to inform the motorist that left turns are made from the right lane. More right-of-way is also required in the quadrants having the loop ramps as compared to the conventional diamond.

6.0 Interchange and Terminal Considerations

As most vehicle interactions occur in the vicinity of interchanges and terminals, their design is critical in terms of efficient operational performance. It is possible to provide an acceptable geometric design that results in less than optimal operational performance. The following subsections address significant considerations in the operational performance of interchanges and terminals.

6.1 Merging Capacity

The presence of any type of merge condition creates a reduction in capacity. Whenever a merge is part of a highway design, the operating conditions should be carefully evaluated to insure that operations will be acceptable. The evaluation should not only examine the merge capacity at the specific point of the merge, but should also evaluate operations upstream and downstream of the merge.

Lanes located downstream of a merge may operate very close to capacity for a short distance downstream of the merge point. This is due to the mixing of two streams into one lane. As the traffic flows downstream, it will redistribute to other lanes. The capacity of lanes located upstream of a merge is restricted by the capacity of the merge itself.

6.2 Major Forks

The location where a highway or freeway splits into two major or separate flows is known as a bifurcation or major fork. Its design should follow all of the operational principles previously discussed, including lane balance. Invariably, operational difficulties will develop unless one of the interior lanes is an optional lane, where vehicles have the choice of taking either route.

Whenever possible, the approach to the fork should be on tangential alignment and one of the forks should continue the tangential alignment. The designated or continuous route is the obvious choice for the route to be located on the tangent. Figure 3-15 illustrates the comparison between alternative designs. The tangential alignment is operationally superior because an indecisive or inattentive driver will be able to continue on the route where the same driver might encroach the gore area with a "Y" design. The tangential alignment also eliminates superelevation transition problems. The diverge at a fork should be accomplished with a diverging tangent followed by a curve as shown in Figure 3-15. This allows each roadway to obtain its own identity with the existing cross-slope, with superelevation introduced after the roadways are separated.

6.3 Freeway-to-Freeway Connections

Freeway-to-freeway connections are formed by the convergence of two major traffic streams. The principles of route continuity (Chapter 2, Section 2, Segment 1.0) and concurrent routes (Chapter 2, Section 2, Segment 2.0) should be followed when considering their design. If possible, the use of inside merges should be avoided.

6.4 Two-Lane Exit Ramps

Some situations may require a two-lane ramp at a point downstream from the exit gore. Reasons for a two-lane ramp include downstream capacity needs, future capacity needs, lane balance requirements at a downstream point, a wide structure for future highway widening, and others.

When a two-lane ramp is justified, lane balance requirements should be satisfied at the exit from the main lanes. An exit maneuver which can be made only from one main lane should have only one lane to exit onto. Figure 3-16 illustrates how lane balance requirements can be satisfied for a two-lane ramp served by a single freeway lane. This configuration has one lane of exiting capacity.

In some cases, capacity needs may require a two-lane exit. This can be done as shown in Figure 3-17 by adding a second lane and continuing the lane upstream as an auxiliary lane for an appropriate distance (desirably 2,000 feet). This configuration has two lanes of exiting capacity.

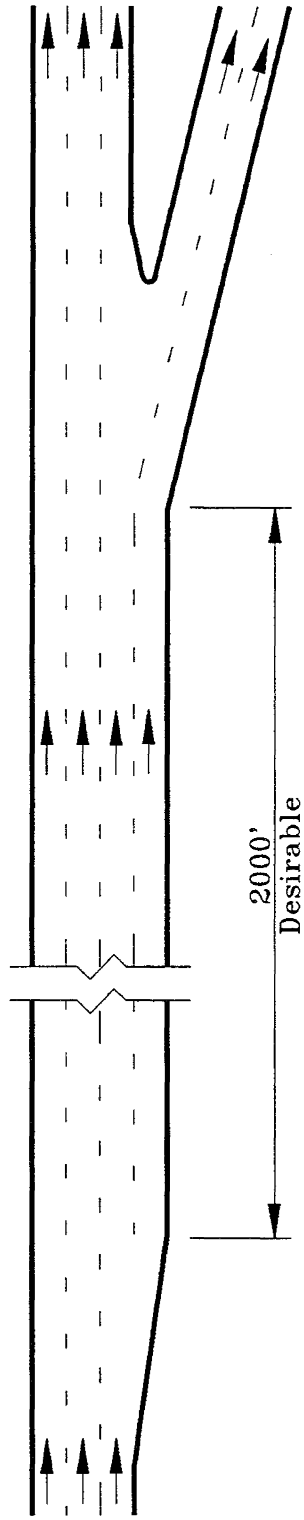


Figure 3–17. Two-Lane Exit Ramp

6.5 Ramp Design and Alignment

Freeway entrances and exits should be located on tangent sections wherever possible in order to provide maximum sight distance and desirable traffic operation. The location of exit ramps on a horizontal curve should be avoided wherever possible. If an exit ramp must be located on a curve, then the ramp should also utilize a curved horizontal alignment. A tangent alignment for an exit ramp located on a curved main lane segment may present the appearance of the main lane alignment and may also draw vehicles into the exit ramp. Locating an exit ramp on a curved main lane section also causes problems for superelevation transition.

6.6 Truck Operation

Truck operations may be an important consideration for interchanges. The larger sizes and decreased performance capabilities of trucks should be considered when evaluating operations of interchanges, particularly on connecting ramps. The selection of horizontal and vertical alignment at interchanges must take into account the operational constraints of trucks and heavy vehicles. Heavy vehicles have different operational characteristics that can inhibit the merging and diverging activities of smaller vehicles. Larger gaps and longer distances are required. Table 3-1 describes specific areas related to truck operations at interchanges which should be evaluated in the preliminary design stage. Whenever possible, the features described in Table 3-1 should be incorporated into interchanges which accommodate large volumes of truck traffic.

Table 3-1. Truck Operational Considerations at Interchanges

- ♦ **Transition to superelevation** - The proper transition to superelevation should be used to increase comfort and/or operational efficiency.
- ♦ **Compound curves** - Whenever possible, ramp curves of different radii should be separated by a tangent section to reduce demands on drivers and reduce the dependency on the side friction factor.
- ♦ **Deceleration lanes preceding an exit** - The deceleration lanes for exit ramps should be of sufficient length to allow trucks to slow down to the necessary speed to negotiate the ramp radius.
- ♦ **Sight Distance** - Whenever possible, additional sight distance should be provided to allow truck drivers to maneuver the truck into the proper position for entering the ramp. The sight distance restrictions of overhead objects should also be considered for trucks.
- ♦ **Downgrade preceding a ramp exit** - Trucks may speed up on downgrades, requiring additional deceleration lane length.

6.7 Collector-Distributor Roads

A collector-distributor (C-D) road is an intermediate facility between the freeway and surface street or frontage road. It provides a buffer between the freeway mainlanes and the surface street or frontage road for accommodating weaving maneuvers. Figure 3-14a illustrates the use of a C-D road with a full cloverleaf interchange. The C-D road removes weaving maneuvers from the freeway, thereby improving traffic flow on the freeway. C-D roads can improve the operational characteristics of a corridor if the characteristics conducive to this type of facility are present. These characteristics include:

- sufficient right-of-way,
- significant separation between major cross-streets,
- significant through and weaving movements on existing freeway mainlanes, and
- adequate intersection geometrics for projected demand.

The design of a collector-distributor freeway system should include the following elements:

- Ramp design should encompass one-lane entrances and two-lane exits.
- Provision should be made for a desirable distance of 3,000 feet between mainlane connector ramps and freeway-to-freeway interchanges.
- Mainlane to collector-distributor ramps should be designed to full freeway standards.
- Weaving areas on the collector-distributor roadway should be at least 1,000 feet long.

This page intentionally left blank

CHAPTER 7
DATA COLLECTION

continued

CHAPTER 7
DATA COLLECTION (continued)

3.0 Vehicle Based Equipment

Vehicles operating in the traffic stream can be used to provide information on traffic conditions in a variety of ways. Equipment located in a vehicle can be used to measure the speed of the traffic stream. These speed measurements can be classified as time-mean speeds or space-mean speeds (Chapter 8, Section 3, Segment 2.0). The speed may be recorded in some form for subsequent use, or may be transmitted from the vehicle to the control center for application to the surveillance system in real-time. The speeds may be transmitted through electronic means or by a human operator in the vehicle as described in Section 4, Segment 4. The most common speed measuring equipment based in vehicles includes radar, the speedometer, and the odometer/clock combination.

3.1 Radar

Vehicle mounted radar units can be used to measure the time-mean speed of other vehicles in the traffic stream. The radar-based vehicle can be moving or stopped. This method is commonly used by law enforcement agencies to identify vehicles exceeding the speed limit.

3.2 Speedometer

A speedometer can be used to measure the time-mean speed of the traffic stream that the vehicle is in. The measuring vehicle paces itself so that it provides a reasonable representation of movement. There are three methods of pacing the vehicle:

- Floating-car technique - driver floats with the traffic by passing as many vehicles as pass the test car.
- Average-car technique - vehicle travels according to the driver's judgement of the average speed of the traffic stream.
- Maximum-car technique - vehicle is driven at the posted speed limit unless impeded by actual traffic conditions.

3.3 Odometer/Clock

A space-mean speed is calculated by dividing a known distance by the time to travel the distance. The distance may be determined from maps or the vehicle odometer. The driver paces the vehicle in the traffic stream to provide a reasonable representation of traffic using one of the three methods described above.

4.0 Emerging Technologies

Several types of detectors are being developed to improve the collection of data for surveillance needs. Following are brief discussions of several of these devices.

4.1 Conductive Plastic Inductive Loop

Conductive plastic inductive loops are being developed to provide a solution to two serious problems commonly experienced with copper wire inductive loops: the susceptibility to breakage by pavement stresses and the deterioration of the copper wire's insulation caused by moisture or chemicals. Conductive plastic inductive loops have been designed to take advantage of the unique characteristics of a plastic (polymer) known as Polyvinylidene Fluoride (PVDF). The loops consist of a layer of conductive ink applied to a cable fabricated from PVDF. PVDF and conductive ink have been shown to be very durable, tough, and flexible even in extremely harsh environments. Testing of conductive plastic loops has shown that the signal will likely require modification for use with a commercially available vehicle classifier.

4.2 Infrared

Active infrared sensors operate by focusing a narrow beam of energy onto an infrared-sensitive cell. Vehicles are detected when they pass through this beam, interrupting the signal. The infrared beam can be transmitted from one side of the road to the other, or from an overhead or roadside position to a device in the pavement surface. Because infrared sensors are mounted either above the pavement surface or at the roadside, disruption to the flow of traffic is minimized for their installation or maintenance. The infrared system provides information on vehicle height and length, and it more accurately monitors vehicles changing lanes near the sensors than the pavement based systems. The infrared system is also a relatively low-cost system. Active infrared sensors can be used as a presence or pulse sensor. The disadvantages of infrared detectors include: inconsistent beam patterns caused by changes in infrared energy levels due to passing clouds, shadows, fog, and precipitation; the lenses used in some devices may be sensitive to moisture, dust, or other contaminants; the difficulties of maintaining alignment of beams on structures where vibrations are a problem; use of an across the road detection system for collecting speed and volume data is limited to one lane roadways (such as the case for the transitways); and they may not be reliable under high volume conditions. For multilane applications, infrared detectors should be mounted overhead for both speed and volume measurements.

4.3 Ultrasonic

Ultrasonic detectors consist of compact electronic signal generation and receiver units that are mounted either over or to the side of the roadway. A vehicle is detected when the energy burst that is directed at a target point is reflected faster than expected. Ultrasonic detectors can be used for both presence and pulse applications. Because the ultrasonic devices are not mounted in the pavement, there is little or no disruption to traffic during installation or maintenance. However, environmental conditions can affect their operation and they require a very high level of special maintenance capability. This technology has been used successfully and extensively on freeways in Japan.

4.4 Microwave and Radar

Microwave and radar sensors direct a beam of microwave energy onto a detection area from an antenna mounted either above the lane or on the roadside. Vehicle sensing is accomplished through detection of a Doppler phase shift. Microwave and radar sensors are not capable of detecting vehicles moving at less than 3 mph. They are expensive to operate, mainly because they must be serviced by technicians with Federal Communication Commission (FCC) licenses.

4.5 Laser

Lasers, an acronym for "light amplification by stimulated emission of radiation," are devices which contain a crystal, gas, or other material in which atoms are stimulated by focused light waves. The unit is mounted either above or at the side of the road. The receiver is built into the transmitter and actuations are detected by changes in the characteristics of the laser beam. The very narrow beam can be more precisely aimed than the infrared or ultrasonic devices, thereby avoiding false actuations from vehicles in adjoining lanes. However, small vehicles, such as motorcycles, that are traveling on the edge of the lane may be missed when using a narrow beam.

4.6 Image Processing

Image processing systems detect vehicles by monitoring specific points in the video image of the traffic scene to determine changes between successive frames. This system consists of the following major elements: (1) one or more cameras located to provide a good perspective on the scene; (2) a microprocessor-based system for processing the video image located either on-site or at a central location; and (3) a module for interpreting the processed images as vehicle detections. The equipment is used to acquire images of the traffic operations from which traffic parameters and other information, such as vehicle classification and incident detection, is derived. The detection site can be moved by repositioning the camera, and the detection zones can be modified electronically with the video signal. The effects of reduced visibility due to weather or lighting have not been fully defined. Image processing systems are also expensive at the present time.

4.7 Automatic Vehicle Identification

Automatic Vehicle Identification (AVI) provides the ability to uniquely identify a vehicle passing through the detection area. The most common use of AVI technology is for collecting tolls. In this use, the toll charges are electronically deducted from the driver's account when they pass through the toll station. Because the tolls are collected electronically, AVI technology allows vehicles to pass through the toll station without stopping.

continued

4.7 Automatic Vehicle Identification (continued)

The original AVI technology, which has been in use for several years, uses a radio frequency signal from the roadside to activate a tag (or transponder) located in the vehicle windshield. The tag answers this signal by sending a response that is encoded with specific information about the vehicle or driver. The response signal is then read by a roadside reader. This form of AVI technology requires the vehicles to be channeled through the detection area. The reader is typically located above the pavement, but it can also be embedded in the pavement.

The next generation of AVI technology is currently under development for use in Intelligent Vehicle/Highway Systems. The new technology will provide the ability for high-speed, multilane, and two-way communication between the vehicle and roadside. Vehicle information such as speed, link time, vehicle pollutants, number of occupants, and toll collection account may be transmitted from the vehicle, and information such as route guidance, traffic information, and road conditions may be transmitted to the vehicle.

5.0 Summary of Data Collection Equipment Characteristics

Table 7-1 provides a summary of the different types of equipment that can be used to collect data.

DATA COMMUNICATION EQUIPMENT

1.0 Function

Once the data is collected by the at-site detectors, it may be collected manually from the device or it may be sent via a communication system to a data collection hub. The path over which the information flows is called a transmission link, or channel, and the composition of the transmission link is called the communication medium. A modulator converts original information into a signal that can be efficiently transmitted over the channel, and a demodulator at the receiving end converts the information to its original form.

Communication systems have three major functions:

- the transmission of data on current operations and performance of traffic and the devices,
- the transmission of voice communications for applications such as: between field maintenance personnel and the control center, disabled motorists using the emergency roadside telephones or call boxes, and for the highway advisory radio systems (see Chapter 11, Section 3, Segment 2.0) for communication to drivers over the car radio, and
- the transmission of video images from closed-circuit television cameras.

The first two functions have communication loads and timing requirements that are well within the ranges of standard data transmission. However video transmission requires a bandwidth (communication load) that greatly exceeds that of the data and voice functions.

The communication element of a traffic control system is critical for the successful implementation, operation, maintenance, and expansion of a system. It is also one of the most costly elements. The publication, *Communications Handbook for Traffic Control Systems* provides information on how to plan, select, design, implement, operate, and maintain communications systems for traffic control. The report contains information on communications fundamentals, field equipment interfaces, communications requirements, communications architecture, land line alternatives, wireless alternatives, system and institutional concerns, and standards. Another publication, *Communications in Traffic Control Systems (Volume II: Final Report)* provides information on communications in general and on specific communications technologies. The report includes a brief tutorial on communications technology and terminology; guidelines for conducting a thorough communications trade-off analysis; a detailed discussion of the types of communications media widely used in traffic control and the successful design and installation of these media; and a discussion of developing technologies. The National Cooperative Highway Research Program report on *Transportation Telecommunication* provides information on the fundamentals of telecommunications, the types of systems available, the current uses in state departments of transportation, and the implementation procedures and alternatives.

2.0 Electronic Transmission Systems

The primary media considered for transmission of electronic traffic data are twisted wire, coaxial cable, fiber optic cable, microwave, radio, narrow band radio, or spread spectrum radio. The systems can be used to transmit digital, voice, and/or video data. Technologies that should be considered for future applications are satellite communications and air-borne lasers.

2.1 Twisted Wire Pair Cable (digital, voice)

Twisted wire pair cable is used for data and voice transmission. Transmission over distances of 10 or 15 miles are possible without repeaters. This medium is the most common found in surveillance systems, and is often used in area networks to interconnect devices. However, it is not typically used for the trunk line function of carrying information from several devices to a control center because of the greater capacity requirements.

2.2 Coaxial Cable (video, digital, voice)

Coaxial cable is the technology most commonly applied to cable television. As with twisted wire pair, it is easily applied to situations requiring connections with numerous field devices. Coaxial cable is suited for video, data, and voice transmission. One problem with this medium is the need for amplification and system maintenance with the longer distances. The medium is also susceptible to outside interference from electrical sources that are attracted to the cable.

2.3 Fiber Optic Cable (video, digital, voice)

Fiber optics communication uses pulsating light waves to digitally transmit data. This can be used to transmit data, voice, and video and has proven to be reliable and free from electrical interference common to wire cable systems. The medium appears to be best suited for long distance trunk applications for digital data and for limited video data, although improvements in the area of short haul transmission and in the capacity of video transmission are expected. The cost of fiber optic technology is also becoming more competitive with other technologies.

2.4 Microwave (video, digital, voice)

Microwave technology is best suited for the transmission of voice and digital data in a trunking capacity, although it is also used for video transmission. The system requires line of sight between transmitter and receiver, and approval by the Federal Communication Commission (FCC). An FCC license may be difficult to obtain in communication intense urban areas. Transmissions may be adversely affected by environmental factors for short periods of time. The costs are competitive with cable systems.

INCIDENT DETECTION TECHNIQUES

Two methods frequently used to collect traffic data are electronic surveillance and closed-circuit television. Electronic surveillance utilizes detectors placed along the roadway. Closed-circuit television utilizes cameras to view traffic. These methods are also frequently used to detect incidents.

Other methods are also used to survey the roadway for incidents. These other methods are not typically considered a part of a data collection system in the sense that traffic measurements are taken. Two such procedures that provide information on incidents are visual observations taken from stationary or moving patrol vehicles and aircraft and reports transmitted by motorists from telephones and roadside call boxes.

Frequently, a combination of detection methods is used so that the ability to detect and verify potential incidents is maximized. The best method or combination of methods depends upon the desired objectives of the incident management system.

1.0 Electronic Surveillance

Electronic surveillance provides real-time monitoring of traffic data through the use of detectors installed along the freeway. Sensors, usually loop detectors embedded in the pavement, are placed along the roadway and on ramps to automatically detect changes in traffic conditions. Some general guidelines indicate that detector spacings over ½ mile produce information which is inadequate for incident detection purposes. In contrast, decreasing spacings below ¼ mile generally produces relatively little or no increase in effectiveness while increasing the cost.

Incidents are detected by logically evaluating the variations that occur in traffic flow. A signal is transmitted from the detector to a roadside terminal which is connected to a computer. An algorithm (Segment 1.1) in the computer interprets the signal. When measurements on the roadway exceed a predetermined threshold, an alarm is triggered signaling the operator of a potential incident.

1.1 Detection Algorithms

Traffic data is transmitted into a computer and an algorithm is used to identify the presence of an incident. Although many detection algorithms and variations of algorithms have been developed and tested, no one algorithm has been found to be superior. The principal problems are the high number of false calls generated by the algorithms and the errors due to inaccurate detector information. The basis for incident detection algorithms is the detection of a disruption to a smooth, continuous flow of traffic. When the incident occurs in congested traffic, spacings between vehicles upstream of the incident decreases, and speeds drop; downstream of the incident, the spacing between vehicles increases and the speeds either remain high, or increase.

continued

1.1 Detection Algorithms (continued)

In general, there are two types of incident detection algorithms: pattern recognition and time series. Pattern-recognition algorithms deal with current traffic patterns and pay no attention to past traffic conditions. Time-series algorithms utilize short-term forecasting techniques to identify the sudden changes in traffic stream behavior which occur during incidents. In both types of algorithms, there is a trade-off in the relationship between the probabilities of detecting incidents and false alarms (signaling of an incident when no incident has occurred). In most cases, a high detection rate results in a high false alarm rate and a low false alarm rate may result in a low detection rate. Furthermore, as the sensitivity of the algorithm is adjusted to detect an incident more rapidly, the probability of generating false alarms increases.

Computer algorithms have been developed to detect incidents in freeway surveillance and control systems. Some of these algorithms compare direct measurements of traffic to preestablished thresholds. Others use statistical procedures to detect changes in traffic conditions over time. Still others use complex theoretical models to predict expected traffic conditions given current conditions and historical trends. The structure of an algorithm can greatly influence its performance in terms of detection rate, false alarm rate, and detection time. These three terms are typically used to assess the performance of incident detection algorithms.

Proper calibration of the algorithm also affects performance. Since geometric anomalies (i.e., lane drops, severe grades, etc.) affect traffic flow, algorithms must be calibrated on a zone-by-zone basis for them to be of use to the operators. Extensive amounts of data, effort, and time are required to properly calibrate an algorithm. In the comparison of algorithms, no single one appears to be superior in terms of its repeated performance, data requirements, ease of implementation, ease of calibration, and operational experience. Results from both on-line and off-line evaluations show that most algorithms achieve similar detection rates, false alarms, and detection times when they are properly calibrated.

2.0 Closed-Circuit Television

Closed-circuit television (CCTV) is used in control systems to detect and/or confirm the presence of an incident and quickly determine the nature and severity of the incident. The image from a CCTV image can also be used to provide an electronic input into an image processing system. Due to the extensive manpower required to constantly monitor the screens, CCTV as the sole detection system is limited to locations where delay-causing incidents occur with regular frequency and fast response is necessary. A primary value of CCTV is its ability to confirm and provide information about the cause of a specific congestion problem. Most CCTV systems are used in conjunction with electronic surveillance systems.

3.0 Motorist Assistance/Courtesy Patrols

Motorist assistance and/or courtesy patrols use vehicles circulating in the traffic stream with the primary purposes of identifying incidents, determining the nature and extent of the incident, providing motorists with assistance if needed, and dispatching the appropriate type of response. Systems for detecting incidents range from routine police patrols in which incident detection is only one of the normal law enforcement responsibilities of the unit, to specially equipped patrol vehicles dedicated to freeway incident detection and response. Some agencies also use special tow trucks, vans, and light-duty trucks as dedicated patrol vehicles. These vehicles are often equipped with gasoline transfer devices, push bumpers, roll-away dollies, multi-purpose jacks, and other items necessary to provide routine or minor repairs to stalled vehicles or to remove the vehicle from the freeway. Motorist assistance patrols are used to provide services ranging from basic assistance for stranded motorists (providing gasoline, water, air, jumper cables, etc.) to sophisticated management at incidents and emergencies (removing spilled loads, righting overturned vehicles, etc.).

The primary advantage of using motorist assistance/courtesy patrols for incident detection is that the detection and response mechanism can be one in the same. The police are usually the first agency to be dispatched to an incident in order to verify the incident and determine the necessary response; therefore, considerable time savings can be achieved by using the police. However, the availability of police for patrols is subject to other, more urgent demands of police work, including public safety needs. Also, many incidents do not require police assistance; therefore, freeway incident detection is not an efficient use of police time.

Patrols sponsored by local citizen groups, private organizations, or transportation agencies utilize the same concept of circulating through the traffic stream. They typically use specially equipped light-duty trucks or vans to detect and respond to incidents. Most patrols are equipped to provide routine assistance to stranded motorists by providing fuel, oil, water, tire changing services, and minor maintenance repairs. Often these vehicles are equipped with police department radios to improve communications and reduce response time.

The primary advantages of motorist assistance/courtesy patrols are that they provide rapid response to motorists' needs while freeing the police to respond to other public safety concerns. They are also cost effective. A patrol system is costly to establish and operate. However, estimates of the benefit/cost ratio of existing programs range between 7:1 and 36:1.

The primary benefit of using motorist assistance patrols as an incident detection technique is that the time required to begin clearing the incident is greatly reduced. Since motorist assistance patrols are equipped to handle most minor incidents, the response and clearance task can begin immediately once the service patrol arrives on the scene. At major incidents, motorist assistance patrols can assist in the clearance functions by performing one or more of the following tasks:

continued

3.0 Motorist Assistance/Courtesy Patrols (continued)

- direct traffic at the incident scene,
- help plan and implement emergency detour routing,
- provide emergency medical assistance until additional help arrives,
- coordinate communications among various response agencies,
- provide traffic reports or other information to highway or enforcement personnel, local media, or the public, and
- provide emergency transportation to motorists and response to medical personnel.

Motorist assistance patrols exist in the cities of Houston, Dallas, Fort Worth, and San Antonio. Although TxDOT is involved in all of the programs, the degree of participation varies. The Dallas, Fort Worth, and San Antonio patrols are all run and supported solely by TxDOT. The Houston patrol is operated by a unique combination of public and private agencies. *Incident Response and Clearance in the State of Texas: Case Studies of Four Motorist Assistance Patrols* provides descriptions of existing programs and useful insight into the various attributes that need to be considered when developing a motorist assistance program.

The time required for a patrol to detect an incident is directly related to the number and frequency of patrol vehicles. For example, the routes for the Houston program are such that a single patrol vehicle will pass any given point on a freeway once per hour. Since patrols monitor both sides of the freeway at once, the effective headway between patrol vehicles is 30 minutes. As a result, the average detection time for incidents on a typical Houston freeway is estimated to be 13.90 minutes.

4.0 Motorist Call Systems

Motorist call systems involve communication equipment located on the roadside. Typically, call devices are spaced at ¼ to ½ mile intervals on both sides of a freeway. Motorists may have to stop at one of these devices in order to report traffic conditions or indicate a problem. There are three basic types of motorist call systems:

- Emergency Telephones
- Emergency Call Boxes
- Cooperative Motorist-Aid Systems

4.1 Emergency Telephones

With telephones, voice communication is used to transmit the details of the situation and the requests for assistance, if any. Emergency telephone systems typically experience fewer false alarms and provide greater certainty of dispatching the appropriate response than call box systems. They also allow more accurate reporting of traffic conditions and provide for two-way communication between the motorists and a dispatcher.

4.2 Emergency Call Boxes

With call boxes, the motorist presses one or more buttons that transmit pulse-coded messages to request various services (police, ambulance, wrecker services, etc.). Call box systems are generally less expensive to install than voice communication systems. With call boxes, confirmation that a distress call has been received is not typically displayed to the motorist; however, this can be remedied by placing a "message sent-message received" indicator in the call box.

4.3 Cooperative Motorist-Aid Systems

Cooperative motorist-aid systems utilize passing motorists or volunteer observers to report an incident. A system in which motorists flash their bright lights at light-sensitive sensors installed next to the roadway can be used to detect incidents. By monitoring each of the detectors, an indication that some sort of incident has occurred upstream of a particular detector location can be obtained. Drivers of transit vehicles can also provide a cooperative motorist-aid system. Another system uses volunteer observers located in buildings overlooking particular sections of freeway to detect incidents.

The cellular telephone has become the primary tool of a cooperative motorist-aid system. Chapter 11, Section 3, Segment 3.0 discusses the cellular telephone in more detail.

4.4 Advantages of Motorists Call Systems

- They are a relatively efficient method of signalling a potential interruption in the traffic stream, a motorist's needs for assistance, and can provide reassurance that aid is forthcoming.
- Cooperative motorist-aid systems have low installation and operating costs.
- Cooperative motorist-aid systems do not require motorists to leave their vehicles in order to summon aid.

4.5 Disadvantages of Motorists Call Systems

- They rely upon individuals to provide a measure of traffic conditions.
- There is an inherent delay associated with the motorist deciding to use the system and making the appropriate report. This can result in significant detection times for incidents.
- There is a high initial installation cost associated with call boxes or telephones. As units must be installed at two or three locations per mile on both sides of a freeway, initial installation costs can be significant.
- They typically experience a large number of "gone-on-arrival" calls.
- Motorists may be exposed to passing traffic if they have to walk to the nearest call box or emergency telephone, increasing the potential for pedestrian/vehicle accidents.
- Call boxes may be subject to vandalism.

Due to the cost, vandalism, and response monitoring demands of motorists call systems, they are not normally used in Texas.

This page intentionally left blank

CHAPTER 8
TRAFFIC OPERATIONS ANALYSIS

continued

CHAPTER 8
TRAFFIC OPERATIONS ANALYSIS (continued)

5.0 Additional Terminology (continued)

- **Platoon.** A group of vehicles traveling together at the speed set by the lead vehicle, rather than at the speeds preferred by the following vehicles.

- **Shock Wave.** A boundary between differing concentrations in the traffic stream. The shock wave can be envisioned as the leading edge of brake lights as they propagate backwards from congestion.

6.0 Traffic Flow Relationships and Analysis

Traffic operations analysis may be defined as the description of traffic behavior by the application of systematic procedures utilizing equations and established relationships. At the present time, there is no single theory which explains the movement of vehicles on a highway. Instead there are several different approaches. Figure 8-1 illustrates generalized relationships between flow, speed, and density. The solid dots represent traffic in free flow conditions and the hollow dots represent forced flow traffic located upstream of a capacity restriction.

The exact shape of the curves used to represent the points in Figure 8-1 is subject to some debate. Research efforts continue to identify and understand the complex relationships that exist between various traffic parameters. Chapter 2 of the *1985 Highway Capacity Manual* provides more information on the relationships between flow, speed, and density.

7.0 Capacity

An clear understanding of the concept of capacity is a fundamental requirement for operations analysis. The capacity of a section of highway is the maximum flow rate at which vehicles can reasonably be expected to traverse the section of highway under the prevailing roadway, traffic, and control conditions. While a highway can be divided into a number of sections, each with its own capacity, the capacity of the full length of the highway is determined by the section with the lowest capacity. When traffic demand is higher than the capacity of a section of highway, queues will form upstream of the point where the lower capacity section begins. The area limiting operations is known as a bottleneck.

7.1 Freeway Capacity

Traditionally, the ideal capacity for freeways has been assumed to be 2,000 passenger cars per hour per lane (pcphpl). However, recent research has shown that a more accurate representation of freeway capacity is 2,300 pcphpl. It should be noted that the 2,300 pcphpl represents the average capacity across all lanes. Actual traffic flow rates for individual lanes may be even higher. The higher flow rates are usually found on the inside (or median) lanes.

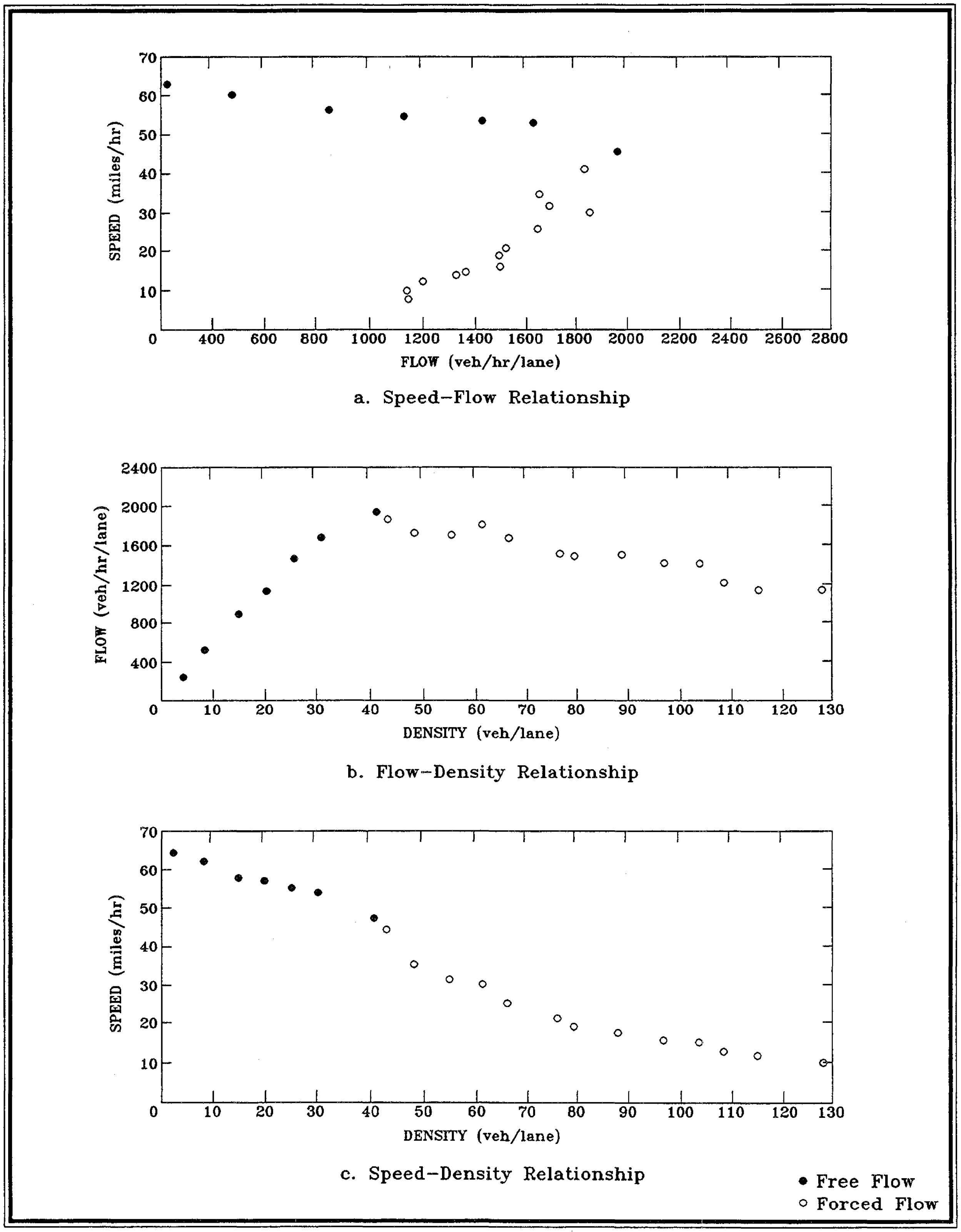


Figure 8–1. Flow, Speed, Density Relationships

7.4 Capacity Improvements (continued)

Table 3 in Figure 8-4 shows the capacity, demand, and flow for each case if the auxiliary lane is provided. In Case 1, the additional capacity provided by the auxiliary at Station 4 results in the demand being less than capacity. No queues will form as a result. However, Case 2 reveals the hidden bottleneck. Although the Case 2 demand at Station 4 is less than capacity, the demand at Station 3 still exceeds the capacity at Station 3, causing a queue to form at Station 3 and extend upstream.

The example in Figure 8-4 illustrates that although the flow rates at Station 3 were well below capacity before the auxiliary lane was added, there was a hidden bottleneck at Station 3 in Case 2. Flow rates at a given location may not represent demand at that location. Demand must be considered in light of upstream and downstream demands and capacities.

Typical low cost improvements in bottlenecks include:

- Using a short section of shoulder as an additional lane.
- Restriping merge or diverge areas to better serve demand.
- Reducing lane widths to add a lane.
- Modifying weaving areas.
- Metering or closing entrance ramps.

8.0 Measures-of-Effectiveness

The results of a traffic operations analysis are described using measures-of-effectiveness (MOEs). MOEs give an indication of how traffic flows under a given set of circumstances or how much improvement results from an optimization. The most common MOE is level of service. Other MOEs include volume, speed, density, and delay.

Level of service provides a qualitative description of the traffic flow. Level of service is based on such factors as speed, density, delay, or other parameters. Level of service is described by the letters A through F, with A being the highest or most desirable level of service. Table 8-1 gives a qualitative description for each level of service.

9.0 Highway Capacity Manual

The *1985 Highway Capacity Manual* (HCM) provides procedures for determining the level of service on a variety of highway types. The *1985 Highway Capacity Manual* contains the most often utilized procedures for performing simple analyses at isolated locations. Computer programs are available that automate all HCM procedures. The HCM also provides information on traffic characteristics and basic principles of traffic flow.

Table 8-1. Level of Service Descriptions

Level of Service	Status	Description
A	Free Flow	Individual users are virtually unaffected by the presence of others in the traffic stream. Freedom to select desired speeds and to maneuver within the traffic stream is extremely high.
B	Stable Flow	Freedom to select desired speeds is relatively unaffected, but there is a slight decline in the freedom to maneuver within the traffic stream. The presence of others in the traffic stream begins to affect individual behavior.
C	Stable Flow	Marks the beginning of the range of flow in which the operation of individual users becomes significantly affected by interactions with others in the traffic stream. Selection of speed is affected by the presence of others and maneuvering within the traffic stream requires substantial vigilance on the part of the user.
D	High-Density Stable Flow	Speed and freedom to maneuver are severely restricted, and the driver experiences a generally poor level of comfort and convenience. Small increases in traffic flow will generally cause operational problems.
E	Unstable Capacity Flow	Operations are at or near capacity. All speeds are reduced to a low, but relatively uniform value. Freedom to maneuver within the traffic stream is extremely difficult, and it is generally accomplished by forcing a vehicle to give way. Operations are unstable because small increases in flow or turbulence within the traffic stream will cause breakdowns.
F	Forced or Breakdown Flow	The amount of traffic approaching a point exceeds the amount which can traverse the point and queues form behind the point. Operations within the queue are characterized by stop-and-go waves and are extremely unstable.

FREEWAY ANALYSIS PROGRAMS

There are four computer programs which are commonly used to evaluate traffic flow on freeways. These programs include the **Highway Capacity Software** (HCS), **FREQ**, **FREFLO**, and **INTRAS**. Another program that is currently being developed is **FRESIM**. Each of these programs is capable of simulating basic freeways sections and other aspects of freeway operations. The **QUEWZ** model can be used to evaluate road user costs and queue lengths associated with freeway work zones. The basics of each program are summarized in the following subsegments, and the differences among the programs are also noted.

The *1985 Highway Capacity Manual* (HCM) procedures, which are automated in the HCS, are useful in analyzing specific highway features. However, as traffic flow approaches capacity at a number of locations on a highway system, it is necessary to evaluate the roadways as a system. The reason for systemwide analysis is that the removal of a bottleneck may create another bottleneck either downstream due to increased traffic volume or reveal a bottleneck upstream that was hidden in the queue of the bottleneck that was removed. Although the analysis can be done manually, computer programs, such as FREQ, FREFLO, INTRAS and FRESIM, allow for better quantification of systemwide effects of alternative improvements.

1.0 Highway Capacity Software (HCS)

The Highway Capacity Software uses a macroscopic, empiric, deterministic, simulation (see Chapter 8, Section 4, Segment 1 for discussions on these terms) approach to evaluate traffic flow at specific highway features. It is based on the *1985 Highway Capacity Manual* which contains widely accepted capacity analysis procedures. The analysis procedures used in the HCS are exactly the same as those of the HCM, but computer automation allows the calculations to be performed in a fraction of the time. References to the HCM or HCS should be construed as the same, unless noted otherwise.

Four chapters of the HCM specifically address freeways. There are also two chapters at the beginning of the HCM which address introductory material and traffic characteristics. The four freeway chapters describe the theory and methods for determining the level of service, capacity, and service flow rates for basic freeway sections, weaving areas, ramps and ramp junctions, and freeway systems. The HCS is more appropriate for relatively quick analyses at specific locations rather than a comprehensive analysis of a freeway system.

2.0 FREQ

FREQ can perform both simulation and optimization of traffic flow. The FREQ freeway program was developed to evaluate uni-directional freeway operations resulting from lane additions, lane blockages (construction or incidents), and various ramp configurations. FREQ may also be used to generate, evaluate, and select an entrance ramp metering scheme that will optimize freeway operations based on a user-specified objective function. Throughout its development, the FREQ program has been widely applied and has received widespread validation. The current version of FREQ is known as FREQ10PC, which can be executed on a microcomputer. FREQ also contains an interactive data input manager which simplifies data entry and coding.

The optimization component in FREQ is used in developing an optimal ramp metering scheme. Freeway operations may be optimized to maximize vehicle input, vehicle-miles of travel, passenger input, or passenger-miles of travel. The simulation component can be used to evaluate the before and after effect of some geometric or demand related alternative. It can also be used to evaluate traffic performance under the ramp metering strategy developed in an optimization analysis. Analysis options that may be invoked include a ramp merging analysis and a weaving analysis, both of which are based on procedures contained in the *1965 Highway Capacity Manual* (not the *1985 Highway Capacity Manual*). The current version of FREQ will allow priority bypass at ramp meters for high-occupancy vehicles. An earlier version of FREQ (FREQ7PL) can be used to evaluate concurrent flow high-occupancy vehicle lanes.

The FREQ input is organized by dividing the freeway into discrete, homogeneous segments in terms of geometry, demands, and capacity. Segment boundaries are located at the entrance and exit ramps. The data requirements for each segment include segment length, number of lanes, grade, capacity, design speed, volumes, percent trucks, ramp configuration, and ramp capacity. Necessary volumes include the mainlane volume entering the first subsection, the mainlane volume leaving the last subsection and all entrance and exit ramp volumes.

FREQ allows the user to specify the amount of information output. The output choices include freeway design features, distribution of vehicle occupancy by segment, freeway travel time, ramp/freeway delay, total travel time, total travel distance, contour maps of speed and density, queuing diagram, volume to capacity ratios, fuel consumption, hydrocarbon emissions, carbon monoxide emissions, nitrous emissions and noise levels. A freeway performance table by segment can also be selected. It includes number of lanes, length, demand volume, serviced volume, capacity, weave efficiency, storage rate, v/c ratio, speed, and emission data. If the analysis is an optimization, then the output will also include ramp metering rates.

3.0 FREFLO

FREFLO was designed to evaluate incidents and entrance ramp operations, and to provide standard measures of travel. The measures that are produced include flow rate, density, space mean speed, and travel time. FREFLO is capable of simulating entire freeway networks in both directions. In addition to incidents and entrance ramp operations, FREFLO can analyze freeway-to-freeway connectors and vehicles can be distinguished by type. Special purpose lanes such as HOV lanes may also be simulated. FREFLO is designed to be executed on a mainframe computer but is presently being converted into a PC version.

Preparing the data input file used in FREFLO is a tedious process, as there is no data input manager. Freeway segments are represented as links and nodes, where links represent segments and nodes represent a change such as a lane drop or ramp. Required link data includes link length, number of lanes, capacity, free flow speed, and entering and exiting volumes.

The FREFLO output includes the density for each link of the network. The level of service for each link is determined from the density using the *1985 Highway Capacity Manual* procedures. Other output includes link volumes and speeds for each time period of simulation, vehicle trips, vehicle miles, vehicle minutes, vehicle average speed, person trips, person miles and person minutes.

4.0 INTRAS

INTRAS, which stands for Integrated TRAffic Simulation, is capable of simulating entire freeway networks, including frontage roads and urban arterial streets. The basis of INTRAS is a set of algorithms which mathematically execute complex maneuvers such as car following, lane-changing, and crash avoidance. At the present time, the large size and complexity of INTRAS restricts its use to mainframe computers only. The size of INTRAS also results in long and expensive computing times. As a result, it is not widely used.

The microscopic nature of INTRAS allows detailed simulations of complicated and unusual traffic operations such as lane additions and removals, ramp and interchange reconfigurations, changes in curvature or grade, incidents (including the time dependent severity and rubbernecking), surveillance system operation, and traffic diversion. Weaving sections may also be analyzed in detail since INTRAS treats each vehicle as a separate unit. INTRAS is also capable of optimizing freeway operations by producing an entrance ramp metering scheme utilizing fixed time, demand responsive, speed control, or gap acceptance metering options.

INTRAS uses a link-node system to code the freeway and street network. INTRAS does not have a data input manager, so data entry is complex. INTRAS data can be divided into required data, optional data, and embedded data. All of this data can be modified in order to calibrate the program to simulate existing conditions.

continued

4.0 INTRAS (continued)

INTRAS produces a large amount of standard and optional output including summary tables of input parameters, vehicles input and output, number of lane changes, vehicle-miles of travel, vehicle-minutes of travel, delay time, volume, speed, density, surveillance data (such as mean speeds and mean headways), fuel consumption, emissions, time-space plots, and contour maps.

5.0 FRESIM

FRESIM is a freeway corridor program which is currently in the development stage. Preliminary documentation indicates that FRESIM is an enhanced, user-friendly, and PC-compatible version of INTRAS. FRESIM enhancements include improvements to both the geometric representation as well as the operational capabilities of the INTRAS program. Thus, FRESIM is able to simulate more complex freeway geometrics. It also provides a more realistic representation of the traffic behavior than INTRAS. These enhancements have also resulted in a more flexible and user-friendly program than INTRAS.

FRESIM is capable of simulating freeway mainlanes, ramps, freeway-to-freeway connectors, variations in grade, curvature and superelevation, lane additions or drops, lane blockages, and acceleration or deceleration on auxiliary lanes. The model also provides simulation of operational features such as ramp metering, freeway surveillance, performance capabilities of six different vehicle types (two types of passenger cars and four truck types), restriction of heavy vehicles from certain lanes, differences in driving habits, and drivers' reactions in terms of lane changing behavior to warning signs, incidents, or exits. The input and output of FRESIM are different from INTRAS in only a few minor areas.

6.0 QUEWZ

QUEWZ (Queue and User Cost Evaluation of Work Zones) is designed to evaluate freeway work zones. An analysis capability of the program is estimating the queue lengths and additional road user costs resulting from freeway work zone lane closures. Another capability is identifying schedules for lane closures so that queuing will not exceed a user-specified queue length or delay. The data requirements include: configuration of the work zone, the schedule of work activities, traffic volumes, and alternative values for program defaults (percent trucks, maximum acceptable delay to motorists, etc.). The output from the program includes a summary of travel impacts and/or an acceptable lane closure schedule. The travel impacts include hourly estimates of diverted traffic, volume through the work zone, approach speed, work zone speed, average queue length, and additional road user costs.

7.0 CORFLO

CORFLO is a name given to the combination of the PC versions of the FREFLO, NETFLO (Levels 1 and 2), and TRAFFIC macroscopic programs. CORFLO may be used to simulate freeways, ramps, frontage roads, and the surrounding urban street system. The CORFLO package was designed to enable the user to simulate an entire urban network with a single model. CORFLO may be used to simulate uni-directional or bi-directional freeway sections, freeway to freeway connectors, interchanges or complete freeway networks. The software can also simulate urban links connected to the freeway (i.e., frontage roads and arterial streets).

8.0 Comparison of Computer Programs

Tables 8-3 and 8-4 summarize the description, capabilities, and differences between the freeway programs discussed previously.

Table 8-3. Summary of Freeway Computer Programs

Model	Analysis Types[a]				Microcomputer Version
	Approach	Basis	Objective	Outcome	
HCS	Macroscopic	Empirical	Simulation	Deterministic	Yes
FREQ	Macroscopic	Analytical	Simulation or Optimization	Deterministic	Yes
FREFLO	Macroscopic	Analytical	Simulation	Deterministic	No[b]
INTRAS	Microscopic	Analytical	Simulation or Optimization	Stochastic	No
FRESIM	Microscopic	Analytical	Simulation or Optimization	Stochastic	No[b]
QUEWZ	Macroscopic	Analytical	Simulation	Deterministic	Yes
CORFLO	Macroscopic	Analytical	Simulation	Deterministic	Yes

[a]Chapter 8, Section 4, Segment 1 includes discussions on the various analysis types.
[b]Microcomputer version is under development.

continued

8.0 Comparison of Computer Programs (continued)

Table 8-4. Advantages and Disadvantages of Freeway Computer Programs

Advantages	
HCS	Widely accepted and easy to use.
FREQ	Easiest of the programs to use. Can optimize ramp meters. Considerable testing, validation, and use nationwide. Operates on a microcomputer. User friendly data input manager.
FREFLO and CORFLO	Explicit treatment of freeway system. Can evaluate temporary changes in roadway characteristics. Compatible with TRAFFIC, an equilibrium traffic assignment program. Can simulate freeway to freeway connectors. Produces density as output MOE. CORFLO operates on a microcomputer.
INTRAS	Explicit treatment of freeway and surface street system. Can evaluate temporary changes in roadway characteristics. Can evaluate complex weaving sections. Can simulate freeway-to-freeway connectors. Can evaluate geometric changes and vehicle/driver characteristics.
FRESIM	Explicit treatment of freeway and surface street system. Can evaluate temporary changes in roadway characteristics. Can evaluate complex weaving sections. Can simulate freeway-to-freeway connectors. Can evaluate geometric changes and vehicle/driver characteristics
QUEWZ	Allows for the estimation of road user costs and queue lengths resulting from lane closures. User friendly, menu driven data input manager.
Disadvantages	
HCS	Empirically based, no systemwide analysis capabilities.
FREQ	Only one directional freeway segment can be evaluated. Only one simplified parallel alternative route can be simulated. Cannot simulate freeway-to-freeway connectors.
FREFLO and CORFLO	Large CORFLO networks have large data requirements and require long computing times.
INTRAS	No data input manager; therefore, extensive input data required. Requires mainframe computer. Requires long computing times.
FRESIM	No data input manager; therefore, extensive input data required. Requires mainframe computer. A microcomputer version is not yet available.
QUEWZ	Only simulates freeway segments between ramp junctions. Limited applications.

OTHER ANALYSIS PROGRAMS

Several computer programs are available to analyze arterial streets and intersections. The **Highway Capacity Software** (described in the previous section) can be used for relatively quick analyses at specific locations or along arterial streets. **PASSER II** is capable of analyzing isolated signalized intersections as well as a series of signalized intersections. **PASSER III** is designed for signalized diamond interchange analyses. The **TEXAS** model is used to analyze single intersections. **TRANSYT-7F** and **NETSIM** are capable of evaluating the operations along a series of intersections with and without signals. **PASSER IV** is an arterial street timing optimization model for networks. Each model has unique qualities which are discussed below.

1.0 PASSER II

PASSER II-90 is capable of optimizing timing for isolated signalized intersections, optimizing signal timing for progressive systems, and analyzing existing timing evaluations. The program is also capable of analyzing various complicated left turn signal treatments either with or without left turn lanes. The package provides the user with a menu driven, graphical input/output processor that is user-friendly. The most current version of PASSER II-90 provides advanced analysis procedures similar to and beyond those used in the *1985 Highway Capacity Manual*. The output from the program includes optimum (within constraints) cycle length, phase sequences, phase durations, progression bandwidths, bandwidth efficiency and attainability, average progression speed, intersection level of service, saturation ratio, stops, delay, fuel consumption, and time-space diagrams. The performance of the system can be observed from an on-screen graphical representation of the traffic operations. The movements of individual vehicles are displayed along with measure-of-effectiveness values. This allows for a visual appreciation of where queues are forming and where excess capacity may exist.

2.0 PASSER III

PASSER III-90 is designed to analyze pretimed or traffic-responsive, fixed sequence signalized diamond interchanges. The program allows the evaluation of existing or proposed signalization strategies for diamond interchanges. It determines which plan best minimizes the average delay per vehicle. It is capable of analyzing various complicated left turn signal treatments either with or without left turn lanes. The program also calculates signal timing plans for interconnecting interchanges along continuous frontage roads. The current version, PASSER III-90, provides enhanced input/output functions and signal timing reports. It also has the capacity to evaluate multiple cycle lengths at isolated interchanges. In addition, it can analyze over-saturated conditions and cycle lengths up to 300 seconds in length. The microcomputer version of PASSER III-90 provides the user with an interactive menu driven program for data entry that is user friendly. An assistant function is provided to expedite the assignment of traffic movements to lanes to optimize lane use assignments. This is a particularly important feature for maximizing frontage road utilization.

3.0 TEXAS

The TEXAS program can be used to evaluate the operational effects of various traffic demands, types of traffic control, and/or geometric configuration at single intersections. The program is a microscopic traffic simulation model for single intersections. It can be applied in evaluating existing or proposed intersection designs and for assessing the effects of changes in roadway geometry, driver and vehicle characteristics, flow-conditions, intersection control, lane control, and signal timing plans upon traffic operations. It is a microscopic computer simulation designed to perform detailed evaluations of traffic operations at isolated intersections. It has recently been upgraded to allow the user to simulate and optimize two intersections only as a diamond interchange configuration. The TEXAS Model is comprised of three sub-models. GEOPRO is used to create the required geometry information. DVPRO is used to randomly generate individual driver pairs. Several driver types and vehicle classifications are used. SIMPRO examines sequentially each driver-vehicle unit in the system. Delay, speed, and volume statistics are accumulated throughout the simulation and reported at the end of user-selected time increments. Animated graphical output of vehicles moving through the intersection is also available using the TEXAS Model.

4.0 TRANSYT-7F

TRANSYT-7F is a traffic signal timing optimization program. Using standard traffic data and timing parameters as inputs, it can both evaluate existing or other predetermined timing plans, and optimize new timing plans that minimize stops, delays, fuel consumption, or cost. A data input manager (DIM) program and a Platoon Progression Diagram (PPD) are included with the TRANSYT-7F program. The DIM is a full screen editor with prompts for each card type to facilitate data entry. The PPD combines the traditional time space diagrams and TRANSYT's "flow profile diagram." The most current public domain version (Release 6) has new algorithms for bandwidth constraint, improved actuated signal modeling, optimized splits for grouped nodes, additional reporting of route summaries, and more powerful objective functions. The program provides signal timing tables and traffic performance summary tables. The signal timing tables include the phase intervals and offsets while the traffic performance summary tables include degree of saturation, travel time, delays, stops, queue lengths, and fuel consumption by link and for the entire network. Optional outputs include flow profile plots and time-space diagrams.

5.0 NETSIM

NETSIM (NETwork SIMulation Model) is a simulation program which can evaluate a variety of proposed operational improvements prior to implementing the changes in the field. It is a microscopic simulation program that provides a detailed evaluation of proposed operational improvement in a signalized network. For example, it can evaluate the effects of converting a two-way street to one-way, adding lanes or turn pockets, moving the location of a bus stop, or installing a new signal (fixed-time or actuated). The output from the program includes information on travel, delay, stops, speeds, queues, link (roadway segments) occupancies, degree of saturation, cycle failures, fuel consumption, and vehicle emissions for each link and for the entire network. This information is provided at several points in time and for the entire simulation period. NETSIM also has the ability to display how the traffic is flowing on screen. Vehicles progressing along the arterial or through the intersections, signal indications, and other information are shown for a specified amount of the network. Using the graphics package, the user can visually appreciate how different improvements affect traffic operations.

6.0 PASSER IV

PASSER IV-94 has been developed to optimize signal timings for large multi-arterial networks based on maximizing platoon progression bandwidth on all arterials. The program can analyze both one-way and two-way arterials in closed networks as well as open networks. PASSER IV-94 can calculate green splits, optimum cycle length for the system, and offsets. The program selects optimum phasing sequences to maximize bandwidth along the arterials. The program can print multiple signal timing reports and generate input data files for the TRANSYT-7F program. Time-space diagrams are generated for each arterial in the network. PASSER IV-94 provides a network signal timing optimization capability that was previously available only for arterial problems through the combined use of PASSER II and the Arterial Analysis Package (AAP).

7.0 Comparison of Computer Programs

Tables 8-5 and 8-6 summarize the description, capabilities, and differences between the signalized intersection programs discussed previously.

Table 8-5. Summary of Signalized Intersection Computer Programs

Model	Analysis[a]			Microcomputer Version
	Approach	Objective	Outcome	
PASSER II	Macroscopic	Optimization	Deterministic	Yes
PASSER III	Macroscopic	Optimization	Deterministic	Yes
TRANSYT-7F	Macroscopic	Optimization	Deterministic	Yes
NETSIM	Microscopic	Simulation	Stochastic	Yes
TEXAS	Microscopic	Simulation & Optimization	Stochastic	Yes
PASSER IV	Macroscopic	Optimization	Deterministic	Yes

[a]Chapter 8, Section 3, Segment 1 includes discussions on the various analysis types.

continued

7.0 Comparison of Computer Programs (continued)

Table 8-6. Advantages and Disadvantages of Signalized Intersection Programs

Advantages	
PASSER II	Widely accepted and used, can optimize a coordinated or simulate an existing signal system. Graphical output is available.
PASSER III	Widely accepted and used for simulating or optimizing the signals associated with the cross-street/frontage road intersections at a diamond interchange.
TRANSYT-7F	Widely accepted and used with continual upgrading. Allows use of stop-controlled approaches and permitted movements. May be used to simulate or optimize any system of intersecting arterial streets.
NETSIM	Detailed simulation of arterial street intersection systems. Allows high quality animated graphical representations of selected intersection operations.
TEXAS	Detailed simulation of an isolated intersection or diamond interchange signal system. Allows animated graphical representations of selected intersection operations.
PASSER IV	Simultaneously maximizes progression bandwidth on all arterials in an open or closed network. Extremely user friendly interface. Can be run in combination with TRANSYT-7F to minimize bandwidth-constrained delay.
Disadvantages	
PASSER II	Awkward data input manager, difficult to edit previously entered data.
PASSER III	Only applicable to diamond interchange signal systems.
TRANSYT-7F	Data input manager is not comprehensive, the input manager is a generic type format which makes the coding of specialized configurations difficult.
NETSIM	Extensive input data required, simulation capability only.
TEXAS	Extensive input data required, isolated intersection or diamond interchange signal system capability only.
PASSER IV	Cannot simulate existing signal timings due to its inability to simulate offsets.

This page intentionally left blank

ANALYSES OF SPECIFIC CIRCUMSTANCES

In some cases, the area of concern may be limited to a certain aspect of freeway operation. The freeway programs previously mentioned provide several alternatives for analyzing common freeway situations. The following sections describe how these programs can be used to analyze weaving, ramp metering, work zones, incidents, and queues on freeways.

1.0 Weaving

Weaving sections impose significant impacts on highway operations. The impact of the weaving section depends on the spacing between interchanges, the traffic volumes of the weaving and non-weaving movements, the speed of the weaving and non-weaving movements, and the number and type of lane changes required.

Analyzing weaving areas is a complicated process. The *Highway Capacity Software (HCS)* procedures provide level of service on an empirical basis. The HCS procedure requires considerable judgment in its application. The weaving analysis in FREQ is based on the *1965 Highway Capacity Manual* (not the *1985 Highway Capacity Manual*). FREFLO contains no weaving analysis, instead as vehicles are introduced at an entrance ramp gore, they are immediately merged into the freeway mainlanes. Both INTRAS and FRESIM, by virtue of their microscopic nature, provide the highest available level of detail possible in simulating traffic behavior. Specifically, individual entrance ramp vehicles are spaced on the ramp to minimize turbulence (adequate following distances). The program then searches for an empty slot of sufficient size in the adjacent freeway lane to accommodate the lead entrance vehicle. This highly detailed process is needed for merging and weaving studies to realistically simulate the vehicle interactions in those areas.

2.0 Ramp Metering

Optimizing freeway operations by varying ramp metering rates is a cumbersome process when done manually. Several freeway models provide a means for determining the desired metering rates in order to maximize various measures of effectiveness.

FREQ allows the user to create an optimal entrance ramp metering plan based on the optimization of any of four objectives: the number of vehicles on the freeway, the total number of vehicle miles of travel, the passenger inputs, or the passenger miles of travel. Maximum and minimum metering rates, as well as queue length limits are options available for controlling the range of metering rates. INTRAS and FRESIM both support four different entrance ramp metering strategies. These are: clock time metering, demand-capacity metering, speed control metering, and gap acceptance metering.

3.0 Work Zones and Incidents

Work zones and incidents have a significant impact on freeway operations. This impact varies according to the nature and the location of the blockage. In terms of simulation, a work zone and an incident are modelled identically. Both are capacity restrictions for a specified period of time. While all of the programs will produce simulated freeway speeds, only FREQ and QUEWZ produce a queue length output, which is a measure of effectiveness most associated with work zones or incidents. FREQ allows the user to reduce the freeway capacity for each subsection for a given period of time to simulate a lane blockage due to either a work zone or incident. QUEWZ estimates the queue length and additional road user costs resulting from a work zone lane closure. The *Highway Capacity Software* provides total and lane capacity values for work zones. FREFLO provides for the representation of an incident or work zone by allowing the specification of a reduced number of lanes and/or a constrained flow rate past a certain point. INTRAS and FRESIM allow the user to simulate work zones, incidents, or lane closures over a subsection length for specific lanes for a given time period. Other features of INTRAS and FRESIM are that advanced warning signs may be placed for the approaching traffic to vacate the appropriate lane and a "rubbernecking" factor may also be applied to the adjacent lanes to simulate the resulting slow down.

4.0 Queue Length

When demand exceeds capacity, a queue will form. Traffic speeds within the queue are reduced, and the length of the queue can increase rapidly. The FREQ and the QUEWZ programs allow the length of a queue to be determined.

5.0 Reduced Lane Widths

Reduced lane widths and/or reduced lateral clearance have been used on freeways in work zones and when adding one or more lanes to an existing freeway. Reduced lane widths can have an impact on operations; however, none of the freeway computer programs can specifically model this restriction. The lane capacity in FREQ and FREFLO and the driver sensitivity factor in INTRAS and FRESIM may be lowered to simulate a reduced lane width or lateral clearance. The *1985 Highway Capacity Manual* contains procedures for calculating the capacity of a freeway segment with reduced lane widths or lateral clearances, but they are not particularly accurate. Lane widths of 11 feet or more are unlikely to significantly affect capacity.

CHAPTER 9
INCIDENT MANAGEMENT

This page intentionally left blank

MANAGEMENT FOR MAJOR EMERGENCIES

A major transportation emergency is considered to be an event which effects the transportation system in such fashion that the response measures required or the resulting traffic impacts are not typical of the normal day-to-day operations of the system. The response may be unusual in terms of the number and types of agencies involved, in the amount of personnel and equipment resources required, or in the actions required away from the emergency scene. Likewise, impacts upon traffic may be unusually severe, of especially long duration, or require very special reactions by the motorists. Examples of major transportation emergencies include hurricane evacuations, nuclear and chemical plant disasters, flooding, tornadoes, hazardous material spills, and damage to the transportation infrastructure.

1.0 Planning for Major Emergencies

Emergencies that affect the transportation system of an area can occur anywhere at anytime. Emergencies can result in major traffic delays and congestion as well as cause risk to life or property. Several categories of preparations have been found through past experiences to have a major effect upon how well an agency is able to cope with the various types of major emergencies:

- transportation system evaluation,
- interagency coordination,
- resource assessment and management, and
- public communication and notification.

Generally speaking, a detailed evaluation of the transportation system should be performed in preparation for those emergencies which afford an agency with some advance warning (i.e., ice storms, hurricanes) or which the location of the emergency can be pinpointed (such as near chemical plants, oil refineries, etc.). The evaluation may include such things as:

- Traffic operations analysis at specific signalized and unsignalized intersections.
- Capacity analysis of key diversion and evacuation routes.
- Identification of "sensitive" locations within the corridor from a transportation perspective (schools, hospitals, etc.).
- Assessment of manpower and traffic control device needs to accomplish real-time traffic management at key points.

The evaluation is an ongoing process in which the agency develops and maintains an awareness of the ability of the system to accommodate travel before, during, and after a major emergency. In this regard, knowledge of temporary conditions within the system (such as roadway construction and non-functioning traffic control devices) are as important in the process as the physical characteristics of the roadway (which do not change).

continued

1.0 Planning for Major Emergencies (continued)

Although each situation is different, experiences suggest that interagency coordination can be enhanced in many cases by establishing:

- Interagency cooperation agreements.
- Interagency communication networks.
- Personnel training programs.

Resource needs change constantly when responding to emergencies, and a mechanism is required for tracking and allocating resources in real-time to react to these changing needs. The importance of keeping up with resources must be stressed prior to an emergency, and agency personnel need to be designated to perform the updating and management function during an actual emergency. Events (i.e., personal crises, other volunteer commitments, etc.) during an emergency may keep some employees from contributing to agency emergency response and traffic management efforts. Consequently, agency response and traffic management plans for emergencies should not be dependent upon the knowledge or capabilities of specific individuals participating in those activities. Rather, efforts should be taken to ensure that more than one person has the necessary expertise to accomplish the activities of the agency.

The amount and type of information to be disseminated to the public by a transportation agency cannot be established prior to an emergency. One of the most important preparations an agency should make is to ensure that a public information coordinator has been appointed to handle the collection and dissemination of transportation information to the media and to the public directly.

2.0 Emergency Response and Management

A number of techniques have been implemented in past emergencies to increase transportation mobility during an emergency condition. These include:

- adjustments in traffic signal timings to favor diversion or evacuation traffic flows,
- left-turn and parking restrictions on emergency routes,
- use of high-occupancy vehicles and HOV facilities to increase evacuation capabilities,
- conversion of two-way and/or freeway facilities to one-way flow away from the emergency,
- stationing tow-trucks along major routes to reduce capacity reductions caused by accidents and stalled vehicles and to promote continued roadway flow,
- suspension of tolls on bridges and toll facilities serving as evacuation or detour routes, and
- prohibiting unauthorized movement of oversize/overweight cargoes within the emergency area.

continued

2.0 Emergency Response and Management (continued)

Certainly, interagency coordination and cooperation are an essential component of the utilization of any of these techniques, which further emphasizes the need for advance planning and preparation in order to be able to implement these techniques.

The report, *Planning Guidelines for Major Transportation Emergencies*, presents guidelines for responding to major emergencies.

3.0 Recovery from an Emergency

Traffic control and management can pose special problems during emergency recovery operations. Existing traffic controls may be missing, damaged, or inoperable; roadway segments may be blocked with debris or structurally damaged, requiring extensive detouring; and traffic demands can be significantly different than normal due to residents returning to their homes (in the case of emergencies requiring evacuations). In addition, special signing may be needed to warn vehicular and pedestrian traffic of structures near collapse, or of rescue and repair work ongoing in the area.

Most of the traffic control and management techniques discussed in the Segment 2.0 are relevant in emergency recovery phases as well. A common problem in past emergencies of a regional nature has been the shortage of normal traffic control devices. Lightweight temporary signs made out of fabric or paper have been used successfully on occasion to ease traffic control needs in major emergency recovery operations. Resource lists are important in this phase of an emergency and can greatly facilitate the procurement and implementation of needed traffic control.

Major traffic control components during emergency conditions are police officers, department of transportation and public works personnel, and even volunteers who provide active traffic control at critical intersections. In the recovery phase of an emergency, a top priority of transportation and public works agencies is to get power and repairs made to traffic signals and street lighting at major intersections so as to free up police and other personnel from this hazardous duty and allow them to focus their attentions elsewhere.

continued

3.0 Recovery from an Emergency (continued)

Officials involved in past emergencies have identified a number of significant issues that have arisen regarding debris clean-up. Some of these are listed below:

- ♦ Several agencies reported severe tire shortages during emergency clean-up and repair activities, as downed power lines and sharp objects in the roadway ruined tires almost as fast as they were changed.
- ♦ Coordination between transportation and public works agencies and the military, when they are involved, has been a point of difficulty in some past emergencies.
- ♦ A lack of knowledge about federal requirements for assistance (regarding bidding procedures, identification of roadway segments to be included, etc.) delayed the beginning of some clean-up activities.
- ♦ A lack of proper performance requirements (in terms of time) of private contractors for debris removal resulted in the awarding of contracts to firms unable to complete the job in a reasonable amount of time.

Transportation agencies need to coordinate and communicate with the other agencies involved in an emergency to determine as soon as possible whether federal assistance is forthcoming (since documentation needs increase dramatically if that occurs) and have preexisting debris removal contracts in place or specifications prepared to implement in the event they are needed.

CHAPTER 10
CONTROL STRATEGIES

This page intentionally left blank

FREEWAY CONTROL STRATEGIES

There are a number of strategies that can be used to control freeway traffic. Most of these strategies are intended to limit the number of vehicles in the freeway system. Examples include ramp metering, ramp closure, mainlane metering, and freeway closure. Other strategies are intended to optimize the use of the freeway. Examples are freeway lane control, priority control, and reversible lane use control.

1.0 Ramp Metering

Ramp metering uses traffic signals to regulate the number of vehicles that can enter the freeway at the entrance ramps. The basic concept is to control the flow so that the combined freeway and ramp flow rates will not exceed the downstream capacity of the freeway. The use of ramp metering provides for maximum utilization of freeway capacity. When demand exceeds capacity, the resulting stop-and-go traffic creates turbulence that prevents the freeway from operating at its theoretical capacity. Figure 10-1 illustrates the capacity that can be gained by using ramp metering to maintain traffic flow just below the freeway capacity.

In addition to its primary purpose of maintaining traffic flow below the freeway's capacity, ramp metering has several other operational benefits. These include restoring the mobility priority of the freeway that is often lost during congested conditions, improving freeway operations in the vicinity of a ramp, and spreading out platoons of arriving ramp vehicles.

When the speed of freeway traffic drops to that of the ramp and there is no ramp metering, the freeway and ramp vehicles share equal access to the freeway. Freeway and ramp vehicles alternate as the two traffic streams merge. As a result, the freeway traffic loses its mobility function and ability to serve through traffic. Ramp metering limits the number of vehicles merging with the freeway traffic, thereby preserving the ability of the freeway to give priority to the through traffic.

When ramp metering is used to limit freeway access to one vehicle at a time, the freeway vehicles can more easily adjust their speeds and positions in the outside freeway lane to accommodate the merge of the entering vehicle. Without ramp metering, queues can form in the ramp merging area, leading to difficult merging maneuvers. Ramp metering minimizes the occurrence of vehicles stopped in the merge area, and therefore, enhances traffic safety.

Entrance ramp traffic often arrive in platoons, resulting from the green indication of the upstream signal at a signalized diamond interchange. Ramp metering distributes the platoons and thereby reduces the short term ramp flow rates of the entering traffic by increasing the time intervals between vehicles entering the freeway so that the total freeway demand does not exceed capacity.

continued

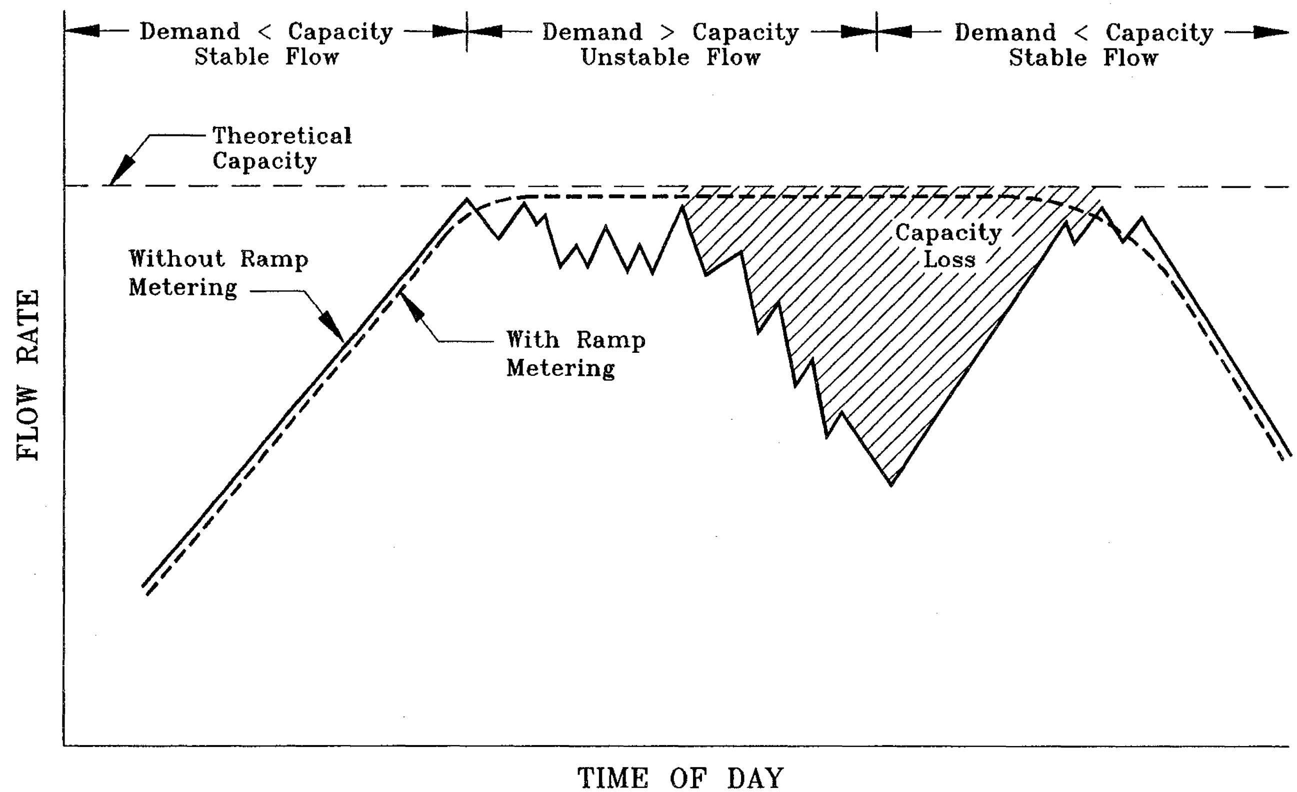


Figure 10–1. Capacity Gain from Ramp Metering

1.0 Ramp Metering (continued)

Even if the ramp traffic demand at a particular ramp does not exceed the capacity of the merging area, it may be necessary to reduce its entrance flow rate to maintain the balance between demand and capacity in a downstream freeway section. This would be necessary when the desired metering rate at one or more ramps cannot be implemented. For example, if a ramp does not have a suitable alternative route and if queues from the ramp signal block critical intersections and driveways, the flow rate on the ramp needs to be higher than that required to balance demand and capacity. Therefore, upstream ramps would have reduced rates to compensate for the lack of downstream control.

The primary function of ramp metering is to maintain the freeway's capacity to efficiently serve high-priority urban traffic demands. Additionally, it may be used to effect travel demand management actions, such as promoting HOV lane operations, congestion management strategies, and traffic safety programs.

Two ramp metering strategies are utilized by TxDOT: local metering and system metering. Local metering is used at ramps with no coordination between ramps. System metering is the operational coordination of a series of local meters along the freeway to provide maximum flow without allowing congestion to form. Software has been developed to aid in the development of ramp metering timing plans for both modes of operation. The software, named RAMBO (Real-time Adaptive Metering Bottleneck Optimization), also provides an evaluation of the metering plans and graphic plots of the results. RAMBO fully supports the TxDOT Freeway Traffic Management system. RAMBO I is the local ramp meter program and RAMBO II is the system program.

An important consideration in entrance ramp control is the availability of alternative routes. If the control strategy requires low metering rates at a time of high entrance ramp demands, the queue lengths and vehicle delays may become excessive. These conditions will encourage drivers to use the alternate routes, to enter the freeway at different ramps, or to use surface streets to avoid the freeway entirely.

A comprehensive discussion of ramp metering, including information on how to implement different metering rates, is presented in the *Traffic Control Systems Handbook* and *Advanced Freeway System Ramp Metering Strategies for Texas*.

2.0 Ramp Closure

There are two choices to consider when circumstances make it impractical to control an entrance ramp by metering:

- do not apply any control to the ramp, or
- apply total control by closing the ramp to some or all traffic.

continued

2.0 Ramp Closure (continued)

The first alternative is not attractive since it negates the benefits of the other parts of the control system. The second alternative is not attractive because it denies access to a public facility. However, this disadvantage can be alleviated by the provision of well defined alternate routes.

The impacts on cross street, frontage road, and driveway operations must be considered if an entrance ramp does not have adequate storage distance for the expected queues that form at the ramp signal. Similarly, if the length of acceleration distance from the ramp signal to the freeway merge area is not adequate, then the installation of ramp metering may not improve the merging operations. Closure of the ramp and provisions for directing the traffic to other ramps and surface streets would be the preferred control method.

If the required metering rate for a ramp would result in long queues and delays, ramp closure may be a viable alternative, even if the geometrics of the designs are adequate. This is especially true if frontage roads and arterial streets in the area provide useful corridor capacity. The destination of entrance ramp traffic is another consideration in ramp closure. If a high percentage of ramp traffic is determined to have short trip lengths on the freeway, ramp closure control should be considered.

3.0 Mainlane Metering

Mainlane metering applies the concept of entrance ramp metering to freeway lanes. If the total traffic flow approaching a freeway section approaches or exceeds the capacity of that section, then congestion and lower levels of service can be expected. If ramp metering cannot adequately adjust the entering flows, then some form of control could be applied to the mainlanes to achieve the desired balance. This concept has not been widely used. To date, its applications have been successful on toll facilities and special control access facilities, such as bridges and tunnels.

4.0 Freeway Lane Control

Control of freeway lanes is accomplished through closing freeway lanes or indicating preferred lanes for travel. There are two types of freeway lane closures. In an informal closure, one or more lanes are closed as the result of an object or objects blocking traffic flow. In a formal lane closure, one or more lanes are intentionally closed using traffic control devices or other official directions such as a police officer. Informing road users of the preferred lanes of travel can be accomplished through the use of signing or lane-use control signals.

continued

4.0 Freeway Lane Control (continued)

The formal closure of a freeway lane or lanes is often associated with specific operations concerning roadway maintenance and construction. Chapter 5, Section 2 addresses methods for closing a lane. In these cases, channelizing devices, barrels, cones, and/or arrow panels may be used to close the lane. A formal freeway lane closure may also be implemented in response to an incident. In these cases, signs and cones which can be carried by response vehicles are used to close a lane or lanes. Police officers and/or flaggers can also be used to close a lane.

An informal lane closure occurs when a vehicle or object blocks one or more freeway lanes. Most often, this occurs as the result of an accident, a vehicle breakdown, or a load which has fallen from a vehicle. Before a response team arrives at the scene, vehicles maneuver around the blockage without the aid of formal traffic control.

The use of lane closure as a control to reduce the capacity of the roadway may be an effective way to control mainlane traffic demands. The closures can be of short duration when peak travel demands cause the ramp metering system to become overloaded and ineffective. This is a variation of the mainlane metering system; the motorists must be aware of the difference in this control and that it is used when a lane is blocked downstream.

The assignment of a lane to a specified class of vehicles is another form of lane control. The designation of a lane for exclusive use by high-occupancy vehicles such as buses and carpools would be a typical strategy to provide preferential treatment for these vehicles. The restriction of large vehicles to one or more lanes is another application of this control, however, with major differences in objectives (e.g., increasing roadway capacity in other lanes or reducing pavement wear in other lanes).

Lane-use control signals can be used to provide advance notice of lane closures or to indicate preferred lanes of travel. The use of lane-use control signals for freeways is addressed in Chapter 11, Section 3, Segment 6.0.

5.0 Freeway Closure

The total closure of a freeway is applied only under extreme conditions when other forms of traffic control are not effective. Reasons for considering the total closure of a freeway include:

- A major traffic accident blocks all lanes. (Essentially, the freeway is closed by default.) Closure warnings are initiated prior to major interchanges to present best alternate route selection.
- A major accident or incident in the vicinity of the freeway (involving hazardous materials which could result in the evacuation of the area).
- A major reconstruction project or maintenance operation that either would endanger the traffic or could not be completed with the presence of vehicular traffic.
- Weather conditions.

This type of control obviously requires a large amount of advance planning, coordination, and cooperation of many agencies and organizations. The diversion of freeway traffic to other freeways and onto city streets must be analyzed for its effects, and the traffic controls on these alternate routes adjusted accordingly. Updates of the operational status of city streets is essential for effective diversion as similar closure problems may occur on them as well. Signs to lead traffic along the designated routes and back to their original route must be provided. The coordination of closure activities for random events are most difficult, unless advanced planning has been conducted.

6.0 Priority Control

The concept of priority control for high-occupancy vehicles (HOV) is to provide preferential treatment for buses, vanpools, and carpools in the form of travel time advantage and reliability over single occupancy vehicles. Preferential treatment is intended to relieve traffic congestion on freeways by encouraging better utilization of highway and vehicular resources. The objective is to better serve the people-demand for the freeway corridor and reduce the vehicle-demand by inducing more people to use HOVs during peak traffic hours. People in HOVs benefit from travel time and reliability improvements. However, people in the regular lanes also benefit because of the diversion to high-occupancy vehicles and the more efficient use of the facility. In addition to reducing vehicular demand, higher vehicle occupancies contribute to reductions in air-pollution and fuel consumption. Different methods of priority control that have been used on freeways are separated facilities, reserved lanes (concurrent flow and contraflow), and priority access control.

6.1 Separated High-Occupancy Vehicle Facilities

Separate roadways or space reserved in median areas provide positive separation of HOV traffic from the rest of the traffic. These are among the most expensive HOV treatments because major construction is required. Separate HOV facilities do not have the same enforcement and safety problems encountered by the non-separated treatments. Separation techniques range from buffer zones without physical barriers to parallel physical barriers.

URBAN STREET CONTROL STRATEGIES

There are numerous alternatives for controlling traffic on urban streets. Most of the alternatives consist of some form of traffic signal control. Signalized control of intersections can be divided into isolated, arterial, or network control. Special considerations for signalized control include diamond interchange operation, flashing operation, and right-turn-on-red. Other considerations for urban street control include dynamic lane use assignment, parking restrictions/prohibitions, and turn prohibitions.

1.0 Isolated Intersections

Signalized control at an isolated intersection operates independently of control at any adjacent intersections. Roadway characteristics, such as the number of approach lanes, traffic volumes, arrival patterns, and number of intersection approaches, are all factors used in determining the appropriate type of intersection control.

Full-actuated control is usually the most efficient type of operation at isolated intersections. When a decision is made to install a traffic signal, full-actuated control should be the first consideration. Pretimed control is best suited for locations where traffic is highly predictable and constant over a long period of time. However, predictable traffic flow does not usually exist at isolated intersections.

2.0 Arterial Street Control

Intersection control in an arterial system is comprised of two or more traffic signals whose operation is time-related. The major concern is the coordination of local controllers along an arterial street to ensure progressive traffic flow. The basic concept of arterial street control is that vehicles on the arterial are grouped in platoons and travel progressively from signal to signal with minimum impediment. Depending upon prevailing traffic demand, this progression may be oriented to one or both travel directions. The main objective is to establish and ensure a time relationship between the beginning of arterial greens at each of the locally controlled intersections, commensurate with progressive flow speed and desired direction, so that continuous traffic flow in defined platoons reduces the number of stops and delay along the arterial.

3.0 Network Control

In a network system, such as a typical central business district (CBD), crossing arterials form a grid pattern with virtually every intersection in the network requiring signal control. Because of the nature of this closely spaced arrangement of signals and a basic desire to provide arterial progression on all of the streets in each travel direction, the prevalent signal control is pretimed operation. Semi-actuated control is used in some network systems at midblock pedestrian signals and, less often, at lighter traveled intersections to provide left-turn protection on demand only.

The objective in the network system is to provide time relationships between the beginning of greens at each of the signalized intersections. The relationship is defined by a timing plan to optimize traffic performance for a given traffic pattern (e.g., inbound peak, balanced light flow, etc.). Provision of safe, orderly, and dependable flow with a minimum of stops and delays over a wide range of traffic volumes is the desired operational objective. Minimizing of queue spillback during high volume conditions is also desired.

4.0 Special Controls for Diamond Interchanges

Special controls are defined as traffic control applications for other than the standard control of signalized diamond interchanges. There are many variations of diamond interchanges: conventional full diamonds, half diamonds, split diamonds, and others. Chapter 3, Section 3, Segment 5.3 contains additional information on the different types of diamond interchanges. Diamond interchanges may or may not have frontage roads. Several operational problems can occur when diamond interchanges are signalized. One problem occurs when there is a spillback from one of the adjacent ramps through one of the signalized intersections. Another spillback that can influence operation is when the left-turn pocket overflows and spills back into a through lane, thus reducing the capacity available for through traffic. A third type of spillback is exit-ramp spillback. This occurs when a long queue of vehicles on the exit ramp backs onto the freeway, thus creating potential conflicts between high-speed freeway vehicles and stopped ramp vehicles. As a result of these factors, diamond interchanges are often controlled by diamond interchange controllers which are specifically designed for this purpose. Dynamic lane assignment (Chapter 10, Section 3, Segment 5.0) can also be used for controlling traffic at a diamond interchange.

5.0 Dynamic Lane Assignment

Turning movement demand at a diamond interchange varies during the day. Where the variability in turning movements becomes substantial, maintaining uncongested traffic conditions throughout the day is a challenging problem because lane assignments for turning movements are made on a permanent basis. Dynamic lane assignment provides the ability to change the lane assignments for turning movements according to the demand. Signs used in dynamic lane assignment applications have the potential to improve the capabilities of the traffic engineer to accommodate variations in traffic demand caused by both recurrent and non-recurrent congestion. Dynamic lane assignment is a fairly new concept and has not been widely used, but it has been very successful in limited field applications. Thus, dynamic lane assignment can now be treated as an acceptable control strategy.

Lane use information at intersections is presently conveyed to drivers via permanent traffic control devices such as pavement markings and lane control signs. The static nature of these traffic control devices results in the inefficient use of available capacity when wide variations in turning movements exist. This problem can become acute, especially on one-way frontage roads that may serve as alternate routes during incidents and pavement maintenance activities.

The concept of dynamic lane assignment is to change the turning movement assignments for each lane according to the demand for the turning movements. Figure 10-2 illustrates this concept. The use of dynamic lane assignment signing provides a more efficient means of responding to cyclical variations in turning movements, allowing lane usage to be optimized based on traffic demand. Dynamic lane assignment can be defined as "space management." When it is used in conjunction with "time management" (the use of demand responsive signal control); it can be a cost-effective alternative to the re-design of major intersections. Dynamic lane assignment can also be used to increase the through capacity of frontage roads in response to a freeway incident or special event.

The design and operation of internally lighted displays depend on basic "rules-of-thumb" and experience. Design procedures for dynamic lane assignment signs are not yet well established, due largely to the rapid development of these types of signs. Design procedures and requirements should take into account the visual capabilities of drivers in both daytime and nighttime driving conditions. Liability issues further mandate that dynamic lane assignment signing conform as closely as possible to the requirements of the MUTCD for signing. *Space Management: An Application of Dynamic Lane Assignment* describes some of the key issues and considerations associated with the use of dynamic lane assignment.

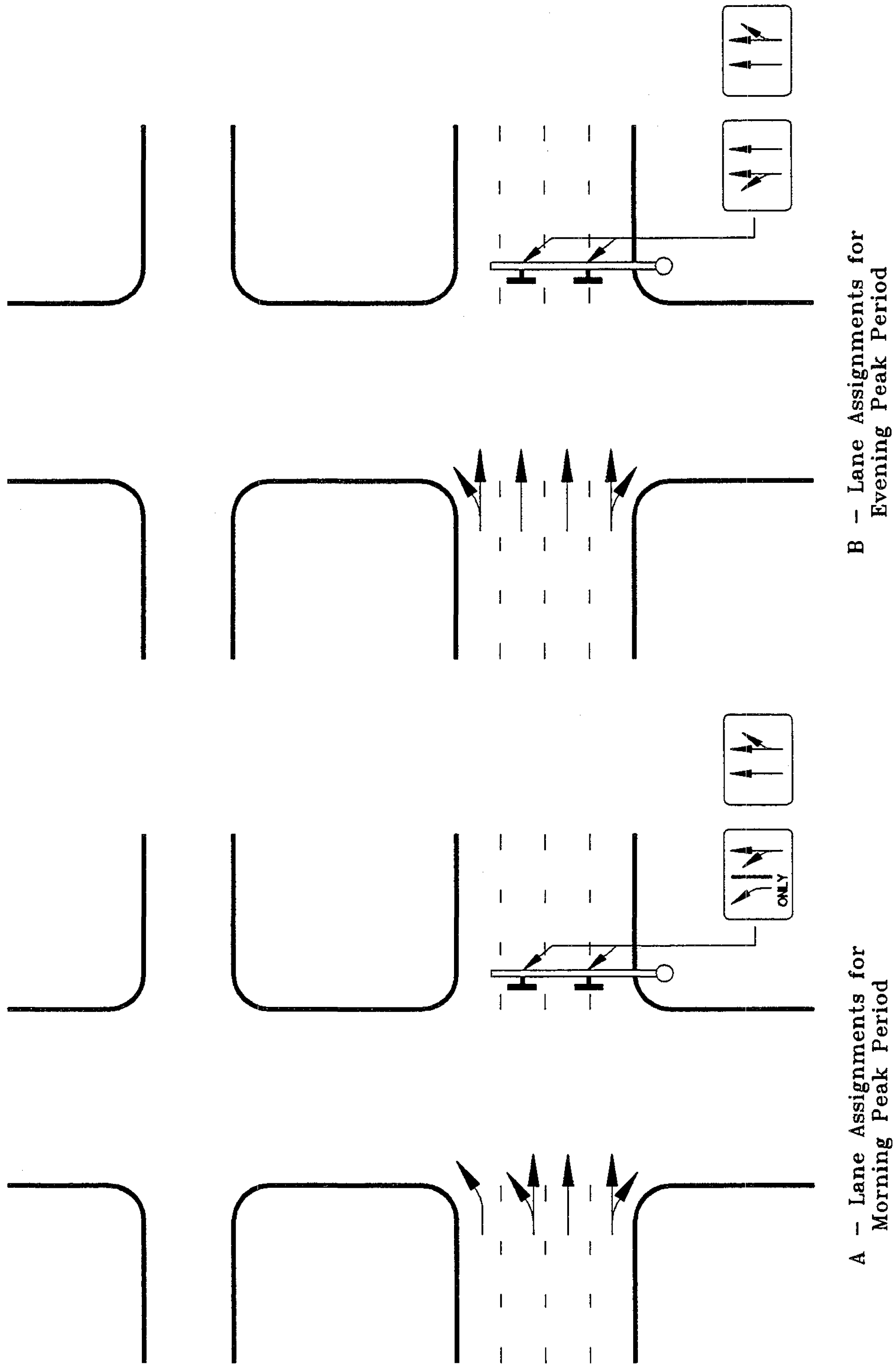


Figure 10-2. Dynamic Lane Assignment Concept

6.0 Flashing Signal Operation or Signal Removal

The traffic conditions which support the installation and operation of a traffic signal may not exist during all periods that the signal is operating, or the conditions may change over time as traffic patterns change. Two options available to address lower traffic volumes at signalized intersections are flashing operation or signal removal.

Signals may be placed in the flashing mode during temporary low-volume conditions. These conditions typically occur during late night or early morning periods. The *Texas Manual of Uniform Traffic Control Devises (TMUTCD)* states (section 4B-18) that pretimed traffic signals should be placed on flashing operation when traffic volumes drop to 50 percent of the warrant volumes for a period of four or more consecutive hours. This section of the *TMUTCD* also contains some guidance for placing signals in flashing operation.

In some cases, traffic demand at a signalized intersection decreases to a level where a traffic signal may not be the most effective means of controlling the intersection. There are no specific guidelines which address the traffic volume below which traffic signals are not appropriate. Instead, many factors must be considered before a traffic signal can be removed, including sight distance, site conditions, traffic volumes, accident impacts of removal, fuel savings, vehicular delay, and alternative improvements. The *TMUTCD* states (section 4C-2) that a traffic signal should not be continued in operation if the warrant requirements are not met. The *User Guide for Removal of Not Needed Traffic Signals* describes an analysis process for evaluating the impacts of removing a traffic signal at a specific intersection.

7.0 Right-Turn-On-Red

Texas law allows vehicles to turn right after coming to a stop when facing a red indication at a signalized intersection, if the turn can be completed in a safe manner, and if there are no signs prohibiting a right turn during the red indication. The right-turn-on-red (RTOR) maneuver provides an opportunity to increase the operational efficiency of a traffic signal by reducing the demand for a green indication. The use of RTOR is especially effective at locations with an exclusive right turn lane. Factors which impact the prohibition of the RTOR include sight distance, pedestrian traffic, bicycle traffic, conflicting traffic volumes, signal phasing, site conditions, and operational experience (i.e., safety problems).

8.0 Parking Prohibition

Prohibiting on-street parking may result in improved traffic operations on urban arterials, particularly in the vicinity of intersections. The advantages of removing on-street parking include increased street capacity resulting from the additional lane or the presence of the wider lane, removal of parking maneuver conflicts, and elimination of potential sight distance restrictions. When on-street parking is removed, consideration should be given to alternate parking areas, and how the relocation of parked vehicles will impact traffic operations.

9.0 Turn Prohibitions/Restrictions

Traffic operations at an intersection may be improved by prohibiting some turning movements. These prohibitions may be on a part-time or full-time basis. Turn prohibitions may be utilized due to insufficient intersection capacity for all turning and through movements, insufficient sight distance, or other site restrictions. Turn prohibitions are most often utilized at signalized intersections. One of the most beneficial applications of turn prohibitions is prohibiting left turns at signalized intersections during peak hours. This prohibition reduces the number of signal phases, thus increasing the operational efficiency of the signal. The prohibition may be applied to the peak direction of travel, the off-peak direction, or both. However, prohibiting left turns does not remove the driver's desire to turn left. Consideration should be given to how the relocation of left turns will impact operations at other locations and to determine that the problem has not been shifted to another location.

CHAPTER 11
INFORMATION SYSTEMS

This page intentionally left blank

3.3 When to Provide Information

There are two schools of thought as to when information should be provided. The first believes some type of information should always be provided by the system, regardless of whether or not there is any new information to be reported. The other school of thought believes information systems should be used only when users need to be notified of unusual or changing conditions.

By always providing some type of information, users are assured the system is operational and they will be informed when something occurs. The argument against this philosophy is that users will become complacent if no new information is provided, thereby limiting the effectiveness of the system when new information is provided.

The other school of thought believes information systems should be used only when users need to be notified of unusual or changing conditions. The philosophy of using information systems only when there is a need is based on human factor principles recommending against providing trivial or irrelevant information. The argument against this philosophy is that users do not know if the system is operational unless information is provided. However, both schools of thought agree it is better to display less or no information if the operator is unsure about the conditions on a facility.

3.4 User Reactions

Users may react differently to the same information depending upon their destination, their preferred mode or route choice, their familiarity with the potential options, and their trip purpose. How individual users react to information also depends upon the type, location, and magnitude of the changing conditions. Some of the reasons motorists react differently to information are:

- unfavorable experiences encountered when responding to past information,
- anticipated unsatisfactory conditions on alternate routes or modes,
- failure to receive or understand the information,
- importance of arriving on time at the current destination,
- time of day,
- unfamiliarity with recommended alternate routes or modes, and
- a lack of confidence in the information.

Research has shown that as much as 10 to 15 minutes of travel time savings must be perceived by motorists before they will divert to an alternate route during peak periods. Motorists may be less sensitive to time savings information during the peak travel periods than during the off-peak periods.

continued

3.4 User Reactions (continued)

Also, some users, such as heavy truck operators or hazardous materials haulers, may be prohibited by law or regulation from responding to the information. Whatever the reasons, some portion of the user population will not react to the information. However, many situations can be improved if only a portion of the users react to the information. Knowing the different ways users may react to information is a valuable asset of information systems.

3.5 Jurisdictional Information

Specific areas which will need to be addressed by transportation agencies in the future are:

- how inter-jurisdictional cooperation and integration of traffic data should be handled,
- what involvement transportation agencies should have in the dissemination and control of traffic information, and
- how information will be best distributed to motorists.

Inter-jurisdictional coordination is a requirement in any effective corridor or regional traffic management system to prevent data collection redundancies and to establish cooperative traffic management strategies among all of the various roadway facilities.

INFORMATION TECHNIQUES

Information can be presented either through static or dynamic devices. Static devices, such as regular traffic control signs and pavement markings, convey the same message to all users, regardless of the conditions. They are most commonly used at locations where the conditions are well-defined and the same response is desired all the time. The Texas Manual on Uniform Traffic Control Devices should be consulted for information dealing with static information devices.

With dynamic or variable systems, information can be altered to reflect changing roadway, traffic, or weather conditions. Dynamic systems are generally used to advise highway and transit users of unusual conditions and to provide recommendations on a course of action that not only benefits individual users, but also enhances the safety and operations of the transportation system as a whole. This section describes some of the existing techniques for providing travelers with information using dynamic systems.

1.0 Changeable Message Signs

Changeable message signs (CMSs) are perhaps the most commonly used technique for providing highway users with current roadway, traffic, and weather information. They are sometimes referred to as variable message signs or dynamic highway signs. Changeable message signs use visual words, numbers, or symbolic displays that can be electronically or mechanically varied to inform motorists of changing traffic conditions. Changeable message signing systems offer tremendous flexibility in types of messages that can be displayed to motorists. For this reason, CMSs are used in freeway and arterial traffic management systems. They are also used in traffic control systems for construction and maintenance work zones, and for special events. They may be either permanent or portable depending upon the type of service they are intended to provide, and can be operated either on a fixed time basis with on-site control or interconnected with a traffic management surveillance system to provide remote automatic control. The signs can be used to perform the following functions:

- Inform motorists of varying traffic, roadway, and environmental conditions.
- Provide more specific information relative to the location and delays associated with incidents.
- Advise motorists on ways to obtain additional information.
- Suggest alternate routes to avoid freeway congestion.
- Reassure drivers on unfamiliar alternate routes.
- Redirect diverted drivers back to freeways.

There are three basic types of CMS: Mechanical, Light Source, and Electromechanical. Each type has its own set of characteristics, advantages and limitations. Table 11-1 lists some of the CMS systems currently available. The *Traffic Control Systems Handbook*, *Manual on Real-Time Motorist Information Displays*, *Guidelines on the Use and Operation of Changeable Message Signs*, and *Guidelines on the Selection and Design of Messages for Changeable Message Signs* should be consulted for more information about the design and operating characteristics of each of type of CMS.

continued

1.0 Changeable Message Signs (continued)

Table 11-1. Types of Changeable Message Signs

MECHANICAL
Foldout - conventional sign with a hinged viewing face that is closed when not needed **Scroll** -flexible cloth or plastic material stretched between rollers **Rotating Drum** - 1 to 4 multifaced rotating drums with each face having a fixed message
LIGHT SOURCE
Neon or **Blank-out** - uses neon tubing to form the legend characters **Fiber Optics** - message formed by light energy dispersed through fiber bundles **Lamp (Bulb) Matrix** - message formed by an array of incandescent lamps **Light Emitting Diode (LED) Matrix** - similar to bulb matrix except uses LED lamps
ELECTROMECHANICAL
Electromagnetic Disc Matrix - legend characters formed by array of reflective discs **Electromechanical Flap Matrix** - matrix of electromechanically actuated flaps **Electrostatic Vane Matrix** - matrix of closely spaced iridium-coated aluminum vanes **Tri-color Sign** - matrix of rotating element with each face having one of three colors

2.0 Highway Advisory Radio

Although not as widely used as changeable message signs, Highway Advisory Radio (HAR) is another means of providing highway users with information. Information is relayed to highway users through the AM radio receiver in their vehicle. Users are instructed to tune their vehicle radio to a specific frequency via roadside or overhead signs. Usually, the information is relayed to the users by a pre-recorded message; although live messages can also be broadcast. Message transmissions can be controlled either on-site or from a remote location through telephone or radio interconnects. Most HAR systems operate at the 530 or 1610 kHz frequency level; however, any available frequency can be used as long as a low enough power level is used. A license from the Federal Communication Commission is required to operate a HAR system at high power levels (10 watts or greater). There are two types of HAR systems: vertical "whip" antenna systems and induction cable antenna systems.

2.1 Vertical Antenna Systems

Vertical "whip" antenna systems use individual antennas or a series of antennas electronically connected together to transmit information. The signal radiates from the antenna in all directions providing a circular area of transmission. Vertical antenna systems are small, easy to install, and can be placed within several hundred feet of the roadway. They are also less costly to purchase and install than induction cable systems. However, they are subject to damage by weather, accidents, and vandalism. They often require special equipment to ensure that the signal is stable, reliable, and easily tuneable. Also, because the information is broadcast in a circular zone of coverage, the signal may interfere with other coverage zones on the same or adjacent roadways.

4.0 Commercial Radio and Television (continued)

The primary disadvantage to using both commercial radio and television is the accuracy of the information. Because commercial radio and television stations have goals other than reporting traffic information, traffic reports often are transmitted only when normal scheduling permits. This may cause considerable time delays from when an incident occurs to when it is reported by the media. Often, many incidents go unreported or are cleared by the time they are reported on the radio or television. The accuracy of the information provided by commercial radio and television is a function of the time between the broadcaster's last communication with the incident reporting source and the number of incidents that have occurred and/or have been cleared during that time.

Public access television is a means of overcoming many of the disadvantages of privately owned media stations. Many city governments are responsible for franchising cable television service within the corporate limits of the city. As part of awarding the franchise to a company, many city governments stipulate that the cable company dedicate channels to be used solely by the public. Many city governments offer their own programming on one or more of these dedicated channels. Public access channels can be used by traffic management agencies to broadcast continuous traffic information during peak hours. Either "crawl" messages across the bottom of the screen or map displays accompanied by voice messages can be used to provide users with information. Traffic reports can also be provided by interrupting normal programming. The primary disadvantage of using public access television is that the information would be available only to cable subscribers. Travelers living outside the service area or not subscribing to the particular cable company would not have access to the information.

5.0 Citizen-Band Radio

Even though it was once considered an excellent means of providing motorists with two-way communications from their vehicle, Citizen-Band (CB) radio has declined in popularity in recent times. However, there are still a significant number of vehicles, particularly commercial vehicles and trucks, equipped with CB radios. In the past, CB radios have been used primarily in motorist-aid systems. A disabled or passing traveler broadcasts a request for assistance on Channel 9. The channel is monitored 24 hours a day, 7 days a week by a police or volunteer organization which dispatches aid to the stranded traveler. The primary advantage of a CB radio system is it permits two-way communication between the traveler and the response agency. Since the effective range of many CB radios is approximately 20 miles (depending upon geographic conditions), CB radio systems are particularly well-suited for rural, less populated areas. Signs should indicate an active CB monitoring area. Chapter 7, Section 4, Segment 4.2 contains information about using CB radio as a data communication tool.

6.0 Lane-Use Control Signals

Lane-use control signals (LCS) are typically used to control traffic on reversible-flow facilities. However, they can also be used on freeways to provide an advance indication of the status of freeway lanes and as a traffic management tool. In freeway applications, the LCS are placed above individual lanes to indicate whether the use of a specific lane or lanes is permitted or prohibited, or to indicate the impending prohibition of use. When one or more lanes are blocked, the LCS provide advanced warning of slow traffic conditions ahead, and advise the motorists which lanes are blocked. Although this does not prevent motorists from using the affected lanes on the approach to the scene, it can provide information on how many lanes are blocked which the motorist can use to determine if alternative routes should be taken. Other conditions, such as lost loads, debris, high water, or pavement failures also warrant the use of LCS. LCS should not be used unless the conditions can be verified.

Some of the LCS applications described in the Texas MUTCD with respect to freeway operations include:

- On a freeway, where it is desired to keep traffic out of certain lanes at certain hours to facilitate the merging of traffic from a ramp or other freeway.
- On a freeway near its terminus, to indicate a lane that ends.
- On a freeway or long bridge to indicate a lane which may be temporarily blocked by an accident, breakdown, etc.

The Texas MUTCD currently recommends the following three LCS symbols for use in freeway traffic management applications:

- Steady Red X - Indicates that the lane below the indication is closed to traffic.
- Green Down Arrow - Indicates that the lane below the indication is open to traffic.
- Steady Yellow X - Indicates that the lane below the indication is about to close (steady red X display) or is experiencing congestion ahead.

When LCS's are used to indicate a complete freeway closure, a green arrow should be displayed over the shoulder lane and red X's over the remaining lanes. This array display proved to be less confusing to drivers as it indicates that they should move to the right side of the freeway, from which police can direct them onto the frontage road. An array with only red X's does not provide drivers an option regarding the correct travel lane to be in.

The mounting location of the LCS over travel lanes can create parallax problems for drivers when viewing them on a curve (LCS will appear displaced one or more travel lanes). To avoid this confusion, LCS should be mounted on tangent freeway sections to facilitate correct association of LCS displays with the lane for which they are intended.

continued

6.0 Lane-Use Control Signals (continued)

Part of the traffic control plan for a freeway work zone may include the operation of lane-use control signals (LCS) in advance of the site. The advanced warning provided by these signals can be helpful in establishing the work zone, as well as providing information during maintenance and construction activities.

When selecting LCS signal heads, consideration should be given to providing the capability of displaying a downward diagonal yellow arrow. Evaluations of the diagonal yellow arrow have found that it provides drivers with useful information. As a result, it may be adopted for use in future LCS installations.

This page intentionally left blank

CHAPTER 14
ANNOTATED BIBLIOGRAPHY

The publications described below are sources of information that the engineer may consult to obtain more detailed material about specific subjects. These publications are listed in alphabetical order by title. They may be purchased from the organization at the appropriate address (addresses are at the end of the annotated bibliography) or they may be borrowed from the D-10R Library.

Texas guidelines or standards may be different than those contained in the publications described below. Therefore, the following publications should be used for informational purposes only. In the case of conflicts between Texas guidelines or standards and those found in the following publications, the Texas guidelines or standards should be used. Consult the appropriate TxDOT Division if appropriate guidelines or standards cannot be found.

A Policy on Geometric Design for Highways and Streets. *American Association of State Highway and Transportation Officials, Washington, D.C., 1990.*

Addresses the geometric features of rural and urban highway design. Contains design practices in universal use as the standard for highway geometric design. Also known as the "*Green Book.*"

Alternative Surveillance Concepts and Methods for Freeway Incident Management: Volume 3 - Computational Example for Selecting Low-Cost Alternatives. *FHWA-RD-77-060. Federal Highway Administration, Washington, D.C., March 1978.*

This report is the third of six volumes describing a research study which identified low-cost incident management systems for responding to freeway disturbances. Volume 3 gives police, highway, and traffic engineering personnel an easy to follow example of the methodology used to conduct freeway incident management analysis.

Communications in Traffic Control Systems: Volume 2 - Final Report. *FHWA-RD-88-012. Federal Highway Administration, Washington, D.C., August 1988.*

This report provides understandable information on communications in general and on specific communications technologies to those persons involved in the planning, design, and implementation of computer-based traffic control systems.

Decision Sight Distance for Highway Design and Traffic Control Requirements. *FHWA-RD-78-078. Federal Highway Administration, Washington, D.C., February 1978.*

This report describes a research project intended to relate the decision sight distance concept to specific road types, design speeds, traffic operating conditions, geometric features, and driver attributes. Recommendations are presented on the decision sight distance criteria, and its application for design and traffic operations.

Formulation of Guidelines for Locating Freeway Sensors. *FHWA-RD-78-137. Federal Highway Administration, Washington, D.C., December 1979.*

This report develops guidelines and procedures for specifying the optimum location and spacing of sensors for detecting freeway incidents. Major emphasis is placed upon assessing the tradeoffs between costs and effectiveness of a variety of candidate sensor configurations.

Framework for Developing Incident Management Systems. *WA-RD 224.1. Washington State Department of Transportation, Olympia, Washington, August 1991.*

This document serves to provide guidance for managing incidents by discussing the process of developing and implementing an incident management system. Specific information, including technique description, relative costs and benefits, operational requirements, and funding variations, is given for each incident management technique described in this report.

Guide for the Design of High-Occupancy Vehicle Facilities. *American Association of State Highway and Transportation Officials, Washington, D.C., 1991.*

The information contained in this guide will be useful for location and design of high-occupancy vehicle lanes. It will also serve as a basis for further refinement as operational experience dictates.

Guidelines for Planning, Designing, and Operating Bus-Related Street Improvements. *Research Report 1225-2F. Texas Transportation Institute, College Station, Texas, August 1990.*

The guidelines in this report address the following aspects of bus-related street improvements: 1) bus service planning, 2) bus facility design, and 3) bus service operations.

Highway Capacity Manual, Special Report 209. *Transportation Research Board, Washington, D.C., 1985.*

This manual is a collection of techniques for estimating highway capacity as the capacity relates to a particular quality or level of service. Portions of the manual address capacity principles, freeways, rural highways, and urban streets. This is the 3rd edition of the Highway Capacity Manual, and reflects a level of sophistication and understanding that will allow more precise and accurate analysis of highway facilities and operating conditions thereon. Some of its procedures are radically different than the 1965 edition.

Highway Design Division Operations and Procedures Manual. *Texas Department of Transportation, Austin, Texas, revised to 1987.*

This manual, also known as the Design Manual, contains the procedures and standards for the geometric design of Texas highways.

Advanced Freeway System Ramp Metering Strategies for Texas. *Research Report 1232-23. Texas Transportation Institute. College Station, Texas, October 1993.*

This report identifies and examines a microcomputer-based optimization scheme that can assist in developing efficient freeway control strategies for on-line freeway surveillance and control. A multi-level freeway control structure is employed for which ramp metering control algorithms are developed for each level of control. Flow-based and lane occupancy-based system algorithms are presented. Detailed data file requirements are provided for each control level.

Communications Handbook for Traffic Control Systems. *FHWA-SA-93-052. Federal Highway Administration, Washington, D.C., April 1993.*

This handbook was written to enable transportation engineers to plan, select, design, implement, operate, and maintain communications systems for traffic control. The handbook provides information on communications media, system architecture, decision-making processes, and trade-off analyses. The handbook will serve as a guide for agencies wishing to initiate a traffic control system that incorporates functional, effective, reliable, and economical communications, and to update and modernize an existing communication system for traffic control.

Driver Interpretation of Existing and Potential Lane Control Signal Symbols for Freeway Traffic Management. *Research Report 1298-1, Texas Transportation Institute, College Station, Texas, November 1993.*

This report documents the results of laboratory studies to assess motorist interpretations of the following symbols used or initially viewed as potential freeway lane control signals: red X, yellow X, green down arrow, yellow diagonal arrow, yellow down arrow, circle with a slash, and a red X superimposed on a green arrow. The effects of flashing indications on motorist interpretation were also evaluated.

Guidelines on the Use and Operation of Changeable Message Signs. *Research Report 1232-9. Texas Transportation Institute, College Station, Texas, November 1992.*

This report is a primer on the characteristics that affect the design, use, and operations of changeable message signs, and provides guidance on the selection of the appropriate type of display. This report is an update and consolidation of *Manual on Real-Time Motorist Information Displays* (FHWA-IP-86-016), *Guidelines on the Use of Changeable Message Signs* (FHWA-TS-90-043), and *Portable Changeable Message Signs at Work Zones* (TTI 292-4).

Guidelines on the Selection and Design of Messages for Changeable Message Signs. *Research Report 1232-10. Texas Transportation Institute, College Station, Texas, November 1992.*

This report presents guidelines on the design of changeable message sign messages for use in freeway corridors for incident management and route diversion. It is a companion to *Guidelines on the Use and Operation of Changeable Message Signs* (TTI 1232-9).

Incident Response and Clearance in the State of Texas: Case Studies of Four Motorist Assistance Patrols. *Research Report 1232-15. Texas Transportation Institute, College Station, Texas, October 1992.*

This report contains case study analyses of four motorist assistance patrol programs in Texas. It also contains discussions of the four incident response and clearance strategies most often pursued by various agencies in the state. This report provides useful insight into the various political and organizational attributes that need to be considered when developing a motorist assistance program.

Planning Guidelines for Major Transportation Emergencies. *Research Report 1231-3F. Texas Transportation Institute, College Station, Texas, November 1991.*

This report presents guidelines as to how transportation agencies can better prepare to handle major transportation emergencies. It is a planning document which will facilitate an agency's ability to maintain and even enhance mobility before, during, and after an emergency. Topics addressed include transportation system evaluation, intraagency and interagency coordination, resource assessment and management, and public communication and notification.

Space Management: An Application of Dynamic Lane Assignment. *Research Report 1232-18, Texas Transportation Institute, College Station, Texas, March 1993.*

This report presents the findings of research on dynamic lane assignment. Issues addressed in the research include testing the sign for human factor measures such as legibility and target value, operational parameters such as sign brightness and light output, and sign placement relative to traffic signals. The report also describes the results of field tests of dynamic lane assignment.

NAMES AND ADDRESSES OF ORGANIZATIONS

American Association of State Highway and Transportation Officials
444 N. Capitol Street, N.W., Suite 225
Washington, D.C. 20021
(202) 624-5800

Federal Highway Administration
Turner-Fairbank Highway Research Center
RD&T Report Center HRD-11
6300 Georgetown Pike
McLean, Virginia 22101-2296
(703) 285-2144

Institute of Transportation Engineers
525 School Street, S.W., Suite 410
Washington, D.C. 20024-2729
(202) 554-8050

ITS America
400 Virginia Avenue, S.W.
Suite 800
Washington, D.C. 20024-2730
(202) 484-4847

Texas Department of Transportation
125 East 11th Street
Austin, Texas 78701-2483

Texas Transportation Institute
Texas A&M University System
College Station, Texas 77843-3135
(409) 845-1734

Transportation Research Board
2101 Constitution Avenue, N.W.
Washington, D.C. 20418
(202) 334-3214

Washington State Department of Transportation
Transportation Building KF-01
Olympia, Washington 98504

This page intentionally left blank

CHAPTER 15
INDEX