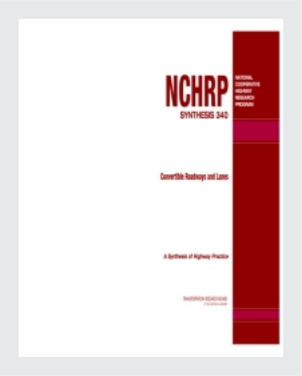

Convertible Roadways and Lanes

DETAILS

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NCHRP

SYNTHESIS 340

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Convertible Roadways and Lanes

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

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NCHRP SYNTHESIS 340

Convertible Roadways and Lanes

A Synthesis of Highway Practice

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Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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FOREWORD

By Staff
Transportation Research Board

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice*.

The synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

This report of the Transportation Research Board will be of interest to transportation agencies, as well as to others in the transportation community who are interested in reversible roadways and operations. The synthesis was undertaken to address the need for an increased level of understanding relative to convertible and reversible lane use. With a better understanding of their characteristics and operational requirements, costs, and benefits, such strategies might be more effectively implemented in the future.

Forty-nine states and local transportation, law enforcement, and emergency management agencies responded with survey information, indicating that 23 of these agencies were using one of more forms of reversible lane operations. A review of published literature and other "difficult-to-access" reports and studies was undertaken, as well as a survey of current and recent practice. Finally, field visits and discussions with practitioners yielded additional information that was used to identify seven specific examples of the variety of design and control characteristics that can make reversible land operations possible.

A panel of experts in the subject area guided the work of organizing and evaluating the collected data and reviewed the final synthesis report. A consultant was engaged to collect and synthesize the information and to write this report. Both the consultant and the members of the oversight panel are acknowledged on the title page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

CONVERTIBLE ROADWAYS AND LANES

SUMMARY

It is no secret that the level of traffic congestion on the nation's roadways continues to increase. Numerous reports and studies have shown that the steady growth in traffic volume has resulted in ever-growing societal and environmental costs associated with delay, pollution, and driver frustration. Although a seemingly endless stream of methods have been proposed to address these problems, including the construction of new roads, use of advanced transportation management systems, and increasing use of transit and travel demand management programs, each method comes with significant monetary costs and, perhaps more importantly, a significant shift in the way personal transportation is funded and used.

The development of new roadways and the conversion of existing ones that can be adapted for different uses at different times of the day has been one method used by transportation agencies to more cost-effectively accommodate the constantly changing needs of highway travel. Convertible roadways encompass a variety of techniques that afford an agency an added measure of flexibility in how and when it responds to the needs for more on-street parking, additional intersection turning lane capacity, and short-term corridor capacity. Originally, the intent of this report was to synthesize information related to convertible lanes. However, owing to the lack of readily accessible information within that topic, the scope of the synthesis was narrowed to primarily cover reversible roadways and lanes, one of the largest and more well-documented subsets of convertible facilities.

Reversible traffic operations are widely regarded as one of the most cost-effective methods to increase the capacity of an existing roadway. The principle of reversible roadways is to configure the lanes of a roadway to match available capacity to the traffic demand. These roadways are particularly effective because they take advantage of the unused capacity in the minor-flow direction lanes to increase the capacity in the major-flow direction, thereby eliminating the need to construct additional lanes. They are most effective when highly unbalanced directional flows are present, such as those that occur during daily peak-period travel times, before and after large events, and during emergency evacuations.

The relatively simple concept of reversible flow roadways belies their actual complexity and complicated operational requirements. They can require considerable effort to plan and design, and they often require special control and management strategies to keep traffic moving safely and efficiently. Surprisingly, despite the long history and widespread use of reversible roadways worldwide, there have been few quantitative evaluations and research studies conducted on their performance. There are also a limited number of published guidelines and standards related to their planning, design, operation, control, management, and enforcement. Therefore, most reversible lane systems have been developed and managed based primarily on experience, professional judgment, and empirical observation. The limited availability of standardized and formalized practices has resulted in considerable variation within the practices, philosophies, and policies associated with their use. Furthermore, many of the actual costs and benefits of reversible lane systems remain largely unexplored, which may in turn mean insufficient understanding of their operational and safety effects.

This synthesis was undertaken to address the need to increase the level of understanding of reversible roadways and to improve the knowledge of their characteristics and operational requirements, costs, and benefits so that reversible operations can be more effectively implemented in the future. The synthesis documents the historical development of reversible lanes, applications for various needs, lessons learned from previous implementation, costs and benefits associated with their use, and various techniques and successful practices that have been developed. The report was based on previous research and evaluation studies, a survey of known and potential users of reversible lanes, and informal interviews with representatives of highway agencies that currently use them.

Four main findings of reversible lane and roadway use were revealed. The first was how common is its use. Reversible lane operations in one form or another are currently (or have been) used in nearly every large city and many small- to medium-size cities in the United States.

Second, there was a general agreement on the conditions that warrant reversible operations and the basic requirements for their effective use. The conditions that warrant reversible operation include volumes at or near capacity, predictable patterns of high demand and/or congestion, limited right-of-way (or ability to acquire it) to construct additional lanes, ratios of primary directional volume to secondary directional volume of approximately 2:1 or greater, and inadequate capacity or mobility on adjacent parallel streets.

Third, there was a wide variety in the design, control, and management methods used to plan and operate reversible roadways. Of the more than 20 locations reviewed as part of the study, no two were alike in their key design, control, or management features. This variability was likely related to a lack of established standards and guidelines for their use.

The fourth finding of the synthesis was the extent to which the benefits and costs of reversible roadway operations are not well understood. Although a handful of comprehensive studies exist in the literature, they do not provide a basis for determining the applicability and effectiveness of reversible lane use in most locations. One significant gap in knowledge exists in the understanding, measurement, and assessment of the fundamental characteristics of reversible traffic streams. Currently, some of the most basic characteristics of reversible lanes, including their capacity, remain unknown. This lack of understanding has led to an inability to accurately assess the benefits (or drawbacks) of reversible lane alternatives and may contribute to the widespread reluctance to implement new reversible facilities and discontinue many of those in use today.

CHAPTER ONE

INTRODUCTION

BACKGROUND

Convertible lanes and roadways encompass a wide variety of facilities on which traffic operations are adjusted at different times to adapt to changing traffic conditions. The modifications might require changes to the direction of flow, the types of vehicles permitted in certain lanes, and the types of maneuvers (through, turning, parking) that are allowed. The conversions might take place in a single lane, the entire roadway, or even on the shoulders. Such changes from one use to another may occur periodically throughout the day or on certain days of the week. The changes may also occur on an occasional basis, on a few rare occasions, or during several planned events a year. The manner in which convertible roadways are operated also varies widely. Some roadways have been controlled through nothing more than traffic signs, whereas others require complex computer-controlled lane use signals and automated barricade systems. Their lengths have been as short as a city block and longer than 100 mi.

One simple type of lane conversion takes place nearly unnoticed every day when on-street parking on urban arterial roadways is prohibited so that the lane can be used for an extra lane of travel during peak-period travel time. More complex examples of convertible roadways include bridges and tunnels that allocate lanes based on the level of directional traffic demand, freeways that reserve lanes for buses or high-occupancy vehicles (HOV) during certain times of the day, tollbooth approaches that accommodate vehicles from either direction, and intersection approaches that convert lanes to serve various directional movements at different times of the day.

Among the most widely applied type of convertible roadways are reversible lane highways. The ITE defines a reversible lane system simply as having an operation in which “one or more lanes are designated for movement one-way during part of the day and in the opposite direction during another part of the day” (ITE 1997). Under certain conditions, a system may even include shoulders or other areas of the roadway cross section that would normally be dedicated to carrying traffic in one direction to accommodate traffic in the opposing direction. The goal of reversible roadways is to provide additional capacity for periodic unbalanced directional traffic demand, while minimizing the total number of lanes on a roadway. One commonly cited example of a multilane reversible highway is a segment of Outer Drive in Chicago, Illinois, in which the eight-lane roadway operates with a 6–2 directional lane split during peak-period travel times.

The relatively simple concept of reversible flow roadways, however, belies their actual complexity and operational requirements. Although widely regarded to be one of the most cost-effective methods for increasing the capacity of an existing roadway, the reversal of traffic flow can require significant investments in traffic control and enforcement. It can also require considerable effort to plan and design facilities for this use. In addition, if not carefully planned, designed, and managed, convertible roadways can be hazardous locations for both vehicular and pedestrian traffic.

OBJECTIVES

Despite the long history and widespread use of reversible roadways throughout the world, there have been relatively few quantitative evaluations and research studies conducted on their performance. Similarly, there is also a comparatively limited amount of published information available on issues related to their planning, design, operation, control, management, and enforcement. Therefore, the majority of reversible lane systems that have been used have been developed and managed based primarily on experience, professional judgment, and empirical observation. The limited availability of standardized and formalized practices has also resulted in considerable variation within the practices, philosophies, and policies associated with their use. In turn, many of the actual costs and benefits of reversible lane systems remain largely unexplored and may have even contributed to an increase in traffic accidents, reduced efficiency, and misallocation of resources.

The motivation for undertaking this synthesis was to address the need to enhance the understanding within the transportation community relative to convertible and reversible lane use. Better knowledge of their characteristics and operational requirements, costs, and benefits, may result in the systems’ being more effectively implemented in the future.

This synthesis report will provide those seeking to develop new, reversible facilities or to improve existing ones, with a single-source document on the current state of the practice and descriptions of operational strategies that are in use or have been used. It also documents the historical development of reversible lanes, their application for various types of needs, lessons learned from previous implementation, costs and benefits associated with their use, and various techniques and successful practices that have been developed.

METHODOLOGY

This synthesis was conducted in three main parts. The first, a review of existing literature, covered two separate although closely related sources of information. The first were the traditional sources of technical information, including scientific and practitioner-oriented journals, conference compendiums, trade publications, research project reports, and nontechnical reports. This effort was undertaken by using various library search services and the National Transportation Library's Transportation Research Information Service. The second was a review of the "gray literature," including unpublished planning studies for local communities; various department of transportation (DOT) reports; law enforcement and emergency management operational manuals; and other location-specific, difficult-to-access reports and studies.

The second part was a survey of current and recent practice conducted by means of a questionnaire developed primarily to determine the number, location, and nature of reversible lane applications throughout the United States and Canada and, to a lesser extent, overseas. The questionnaire was also used to gauge some of the general trends and philosophies that have existed within this traffic management strategy.

Both the survey and the literature review were integral to the third and last step of the synthesis, which included field visits and discussions with practitioners where reverse-flow lanes have been used. These interviews and site visits were a key component of the synthesis effort because they permitted a firsthand review of the facilities and their operations. They also permitted more specific questions to be answered and copies of plans and reports to be obtained.

SYNTHESIS ORGANIZATION

This synthesis report features seven chapters that describe the history and practices associated with reversible lanes and roadways. Where appropriate, the information is presented in chronological order to illustrate the development of convertible lane use and its associated issues over time.

Chapter two summarizes the general concepts and objectives of reversible flow facilities. It includes a brief history of their development and some of the key terms that are associated with their use. Chapter three focuses on the planning and design of reversible facilities. The first half of the chapter pays particular attention to the warrants and criteria for reversible roadways, as well as some of the operational policies that often must accompany their use. The second half concentrates on the design aspects of reversible roadways, including the various standards, criteria, and philosophies that have governed the design of new facilities, as well as the adaptation of existing nonreversible roadways for reversible operation. The material presented in the design sections includes discussions at both overall system level and local facility level. Chapter four synthesizes information related to the management, control, and enforcement of reversible facilities. This chapter includes strategic management and control techniques as well as the application of specific control devices. Particular attention is paid to the primary locations and time periods that are associated with the transition of flow from one direction to the other. Chapter five focuses on the performance assessment of reversible roadways, including the determination of their costs and benefits. That chapter synthesizes both the measures of performance and the analytical methods used in assessing the operational and safety aspects. Chapter six synthesizes the current state of practice, summarizing the results of the survey, and it presents six different applications of reversible flow facilities. The conclusion, chapter seven, summarizes the major findings of the synthesis effort as well as some of the lessons learned, examples of successful practices, and needs and suggested areas of future research. The project survey questionnaire is included in Appendix A, and the results gathered from the survey are summarized in Appendix B.

CHAPTER TWO

BACKGROUND

For approximately 75 years, many different forms of reversible roadways have been used throughout the world to address a variety of needs. The three principal uses have been to accommodate the demand associated with frequent and predictable unbalanced peak-period travel times, infrequent planned events of varying duration, and emergency conditions such as evacuations. One of the earliest referenced uses of reversible roadways was in Los Angeles in 1928, with a convertible lane variant known as off-center lane movement (Dorsey 1948). The history of reversible flow use shows that its popularity on arterial roadways in urban areas increased significantly from the 1940s to the 1960s with the widespread construction of freeways. Later uses of reversible lanes during the 1970s were associated with freeways, bridges, and tunnels both in the United States and overseas, particularly in Europe and Australia. During the late 1970s and 1980s, reversible lane systems were used more extensively in conjunction with managed lane facilities such as HOV lanes on freeways and exclusive reversible bus lanes in urban population centers. Though the situation is not as well documented, it is also known that reversible lane operation has been widely used for dealing with special event directional traffic scenarios, such as those associated with large sporting events, concerts, and festivals. The most recent interest in reversible lanes in the United States has been sustained since 1999, in the form of freeway contraflow for hurricane evacuation.

Table 1 lists the locations and names of reversible facilities identified during the preparation of this report. Admittedly, this list is by no means comprehensive; however, it illustrates the characteristics of reversible facilities currently or recently in operation. Additional online sources of information on reversible lanes were also identified. They include a listing of existing and proposed HOV facilities with and without reversible operations, available online at http://hovpfs.ops.fhwa.dot.gov/inventory/inventory.htm.

The conceptual layout of all reversible segments is generally similar. However, the specific design of any particular facility varies significantly based on the goals, topography, and traffic characteristics of the local area. Two of the primary considerations that control the design and operational characteristics of reversible lane segments are the distance over which the reversible length segment will be used and the times during which it will be used. These distances and times also include the transition segments and time periods to reverse the flow direction back and forth from normal operations. The following sections provide a general discussion of some spatial and temporal characteristics.

SPATIAL CHARACTERISTICS

Lathrop (1972) generalized the configuration of reversible roadway segments within the context of five zones, illustrated and numbered in Figure 1. Zone 1 is regarded as the approach zone. In this zone, drivers need to be informed that a reversible roadway is ahead. Information given to drivers should include how many and which lanes are open and available to them. Zone 2 is the decision zone whereby drivers must move into or out of the reversible lanes. That area is often regarded as the most potentially hazardous, because merging and weaving movements are occurring and the number of lanes is changing; therefore, it needs to be carefully designed. In Zone 3, drivers continue in the normal and reversible lanes. Typically, various traffic control devices are used to remind drivers about which lanes are open for use in each direction. Adequate control in Zone 3 is critical, because opposing traffic may exist in an adjacent lane, increasing the risk of head-on collisions. The transition from the reverse flow lanes back to the normal lanes occurs in Zone 4. As is the case with Zone 2, the length of Zone 4 must be properly designed, because converging maneuvers will be taking place within that area. In Zone 5, traffic departs the reversible section and continues in normal flow patterns.

Given the space requirements for reversible lane use, it is surprising that many reversible lane segments have actually been quite short. A review of reversible lane facilities in Great Britain showed that 11 of the 15 reversible lane systems in use were 1 km (0.62 mi) or less, with two spanning just 300 m (328 yd) (McKenna and King 1987). One of the factors that often constrain the overall length of a reversible segment is the frequency of intersecting roadways along its length (this will be discussed in more detail in chapter three). The length of reversible segments in the United States has varied more significantly, from approximately 1 km (0.62 mi) to more than 240 km (150 mi) in the case of contraflow segments for evacuations.

From an operational standpoint, the most critical areas of reversible segments are the transition zones. For reversible lanes to be effective, the capacity of the transition sections must accommodate the increased volume, or else the reversible effort is naught. Several reversible lane segments

TABLE 1

REVERSIBLE FLOW FACILITIES AS REPORTED BY SURVEY RESPONDENTS

	Location		Highway Name	Facility Type	Reversible Segment Length (miles)	No. of Lanes		Control Strategy	Purpose	Frequency of Use	Duration of Reverse Operation	Managing/Operating Agency	Status
	City	State			(approx.)	Total	Reversible Config.(s)				(approx.)		
1	Mobile to Montgomery	AL	Interstate 65 (northbound)	Freeway	135	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	AL State Police & DOT	Active
2	San Diego	CA	Interstate 15	Freeway	8	2	2:0	Overhead signs Automated Delineation	Commuter Traffic (HOV lane)	Daily AM/PM	7 h each way	CA DOT	Active
3	San Diego	CA	State Route 75	Expressway	2.3	5	3:2	Moveable Barrier	Commuter Traffic	Daily AM/PM	4 h each way	CA DOT	Active
4	Summit County	CO	Interstate 70 - Eisenhower Tunnel	Freeway Tunnel	2	4	3:1	Roadside Signs/Overhead Signals	Weekend "Recereational" Traffic	10-12 times/year	4--5 h	CO DOT	Non-active
5	Washington	DC	Canal Road	Minor Arterial	3	2	2:0	Roadside Signs/Signals	Commuter Traffic	Daily AM/PM	2.5 h	District DOT	Active
6	Washington	DC	Connecticut Avenue	Arterial	2.5	6	4:2	Roadside Signs/Pavement Markings	Commuter Traffic	Daily AM/PM	2.5 h	District DOT	Active
7	Washington	DC	Rock Creek Parkway	Arterial	4	4	4:0	Roadside Signs and Traffic Enforcement Police	Commuter Traffic	Daily AM/PM	2.5 h	District DOT	Active
8	Jacksonville to Tallahassee	FL	Interstate 10 (westbound)	Freeway	180	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	FL State Police & DOT	Active
9	Pensacola to Tallahassee	FL	Interstate 10 (eastbound)	Freeway	180	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	FL State Police & DOT	Active
10	Florida State Rd. (SR) 520 to SR 417	FL	SR 528---The Beeline Expressway (westbound)	Freeway	20	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	FL State Police & DOT	Active
11	Tampa to Orange Co.	FL	Interstate 4 (eastbound)	Freeway	110	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	FL State Police & DOT	Active
12	Charlotte Co. to I-275	FL	Interstate 75 (northbound)	Freeway	85	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	FL State Police & DOT	Active
13	Ft. Pierce to Orlando	FL	Florida Turnpike	Freeway	75	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	FL State Police & DOT	Active
14	Ft. Lauderdale to Naples (and vice-versa)	FL	Interstate 75---Alligator Alley	Freeway	100	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	FL State Police & DOT	Active
15	Savannah to Dublin	GA	Interstate 16 (eastbound)	Freeway	120	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	GA State Police & DOT	Active
16	Peoria	IL	McClugage Bridge	Freeway	0.75	3	2:1	Moveable Barrier	Construction Zone Commuter Traffic	Continuous	3 h	IL DOT	Non-active
17	Lexington	KY	Nicholasville Road	Major Arterial	2.6	5	3:1:1	Overhead Signs/Signals	Commuter Traffic	Daily AM/PM	2 h	KY DOT	Active
18	Baton Rouge	LA	Highland Road	Minor Arterial	1.5	2	2:0	Traffic Enforcement Police	Planned Events (LSU football games)	Seasonal (as needed)	1--2 h	Baton Rouge Police Department	Active
19	New Orleans	LA	Interstate 10 (westbound)	Freeway	20	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	LA State Police & DOT	Active
20	New Orleans, LA to Hattiesburg, MS	LA, MS	Interstates 10 & 59 (northbound)	Freeway	115	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	LA/MS State Police & LA/MS DOTs	Active
21	Ocean City to U.S. 50	MD	MD-90	Primary Arterial	11	2	4:0 (w/shldrs)	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	MD State Police & DOT	Active
22	Washington DC Metro Area	MD	MD-97 Georgia Avenue	Arterial	0.5	6	4:2	Pavement Markings	Commuter Traffic	Daily AM/PM	5 h	MD DOT	Active
23	Washington DC Metro Area	MD	US-29 Colesville Road	Arterial	1	7	5:2	Overhead Signs/Signals, and Pavement Markings	Commuter Traffic	Daily AM/PM	2--3 h	MD DOT	Active
24	Anne Arundel Co.	MD	MD-77 Mountain Road	Arterial	1.5	3	2:1	Overhead Signs/Signals, and Pavement Markings	Commuter Traffic	Daily AM/PM	2-3 h	MD DOT	Active
25	Baltimore	MD	Erdman Avenue	Arterial	1	3	2:1	Overhead Signals and Pavement Markings	Commuter Traffic	Daily AM/PM	2--3 h	MD DOT	Active
26	Baltimore	MD	Hanover Street Bridge	Arterial	0.5	4	3:1	Overhead Signals and Pavement Markings	Commuter Traffic	Daily AM/PM	2--3 h	MD DOT	Active
27	Annapolis Area	MD	US-50/301Bay Bridge	Freeway Bridges	5	5 total 2 one-way bridges (3-lane and 2-lane)	2:1 on the 3-lane bridge and 1:1 on the 2-lane bridge	Overhead Signs/Signals, and Pavement Markings	Commuter Traffic, Recreational Traffic, and Bridge Maintenance	Daily AM/PM	2--3 h	MD DOT	Active
28	Washington DC Metro Area	MD	US-29 and I-495	Arterial and Freeway	4 and 7	-na-	Shoulders	None	Transit Bus	Daily AM/PM	2--3 h	MD DOT	Active
29	Washington DC Metro Area	MD	Brightside Road	Arterial	0.75	5 and 6	4:1, 5:1, 3:2, and 4:2	Overhead Signs/Signals	Planned Events (Washington Redskins football games)	Seasonal (as needed)	2--3 h	MD DOT	Active
30	Flint	MI	Interstate 75	Freeway	5.5	5	3:2	Moveable Barrier	Construction Zone "Recereation" Traffic	Continuous	3--4 days	MI DOT	Active
31	Deaborn	MI	Michigan Avenue	Arterial	3	6	4:2	Roadside Signs/Overhead Signals	Commuter Traffic	Daily AM/PM	3 h	MI DOT	Non-active
32	Pontiac	MI	Opdyke Road	Arterial	2	5	5:0	Overhead Signals/Traffic Enforcement Police	Planned Events (Detroit Lions football games)	Seasonal (as needed)	1--2 h	Oakland Co. Rd. Commision & Sheriff's Dept.	Non-active
33	Charlotte	NC	Tyvola Road	Major Col/Dist	3.5	5 and 6	4:1 and 6:0	Overhead Signals/Traffic Enforcement Police	Planned Events (Charlotte Hornets basketball games)	Seasonal (as needed)	1--2 h	Charlotte Dept. of Public Works & Police Department	Non-active

TABLE 1 (*Continued*)

	Location		Highway Name	Facility Type	Reversible Segment Length (miles)	No. of Lanes		Control Strategy	Purpose	Frequency of Use	Duration of Reverse Operation	Managing/Operating Agency	Status
	City	State			(approx.)	Total	Reversible Config.(s)				(approx.)		
34	Charlotte	NC	7th Street	Minor Arterial	1	3	2:1	Overhead Signs/Signals	Commuter Traffic	Daily AM/PM	2 h	Charlotte Department of Public Works	Active
35	Wilmington to Benson (I-95)	NC	Interstate 40 (eastbound)	Freeway	90	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	NC State Police & DOT	Active
36	Dennis Twp. to Maurice River Twp.	NJ	NJ-47/NJ-347	Primary Arterial	19	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	NJ State Police & DOT	Active
37	Atlantic City to Washington Twp.	NJ	Atlantic City Freeway	Freeway	44	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	NJ State Police & DOT	Active
38	Ship Bottom Borough to Southhampton	NJ	NJ-72/NJ-70	Primary Arterial	29.5	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	NJ State Police & DOT	Active
39	Mantoloking Borough to Pt. Pleasant Beach	NJ	NJ-35	Primary Arterial	3.5	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	NJ State Police & DOT	Active
40	Wall Twp. to Upper Freehold	NJ	NJ-47/NJ-347	Freeway	26	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	NJ State Police & DOT	Active
41	Charleston to Columbia	SC	Interstate 26 (eastbound)	Freeway	95	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	NC State Police & Dept. of Transportation	Active
42	Memphis	TN	Union Avenue	Arterial	4	6	4:2	Overhead Signs/Signals	Commuter Traffic	Daily AM/PM	2--3 h	Memphis Department of Public Works	Non-active
43	Houston	TX	Interstate 10---The Katy Freeway	Freeway	13	7	4:3	Exclusive Lane Movable Gates & Signs	Commuter Traffic (HOV only)	Daily AM/PM	2-3 hours	TX Dept. of Transportation	Active
44	Corpus Christi to San Antonio	TX	Interstate 37 (northbound)	Freeway	90	4	4:0	Traffic Enforcement Police	Emergency Use (hurricane evacuation)	As needed	2 days	TX Dept. of Public Safety and DOT	Active
43	Alexandria Co.	VA	Interstate 95	Freeway	18	7	4:3	Exclusive Lane Movable Gates & Signs	Commuter Traffic (HOV only)	Continuous	2--3 h	VA DOT	Active
44	Seattle	WA	I-5	Freeway	10	2	2:0	Exclusive Lane Movable Gates & Signs	Commuter Traffic/Special Event	Daily AM/PM & As needed	1--2 h	WA State DOT	Active
45	Seattle	WA	I-90	Freeway	10	2	2:0	Exclusive Lane Movable Gates & Signs	HOV Traffic/Special Event	Daily AM/PM & As needed	1-2 hours	WA State DOT	Active

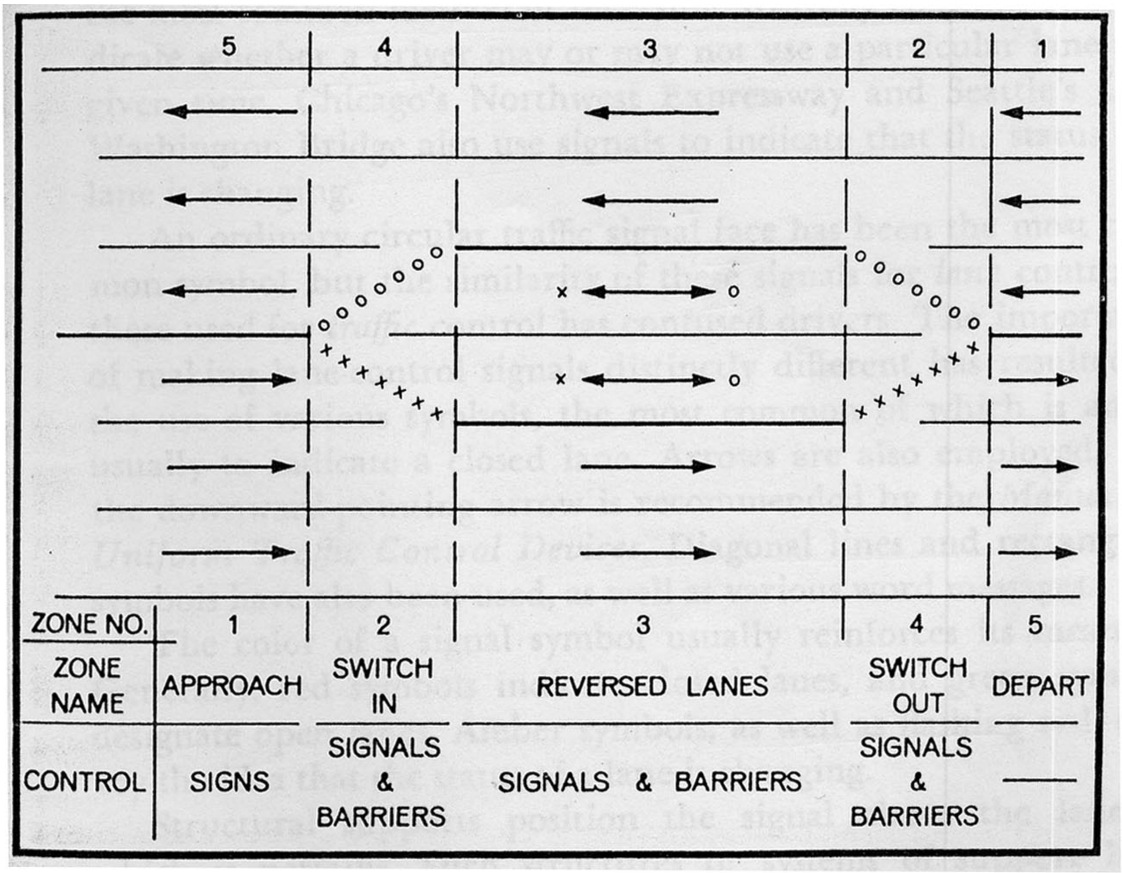

FIGURE 1 General configuration of reversible lane facilities (Lathrop 1972).

have been discontinued because the capacity of the downstream terminus was less than that of the reversible segment. The result was a slow buildup of congestion within the segment that diminished or eliminated the anticipated benefit from the additional lane.

Another important spatial consideration for reversible lanes is the “default” condition or the operational configuration in which a segment is used during nonreversible conditions. For reversible roadways that normally carry two-way traffic, this is not a problem, because the default condition is the normal two-way pattern. On freeways, where median lanes are used for reversible traffic flow, the situation can be somewhat more complicated, particularly in moderate- to low-flow periods such as nights and weekends. In Seattle, Washington, the Washington State DOT (WSDOT) typically maintains inbound operation on its freeway reversible lanes to serve commercial traffic into the downtown area.

TEMPORAL CHARACTERISTICS

By definition, the direction of traffic flow on reversible roadways is never permanent. The reversible operation on the roadway may, however, be permanent. Because most reversible lanes and roadways are used to address daily periodic needs, most configuration arrangements are used for brief durations, in most cases for 1 to 3 h during morning and evening peak periods. However, there are also many examples in which some configuration setups have lasted substantially longer—for days or even months.

As with spatial characteristics, temporal characteristics of reversible roadways can be viewed according to the time taken to effect a transition from one direction to another and the duration for which they are in use. The time required to effect the transitions is the temporal equivalent to Zones 2 and 4, and the period of operation is equivalent to Zone 3. The overall duration of a lane or road segment configured for use in one or another direction is usually based on the temporal characteristics of the demand. For example, it is common practice to use reversible lanes in urban areas for 4 h a day—2 h (usually 7 a.m. to 9 a.m.) during the morning peak period and 2 h (usually 4 p.m. to 6 p.m.) during the evening peak period. Many freeway reversible sections operate on half-day cycles, in which the convertible lane is one direction during the morning hours and the other direction during the afternoon and evening hours. Certain conditions such as road construction and hurricane evacuations may require lanes to be converted for several days at a time.

The most critical periods for reversible operations occur during the conversion of flow from one direction to another. That period is of particular importance, because, if it is not accomplished properly, the transition period has the highest potential for opposing vehicle conflicts. In general, the transition period requires enough time for vehicles to fully clear the converted segment before opposing traffic is permitted to use it. In the case of long segments, this could take several hours. Necessary conversions of control devices and guidance features also take place during that period.

Furthermore, it is desirable for the transition period to be as brief as possible. However, the speed at which the transition takes place cannot be excessively rapid so that it affects the safe operation of the roadway. A more detailed discussion of the management of reversible lane transitions is included in chapter four.

TERMINOLOGY

Over the years, a number of terms and definitions have been associated with convertible and reversible facilities and operations. Although the general definition of a reversible lane was given earlier in this chapter, there are a number of other terms that have similar or closely related meanings. The review of published literature and discussions with practitioners also showed evidence of variations in the use of the terms.

Because in most cases there are no published technical definitions of the following terms, the definitions as provided represent their commonly accepted meanings, by prevailing use in the literature and through feedback from practitioners. The order presented here also reflects the approximate level of generality in use, from broad-based to more specific.

Convertible Operations and Facilities

Convertible lanes include a variety of applications and operations. “Convertible” is also the broadest definition under which a number of more specifically titled forms are included. Although no specific definition for convertible facilities exists in the literature, the generally accepted one for convertible facilities includes those in which traffic operations within them change on a periodic basis. These operations may include the direction of flow, allowable maneuvers and turning movements, permitted vehicles, or fees charged to use them. Convertible lanes may also include normal travel lanes as well as shoulders.

Managed Lanes and Facilities

Managed facilities encompass a variety of operational configurations and strategies. The Texas DOT (TxDOT) (“Managed Lanes . . .” 2002) defines a managed lane facility as “one that increases freeway efficiency by packaging various operational and design actions. Lane management operations may be adjusted at any time to better match regional goals." Included are reversible lanes as well as other types of special-use and priority facilities, such as HOV lanes, transit lanes, and toll lanes.

Managed lanes can be used to restrict access to certain lanes at different times of the day, and they can involve "value pricing," whereby drivers are charged for using the lanes during specific time periods. Among the goals of managed lanes are to maximize capacity, manage demand, and improve safety ("Managed Lanes . . ." 2002). Some examples of managed lanes include the I-15 FasTrak project in San Diego, California ("I-15 FasTrak Online" 2002) and sections of I-5 and I-90 in Seattle ("I-5 and I-90 Express Lanes" 2001).

Reversible Operations and Facilities

Reversible lanes also encompass a range of applications and operations. However, they are a more specific form of a convertible facility in which the flow in a lane or on a segment of the roadway moves in an opposing direction at different times or, in the case of continuous center left-turn lanes, at the same time. Although not specifically defined, the parameters guiding the design and control of reversible lane systems are highlighted in both AASHTO's *A Policy on Geometric Design of Highways and Streets* (more commonly known as the "Green Book") (2001) and the *Manual on Uniform Traffic Control Devices* (MUTCD) (from FHWA 2001). A description of their effect on safety and operational efficiency has also been published by the Institute of Transportation Engineers ("A Toolbox . . ." 1997).

Tidal Operations and Facilities

"Tidal conditions" is a phrase that is more commonly used overseas, particularly in Europe and Australia, to denote both unbalanced directional flow conditions and the facilities and techniques that are used to accommodate them. McKenna and King (1987) have defined tidal flow operation as "a management process whereby the carriageway width (roadway cross-section) is shared between the two directions of travel in near proportion to the flow in each direction." Arnold (1962) further clarified the concept of tidal flow, stating, "The term is something of a misnomer since the tides on our coasts do not flow and ebb at the same time each day whereas commuter peaks do occur at regular time daily." Generally speaking, however, tidal facilities are synonymous with reversible roadways as used in the United States.

Off-Center Operation

"Off-center" has been used to refer to two different, though related, types of operation. The first, reported by Dorsey (1948), describes off-center operation as "a condition that occurs when the number of lanes dedicated to traffic movement in one direction is not equal to the number of lanes in the other direction." Simply stated, the number of lanes on each half of the road is not equal. Under such conditions, three lanes may be used to carry traffic in one direction, with only two in the other direction. The imbalance might be permanent or it might vary based on time of day. This would seem to be a rare application, because the traffic flow is generally thought to be a balanced process, in which the demand that goes one way is typically comparable with the demand in the other direction, albeit at a different time. There are some instances, however, where this may not be the case, particularly where adjacent one-way streets are available.

The second use of off-centre operation was documented by Thorpe (1966) to explain the operation of several road segments in Melbourne, Australia. He described an application in which vehicles were directed to drive outside of their existing lane lines to maximize the usable space within the cross-section width of the roadway. For example, the width of two normal lanes may be used to carry three lanes of traffic during certain periods of the day. Overhead signals were used to direct lane location in Melbourne.

Contraflow Operations and Facilities

Contraflow is a specific type of reverse flow, simply defined by AASHTO as the reversal of flow on a divided highway (*A Policy* . . . 2001). The distinction is made because reverse flow operations are widely regarded to be more difficult to manage and control, especially in the vicinity of intersections where there is conflicting cross-street and turning traffic and where pedestrians are present. The most extreme application of contraflow has been a more recent development, in which freeway contraflow operation is widely planned for evacuating vulnerable coastal regions under the threat of hurricanes (Wolshon 2002b).

Another study focusing on priority techniques for HOVs on arterial roadways defines contraflow somewhat differently (Urbanik and Holder 1977). In that report, contraflow is defined as "a concept whereby high-occupancy vehicles travel on an arterial in the direction opposite the normal flow," and such operations can be accommodated on both divided and undivided roadways.

Contraflow has also been used extensively for exclusive bus and HOV lanes on freeways, including locations in New Jersey, Boston, New York, Los Angeles, and Marin County, California (Link 1975). Although the specific design and operational features of these facilities have varied from location to location, many of the technical issues and challenges have remained constant. Details of those features are discussed in later chapters.

Major-Flow and Minor-Flow Directions

"Major" and "minor" directions of flow are terms frequently associated with reversible lane operations. The major-flow direction on a roadway is the one that has the highest volume during an assessment period. In a typical urban commuter situation, the major-flow direction would be inbound into the central business district (CBD) in the morning and then outbound during the evening peak-period travel time. The major-flow direction would also receive additional lanes during reversal periods. A common notation used to indicate the lane use configuration on reversible roadways is number of lanes in major direction: number of lanes in minor direction. For example, a six-lane highway with three lanes in each direction would operate in a 3:3 configuration during nonpeak periods and 4:2 during peak periods.

Other Terms

The review of literature and practice showed the use of several other terms similar to contraflow that are and have been used for applications of both reversible and nonreversible flow lanes. One of these is "concurrent flow." Black (1995) defined a concurrent flow lane as one in which "a freeway lane is designated as an HOV lane but is not physically separated." Concurrent flow lanes differ from contraflow lanes in that their flow is not reversed, although they are reserved for use by priority vehicles on a full-time or peak-period basis. Another term commonly associated with temporary and permanent reversible lanes that incorporate movable barriers is "zipper lanes." These facilities get their name from the appearance of the lateral movement of the barriers from one lane edge to another. This type of design and control is discussed in detail in chapters three and five. "Counterflow" is yet another term that has been used interchangeably with contraflow. However, searches of relevant sources of information have shown that there are no technical definitions of or references to this term. Therefore, it is assumed that though commonly used, counterflow is likely a misnomer. Other terms for reversible lanes, used primarily within the context of transit operation, are "with-flow" and "contraflow preferential lanes." Such facilities are typically seen on arterial roadways in urbanized areas in which lanes are reserved for the exclusive use by multiple occupant vehicles, including buses, carpools, vanpools, and others (Caudill and Kuo 1983).

There are other instances of unconventional lane use configurations that may or may not be reversible. Most do not have designated names and their control and management can vary significantly from location to location. One example of a configuration that defies definition is a segment of Charles Street near the campus of Johns Hopkins University in Baltimore, Maryland. At that location, Charles Street features a symmetrical six-lane cross section that incorporates a four-lane "center" roadway, two landscaped medians, and two 14-ft outer travel lanes that serve single northbound and southbound lanes of travel. On the outer northbound lane, on-street parking is permitted at all times. One of the four center roadway lanes is also used for parking in the northbound direction, and two of the other adjacent lanes serve northbound traffic. To balance operations in the remaining lanes, one of the four center roadway lanes is also used for southbound traffic. What makes this southbound lane even more interesting is that traffic is prohibited from using it at all times other than during the morning peak period (7 a.m. to 9 a.m.). That use plan was developed to reduce the potential for pedestrian accidents at the north termini point, where pedestrians assumed that traffic in the lane would be traveling in the northbound direction. Views of this location at the north terminus and from the northbound lanes are shown in Figures 2 and 3, respectively. In Figure 2, the red "X" that motorists observe above the counterflow lane indicates the closure of this lane. In Figure 3, a southbound vehicle (in violation of the lane use signal) can be seen in the lane.

FIGURE 2 North terminus of Charles Street concurrent flow lane, Baltimore, Md.

FIGURE 3 Charles Street southbound concurrent flow lane, Baltimore, Md.

CHAPTER THREE

PLANNING AND DESIGN

The review of planning and design for reversible lane systems showed that the implementation of reversible segments has occurred through the use of a variety of techniques and levels of effort. The size and formality of the effort have largely been a function of the frequency, permanence, and characteristics of its use. At one end of the spectrum are the design preparation and planning analyses conducted for permanent major reversible lane facilities on freeways, bridges, and tunnels. These types of projects have often involved cost–benefit analyses of multiple alternatives, evaluations of the impact that reversible operations have on other multipassenger transportation modes, and assessment of varying traffic patterns that would result and their effect on other highways in the vicinity of the reversible lane facility. At the other end of the spectrum are the informal practices used for reversible facilities associated with short-term conditions (days to weeks) associated with a temporary situation (e.g., emergency or construction) or various seasonal planned events (e.g., sporting events, concerts, and fireworks). Frequently, the planning of these types of applications was undertaken by law enforcement agencies with little or no involvement from transportation professionals. Also, because the configurations were often temporary, very few design efforts were undertaken for them. They typically require a plan for placement of traffic control devices and positioning of enforcement personnel.

The review for this synthesis found that most agencies appear to consider reversible facilities a low priority option, regardless of the needs or conditions. The decision to use reverse flow, especially on conventional nonreversible roadways, has tended to be a reluctant one, typically made after most conventional alternatives have been ruled out.

This chapter focuses on the way in which transportation planning processes and roadway design practices have been applied and adapted for the development and implementation of reversible roadways. Because the methods used for reversible roadways generally have not varied significantly from those used for conventional operational strategies, emphasis here has been placed on those that differ or have been developed specifically for such roadways. Among them are the development and application of warrants for reversible operation and the strategic and tactical policies that have been adopted to facilitate their effective operation, including how and why it should be used, managed, and enforced. Similarly, the design sections discuss both system-level and facility-specific techniques and standards that have been applied or developed for this particular use.

PLANNING

The traditional transportation planning process uses a developed set of principles to analyze, evaluate, and select appropriate projects to meet the needs of a location. In addition to describing the costs and benefits of a proposed improvement to the transportation system, planning processes can be used to identify the impact on the development of communities, in terms of social and environmental costs. The initial elements of the planning process include the identification and definition of problems that need to be addressed by a facility or operational strategy, followed by the development of goals that would be achieved with its implementation. With this knowledge in hand, alternative designs and strategies are generated and then evaluated to assess how each of them achieves the established goals and delivers the highest comparative benefit at an acceptable level of cost.

Although planning for some of the reversible roadway systems has followed such traditional processes, the review for this synthesis indicated that for the most part, planning activities to show the need for and use of reversible facilities have been considerably less formal. In general, decisions to implement a reversible lane have tended to be made informally after it was determined that, despite the need for added capacity, it was neither economically or practically feasible to construct any new lanes. For instances in which reversible operation was needed for temporary and immediate capacity increases, particularly for event-oriented and construction-related situations, predeployment planning and evaluation studies, although needed, have rarely been conducted.

The exception to that practice, however, was for new facilities conceived from the beginning for reversible operation. Some examples of facilities designed specifically for reversible use have included HOV freeway lanes, tunnels, bridges, and roadways that serve recurrent special event traffic. Planning for these roadways has followed more conventional planning processes, including the assessment of competing alternatives and the evaluation of costs and benefits.

Previous Study Methods and Techniques

Despite the extensive use of reversible operation, there were few widely disseminated planning studies in the literature. Furthermore, many of the studies were theoretical, carried out to test methods for determining the benefits of reversible operation rather than to justify their application from among a set of possible alternatives.

One of the earliest planning studies was conducted by the WSDOT to evaluate the feasibility of reversible lanes on Interstate 5 in Seattle. A later published planning study was carried out to examine the feasibility of reversible lane facilities, based on the Shirley Highway in metropolitan Washington, D.C. (MacDorman 1965). The Shirley Highway study was particularly interesting, because the results of the benefit–cost comparisons were also used to determine the sensitivity of various combinations of alternative design and development scenarios. The analyses incorporated many of the processes of the traditional urban transportation planning procedures as well as various safety and operating cost analyses. The results of the study showed that the preferred alternative was a reversible bridge configuration, because it could provide adequate capacity with lower levels of capital investment in highway infrastructure and operating costs. A similar result was found in Seattle, where a reversible lane was found to be the most cost-effective alternative.

A more theoretically oriented and technically sophisticated analysis of reversible lane segments was developed as part of a project to optimize the allocation of roadway capacity between opposing directions of traffic flow (Glickman 1970). In the study, a mathematical approach was taken to determine when to transition the flow in the reversible lanes from one direction to another to minimize delay experienced by vehicles traveling in one direction or the other. The principal limitation of the study was that it was primarily a theoretical exercise and did not appear to have ever been applied to field conditions.

A later feasibility study was carried out in Denver, Colorado (Hemphill and Surti 1974). It used an observation-based empirical approach focusing on the reversal of a pair of one-way streets through a congested commercial corridor in the Denver CBD. Using *Highway Capacity Manual* (2000) curves relating to volume and speed, the evaluation estimated that the additional lanes of a reversible lane configuration would more than double the peak-period operating speeds for the existing volume. That, in turn, would result in a 3-year savings of $697,400, in 1973 dollars.

Later, the impact of reversible lanes was assessed using somewhat more complex methods and with the aid of computer-based planning models. A model was developed and applied for the assessment of preferential transit contraflow lanes (Caudill and Kuo 1983), for the competing alternatives of automobile drive-alone, transit and shared-ride, shared-ride and drive-alone, and those three modes used simultaneously. It involved the fusion of three existing submodels to first estimate the modal split of the various alternatives, then to predict the flow density within the contraflow lane based on these splits, and then to estimate the average delay for vehicles waiting to enter the contraflow lane. The output statistics could then be used to predict the expected operating characteristics and provide justification for the use of a contraflow lane. Although there was no evidence that this model was used in practice, it was applied on a demonstration basis on a hypothetical corridor in Washington, D.C. There it was shown that speeds, vehicle flow rates, and transit ridership would all increase significantly, with corresponding decreases in traffic stream density.

A design and planning study carried out to evaluate the feasibility of implementing reversible operations on Leetsdale Drive in Denver, Colorado, included both an analysis of the need for the reversible operations and an evaluation of other competing alternatives (Markovetz et al. 1995). The criteria for considering the use of reversible operations in this location were based on a set of factors developed by ITE and are discussed in the following section. The use of these criteria was complicated by the high left-turn volume at several key intersections and the combined effect of steep grades and buses stopping along the route. In addition to reversible lanes, three other low-cost alternative were evaluated, including retiming traffic signals, modifying traffic signal sequences, and restricting left turns. Each of the alternatives was evaluated through a set of traffic analysis software packages that applied three measures of effectiveness: including, level of service and average delay at the signalized intersections, ratio of volume to capacity, and average delay time for the vehicle. The study results showed that a reversible lane would be the best alternative for the subject section of road.

Warrants

Historically, the need for reversible lanes has been driven by several varying objectives, including the need to increase roadway capacity and travel speeds as well as decrease congestion and travel time. Not surprisingly, the warrants that have been developed to guide their implementation have been based on those same objectives. Current warrants for reversible lanes have developed over the years as traffic engineers have become more familiar with the characteristics associated with their use as well as their inherent costs and benefits. Although those aspects have changed somewhat over time, the general concepts that justify the use of reversible lanes have not varied significantly.

The need for reversible lanes often starts by identifying locations of known congestion and growth projections that are anticipated for future development and travel growth. Although there is no single set of warrants that has been universally agreed on or adopted, a general uniformity in practice has developed in assessing the need for such facilities. Professional transportation organizations such as AASHTO and ITE have developed consistent guidelines for their use, as have many overseas highway agencies. Some of these warrants also vary slightly depending on whether the reversible operations are going to be adapted to an existing facility or if the operations are being designed into a new facility.

The AASHTO *Green Book* states that reversible operations are justified when "65 percent or more of the traffic moves in one direction during peak hours" ("A Policy . . ." 2001). In being consistent with the generally accepted principle that it is not advisable to have fewer than two lanes for the minor-flow direction (discussed later in this chapter), AASHTO also suggests that with "a six-lane street width directional distribution of approximately 65 to 35 percent, four lanes can be operated inbound and two lanes outbound."

ITE described reverse laning on existing facilities as "potentially one of the most effective methods of increasing rush-hour capacity of existing streets under the proper conditions" (1999). Such a system would be "particularly useful on bridges and tunnels, where the cost to provide additional capacity would be high and, perhaps, impossible." Although ITE does not offer specific warrants, it does suggest a combination of criteria and studies that should be evaluated to decide if they are needed and to ensure that they will operate in an advantageous manner once they are implemented. The four ITE test criteria to determine the need for reversible lanes are as follows:

1. The average speed of the freeway should decrease by at least 25% during the trouble periods over the normal speed, or there should be a noticeable backup at signalized intersections leading to vehicles missing one or more green signal intervals. That is, the demand should be greater than the capacity of the freeway.
2. The traffic congestion problem under investigation should be both "periodic and predictable."
3. The ratio of a major to minor traffic count should be at least 2:1 and preferably 3:1. Otherwise, the installation of a contraflow lane could be the cause of a new traffic problem on the minor-flow side of the freeway.
4. The contraflow lanes must be designed with adequate entrance and exit capabilities in addition to providing easy transition between the normal and reverse flow lanes. Otherwise, the contraflow lane could be the cause of bottlenecks and other traffic problems in addition to the existing traffic congestion.

ITE also suggests six other criteria that should be examined before the implementation of reversible lanes. The first is the completion of traffic studies that show the following results:

- A lack of an adequate adjacent street, ruling out the consideration of one-way operation.
- Side streets of five or more lanes with ratios of major to minor traffic flows of at least 2:1. Another study suggests that a reversible lane system "works best when the directional distribution during the peak hour flows are over 70% in the predominate direction" (Bretherton and Elhaj 1996).
- A high proportion of commuter-type traffic that desires to traverse the area without turns or stops.
- Terminal conditions that facilitate the full utilization of the additional lanes.

The second and third criteria are associated with congestion. The ITE guidelines state that reversible lanes can be considered when the demand exceeds the street capacity and "the periods during which congestion occurs are periodic and predictable." The exceeding of street capacity during peak hours was also used as a motivation for a reversible flow segment along a 2-mi segment of East Fourth Street in Charlotte, North Carolina (Hoose 1963).

The fourth criterion is an assessment of the ratio of directional traffic volumes. ITE recommends traffic counts at various locations to determine how much volume should be allocated for each direction and where the directions should begin and end. ITE also urges maintaining a minimum of two lanes open to traffic in each direction. That recommendation was also strongly suggested by the results of the Fourth Street application, in which studies indicated that even the low volume of the minor-flow direction would force the lane to function very near its capacity. It was concluded that serious congestion would occur if storage were not provided for right- and left-turning traffic, because even a few turning vehicles would cause a queue of vehicles behind them as they waited for an adequate gap in opposing traffic to complete a turn. Experience with bus contraflow lanes also showed that the efficiency of single-lane minor-flow direction operations can be significantly affected by the presence of heavy vehicles and even minor incidents (Link 1975).

The fifth criterion, an assessment of the capacity of the reversible segment access points, is a critical one that can be overlooked in the evaluation process. ITE states that adequate capacity must be maintained at both of the termini, and that the transition from the normal operation to the reversible segment must be easy for drivers to negotiate. Inadequate capacity of these points would result in the creation of bottlenecks that would diminish (or even eliminate) the utility of the reversible section.

The sixth criterion is the conclusion that there are no other acceptable alternative improvement scenarios. Cost factors may be involved, such as right-of-way limitations that preclude widening an existing facility or constructing a parallel roadway on a separate right-of-way.

Recommendations for the application of reversible lanes have also been documented in previous versions of the MUTCD. Although the Millennium Edition of the MUTCD provides guidance for the application of various forms of control for reversible lane facilities (discussed in chapter four), it does not offer specific criteria for when they could be used. Earlier versions of the manual did, however, imply that reversible lanes could be effective when

> vehicular traffic flow in one direction on a two-way street, highway, bridge, or tunnel having three or more lanes is sufficiently congested that average vehicle speed during peak periods decreases by at least 25 percent over normal period experience and this congestion occurs at relatively stable and predictable periods. A suitable ratio of directional traffic volumes, with at least 66 to 75 percent in the predominant direction is also necessary, as is adequate capacity at the terminal points to effectuate an easy transition of vehicles between the normal and reversed lane conditions.

The key points of that recommendation are that the road under consideration have at least three lanes, that directional traffic demand be suitably unbalanced, and that special care be exercised in dealing with the initiation and termination points of the reversible section. Operational difficulties have been experienced in several locations when these conditions were not adequately met.

Lathrop (1972) made an additional suggestion that potential users would do well to answer four simple questions during the planning of a reversible lane system, to make sure that if it is implemented it will improve rather than degrade the overall transportation system. Questions to be asked are will it be safe and will it be reliable?

At the most basic level, the system should be reliable in all weather conditions. Lathrop (1972) also suggested that the system be designed with redundancy so that if any single part fails, it will still work safely. Also, if there is a systemwide failure, the default design will allow the system to be usable. Additional questions to ask are will it be aesthetically acceptable and will its costs be justified?

In addition to considering the cost of implementation, Lathrop recommends that the operational costs associated with maintenance and safety be assessed against the benefits of system flow improvements.

Use Policies

Policies for the use of reversible lanes have been developed to enhance the safety and efficiency of the segments. The usage policies of reversible facilities are important, because they can affect the levels of mobility on and accessibility from that roadway as well as others adjacent to it. Although the objective of these policies is to serve the mobility needs of the overall population, they often meet that objective by the restriction of movement and accessibility for individual drivers. Two examples of such policies are the prohibition of left turns and the prohibition of on-street parking during periods of reversible operation. In the following sections, the need for these policies is discussed, along with how they have been implemented and managed in previous applications.

Lane Assignment

The most basic policy for the use of reversible lanes is the assignment of the available capacity of the roadway. Policies on the assignment of lanes directly influence the capacity of the subject roadway, and they can also affect operations on adjacent roadways as directional flows are shifted to other roads in the vicinity and as drivers are forced to use alternative routes to reach their destinations.

Although it is logical to assign lane direction purely on the basis of directional volume ratios, it is critical to maintain adequate capacity to serve demand in the minor-flow direction, although the assignment may be inconsistent with the ratio of volumes. This is especially true when the directional demand may dictate the assignment of only a single lane.

In practice, the assignment process is based on a number of factors associated with specific locations. There are three basic methods that have been employed for configuring the use of reversible lanes (ITE 1999):

1. Reversal of flow in all lanes of a one-way street from one direction to the other, creating a fully directional one-way street;
2. Reversal of flow in all lanes of a two-way facility, effectively creating a one-way street during some periods and two-way operation during all other periods; and
3. Reversal of one or more lanes of a two-way facility to create an unbalanced operation during some periods and a balanced two-way operation during all other periods.

A common application of the third assignment method is to use a two-way center left-turn lane as a reversible through lane during peak-period travel times.

ITE has also acknowledged the advantages and disadvantages of these various operational configurations (ITE 1992), ranging from the obvious to the subtle. The clearest advantage is that the configurations all provide additional capacity for flow in the primary direction. Furthermore, the added capacity can be accommodated on the same street for both morning and evening peaks. Other advantages include the elimination of the need for "paired streets," such as would be required for exclusive one-way streets; more efficient utilization of parallel arterial roadways; and elimination of the need for traffic to shift to another street. Among the disadvantages are reduced capacities for flow in the minor direction, operational difficulties at the termini, and need for concentrated law enforcement to prevent violations of lane-use restrictions. ITE also suggested that the cost of installation and operation may be high for both permanent and periodic traffic control devices. However, many users of reversible flow facilities believe that the benefits gained for its use offset such added costs.

As discussed in the section on warrants, the logical process for lane assignment is the allocation of lane capacity by volume demand. However, there are often other concerns that would supersede this practice. Among these concerns are the need to maintain a minimum number of lanes for the off-peak traffic direction and in some cases the assignment of an unused lane to serve as a buffer between opposing directions of traffic (Link 1975).

Left-Turn Prohibition

Among the commonly used policies for reversible roadway segments is the prohibition of left turns within unbalanced reversible lane sections (Dorsey 1948). Left-turn prohibitions are important from the standpoints of both operational efficiency and safety enhancement. Operationally speaking, left turns slow and often stop through traffic streams as turning drivers wait for adequate gaps in the oncoming traffic streams. Because the primary reason for using reversible lanes is to keep through traffic moving, it defeats their purpose to slow traffic to allow left turns. Other areas of potential confusion for drivers concern their knowing which is the furthest left lane and their correct reactions at signalized major intersections

Previous experience with reversible lanes in Memphis, Tennessee, showed an increase in same-direction sideswipe accidents as a result of drivers turning left from a through lane that has another through lane to its left (Upchurch 1971, 1975). In effect, this meant that drivers were not aware that the lane to their left was being used by traffic in the same direction of travel. Confusion could be potentially acute in configurations where an off-peak continuous center lane for left turns would be converted to a reversible through lane during peak periods.

Furthermore, problems with left turns can be serious at approaches to signalized intersections on reversible road segments. Because drivers have often come to expect left turns at intersections to be designated by pavement markings and overhead traffic signals, they may become confused if they encounter a reversible road there. One example of solving this problem is through the use of a continuous center left-turn lane with dynamic overhead lane signals, such as the intersection along the reversible section of Tyvola Road in Charlotte, North Carolina, as shown in Figures 4 and 5. These photographs show the approach to and departure from the lane configuration of the Tyvola Road/Tryon Road intersection. At this location, the two center reversible lanes are designated by the overhead signals for use by left-turning traffic during off-peak hours.

FIGURE 4 Eastern terminus of the Tyvola Road reversible segment, Charlotte, N.C.

FIGURE 5 Western terminus of the Tyvola Road reversible segment, Charlotte, N.C.

Another approach configuration that is difficult to control is the added left-turn lane. In these configurations, a left-turn lane is added at the intersection approach by shifting each outer edge of pavement 6 ft outward to create an additional 12-ft center left-turn lane on both sides of the cross street. If, for example, reversible lanes were desired on a four-lane or six-lane roadway with flared intersections, drivers would be required to operate their vehicles while straddling a lane line.

On-Street Parking Prohibition

As with other use policies, the prohibition of on-street parking on reversible roadways in densely developed urban areas can have mixed impacts. The main reason to disallow parking is to make more of the road cross section usable for the movement of traffic. Depending on the width of the parking lane, an additional lane can be gained in both the major- and minor-flow directions. The obvious advantage that this affords is added capacity in the major direction and an additional lane to maneuver in the minor-flow direction. The provision of a minimum of two lanes in the minor-flow direction has been regarded as critical to avoid causing frequent blockages and stopped queues on reversible highways (Arnold 1962). Thus, traffic has room to maneuver around slower merging and diverging traffic.

Another benefit to prohibiting parking is in the area of crash reduction. A study conducted on an early reversible road segment in Michigan showed a significant decrease in all accidents during hours of operation (DeRose 1966). This result was not unexpected, because many of the "before" accidents were related to conflicts between through and parking vehicles.

Although parking prohibitions have a generally positive effect on the movement of traffic, they can be troublesome for local residents and commercial properties adjacent to a reversible roadway. The 1.5-mi reversible segment in Michigan experienced a loss of 170 parking spaces during reversible flow operation. However, the city provided off-street parking accommodations to more than offset these losses. In areas such as Washington, D.C., where accommodations have not been possible, parking regulations have resulted in inconvenience to the residents and businesses directly adjacent to the roadway.

Temporary and Emergency Use Policies

For reversible segments used for temporary or emergency circumstances, use policies can be considerably more disruptive and restrictive. In most cases, law enforcement and DOT personnel plan to close most entry points into the contraflow segments during evacuations. Doing so reduces the number of traffic control personnel required at these locations and reduces the anticipated level of driver confusion at exit ramps, where vehicles would be traveling in the "wrong" direction onto the surface highways. Because flow reversals for evacuations are done as a matter of life and death rather than for driver convenience, many plans eliminate route choices, forcing traffic into certain routes rather than allowing drivers to make their own decisions.

It is recognized, however, that some evacuees will need to exit for fuel, food, and use of personal facilities. To this end, all contraflow plans will permit periodic egress opportunities within the intermediate segment, although reentry into the segment will be permitted only into the normal outbound lanes of travel.

Use Eligibility Policies

Another group of policies that have impact on the use of reversible facilities are those associated with the eligibility requirements for certain vehicles to use the reversible lanes. These policies are implemented most often to give priority to certain vehicles to use the reversible lanes and to restrict other vehicles from doing so. One of the most common policies used to manage the accessibility of reversible facilities, particularly on freeways, is to limit their use to transit and HOV vehicles. These policies have been in use on freeways in several urban centers in Florida and Texas. Another example of such policies has been to limit reversible lanes only to toll-paying users. Although such policies may limit the total number of users, they can help to reduce overall congestion and serve as a source of revenue for highway agencies.

Public Acceptance, Information, Education, and Communication

Assessments of public understanding and acceptance of reversible flow facilities have been conducted virtually since their inception. Although the development of clearer and more uniform traffic control devices and practices has helped to convey key operating information, anecdotes of initial mixed public opinion turning to favorable views have been fairly consistent over the years. Because the implementation of reversible lane systems has been a relatively uncommon practice, a significant portion of drivers are unfamiliar with their operation and management strategies. The result is a consistent pattern of initial driver confusion and aversion that typically changes to acceptance and enthusiasm for such strategies. This support typically comes once drivers begin to take advantage of the additional lane and begin to experience less congestion and savings in travel time (DeRose 1966). The wide appeal of reversible lane roadways was recently demonstrated in the results of a 2001 WSDOT survey, in which broad public support was shown for that state's reversible freeways.

One group that has shown resistance to reversible lane configurations has been retail business owners situated along streets with such operations (Dorsey 1948). Their objections are rooted in the belief that congestion in front of their establishments is good for business, because drivers may be better able to see their shops while driving slowly or may be more inclined to visit rather than wait in traffic. Additional problems are that reversible flow operations usually require the prohibition of on-street parking and left-turn movements, as discussed in detail later in this chapter. Conversely, however, it has also been suggested that uncongested traffic flow actually encourages more shoppers to use the businesses, because they are able to access them conveniently.

Such a scenario prevailed on Wilshire Boulevard in Los Angeles, where local business owners believed that the use of no left-turn restrictions at major intersections to make the street into a primary thoroughfare was depriving them of business. Although some merchants found that the operation increased business because more people were using the street and learning the locations of stores, the local business association persuaded the city council to discontinue reversible operations citywide. They based their contention on the grounds that they paid the majority of the assessment for the construction and maintenance of the street and thus should have primary consideration in its use. This move occurred despite a study that demonstrated that 98.5% of the drivers using Wilshire Boulevard were in favor of the reversible lane configuration, and 94% were in favor of peak hour on-street parking prohibitions (Dorsey 1948).

The application of reversible flow in Charlotte, North Carolina, showed clear public acceptance of the system from the first day of operation (Hoose 1963). This occurred because that location experienced little congestion from turning vehicles on the segment and no increase in accidents even with parking prohibitions on both sides of the street during peak hours. In Dearborn, Michigan, after the elimination of on-street parking through a key commercial district, for the implementation of reversible operations, many retailers were not pleased. However, once the city made it clear to drivers that off-street parking was available, local merchants were satisfied with the results (DeRose 1966).

The Maryland DOT has also found a high level of public acceptance of its use of reversible lanes—perhaps partly related to the agency's routine use of public involvement from the outset for most projects of this type. A Maryland DOT official stated that the agency is very reluctant to undertake projects that are not perceived as a need by the public; a lack of public acceptance of and support for projects usually demonstrates that they are unwarranted. Maryland officials also indicated that public acceptance evaluations of projects do not necessarily need to be quantitative. Often they measure public discontent by the number (or lack) of telephone calls to their traffic engineering offices.

Other Planning Related Issues

There are a number of policies affecting the operation of reversible facilities that are also addressed at the planning level. They include matters such as interjurisdictional agreements and arrangements for situations in which reversible operation is required to cross from one municipality or authority into another; liability concerns associated with safety; and, more recently, pertinent issues such as community livability, sustainability, and others. Although attempts were made to investigate these issues for this synthesis, no information could be attained on how they are being addressed.

DESIGN

The design criteria used for the development of reversible roadway segments are similar to those for conventional highways. The review of practice and literature showed that the design features of reversible roadways, including elements such as turning radii, sight distances, taper lengths, lanes widths, etc., were in all cases identical to the standards and policies set forth in the AASHTO *Green Book* and in the MUTCD. Certainly, the vehicle and driver characteristics are the same, irrespective of the operation of a facility. The finding is likely also because most reversible operations have been implemented on roads that were originally intended for conventional use.

The review also showed, however, that the unique nature of reversible facilities often requires special design treatments. This is especially true for newly designed facilities and on freeways where it is necessary to provide a physical separation between opposing traffic streams. Special designs have also been used on conventional roads that have been reconfigured or retrofitted to permit reversible operations.

The design of reversible facilities at the system level also differs philosophically from that of nonreversible roadways. These differences are primarily associated with the need to incorporate transition areas, midsegment and ramp entry–exit points, and adequate cross-section width. General concepts and suggested practices for the design of reversible freeway systems as well as individual segment elements were proposed in a paper by Drew (1967). As part of this work, he also developed theoretical capacity values for specific locations within the segment, such as lanes and weaving areas. More recently, design and operational guidelines for various types of HOV reversible configurations on controlled and uncontrolled access were proposed by AASHTO (*Guide for the Design* . . . 1992). The AASHTO guide also provided design recommendations for median crossovers and cross-section configurations for contraflow lanes on arterial roadways and freeways.

In the following sections, the application of various design standards, philosophies, and criteria for reversible facilities are summarized. Where relevant, facility-related

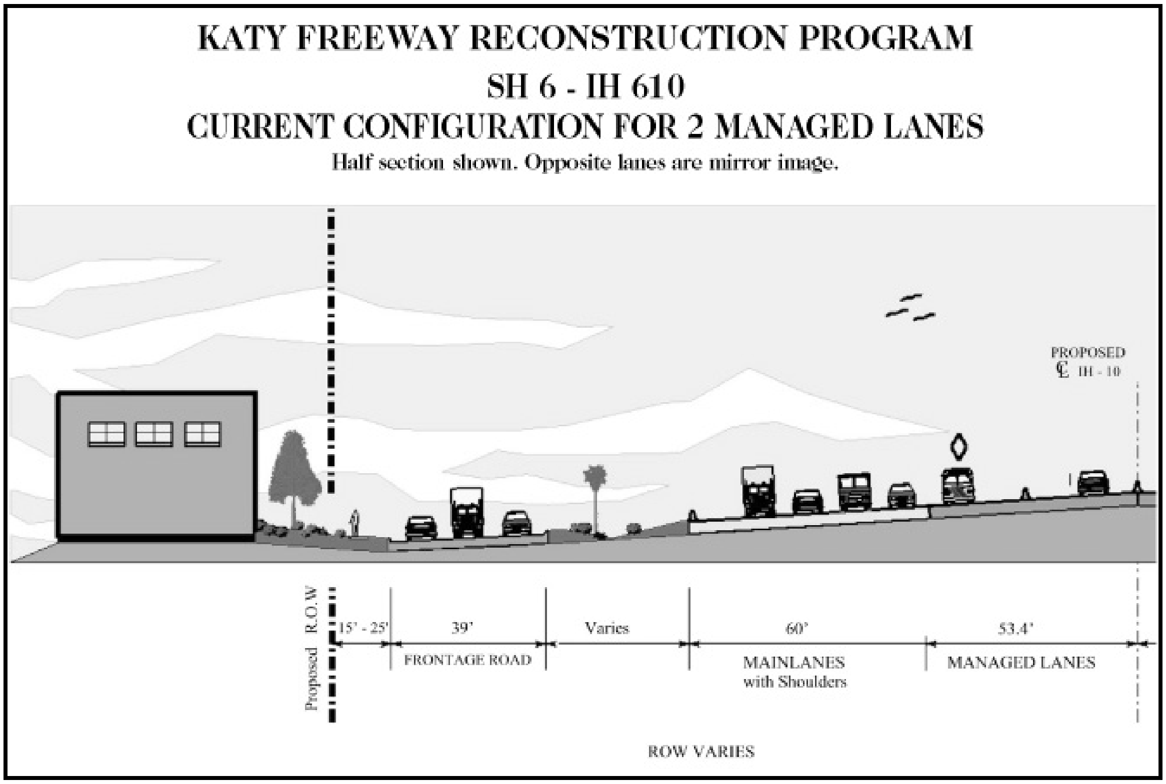

FIGURE 6 Proposed future cross section for the Katy Freeway (*Source*: Texas DOT 2003).

differences, such as those between limited access highways and freeways versus nonrestricted access roadways and those between divided and undivided arterial streets are discussed. Also discussed are the differences between the design of new reversible facilities and the adaptation of nonreversible roads for reversible use.

Cross-Section Features

In general, the horizontal and vertical design features of reversible roadways are no different from those of standard roadways. This is mainly because requirements for these alignments (e.g., efficient operations, safety sight distance, and drainage) are the same for conventionally operating highways. However, a minor exception is for the cross section.

The primary features of the roadway cross section are the lanes, shoulders, and features lateral to them, such as medians and embankments. The design of these elements focuses on the required widths, slopes, and surface conditions necessary to separate and guide traffic safely and efficiently, including the need to separate opposing traffic streams, reduce the potential for vehicle rollover, adequately drain the roadway, and minimize cost. Cross-section designs of reversible roads warrant special consideration because the direction of travel in some of the lanes changes periodically. Safety features such as guardrails, crash cushions, and breakaway devices and slope grades on freeways, which are designed for a single direction of travel, may also need to be redesigned for vehicles traveling in either direction. Additional width may also be required to separate opposing flows with portable temporary traffic control devices such as cones or fixed permanent features such as barriers. An example of how the additional cross section is used can be seen on the Katy Freeway in Houston, Texas, as shown in Figure 6. Examples of wider suburban and narrower urban reversible freeway cross sections are illustrated by a segment of I-95 in suburban Washington, D.C., and a segment of I-25 near downtown Denver, in Figures 7 and 8, respectively. Where right-of-way is severely restricted, such as on the Lee Roy Selmon Expressway in Tampa, Florida, officials are planning to construct two elevated reversible lanes within the existing median area (“Narrow Median . . .” 2000). One of the concerns with restricted width cross sections, however, is the inability to provide suitable shoulder areas for enforcement patrol vehicles and incident responders, as well as for emergency stopping areas.

Another cross-section element that has varied in many retrofitted reversible lane systems has been lane width. Although the AASHTO standard (*Green Book*) permits some variation, a standard highway lane width is 12 ft. This width accommodates most vehicle configurations and accounts for some lateral movement while one is driving; it also maintains a separation between opposing and same direction

FIGURE 7 Reversible freeway segment with wide cross section, suburban Washington, D.C. and suburban Virginia.

FIGURE 8 Reversible freeway segment with narrow cross section, Denver, Colo.

raffic streams. One of the problems of adapting reversible operations to conventional roadways is the need to fit an additional lane(s) into an exiting fixed cross-section width. Although efforts have been made to maintain 12-ft widths, reversible lanes are often created by converting nonthrough travel areas, such as on-street parking lanes, two-way center left-turn lanes, and limited right-of-way, into as many lanes as possible. Doing so often means that lanes are substantially narrower than 12 ft; some even as narrow as 9.5 ft carry transit buses (Link 1975). One method in which the problem of narrow lane width has been overcome in the past is through an off-center operation, whereby vehicles may operate while overlapping lanes, whereas others shift to the outsides of the lanes. For example, two 15- or 16-ft lanes have accommodated three lanes of through traffic by permitting a middle flow lane that straddles the other two.

Terminal and Transition Areas

Two key areas that can significantly impact the overall effectiveness of reversible flow segments are the entry and departure termini (Bartelsmeyer 1962). Adequate capacity and smooth operations within these areas are crucial, because they can dictate the capacity and quality of service conditions on the entire segment. If there is a restriction that limits the flow of vehicles into the segment, then the volume through it will never be maximized. Similarly, if there is a restriction at the outflow end of the segment, such as a lane drop merge, congestion will ultimately extend upstream into the segment, causing congestion and limiting the segment's effectiveness.

Termini Configurations

Flow into and out of reversible lane configurations varies by the nature of the use of the lane as well as the type of facility on which it is used. Ingress and egress can also be controlled by effective design or traffic control, or better yet, a combination of the two. As with most other reversible roadway designs, there is a wide array of configurations and systems, varying from nothing to complex automated gate and arrestor systems. Among the simplest transition designs was one found on Monroe Street in Charlotte, North Carolina. There, the transition length is effectively zero as the road cross section narrows from four to three lanes. As shown in Figure 9, vehicle movements within this area are controlled through the use of both pavement markings and overhead static and changeable lane use signs and signals.

FIGURE 9 Simple reversible lane transition, Charlotte, N.C.

Although transitions and entry and egress into the reversible lanes on arterial roadways are usually brought about by the use of only traffic control features (discussed further in the following chapter), transitions on reversible freeway segments are more complex and require a higher degree of driver guidance, which can be more adequately provided through design. For the most part, the design of reversible lane entry–exit points on limited access road-

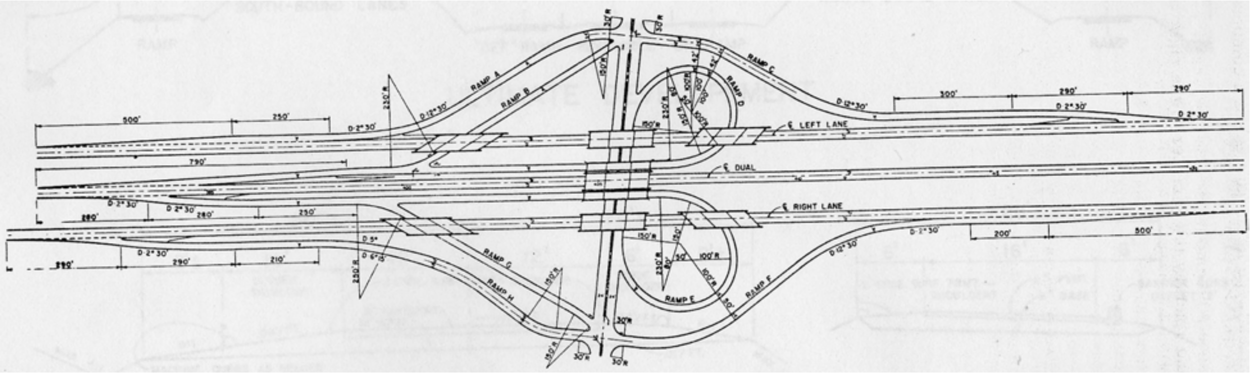

FIGURE 10 Reversible flow freeway interchange (*Source*: Drew 1967).

ways is similar to that of ramps on conventional facilities. The most basic are median crossover designs that typically incorporate a transition taper/lane and then an acceleration lane and taper to move traffic laterally from one lane to the other. Similar designs are commonly used for access–egress maneuvers along the intermediate segment as well. Termini movements can also be accommodated by the use of various ramp designs to exit to and from the main-line travel lane, or as illustrated in the layout plan of Figure 10, directly to and from the surface street network.

Use of Barriers

Various types of barriers have also been used for reversible lane segments. As shown previously in Figures 7 and 8, most of them incorporate standard barrier designs. A more innovative barrier system that has been gaining in popularity for reversible roadways is the movable barrier. Movable barriers have been used both on permanent bases for roadways and bridges and on temporary bases within construction zones where unbalanced directional flows are experienced. Movable barriers have been used on bridges throughout the world—including on both the Coronado Bridge in San Diego and the Tappan Zee Bridge in New York (Dietrich and Krakow 2000).

The appearance and performance of movable concrete barriers are similar to those of fixed concrete barriers (Cottrell 1994). The main difference is that each segment incorporates a top cap that is used by a moving vehicle to lift and laterally reposition the barrier. The vehicle can move at speeds up to 10 mph and is able to shift barriers across two lanes. A reversible movable barrier segment and the repositioning vehicle on the Coronado Bridge in San Diego are shown in Figure 11. The MUTCD offers guidance in the application of movable barriers in temporary construction zones in section 6H.01 (MUTCD 2001).

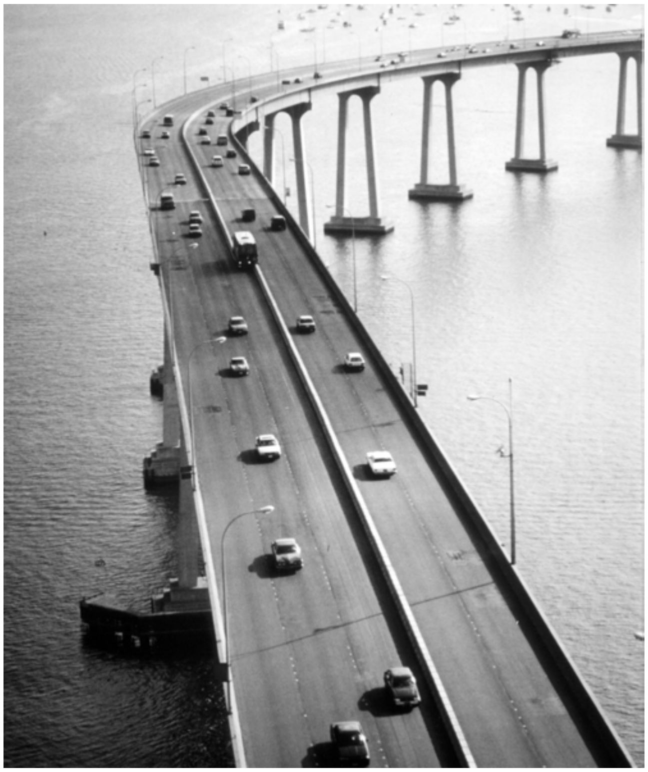

FIGURE 11 Movable barrier system, Coronado Bridge, San Diego, Calif.

Automated gated systems are also very common in locations where traffic flow direction is converted on a more frequent basis, such as twice-daily commuter periods. A typical example of this type of control is shown in Figure 12 in a photograph taken along I-95 in Virginia. At this location, a series of variable lengths restrict entry into the reversible median lanes. An overhead dynamic message sign also indicates the availability of these lanes. Figure 13 shows a similar configuration on I-5 in Seattle, Washington, from a different angle. The figure illustrates the need to have the gates operational for the main-line travel lane and the reversible lane (in the opposite direction). A variant of these gate systems was developed recently for use at interchange ramps where contraflow evacuations are planned ("Road, Bridge, and Rail Barrier Gates" 2003). The contraflow gate, whose diagram is shown in Figure 14,

FIGURE 12 Gated reversible lane entry point, suburban Washington, D.C. and suburban Virginia.

FIGURE 13 Typical gate design to prevent bidirectional entry, Seattle, Wash. [*Source*: "High Occupancy Vehicle (HOV) Interactive 1.0" 1996].

is composed of a single barrier, similar to a railroad crossing gate, which is manually positioned into place. This gate is also similar to gates used in Western and Plains states, where snowstorms occasionally require the closure of Interstate freeways.

Transition point designs of evacuation contraflow sections are interesting, because the infrequency of their use dictates that they be of fixed and permanent design to prohibit unauthorized entry into an oncoming lane. Still, they also need to be portable, owing to the need to remove them quickly. As a result, several different configurations are in use. The contraflow gate mentioned earlier remains in the open position until lanes need to be closed. Most transition barriers, however, close crossovers until they are needed. An example of a location in which concrete barriers are used is at the entry point to the evacuation contraflow section on I-37 in the vicinity of Corpus Christi, Texas, as shown in Figure 15. Despite the added difficulty in their having to be moved, concrete barriers were regarded as the best alternative at this location, as a result of safety considerations. It was believed that because evacuations are relatively infrequent events, it was more appropriate to have a more permanent configuration of lanes. Similar reversible evacuation segment termini in New Orleans, Louisiana, and in Columbia, South Carolina, have used lighter-weight, water-filled barriers in the median crossover lanes. Water-filled barrier systems have also been used to separate opposing contraflow traffic streams in France. An example of the water-filled barrier outside of New Orleans is shown in Figure 16.

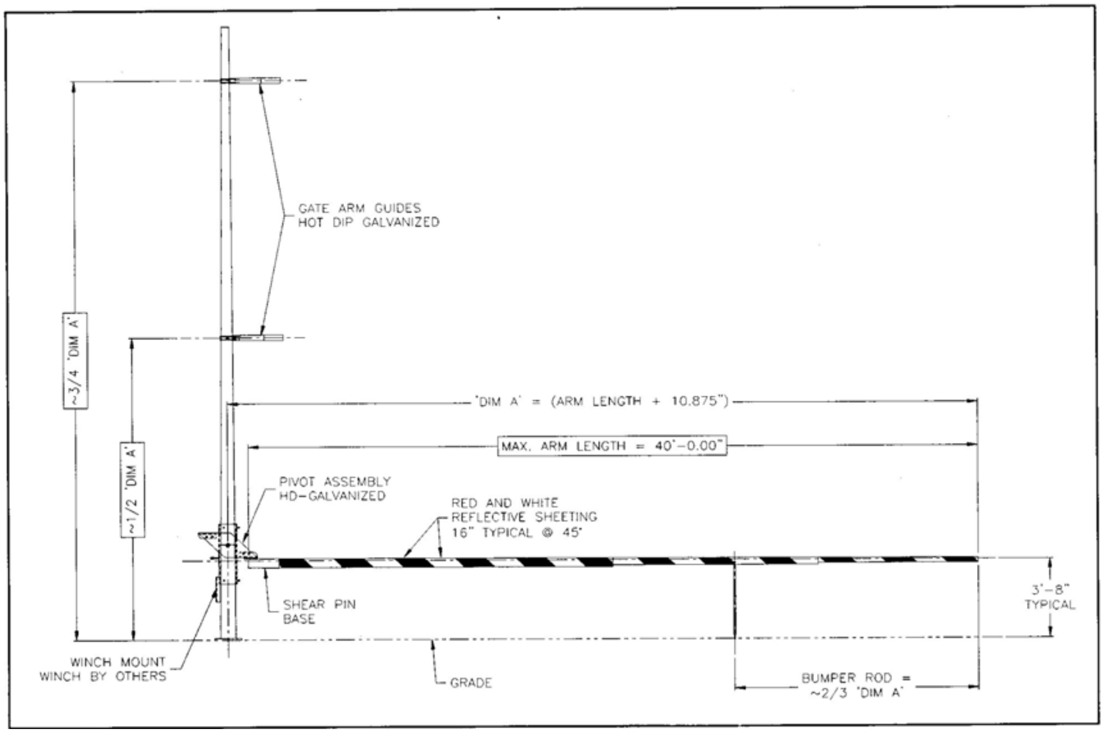

FIGURE 14 Details of a contraflow gate (*Source*: "Road, Bridge, and Rail Barrier Gates" 2001).

FIGURE 15 I-37 evacuation contraflow entry point, Corpus Christi, Tex. (*Courtesy*: Garry Ford, Texas Transportation Institute, San Antonio).

FIGURE 16 I-10 evacuation contraflow entry point, Kenner, La.

Despite the use of these various gate and barrier systems, experience has shown that they do not always fully restrict unauthorized entry into reversible lanes. To prevent wrong-way entrances and their devastating consequences, various arrestor systems have been developed and incorporated into reversible lane segments. One such system, called the "Dragnet," uses net and cable arrestors that are based on the principle used to stop airplanes on aircraft carriers, to smoothly and safely decelerate vehicles from as small as an 1,800 lb automobile to as large as an 80,000 lb tractor trailer ("Dragnet Vehicle . . ." 1999). It and similar systems have also been tested for use in work zones, truck emergency runoff ramps, and railroad crossings. Both remote and manually controlled vehicle-arresting systems have been used recently on reversible roadways in Seattle, Washington, and Dallas and Houston, Texas ("Two Types . . ." 2002) and are also described in detail in the Colorado DOT's *Crash* "Cushion and End Treatment Selection Guide" (2003). WSDOT also uses hydraulically operated guardrails to close reversible freeway lanes.

SUMMARY OF KEY FINDINGS

The review of the planning and design of reversible lane systems revealed the following points:

- Limited resources are available to guide the planning and design of convertible facilities.
- Criteria for use include
  - Predictable congestion patterns,
  - Flow imbalance of at least 2:1 and preferably 3:1,
  - Ability to maintain a minimum of two lanes in minor-flow direction, and
  - Avoiding stops and turns in through traffic.
- The range of practices pertain to the amount and formality of the planning and design effort, largely a function of the frequency, permanence, and characteristics of the use application.
- There is little consistency in designs. Design similarities have been seen in similar types of application (e.g., peak-period commuter traffic, planned event, and evacuation) and for similar roadway functional classifications.
- Transition areas are critical: they must maintain adequate entry and exit capacity and they need to be carefully controlled.
- Operational policies should be established for user eligibility, parking restrictions, and turning restrictions.
- Reversible lane applications have been generally very well received by the public.

CHAPTER FOUR

CONTROL, MANAGEMENT, AND ENFORCEMENT

Because of the variable nature of reversible roadways, effective traffic control is vital to their safe operation. In addition to guiding vehicles into and out of the vicinity of the reversible segments, control features must be used to effectively communicate critical information, such as where and when reversible operations begin and end, and what lanes are available to drivers. In some cases, such information actively prevents improper ingress and egress to and from adjacent nonconverted lanes.

FINDINGS FROM THE LITERATURE

The review of research literature and current practice showed that there are five basic techniques by which reversible traffic operations are controlled. They are curb-mounted signs; overhead signs; lane-use control signals; pavement markings; and portable devices such as pedestals, tubes, and cones. However, there is also considerable variation in the way that devices within those five categories have been applied. Devices have ranged from the use of familiar signs, signals, and pavement markings to more complex and manpower-intensive methods such as automated dynamic lane-use controls and activity by the traffic enforcement personnel. Traffic control devices and management strategies have been based largely on factors specific to particular reversible segments, including their design, anticipated operating speeds, number of points of conflict (e.g., intersections and driveways), frequency of use, and familiarity of local drivers with this form of operation. Reviews of reversible lane facilities in England and Australia showed that 17 of the 22 systems in those countries, as well as most installations in the United States are controlled with overhead changeable lane-use signals. The specific type of control is also based on the nature and frequency of the reversible operation. The relative infrequency of lane reversals for emergencies would not justify the need for complex and expensive lane-use control systems.

The review of reversible lane control included both devices and control practices and protocols. Particular emphasis was placed on control mechanisms and practices within and during the transition areas of the reversible segments, because those are both locations and times at which conflicting traffic movements are most evident and potential conflicts and driver confusion are at their highest. Another focus was on the more difficult-to-control locations, such as intersecting roadways, driveways, and crosswalks along the intermediate reversible sections. At those locations, multiple hazards and conflicts may be encountered—by the traffic on the reversible roadway as well as by the vehicular or pedestrian traffic that may be crossing or entering the reversible lanes. A potentially hazardous situation is the accommodation of left-turning traffic from converted lanes at cross streets and driveways. Adequate information is needed for pedestrians about the direction from which they should expect approaching cross traffic. However, effective designs that clearly delineate any potential conflict points can minimize the potential for conflicts.

The following sections of this chapter discuss the issues of controlling traffic operations both within and adjacent to reversible lane segments. Presented are standard techniques and the application of nonstandardized methods for communicating information on the use of such facilities.

TRAFFIC CONTROL DEVICES

The predominant means of guiding and controlling traffic moving into, out of, and within reversible segments are conventional roadway signs, signals, and pavement markings. The review of previous and current practice showed that in the majority of locations, particularly those of a permanent nature, the most commonly employed devices were standard MUTCD applications, some of which were adapted for use under reversible operation. The history of previous installations has also shown that many of the designs currently in use and contained in the MUTCD follow years of evolutionary trial-and-error development.

Signs

The information conveyed by road signs has not changed significantly over the near 80 years of reversible lane use. Signs have always needed to convey information, such as times of operation, available lanes, and traffic shift locations. Signs for reversible lane segments may be placed either overhead above the lanes or along the roadside. The earliest reversible segments were controlled nearly exclusively by signs, although many also involved traffic enforcement personnel. The earliest signs were two sided (for guiding both directions of flow) and pedestal mounted so that they could be moved into and out of position. They were placed directly on the pavement surface, between lanes, and, in some cases, immediately off the roadway edge (Dorsey 1948). As shown in Figure 17, they incorpo-

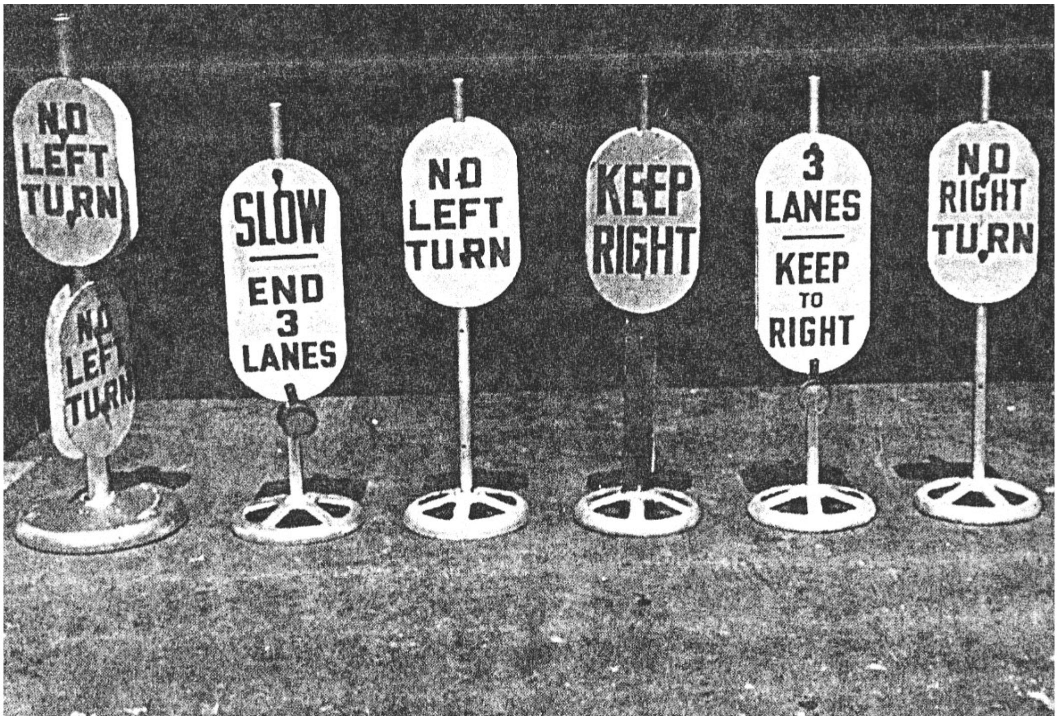

FIGURE 17 Early pedestal-mounted reversible lane signs (*Source*: Dorsey 1948).

rated very simple messages such as “Keep Right” and “No Left Turn” and they indicated the number of lanes available in a particular direction. Because many reversible lane locations are on arterial highways, these signs have also been commonly used in conjunction with on-street parking restriction signs.

Because they have been used periodically, early reversible roadway segments relied heavily on manual labor to move temporary signs into and out of position at different times of the day (Dorsey 1948). The effort and expense required to move many signs, four times a day (setup and removal for the morning and evening peak periods), over several miles of roadway, could make some early reversible road segments cost prohibitive. To address this problem, later reversible roadway applications have relied more heavily on automated installations, electrical and mechanical devices, and, most recently, dynamic control and communication systems (discussed in more detail in the following section).

The most current standards for the design and placement signs for reversible roadways are contained in the MUTCD (2001). The seven signs related to reversible operations are shown in Figure 18. They are all within the regulatory category. Because reversible lanes are used periodically, these signs tend to be text oriented to convey periods of use, rather than being symbolic.

The MUTCD (2001) allows for the use of both roadside ground-mounted signs and overhead signs for use on reversible arterial facilities. However, it also requires that all reversible lane control signs be mounted overhead; ground signs would be used only as a supplement. As shown in Figure 19, the MUTCD also offers a generic placement location diagram to indicate the approximate and relative locations for the installation of these signs. Another key MUTCD requirement for these signs is that they be installed so that “at least one, and preferably two signs” be visible at all times so that “the driver will have a definite indication of the lanes specifically reserved for use at any given time.” Doing so would be especially critical in the vicinity of curves and major traffic generators, wherein drivers would enter the reversed segment after the beginning of its transition location.

Additional guidance for the application of signs and other traffic control devices, particularly for safety concerns, is included in Chapter 13 of the *Traffic Safety Toolbox* (Wainwright 1997).

Signals

After World War II, the use of automated traffic control systems became more widespread. By the 1950s and 1960s, traffic operations in and around reversible lane segments were being guided and controlled with less labor-intensive (and more visible) electrical and mechanical devices. Such systems also decreased the time required for and cost of flow conversions. They also generally simplified the process of effecting flow conversions. The most common of these devices was the lane-use control signal.

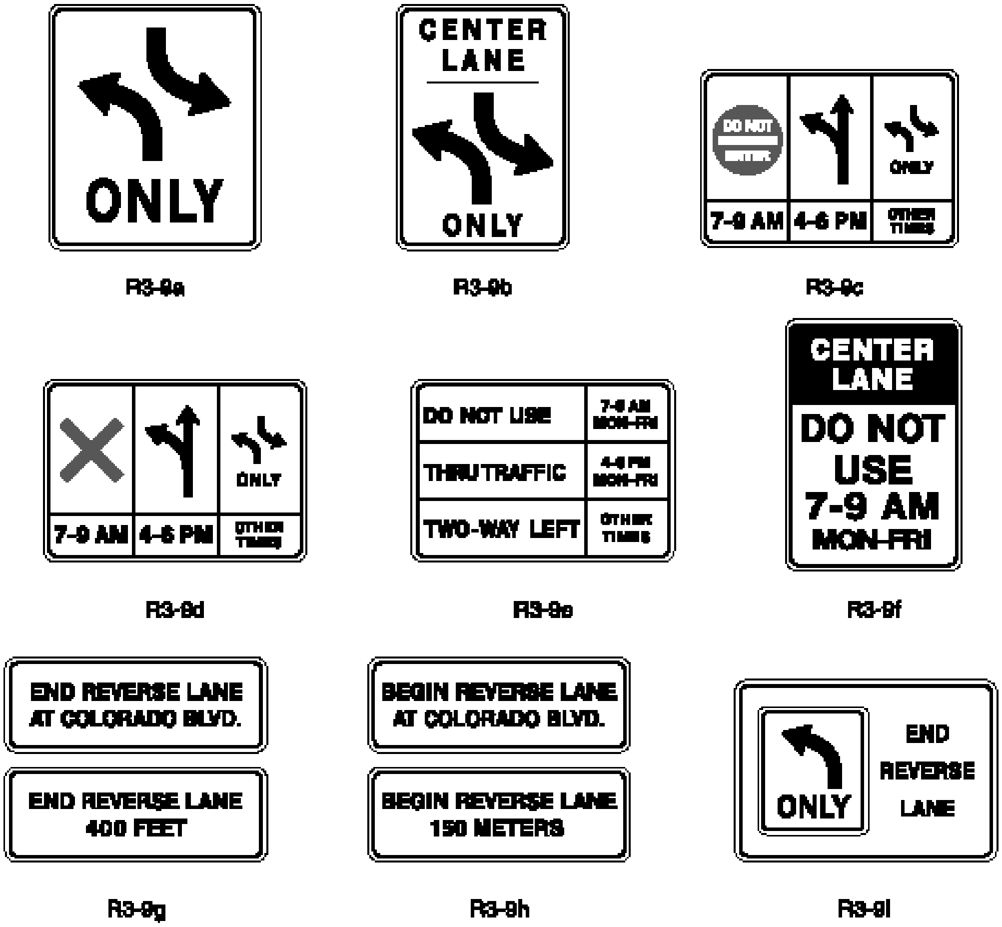

FIGURE 18 Standard reversible lane signs (*Source*: MUTCD 2001).

Lane-use signals are used to indicate which lanes of a reversible roadway are available (or not available) for use in a particular direction. In some cases, they indicate which lanes may be in the process of changing operation. An early example of a reversible lane signal system was developed by the Michigan DOT (MDOT) for use on a reversible segment of Michigan Avenue in Dearborn (DeRose 1966). MDOT signals were among the first applications of the illuminated, changeable red “X” and green arrow system to designate open and closed lanes. Interestingly, the arrows used to indicate usable lanes in that early application pointed upward rather than downward, as is the current practice. Because the reversible lane on Michigan Avenue was used as a bidirectional one for the left-turn lane during nonpeak hours (when not for directional through traffic), the sign also included a changeable left-turn guidance. It indicated “NO” during reversible through movement periods and “ONLY” during the bidirectional left-turn lane periods.

Guidance of the design and application of lane-use signals is included in the MUTCD. The current guidelines permit five different indications on these signals:

- A downward-pointing green arrow positioned over a lane to indicate that drivers are permitted to drive in that lane;
- A yellow “X” positioned over a lane to indicate that a control change is about to occur and drivers should begin to leave the lane;
- A red “X” positioned over a lane to indicate that drivers are not permitted to drive in that lane;
- A white two-way, left-turn arrow to indicate that the lane can be used for left turns in both directions, but not for through travel; and
- A white one-way, left-turn arrow to indicate that the lane can be used for left turns in the direction indicated, but not for through travel.

In addition to providing those indications, the MUTCD describes their operation based on the direction of approach and transition requirements. The manual also offers guidance on horizontally and vertically locating those devices along the roadway, stating that they must be visible for a distance of 700 m (2,300 ft). The visibility requirements of signals are similar to those for signs in that they need to be installed so that at least one and preferably two signs are visible at all times. The implementation of the various requirements can be seen in Figure 20, a photograph of a section of Tyvola Road in Charlotte, North Carolina.

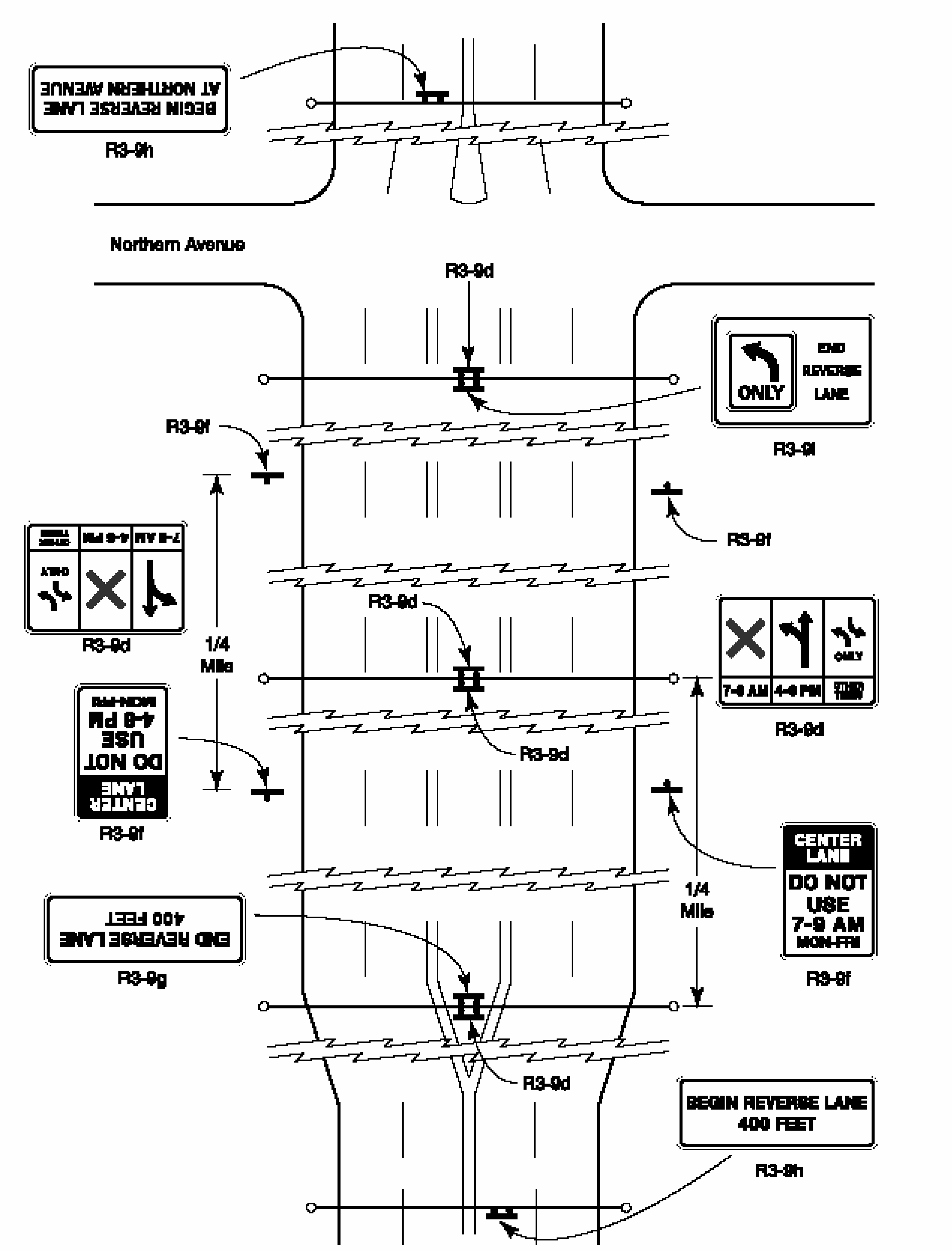

FIGURE 19 Installation requirements for reversible lane signs (*Source*: MUTCD 2001).

FIGURE 20 Overhead lane-use signals, Tyvola Road, Charlotte, N.C.

Pavement Markings

As with signals and signs, pavement markings for reversible roadway segments have changed over time. Early pavement markings for many early reversible lanes were primarily conventional solid white or yellow lane lines. However, some experimental methods were also attempted (Lathrop 1972). One involved the testing of a line of plastic plates that could be turned face up or face down by a jet of air from a maintenance vehicle. Depending on the direction of travel, the plates would be turned to reveal a white or yellow plate, or one painted to match the road surface. Another experimental approach involved the use of air-inflatable rubber strips. When inflated, the strip expanded to reveal a white surface that served as the lane line. When the strip was deflated, its color matched that of the road surface so that no markings were visible. This system was also similar to a "disappearing curb" device used on Outer Drive in Chicago. The device could be raised above and lowered below the surface of the pavement depending on need (Dorsey 1948). However, none of the systems have proved to be practically successful over the long term.

Pavement markings on current reversible roadways are the more conventional painted-on variety, although their patterns vary somewhat from those of earlier periods. The MUTCD guidelines for reversible lane pavement markings require that they consist of "two normal broken yellow lines [on each side of the lane] to delineate the edges of a lane in which the direction of travel is reversed" (MUTCD 2001). An example of this marking policy can be seen in the segment of Tyvola Road pictured in Figure 21, in which all five lanes of the cross section are reversible. This differs slightly from the segment shown in Figures 4 and 20, where one or more of the outside lanes were not reversible. The MUTCD also gives guidance on the use of raised pavement markings for reversible roadways, including lateral positioning and longitudinal spacing.

FIGURE 21 Reversible lane pavement markings, Tyvola Road, Charlotte, N.C.

A subtle variation to the Tyvola Road pavement marking scheme can be seen on a reversible section of Opdyke Road in Pontiac, Michigan. As with Tyvola Road, this application was installed for traffic management associated with events (primarily Detroit Lions National Football League games). The nonevent operational configuration features two travel lanes in each direction with a continuous two-way center lane for left turns. Before and after the football games, up to four of the five lanes were dedicated for the movement of traffic into and out of the stadium vicinity. The number of lanes that needed to be reversed would be dictated by the prevailing traffic conditions. Because traffic volumes in this area did not justify the use of reversible operation at other times, the Road Commission for Oakland County deactivated the overhead lane-use signals when reversible operation was not used, as shown in Figure 22. Also visible in the figure is the use of conventional, rather than reversible, pavement markings.

FIGURE 22 Deactivated lane-use signals and nonreversible pavement markings, Opdyke Road, Pontiac, Mich.

The review of practice also showed other variations in traffic control devices for reversible lanes. Figure 23 shows a photograph from a location in Hanover, Germany, where overhead lane-use signals have been augmented with a series of variable graphical image signs that schematically illustrate the location of access and egress points.

FIGURE 23 Tidal flow transition control devices, Hanover, Germany (*Source*: Fellendorf et al. 2000).

Other Devices

The review of current practice showed that a variety of other devices have also been used on reversible roadways. They involve various barrier and barricade systems, including automated, manual, active, and passive systems, as well as various channelizing devices. Where reversible operations are used on high-speed and high-volume roadways, these systems are typically sturdier and more expensive and often more complicated to install and modify than other systems.

Devices such as barricades are used to alert drivers to road closures and to designated closed lanes in construction work zones. Channelizing devices, such as traffic cones and tubular markers, have been used to add emphasis to reversible lane delineation (MUTCD 2001). Although these types of devices are suited for temporary uses and are relatively portable, they have little capability of preventing unauthorized lane changes or entries into converted lanes. Nevertheless, both cones and tubular lane markers have been used extensively for bus contraflow lanes on freeways (Link 1975). One problem associated with these devices, however, has that approximately 35% of them are being knocked down on a daily basis from back drafts of buses and other heavy vehicles. ITE has also discussed the use of traffic cones and movable pedestals, particularly for temporary situations. The MUTCD standards for the design of Type III barricade devices are included in Section 6F.60 of the MUTCD and channelizing devices in Section 6F.55.

In addition to using standard traffic control devices, WSDOT developed and installed unidirectional lane markers for reversible roadways in Seattle (Ching 1989). The purpose of the markers was to delineate the termini and transition area between reversible and main-line roadways. As part of the application, WSDOT personnel sawed standard two-way raised reflecting pavement markers in half and glued various color combinations (black/white, black/yellow, white/yellow) together so that lane edges would be visible from one direction and the black would make them not visible from the other direction. The markers were particularly useful within transition areas where vehicles were required to cross lanes within the transition where standard thermoplastic pavement markings were creating confusion among drivers. WSDOT reported that similar markings were also found to be useful for controlling movements within temporary construction areas with reversible operations. Although the cost of the markers was about 15% to 20% more than for standard markers, their maintenance requirements were the same.

Enforcement

Reversible roadway traffic operations in the United States have also been controlled by devices other than signs, signals, and pavement markings. Control methods include portable and fixed barricades and delineators as well as various active and passive control mechanisms. The specific nature of these devices typically reflects the function of the reversible segment—for example, temporary versus permanent, high versus low operating speed, occasional versus frequent use, etc.

One of the most common types of control for short-term (less than a few hours), infrequent reversible operations involves traffic enforcement and control personnel. In locations where a reverse flow operation may be required for occasional special events and it is not cost-effective to install permanent control features, traffic enforcement personnel are often used at the beginning and ending points of a converted segment to direct traffic into the appropriate lanes. Their efforts build on an additional advantage that can be gained from the use of manual control at the entry point: flow can be balanced in the normal and converted lanes, if necessary. In these types of configurations it is also common to see the placement of enforcement personnel at critical intersecting road locations to both prevent unwanted access to the segment and, in some cases, to prevent unauthorized departures from the converted traffic stream. At the converted segment termination, enforcement personnel have also been used to manually regulate traffic signals and to use other methods to transition vehicles back into the normal lanes.

An example of an event-oriented enforcement control is used by the Baton Rouge Police and East Baton Rouge Parish Sheriff's Department following Louisiana State University (LSU) football games (described further in chapter five). At that location, the entire reversible operation is controlled by little more than traffic police personnel who use inexpensive and portable traffic control devices such as cones and flares. Similar event-oriented enforcement control is used for sporting events and other public gatherings in Ann Arbor, Michigan; Knoxville, Tennessee; and Daytona Beach, Florida.

The use of traffic enforcement personnel on reversible roadways is also helpful for clearing the segment of "stray" vehicles that have yet to exit the segment or reorient their travel to the proper direction. Segment clearing is most critical in long reversible segments, such as those used for evacuation contraflow. In those applications, officials will probably plan to use air patrols, video surveillance, and relay-type police patrols to clear the section on a segment-to-segment basis from one interchange to the next.

One other advantage of reversible lanes, from the standpoint of traffic enforcement personnel, is that vehicles can enter and exit the segment only at a limited number of points. Violators of HOV lane restrictions are easier for the police to catch and ticket (Urbanik and Holder 1977).

SUMMARY OF KEY FINDINGS

The control of most reversible lane applications is accomplished through conventional devices, such as signs, lane-use control signals, pavement markings, and portable devices such as pedestals, tubes, and cones. Many operating agencies have developed their own sign and pavement marking symbols and legends. Operational and management strategies pertaining to the use of control features for reversible roads vary considerably among agencies. The review of the literature and current practice also revealed that

- Levels of complexity, sophistication, and cost of control systems are typically a function of the frequency of a system's use.
- Control of the termini transitions and intermediate entry and exit areas are most critical. These areas often have the highest levels of driver confusion.
- Additional consideration must also be given to the control of pedestrian movements across reversible lanes.
- Enforcement of speed limits and user eligibility can be problematic; narrow cross sections and shoulder areas limit the ability to position enforcement patrol vehicles.
- Costs associated with the implementation and removal of control devices can be high. Automated and remotely controlled devices are preferred, although they may also be expensive.
- There is a need to establish policies for the use and control of reversible lanes during non-use, low use, or balanced volume periods.

CHAPTER FIVE

ASSESSMENT AND EVALUATION

Essential to reversible roadway and lane use is the evaluation of performance. Review of the literature and current practice showed that there have been some efforts to assess and evaluate the benefits and the costs of reversible roadway operations. The reviews showed that the performance benefits of these systems have been fairly consistent over their nearly 80-year history. However, the costs have varied over time as control systems and operational strategies have become more complex, and as reversible lane practices have been applied to higher classification highways, such as freeways. Another area of variation has been in the manner in which the professional transportation community, elected officials, and the public have viewed these benefits and costs. This chapter summarizes the assessment and evaluation of reversible roadways, including the performances measure used to evaluate them; how their performance has been measured; what techniques have been used to evaluate them; costs associated with their use; and how these assessment and evaluation techniques have been used to support decisions to modify, continue, or terminate the system's use.

PERFORMANCE MEASURES AND EVALUATION

The overall goal of reversible lane use has been fairly consistent over its history—that is, to increase directional capacity of a roadway during various periods to accommodate or match unbalanced demand without the need to construct additional lanes or roadways. Therefore, it is not surprising that the most common measure of effectiveness for reversible lane systems has been traffic volume, primarily on 15-min, hourly, or peak-period bases. Other evaluation efforts have focused on measures such as travel time, travel speed, overall segment level of service, and crashes. Examples of studies and their findings are summarized here.

An evaluation of an early reversible segment in Dearborn, Michigan, used four criteria in a before-and-after study design (DeRose 1966). The comparison criteria included volume, travel time, travel speed, and accidents. The comparison of traffic volume included statistics from the total 3-h peak-period volume, the highest 2-h period, the highest 1-h period, and the high 15-min flow during the afternoon and evening peak-period travel times. Three collection locations were selected along the 1.2-mi segment immediately upstream and downstream of three signalized intersections. The volume comparisons showed an average total traffic volume increase of approximately 3.5% during the peak 3-h period, from about 5,415 to 5,605 vehicles; an average increase in the high 2-h traffic volume of approximately 3.4%, from about 4,029 to 4,172 vehicles; a highest 1-h traffic volume increase of approximately 7.1%, from about 2,213 to 2,373 vehicles; and a high 15-min volume increase of approximately 5.9%, from about 627 to 665 vehicles. An additional volume comparison showed that overall, the 2-h high volume peak was shortened by an average of 12 min, to approximately 1 h and 48 min.

The comparison of travel time and travel speed also showed improvement over conventional nonreversible operations. The time and speed were conducted during both the morning (7 a.m. to 9 a.m.) and afternoon (4 p.m. to 6 p.m.) peak-period travel times. The travel time comparison showed that, on average, the time required to traverse the reversible segment dropped an average of 16.5%, from 3 min 28 s to approximately 2 min 52 s in the morning peak and from 4 min 39 s to approximately 3 min 57 s in the afternoon peak. The comparison travel speeds showed that the average speeds recorded at the three stations within the segment increased by an average of 21.6%, from 24.2 mph to about 29.4 mph in the morning peak and from 18.1 mph to 21.3 mph during the afternoon peak period.

Two comprehensive studies of the characteristics and performance of reversible flow were conducted as part of a master's thesis at the University of Illinois (Upchurch 1971) and by the Kentucky DOT (KDOT) (Agent and Clark 1980). The University of Illinois study focused on a segment of Union Avenue in Memphis, Tennessee. The 4-mi-long reversible segment included 12 signalized intersections and featured a 4:2 unbalanced lane split during the morning and evening peak periods. The operational evaluation was based on a capacity and level of service analysis (using travel time and delay measures), plus safety considerations. The overall conclusion was that the reversible operation allowed flows of 2,500 to 2,800 vehicles per hour to be accommodated at a Level of Service C in four lanes of the six-lane roadway. It was also believed that even higher flow rates could have been achieved if drivers had been more willing to use the outermost reversible lane. Lane-specific traffic counts showed that 25% of the total volume used the curb lane, 33% the inner lane, 30% the center lane, and only 12% the outermost lane. Part of the problem was assumed to be that the use of 10-ft lanes made drivers uncomfortable when driving next to oncoming traffic. It should be noted that Memphis traffic officials ultimately discontinued reversible operations on Union Avenue because of a number of operational and safety concerns. Currently, that roadway operates as a balanced six-lane facility with three travel lanes in each direction.

The KDOT study was conducted on a 2.6-mi segment of Nicholasville Road (US-27) in Lexington, Kentucky. Initially, the roadway operated in a 2-1-2 configuration during periods of reversible operation. That was changed to 3-1-1 operation to maintain a two-way, left-turn lane (TWLTL). Despite initial apprehension, it was concluded that reversible operations at that location were a success. Travel delays were reduced and speeds increased during the morning and evening peak periods, and the benefit–cost ratio was computed to be 6.90 to 1. However, it was also noted that delay to minor-flow direction traffic increased during off-peak periods as well as during the evening peak period. KDOT officials believed that encouraging minor-flow direction drivers to use alternate routes could lessen this condition. Experiences at other locations suggested, however, that more than one lane is required in the minor-flow direction. The evaluation of this roadway also examined a number of factors, including noise, air pollution, fuel consumption, and stop-time, as well as studies of delay on approaches to minor street intersections and adjacent parallel streets.

A project to improve operations on Memorial Drive in Atlanta, Georgia, involved the evaluation of a reversible operation. It was reported that although traffic volumes "increased modestly after the improvement," morning travel times in the major-flow direction decreased by 25% and by 5% in the minor-flow direction. During the evening peak period, travel time reductions were reduced by 24% for flows in the heavier directions and 3.5% in their lighter directions ("The 1974 Annual Report . . ." 1973).

SAFETY HISTORY

Among the most consistent areas of concern with reversible lane segments is traffic crashes. Safety concerns are related to a several factors, including conflicts between opposing main-line vehicles; through and turning vehicles; entering of side street and driveway traffic; and general driver confusion associated with unfamiliarity with reversible operations, control systems, and movements. Three primary types of accidents are typically associated with reversible operations on arterial roadways (Markovetz et al. 1995):

1. Left turns in front of traffic moving in the same direction. These accidents occur when drivers are unclear about which lanes have been reversed and they conflict with traffic in the adjacent left lane(s).
2. Left turns into the direction reversible roadway. These accidents occur when drivers are required to cross fewer or more lanes (because the lanes have been reversed) than they would in nonreversible conditions.
3. Left-turning traffic is struck from the opposing traffic or from behind in a reversible lane. The accidents occur where left turns have been prohibited owing to the implementation of reversible operations.

Concern about safety on reversible lanes on freeways is somewhat different from that on arterial roadways, because access is more strictly controlled. However, even freeways have potential risks associated with their use, from head-on crashes and conflicts that could be encountered at the segment entry and exit points.

Despite the safety concerns with the operations, the literature showed relatively few efforts that evaluated safety effects of reversible segments. *Better Roads*, a publication serving the public- and private-sector transportation engineering and construction fields, touted reversible traffic lanes as one of its "10 Ways to Make Busy Commercial Streets Safer" (2002). The following paragraphs summarize some of the specific results of several studies of safety conditions associated with reversible facilities.

The crash evaluation of safety-related statistics for Michigan Avenue in Dearborn, Michigan, showed an overall decrease in accidents during the use of the reversible lane operation (DeRose 1966). Crash frequency dropped by 3.5%, 345 to 335 during the first "after year" period, with a 19% decrease to 279 accidents during the second after year of reversible operation. Although some types of accidents increased during the 2-year study period, they were not believed to be related to the reversible lane system. It was also concluded that the significant overall decrease in accidents stemmed from the prohibition of on-street parking during the hours of operation than from reversible lanes. The accident record of the segment during the periods of nonuse essentially remained unchanged during the study period.

The Union Avenue study in Memphis showed that the segment experienced 817 accidents, with 137 (16.8% of the total) related to the reversible operation. Of the 137 related accidents, 81% were directly related to unauthorized left turns that were made across an adjacent lane with flow in the same direction. No overhead "No Left Turn" signs were initially used in that location (Upchurch 1975).

The KDOT safety study on Nicholasville Road showed no significant increases in crashes before and after the implementation of reversible flow. Records were compared for 1-year periods before and after the change and were compared based on severity, type, location, and direction for the a.m., p.m., and off-peak periods (Agent and Clark 1980).

An evaluation of the safety impact of contraflow freeway bus lanes showed statistics that "disclaim head-on collisions as a risk" (Link 1975). Accident rates for these lanes showed the following:

- None of the three busiest contraflow bus lanes in New York had abnormal accident trends.
- There were no perceptible changes in accident patterns on I-495.
- Boston had one fatal accident, although it involved a maintenance crew and not drivers using the lanes.
- There were no accidents in Marin County, although the number of accidents during the off-peak and setup periods in the segment doubled during the first year of operation.

Another comprehensive study of reversible roadway safety involved the conversion of US-78 in Gwinnett County, Georgia (Bretherton and Elhaj 1996). In the study, four hypotheses were developed and tested: those that looked at accidents attributed to driver confusion, left turns, lane control signalization, and turning movements out of side streets and driveways. The study provided interesting and informative results and included the following:

- There was a 1-month (or less) learning curve associated with reversible lane operations.
- Left-turn maneuvers caused the most conflicts and resulted in 43 accidents during the 6-month study period. The most prevalent type of crashes was rear-end accidents by left turners from a through lane.
- Drivers appeared to be confused by the overhead signal indications, resulting in 16 accidents during the study period. Although strobe lights were added to the signals, they had little effect on crash frequency.
- Accidents associated with turning movements into the reversible section were similar to those for a six-lane roadway.

On the basis of these findings, the Georgia DOT made modifications to the traffic control features of the roadway. They included restriping the convertible lanes from a double yellow 10-ft stripe/30-ft skip to a 10-ft stripe/10-ft skip configuration. This change had little impact, however, on the crash rates. The overall conclusion was that the reversible segment had an "accident experience no higher than a 6-lane road with a two way left turn lane. However, injury and fatality rates are significantly greater than [on] the TWLTL roadway" (Bretherton and Elhaj 1996). Ultimately, the general feeling was that the reversible operation was dangerous and the section of highway would be reconstructed to a divided highway.

A lightly studied area related to reversible lanes and roadway safety is the effect on pedestrians. It is assumed that pedestrian problems would be limited to arterial roadways, in which people would not be aware of the direction from which traffic was approaching. The effect for pedestrians could be most significant for fully reversible roadways where traffic in the lane adjacent to the pedestrian walkway would be flowing in either direction during different times of the day.

One example was encountered on Charles Street in Baltimore, Maryland, where two southbound lanes are separated by a grass median. The problem at that location is the natural reaction on the part of pedestrians to assume that traffic on the far side of the median will be flowing in the opposite direction. To reduce the danger to pedestrians at that location, Baltimore traffic officials prohibited the use of the lane at all times except during the morning peak-period travel time.

OTHER COSTS AND BENEFITS

The benefits of reversible lane systems have been widely recognized for some time. ITE has described them as "one of the most efficient methods of increasing rush-period capacity of existing streets" ("A Toolbox . . ." 1997). This is so because, depending on the configuration, they typically can be implemented with minimal capital cost, particularly on segments such as tunnels and bridges, where the cost of adding new lanes would be very high if not impossible. Although the precise dollar value of these benefits is often debated, in general, they are better understood than the costs associated with reversible lane operations.

The costs of reversible lane operation are usually measured in terms of operations, safety, and/or construction and maintenance. Aside from the aforementioned studies that evaluate the number of accidents and travel delays, there are relatively few documented sources that discuss the costs associated with these measures and even fewer that discuss the direct costs of construction and periodic maintenance. Still, it is a generally accepted notion that the costs of reversing lanes on an existing roadway are significantly less than those of constructing new ones.

ITE stated that some of the noteworthy disadvantages of reversible operation were a reduced capacity for flow in the minor direction and operational difficulties at the termini. Unfortunately, however, neither of these phenomena has been evaluated in significant detail.

There may also be other fixed costs associated with the management of the reversible facility, such as police for concentrated enforcement to prevent violations of lane-use restrictions, maintenance personnel to set up and remove traffic control devices, and operational staff to operate and strategically manage the system. Another potential area of concern is increased liability. Although this topic has been mentioned only once in the literature (by the Port Authority of New York and New Jersey), it is a persistent source of cost to highway agencies. To offset potential risks associated with its contraflow bus lane (CBL) operation, the Port Authority increased its amount of liability insurance to cover potential lawsuits for CBLs (Link 1975). It was mentioned, however, that no lawsuits had been filed against the Port Authority or the other agencies (including Boston, Los Angeles, and Marin County, California) that were operating CBLs at the time.

SUMMARY OF KEY FINDINGS

There are few widely disseminated or easily available evaluations and assessments of reversible lane performance. Reviews of those evaluations and assessments however revealed the following:

- A recognized need for better assessments of reversible operations, including comprehensive evaluations of both costs and benefits.
- A further need to have a set of criteria and guidelines that can be used to determine the conditions that might warrant a cost-effective implementation of new reversible lanes or the conversion of an existing non-reversible facility for reversible use.
- Qualitative assessments have been based mainly on volume, travel time, and level of service.
- Safety studies have been used to find the types of accidents associated with reversible operation.
  - Empirical observation and anecdotal evidence suggest that reversible lanes do not contribute significantly to increased frequency or severity of accidents.
  - The frequency and type of accidents associated with arterial reversible lanes are different from those associated with freeway reversible lanes.
- Many assessments have been based on empirical evidence and general motorist reaction to previous installations.
- The effect of reversible operations on pedestrians is largely unknown.
- Costs to maintain and operate reversible roadways are largely unknown.

CHAPTER SIX

CURRENT STATE OF THE PRACTICE

As part of the synthesis, reviews of both published and unpublished sources of literature were conducted. The published sources included more traditional research and assessment literature, such as technical journals, research reports, and practitioner and trade publications. The review of unpublished sources included less widely disseminated sources, such as unpublished local studies for local agencies, internal DOT reports, law enforcement operational manuals, and other location-specific and difficult-to-access interim reports and feasibility studies. Because the subject of reversible roadways has not been widely studied, it was assumed that the review of unpublished literature sources would be particularly useful. To gain access to the most current sources of information, a survey of previous, current, and potential reversible roadway users was undertaken.

Surveys were sent to highway agencies throughout the United States and in several foreign countries, as well as to scores of private-sector and law enforcement agencies throughout the country. The survey served three main purposes. Most importantly, it was used to gather the most current information for the widest possible cross section of users, configurations, and locations. That information was used to identify who is using a reversible lane system, where and how it is being used, and the purpose for its use. The findings, in turn, permitted direct interviews with the officials in charge and field visits to selected locations. The survey also allowed the less widely disseminated information to be gathered directly from the source. Finally, the survey made it possible to compare and contrast the policies and practices that have been used for the planning of reversible highway facilities.

This chapter focuses on the findings of the practice survey and the additional information that was gathered during follow-up interviews and site visits. Included are the general findings of the survey, as well as specific instances in which an agency has employed practices that are different from the more generally accepted practice. To highlight the variety in design and control characteristics, seven specific examples of reversible roadways are also presented. The locations were Charlotte, North Carolina; Houston, Texas; Washington, D.C.; New Orleans and Baton Rouge, Louisiana; Summit County, Colorado; and Peoria, Illinois. They were selected to illustrate the wide variety of reversible flow uses, including facility type, purpose, management, and duration of use.

SURVEY OF PRACTICE

The survey of reversible roadways was conducted over a 5-month period between January and May 2003. Survey questionnaires were sent to local representatives in all 50 states and U.S. territories for distribution to the appropriate highway department officials. A supplementary list of approximately 160 potential users of reversible roadways was developed, and the survey was also distributed to those users. The supplemental survey list was developed from the initial findings of the literature review that indicated the probable types of facilities on which reversible operations have been applied. The potential users included departments of public works in major urban areas; tollway, tunnel, and bridge authorities; cities where major special events are held; campus police of major universities; and international transportation authorities. It was anticipated that the targeting of this group of higher potential users would increase both the breadth and depth of the findings. A total of 49 responses from the 209 surveys issued were received by mail, fax, and e-mail; a response rate of 23%.

The survey questionnaire (included in Appendix A) consisted of 27 questions that, using a simple checkbox and fill-in-the-blank format, investigated five key areas of interest: uses and locations; design; management, control, and enforcement; assessment; and planning. The uses and locations questions were developed to determine where and when convertible lanes have been, or are currently being used or planned, as well as their purpose and the type of facility on which they were used. The design questions focused primarily on the design geometrics and traffic control design aspects of convertible lane systems. They also sought to determine the extent to which existing or standard design practices were used to guide their design, as well as to determine if the conversion had been planned from the outset for the facility or if it was adapted to fit an existing configuration. The management, control, and enforcement questions were used to determine and assess the various operational aspects of various convertible roadways, including how and if a reversible lane system was deemed necessary. Additional areas of interest in that section dealt with policy issues relative to reversible roadways, their operation across jurisdictional boundaries, and their operation during various weather and day and night conditions. The assessment section of the survey addressed issues associated with the benefits of convertible roadway use pertaining to added capacity, travel time savings, and others. The remaining questions were used to determine the

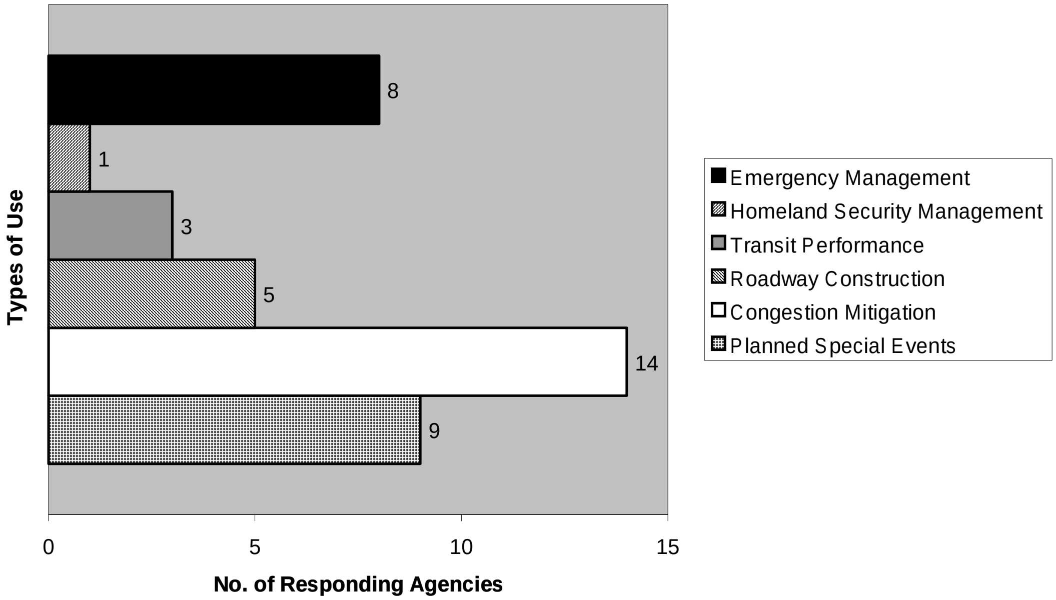

FIGURE 24 Uses of reversible lane facilities.

costs associated with their use, particularly crash histories and public acceptance. The planning section of the survey dealt with similar questions, although more in regard to the tools and methods used to forecast the future performance of these systems. The following sections highlight and summarize the responses to the questionnaire and include some of the more unique techniques that have been applied.

Uses and Locations

Twenty-three of the 49 respondents to the survey indicated the use of one or more forms of reversible lane operation. The general categories for reversible operation used in the survey as well as the type and number of uses are shown in Figure 24. The survey showed that the most common applications were associated with congestion mitigation, planned special events, and emergency management. Follow-up discussions with the users showed that the majority of the congestion mitigation uses were designed to deal with recurrent patterns of unbalanced commuter flow on thoroughfares into and out of CBD.

Reversible lane operations for special event traffic were most common in medium-sized cities and rural areas where normal traffic volumes rarely reached capacity, but where periodic event traffic overwhelmed the existing road system. To limit travel delay into and out of events would require the construction of multilane roadways. However, the cost associated with permanent facilities to serve that level of demand would not be justified. Therefore, the use of reversible operations on existing facilities would provide the desired capacity without adding cost.

One of the most recent widespread applications of reversible lane systems was for emergency management. Within the past 5 years, every coastal state in the southeastern United States has developed plans to reverse freeway and arterial roads to increase outbound roadway capacity in the event of a major hurricane. As with the applications associated with nonemergency traffic scenarios, the specific planning, design, and management of evacuation-oriented contraflow vary (Urbina and Wolshon 2003). It was interesting to note that one of the survey respondents also indicated that reversible lane systems would be used for homeland security management. Since the terrorist attacks of 2001, transportation issues associated with homeland security have received high priority, and evacuation has been suggested as a key tool for emergency preparedness and response. As a result, many civil defense agencies are in the process of updating existing plans or formulating new plans to evacuate cities under threat of terrorist attacks. Although some agencies were forthcoming about the use of evacuation-related applications of reversible lane systems, others regarded homeland security-related issues as sensitive material and would not discuss evacuation strategies that might reveal certain weaknesses that could be exploited. This was especially true of plans for bridges and tunnels.

One of the recognized limitations of using reversible lane systems (or any other evacuation plan) for security-related emergency management is that terrorist attacks typically come with no advance warning. Unlike hurricanes, in which there are often days to prepare, a terrorist attack would not allow time to deploy personnel and prepare a road for evacuation. Thus, an evacuation would most likely be used to move people after an event, such as was

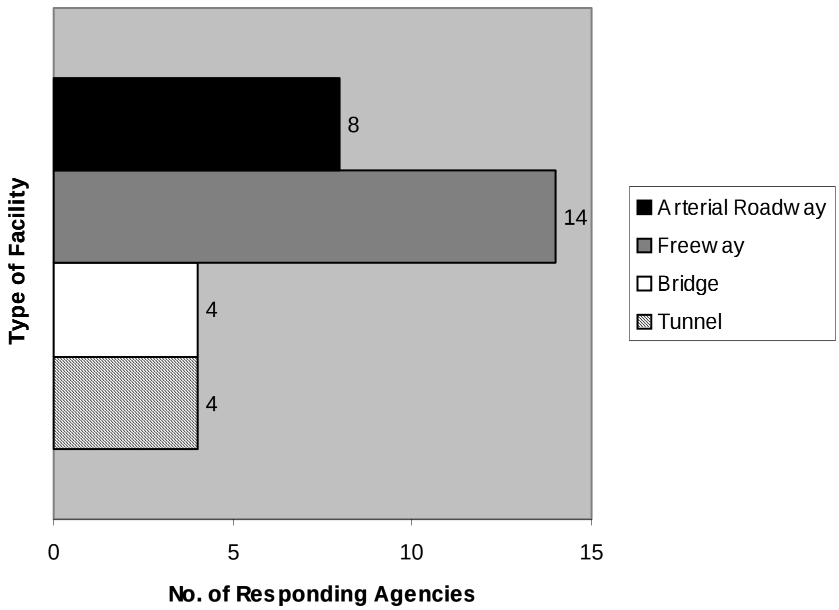

FIGURE 25 Reversible roadway type.

the case in Washington, D.C., in 2001, where traffic control devices were switched to an afternoon commuter setting to increase outbound capacity.

Figure 25 shows the types of highway facilities on which surveyed users have implemented reversible operations. Freeways and arterial roadways were the most common locations. In older and more urbanized areas, it was most common for reversible flow to be used on these types of facilities, because the original rights-of-way width secured for the roadway have not been adequate to accommodate the growth in traffic that has occurred over time. This condition is even more acute in the cases of bridges and tunnels, where it is usually not economically or environmentally feasible to add more lanes.

Reversible lane operations have also been used on freeways to provide a more cost-effective and expedient method to increase capacity. One of the benefits of reversible lane operations on freeways is that they require less control over the length of the segment, owing to the limited number of access points. Once drivers have moved through the transition zone, the need for frequent traffic control devices and guidance is lessened. Having fewer access points also means that there are the fewer conflicting movements. Two concerns of reversible lane systems on freeways, however, are the high operating speeds and volumes typically associated with those facilities. Later sections of this report discuss the issues and how they have been addressed.

Control

The initial field review of traffic control devices for reversible lanes showed a high level a variation in the development and application of such devices. In many instances, the signs that are currently used to guide traffic are nonstandard MUTCD designs, nor are they consistent with many recognized state-level traffic control device standards manuals. Several questions were included in the survey to determine the level at which agencies using reversible roadways are using conventional MUTCD-compliant traffic control devices, have developed their own local guidelines, or have informally created new signs to address specific needs.

Of the 23 agencies responding to the question, 14 reported that the devices used on their reversible roadways are based on written standards. The most common was the MUTCD, although several respondents had also developed their own at the local level. This meant that nearly 40% of the agencies have created new (nonstandard) signs. As shown in Figure 26, fewer agencies indicated that they use documented standards for pavement markings and other devices such as lane delineators and markers, although according to discussions with some of them it was found that they either use standard MUTCD designs or do not have as much need for special-use devices. An example was the use of pavement markings in which the broken double-stripped yellow lines were so commonly accepted and understood by drivers that the agencies did not require the development of any new local standards.

There are a variety of signs that have been locally customized to display the hours of operation or lane-use configuration. Most of these signs, however, are not MUTCD compliant, although most are a composite of MUTCD-compliant signs. For example, the lettering and material of which the sign is constructed may be MUTCD compliant, but the application is not found in the manual. Figure 27

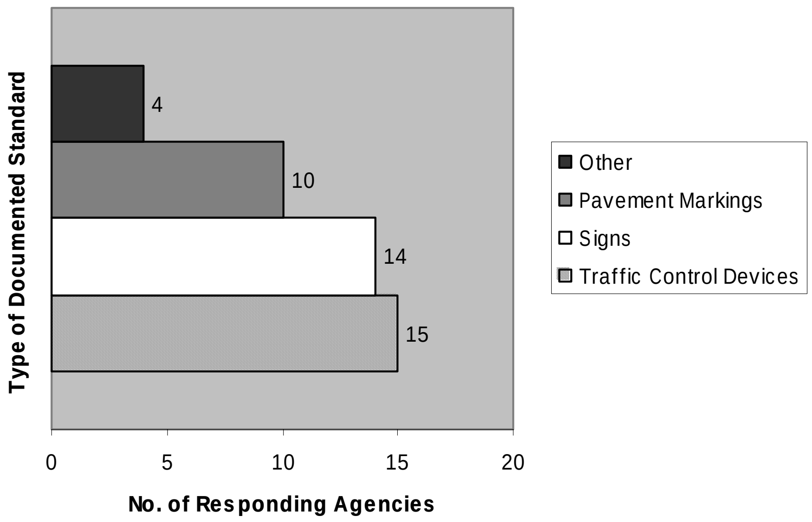

FIGURE 26 Documented standards for reversible roadway facilities.

shows an example of a composite sign located along a reversible segment of Canal Road in Washington, D.C.

FIGURE 27 MUTCD-compliant composite sign, Washington, D.C.

Another example of a modified MUTCD-compliant traffic control device is used on the William Preston Lane Jr. Memorial Bridge. Also known as the Bay Bridge, this 4.3-mi facility spans the Chesapeake Bay as part of US-50/301, providing a connection between the coastal areas of Maryland's Eastern Shore and the metropolitan areas of Baltimore, Annapolis, and Washington, D.C. On the bridge, a strobe light has been added to enhance the visibility of the red "X" of the overhead lane-use control signals. It was believed that this added measure was needed, owing to the combined effect of the length of the bridge, lack of shoulders for incident management, high volumes, and adjacent lanes with opposing directions of flow. The use strobe lights is not addressed specifically in the MUTCD; however, the manual does give specifications for the use of beacons, although this application is for a flashing circular yellow signal, not a strobe light.

Design

The review of published literature related to reversible lane facilities (discussed in chapter four) showed that there are no dedicated sources that govern their design. The most widely accepted highway design manual, AASHTO's *Green Book* (2001), discusses the general principles of reverse-flow lanes, although it offers little specific design criteria. In essence, AASHTO suggests that reversible lanes be designed as normal travel lanes. Another widely applied manual, the *Guide for the Design of High Occupancy Vehicle Facilities* (AASHTO 1992) supplements the *Green Book* on issues related to the use of reversible lane strategies for HOV facilities. Again, however, it does not offer much specific design guidance. This absence of guidance in the design of reversible facilities, as well as a lack of uniform standards for their use, has led some state and local transportation agencies to develop their own standards. Figure 28 shows the elements of reversible facilities for which various agencies have developed their own design standards and recommendations.

More than two-thirds of the responding users have developed their own standards to address local design issues. However, that finding is not surprising, because more than one-half of the facilities reported in this survey were retrofitted to an existing facility, a topic not covered in any of the existing literature. Adapting existing facilities for re-

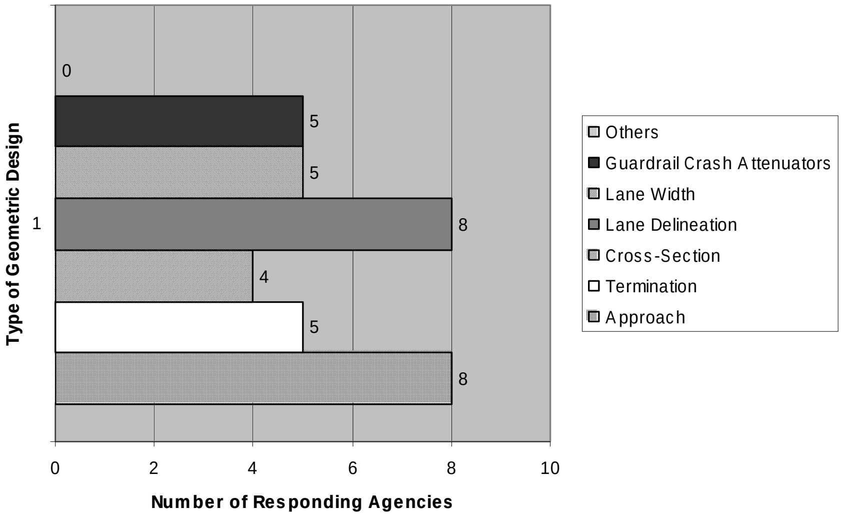

FIGURE 28 Design elements with local design standards and recommendations.

versible use can present many design challenges and has resulted in an equal number of unique and unorthodox solutions. For example, it was found that Union Avenue, a reversible roadway in Memphis, Tennessee, measured 64 ft curb to curb. Although that was not wide enough for six 12-ft lanes, two 12-ft and four 10-ft travel lanes were fit into the cross section. A similar situation has occurred on freeways where separate interior reversible lanes occasionally need to be reduced to 10 ft in width because of existing overpass support columns. Such lane reductions are evident on the Katy Freeway in Houston, Texas.

Management, Control, and Enforcement

One of the key management topics on which information was sought in the management section of the survey were criteria for initiating and terminating the reversible lane system. Officials at the District of Columbia DOT (DDOT) operate on a routine and timed schedule before the morning and afternoon commute periods for consistency. On the campus of the College of William and Mary (Williamsburg, Virginia), where reversible operations are used only for special events, those operations begin 60 to 90 min before the events and terminate at the end of the event. Those are the periods when traffic volume is sufficiently low to allow safe operations using normal traffic control devices.

The survey showed that reversible lanes used to mitigate congestion during peak travel times typically operate from 2 to 4 h. In most cases, the hours of operation are the same in the morning as they are in the evening. In a few isolated cases, however, the morning and evening operations are not the same length. Such is the case in the Queens Midtown Tunnel in New York City. It is the result of two factors that lessen the need to increase the outbound capacity in the afternoon. First, after the morning commute period, the directional traffic volumes become balanced. Second, the buses take a different route on their return trips across the river.

Only about half of the agencies surveyed responded to the question about how drivers are notified of the hours of operation. The most common method was by variable message signs (VMSs) and static signs indicating the hours of operation. Another growing trend is for agencies to post the information on a website. WSDOT uses the Internet to post hours of operation for regular commuter schedules as well as special event schedules for the reversible “express lanes” (see http://www.wsdot.wa.gov/regions/northwest/traffic/expresslanes/#I5Express).

Although the authority over reversible lane operations varies by the location and type of use, the majority of the responding agencies reported that authority came from a state DOT. That finding is not surprising, because most of the responders were state-level agencies, and DOTs also maintain freeways. As shown in Figure 29, several law enforcement agencies also control reversible segments, although most of the segments involved were event-oriented configurations.

When asked if the reversible lane operations crossed political lines, half of the survey participants responded in the affirmative and half in the negative. In some instances, bridge, turnpike, and tunnel authorities have been formed to operate in multiple political districts. Such arrangements are effective for addressing the issue of overlapping jurisdictions, cost of operation, chain of command, and resources. Also, there may be a problem in that only one end of the reversible segment derives any benefits from the op-

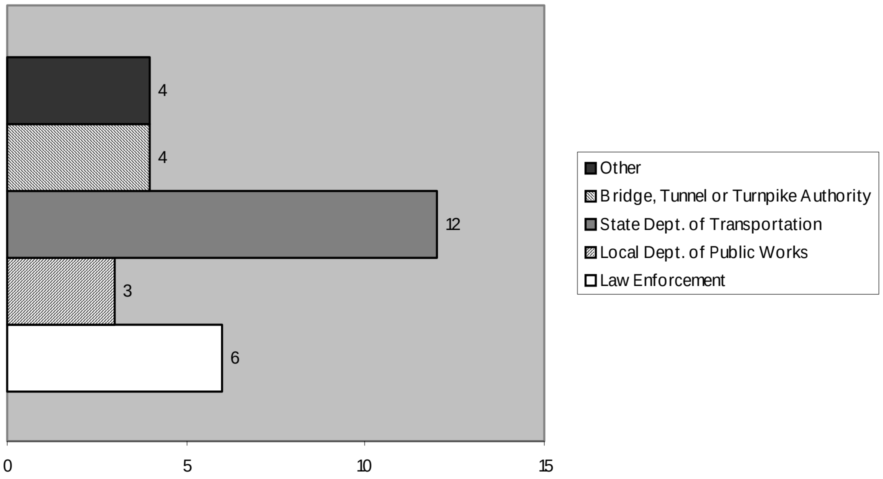

FIGURE 29 Agency responsible for reversible operation.

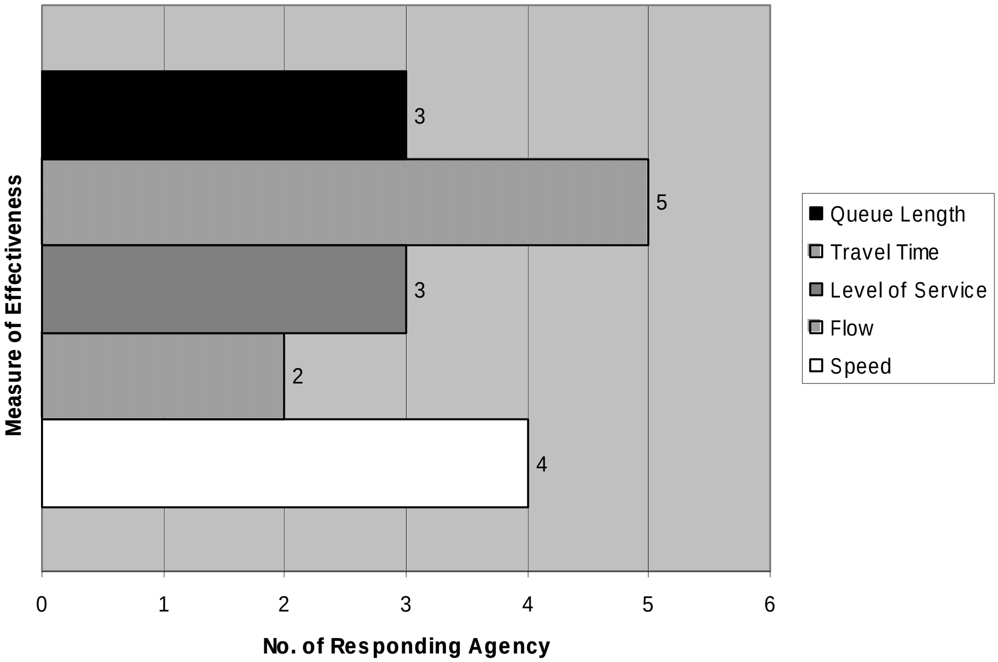

FIGURE 30 Measures of effectiveness of reversible lane systems.

eration. For example, when reversible lanes are used for evacuation, one jurisdiction generates evacuees and another one must receive and care for them. Where such cases have occurred, the receiving jurisdictions wanted to be compensated for the additional resources required to operate the reversible lane system.

Most agencies surveyed have not had to create any new law enforcement methods to ensure compliance; only three responded that they did create new ones. This finding could be attributed to the concept that most noncompliant movements can be enforced through existing laws. Still, in some cases, drivers are physically separated and prohibited from operating in noncompliant movements, through the use of drop gates and moveable barriers.

Many agencies surveyed view operating during daylight hours as optimal, but not mandatory. Only seven responding agencies prohibit reversible operations at night. Interestingly, officials at WSDOT cited noise, not safety issues, as the reason for discontinuing the use of reversible lane system at night.

Assessment

Although historically few agencies have monitored, evaluated, or reported on the performance of reversible lane system characteristics, 13 of the responding agencies reported measuring the traffic flow characteristics of their facilities. As shown in Figure 30, most of these studies have been associated with travel time and operating speed and, to a lesser extent, with volume-related evaluations of queue length and level of service. Only two of the surveyed agencies have undertaken studies to assess public opinion relative to the use of reversible lane operation. Because most agencies operate with strict budgets, and traffic assessment studies can be costly, a lack of complaints has been the most common method to gauge the level of public satisfaction.

Only five of the respondents reported that they completed analyses and documentation of costs and/or benefits associated with the reverse-flow and contraflow operation. The Ministre des Transports of the Government of Quebec conducted a study of the cost savings of using a reversible lane system in lieu of new construction on the bridge (i.e., structural modification of the existing bridge). Officials from WSDOT also studied the use of I-5 lanes at night to decide on closures to reduce the impact of noise on neighborhoods. Similarly, officials of the city of Charlotte DOT conducted a study of the cost of widening and the impacts to adjacent property.

Eight of the responding agencies also reported the discontinuation of reversible operations. Officials from the Memphis, Tennessee, Engineering Division indicated that the city council believed the operations to be confusing and directed the Engineering Division to discontinue the operation after a feasibility study. Officials from the Charlotte DOT also removed a reversible lane system after a road widening increased the operating capacity. Officials from the city of Vancouver, British Columbia, discontinued its system during major road construction activities, to limit variations in lane-use configurations and closures that were necessary during road works. That was a unique situation, because reversible lane systems for road construction projects are typically used to increase capacity.

Planning

The final area of inquiry within the survey pertained to the planning of reversible lane systems. Covered were topics on planning methods used in previous applications and planning of future systems. It was found that, much as with design, the planning for reversible facilities is not substantially different from that for conventional facilities. In the case of temporary and short-term applications, where the need for added capacity is obvious and improvement options are limited, planning activities could often be characterized as informal.

From the survey responses, as shown in Figure 31, the main decision to consider the use of reversible lanes is based on the need to increase traffic flow volume. The limitation of queue length and reduction of travel time have also been considered to be important criteria. One of the difficulties in making planning assessments of reversible facilities has been the lack of reliable data on which to base the facilities' expected performance. Of all the agencies surveyed, only four reported that they had estimated flow rates for reversible lane system applications. Officials in Vancouver based their estimated flow rates on manual counts, whereas those at WSDOT based the rates on historical data. Furthermore, officials at the New Jersey DOT based their flow rates on results from its simulation laboratory.

The survey also showed some of the future applications of reversible lane systems. Figure 32 indicates a shift in philosophy about reversible lane system applications. Most

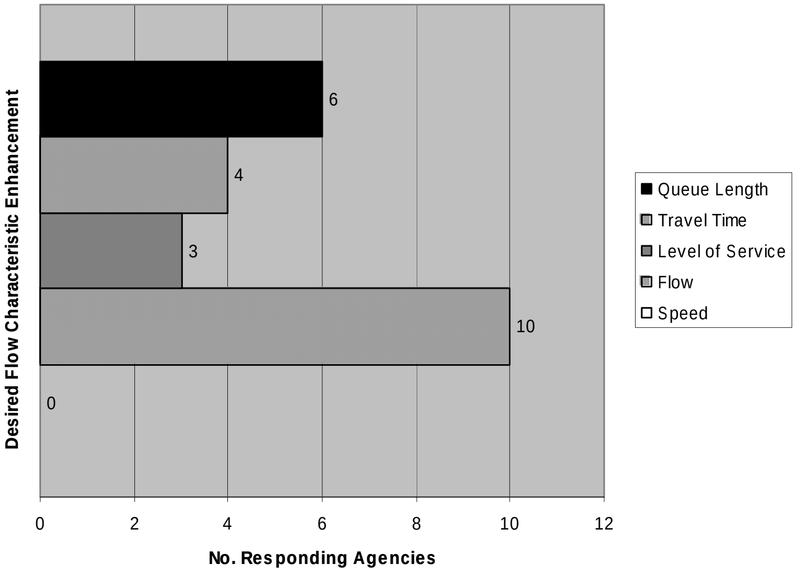

FIGURE 31 Criteria cited for implementing reversible lanes.

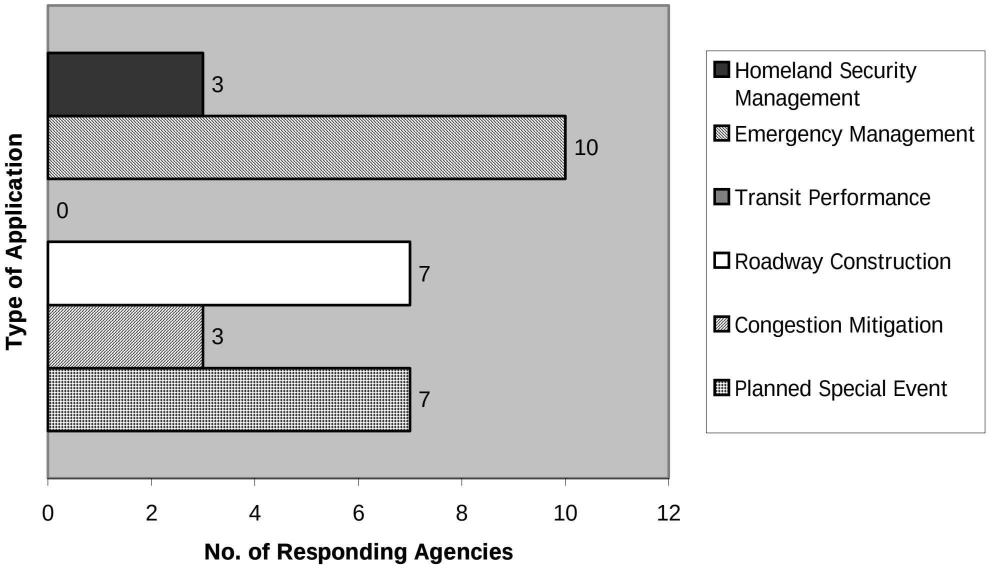

FIGURE 32 Applications of reversible lane systems currently being considered.

of the applications have been in use for more than 20 years and have been used for purposes of increasing transit performance and mitigating congestion. However, the most often cited reason for future use was emergency management. In light of the new focus of many governmental agencies on emergency and homeland security management, officials are trying to develop methods to increase capacity despite limited funds and the need for rapid implementation, to bring about a perfect match for reversible lane operations.

The final questions of the survey asked agencies to list any aspects of convertible lanes that they would like addressed. Officials at the Maryland Transportation Authority suggested studies of cost–benefit and safety, as well as the need for contraflow operation based on the level of congestion. Officials at the South Carolina DOT suggested a study on the issues of safety where guardrail and bridge ends are not protected in the reversed direction. Also, officials at the Oregon DOT suggested a study on the entry and exit conflicts and automation.

IMPLEMENTATION EXAMPLES

The survey illustrated the breadth of reversible highway configurations, as well as the manner in which the roadways are controlled and the types of conditions for which they have been needed. On the basis of the survey results, seven case examples were selected for additional discussion to highlight features that pertain to specific locations, facility types, and needs. The cross section of case examples includes both restricted and nonrestricted access facilities that have been used, or are planned to be used, on routine, special event, and emergency bases, and that can be considered to be permanent or temporary. The case examples also illustrate reversible facilities in urban and nonurban areas.

The following sections describe the general characteristics of each of these facilities, including their design and control features. When information was available, an attempt was also made to present the reason(s) why reversible operations were needed in each location, the approximate flow conditions associated with them, their associated crash histories, and levels of public acceptance and user satisfaction.

Urban Arterial Commuter Traffic Management

Canal Road—Washington, D.C.

Washington, D.C., is unique among users of reversible roadways, for it operates several within its jurisdiction, on both limited access roadways and multilane arterial roadways with regularly spaced signal controlled intersections. Canal Road and Connecticut Avenue are two examples of reversible roadways in the city. Although they are similar in some respects, they are also different in that Canal Road is limited access and is converted to full one-way operation, whereas Connecticut Avenue is an unrestricted access facility that maintains two-way operation with preference given to the major-flow direction of travel.

Canal Road is a key highway linking residential areas of Maryland and Virginia to Georgetown and downtown Washington, D.C. During the morning peak-period travel time, the predominant travel direction on Canal Road is into the city. During the evening peak-period travel time most travel is outbound. DDOT officials employ reversible operation on Canal Road to mitigate daily peak-period congestion associated with those directional traffic patterns. During nonpeak periods, Canal Road operates as a bidirectional facility. During peak periods, it is converted to two-lane, one-way operation. As shown in Figure 33, the typical cross section of the reversible segment of Canal Road includes two 12-ft travel lanes with little or no shoulders and a double-striped, broken yellow line to separate the opposing traffic streams. Because, reversible operations were not originally planned for this road, it has been adapted to accommodate their use.

FIGURE 33 Canal Road—reversible lane segment, Washington, D.C.

Reversible operations on Canal Road occur over a 3-mi segment. The beginning and ending termini are the intersections of Foxhall Road (M Street) and Chain Bridge Road. The hours of reversible operation consist of nonholiday Monday through Friday, from 6:00 a.m. to 10:15 a.m. and from 3:00 p.m. to 7:00 p.m.

Reversible operations along the segment are controlled by a combination of static signs mounted on utility poles and VMSs located at the Chain Bridge Road terminus. As shown in Figure 34, a static sign at Foxhall Road shows the allowable traffic movements by featuring arrow symbols and a text legend defining the periods of operation. The arrows at the top of the sign in the figure indicate the reversible configuration flow, and the arrows at the bottom of the sign indicate the normal bidirectional flow. During reversible operation, the VMS displays the message “USE 2 LANES,” as shown in Figure 35. During nonreversible periods, the VMS displays a “DO NOT ENTER” message consistent with the MUTCD sign “R5-1” (FHWA 2001).

FIGURE 34 Canal Road—reversible lane control sign at Foxhall Road, Washington, D.C.

FIGURE 35 Canal Road—reversible lane variable message sign, Washington, D.C.

The transition period for reversible operations on Canal Road occurs over a 15-min period beginning at 6:00 a.m., during which traffic is not allowed to enter the segment at the Foxhall Road intersection. At 6:15 a.m., traffic is permitted to enter the reversed lane in the inbound direction at the Chain Bridge Road. At 10:00 a.m., reverse operation is discontinued and drivers are no longer permitted to enter the reversed lane. At the opposite terminus, the intersection of Chain Bridge and Canal Roads is controlled by a signalized “T” intersection. Vehicles entering that location are channeled into directional preference and are queued and released by a traffic signal.

Despite the traffic control devices present at that location, a recent study of reversible operations on Canal Road showed the potential for conflicting traffic operations during the transition period (Lambert 2003). During the 15-min transition period when outbound traffic is allowed to completely clear the segment, the entry of 24 vehicles into the reversed lane was recorded. Because vehicles are not physically prohibited from traveling on the reversed lane, it is assumed either that drivers are using the reversed lane to pass slower vehicles during the transition or, more likely, that a number of drivers are unaware of the termination of the operation and have remained in the reversed lane. Nevertheless, discussions with Washington, D.C., traffic officials did not indicate any clear or persistent safety problems within the vicinity of the reversible section.

The reversible segment of Canal Road also includes two intermediate access points along its length. The first point is a lightly traveled road that approaches Canal Road at an acute angle. Owing to that geometric feature, left-hand turns are restricted onto Canal Road. Right-hand turns are permitted as long as vehicles are not turning into conflicting traffic streams. Drivers approaching from the minor streets are made aware of the reversible operation by curb-mounted signs. The second point is the signal controlled “T” intersection at Arizona Avenue, located less than one-quarter mile from the Chain Bridge Road terminus.

Although no formal studies of the safety or operational characteristics of Canal Road have been undertaken, DDOT is generally satisfied with its performance. Typical traffic volumes during peak weekday periods exceed 1,000 vehicles per hour per lane (vphpl) with little or no queuing. Although there are no significant changes in vertical grade along this segment, there are several horizontal curves where drivers do not have clear lines of sight. Although the MUTCD recommends the use of overhead signs to indicate active lane-use directions, there are none along the 2-mi segment from Arizona Avenue to Foxhall Road. DDOT traffic officials believed that such signs were not warranted, because there is only one intermediate access point between Arizona Avenue and Foxhall Road and the hours of operation are posted at the access points. The restricted cross-section width also allows little room for law enforcement personnel to control traffic, raising the issue of speed limit compliance. The recent Canal Road traffic study showed that less than 2% of the vehicles in either lane were traveling at or below the posted speed limit of 35 mph during hours of reversible operation (Lambert 2003).

Connecticut Avenue—Washington, D.C.

Another example of a reversible roadway in Washington, D.C., is Connecticut Avenue. Although the motivation (mitigation of recurrent peak-period congestion) for reversible operation on Connecticut Avenue was the same as for Canal Road, the facilities differ considerably. The typical cross section of Connecticut Avenue is four lanes (two lanes in either direction) with two parking lanes. The reversible segment spans approximately 2.5 mi and is bounded by Garfield and Legation Streets. The land use along the reversible lane segment is varied. It includes stores, restaurants, churches, a school, and, most notably, the Smithsonian Institution’s National Zoological Park. Thus, the demand for short-term parking is high.

Reversible operations are used on Connecticut Avenue Monday through Friday from 7:00 a.m. to 9:30 a.m. and from 4:00 p.m. to 6:30 p.m. During these periods, the parking lanes are also converted to travel lanes, resulting in a six-lane facility with four lanes in the major direction of flow and two lanes in the minor direction of flow. Traffic control along this segment is provided by pavement markings and static and VMS, mounted both at the road edge and above the travel lanes. Pavement markings within the segment are standard MUTCD design, with single white skip lines delineating the normal travel lanes and shorter double yellow skip lines delineating the two interior reversible lanes.

The transition to reversible operation occurs over a 15-min period during which all VMSs display the appropriate number of lanes to use for the duration of the operation. The burden is placed on the motorist to comply with the reversed lane configuration without assistance or guidance from the police department. Drivers are advised of the reversible operation one block before the transition zone. In this area, signs are posted to show the hours of operation and lane configuration, as shown in Figure 36. The entrance transition occurs over a block-long segment that incorporates a sign showing the lane configuration, along with a VMS mounted above the traffic signals. Pavement markings within the transition zone consist of double, broken yellow lines for the reversible lanes with a diagonal arrow to direct drivers into the reversible lanes. These pavement markings are shown in Figure 37. The termination transition process is very similar to the initiation process. The one-block transition zone begins with a sign advising the beginning of a three-lane configuration at the next intersection, shown in Figure 38. At the departure end, the termination of reversible operations is indicated with the sign shown in Figure 39. This sign also features a bright orange background to draw the attention of drivers. Although the pavement markings for the lane delineation are consistent with MUTCD guidelines, the static signs and arrow for lane transition are not.

FIGURE 36 Connecticut Avenue—reversible lane configuration and hours of operation, Washington, D.C.

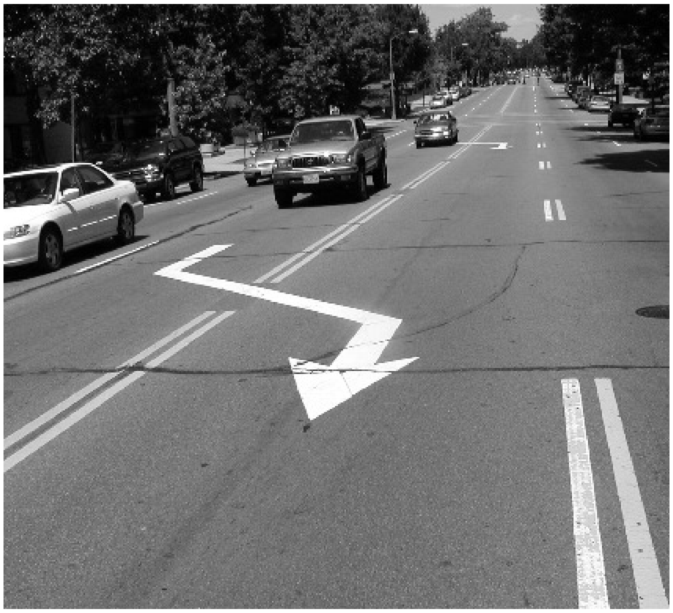

FIGURE 37 Connecticut Avenue—transition zone pavement markings, Washington, D.C.

FIGURE 38 Delineation of the beginning of terminus zone, Connecticut Avenue, Washington, D.C.

FIGURE 39 Notification of the end of reversible operations, Connecticut Avenue, Washington, D.C.

Two additional factors that complicate reversible operations on Connecticut Avenue are the large number of intersecting streets and driveways and the accommodation for off-peak, on-street parking. Drivers approaching the facility from intersecting roadways are notified by signs about allowable movements through the intersection. Because some of the intersecting streets are two-lane, one-way streets, right turns are permitted only from the approaching right lane during off-peak periods. However, during the reversible operation, right turns are permitted to the major direction from both lanes. This situation also improves flow on the intersecting streets. An example of a sign installation at a minor street approach is shown in Figure 40.

To accommodate the needs of local residents and businesses, on-street parking is permitted on Connecticut Avenue. However, it is limited to off-peak traffic periods. Before commencing reversible operation during the peak

FIGURE 40 Minor approach indicated by a lane-use sign, Connecticut Avenue, Washington, D.C.

period, the segment is inspected and, if any vehicles are in the parking lanes, the vehicles are towed. After the morning operation is terminated, parking is permitted once again between 9:30 a.m. and 4:00 p.m. At 4:00 p.m., the road is inspected and cleared once again for the afternoon reversible operation. Drivers are advised of these hours by means of signs such as that shown in Figure 41. Although the inspection and removal of illegally parked vehicles can be a daunting task, because there are about 5 mi to regulate, DDOT officials are very pleased with the operation and have stated that noncompliance is not a significant problem.

The regulation of parking on Connecticut Avenue also means that it is one of the few reversible roadways where capacity is not diminished in the minor-flow direction. This is not typical of most reversible facilities, in which one or more lanes are taken away from the minor direction.

Event Traffic Management

Tyvola Road—Charlotte, North Carolina

In Charlotte, North Carolina, a reversible lane system was created to accommodate the traffic demand associated with special events at the Charlotte Coliseum. Originally, it was assumed that an eight- to nine-lane roadway would be required to empty a 10,000-space (later reduced to 8,000) parking lot within 1 h. However, to save on cost, it was alternatively proposed that a five-lane road be constructed with three reversible lanes so that four lanes could be used before and after events. Tyvola Road was constructed in 1998 at a cost of $22 million to meet this need.

FIGURE 41 Connecticut Avenue—parking restriction sign, Washington, D.C.

The Tyvola reversible lane system is one of the most technologically sophisticated in the United States. It incorporates 196 fiber-optic lane control signals, each mounted on mast arm poles and controlled by 9 field programmable logic controllers (PLCs). An example of these PLCs is shown in Figure 42. Software for the PLCs allows for nine different combinations of reversible lanes. The specific pattern varies with the size and type of event at the coliseum. For a sold-out basketball game, for example, Tyvola Road can be configured so that four lanes can be used for vehicles to enter and exit each half of the coliseum before and after the game. During daylong events, such as circuses, when vehicles enter and exit continuously, two lanes may be used simultaneously from each side of the coliseum entrances, and a center lane can be used as a TWLTL. The pavement markings on Tyvola Road, visible in Figure 42, also facilitate such traffic movements.

Transitions on Tyvola Road are implemented through a computerized control system to ensure driver safety, although traffic cones and barricades have also been used for some situations. Sign changes occur sequentially throughout the system, so that motorists do not encounter multiple changing signals during the transition. The transition is

FIGURE 42 Tyvola Road—lane-use control signals, Charlotte, N.C.

also timed for a travel speed slower than at what most drivers travel. Therefore, a driver should see at most only a single sign change during the transition interval. Police are also required to assist with the reversible lane operation. As many as 22 officers may be required to control traffic, and the operation can be labor intensive and require minute-by-minute monitoring and adjusting.

The Tyvola Road reversible lane system works in tandem with the traffic signal system. As each lane-use signal pattern is called up for use, the traffic signal master controller automatically selects a complementary traffic control pattern. Five video cameras have also been located along the segment to provide visual confirmation of the current traffic conditions. Technicians in the control center are able to detect accidents and monitor congestion. Furthermore, the system incorporates VMSs to communicate information to drivers.

Currently, a new sports arena is under construction and is expected to be completed in 2005. It is anticipated that the new arena will eliminate the need for the current Tyvola Road reversible traffic system, because the system is not used during any periods other than for events at the existing stadium. However, interviews with local traffic officials revealed that although the reversible lane system was an effective method to mitigate the occasional high-volume demands, it would not be missed by its operators. The reason is primarily that the system and facilities require a significant amount of maintenance, which the operators regard as a nuisance.

Highland Road—Baton Rouge, Louisiana

A common application of reversible lanes is to facilitate the movement of the short-term directionally unbalanced traffic conditions associated with planned public gatherings, including concerts, sporting competitions, festivals, and fireworks displays. Reversible lane use for planned events typically differs from daily uses in that it is used infrequently and for a short duration, and it is nearly always managed by law enforcement officers using modest traffic control devices (flares, cones, barricades). Although the traffic conditions associated with events can vary considerably, the typical travel pattern associated with these types of events includes a peak traffic period that lasts for approximately 1 or 2 h. Because the arrival of traffic at many events is spread out over a number of hours, it is common that additional road capacity is required only at the end of the event, when the majority of people depart at approximately the same time.

Reversible lane operations have proven to be particularly effective at locations such as Daytona Beach, Florida, during Bike Week and at Ann Arbor, Michigan, for University of Michigan football games, where the occasional event traffic would not justify constructing additional lanes to accommodate the occasional demand. Other advantages of short-term reversible operations are that they are highly adaptable and can be deployed on an as-needed basis with little need for permanent or long-term control systems and equipment. As a result, they are far less expensive than similar permanent configurations.

FIGURE 43 East campus boundary and beginning of the reverse-flow segment, Highland Road, Baton Rouge, La.

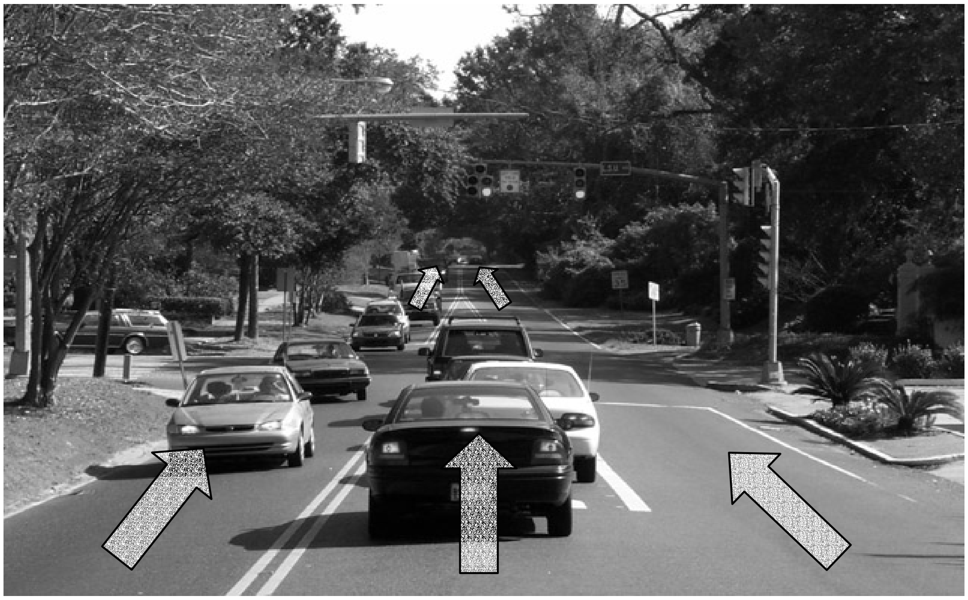

FIGURE 44 Lane drop of two-way, left-turn lane on the reverse flow segment at the intersection of Highland Road and College Drive, Baton Rouge, La.

An illustration of a temporary, event-oriented reversible lane operation is used on Highland Road, adjacent to the campus of LSU in Baton Rouge, Louisiana. Highland Road is a minor arterial highway that serves a primary route into the LSU campus and carries about 8,000 to 10,000 vehicles per day. On football Saturdays, the 650-acre campus hosts well in excess of 150,000 people and more than 50,000 vehicles. To accommodate postgame traffic, the Baton Rouge police reverse the flow in the inbound lane of Highland Road to the outbound direction.

The length of the Highland Road reverse flow segment is only approximately 1.5 mi. The operation begins on campus and incorporates three outbound lanes, the normal outbound lane, the opposing inbound lane, and a TWLTL, as shown in Figure 43. At about one-third of the way into the segment, traffic merges into two lanes after the TWLTL is dropped at the intersection of College Drive (see Figure 44). Traffic then continues in two lanes for the length of the segment, as shown in Figure 45. Although numerous residential side streets and dozens of commercial and residential

FIGURE 45 Downstream two-lane, reverse-flow segment cross section, Highland Road, Baton Rouge, La.

driveways intersect with Highland Road, the familiarity of the local residents, coupled with the absence of gaps in the reverse-flow lane, prevents authorized entries into the reverse lane. This situation also allows the overall traffic enforcement presence along the segment to be kept to a minimum.

Reversible operations are particularly effective at this location, owing to the high capacity of the segment termination point. At the outbound terminus, all traffic in the reverse-flow lane is required to turn left onto a perpendicular intersecting roadway, whereas all other traffic continues eastbound in the normal outbound lane of Highland Road. The transition from normal operation to reverse flow is accomplished in a relatively simple manner. The low volume and low operating speeds in the inbound direction allow the reverse flow platoons to be led out by a police vehicle. When inbound vehicles were present in the reversed lane during the transition, they were required to make a U-turn into the outbound lane.

A study of the Baton Rouge reverse-flow segment showed that traffic flow rates in those lanes averaged approximately 950 vphpl at speeds of about 20 to 23 mph (Wolshon 2002a). When measurements from four separate events were used, no significant differences in the basic flow parameters (speed, flow, and occupancy) between the normal and reverse-flow lanes could be identified. Similarly, there did not appear to be a driver preference for selection of the normal versus the reverse-flow lane. That finding is in contrast to the widely held belief that drivers will have a tendency to avoid the reversible lane. An interesting note about the Baton Rouge reversible lane segment is that all of the operations occur late at night. Because LSU football games are almost always played at night, reversible operations on Highland Road typically do not begin until about 10:30 p.m. and last until around midnight. Despite the nighttime operation, there have been no indications that the reversible operation has resulted in any safety problems.

HOV Commuter Traffic Management

Interstate 10 (the Katy Freeway)—Houston, Texas

One of the fundamental benefits of reversible lanes is that it maximizes capacity by using the existing cross section. When freeway right-of-way widths are limited owing to environmental or cost considerations, it may be necessary to add additional travel lanes between the existing median lanes rather than to add outer lanes. In some cases, there may also not be sufficient width to construct additional lanes in both travel directions. To overcome the problem of adding capacity within limited right-of-way locations, several cities have developed barrier-separated reversible median lanes for HOV traffic.

An example of this type of design can be seen on a section of I-10 in Houston, Texas. Known locally as the Katy Freeway, it extends from the Houston CBD westward to the Brazos River, a distance of 35.6 mi. The area served by the Katy Freeway, generally referred to as West Houston, is one of the fastest growing areas in the Houston region, and this segment of highway serves in excess of 200,000 vehi-

FIGURE 46 Reversible segment of the Katy Freeway, Houston, Tex. ["High Occupancy Vehicle (HOV) Interactive 1.0" 1996].

TABLE 2
KATY FREEWAY—REVERSIBLE LANE AND USE OF HOV REQUIREMENTS

Day(s)	Time	Travel Direction	Occupancy Requirement
Monday–Friday	6:00–6:45 a.m.	Inbound	2+
Monday–Friday	6:45–8:00 a.m.	Inbound	3+
Monday–Friday	8:00–11:00 a.m.	Inbound	2+
Monday–Friday	2:00–5:00 p.m.	Outbound	2+
Monday–Friday	5:00–6:00 p.m.	Outbound	3+
Monday–Friday	6:00–8:00 p.m.	Outbound	2+
Saturday	5:00 a.m.–8:00 p.m.	Outbound	2+
Sunday	5:00 a.m.–8:00 p.m.	Inbound	2+

cles a day. The convertible lane segment spans 13 mi of the Katy Freeway from I-610 to Texas State Highway (SH) 6. As seen in Figure 46, the cross section of the segment incorporates two three-lane directional main-line travel lanes, a single barrier-separated reversible HOV lane in the median, and two two-lane directional parallel frontage roads.

The Katy Freeway reversible lane differs from most arterial reversible lanes because its operation is also managed. Initially, the reversible lane was operated for vehicles with a minimum occupancy of two passengers (HOV 2). Later it was increased to an HOV 3 lane, because it was heavily used. However, that also resulted in excess capacity in the lane during the peak periods. As a result, the QuickRide program was introduced, allowing HOV 2 vehicles to pay $2.00 per trip to use the lane during peak periods, through the use of a QuickRide account with the accompanying transponder and windshield tag. Meanwhile, the program allows HOV 3+ vehicles to continue to travel at no additional cost. The specifics of the use requirements are shown in Table 2.

The Katy Freeway flow reversals require an on-site confirmation and manual placement of gates, cones, and other traffic control devices to ensure proper operation. There are also on-site wreckers that remove any stalled vehicles. Stalled vehicles are not permitted to remain in the reversible lane before or during transitions, and they are promptly removed during periods of operation. The lane is fully closed during nighttime periods. TxDOT also prohibits from the reversible lane single-occupant vehicles, vehicles towing trailers of any sort, and trucks with more than two axles or a gross weight capacity greater than 1 ton.

Entry to or exit from the lane can be accomplished using ramps to and from park-and-ride lots, transit centers, and main-line traffic lanes. Four different types of ramps are used on the Katy Freeway:

1. One-way ramps for entries in the morning and exits in the evening;
2. Two-way ramps for entries and exits in the mornings and evenings;
3. Cross ramps designed to allow access to and from both sides of the freeway; and
4. Slip ramps that allow merges into or out of main-line freeway traffic; most HOV lanes start and end with this type of ramp.

The elevated ramp shown in Figure 47 is located at the Addicks park-and-ride lot on the Katy Freeway transitway in West Houston ("High Occupancy Vehicle . . ." 1996). The ramp is elevated to span a railroad track and parallel street before returning to grade in the bus loading area of the lot. Only right turns are permitted at the ramp; no crossing movements are allowed at the intersection. Bus headways from the Addicks lot usually approach 3 min during the peak hours.

FIGURE 47 Elevated access ramp, Houston, Tex. ["High Occupancy Vehicle (HOV) Interactive 1.0" 1996].

Another type of access, seen at the termini of the Katy Freeway, is provided by at-grade slip ramps to the adjacent main-line lanes. Figure 48 shows the ramp near Gessner Street, which provides intermediate access from I-10 eastbound in the morning and exits to the westbound lanes in the afternoon. Manually operated gates, cones, and signs are used to prohibit wrong-way movements.

The average peak-period speed on Houston freeways is roughly 24 mph, although the reversible HOV lane maintains an operating speed of roughly 50 to 55 mph, reducing an average commuter trip by 12 to 22 min. Discussions with TxDOT officials revealed that no significant accident problems or driver confusion has been experienced on either of the transitions (east or west ends) during the past 20 years of operation.

FIGURE 48 Intermediate access ramp, Houston, Tex. ["High Occupancy Vehicle (HOV) Interactive 1.0" 1996].

Some of the public complaints about the reversible HOV lanes include too few access points and an inability to serve increasing levels of two-way travel. In many locations, the inbound and outbound traffic are equally congested, and METRO buses serving corridor park-and-ride lots have long travel times on their return trips to the park-and-ride lots. To address such issues and the need for greater capacity, TexDOT has developed a new design that calls for four main-line travel lanes and two managed lanes in each direction. That cross section was shown earlier in Figure 6. The managed lanes will be reserved for METRO buses, HOV 3+, and high-occupancy toll vehicles ("Katy Freeway Reconstruction . . ." 2003).

I-93 Southeast Expressway—Boston, Massachusetts

The Massachusetts Highway Department (Mass Highway) operates the I-93 Southeast Expressway HOV lane, a 6-mi contraflow facility connecting Quincy and Boston. The HOV lane is based on a contraflow design, which borrows an underused off-peak direction lane and converts it to a peak-period direction HOV lane during periods of morning and afternoon congestion. The HOV lane is separated from oncoming traffic by a 6-mi flexible wall made up of moveable hinged concrete barriers, which are repositioned twice each day. The moveable barrier system cost approximately

$10.3 million to install; each barrier transfer vehicle cost $650,000.

During the morning peak period (6:00 a.m. to 10:00 a.m.) the Southeast Expressway has five lanes (including one HOV lane) operating northbound, and three southbound general-purpose lanes. During the afternoon peak period (3:00 p.m. to 7:00 p.m.), the highway operates with five southbound lanes (including one HOV lane) and three northbound general-purpose lanes.

Mass Highway opened the HOV lane in 1995. The entry requirement is two persons per vehicle. The HOV lane also incorporates an advanced transportation management system, whose principal components are a highway surveillance system (cameras, VMSs, and volume and speed detectors), a communication link between the surveillance system and the centralized operations and information center, and a computer system to support a traffic operations center.

Construction Zone Traffic Management

McClugage Bridge Rehabilitation—Peoria, Illinois

Another widely applied purpose for reversible lanes pertains to construction work zones. Reversible lanes are well suited for those areas, because capacity is still required within restricted rights-of-way, especially on bridges and within tunnels. The Illinois DOT (IDOT) employed a moveable barrier reversible lane system to reduce traffic delays during the rehabilitation of the McClugage Bridge over the Illinois River near Peoria, Illinois. The 4,750-ft long structure was constructed in 1949 and is the second most heavily traveled river crossing in Peoria, with an average daily traffic of 42,500 vehicles.

With a substantial percentage of Peoria's work force living in communities on the east side of the river and working on Peoria's north side, directionally unbalanced peak-period volumes exist on the bridge from 6:00 a.m. to 9:00 a.m. and from 3:00 p.m. to 6:00 p.m. After analysis, IDOT engineers recognized that one lane of traffic would not provide an acceptable level of service in the peak direction and that two lanes were essential to provide adequate capacity. That presented a problem, because the structure was wide enough only for three lanes of traffic during the construction period.

To address this problem, a moveable barrier was installed to provide two lanes in one direction and one in the other depending on the need. The 6,000-ft barrier could be realigned in approximately 25 min with only minor disruptions to traffic. While in operation, the 16-ton moving machine (known as the "Zipper") would lift the barrier wall and make a 12-ft lateral transfer at speeds up to 10 mph. The entry transition area and the barrier moving process are shown in Figures 49 and 50.

FIGURE 49 The "Zipper" moving the barrier into configuration for morning peak period, Peoria, Ill. (*Source*: "Fact Sheet 5—Innovation During Bridge Rehabilitation Improves Mobility" 2003).

FIGURE 50 West entrance of the McClugage Bridge construction zone reversible segment, Peoria, Ill. (*Source*: "Fact Sheet 5—Innovation During Bridge Rehabilitation Improves Mobility" 2003).

The use plan for this segment involves the conversion of the center lane to accommodate the evening peak-period travel time at 11:00 a.m. each day (except Sunday), so that two outbound lanes and one inbound lane from and to Peoria were available. The opposite configuration is provided from 9:00 p.m. to 11:00 a.m. each day. IDOT officials reported that the moveable barrier wall system eliminated the daily congestion that had been commonplace during previous construction projects in the vicinity of the bridge.

A similar system is also used on the Tappan Zee Bridge in New York City ("Tappan Zee Bridge . . ." 2003). Although the systems and goals are nearly the same, the difference between the New York and Illinois applications is that the moveable barrier on the Tappan Zee Bridge is a permanent feature used to facilitate morning and evening peak-flow volumes.

Interstate 75 Reconstruction—Flint, Michigan

Another example of reversible lanes in a construction zone is illustrated by MDOT's application of a moveable barrier reversible lane system on I-75 in the vicinity of Flint, Michigan. The reversible lane segment spans a distance of approximately 5.5 mi and was implemented to accommodate the heavy volume of directional recreational commuters experienced on this roadway during weekends and holidays.

In general, the segment is configured for three northbound lanes and two southbound lanes from about midday Thursday, and then the mirror image for returning traffic from about midday Sunday through midday Monday. Because MDOT uses a moveable barrier system, the lane conversion occurs under normal traffic. MDOT officials estimated that a complete conversion of operations in this area takes about 3 h—typically 1½ h to move the barriers and another 1½ h to change the static signs and VMSs.

Because of the configuration of the work zone, both the inside and outside shoulders of the (final) southbound lanes were used to carry through traffic, as shown in Figures 51 and 52. MDOT's experience is one of the few applications of this type, because shoulder widths and pavement thicknesses are not commonly designed to carry normal freeway traffic loads. Given that the shoulders in this area would be used to carry traffic, they were designed to a 12-ft width and with a full-depth concrete pavement section to accommodate heavy loads. The cross-section modifications included a further lateral placement of the (permanent) guardrail. Embankment guardrails were constructed at their final location for the final design. This meant that they are closer than normal for a typical freeway design. However, it was believed that the temporary nature of the configuration, the reduced speed limits in the area, and the need to reduce the potential for congestion problems in this location dictated the use of the design.

MDOT officials have been very satisfied with the performance of this system and have plans for its use in three other locations around the state. One interesting negative aspect of moveable barriers for temporary reversible lanes in Michigan, however, has been the problem of debris collecting next to the base of the barrier. When the wall is moved laterally, any debris that has collected near the barrier base will end up in the middle of two travel lanes. Although seemingly a minor problem, it can lead to flat tires and disabled vehicles, which can be treacherous because the restricted cross section limits motorist's opportunities

FIGURE 51 Cross-section view of the use of shoulders as outer reversible lanes, Genesee County, Mich. (*Courtesy*: Armando Lopez, Michigan DOT).

FIGURE 52 Overhead view of the use of shoulders as outer reversible lanes, Genesee County, Mich. (*Courtesy*: Armando Lopez, Michigan DOT).

to stop and limits the accessibility to disabled vehicles in work zones and on bridges. To overcome this problem, MDOT officials required the use of an additional laborer to ride at the front of the barrier as it is moving and to retrieve any potentially hazardous surface debris, as shown in Figure 53.

FIGURE 53 Cleaning of debris adjacent to movable barrier, Genesee County, Mich. (*Courtesy*: Armando Lopez, Michigan DOT).

Emergency Traffic Management

Interstate 10—New Orleans, Louisiana

One of the most recent widespread applications of reverse-flow operation in the United States has been for emergency management. Although largely the result of the traffic jams associated with Hurricane Floyd in 1999, the use of freeway contraflow has also been suggested as a response measure to a variety of other natural and manmade hazards, including nuclear, biological, chemical, and terrorist threats. Currently, 15 states have plans for the use of contraflow operation for hurricane evacuation. These plans vary considerably in their design and management and segment lengths, which range from less than 10 mi to greater than 120 mi (Urbina and Wolshon 2003).

One example of freeway contraflow for emergency evacuation is planned in New Orleans, Louisiana. The Louisiana State Police (LSP), working in conjunction with officials from the Louisiana Office of Emergency Preparedness and the Louisiana Department of Transportation and Development (LDOTD), developed the New Orleans plan. In comparison with most other locations, the westbound contraflow segment is short, approximately 20 mi. However, what this segment lacks in length, it makes up for in efficiency, because it does not include any on-ramps along the route and does not merge the separate traffic stream back together at its terminus.

Under the New Orleans plan, traffic evacuating the metropolitan area will be divided into two separate streams at the approach to two bridge sections on the east and west sides of town. At both locations, LSP personnel will route traffic in the two left lanes of outbound Interstate 10 into the inbound lanes, using two-lane paved median crossovers. Lightweight water-filled barriers prohibit median crossings at this location during nonevacuation periods. Before an evacuation, they will be drained and removed by LDOTD personnel.

On the west side of the city, the evacuating traffic streams will be parallel with one another over the Bonnet Carre Spillway Bridge section of I-10 over the south shore of Lake Pontchartrain. At the I-10/I-55 interchange, all traffic moving in the normal westbound lanes will be forced north onto I-55. After the interchange, the contraflow traffic in the eastbound lanes will cross back into the westbound lanes of I-10, using a median crossover. A similar configuration will be used on the east side of the city on the Twin Span bridges between New Orleans and Slidell. However, the length of the eastbound segment will vary based on the location of the contraflow termination point. The cooperative agreement between Louisiana and Mississippi calls for contraflow operations to continue as far north as Meridian, Mississippi (approximately 120 mi to the northeast), if warranted by the demand. Under less threatening conditions, contraflow operation could terminate as early as the Louisiana–Mississippi border. The crossing of the state line is one of the unique features of the New Orleans contraflow plan and will likely make the challenge of coordinating traffic control and enforcement even more difficult.

The decision to close these routes will be made by a state police commander, in conjunction with officials from LDOTD and the Office of Emergency Preparedness. The LSP will in advance position wreckers at strategic locations to remove disabled vehicles on these routes. Evacuation traveler information will be available from two local radio stations through the Emergency Broadcast System. The LDOTD highway advisory radio network will also provide traveler information.

Merge congestion is also a concern in several contraflow evacuation segments. The advantage of these segments is that their significant lengths (100 mi or more) will permit a reduction volume before the merge point. Adequate capacity at the entry of the segment is also important because the segment cannot flow “full” of flow if entry volumes are restricted. The likelihood for that condition was recently illustrated in a study of the contraflow evacuation segment out of New Orleans (Theodoulou and Wolshon 2003). A simulation of the location showed that the full potential of the added lanes is not likely to be realized, because the entry point limits the segment volume. The study revealed that this situation could be offset by adding more volume from downstream entry points.

Finally, the use of evacuation contraflow segments differs from nonemergency uses in that a premium is placed on efficiency because of the scope of the threat. Thus, "luxuries" such as route choice, access and egress availability, and even some standard safety measures will be sacrificed to move a high number of people out of the threat area. A key point about evacuation contraflow is that little is known about its effectiveness, because it has been used in only two isolated cases. Although it is expected that much will be learned about this practice after it is more widely used, additional information on many of the recognized issues and limitations associated with evacuation contraflow are discussed in separate reports (Wolshon 2001 and Wolshon 2002b).

Tunnel Traffic Management

Eisenhower Tunnel—Summit County, Colorado

As mentioned earlier, among the most practical conditions for the application of reversible traffic operations are where it is not economically or environmentally feasible to obtain right-of-way or construct additional lanes on an existing facility. Prominent examples of these locations are bridges, tunnels, and roads within intensively developed commercial and residential areas. An illustration of the application of reversible operations within a tunnel was the Eisenhower Tunnel section of I-70 between Summit and Clear Creek Counties, Colorado, some 60 mi west of Denver.

The need for reversible operations at that location was brought about by very high weekend and holiday traffic volumes as people from the heavily populated region around Denver returned from activities in the central and western areas of the state. Although reversible operations were used in this location for approximately 12 years, they were discontinued owing to congestion in the single lane of the minor-flow direction as traffic volume in that direction also increased.

The Eisenhower Tunnel is made up of two separate, though joined tubes. The twin tubes are approximately 115 ft apart and run for a length of about 1.7 mi, with an average grade of about 1.6% rising from east to west. During peak periods, the traffic demand on the four-lane section of I-70 was approximately 2,400 to 3,200 vph in the major-flow direction and approximately 500 to 600 vph in the minor-flow direction. However, one of the factors that contributed to congestion in this vicinity was the approach grades to the tunnel, which rose at about 6% to 7% into both entrances ("The Eisenhower/Johnson Memorial Tunnels" 2003).

Reversible operations through the tunnel were accomplished by reversing the flow direction in the median lane of the westbound tube for a 3:1 lane-use ratio. The transition was accomplished over a distance of approximately 1,500 ft by separating traffic in the two eastbound lanes into three lanes, as shown in Figure 54. Opposing traffic streams in the westbound tube were separated by construction barrels. Flip-up signs that were opened during periods of reverse operation, and indication signals within the tunnel by overhead dynamic message signs and lane-use signs, provided additional traffic control on the approach transition (described in chapter five) within the tunnel. The flip-up signs are illustrated in Figure 55.

FIGURE 54 Transition area at the Eisenhower Tunnel entrance, Summit County, Colo. (*Source*: Colorado DOT 2003).

The use duration for the reversible configuration was typically 4 to 5 h. Because most of the traffic control devices were maintained on site, the amount of time required to configure the area for reversible operations was brief. Typically, the time required for a 20-person crew to prohibit movements into the segment and then set up or remove the control items was about 1 h. The reversible operations were usually needed on an occasional basis—typically several weekends during the summer vacation and winter ski seasons. Reversible operations were not required to accommodate westbound traffic in the tunnel, however,

FIGURE 55 Eisenhower Tunnel flip-up signs (nonreverse flow operation), Summit County, Colo.

because experience showed that the peak for outbound travel tended to be lower, although more spread out in that direction.

Experience in regard to the Eisenhower Tunnel showed no adverse safety impacts resulting from the reversible lane configuration. Although no detailed studies were conducted, anecdotal evidence showed no significant increases in accidents within the vicinity of the segment. It was noted that some rear-end accidents were evident in the areas upstream of the segment as vehicles slowed or stopped in congestion upstream of the tunnel. It was also suggested that the good safety record of the segment may have also been associated with the relatively low operating speeds within the tunnel vicinity during nearly all of the reversible lane-use periods.

The two factors that contributed to the Colorado DOT's discontinuation of the reversible operation in the tunnel were the capacity limitations at the downstream terminus and the growth of traffic volume in the minor-flow direction. At the end of the reversible segment, the three eastbound lanes were required to merge back into two lanes. Over several hours of operation, this situation caused congestion and eliminated the benefit of the third lane. Over the 12-year operating period, the growth in westbound traffic volume, exceeding 1,000 vph during the eastbound peak, also resulted in congestion leading into the westbound lane drop before the tunnel. This condition was exacerbated by the steep grades within these areas that, when combined with significant levels of heavy vehicle traffic, further diminished the capacity.

Use of Freeway Shoulders

Interstate 66— Suburban Virginia and Washington, D.C.

Another form of conversion, although not reversible, takes place on I-66 in suburban Washington, D.C. The right shoulders of a 6-mi segment of I-66 are used as an additional travel lane to accommodate traffic during peak-period travel times. Use of the eastbound shoulder lane by traffic is permitted from 5:00 a.m. to 10:00 a.m. and use of the westbound shoulder lane from 3:00 p.m. to 8:00 p.m. The shoulder lane gives the Virginia DOT (VDOT) the ability to maintain three unrestricted travel lanes during the periods when the left (median) lane is converted for restricted HOV use.

Entry into the shoulder lane is controlled by a combination of overhead lane-use information signs and conventional overhead lane-use signals as shown in Figure 56. Drivers are notified about the conversion by roadside signs placed in advance of the beginning of the shoulder lane segment, and then within the segment by the red "X" and green arrow signals.

FIGURE 56 I-66 shoulder lane-use control sign and signal, Fairfax County, Va.

Because use of the shoulder effectively eliminates the ability of drivers to stop, a series of emergency pullout areas have been provided at intervals along the segment. Road service patrols are also used to assist motorists whose vehicles become disabled and who are unable to drive into one of the designated stop areas. In such cases, a patrol vehicle is used to push a disabled vehicle to the stop area or to block approaching traffic in the shoulder lane before the incident. The service patrols and the Virginia State Police also maintain close surveillance of these shoulder areas during nonuse periods to be sure that they are kept clear of disabled vehicles and debris so that any objects do not become hazards after the shoulder is converted to a travel lane. Although one of the other reasons often cited for not using shoulders is pavement thickness, it is not a problem in this section, because the pavement section of the shoulder was originally designed to accommodate the load of through traffic.

Aside from featuring guidance signs and lane-use signals, the segment incorporates relatively few special traffic control devices. In the vicinity of entry and exit ramps, drivers use the deceleration and acceleration lanes for through travel, and they routinely traverse the pavement markings used for the delineation of these areas during conventional nonuse operating periods.

Empirical observation and experience have not shown any significant increases in accidents or driver confusion in this area. Anecdotal evidence also suggests that the driving public has been supportive of the lanes, and few complaints have been received. Interestingly, VDOT has received complaints when the shoulder lanes are *not* opened during off-peak periods, when capacity-restricting incidents occur in the other lanes. For this reason, VDOT maintains a flexible operating policy that allows them to activate the shoulder lane as an incident management tool to increase the segment capacity when conditions warrant their use.

The use of shoulders for additional travel lanes during peak periods has also been used along a section of Route 128 (I-95) outside of Boston, Massachusetts. Although the technique appeared to offer benefits without causing major problems, it has been viewed as an interim solution as plans to widen the highway are advanced.

SUMMARY OF KEY FINDINGS

Reversible lanes and roadways are most often used to mitigate congestion during directionally unbalanced flow conditions by adding additional capacity in the major-flow direction. Other most common uses are for planned special events and emergency management. The most common roadways for reversible operation are freeways, followed by arterial roadways. Other popular applications are on bridges and in tunnels. Additional findings were as follows:

- Reversible roadways are most commonly used by state-level DOTs followed by law enforcement officials; other users include local departments of public works and bridge and tunnel authorities.
- Most of the surveyed users of reversible roadways developed their own standards for the system’s designs and operations.
- The most commonly cited reasons for using reversible operations in the future are for emergency management and for the management of traffic associated with planned events and roadway construction.
- Transition area planning and design are critical to the effective use of reversible lane systems.

CHAPTER SEVEN

CONCLUSIONS

The synthesis review of reversible roadway practice demonstrates several points relative to its use over the last 75 years. Historically, the goal of reversible roadway segments, to adapt the direction of flow in one or more lanes to meet the directional capacity needs during periods of high and unbalanced directional travel demand, has remained unchanged. Their utility results from the advantage they take of the unused capacity of the minor-flow direction lanes to increase the directional capacity in the major-flow direction, thus negating the need to construct additional lanes. Within these broad purposes, however, are scores of varied applications. The reversible traffic operations within this study have all been applied for reasons associated with one of five general categories:

- Mitigation of routine peak-period congestion,
- Enhancement of transit and high-occupancy vehicle (HOV) operations,
- Traffic management for planned special events,
- Maintenance of capacity through construction work zones, and
- Emergency movement of people out of threatened areas.

Nearly as varied as the applications has been the extent to which aspects of their design and management have differed in their history. Despite the similarity of the goals of reversible lanes, the design, control, and management methods used to achieve them have rarely been the same. Indeed, this review showed that such features of any two applications have rarely, if ever, been the same.

Despite the general lack of uniformity of design and management, the results of existing and discontinued reversible lane segments have been generally viewed as positive. Perhaps this suggests that the relative lack of standards and guidance has permitted users to be flexible in their applications and has allowed practices to evolve and be adapted to best fit the needs of specific locations. Overall, the majority of reversible lane applications have been able to achieve their operational objectives with relatively low safety impacts and with surprisingly high levels of public understanding and acceptance.

As is the case with any highway design treatment or management strategy, however, there are both positive and negative aspects to reversible roadways. Another finding of this synthesis effort pertained to the conditions under which reversible operations were best suited and some of the locations, configurations, and techniques that have been applied to most effectively use reversible operation. The review also brings to light many of the shortcomings of such operations, as well as some of the needs that would help future users to better plan and manage reversible lane systems—including a better understanding of the operational and economic benefits as well as the safety, manpower, and control and facility costs.

Although various practitioners and researchers have established an assortment of criteria to determine the level of need for reversible lane systems, their general principles are relatively similar. They include

- Volumes at or in excess of capacity,
- Predictable patterns of high demand and/or congestion,
- Limited right-of-way (or ability to acquire it) to construct additional lanes,
- Ratios of major street volume to minor street volume of about 2:1 or greater, and
- Lack of capacity or mobility on adjacent parallel streets.

The general requirements for making effective use of reversible operations include

- Segment entry and departure conditions that permit a high utilization of the additional lanes,
- Ability to maintain at least two lanes (or at least one through and one turning lane) in the minor-flow direction,
- Predominantly through traffic, and
- Relatively low percentage of heavy vehicles in the minor-flow direction.

Contrary to what is often assumed, nearly all of the agencies surveyed as part of this synthesis effort did not report any significant safety problems or driver confusion. This report features both freeway and arterial street applications and examples in each of aforementioned five use categories, including some that have been in operation for more than 15 years. Many of the same agencies also reported that the overall response from the majority of drivers was very positive. This finding suggests that reversible operations have not been as complicated, controversial, or dangerous as most agencies originally believed that they would be.

However, many agencies have remained hesitant to implement reversible operations if they could avoid it. Reluctance comes in part because they believe that the reversible operations may be confusing to drivers not familiar with this type of operation and that the agencies will require additional staffing to manage and enforce the operations. Although there have not been many analyses of the safety effect of reversible operations, a body of empirical evidence gained from past experience has shown that, to the contrary, drivers adapt to them readily. Even in locations where reversible operations were less familiar to local drivers or not well marked, the empirical evidence suggests that operations were generally safe and efficient. The common belief is that once operations are under way in a reversible lane, the follow-the-leader nature of traffic should minimize head-on conflicts.

Still, that is not to suggest that reversible lane systems are totally problem free. One of the most detailed studies conducted on an arterial reversible segment in Memphis, Tennessee, revealed that an abnormal number of accidents were associated with lane reversals. Crashes at that location were associated with left turns made from improper lanes. After the addition of better traffic control devices, this problem was reduced. Another concern along the intermediate segments is midblock entry points that can result in unauthorized turns and entry into improper lanes. To reduce these problems along Connecticut Avenue in Washington, D.C., where signal control is present, lane-use and turning restriction signs have been installed at minor street intersection approaches. In general, many of these problems are also greatly reduced in high-volume, minimum-headway conditions when acceptable gaps for turning movements are minimized.

The most critical locations and periods for reversible operation were the transitions. One of the keys to effective operation is adequate capacity at the ends of the segment, particularly at the departure end. Logically, any added capacity from a reversible lane would be negated by inadequate capacity at the departure end of the segment. An example was observed at the Eisenhower Tunnel in Colorado, where three lanes were reduced to two at the departure end. Over time, congestion from the lane drop would propagate back into the segment. Reversible operations were still useful at this location for a time, however, because one of the three entry lanes was a passing lane rather than a travel lane.

The synthesis review also showed that over time the use of many reversible systems has been discontinued. In Charlotte, North Carolina, and in Pontiac, Michigan, such removal has occurred because the event traffic associated with sports arenas has been eliminated. A more common reason for ending reversible operations, as seen in the Eisenhower Tunnel in Colorado and on Union Avenue in Memphis, was the evolution of more balanced directional flow. Such balance appears to be an increasing trend for many cities that are experiencing high traffic demand in all directions of travel, rendering reversible operations ineffective. It was also interesting to discover that some agencies operating reversible lane systems believe that they are often troublesome to operate. This was particularly the case for some permanent installations with sophisticated automatic control systems that frequently required service maintenance.

Reversible flow applications have two temporal variants: the frequency of their use and the duration of a particular direction of flow. The selection of a specific duration and frequency depends on the nature of the traffic conditions and the nature of the available road infrastructure. Among the briefest operational durations are those associated with commuter demand. Reversible operations for daily peak periods typically last the length of the commute, usually 2 to 4 h. Other brief duration uses have been associated with planned events such as festivals, concerts, and sporting events. Unlike with predictable commuter patterns, the required duration of reversible operations for emergency situations can vary more widely. Hurricane evacuation contraflow in some locations is expected to last more than 18 h. The frequency of an application also depends on the nature of traffic patterns and the regularity for increased capacity needs. The most frequent is the twice-daily conversion required for commuter patterns, whereas an infrequent use would be an application such as evacuation contraflow, which may be needed only once a decade.

The types of facilities on which reversible operations have been most often implemented (e.g., arterial roadways and freeways) also reflect the fundamental reason for their use. All arterial facilities reviewed in this synthesis were adaptations of existing nonreversible roadways to permit reversible flow using various design and traffic control measures. A rare exception was represented by Tyvola Road in Charlotte, which was conceived at the outset as a reversible facility. Other exceptions have been several freeways constructed since the early 1970s, such as the Katy Freeway in Houston and I-95 in suburban Washington, D.C., which feature a separated median HOV and transit reversible lane. Also, except for a few isolated cases, reversible flow on bridge and tunnel facilities has been retrofitted to an existing design.

Despite specific guidance in the *Manual on Uniform Traffic Control Devices*, the control features of existing reversible facilities varied significantly, both in the design and use of control devices. For applications in which reversible operations were used infrequently, traffic control was often kept to a minimum, by way of simple and easily modifiable equipment. In many cases, that included nothing more than traffic enforcement police accompanied by cones and flares. For more frequent uses and permanent configurations, especially those on high-speed facilities such as freeways, control systems were much more complex. Reversible freeway lane systems required barrier separation between lanes, gates at entry and exit points, and variable message signs. Because most freeway applications were also used on a daily basis, many of their control systems needed to be automated to reduce the need for manual labor before, during, and after flow conversions.

Other important considerations in the control and management of reversible roadways are maintenance, enforcement, and incident management. Previous uses have demonstrated that reversible lanes can involve an intensive labor effort to implement and remove. Given a typical twice-daily peak-period application on an arterial highway, such efforts would need to be expended four times a day. In many cases, doing so would be cost prohibitive. To lessen this burden, automated control features have been widely implemented, particularly on freeways. However, such control elements can still involve significant investments in equipment and control systems.

Enforcement and incident management on many reversible segments can also become problematic. Because one of the primary motivations of reversible lane use is to limit the overall cross-section width of a road, shoulders along many segments are often narrow or nonexistent. This situation eliminates the ability to use roadside traffic enforcement vehicles. It also greatly limits the ability of vehicles to make emergency stops and of service vehicles to respond to incidents.

The review of reversible roadway assessment and evaluation showed that although various performance reviews have been undertaken (associated with volume, travel time, and safety), the results of very few of them have been widely disseminated in the general literature. Thus, many of the costs and benefits of the systems' use are not widely known. As a result, there is a need for more widely available assessments of reversible operations. One of the most obvious applications of such information would be a set of criteria/guidelines that can be used to determine the conditions that might warrant a cost-effective implementation of new reversible lanes or the conversion of an existing nonreversible facility for reversible use.

The safety studies that have been conducted have identified the characteristics of accidents often associated with reversible operations. Although there are a limited number of quantitative studies to support it, empirical observation and anecdotal evidence suggest that reversible lanes do not contribute significantly to increased frequency or severity of accidents. Most managing agencies have reported little change in accident frequency or severity. In several cases, it was believed that the added capacity and uniformity of operation on reversible roadways actually contributed to greater safety. Another area where the safety effects of reversible operations have yet to be studied is on pedestrians. Finally, the many empirical assessments of reversible roadway segments have suggested that they have been largely well received by motorists, although again, those assessments have not been quantitative.

The development of this synthesis revealed several needs in regard to convertible roadways and lanes. The most notable is a general need for more information on convertible lanes. Although a considerable amount of information was available specifically on reversible lanes, comparatively little was found on many of the other types of convertible lanes, including the planning of convertible parking lanes, convertible shoulders, and so forth.

In the specific area of reversible roadways, the most significant need appears to be for a more quantitative understanding of benefits and costs. As part of the survey, a question about what information is needed or would be useful to reversible road users was asked. In general, the direct costs of reversible roadways appear to be moderately well understood and have been developed for items associated with construction, control, enforcement, etc. Indirect costs, such as those associated with traffic crashes and accommodating pedestrians along reversible segments, have been more lightly evaluated.

Although there have been some efforts to quantify the volume, travel time, and speed benefits of reversible roadways, such studies have focused on specific facilities, with little information to judge the transferability of the results to other locations and facility types. The survey results showed the need to better estimate reversible lane benefits, particularly for added volume and capacity. One example pertains to capacity estimation. Discussions with users and potential users of reversible facilities revealed that the estimated flow rates and capacities of reversible lanes have ranged from those of normal flow lanes to a reduction to half of this value. Low estimates have been suggested based on the logical assumption that because signs, pavement markings, and safety appurtenances would be oriented in the "wrong" direction, motorists would tend to drive more slowly, more cautiously, and they would avoid driving in reversible lanes altogether if an adjacent normal flow lane were available. Unfortunately, these widely divergent estimates can significantly bias the predicted benefit (or drawback) of a particular project. More critically, these estimates have been used to determine the rates at which people can be evacuated from a threatened area. Two of the few studies of reversible flow on a lane-by-lane basis showed that the flow characteristic of such lanes were nearly the same

In the survey, officials from the Maryland Transportation Authority suggested the development of methods to better assess the costs and benefits of reversible operation in combination with their safety impact and to determine the level of congestion that would indicate the most effective use of contraflow. Officials at the South Carolina Department of Transportation suggested an assessment on the issues of safety where guardrail and bridge ends are not protected in the reversed direction. Officials at the Oregon Department of Transportation suggested a study on the entry and exit conflicts and the automated devices at termini locations.

Other identified needs included

- Improved access into reversible segments,
- Methods to estimate the cost of operation,
- Methods to compare and evaluate the needs to "flush" traffic through a corridor while maintaining accessibility to local businesses,
- Use of more automation to optimize and shorten the transition periods,
- Methods to determine when and how to switch directions as directional flows become more balanced and during off-peak/weekend periods,
- Methods to improve incident response and traffic enforcement within reversible segments, and
- Methods to develop and implement policies on user eligibility.

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APPENDIX A

Survey Questionnaire

TRANSPORTATION RESEARCH BOARD (TRB)
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Project 20-5, Topic 34-06

Convertible Roadways and Lanes Questionnaire

Name of respondent: ____________________

Agency: ____________________

Title: ____________________

Address: ____________________

Telephone no.: ____________________ Best time to call: ____________________

Fax: ____________________

E-mail address: ____________________

Overview and Instructions

The information collected will be used to develop a National Cooperative Highway Research Program (NCHRP) synthesis on "Convertible Roadways and Lanes." If you or your agency have used, studied, considered, or have an opinion on this form of operation, please review and respond to this survey.

Convertible roadways and lanes may include the use of reversible lanes, shoulders, and contraflow lanes, among other applications to accommodate varying travel demand and during planned or unplanned events. Convertible roadways and lanes on freeways and surface streets have been deployed throughout the United States for years. However, the conditions that warrant the consideration and use of convertible lanes and their impacts on safety, operations, and the environment, as well as design and implementation issues, have yet to be documented.

The main purpose of this survey is to develop a report on current practices and suggestions for improving future practice. The results may also be used to help in the development of plans and simulation models for the evacuation of major urban areas.

This questionnaire should be completed by that person(s) with knowledge of your organization's activities related to convertible roadways and lanes. Please answer as many of the following questions as possible, attaching additional sheets if necessary. Send copies of any related material and your completed questionnaire by April 30, 2003 to

Laurence Lambert, P.E.
HOTO-1, Room 3408
400 Seventh Street, SW
Washington, DC 20590
Fax: (202) 366-3225

If you have any questions, do not hesitate to contact Brian Wolshon (225) 578-5247, e-mail: brian@rsip.lsu.edu or Laurence Lambert (202) 366-2171, e-mail: Laurence.Lambert@fhwa.dot.gov

WE APPRECIATE YOUR RESPONSE—THANK YOU

Uses and Locations

1. Are you currently using reverse-flow (RLS)/contraflow operations?
   - ☐ Yes
   - ☐ No (If no, skip to Question 22)
   - ☐ Do not know—Try contacting this person → Name:______________________

Phone:______________________

E-mail:______________________

If so, which best describes your application(s)?

☐ Planned Special Event ☐ Roadway Construction ☐ Emergency Management

☐ Congestion Mitigation ☐ Transit Performance ☐ Homeland Security Management

2. On which type(s) of facilities do you use RLS?

☐ Tunnel ☐ Bridge ☐ Freeway ☐ Arterial Roadway

3. List the road systems where you are using (or have used) RLS, its length, and location of initiation and termination points.

Name (i.e., US I-10)	Length	Initiation Point	Termination Point	No. of RLS Lanes

Design

4. Do you have documented standards/recommendations for traffic control on RLS? If so, do they include any of the following?

☐ Traffic Control Devices ☐ Signs ☐ Pavement Markings ☐ Other: ______________

5. Which of the following do you have written standards/recommendations for the geometric design of RLS?

☐ Approach ☐ Termination ☐ Cross Section ☐ Lane Delineation ☐ Lane Width

☐ Guardrail Crash Attenuators ☐ Other: ______________________________

6. Have you had to develop any of your own standards, procedures, or specifications for RLS use?

☐ Yes ☐ No

7. Which of the following best describes the type of construction for the installation of your RLS?

☐ Retrofit ☐ New Construction

Management, Control, and Enforcement

8. How did you arrive upon your criteria for starting and stopping RLS? ____

____

9. How is the public educated or notified about when and how the RLS is operated?________________________________

____

10. Does your agency have a website that includes any RLS information? ☐ Yes ☐ No

If so, what is the website address?____

11. Who is in charge of the setup, management, and shutdown of your RLS?

☐ Law Enforcement ☐ Local Dept. of Public Works ☐ State Dept. of Transportation

☐ Bridge, Tunnel, Turnpike, or Tollway Authority ☐ Other:____________________________________

12. Does the RLS operate across political jurisdictions? ☐ Yes ☐ No

13. Have you had to create any new law enforcement methods to enforce compliance? ☐ Yes ☐ No

14. Do you discontinue the use of reverse-flow/contraflow at night? ☐ Yes ☐ No

15. Do you discontinue the use of reverse-flow/contraflow for any of the following adverse weather conditions?

☐ Snow ☐ Icy Conditions ☐ Fog ☐ Heavy Rain ☐ High Wind

Assessment

16. Have you ever conducted a survey to assess the opinion of the public concerning RLS? ☐ Yes ☐ No

17. Have you ever collected or directly measured traffic flow data, such as speed, flow, or headway? ☐ Yes ☐ No

18. Do you compile or maintain accident reports for reverse-flow/contraflow systems? ☐ Yes ☐ No

19. Have you developed special methods or procedures for monitoring, evaluating, or reporting the performance of the following RLS characteristics?

☐ Speed ☐ Flow ☐ Level of Service ☐ Travel Time ☐ Queue Length

20. Have you ever analyzed and documented the costs and/or benefits associated with the reverse-flow/contraflow operation?

☐ Yes ☐ No

What were the important criteria for such a comparison? ______________________________

21. Have you ever used RLS in the past, but discontinued its use for any reason? ☐ Yes ☐ No

If so, why? ______________________________

____

Planning

22. Which of the following applications, if any, are you planning to use RLS? (If none, skip to Question 27):

☐ Planned Special Event ☐ Roadway Construction ☐ Emergency Management

☐ Congestion Mitigation ☐ Transit Performance ☐ Homeland Security Management

23. Which of the following have you established as criteria that warrant its use?

☐ Desired Speed ☐ Desired Flow ☐ Desired Level of Service ☐ Desired Travel Time

☐ Desired Queue Length

24. What guidelines or standards are you using to develop your plans? ______________________________

____

25. Do you have any estimation for the flow rates for RLS? ☐ Yes ☐ No

If so, how did you arrive upon your figures? ______________________________

26. Are there any aspects of reverse-flow/contraflow operation that you feel require further investigation or that you would like answered?

____

____

27. Please list any other agencies that you know to use reverse-flow/contraflow systems.

Name:____ Name:____

Agency:______________________________________ Agency:______________________________________

Phone: _______________________________________ Phone: _______________________________________

We would also appreciate receiving any additional reports, studies, or literature that you feel may be relevant to this survey. You may contact us: Brian Wolshon (225) 578-5247, e-mail: brian@rsip.lsu.edu or Laurence Lambert (202) 366-2171, e-mail: Laurence.Lambert@fhwa.dot.gov

Thank you for your time!

APPENDIX B

Survey Results

Uses and Locations

Question 1: Are you currently using reverse-flow (RLS)/contraflow operations?
If so, which best describes your application(s)?

Agency	**Response**
City of Memphis, Engineering Division	No
Denver Department of Public Works	Planned Special Event Transit Performance
Washington State DOT	Planned Special Event Congestion Mitigation Roadway Construction Transit Performance Emergency Management
Mississippi DOT	Emergency Management
North Texas Tollway Authority	Planned Special Event
Kansas Turnpike Authority	Congestion Mitigation
Washington, DC DOT	Planned Special Event Congestion Mitigation
Ohio Turnpike Commission	Congestion Mitigation
Iowa DOT	No
Charlotte DOT	Planned Special Event Congestion Mitigation
College of William and Mary Campus Police	Planned Special Event
University of Oklahoma Police Department	Planned Special Event
University of Idaho	No
Maryland Transportation Authority	Planned Special Event Congestion Mitigation Roadway Construction Emergency Management
Mississippi DOT	Emergency Management
South Carolina DOT	Emergency Management
City of Vancouver	Congestion Mitigation Emergency Management
Alabama DOT	Emergency Management
Oregon DOT	No
New Jersey DOT	Homeland Security Management Emergency Management

Government of the Northwest Territories	No
Virginia DOT	Congestion Mitigation
Ministre des Transports—Government of Quebec	Congestion Mitigation Roadway Construction
Louisiana DOT	Emergency Management
Illinois DOT	Congestion Mitigation
New York City DOT	Congestion Mitigation
Texas DOT	Emergency Management Congestion Mitigation Transit Performance

Uses and Locations

Question 2: On which type(s) of facilities do you use RLS?

Agency	**Response**
City of Memphis, Engineering Division	N/A
Denver Department of Public Works	Arterial Roadway
Washington State DOT	Tunnel Bridge Freeway
Mississippi DOT	Freeway
North Texas Tollway Authority	Tunnel
Kansas Turnpike Authority	Toll Plaza
Washington, D.C. DOT	Freeway
Ohio Turnpike Commission	Toll Plaza
Iowa DOT	N/A
Charlotte DOT	Arterial Roadway
College of William and Mary Campus Police	Arterial Roadway
University of Oklahoma Police Department	Arterial Roadway
University of Idaho	N/A
Maryland Transportation Authority	Bridge
Mississippi DOT	Freeway
South Carolina DOT	Freeway Arterial Roadway
City of Vancouver	Arterial Roadway
Alabama DOT	Freeway
Oregon DOT	N/A
New Jersey DOT	Freeway Arterial Roadway

Government of the Northwest Territories	N/A
Virginia DOT	Freeway
Ministre des Transports—Government of Quebec	Bridge Freeway
Louisiana DOT	Freeway Arterial Roadway
Illinois DOT	Freeway
New York City DOT	Freeway
Texas DOT	Freeway

Uses and Locations

Question 3: List the road systems where you are using (or have used) RLS, its length, and location of initiation and termination points.

Agency	Name	Length	Initiation Point	Termination Point	No. of RLS Lanes
City of Memphis, Engineering Division	N/A				
Denver Department of Public Works	D Line LRT	11 blocks	14th and California	14th and Stout	1
	Lincoln St.	4 blocks	17th and Lincoln	13th and Lincoln	1
	16th St.	0.75 mi	16th/Central	16th and Wazel	2
Washington State DOT	I-5	9 mi	MP 165	MP 174	1–3
	I-90	9 mi	MP 0	MP 9	2
Mississippi DOT	I-59	90 mi	LA/MS State Line	Mile Marker 90	4
North Texas Tollway Authority	Toll Tunnel	0.7 mi	Midway Rd.	Addison Rd.	2
Kansas Turnpike Authority	US I-35				
Washington State DOT	I-5	8 mi	Downtown Seattle	King/Sno Co. Line	Varies
	I-90	9 mi	Downtown Seattle	Bellvue	2
Ohio Turnpike Commission	Ohio Turnpike (I-76, 80, 90)				
Iowa DOT	Not Listed				
Charlotte DOT	Tyvola Rd.	3.2 mi	Nations Ford Rd.	Billy Graham	4
	Monroe	0.85 mi	Independence Blvd.	Laurel Ave.	1
	Poplar St.	0.50 mi	2nd St.	Trade St.	3
College of William and Mary Campus Police	Brooks St.	0.50 mi	McClurg St.	Campus Dr.	2
University of Oklahoma Police Dept.	Van Vleet Oval	0.2 mi	Lindsey St.	Brooks St.	2
	Asp Ave.	0.2 mi	Brooks St.	Lindsey St.	2

University of Idaho	Not Listed				
Maryland Transportation Authority	US 50 direction	5.3 mi	Toll Plaza	MO 8 interchange	Varies-1 each
Mississippi DOT	I-59	90 mi	MS St. Line (MP 1)	Laurel, MP 90	2
South Carolina DOT	I-26	96 mi	I-526	I-77	2
	US 378	7 mi	US 278 bus	SC 46	1
City of Vancouver	Georgia St.	650 m	Cardero	Stanley Park Cwy.	1
	Various	<200 m	through/around construction areas (major projects only)		
Alabama DOT	I-65	75 mi	N. Mobile	S. Montgomery	2
Oregon DOT	Not Listed				
Washington State DOT	I-5	7.2 mi	mp 165.29	mp 172.43	2-4
	I-90	7.4 mi	mp 1.99	mp 9.44	3
New Jersey DOT	State Rte. 47/347	17.5 mi	mp 17.5	mp 35	1
	State Rte. 72	28 mi	mp 28	mp 0	1
	I-195	50 mi	mp 0	mp 50	2
Government of the Northwest Territories	Not Listed				
Virginia DOT	I-395	10 mi	I-495	14th St. Bridge	2
	I-95	20 mi	South of Rte. 234	I-495/I-395	2
Ministre des Transports—Government of Quebec	A-13/ Bisson	1.7 km	300 m on Montreal Side	300 m on Laval Side	1
	Several Construction Sites				
Louisiana DOT	I-10	35 mi	New Orleans	SORRENTO	4
	US 90	40 mi	TBA	TBA	4
	US 61	40 mi	TBA	TBA	4
Illinois DOT	I-90/I-94 (Kennedy)	~6 mi	Ohio/Ontario (Chicago Loop)	Montrose (Eden Junction)	2
New York City DOT	I-495	2.1 mi	Queens Midtown Tunnel	58th Street	1
Texas DOT	IH 30	5.2 mi	Jim Miller Rd.	IH 45	1
	IH 35E	4.5 mi	IH 30	US 67	1
	IH 10	10.6 mi	SH 6	Washington State Ave.	1
	IH 45	28.8 mi	Dixie Farm	FM 1960	1
	US 290	15.4 mi	FM 1960	IH 10 Transit Center	1
	US 59	24.0 mi	W. Airport	Will Clayton Pky.	1

Design

Question 4: Do you have documented standards/recommendations for traffic control on RLS? If so, do they include any of the following?

Agency	Response
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	Traffic Control Devices Signs Pavement Markings
Washington State DOT	Traffic Control Devices Signs Pavement Markings
Mississippi DOT	Traffic Control Devices Signs Other: VMS
North Texas Tollway Authority	No Response
Kansas Turnpike Authority	Signs
Washington, DC DOT	No Response
Ohio Turnpike Commission	Traffic Control Devices Signs
Iowa DOT	No Response
Charlotte DOT	Traffic Control Devices Signs Pavement Markings
College of William and Mary Campus Police	No Response
University of Oklahoma Police Department	No Response
University of Idaho	No Response
Maryland Transportation Authority	Traffic Control Devices Pavement Markings
Mississippi DOT	Traffic Control Devices Signs
South Carolina DOT	Traffic Control Devices Signs
City of Vancouver	Other: Refer to provincial standards for temporary traffic controls
Alabama DOT	Traffic Control Devices Signs Pavement Markings Other: Highway advisory radio
Oregon DOT	No Response
New Jersey DOT	Traffic Control Devices Signs Pavement Markings Other: Staffing, equipment
Government of the Northwest Territories	Other: Staffing, equipment
Virginia DOT	Traffic Control Devices Signs Pavement Markings Other: Gates and VMS

Ministre des Transports—Government of Quebec	No Response
Louisiana DOT	Traffic Control Devices
Illinois DOT	Traffic Control Devices Signs Pavement Markings
New York City DOT	Traffic Control Devices Signs Pavement Markings
Texas DOT	Traffic Control Devices Signs Pavement Markings

Design

Question 5: Which of the following do you have written standards/recommendations for the geometric design of RLS?

Agency	**Response**
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	Lane Delineation Lane Width
Washington State DOT	Approach Termination Cross Section Lane Delineation Lane Width Guardrail Crash Attenuators
Mississippi DOT	Approach Termination
North Texas Tollway Authority	No Response
Kansas Turnpike Authority	Approach Lane Delineation
Washington, DC DOT	No Response
Ohio Turnpike Commission	Approach Cross Section Lane Delineation Lane Width Guardrail Crash Attenuators
Iowa DOT	No Response
Charlotte DOT	No Response
College of William and Mary Campus Police	No Response
University of Oklahoma Police Department	No Response
University of Idaho	No Response
Maryland Transportation Authority	Lane Delineation
Mississippi DOT	Approach Termination
South Carolina DOT	No Response

City of Vancouver	No Response
Alabama DOT	No Response
Oregon DOT	No Response
New Jersey DOT	Approach Lane Delineation
Government of the Northwest Territories	No Response
Virginia DOT	Approach Termination Cross Section Lane Delineation Lane Width Guardrail Crash Attenuators
Ministre des Transports—Government of Quebec	No Response
Louisiana DOT	No Response
Illinois DOT	No Response
New York City DOT	Approach Termination Cross Section Lane Delineation Lane Width Guardrail Crash Attenuators
Texas DOT	No Response

Design

Question 6: Have you had to develop any of your own standards, procedures, or specifications for RLS use?

Agency	**Response**
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	Yes
Washington State DOT	Yes
Mississippi DOT	Yes
North Texas Tollway Authority	No
Kansas Turnpike Authority	Yes
Washington, DC DOT	Yes
Ohio Turnpike Commission	No
Iowa DOT	No Response
Charlotte DOT	Yes
College of William and Mary Campus Police	No
University of Oklahoma Police Department	No
University of Idaho	No Response
Maryland Transportation Authority	Yes
Mississippi DOT	Yes
South Carolina DOT	Yes
City of Vancouver	No
Alabama DOT	Yes
Oregon DOT	No Response
New Jersey DOT	Yes
Government of the Northwest Territories	No Response

Virginia DOT	No
Ministre des Transports—Government of Quebec	Yes
Louisiana DOT	No
Illinois DOT	Yes: Hours of operation
New York City DOT	Yes
Texas DOT	Yes

Design

Question 7: Which of the following best describes the type of construction for the installation of your RLS?

Agency	Response
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	Retrofit
Washington State DOT	New Construction
Mississippi DOT	Retrofit
North Texas Tollway Authority	No Response
Kansas Turnpike Authority	Retrofit
Washington, DC DOT	New Construction
Ohio Turnpike Commission	New Construction
Iowa DOT	No Response
Charlotte DOT	Retrofit New Construction
College of William and Mary Campus Police	No Response
University of Oklahoma Police Department	No Response
University of Idaho	No Response
Maryland Transportation Authority	Retrofit
Mississippi DOT	Retrofit
South Carolina DOT	Retrofit
City of Vancouver	New Construction
Alabama DOT	Retrofit New Construction
Oregon DOT	No Response
New Jersey DOT	Retrofit
Government of the Northwest Territories	No Response
Virginia DOT	New Construction
Ministre des Transports—Government of Quebec	Retrofit
Louisiana DOT	Retrofit
Illinois DOT	New Construction
New York City DOT	Retrofit
Texas DOT	Retrofit

Management, Control, and Enforcement

Question 8: How did you arrive upon your criteria for starting and stopping RLS?

Agency	Response
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	Safety, geometrics, operations, system impacts
Washington State DOT	Mainly on a routine and timed schedule for consistencies. Other time, by special event schedule such as major ball game, major festival, major construction. Other time by emergency need.
Mississippi DOT	A request from Louisiana to assist with their hurricane evacuation. Will stop when traffic flow dictates.
North Texas Tollway Authority	RLS is used on the Addison Airport Toll Tunnel (AATT) as a special event traffic management system for the July 4th fireworks event sponsored by the town of Addison once a year. For a couple of hours the AATT is closed to normal two-way traffic and the two-lane tunnel is transformed into a one-way operation to facilitate moving traffic into and subsequently out of the town's July 4th fireworks event held immediately adjacent to the facility. Uniformed policemen are used to direct traffic movement.
Kansas Turnpike Authority	Length of back up at toll plaza
Ohio Turnpike Commission	Queue length
Iowa DOT	No Response
Charlotte DOT	Function of the project and specific to that purpose
College of William and Mary Campus Police	We use this form of traffic control for special events only. We start RLS approximately 1 to 1 and 1/2 hours before the event. It is terminated when at the end of the event the traffic flow is at a point were it can proceed safely with only normal traffic control devices.
University of Oklahoma Police Department	Starting and ending times for football games
University of Idaho	No Response
Maryland Transportation Authority	Traffic congestion and other operational considerations
Mississippi DOT	Traffic Volume Estimate and Hotel Availability
South Carolina DOT	Began at point of major road merges. End at point where reversed lanes can be accommodated
City of Vancouver	Existing roadway geometry
Alabama DOT	Location of introduction of significant evacuation traffic/location of alternate north "scatter" routes
Oregon DOT	No Response
Washington, DC DOT	Planning study
New Jersey DOT	Coordinating/planning meetings with office of emergency management/NJDOT/local and county governments and interested private groups
Government of the Northwest Territories	No Response
Virginia DOT	HOV operating hours are established by code and the reversible lanes were designed and constructed to serve that need. Weekend operating hours were established based on traffic volumes and demand.
Ministre des Transports—Government of Quebec	Hourly traffic flow (at rush hours)

Louisiana DOT	Depends on the movements and type of emergency
Illinois DOT	Coordination with downtown area (loop) and junction with other expressways
New York City DOT	Queue by-pass requirements
Texas DOT	Geometrics, origin destination criteria

Management, Control, and Enforcement

Question 9: How is the public educated or notified about when and how the RLS is operated?

Agency	**Response**
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	Media and public meetings
Washington State DOT	RLS serve commuters on a regular schedule, so it does not take long for commuters to catch on. We have website to post schedules. We have extensive VMS and static signs approaching the reversible facilities. When we alter the regular schedule, we send out press releases.
Mississippi DOT	Public radio and news releases
North Texas Tollway Authority	Special event traffic only. No separate notification used.
Kansas Turnpike Authority	No advance notice
Washington, DC DOT	Both RLS run on a regular schedule. Media are notified when schedule is changed. Website and hotlines include RLS status.
Ohio Turnpike Commission	Signage at toll plaza lane
Iowa DOT	No Response
Charlotte DOT	VMSs and overhead reversible lane control signs
College of William and Mary Campus Police	Signs are posted at special events indicating traffic flow.
University of Oklahoma Police Department	Media and ticket sales
University of Idaho	No Response
Maryland Transportation Authority	Overhead and portable VMS, Highway Advisory Radio/Traveler Advisory Radio; website and overhead lane signs
Mississippi DOT	Television and radio
South Carolina DOT	News media and state map
City of Vancouver	No Response
Alabama DOT	Planning a public awareness campaign
Oregon DOT	No Response
New Jersey DOT	Literature, media/TV, and radio
Government of the Northwest Territories	No Response
Virginia DOT	Gates and VMS at reversible lane entry point approaches, brochures, and VDOT website.
Ministre des Transports—Government of Quebec	With the use of standard traffic control devices
Louisiana DOT	Radio, TV, and Internet
Illinois DOT	Through many media contacts and traffic control agencies
New York City DOT	Press release, changeable message signs

Texas DOT	Static and dynamic signs, transit authority public information

Management, Control, and Enforcement

Question 10: Does your agency have a website that includes any RLS information?

Agency	Response
City of Memphis, Engineering Division	No
Denver Department of Public Works	No
Washington State DOT	http://www.wsdot.wa.gov/regions/northwest/traffic/expresslanes/ http://www.wsdot.wa.gov/pugetsoundtraffic/
Mississippi DOT	www.gomdot.com
North Texas Tollway Authority	No
Kansas Turnpike Authority	No
Ohio Turnpike Commission	No
Iowa DOT	No
Charlotte DOT	No
College of William and Mary Campus Police	No
University of Oklahoma Police Department	No
University of Idaho	No
Maryland Transportation Authority	No
Mississippi DOT	www.mdot/cetrp/default.htm
South Carolina DOT	No
City of Vancouver	No
Alabama DOT	No
Oregon DOT	No
New Jersey DOT	No
Government of the Northwest Territories	No
Virginia DOT	www.VirginiaDOT.org
Ministre des Transports—Government of Quebec	No
Louisiana DOT	www.dotd.state.la.us
Illinois DOT	www.travelinfo.org
New York City DOT	
Texas DOT	No

Management, Control, and Enforcement

Question 11: Who is in charge of the setup, management, and shutdown of your RLS?

Agency	Response
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	Local department of public works Others: Special event promoters; regional transit district (permanent installation)

Washington State DOT	State DOT
Mississippi DOT	Law enforcement State DOT
North Texas Tollway Authority	Law enforcement Bridge, Tunnel, Turnpike, or Tollway Authority
Kansas Turnpike Authority	Other: Toll supervisor
Washington, DC DOT	State DOT
Ohio Turnpike Commission	Bridge, Tunnel, Turnpike, or Tollway Authority
Iowa DOT	No Response
Charlotte DOT	Other: Local DOT
College of William and Mary Campus Police	Law enforcement
University of Oklahoma Police Department	Other: Parking department
University of Idaho	No Response
Maryland Transportation Authority	Bridge, Tunnel, Turnpike, or Tollway Authority
Mississippi DOT	State DOT
South Carolina DOT	Law enforcement
City of Vancouver	Local department of public works
Alabama DOT	State DOT
Oregon DOT	No Response
New Jersey DOT	Law enforcement State DOT
Government of the Northwest Territories	No Response
Virginia DOT	State DOT
Ministre des Transports—Government of Quebec	State DOT
Louisiana DOT	Law enforcement State DOT
Illinois DOT	State DOT
New York City DOT	Local department of public works
Texas DOT	Other: Transit authority

Management, Control, and Enforcement

Question 12: Does the RLS operate across political jurisdictions?

Agency	Response
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	No
Washington State DOT	Yes
Mississippi DOT	Yes
North Texas Tollway Authority	No
Kansas Turnpike Authority	No
Washington, DC DOT	Yes
Ohio Turnpike Commission	No
Iowa DOT	No Response
Charlotte DOT	No
College of William and Mary Campus Police	No
University of Oklahoma Police Department	No
University of Idaho	No Response

Maryland Transportation Authority	Yes
Mississippi DOT	No
South Carolina DOT	Yes
City of Vancouver	No: but it does link into a reversible lane managed by the province of British Columbia (Causeway and Lions Gate Bridge).
Alabama DOT	Yes
Oregon DOT	No Response
New Jersey DOT	Yes
Government of the Northwest Territories	No Response
Virginia DOT	Yes
Ministre des Transports—Government of Quebec	Yes
Louisiana DOT	No
Illinois DOT	No
New York City DOT	No
Texas DOT	No

Management, Control, and Enforcement

Question 13: Have you had to create any new law enforcement methods to enforce compliance?

Agency	**Response**
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	No
Washington State DOT	No
Mississippi DOT	No
North Texas Tollway Authority	No
Kansas Turnpike Authority	No
Washington, DC DOT	No
Ohio Turnpike Commission	No
Iowa DOT	No Response
Charlotte DOT	No
College of William and Mary Campus Police	No
University of Oklahoma Police Department	No
University of Idaho	No Response
Maryland Transportation Authority	No
Mississippi DOT	Yes
South Carolina DOT	Yes
City of Vancouver	No
Alabama DOT	No
Oregon DOT	No Response
New Jersey DOT	No
Government of the Northwest Territories	No Response
Virginia DOT	No
Ministre des Transports—Government of Quebec	No
Louisiana DOT	No
Illinois DOT	No

New York City DOT	Yes
Texas DOT	Yes

Management, Control, and Enforcement

Question 14: Do you discontinue the use of reverse-flow/contraflow at night?

Agency	**Response**
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	No
Mississippi DOT	No
North Texas Tollway Authority	No
Kansas Turnpike Authority	No
Washington State DOT	Yes: I-5 for its noise
Ohio Turnpike Commission	No
Iowa DOT	No Response
Charlotte DOT	No
College of William and Mary Campus Police	No
University of Oklahoma Police Department	No
University of Idaho	No Response
Maryland Transportation Authority	No
Mississippi DOT	No
South Carolina DOT	Yes
City of Vancouver	No
Alabama DOT	No
Oregon DOT	No Response
Washington, DC DOT	Yes
New Jersey DOT	No
Government of the Northwest Territories	No Response
Virginia DOT	No
Ministre des Transports—Government of Quebec	Yes
Louisiana DOT	No
Illinois DOT	Yes
New York City DOT	Yes
Texas DOT	Yes

Management, Control, and Enforcement

Question 15: Do you discontinue the use of reverse-flow/contraflow for any of the following adverse weather conditions?

Agency	**Response**
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	No Response
Mississippi DOT	High Wind
North Texas Tollway Authority	No Response
Kansas Turnpike Authority	No Response
Washington State DOT	Snow Icy Conditions High Wind

Ohio Turnpike Commission	No Response
Iowa DOT	No Response
Charlotte DOT	No Response
College of William and Mary Campus Police	No Response
University of Oklahoma Police Department	No Response
University of Idaho	No Response
Maryland Transportation Authority	Snow Icy Conditions High Wind
Mississippi DOT	No Response
South Carolina DOT	No Response
City of Vancouver	No Response
Alabama DOT	No Response
Oregon DOT	No Response
Washington, DC DOT	Snow: The lanes are closed until the main line is clear during a significant event.
New Jersey DOT	High Wind
Government of the Northwest Territories	No Response
Virginia DOT	No Response
Ministre des Transports—Government of Quebec	No Response
Louisiana DOT	No Response
Illinois DOT	Snow Icy Conditions
New York City DOT	Snow Icy Conditions
Texas DOT	No Response

Assessment

Question 16: Have you ever conducted a survey to assess the opinion of the public concerning RLS?

Agency	**Response**
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	No
Washington State DOT	No
Mississippi DOT	No
North Texas Tollway Authority	No
Kansas Turnpike Authority	No
Ohio Turnpike Commission	No
Iowa DOT	No Response
Charlotte DOT	No
College of William and Mary Campus Police	No
University of Oklahoma Police Department	No
University of Idaho	No Response
Maryland Transportation Authority	No
Mississippi DOT	No
South Carolina DOT	No
City of Vancouver	No
Alabama DOT	No

Oregon DOT	No Response
Washington DOT	Yes
New Jersey DOT	No
Government of the Northwest Territories	No Response
Virginia DOT	Yes
Ministre des Transports—Government of Quebec	No
Louisiana DOT	No
Illinois DOT	Respondent not sure
New York City DOT	No
Texas DOT	Yes

Assessment

Question 17: Have you ever collected or directly measured traffic flow data, such as speed, flow, or headway?

Agency	**Response**
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	No
Washington State DOT	Yes
Mississippi DOT	Yes
North Texas Tollway Authority	No
Kansas Turnpike Authority	Yes
Ohio Turnpike Commission	No
Iowa DOT	No Response
Charlotte DOT	Yes
College of William and Mary Campus Police	Yes
University of Oklahoma Police Department	No
University of Idaho	No Response
Maryland Transportation Authority	Yes
Mississippi DOT	No
South Carolina DOT	No
City of Vancouver	Yes
Alabama DOT	No
Oregon DOT	No Response
Washington, DC DOT	Yes
New Jersey DOT	Yes
Government of the Northwest Territories	No Response
Virginia DOT	Yes
Ministre des Transports—Government of Quebec	Yes
Louisiana DOT	No
Illinois DOT	Yes
New York City DOT	No
Texas DOT	Yes

Assessment

Question 18: Do you compile or maintain accident reports for reverse-flow/contraflow systems?

Agency	Response
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	Yes
Washington State DOT	Yes
Mississippi DOT	No
North Texas Tollway Authority	No
Kansas Turnpike Authority	No
Washington, DC DOT	Yes
Ohio Turnpike Commission	No
Iowa DOT	No Response
Charlotte DOT	Yes
William and Mary Campus Police	No
University of Oklahoma Police Department	No
University of Idaho	No Response
Maryland Transportation Authority	Yes
Mississippi DOT	No
South Carolina DOT	No
City of Vancouver	Yes
Alabama DOT	No
Oregon DOT	No Response
New Jersey DOT	No
Government of the Northwest Territories	No Response
Virginia DOT	Yes
Ministre des Transports—Government of Quebec	Yes
Louisiana DOT	No
Illinois DOT	Yes
New York City DOT	No
Texas DOT	Yes

Assessment

Question 19: Have you developed special methods or procedures for monitoring, evaluating, or reporting the performance of the following RLS characteristics?

Agency	Response
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	Speed Travel Time
Washington State DOT	Speed Flow Level of Service Travel Time Queue Length
Mississippi DOT	No Response
North Texas Tollway Authority	No Response
Kansas Turnpike Authority	Level of Service
Ohio Turnpike Commission	Queue Length

Iowa DOT	No Response
Charlotte DOT	Level of Service Travel Time
College of William and Mary Campus Police	No Response
University of Oklahoma Police Department	No Response
University of Idaho	No Response
Maryland Transportation Authority	No Response
Mississippi DOT	No Response
South Carolina DOT	Speed
City of Vancouver	No Response
Alabama DOT	No Response
Oregon DOT	No Response
Washington, DC DOT	No Response
New Jersey DOT	Speed Flow Travel Time Queue Length
Government of the Northwest Territories	No Response
Virginia DOT	No Response
Ministre des Transports—Government of Quebec	No Response
Louisiana DOT	No Response
Illinois DOT	No Response
New York City DOT	No Response
Texas DOT	No Response

Assessment

Question 20: Have you ever analyzed and documented the costs and/or benefits associated with the reverse-flow/contraflow operation? What were the important criteria for such a comparison?

Agency	**Response**
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	No
Mississippi DOT	No
North Texas Tollway Authority	No
Kansas Turnpike Authority	Length of backup—safety and service
Washington State DOT	Looked at usage of I-5 lanes at night to decide on closures to reduce neighborhood noise impacts.
Ohio Turnpike Commission	No
Iowa DOT	No Response
Charlotte DOT	Cost of widening, impacts to adjacent property
College of William and Mary Campus Police	No
University of Oklahoma Police Department	No
University of Idaho	No Response
Maryland Transportation Authority	No
Mississippi DOT	No
South Carolina DOT	No
City of Vancouver	No
Alabama DOT	No

Oregon DOT	No Response
Washington, DC DOT	Demand, travel time, accident performance, transit reliability, incident response/nonrecurring delay
New Jersey DOT	No
Government of the Northwest Territories	No Response
Virginia DOT	No
Ministre des Transports—Government of Quebec	Cost benefit by avoiding new construction on the bridge (i.e., structural modification of the existing bridge)
Louisiana DOT	No
Illinois DOT	No Response
New York City DOT	No Response
Texas DOT	No Response

Assessment

Question 21: Have you ever used RLS in the past, but discontinued its use for any reason?

Agency	**Response**
City of Memphis, Engineering Division	Council thought it was confusing and directed us (engineering) to conduct a test to see if removal system could work.
Denver Department of Public Works	1)16th Street viaduct project was installed during construction and removal after completion 2) Lincoln Street RLS during a special event only.
Washington State DOT	No
Mississippi DOT	No
North Texas Tollway Authority	Reversible toll lanes were used for many years at main lane plazas on the Dallas North Tollway to provide additional capacity at the plazas during peak traffic periods. As a commuter roadway, the Tollway had a significant inbound traffic demand in the AM and outbound in the PM. About 10 years ago, the system was discontinued due to a gradual evening of traffic demands caused by suburban business growth and owing to implementation of Automated Vehicle Identification in the lanes closest to the roadway centerline.
Kansas Turnpike Authority	No
Ohio Turnpike Commission	No
Iowa DOT	No Response
Charlotte DOT	System removed due to road widening
College of William and Mary Campus Police	No
University of Oklahoma Police Department	No
University of Idaho	No Response
Maryland Transportation Authority	No
Mississippi DOT	
South Carolina DOT	No
City of Vancouver	The reversible lane was shut down during major road construction activities in order to limit variations in lane usage and other lane closures that were necessary during road works.

Alabama DOT	No
Oregon DOT	No Response
Washington, DC DOT	The RLS was an interim facility.
New Jersey DOT	No
Government of the Northwest Territories	No Response
Virginia DOT	No
Ministre des Transports—Government of Quebec	No
Louisiana DOT	No
Illinois DOT	No Response
New York City DOT	No Response
Texas DOT	The roadway was reconstructed and the contraflow lane converted to a barrier-separated reversible HOV lane. The roadway was IH 45 in Houston.

Planning

Question 22: Which of the following applications, if any, are you planning to use RLS?

Agency	**Response**
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	Planned Special Event Roadway Construction
Washington State DOT	No Response
Mississippi DOT	Emergency Management
North Texas Tollway Authority	No Response
Kansas Turnpike Authority	Congestion Mitigation
Ohio Turnpike Commission	Planned Special Event Congestion Mitigation
Iowa DOT	Planned Special Event Roadway Construction Emergency Management
Charlotte DOT	No Response
College of William and Mary Campus Police	Planned Special Event
University of Oklahoma Police Department	Planned Special Event
University of Idaho	Planned Special Event Emergency Management Homeland Security Management
Maryland Transportation Authority	No Response
Mississippi DOT	Emergency Management
South Carolina DOT	Emergency Management
City of Vancouver	Roadway Construction
Alabama DOT	Emergency Management
Oregon DOT	Roadway Construction Emergency Management
Washington, DC DOT	No Response
New Jersey DOT	Emergency Management Homeland Security Management
Government of the Northwest Territories	Roadway Construction
Virginia DOT	No Response

Ministre des Transports—Government of Quebec	Roadway Construction
Louisiana DOT	Emergency Management
Illinois DOT	Planned Special Event Congestion Mitigation Roadway Construction Emergency Management Homeland Security Management
New York City DOT	No Response
Texas DOT	Emergency Management Congestion Mitigation Transit Performance

Planning

Question 23: Which of the following have you established as criteria that warrant its use?

Agency	Response
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	No Response
Washington State DOT	No Response
Mississippi DOT	Desired Queue Length
North Texas Tollway Authority	No Response
Kansas Turnpike Authority	Desired Flow Desired Queue Length
Ohio Turnpike Commission	Desired Queue Length
Iowa DOT	Desired Flow
Charlotte DOT	No Response
College of William and Mary Campus Police	Desired Flow
University of Oklahoma Police Department	Desired Flow
University of Idaho	Desired Level of Service
Maryland Transportation Authority	No Response
Mississippi DOT	Desired Flow
South Carolina DOT	Desired Travel Time
City of Vancouver	Desired Flow Desired Queue Length
Alabama DOT	Desired Flow
Oregon DOT	Desired Level of Service Desired Queue Length
Washington, DC DOT	No Response
New Jersey DOT	Desired Flow Desired Travel Time
Government of the Northwest Territories	Desired Level of Service
Virginia DOT	No Response
Ministre des Transports—Government of Quebec	Desired Flow Desired Travel Time Desired Queue Length
Louisiana DOT	No Response
Illinois DOT	Desired Flow Desired Travel Time

New York City DOT	No Response
Texas DOT	No Response

Planning

Question 24: What guidelines or standards are you using to develop your plans?

Agency	**Response**
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	MUTCD
Washington State DOT	No Response
Mississippi DOT	Used Alabama DOT I-65 Lane Reversal Plan as guide.
North Texas Tollway Authority	RLS is used as a specific special event traffic handling method on one facility. Since this is a low-volume facility and the town of Addison guarantees the toll revenue impact, RLS is used for the July 4th fireworks special event to help clear traffic after the event is over and a mass of traffic is leaving. No other systems are currently contemplated.
Kansas Turnpike Authority	No Response
Ohio Turnpike Commission	No Response
Iowa DOT	No Response
Charlotte DOT	No Response
William and Mary Campus Police	No Response
University of Oklahoma Police Department	Parking/traffic access to football stadium
University of Idaho	No Response
Maryland Transportation Authority	No Response
Mississippi DOT	MUTCD and normal Mississippi DOT standards for median crossover
South Carolina DOT	No Response
City of Vancouver	No Response
Alabama DOT	MUTCD, AASHTO Design Guide
Oregon DOT	No Response
Washington DOT	No Response
New Jersey DOT	Inclusive coordination meetings with all players/NJ standard highway and bridge specs
Government of the Northwest Territories	MUTCD for Canada
Virginia DOT	No Response
Ministre des Transports—Government of Quebec	Government standards
Louisiana DOT	No Response
Illinois DOT	Need capacity out of CBD: for peak times, for various times, and special events. Varies by situation.
New York City DOT	No Response
Texas DOT	No Response

Planning

Question 25: Do you have any estimation for the flow rates for RLS? If so, how did you arrive upon your figures?

Agency	Response
City of Memphis, Engineering Division	No Response
Denver Department of Public Works	No Response
Washington State DOT	No Response
Mississippi DOT	No
North Texas Tollway Authority	No
Kansas Turnpike Authority	No Response
Ohio Turnpike Commission	No
Iowa DOT	No
Charlotte DOT	No Response
College of William and Mary Campus Police	No
University of Oklahoma Police Department	No
University of Idaho	No
Maryland Transportation Authority	No Response
Mississippi DOT	No
South Carolina DOT	No
City of Vancouver	Manually counted
Alabama DOT	No Response
Oregon DOT	No
Washington, DC DOT	Historical data
New Jersey DOT	Exercise/military simulations lab
Government of the Northwest Territories	No
Virginia DOT	No Response
Ministre des Transports—Government of Quebec	No
Louisiana DOT	No
Illinois DOT	Actual past performance—Traffic System Center. We have meters on all expressways in Chicago area.
New York City DOT	No Response
Texas DOT	No Response

Planning

Question 26: Are there any aspects of reverse-flow/contraflow operation that you feel require further investigation or that you would like answered?

Agency	Response
City of Memphis, Engineering Division	We (engineering) have data from our test period, but it has not been put in a report format.
Denver Department of Public Works	No Response
Washington State DOT	No Response
Mississippi DOT	No Response
North Texas Tollway Authority	No Response
Kansas Turnpike Authority	We only do this at one of our 20 plaza locations and only during selected holidays (2–3 days per year). Facility is old and does not have enough lanes, so we “switch” one lane from entry to exit.

Washington, DC DOT	No Response
Ohio Turnpike Commission	No Response
Iowa DOT	No Response
Charlotte DOT	No Response
College of William and Mary Campus Police	No Response
University of Oklahoma Police Department	No Response
University of Idaho	No Response
Maryland Transportation Authority	Cost/benefit and safety; congestion vs. contraflow
Mississippi DOT	No Response
South Carolina DOT	Safety factor of reversing traffic flow on roads where guardrail and bridge ends are not protected in contraflow direction
City of Vancouver	No Response
Alabama DOT	No Response
Oregon DOT	Terminals—entry/exit conflicts…automation
New Jersey DOT	NJ constantly reviews updates plans, which will include items needing further work.
Government of the Northwest Territories	Due to low traffic volumes we rarely, if ever, use RLS. The closest we come is a lane closure for road construction and then we follow the manual above for signage, etc.
Virginia DOT	No Response
Ministre des Transports—Government of Quebec	No
Louisiana DOT	No Response
Illinois DOT	At times of day and events we are beyond capacity in both directions. At that point the entire system operates in direction to improved capacity on flow of other connecting system. Hard to explain to public.
New York City DOT	No Response
Texas DOT	No Response

Abbreviations used without definition in TRB Publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation