



Transportation Association of Canada

*Guidelines for the Planning,
Design, Operation and Evaluation of
Reversible Lane Systems*

February 2010

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Transportation Association of Canada
2323 St. Laurent Blvd.
Ottawa, ON K1G 4J8
Tel. (613) 736-1350 ~ Fax (613) 736-1395
www.tac-atc.ca

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Author(s) Alfred A. Guebert		Corporate Affiliation(s) and Address(es) AECOM Canada Ltd. 2540 Kensington Road NW, Calgary, AB, T2N 3S3 Canada
Abstract <p>A reversible lane or roadway is one in which the direction of traffic flow in one or more lanes or shoulders is reversed to the opposing direction for some period of time. Its benefit is derived from taking advantage of the unused capacity of the minor flow direction to increase capacity in the major flow direction, potentially negating or deferring the need to construct additional lanes.</p> <p>This document presents a set of national guidelines and list of considerations for planning, design, operation and evaluation of reversible lane systems with the intent to enhance the understanding of, and promote consistency with regard to, reversible lane systems. Through these guidelines, it is hoped that the safety and efficiency of reversible lane systems will be enhanced.</p> <p>The purpose of the document is to:</p> <ul style="list-style-type: none"> • increase the understanding of reversible lane and roadway use; • serve as a practical guide to planning, design, implementation, management, and evaluation; • promote reversible lane systems as a viable, sustainable, and cost-effective solution for consideration when developing alternatives to improve mobility and reduce congestion within constrained corridors in a cost-effective and environmentally-sustainable manner; and • provide guidance for uniformity in their design and operation, with the goal of improving road user comprehension as well as operational efficiency and safety. 		Keywords Traffic and Transport Planning -Traffic Control -reversible lane -planning -layout -traffic control -specifications -guidance
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Project Team

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Dave Keenan (Chair)
City of Calgary

Andrew Beal
Ministry of Transportation Ontario

Gord Cebryk
City of Edmonton

Winston Chou
City of Vancouver

Richard Chow
Alberta Transportation

Phil Corkum
Nova Scotia Department of Transportation & Infrastructure Renewal

David McCusker
Halifax Regional Municipality

Ed Miska
British Columbia Ministry of Transportation and Infrastructure

Jama Mohamed
City of Ottawa

Hart Solomon
City of Hamilton

Simon Trépanier
Ministère des Transports du Québec

Hansel Wang
South Coast British Columbia Transportation Authority (TransLink)

Yeatland Wong
City of Calgary

Sandra Majkic
TAC Project Manager

Executive Summary

A reversible lane or roadway is one in which the direction of traffic flow in one or more lanes or shoulders is reversed to the opposing direction for some period of time. Its benefit is derived from taking advantage of the unused capacity of the minor flow direction to increase capacity in the major flow direction, potentially negating or deferring the need to construct additional lanes.

This document presents a set of national guidelines and list of considerations for planning, design, operation and evaluation of reversible lane systems with the intent to enhance the understanding of, and promote consistency with regard to, reversible lane systems. Through these guidelines, it is hoped that the safety and efficiency of such systems will be enhanced.

The purpose of the document is to:

- increase the understanding of reversible lane and roadway use;
- serve as a practical guide to planning, design, implementation, management, and evaluation;
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- provide guidance for uniformity in their design and operation, with the goal of improving road user comprehension as well as operational efficiency and safety.

The guidelines will be of interest to transportation practitioners and others in the transportation industry considering the implementation of reversible lanes and roadways.



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1. Introduction

1.1 Context

Across Canada, population growth in and around urban areas is placing ever-increasing demands on existing transportation infrastructure, particularly on controlled-access and arterial roadway networks. The construction of sufficient lane capacity to satisfy current and future demands during peak travel periods is often perceived as infeasible due to cost or right-of-way constraints or contrary to longer-term environmental and transportation sustainability goals.

One viable method for meeting mobility and sustainability needs within constrained rights-of-way and budgets is the concept of active lane management. Active lane management involves strategies to optimize the operational efficiency of available infrastructure, through a dynamic and flexible response to changing traffic demand, in a manner consistent with identified community needs and priorities.

In this context, active lane management may be applied to all roadway classifications for which vehicular mobility is a functional priority (generally considered to encompass both access-controlled and arterial roadways). It may be applied to individual corridors or on a network-wide basis, to implement strategies which:

- Increase overall mobility, while reducing vehicular congestion;
- Provide a preferential level of service to specific vehicle types or those meeting minimum occupancy requirements, such as high-occupancy vehicles, to maximize the person-moving capacity of roadway facilities;
- Provide for fuel conservation; and
- Improve air quality by reducing vehicle emissions caused by traffic congestion.

In terms of functional design, managed lanes may involve the following traffic design strategies:

- On-street parking restrictions during peak periods;
- High-occupancy vehicle (HOV) regulations and policies;
- Value-priced and high-occupancy toll (HOT) regulations and pricing models;
- Exclusive facilities for specific user groups (i.e. emergency vehicles, mass transit);
- Conversion of paved shoulders to travel lanes, for specific or general use;
- Dual facilities to separate local and longer-distance trips; and
- Reversible lane systems (RLS).

Temporal flexibility is a key enabling attribute of the managed lanes concept. Strategies may be applied:

- On a continual, demand-responsive basis;
- On a fixed-time basis, by time-of-day and/or day-of-week;
- Infrequently, in response to pre-planned events; or
- On a contingency basis, in response to natural or man-made emergencies.

1.2 Reversible Lanes

A reversible lane or roadway is one in which the direction of traffic flow in one or more lanes or shoulders is reversed to the opposing direction for a temporary period of time. The benefits of reversible lanes are derived from utilization of the unused lane capacity within the minor-flow direction to increase capacity in the major-flow direction, which may negate the need to construct additional lanes.

A central strategy within many active lane management schemes is the introduction of reversible lanes or roadways as a more economical means of maximizing the utilization of existing infrastructure, while continuing to meet project mobility and environmental sustainability objectives.

Despite the apparent simplicity of the concept, implementation of a successful (safe and efficient) reversible lane system requires careful planning, design, implementation and management. The limited availability of standardized and formalized guidance for reversible lane systems has resulted in considerable variation in the planning, design, operations and management across jurisdictions.

This lack of uniformity has potential implications in terms of road user comprehension, performance, efficiency and safety. Many of the actual costs and benefits of reversible lane systems have not been documented, and there appears to be no general consensus on applicable performance measures and benchmarks, either in planning or post-implementation. Collectively, this knowledge gap may be contributing to higher collision frequencies, reduced efficiencies, and the misallocation of resources. It also tends to support the contention that reversible lane systems represent a compromise of road user safety in the interests of efficiency.

The *Manual on Traffic Control Devices for Streets and Highways* (2003) and *Manual of Uniform Traffic Control Devices for Canada* (1998) contain guidance on the control of reversible roadways, including recommended signs, signals and pavement markings. In many cases, local treatments and practices have evolved, in spite the lack of guidance available. Organizations such as Institute of Transportation Engineers (ITE), the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) have proposed warrant criteria for reversible lane systems, as well as guidelines for planning, design, operations and management. However, regarding scope and intent, inconsistencies exist between the proposed warrant criteria from these sources.

1.3 Reversible Lane System (RLS) Guidelines

In recognition of the need for more comprehensive documentation on reversible lane planning, design and management practices, the Transportation Research Board released the Synthesis 340 *Convertible Roadways and Lanes* (2004). With similar recognition, the FHWA and the Texas Department of Transportation produced the *Managed Lanes Handbook* (Kuhn et al. 2005).

Recognizing the lack of any comprehensive guidelines relative to reversible lane systems, this document is a result of the study initiated to investigate and present the current practices in North America and internationally, relative to reversible lane systems and to produce a set of national guidelines for such systems. The motivation for undertaking this project is to enhance the understanding within the transportation community relative to reversible lane systems and to develop a preliminary set of guidelines for RLS which can be updated over time as the use of them evolves. The guidelines and considerations identified in this project build upon the above-mentioned references, along with other resources and provide guidance that promotes consistency in planning, design, operation, management, and enforcement of reversible lane systems. The intention is that these guidelines will enhance the safety and efficiency of such systems. As such, the following information will be of interest to transportation agencies and others within the transportation community who are interested in implementing reversible lanes and roadways.

1.4 Purpose and Audience for Guidelines

The principles and practices outlined in these guidelines are based on current experience in Canada and internationally, drawing from key reference documents relating to:

- Geometric design;
- Applied human factors (road user) information; and
- Uniformity and consistency in selection, design, and application of traffic control devices.

The guidelines are intended to provide transportation practitioners with guidance that will enable them to plan, design and operate an reversible lane system (RLS) consistently.

The purpose of the document is to:

- address the need for an increased level of understanding relative to reversible lane and roadway use;
- serve as a practical guide to planning, design, implementation, management, and evaluation;
- promote reversible lane systems as a viable, sustainable, and cost-effective solution for consideration when developing alternatives to improve mobility and reduce congestion within constrained corridors in a cost-effective and environmentally-sustainable manner; and
- provide guidance for uniformity in their design and operation, with the goal of improving road user comprehension as well as operational efficiency and safety.

It is believed that this document will promote standardization, current practices, economy of use, operational efficiency and safety in the application of reversible lane systems to Canadian roadways. With a better understanding of their characteristics and operational requirements, such RLS strategies might be more broadly and consistently implemented in the future.

1.5 Methodology and Document Organization

Development of this document involved a review of available literature from North America and abroad, a survey of Canadian jurisdictional practices and the synthesizing of the findings. The principles and practices recommended in this document are a result of research and selection of the most appropriate criteria for each component through implementation of a RLS.

This document is organized into six chapters, as follows:

1. Introduction
2. Background
3. Current State of the Practice
4. Planning Stage
5. Design Stage
6. Reversible Lane System Operations



2. Background

The principle of reversible roadways is to configure the lanes of a roadway to match available capacity with traffic demand. The Institute of Transportation Engineers (ITE) defines a reversible lane or reversible roadway system 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*” (Meyer, 1997). Such reversible roadways are 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 maximizing the usable operation within the existing infrastructure. Reversible traffic operations are widely regarded as one of the most cost-effective methods of increasing the capacity of an existing roadway without physically increasing the roadway cross-section. Specifically, effective RLS implementation can eliminate or delay the need to construct additional lanes (TRB 2004), which are only needed to accommodate periodic increases in traffic volume. These systems are particularly beneficial within constrained roadways such as bridges and tunnels.

This chapter provides an introduction to the concept and application of reversible lane systems. The following is addressed:

- A brief history of reversible lane systems development;
- The physical characteristics common to reversible lane systems;
- The temporal characteristics common to reversible lane systems; and
- Reversible lane system variants and applications.

2.1 History of Reversible Lane Systems

One of the earliest referenced uses of reversible-flow roadways was in 1928 with a convertible lane variant known as off-center lane movement (TRB 2004). It was the brainchild of Ralph T. Dorsey (City of Los Angeles CA) and was first tested on 8th Street in Downtown Los Angeles in 1928. During the morning, three lanes provided eastbound travel and one lane was for westbound traffic. This was reversed for the evening with three lanes westbound and one lane eastbound. In 1937, this treatment was implemented along six miles of Wilshire Boulevard (Figure 1). It was immensely successful. However, with Wilshire Boulevard as the premier retail street of Los Angeles, it needed to serve local circulation needs as well as accommodate through traffic. As a result, the operation was overturned three years later by the City Council.



Figure 1: Wilshire Boulevard at Western Avenue with Reversible Lanes, 1937
(Source: <http://www.ci.la.ca.us/ladot/TopicsAndTales/Pavementmark4.pdf> - Accessed in November 2008)

Application to 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 North America 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 high occupancy vehicle (HOV) lanes on freeways and exclusive reversible-flow bus lanes in urban population centers.

Although not well documented, reversible lane operation has also been widely used for dealing with special event directional traffic scenarios, such as those associated with large sporting events, concerts, and festivals. More recently, reversible lanes have seen broader use in the form of freeway contraflow for hurricane evacuation in the United States (TRB 2004). (Figure 2)



Figure 2: Reversible Flow Lane Operation during the Evacuation of Houston TX
(Source: <http://en.wikipedia.org/wiki/Image:RitaHoustonEvacuation.jpg> – Accessed in November 2008)

2.2 Physical Characteristics

The key physical elements of a roadway configured with a reversible lane system include the following:

- Geometric features such as its overall length, cross-section, horizontal and vertical alignment, intermediate points of ingress and egress, number of through lanes, presence of auxiliary lanes, interchanges and intersections, driveways, pedestrian crossings, and the configuration and length of the inbound and outbound transitions;
- Traffic control devices directly related to the reversible lane system, including traffic control signals, regulatory, warning and information signs (both static and those with variable message capabilities), lane control signals, pavement markings, and delineation;
- Gates and barriers which assist in delineating lanes, guiding and directing traffic, as well as preventing wrong way manoeuvres; and
- Roadway illumination.

Reversible lane systems are generally considered to be comprised of five zones. They are depicted schematically in Figure 3.

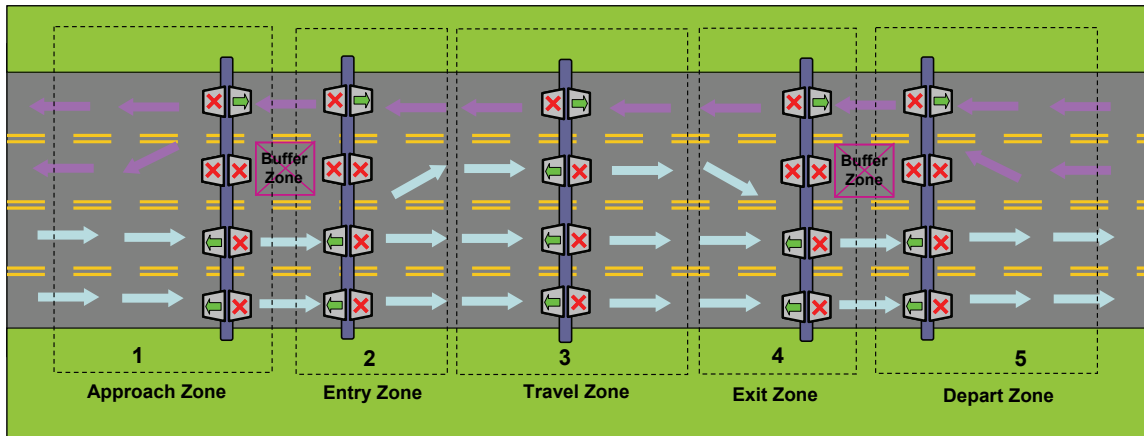


Figure 3: Different Zones on Reversible Lane Systems

1. *Approach Zone* – is the section of road where users need to be made aware of the presence of reversible lane(s), and any applicable usage criteria (i.e. number of occupants, vehicle classification, open or closed tolling requirement, etc.);
2. *Entry Zone* – the point at which the road user must decide whether or not to access the reversible lane(s) or remain within the general traffic stream. This area is typically characterized by diverging movements, and a higher relative potential for vehicle-vehicle conflicts. To minimize conflicts, a buffer zone may be considered at the beginning of the entry zone. This buffer zone consists of a section of roadway in which vehicular travel is prohibited;
3. *Travel Zone* – the area of the RLS where the alteration of lane usage has been established and where the capacity of the major-flow direction is enhanced by additional lanes. Depending on system configuration, (i.e. non-access-controlled) road users may have the option to enter or exit the reversible lane(s) while within the travel zone. Road users are provided with periodic information about which lanes are open for use, and the criteria for use. This is critical in that adjacent lanes may be open to opposing traffic, posing the risk of opposing-type collisions if road users fail to heed or misinterpret the information provided to them;
4. *Exit Zone* – the transitional area where traffic in the reverse lane is re-integrated with mainline traffic. The road user must exit the reversible lane(s) and rejoin the general traffic stream. In this zone, there must be some signs or other control devices in place to notify the drivers of the termination of reversible lane system. Like the intermediate exit decision zones, this area is typically characterized by merging and weaving movements, and a higher relative potential for vehicle-vehicle conflicts. To minimize conflicts, a buffer zone may be considered at the end of the exit zone. This buffer zone consists of a section of roadway in which vehicular travel is prohibited;
5. *Departure Zone* – the terminal point of a reversible lane system. Provision for reversible lanes is ceased and traffic must resume normal lane usage and flow patterns.

2.3 Temporal Characteristics

The primary temporal components of a reversible lane system include the following:

- Frequency and duration of a particular configuration:
 - Most systems are “fixed time”, meaning that they start and end at the same time, usually on weekdays;
 - Some systems are manual, meaning that they are implemented by an operator (or a field crew) when they are deemed to be beneficial; and
 - Some systems are automated, meaning that they are implemented when certain criteria are met, such as traffic volume thresholds, v/c thresholds or queue length thresholds. These automated systems also need to consider the sustainability of the threshold values to ensure the system doesn’t activate for a very short demand peak.
- Time required to transition traffic from one configuration to another:
 - Most systems use a calculated transition time based on the length of the reversible portion of the roadway traffic speed;
 - Some systems transition the reversal lane by moving physical barriers; and
 - Some systems monitor the reversible lane traffic (either by CCTV camera or in person) in real time and make the switch when the lane is clear.

Clearly, the most critical periods for reversible lane system operation occur when flow in the managed lane or lanes is transitioning from one direction to the other. While there is a continual risk of an opposing-type collision on a reversible lane system without a directional dividing barrier, the transition period is a period of vulnerability for all reversible lane systems, regardless of type.

From the perspective of efficiency, the transition period should be as brief as possible. From a road safety perspective, the transition must occur over a sufficiently long period to allow road users to perceive, understand and respond to the changing lane allocation. This time must also allow motorists to clear the lane or lanes being re-assigned, before conflicting traffic is released. As an example, the City of Edmonton calculates the transition time as equivalent to the travel time for the entire length of the reversal lane plus the time for one full cycle of the traffic signals within the corridor.

Temporal characteristics are important considerations, both in terms of tidal demand and during transition periods. Manual and temporary systems (those not operated by a traffic management centre) rely on the use of police or agency staff to clear the reversible lanes during the transition by moving barriers or delineators into place to separate opposing flows. Lane control signals allow for a “cascading” transition in lane allocation which shortens the transition period.

2.4 Variations and Applications of Reversible Lane Systems

Reversible lanes strategies are becoming a popular solution for the mitigation of traffic congestion, as they afford the flexibility of revising lane use to fit changing demand patterns. This strategy affords jurisdictions the ability to improve operations within corridors where it is economically or physically impractical to add capacity. Often, reversible lane operations are employed when escalated user demand results from disparate traffic flows, roadway construction, planned special events, or emergency evacuations. As such, various RLS operations and applications exist that can address individual congestion issues. The two primary system types are temporary applications and permanent facilities.

2.4.1 Temporary RLS

Temporary reversible lane applications are typically informal and often initiated by authorities on the road (i.e. emergency services). Additionally, temporary RLS can be driven by demand where highly dichotomous directional traffic splits occur. The following are situations where temporary applications are used:

- Periods of construction work: maintain capacity while some portion of the roadway is occupied by a work zone
- Infrequent and/or special events (e.g. the Olympics): facilitate a significant flow prominently accessing to or egressing from a specific direction/destination
- Emergency evacuations: make the majority or entirety of a roadway's capacity available for exodus

2.4.2 Permanent RLS

Two prominent permanent types of reversible lane facilities exist, physically separated and off-centre. Both operations address unbalanced directional flow (i.e. peak commute hours).

Physically separated systems can be integrated into the infrastructure employing ramps and barriers, such as the automatic reversible lane change system (REVLAC) along the Kennedy Express Way in Chicago (Anderson and Murphy 1998). These facilities have been used for high occupancy vehicle (HOV) and toll lanes, and are labelled by AASHTO as contraflow when operated within a divided highway.

Off-centre applications refer to appropriating minor-flow (off-peak) lane(s) for traffic utilization in the major-flow (peak-flow) direction. Common operation involves reversing lane(s) at a specified time for a predetermined duration. However, variations do exist in which activation is dependent upon traffic flow rather temporally based. Off-centre conditions can be applied to either arterial roadways or freeway sections and may be designed into the existing network without requiring reconfiguration or additional lane creation.

3. Current State of Practice

In order to gain access to the most current sources of information, a survey of previous and current reversible roadway users was undertaken. This chapter provides a summary of current state of practice.

3.1 Survey of Practice

The survey questionnaire consisted of several questions, investigating five key areas of interest: planning, design, operations, safety, and evaluation methods. The questions were developed to determine if there were any warrants or thresholds applied in the implementation of reversible lane systems. It also looked into the extent to which standard design practices were used to guide their implementation.

Subsequent to the initial questionnaire, a follow up survey questionnaire involving a series of detail oriented questions was sent to all previously participating agencies to explore the characteristics of each individual reversible lane system.

The most common application of RLS was associated with congestion mitigation during peak hour periods. Other applications of RLS currently under consideration include emergency evacuation-related routes, temporary detour situations and congestion mitigation during special events. The survey results showed that Canadian reversible lane systems are in use to efficiently accommodate traffic flow on controlled access facilities, where the cost of adding new lanes would be very high if not impossible, as well as on congested arterial streets. The following subsections were specifically dedicated to the findings of the current practices review with respect to planning, design, operations, and evaluation method of reversible lane systems.

3.1.1 Planning

It was found that the planning for reversible facilities is not substantially different from that for conventional facilities. Based on the review of current practices, the main decision to consider the use of reversible lanes is based on the need to increase traffic flow capacity in one direction.

- In Calgary, Edmonton, Montreal, and Halifax the implementation of reversible lane systems is considered when directional split of traffic volumes significantly exceeds the directional capacity split, and significant additional capacity can be gained by reversal of flow in one or more lanes. Consideration is also given to the resulting capacity of the direction that loses capacity upon the implementation of the system.
- National Capital Commission (NCC) in Ottawa noted that they implemented an RLS for high occupancy vehicles use.
- The use of reversible lane in Montreal is an option where additional capacity is needed but additional right-of-way is not available. Political support is a key element in the decision to implement RLS.
- In Halifax, reversible lane systems are considered particularly in roads serving through traffic with low demand for left-turning movements to/from side streets.
- Respondents from the British Columbia Ministry of Transportation and Infrastructure, National Capital Commission and Halifax Regional Municipality indicated considering a benefit-cost analysis approach to evaluate the RLS alternative.

- Safety risks are specifically taken into consideration in the RLS analysis in some jurisdictions.

3.1.2 Design

The review of published literature related to reversible lane facilities showed that there are no dedicated references that govern their design. The survey also showed that reversible lanes are mainly designed as normal travel lanes and applicable national and provincial standards apply. It was found that:

- Practitioners in the British Columbia Ministry of Transportation and Infrastructure as well as in the City of Montreal follow existing geometric design standards provided in the *Geometric Design Guide for Canadian Roads* (1999) and the *Manual of Uniform Traffic Control Devices for Canada* (1998) along with engineering judgment to ensure reversible lane systems are properly designed and operated.
- The required width of reversible lanes in Montreal is 4.0 metres to allow double stripe markings and a comfort zone for traffic. Other lanes must be a minimum of 3.20 metres to provide for trucks and buses.
- The British Columbia Ministry of Transportation and Infrastructure uses loop detectors to gather speed, volume and occupancy data, while the National Capital Commission uses detectors for traffic volume data only. In all other cases the RLS was designed for pre-timed operation with no detection.

3.1.3 Operations

The review of traffic control devices including pavement markings, signs, and signals for reversible lanes showed a considerable variation in the development and application of such devices. Reversible lane transition zones already in use in Canada vary in terms of minimum length, signal head types and sizes, signal spacing, operation and the application of traffic control devices.

- In the case of Jarvis Street in Toronto central business district (CBD), the signal heads are installed only over the reversible lane(s), whereas in almost all other cases, signal heads have been installed over every traffic lane.
- Advanced RLS warning information is provided to motorists through the use of both static and dynamic signs. City of Edmonton has installed overhead variable message signs (VMS) in combination with pavement markings to guide drivers along the reversible lane facility. They stated that the spacing of signs and signal heads must be in a way to ensure that through the length of a reversible lane system zone, motorists always have a view of at least two signs/signals along the length of the zone.
- City of Montreal uses overhead lane use signals with flashing amber arrows to notify the drivers what lanes they will have to migrate to ahead.
- In terms of pavement markings, most jurisdictions have adopted broken double-stripped yellow lines on both sides of reversible lane.
- The transition period in almost all jurisdictions has a downward green arrow that changes to a flashing red "X" which is displayed for a minimum of less than a minute to a maximum of 15 minutes and eventually turns to solid red "X" before opening the lane in the opposite direction. In Edmonton, the duration of this transition is equivalent to the travel time for the entire length of the reversible lanes plus the time for the one full cycle of the longest signal cycle of an intersection within the reversible lane facility.
 - Vancouver and Montreal have adopted slightly different types of signal head phasing during transition period. They have been using flashing and solid amber "X" (in Vancouver) and downward yellow arrow (in case of Montreal) on signal

- heads above the reversible lane for a certain period of time during clearance interval (lasting between 1 to 15 minutes) to ensure a smooth transition.
- In Halifax and the Sherman access road in Hamilton, gates have been used as supplementary devices during the transition periods.
 - The British Columbia Ministry of Transportation and Infrastructure uses loop detectors to gather speed, volume and occupancy data, while the National Capital Commission uses detectors for traffic volume data only. The others all indicated the RLS was designed for pre-timed time of day operation with no detection.
 - There have been some attempts in the past to upgrade the pre-timed control methods of existing reversible lane facilities. For instance, to improve the pre-timed traffic control method, the British Columbia Ministry launched an “optimal responsive contraflow control” project in 1992 that used a model for estimating the traffic demand using traffic flow information near the tunnel. The counter flow optimization software was used for several years and it was found that the traffic patterns did not vary sufficiently to warrant the ongoing cost of system operations and maintenance. The system was discontinued.
 - No specific maintenance procedures have been put in place for reversible lane systems. However, the City of Montreal officials have stated that the higher priority has been given to maintenance of reversible lane systems in comparison to other roadways.
 - Montreal was the only jurisdiction to report police attendance for enforcement purposes to prevent traffic violations.
 - With respect to incident management systems, no specific strategy is in place except for the applications used in the City of Edmonton for which the flashing red “X” in both directions are displayed to notify the drivers of incident occurrence prompting them to avoid using those lanes.

3.1.4 Evaluation

The review of current practices identified that there was no standard evaluation program in place. Very few jurisdictions have monitored, evaluated, or reported on the performance of reversible lane systems.

- There is a certain degree of public dissatisfaction over reversible lane projects in Montreal due to the loss of curb-side parking spaces adjacent to retail establishments.
- Safety risks and implications on collisions as part of their evaluation analysis are considered in Halifax and Montreal.
- Pedestrian safety is one main issue in Montreal in terms of safety consideration of such systems. To enhance the level of safety with respect to such systems, officials in Montreal have had their control system designed in a way that in case of burning out of two or more signals in a zone, the controller will shut down the entire reversible lane operation.
- British Columbia Ministry has been conducting counts from loop detectors to evaluate the system in terms of capacity and accommodated traffic flow. They also have done before/after studies on some of the large projects.

3.1.5 Justification Criteria and System Failure

Implementation of reversible lanes was largely justified through benefit-cost analyses or increased capacity expectations.

- Vancouver, British Columbia Ministry of Transportation and Infrastructure, Edmonton, National Capital Commission, and Halifax improved traffic carrying efficiency and/or easing of peak-flow congestion,

- A benefit-cost analysis was conducted for British Columbia Ministry's system and the City of Calgary has justified a future RLS through a benefit-cost evaluation.

Road authorities provided information regarding road user reaction to a system failure. It was noted that motorists' reactions are mixed.

- The City of Vancouver reported calls received from commuters, but no on-road issues.
- Commuters in Edmonton and Ottawa (NCC) treated the failure as if it was a transition and cleared the reversible lanes.
- The City of Hamilton reported only motorist confusion.
- Calgary's system failure resulted in motorist behaving as if the lane reversal was in effect, despite lane indicators to the contrary. Motorist confusion was reported, particularly at signalized intersection, but ultimately motorists asserted their own right of way.

The review of current practices provided a significant input in developing the guidelines. The following sections offer guidance on planning, design and operation of reversible lane systems.

4. Planning Stage

The transportation planning process involves: problem identification and definition, setting project goals, objectives and performance measures, assessing existing conditions and constraints, and developing and evaluating competing solutions to arrive at a preferred solution which best fits requirements. This preferred solution is then developed to the level of a functional design and an operating strategy, which is assessed in greater detail as to its costs and benefits prior to detailed design and implementation.

The inclusion of a reversible lane system solution as an alternative in the planning process follows this general outline, but requires the consideration of a broad range of factors – some of which are unique to reversible lane systems. This chapter provides an overview of the considerations and guidelines which should be taken into account during planning.

4.1 Key Planning Considerations

Historically, the need for reversible lanes has been driven by several 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. Considerations for when to implement reversible lanes have developed over the years as traffic engineers have become more familiar with the characteristics associated with their use, including 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, such as:

- Heavy directional split (65/35) of traffic that reverses at different times of the day;
- Over-saturated conditions (sustained over a period of time) in the heavy direction and under-saturated conditions in the opposite direction;
- Operating speed reduction of more than 25%;
- Constrained right-of-way and/or prohibitive cost to obtain right-of-way;
- Adequate space and conditions for the approach and departure zones;
- Limited left turn requirements throughout the RLS zone;
- Cross-section elements adequate for traffic mix (trucks/ buses); and
- Over-all reduction in vehicle (person) delay with implementation.

The need for reversible lanes often starts by identifying locations of known congestion and growth projections that are anticipated for the future. Although there is no single set of warrants that has been universally agreed on, a general uniform practice has developed in assessing the need for such facilities. Professional transportation organizations such as AASHTO and ITE have developed consistent guidelines, 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.

Lathrop (1972) suggested that potential users should answer a few 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. These questions are:

- Will it be safe and will it be reliable?
- Will it be reliable in all weather conditions?

- Will the system be designed with redundancy so that if any single component fails, it will still work safely?
- If there is a system-wide failure, will the design allow the system to be usable?
- Will it be aesthetically acceptable?
- Will its costs (implementation costs as well as operational costs associated with maintenance and safety) be justified with the benefits of system flow improvements?

4.1.1 Mobility Considerations

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” (AASHTO 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 suggests a combination of criteria and traffic studies that should be evaluated before deciding if reversible lane systems are needed, and to ensure that they will operate in an advantageous manner once they are implemented. Otherwise the installation of a contraflow lane could be the cause of a new traffic problem on the minor-flow side of the facility. The 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 compared to the normal speed, or there should be a noticeable backup at signalized intersections leading to vehicles missing one or more green signal intervals;
2. There are limited alternatives (a lack of an adequate adjacent street, ruling out the consideration of one-way operation). 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;
3. There is a traffic congestion problem. 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”;
4. The ratio of a major to minor traffic count should be at least 2:1 and preferably 3:1 (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)). 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;
5. There must be adequate entrance and exit capabilities in addition to providing easy transition between the normal and

Recommended Mobility Considerations for Implementing an RLS:

Temporary (work zone or special event)

- ✓ Expected conditions will create unbalanced flows
- ✓ Queue lengths are expected to be unreasonable in heavy direction
- ✓ Special event activity

Arterial (at-grade, minor or unrestricted access)

- ✓ Actual conditions create unbalanced flow (65/35 split)
- ✓ Significant queues along corridor
- ✓ Major flow demand exceeds capacity
- ✓ Demand is periodic and predictable (high % commuter traffic)
- ✓ Congestion is typically sustained over a period of time (>60 minutes) during peak hours

Freeway (limited access)

- ✓ Actual conditions create unbalanced flow (65/35 split)
- ✓ Speed reductions >25% in peak direction
- ✓ Demand is periodic and predictable (high % commuter traffic)
- ✓ Congestion is typically sustained over a period of time (>60 minutes) during peak hours

reverse flow lanes. Otherwise, the contraflow lane could be the cause of bottlenecks and other traffic problems in addition to the existing traffic congestion;

6. There is a high proportion of commuter-type traffic that desires to traverse the area without turns or stops; and terminal conditions that facilitate the full utilization of the additional lanes;
7. ITE also urges maintaining a minimum of two lanes open to traffic in each direction. 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); and
8. An assessment of the capacity of the access points to the reversible segment is a critical one that is sometimes 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, as well as the reverse operation, 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.

4.1.2 Traffic Considerations

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 configurations that have been employed for 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 an 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.

Recommended Traffic Considerations for Implementing an RLS:

Temporary (work zone or special event)

- ✓ Parking restrictions can be implemented to provide additional lane
- ✓ Incident management should be considered if design results in a single lane operation

Arterial (at-grade, minor or unrestricted access)

- ✓ There is a limited left (or right) turn demand along the corridor
- ✓ Incident management should be considered if design results in a single lane operation
- ✓ Parking restrictions should be considered to provide for passing opportunities (but may need to provide alternate parking)

Freeway (limited access)

- ✓ There is an opportunity for using the shoulder as a driving lane (in order to maintain 2 lanes in reverse direction)
- ✓ Cross-over opportunities exist or can be created
- ✓ Changes to speed limit (speed advisory) are possible

Where there is the potential for a single lane in the reverse direction (3:1), consideration should be given to managing incidents in this lane, especially for emergency vehicles. For arterials, the use of parking lanes or wide curb lanes may be considered. In the case of freeways, where 2 lanes are necessary in the reverse direction, the use of the shoulder may be considered to ensure there are passing opportunities.

ITE has also acknowledged the advantages and disadvantages of these various operational configurations (ITE 1992), ranging from the obvious to the subtle. The advantages include:

- Additional capacity for flow in the primary direction;
- Additional capacity can be accommodated on the same street for both morning and evening peaks;
- 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.

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 is 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. Generally, the minimum number of lanes in the off-peak direction is two (to provide room for emergency vehicles and mixed traffic flow). However, there are times when a single lane will suffice (very low traffic flow in the off-peak direction, undivided arterial roadway).

Left-turn Prohibitions

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

Recommended Network Considerations for Implementing an RLS:

Temporary (work zone or special event)
✓ There are limited alternative routes
Arterial (at-grade, minor or unrestricted access)
<ul style="list-style-type: none"> ✓ There are limited alternative routes with adequate capacity to re-direct traffic flow ✓ There is adequate entrance/exit capability ✓ To ensure emergency vehicle access, passing opportunities should be available in the reverse direction ✓ Consider transit routes (lay-byes and service changes) as a result of RLS ✓ If resulting single lane in reverse direction, also need to consider incident management
Freeway (limited access)
<ul style="list-style-type: none"> ✓ To ensure emergency vehicle access, passing opportunities are necessary (maintain 2 lanes) in the reverse direction ✓ O/D mapping should be considered for entrance/exit locations

On-Street Parking Prohibitions

As with other road-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 traffic movements. 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 manoeuvre in the minor-flow direction. The provision of a minimum of two lanes in the minor flow direction is preferred, to avoid causing frequent blockages and stopped queues on reversible roadways. Thus, traffic has room to manoeuvre around slower merging and diverging traffic.

Another benefit to prohibiting parking is in the area of collision reduction. A study conducted on an early reversible road segment in Michigan showed a significant decrease in all collisions during hours of operation. This result is not unexpected, because many of the “before” collisions were related to conflicts between through traffic 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. A pro-active public engagement process is recommended prior to implementing an RLS.

4.1.3 Risk / Safety Considerations

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. Also, in general, as collisions generally occur infrequently, the sound evaluation of safety performance of reversible lane systems requires a long evaluation periods (at least three years after the implementation of the treatment). No Collision Modification Factors (CMF) have been found in the literature dealing with the safety effect of change in operation of a facility from normal to reversible lane operation.

According to Markovetz et al. (1995), three primary types of collisions are typically associated with reversible operations on arterial roadways and they are all involving either left-turning traffic from or to reversible lanes, or left-turn from lanes immediately adjacent to reversible lanes. Also another study conducted by Bretherton and Elhaj (1996) also showed that left-turn manoeuvres caused the most conflicts. They also found that the most prevalent type of crashes was rear-end collisions by left turners from a through lane. Therefore, number of collisions involving a left-turning vehicle may be a good representative for safety performance of reversible lane systems.

Recommended Risk / Safety Considerations for Implementing an RLS:

Temporary (work zone or special event)
✓ The potential for head-on collisions can be minimized
✓ System design can minimize driver perceptive workload
✓ Pedestrian safety can be accommodated
✓ Satisfactory merge/ diverge transition zones can be designed

(cont'd)

Recommended Risk / Safety Considerations for Implementing an RLS:

(cont'd)

Arterial (at-grade, minor or unrestricted access)

- ✓ There is minimal entering traffic from side streets or from RLS lanes
- ✓ Satisfactory merge/ diverge transition zones can be designed
- ✓ The potential for head-on collisions can be minimized
- ✓ System design can minimize driver perceptive workload
- ✓ Pedestrian safety can be accommodated

Freeway (limited access)

- ✓ If there is no physical barrier, potential for head-on collisions must be minimized (consider speed reduction)
- ✓ System design can minimize driver perceptive workload
- ✓ Satisfactory merge/ diverge transition zones can be designed

Another important safety issue on arterial roadways under reversible lane operation is related to pedestrian safety. According to NCHRP Synthesis 340 (TRB 2004), there have been examples of reversible lane (Charles Street in Baltimore, Maryland) where pedestrians and to certain extent cyclists, made errors in judgement regarding the direction from which the traffic is approaching on reversible lanes. This led to a dangerous situation in terms of road safety. 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. Hence, the number of collisions involving pedestrians may be identified as another safety performance measure of reversible lane systems.

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. Therefore, frequency of head-on collisions could be a proper choice based on which the safety performance of reversible lanes on freeways can be evaluated.

In addition the safety associated with adopting different traffic control devices including signs, signals, pavement markings, barriers (permanent or moveable), traffic cones, gates (automated or swing), and etc. must be closely examined.

4.1.4 Environmental Considerations

Reduction of adverse environmental impacts in terms of air pollution and fuel consumption is one of the motivating factors behind the implementation of reversible lane systems. Environmental effects can be estimated as a junction of travel speeds.

Environmental issues are a concern for most urban areas. Congestion results in vehicles moving at a slower speed, thereby increasing noise and pollution levels. Vehicles moving in a free-flow traffic environment generate much less exhaust emissions, and fuel consumption is minimized. Travelling the same distance, under congested conditions, results in significantly increased pollution levels and fuel consumption. One main premise of RLS is that they can have a favourable impact on air quality and energy savings due to decreased fuel consumption. The actual quantification of these savings should be enhanced to strengthen policy arguments on the basis of environmental criteria. These aspects often make RLS attractive to environmental groups. However, environmental groups may also oppose the implementation of RLS because of increased land usage or expanding vehicle capacity of the roadway.

Recommended Environmental Considerations for Implementing an RLS:

Temporary (work zone or special event)

- ✓ Potential for reduced emissions (quantified through modelling) & energy savings (network analysis should be done, not just corridor)

Arterial (at-grade, minor or unrestricted access)

- ✓ Potential for reduced emissions (quantified through modelling) & energy savings (network analysis should be done, not just corridor)
- ✓ Better use of existing infrastructure
- ✓ Reduced energy resources needed to build extra lanes
- ✓ Delay or eliminate need to take up more land

(cont'd)

Busway lanes typically have a favourable impact on mobility, resulting in air quality improvement, energy savings from decreased fuel consumption, and a reduction in the growth rate of vehicle miles of travel. Truck restrictions or exclusive truck facilities also have potential to improve air quality.

Recommended Environmental Considerations for Implementing an RLS (cont'd):

- | Freeway (limited access) |
|---|
| <ul style="list-style-type: none"> ✓ Potential for reduced emissions (quantified through modelling) & energy savings (network analysis should be done, not just corridor) ✓ Better use of existing infrastructure ✓ Delay or eliminate need to take up more land |

4.1.5 Policy and Societal Considerations

Recommended Policy and Societal Considerations for Implementing an RLS:

- | Temporary (work zone or special event) |
|--|
| <ul style="list-style-type: none"> ✓ Business impact |
| Arterial (at-grade, minor or unrestricted access) |
| <ul style="list-style-type: none"> ✓ Special use vehicles (bus, HOV) ✓ Neighbourhood short-cutting considerations ✓ Business impact ✓ Neighbourhood access ✓ Freight mobility |
| Freeway (limited access) |
| <ul style="list-style-type: none"> ✓ Special use vehicles (bus, HOV) ✓ Quick-clear policies (service vehicle programs) ✓ Freight mobility |

Temporary and Emergency Use Policies

For reversible segments used for temporary or emergency circumstances, road-use policies can be considerably more disruptive and restrictive. In most cases, law enforcement and local transportation personnel jointly prepare plans to control most entry points into the contraflow segments during evacuations. Pre-planning for emergency use of RLS systems will help facilitate the transition to emergency evacuation routes and reduce confusion at access points, where vehicles would be traveling in the “wrong” direction. Because flow reversals for evacuations are done in an emergency situation rather than for driver convenience, many plans restrict route choices.

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 should permit periodic egress opportunities within the intermediate segment, although re-entry into the segment will be permitted for the normal outbound lanes of travel.

Vehicle Type Eligibility Policies

Other policies that impact on the use of reversible facilities are those associated with the eligibility requirements for particular vehicles. These policies assign RLS usage priority to certain vehicle classifications or restrict the RLS usage to others. 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 high occupancy vehicles (HOV). 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 to toll-paying users. Although these policies may limit the total number of users, they may reduce overall congestion and serve as a source of revenue for highway agencies.

Societal Issues

The impact of RLS on local businesses and communities also needs to be taken into consideration. An RLS may have a detrimental impact on businesses along the corridor either through parking restrictions, limitation to freight movements or access to their place of business. Access to local communities can

also be affected through turning restrictions or neighbourhood short-cutting. However, RLS implementation may work to decrease neighbourhood short-cutting by improving the capacity along the primary corridor.

4.1.6 Benefit / Cost Considerations

Reversible lane systems typically can be implemented with minimal capital cost, relative to the cost of adding new lanes would be very high if not impossible. The costs of reversible lane operation are usually measured in terms of operations, safety, environmental impacts, and/or construction, maintenance, and operation. Aside from the aforementioned performance measures that evaluate the number of collisions and travel delays in both directions and their associated monetary costs, there are some other direct costs of construction and periodic maintenance of such systems. There may also be other fixed costs associated with the operation and management of the reversible facility, such as police for concentrated enforcement to prevent violations of lane-use restrictions, maintenance personnel to set up, monitor, and remove traffic control devices, and operational staff to operate and strategically manage the system. Therefore, in assessment of reversible lane systems, construction, maintenance, and operation costs of such systems must be closely evaluated.

The pros and cons of implementing an RLS within a corridor need to be quantified and documented in order to justify the system. While an RLS installation may incur significant start-up implementation costs, the benefits of such a system may far out-weigh those costs. Some jurisdictions in Canada use a “multiple-account” benefit / cost analysis for justification of the system. Generally, the capital and operating costs of the system must be less than the benefits associated with:

- Improved capacity (reduced congestion and travel time);
- Delayed (or eliminated) capital costs of widening the corridor to meet the traffic demands (including the costs of additional right-of-way);
- Reduced neighbourhood short-cutting;
- Improved freight mobility; and
- Improved air quality (through reduced emissions).

Other jurisdictions provide project justification through the development of business case scenarios.

Recommended Benefit / Cost Considerations for Implementing an RLS:

Temporary (work zone or special event)
<ul style="list-style-type: none"> ✓ Work zone constraints ✓ Delay or eliminate need for additional lanes ✓ Benefit / cost (multiple account) analysis (can be quantified through modelling)
Arterial (at-grade, minor or unrestricted access)
<ul style="list-style-type: none"> ✓ Consider developing a business case for RLS ✓ Cost of physical constraints ✓ Delay or eliminate need for additional lanes ✓ Benefit / cost (multiple account) analysis (can be quantified through modelling)
Freeway (limited access)
<ul style="list-style-type: none"> ✓ Consider developing a business case for RLS ✓ Cost of physical constraints ✓ Delay or eliminate need for additional lanes ✓ Benefit / cost (multiple account) analysis (can be quantified through modelling)

4.2 Assessment and Evaluation

Assessment and evaluation of performance is essential to justifying and optimizing reversible lane systems. Review of the literature and current practices showed that there have been some efforts to assess and evaluate the benefits and the costs of reversible roadway operations. However, those documents were largely limited to site-specific evaluation studies, and no common method has been applied. Appendix A provides a brief history of past RLS performance evaluation.

The assessment methods should reflect the reasons behind the implementation. Congestion reduction or improved mobility (along both the reversible facility and its parallel/adjacent routes), enhanced system reliability, improved level of safety, reduction of environmental impacts (in terms of emissions and fuel consumption), transit service improvement, lower construction and maintenance cost, and higher public satisfaction rates are all motivating factors for implementation of reversible lane systems. Also, RLS are unique in a way that they typically require a higher degree of active (sometimes real time) management in order to address some other specific goals (e.g. transit service levels, person throughput, vehicle delay, etc.) that may be inconsistent with the general-purpose road facility. The broad range of these motivating factors and the unique management issues along with the diversity of reversible lane systems in terms of configuration and operation make gauging the success or failure of reversible lane systems a challenging task.

According to NCHRP Synthesis 340 (TRB 2004), the performance benefits of these systems have been fairly consistent over their nearly 80-year history (improved directional capacity of a roadway during various periods of the day). 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 transportation practitioners, elected officials, and the public have viewed these benefits and costs. This section summarizes the assessment and evaluation of reversible roadways, including:

- Performance measures used to evaluate them;
- Different perspective for measuring their performance;
- Techniques used to evaluate them;
- Costs associated with their use;
- Their public acceptance, and
- Use of assessment and evaluation techniques to support decisions to modify, continue, or terminate the system's use.

4.2.1 Appropriate Performance Measures

Identification of appropriate performance measures, definition of proper evaluation techniques, and consequently identification of required data, in order to accurately evaluate attainment of the desired goals and objectives of reversible lane systems are vital to a successful performance monitoring and evaluation program of such systems.

According to Kuhn et al. (2005) the selected measures of performance for such systems should be:

- Limited in number to prevent data collection and analytical requirements from overwhelming an agency's resources or decision makers;
- Simple and understandable with consistent definitions and interpretations to address the needs of a wide-ranging audience, while still achieving the required precision, accuracy, and detail to facilitate system or program improvement;

- Easily captured either automatically using technology or manually with minimal data entry and processing to produce usable results;
- Sensitive to change and able to adequately capture observed changes in system or program performance; and
- Geographically appropriate with decision-making needs, ranging from corridor specific to region-wide, province-wide, or even nation-wide performance standards.

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. Travel time savings and reliability are of primary importance. Although safety and environmental impacts are important factors they are of secondary interest in comparison to mobility-related objectives of reversible lane systems unless the reversible lane was implemented to remedy a particular problem with safety or environment.

4.2.2 Operational Assessment

In general, reversible lane system facilities can be measured and evaluated using standard procedures. The assessment methods used in evaluating a reversible lane system facility should reflect the reasons behind the implementation. Congestion reduction, emissions reduction, transit service improvement, and peak period demand accommodation are all goals that may be desired with each facility. Gauging the success or failure of an RLS should also consider parallel and adjacent routes where the volumes may change dramatically during and after reversible lane system implementation. The presented metrics reflect the appropriate methods for evaluating the success or failure based on the planning reason.

Mobility/Reliability Assessment

Standard evaluations for intersections, road segments and arterials are as valid for RLS facilities as for any facility. The implementation of a reversal does not fundamentally change the expectations for roadway facilities. Therefore the various methodologies, as described in the Highway Capacity Manual (HCM) (TRB 2000) and the Canadian Capacity Guide (CCG) (ITE 2007), for example, are still valid for use by controlling jurisdictions.

In general, in terms of operation, reversible lane systems achieve increased level of passenger throughput and travel speeds. Therefore, it is not surprising that according to NCHRP Synthesis 340 (TRB 2004), 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, and overall segment level of service. Mobility measures should be based on travel time, or other similar derivatives of speed and delay as they are easily communicated by practitioners and understood by the public. The following metrics reflect the appropriate methods for evaluating reversible lane systems, mobility and efficiency.

Capacity

Capacity measurement for a reversible lane system should be based on a directional basis. Both the primary and secondary direction of travel should be quantified. The secondary direction will have reduced capacity due to the reversal so it is critical to evaluate both directions. Directional throughput

Assessment & Evaluation Issues:	
Temporary (work zone or special event)	<ul style="list-style-type: none"> ✓ Rarely done
Arterial (at-grade, minor or unrestricted access)	<ul style="list-style-type: none"> ✓ Before & after analysis (volume, speed, travel time, collisions, queue length, level of service LOS) ✓ Upstream / downstream effect of RLS ✓ Reliability assessment ✓ Effect of RLS on modal shift
Freeway (limited access)	<ul style="list-style-type: none"> ✓ Before & after analysis (volume, speed, travel time, collisions, queue length, level of service LOS) ✓ Upstream / downstream effect of RLS ✓ Reliability assessment ✓ Effect of RLS on modal shift

(peak hour flow or event flow) is typically the reason for implementing a reversible lane system. Therefore, the evaluation should be based on the total throughput rather than on a lane-by-lane basis.

Reversible lane systems have unique operational requirements. Since they are typically in locations where linear throughput is of priority, limiting or eliminating turning movements may be highly desirable. Junctions with left turn demands can effectively eliminate any throughput gained by implementing the reversal. Therefore, there must be a thoughtful analysis regarding the turns that will be permitted in the facility. Bridges and other access controlled facilities are not impacted by turns but these issues remain at the terminus of the lane reversal.

Simple lane capacity evaluation can be used for commuter routes with limited transit service. In general, a reversible lane system must provide more directional capacity than the standard configuration. Fundamental transportation theory explains that the addition of lanes does not have a linear relationship to increasing capacity. Similarly, the elimination of lanes in the secondary direction can have a significant impact on capacity.

Level of Service (LOS)

Standard intersection evaluations for intersections, road segments and arterials are as valid for RLS facilities as for any facility. The implementation of a reversal does not fundamentally change the expectations for roadway facilities. Therefore, the various methodologies (e.g. Highway Capacity Manual, Canadian Capacity Guide, etc.) are still valid.

Level of service analysis is best applied to the merge/diverge points and entry/exit points of a reversible lane system facility. These critical junctions include the beginning and end of the facility as well as intersections where turns are permitted. Level of service is an absolute value and should not be averaged across the facility. For example, on an arterial roadway with a peak hour reversal, there may be a series of intersections that would theoretically be operating at LOS A or LOS B but the terminus of the reversal is operating at LOS E. The overall level of service should be considered to be LOS E rather than an averaged LOS C.

Weaving between lanes in an RLS will impact operations and affect the total system capacity. The design of the facility should carefully consider the origin-destination matrix of vehicles in the facility. Critical weaving and merging locations should be evaluated during the planning stage.

Travel Time, Speed and Delay

Efficient movement of traffic, including transit vehicles, can be measured by speed and delay. The evaluation of a corridor can be reviewed by assessing the flow of the entire RLS segment. Travel time between key junctions is a useful measure of whether the reversal is truly improving overall flow. By combining travel time data with traffic count data, the total delay for the facility can be calculated.

Impacts on Traffic and Pedestrian Signals

Intersection traffic signal phasing along the RLS corridor is similar, if not identical, to the phasing used whether the RLS is active or not. The changes to signal operations occur with the installation of hardware that indicates which lanes have which permissions. The result is the provision of information to drivers rather than control of the facility. The reversal of traffic lanes should not have an impact on pedestrian movements if all pedestrians use the appropriate crossings. The allotment of crossing time to the Walk and Don't Walk phases are not impacted by the direction of travel. Therefore, there should be limited, if any, changes to the pedestrian crossing schemes to accommodate a reversal.

Transit operations may be impacted if facilities are converted to exclusive one-way facilities. Consideration must be given to transit routing and the location of transit stops. The reversal may increase the complexity of weaving for transit vehicles (dependant upon their origin-destination).

Exceptions for transit vehicles may be considered at location where there are left turn restrictions but this should be avoided if possible.

4.2.3 Public Acceptance, Education and Communication

Assessment of public understanding and acceptance of reversible flow facilities have been conducted since their inception. Although the adoption of uniform traffic control devices and more consistent operating practices help convey a clearer indication of driver actions, anecdotes of initial mixed public opinion turning to favourable views have been fairly consistent over the years. Since reversible lane system implementation has been a relatively uncommon practice, a significant number of drivers are unfamiliar with its operation and management strategies. The result has been a pattern of initial driver confusion and aversion that typically changes to acceptance and enthusiasm. This support typically comes once drivers take advantage of the additional lane capacity, decreased congestion and reduced travel time.

In order to help build public understanding and acceptance, a strategic public education program is recommended, especially for municipalities that are implementing the first RLS within their jurisdiction. To capture public perception data, focus groups, stated preference surveys, or revealed preference surveys can be conducted to better evaluate the level of public satisfaction of reversible lane systems.

4.2.4 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 inter-jurisdictional 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 liveability and sustainability.

4.3 Recommended Guidelines for RLS Planning

The recommended guidelines for RLS planning are summarized as follows:

Planning Considerations for implementing RLS	Temporary (work zone or special event)	Arterial (at-grade, minor or unrestricted access)	Freeway (limited access)
Mobility (congestion-related) considerations	<ul style="list-style-type: none"> ✓ Expected conditions will create unbalanced flows ✓ Queue lengths are expected to be unreasonable in heavy direction ✓ Special event activity 	<ul style="list-style-type: none"> ✓ Actual conditions create unbalanced flow (65/35 split) ✓ Significant queues along corridor ✓ Major flow demand exceeds capacity ✓ Demand is periodic and predictable (high % commuter traffic) ✓ Congestion is typically sustained over a period of time (>60 minutes) during peak hours 	<ul style="list-style-type: none"> ✓ Actual conditions create unbalanced flow (65/35 split) ✓ Speed reductions >25% in peak direction ✓ Demand is periodic and predictable (high % commuter traffic) ✓ Congestion is typically sustained over a period of time (>60 minutes) during peak hours
Traffic / Parking / Pedestrian considerations	<ul style="list-style-type: none"> ✓ Parking restrictions can be implemented to provide additional lane ✓ Incident management should be considered if design results in a single lane operation 	<ul style="list-style-type: none"> ✓ There is a limited left (or right) turn demand along the corridor ✓ Incident management should be considered if design results in a single lane operation ✓ Parking restrictions should be considered to provide for passing opportunities (but may need to provide alternate parking) 	<ul style="list-style-type: none"> ✓ There is an opportunity for using the shoulder as a driving lane (in order to maintain 2 lanes in reverse direction) ✓ Cross-over opportunities exist or can be created ✓ Changes to speed limit (speed advisory) are possible
Network considerations	<ul style="list-style-type: none"> ✓ There are limited alternative routes 	<ul style="list-style-type: none"> ✓ There are limited alternative routes with adequate capacity to re-direct traffic flow ✓ There is adequate entrance/ exit capability ✓ To ensure emergency vehicle access, passing opportunities should be available in the reverse direction ✓ Consider transit routes (lay-byes and service changes) as a result of RLS ✓ If resulting single lane in reverse direction, also need to consider incident management 	<ul style="list-style-type: none"> ✓ To ensure emergency vehicle access, passing opportunities are necessary (maintain 2 lanes) in the reverse direction ✓ O/D mapping should be considered for entrance/exit locations
Risk / Safety considerations	<ul style="list-style-type: none"> ✓ The potential for head-on collisions can be minimized ✓ System design can minimize driver perceptive workload ✓ Pedestrian safety can be accommodated ✓ Satisfactory merge/ diverge transition zones can be designed 	<ul style="list-style-type: none"> ✓ There is minimal entering traffic from side streets or from RLS lanes ✓ Satisfactory merge/ diverge transition zones can be designed ✓ The potential for head-on collisions can be minimized ✓ System design can minimize driver perceptive workload ✓ Pedestrian safety can be accommodated 	<ul style="list-style-type: none"> ✓ If there is no physical barrier, potential for head-on collisions must be minimized (consider speed reduction) ✓ System design can minimize driver perceptive workload ✓ Satisfactory merge/ diverge transition zones can be designed

Planning Considerations for implementing RLS	Temporary (work zone or special event)	Arterial (at-grade, minor or unrestricted access)	Freeway (limited access)
Environmental considerations	<ul style="list-style-type: none"> ✓ Potential for reduced emissions (quantified through modelling) & energy savings (network analysis should be done, not just corridor) 	<ul style="list-style-type: none"> ✓ Potential for reduced emissions (quantified through modelling) & energy savings (network analysis should be done, not just corridor) ✓ Better use of existing infrastructure ✓ Reduced energy resources needed to build extra lanes ✓ Delay or eliminate need to take up more land 	<ul style="list-style-type: none"> ✓ Potential for reduced emissions (quantified through modelling) & energy savings (network analysis should be done, not just corridor) ✓ Better use of existing infrastructure ✓ Delay or eliminate need to take up more land
Policy considerations		<ul style="list-style-type: none"> ✓ Special use vehicles (bus, HOV) ✓ Neighbourhood short-cutting considerations 	<ul style="list-style-type: none"> ✓ Special use vehicles (bus, HOV) ✓ Quick-clear policies (service vehicle programs)
Societal considerations	<ul style="list-style-type: none"> ✓ Business impact 	<ul style="list-style-type: none"> ✓ Business impact ✓ Neighbourhood access ✓ Freight mobility 	<ul style="list-style-type: none"> ✓ Freight mobility
Benefit / Cost considerations	<ul style="list-style-type: none"> ✓ Work zone constraints ✓ Delay or eliminate need for additional lanes ✓ Benefit / cost (multiple account) analysis (can be quantified through modelling) 	<ul style="list-style-type: none"> ✓ Consider developing a business case for RLS ✓ Cost of physical constraints ✓ Delay or eliminate need for additional lanes ✓ Benefit / cost (multiple account) analysis (can be quantified through modelling) 	<ul style="list-style-type: none"> ✓ Consider developing a business case for RLS ✓ Cost of physical constraints ✓ Delay or eliminate need for additional lanes ✓ Benefit / cost (multiple account) analysis (can be quantified through modelling)
Assessment & Evaluation	<ul style="list-style-type: none"> ✓ Rarely done 	<ul style="list-style-type: none"> ✓ Before & after analysis (volume, speed, travel time, collisions, queue length, LOS) ✓ Upstream / downstream effect of RLS ✓ Reliability assessment ✓ Effect of RLS on modal shift 	<ul style="list-style-type: none"> ✓ Before & after analysis (volume, speed, travel time, collisions, queue length, LOS) ✓ Upstream / downstream effect of RLS ✓ Reliability assessment ✓ Effect of RLS on modal shift

5. Design Stage

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 *Geometric Design Guide for Canadian Roads* (GDG) (TAC 1999), MUTCDC (TAC 1998), AASHTO *Green Book* (AASHTO 2001) and other applicable jurisdictional standards. 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.

Recommended Design Considerations for RLS Cross-Sectional Elements:	
Temporary (work zone or special event)	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) (cross section, lane width) ✓ Desirable lane width - 3.7m ✓ Minimum lane width - 3.0m
Arterial (at-grade, minor or unrestricted access)	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) (cross section, lane width, medians) ✓ Desirable lane width - 3.7m ✓ Minimum lane width - 3.2m
Freeway (limited access)	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) (cross section, lane width, shoulders, medians) ✓ Can consider separate guide ways (elevated or in the median) ✓ Need to consider bi-directional designs for guardrails, collision cushions, and breakaway devices and slope grades ✓ Minimum width between barriers - 6.0m

5.1 Geometric Design Considerations

In the following sections, the application of various design standards, philosophies, and criteria for reversible facilities are summarized. Facility related differences (such as those between divided and undivided arterial streets) are presented where relevant.

The design of reversible facilities at the system level also differs philosophically from that of non-reversible roadways. These differences are primarily associated with the need to incorporate transition areas, mid-segment and ramp entry/exit points, and adequate cross-section width. Design and operational guidelines for various types of HOV reversible configurations on controlled and uncontrolled access were proposed by AASHTO (1992). The AASHTO guide also provided design recommendations for median crossovers and cross-section configurations for contraflow lanes on arterial roadways and freeways.

5.1.1 Cross-Sectional Elements

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 features focuses on the need to separate opposing traffic streams, reduce the potential for lane departure, and provide for adequate drainage. They include identifying appropriate width, slope, and surface conditions. 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, collision cushions, and breakaway devices and slope grades on freeways, which are designed for a single direction of

travel, may need to be redesigned for vehicles traveling in both directions. Additional lane width may be required to separate opposing flows with portable traffic control devices such as cones or fixed permanent features such as barriers.

Where right-of-way is severely restricted, construction of two elevated reversible lanes within the existing median area can be considered (such as the Lee Roy Selmon Expressway in Tampa FL). One of the concerns with restricted width cross sections however, is the inability to provide suitable shoulder areas for enforcement 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 current standard (TAC 1999) permits some variation, a standard highway lane width is 3.7 metres. 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 traffic streams. One of the problems of adapting reversible operations to conventional roadways is the need to fit an additional lane(s) into an existing cross-section. Although efforts have been made to maintain 3.7 metre widths, reversible lanes are often created by converting non-through travel areas, such as on-street parking lanes, two-way center left-turn lanes, and limited right-of-way, into additional travel lanes. Doing so often means that lanes are narrower than 3.7 metres; some even as narrow as 3.0 metres.

5.1.2 Horizontal and Vertical Alignment

In general, the horizontal and vertical design features of a reversible roadway are no different from those of a standard roadway. This is mainly because requirements for RLS (e.g., efficient operations, safety sight distance, and drainage) are the same as for conventional roadways.

The most critical issues for an RLS installation are:

- to ensure consideration is given to the sightline calculations for the reverse direction (stopping sight distance, and decision sight distance); and
- to ensure that corner radii and median nose placement is appropriate for RLS operation within each intersection along the RLS corridor.

Recommended Design Considerations for RLS Horizontal Alignment:

Temporary (work zone or special event)

- ✓ Geometric Design Guide for Canadian Roads (1999) (design vehicle, design speed, tapers)
- ✓ Need to examine turning radii with changing lane configurations
- ✓ Need to consider sightline issues

Arterial (at-grade, minor or unrestricted access)

- ✓ Geometric Design Guide for Canadian Roads (1999) (design vehicle, design speed, tapers)
- ✓ Need to examine turning radii with changing lane configurations
- ✓ Need to consider intersection treatments
- ✓ Need to consider sightline issues

Freeway (limited access)

- ✓ Geometric Design Guide for Canadian Roads (1999) (design vehicle, design speed, tapers)
- ✓ Higher speeds emphasize need to maintain TAC standards
- ✓ Need to consider sightline issues

Recommended Design Considerations for RLS Approach, Departure, Buffer and Transition Areas:

Temporary (work zone or special event)

- ✓ Geometric Design Guide for Canadian Roads (1999)- based on speed and road classification (weaving, tapers)
- ✓ MUTCDC (1998) - Temporary conditions – based on speed and road classification

Arterial (at-grade, minor or unrestricted access)

- ✓ Geometric Design Guide for Canadian Roads (1999) – based on speed and road classification (weaving, tapers)
- ✓ MUTCDC (1998) – Temporary conditions – based on speed and road classification
- ✓ Lane drop / merge area capacity

Freeway (limited access)

- ✓ Geometric Design Guide for Canadian Roads (1999) – based on speed and road classification (weaving, tapers)
- ✓ MUTCDC (1998) – Temporary conditions – based on speed and road classification
- ✓ Lane drop / merge area capacity
- ✓ Merge / diverge area - median crossover designs incorporate a transition taper/lane and then an acceleration lane and taper
- ✓ Reduced design speed for crossovers or lane add/drop

5.1.3 Approach, Departure 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, as they can dictate the capacity and quality of service for 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. Inadequate entry termini design which results in restricted vehicle capacity will reduce the overall RLS capacity.

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. In other reversible roadway designs, there is a wide array of configurations and systems, varying from nothing to complex automated gate and arrestor systems.

5.1.4 Intersections and Interchanges

Although transition zones, as well as entry and egress areas for reversible lanes on arterial roadways are usually brought about by the use of only traffic control devices (discussed further in the following chapter), transitions on reversible freeway segments are more complex and require a higher degree of driver guidance, provided through design. For the most part, the design of reversible lane entry-exit points on limited access roadways 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 manoeuvres 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 directly to and from the surface street network.

Recommended Design Considerations for Intersections & Interchanges of an RLS:

Temporary (work zone or special event)

- ✓ Need to consider use of various temporary traffic control accommodations (barriers, cones, signs, signals, pavement markings)

Arterial (at-grade, minor or unrestricted access)

- ✓ Need to consider use of various traffic control devices (signs, signals, pavement markings)

Freeway (limited access)

- ✓ Need to consider various ramp designs to exit to and from the main-line travel lane, or directly to and from the surface street network
- ✓ Need to consider how RLS lanes transition through interchanges

5.1.5 Use of Barriers

Various types of barriers have also been used for reversible lane segments. 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). In addition to reducing transition times by providing a “cascading” transition, the moveable barrier provides positive delineation and a physical separation between opposing traffic flows (Figure 4).



Figure 4: Barrier Transfer Vehicle

(Source: <http://www.flickr.com/photos/scleroplex/370697446/sizes//> - Accessed in November 2008)

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 16km/h and is able to shift barriers across two lanes.

Automated gated systems are also very common in locations where the direction of traffic flow is converted on a more frequent basis, such as twice-daily commuter periods. At these locations, a series of variable length gates restrict entry into the reversible median lanes (Figure 5). An overhead dynamic message sign can also be used to indicate the availability of these lanes. A variant of these gate systems was developed recently for use at interchange ramps where contraflow evacuations are planned (B&B Electromatic Inc. 2003). The contraflow gate 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.



Figure 5: Typical Gate Design, Seattle, WA.

(Source: "High Occupancy Vehicle (HOV) Interactive 1.0" 1996)

Transition point designs of evacuation contraflow sections, 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 adjustable, owing to the need to change 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. 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.

Despite the use of these various gate and barrier systems, experience has shown that they do not always completely 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.

Recommended Design Considerations for Barriers of an RLS:

Temporary (work zone or special event)

- ✓ MUTCDC (1998) - Temporary Conditions
- ✓ Temporary barriers

Arterial (at-grade, minor or unrestricted access)

- ✓ Portable or none

Freeway (limited access)

- ✓ Need to consider barrier to separate opposing traffic
- ✓ Fixed or moveable concrete barriers have been used in different jurisdictions

5.2 Recommended Guidelines for RLS Geometric Design

The recommended guidelines for RLS geometric design are summarized as follows:

Geometric Design Considerations for RLS	Temporary (work zone or special event)	Arterial (at-grade, minor or unrestricted access)	Freeway (limited access)
Cross Section	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) (cross section, lane width) ✓ Desirable lane width - 3.7m ✓ Minimum lane width - 3.0m 	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) (cross section, lane width, medians) ✓ Desirable lane width - 3.7m ✓ Minimum lane width - 3.2m 	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) (cross section, lane width, shoulders, medians) ✓ Can consider separate guide ways (elevated or in the median) ✓ Need to consider bi-directional designs for guardrails, collision cushions, and breakaway devices and slope grades ✓ Minimum width between barriers - 6.0m
Horizontal / Vertical	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) (design vehicle, design speed, tapers) ✓ Need to pay attention to turning radii with changing lane configurations ✓ Need to consider sightline issues 	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) (design vehicle, design speed, tapers) ✓ Need to pay attention to turning radii with changing lane configurations ✓ Need to consider intersection treatments ✓ Need to consider sightline issues 	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) (design vehicle, design speed, tapers) ✓ Higher speeds emphasize need to maintain TAC standards ✓ Need to consider sightline issues
Approach / Departure zones	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999)- based on speed and road classification 	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999)- based on speed and road classification 	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999)- based on speed and road classification
Entry / Exit Transition zones	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) (weaving, tapers) 	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) (weaving, tapers) ✓ Lane drop / merge area capacity 	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) (weaving, tapers) ✓ Merge / diverge area - median crossover designs incorporate a transition taper/lane and then an acceleration lane and taper ✓ Reduced design speed for crossovers or lane add/drop
Buffer zones	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) ✓ MUTCDC (1998) - Temporary conditions – based on speed and road classification 	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) ✓ MUTCDC (1998) - Temporary conditions 	<ul style="list-style-type: none"> ✓ Geometric Design Guide for Canadian Roads (1999) ✓ MUTCDC (1998) - Temporary conditions
Intersection/ Interchanges	<ul style="list-style-type: none"> ✓ Need to consider use of various temporary traffic control accommodations (barriers, cones, signs, signals, pavement markings) 	<ul style="list-style-type: none"> ✓ Need to consider use of various traffic control devices (signs, signals, pavement markings) 	<ul style="list-style-type: none"> ✓ Need to consider various ramp designs to exit to and from the main-line travel lane, or directly to and from the surface street network ✓ Need to consider how RLS lanes transition through interchanges
Barriers	<ul style="list-style-type: none"> ✓ MUTCDC (1998) - Temporary conditions ✓ Temporary barriers 	<ul style="list-style-type: none"> ✓ Portable or none 	<ul style="list-style-type: none"> ✓ Need to consider barrier to separate opposing traffic ✓ Fixed or moveable concrete barriers have been used in different jurisdictions



6. Reversible Lane Systems Operations

6.1 Traffic Control Devices

The predominant means of guiding and controlling traffic moving into, out of, and along 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 MUTCDC 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 MUTCDC follow years of evolutionary trial-and-error development.

6.1.1 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.

Recommended RLS Operational Considerations for Signs:

Temporary (work zone or special event)

- ✓ MUTCDC (1998) - Temporary Conditions
- ✓ Flaggers may be considered
- ✓ Needs to be well-signed to provide clarity to drivers
- ✓ Consider use of portable DMS
- ✓ Typically reduced speeds

Arterial (at-grade, minor or unrestricted access)

- ✓ Needs to be well signed to provide clarity to drivers; both main street and side street signage is recommended
- ✓ Consider use of DMS

Freeway (limited access)

- ✓ MUTCDC (1998)
- ✓ Needs to be well signed to provide clarity to drivers
- ✓ Consider use of DMS

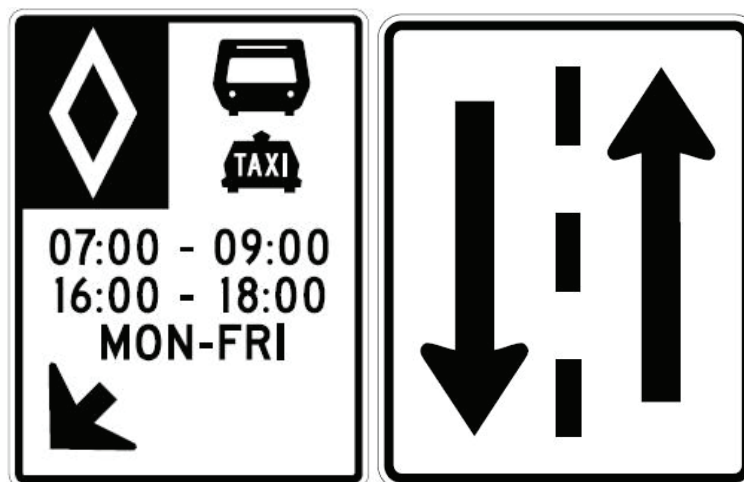


Figure 6: RB-80 (Reserved Lane) and RB 24 (Two-Way Traffic) Sign.

(Source: MUTCDC 4th Edition, Transportation Association of Canada 1998)

There are a number of other signs that have evolved over the years, such as the one shown in Figure 7, to indicate the actual number of lanes in each direction during the associated peak hours. These types of signs are used where the RLS control is “time of day” operation (TOD).



Figure 7: Signs Used on Connecticut Avenue, Washington DC.

(Source: NCHRP Synthesis 340, Transportation Research Board 2004)

6.1.2 Signals

Lane control signals are used to indicate which lanes of a reversible roadway are available (or not available) for use in a particular direction. Lane control signals must feature two types of displays: a downward pointing green arrow, and a red “X”, both on a black background. The red “X” must be capable of both flashing and solid operation. The lenses must be at least 300mm in diameter.

In reversible flow lane applications the face must be visible to both directions of intended travel. The system must not permit simultaneous display of green down arrow to both directions in any lane. All lanes of an RLS should have a lane control signal (or a 900x900mm lane designation sign if that lane does not change) to give positive guidance to the driver.

Four states of operation must be provided for over each reversible lane as shown in Figure 8. The states are as follows:

- **State 1:** A downward pointing green arrow indication is displayed for direction A, and a solid red “X” is displayed for direction B. State 1 must always follow state 4.
- **State 2:** A flashing red “X” is displayed for direction A, and a solid red “X” is displayed for direction B. State 2 is a transition interval that must be used between state 1 and state 3. Consideration should be given to including a solid red “X” in both directions (all red) prior to moving to state 3.
- **State 3:** A solid red “X” is displayed for direction A, and a downward pointing green arrow is displayed for direction B. State 3 must always follow state 2.
- **State 4:** A solid red “X” is displayed for direction A, and a flashing red “X” is displayed for direction B. State 4 is a transition interval that must be used between state 3 and state 1.

In addition to providing those indications, the MUTCDC describes their operation based on the direction of approach and transition requirements. The manual also offers guidance on the horizontal and vertical location of the devices, stating that they must be visible for a distance of 700 m. 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 signals are visible at all times.

The RLS signals must incorporate a conflict monitor process whereby the system and users are protected from conflicting displays.

Recommended RLS Operational Considerations for Signals

Temporary (work zone or special event)

- ✓ Typically implemented without signals (use of signs and pavement markings)

Arterial (at-grade, minor or unrestricted access)

- ✓ Green “down arrow”; flashing red “X”; solid red “X”
- ✓ Where RLS signals are in close proximity to intersection traffic signals, consideration should be given to turning off the green arrow when a red signal is displayed for that approach
- ✓ Typically every 75m or to fit situation (mid-block on closely spaced blocks)
- ✓ Drivers must be able to see at least 2 signal sets at a time
- ✓ Every attempt should be made to position the RLS signals so that they do not conflict with intersection traffic signals (not within ~35 metres)
- ✓ Conflict monitor to protect against conflicting displays

Freeway (limited access)

- ✓ Green “down arrow”; flashing red “X”; solid red “X”
- ✓ Drivers must be able to see at least 2 signal sets at a time
- ✓ Where barrier separation is provided, may only need signals in transition zone
- ✓ Conflict monitor to protect against conflicting displays

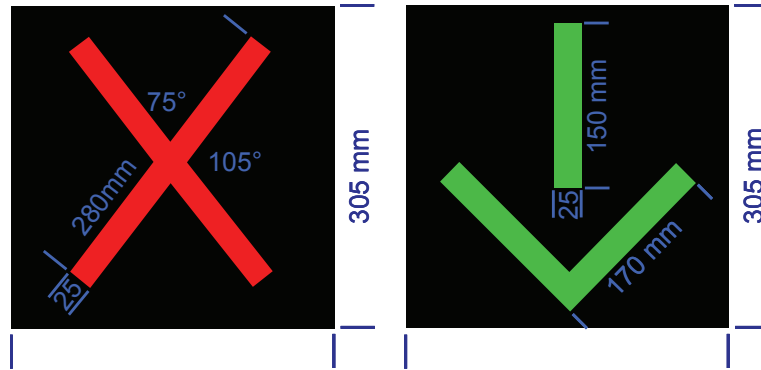


Figure 8: Lane Use Control Signals.

STATE	INDICATION OVER REVERSIBLE LANE DIRECTION B	INDICATION OVER REVERSIBLE LANE DIRECTION A
<p>1. Reversible lane flows in Direction A. Direction B traffic sees a solid red "X" over the reversible lane. Direction A sees a solid green arrow.</p>		
<p>2. Reversible lane enters a transition state. Signal over reversible lane flashes a red "X" for Direction A traffic.</p>		
<p>2a. Signal over reversible lane displays a solid red "X" for both directions.</p>		
<p>3. Reversible lane allows flows in direction B. Green Arrow is displayed over reversible lane for Direction B.</p>		
<p>4. Reversible lane enters a transition state. Signal over reversible lane flashes a red "X" for Direction B traffic. Signal would then display solid red "X" as in state 2a, before reverting to State 1.</p>		

Figure 9: Lane Use Control Signals Transition States

6.1.3 Pavement Markings

In a reversible lane system, pavement markings are used to guide traffic into and out of the reversible lane. Pavement markings for arterial and freeway RLS are typically permanent markings. For temporary construction zones, paint markings are used.

In general, the design of the pavement markings should comply with provincial design standards, the MUTCDC, and other appropriate published standards. Double yellow broken lines should be used to delineate the directional dividing line for traffic flow at different times of the lane reversal.

Markings for reversible lanes should be as per the MUTCDC (1998) recommendation of double yellow broken markings: 3.0m long with a 6.0m longitudinal gap; 100mm to 150mm width separated laterally by a 100mm to 150mm gap.

Recommended RLS Operational Considerations for Pavement Markings:

Temporary (work zone or special event)

- ✓ MUTCDC (1998)- C.2.7.1- broken double yellow line dividing directional flows for different times of day

Arterial (at-grade, minor or unrestricted access)

- ✓ MUTCDC (1998)- C.2.7.1- broken double yellow line dividing directional flows for different times of day

Freeway (limited access)

- ✓ Physical separation is preferred over lane markings to separate directional flows in freeway reversible lanes
- ✓ Where physical separation is impractical, speed restrictions should be considered where used in conjunction with broken double yellow dividing lines as per MUTCDC (1998) - C.2.7.1

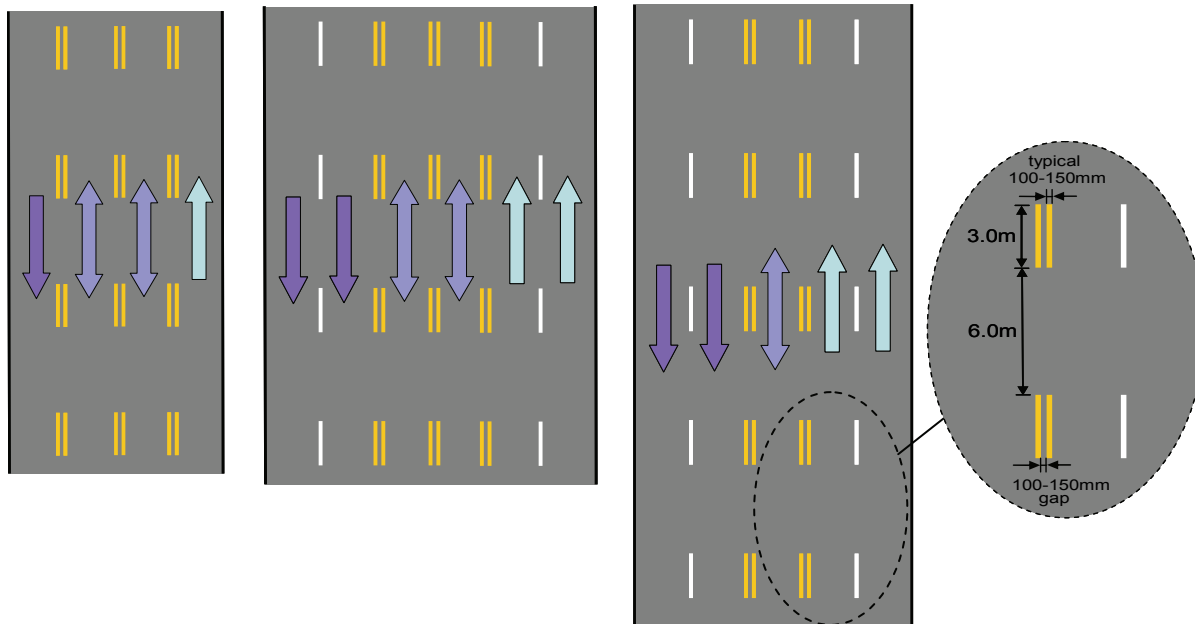


Figure 10: Typical Pavement Markings for Reversible Centre Lane

6.1.4 Other Devices

Other reversible lane traffic control devices include automated barrier gate and swing gates at the terminal areas, traffic cameras, vehicle detectors, permanent and movable barriers, dynamic message signs (DMS); changeable lane designation signs and temporary traffic cones and tubular markers.

Automated gates and swing gates should be employed to notify drivers that the reversible lane is closed on the highway in that particular direction. Gates could be used with permanent reversible lane systems. For safety reasons, the height of the gate arm should not exceed 760 mm in order to avoid damaging a vehicle's windshield if it hits the gate.

CCTV cameras may be used to confirm status of other reversible lane traffic control devices, traffic on the reversible lane, and any incident that may occur. Vehicle detectors may be used throughout the reversible lane system allow for monitoring of traffic on the RLS. Any type of vehicle detectors can be applied to permanent reversible lane systems and video detectors or other portable devices may be used in temporary applications.

Dynamic message signs (DMS) may be used to indicate the operational status of a reversible lane. This could indicate the direction of travel or other information such as restricted use of the RLS or hours of operations.

Permanent and/or movable barriers may be applied to guide traffic flow in the reversible lane in a freeway/expressway RLS. Traffic cones and tubular markers would help channelize lanes on short-term and temporary reversible lane systems.

Recommended RLS Operational Considerations for Other Traffic Control Devices:

Temporary (work zone or special event)

- ✓ MUTCDC (1998) - Temporary conditions
- ✓ Portable DMS should be considered in approach and transition zones to provide additional driver information
- ✓ Traffic cones / barrels
- ✓ Temporary barriers/barricades

Arterial (at-grade, minor or unrestricted access)

- ✓ Retractable gates may be considered where physical delineation is preferred
- ✓ Changeable lane designation signs may help to provide additional clarity to drivers at intersections
- ✓ DMS should be considered in approach and transition zones to provide additional driver information
- ✓ "Tri-state" guide signs may be considered on the approaches to the RLS to provide better driver comprehension

Freeway (limited access)

- ✓ Movable barriers may be considered in some freeway/ bridge applications
- ✓ Retractable gates may be considered where automation is a priority
- ✓ DMS should be considered in approach and transition zones to provide additional driver information
- ✓ "Tri-state" guide signs may be considered on the approaches to the RLS to provide better driver comprehension
- ✓ In-pavement LED markers may be considered to enhance the pavement markings

Recommended Operational Considerations for Detection in an RLS:

- Temporary (work zone or special event)**
- ✓ Typically none
 - ✓ CCTV occasionally used for monitoring large construction zones

- Arterial (at-grade, minor or unrestricted access)**
- ✓ Should be used where automation is preferred (volume, speed density)
 - ✓ Should also be considered for arterial incident management applications
 - ✓ Video or loops
 - ✓ CCTV also used for monitoring
 - ✓ Automated incident detection to reduce staffing resource needs
 - ✓ Detection zone generally located mid block in the RLS zone

- Freeway (limited access)**
- ✓ Should be used where automation is a priority (volume, speed density)
 - ✓ Should also be used for freeway/ bridge/ tunnel incident management applications
 - ✓ Video or loops
 - ✓ CCTV also used for monitoring
 - ✓ Automated incident detection to reduce staffing resource needs
 - ✓ Detection zone generally between interchanges or every 500 m

6.2 System Detection

System detectors can be used for many purposes in an RLS application. They can collect information to be used for monitoring traffic volumes, speed and traffic density at various points along the corridor. This information, can then be used to trigger the RLS operation based on pre-determined thresholds, or it can be used for incident management purposes to trigger appropriate response to the incident.

Most temporary work zones do not use system detectors, but use on-site personnel to make changes to the RLS operation. However, on major construction projects, detectors are sometimes used to provide more responsive changes in the RLS operation.

6.2.1 Detection Devices

Detection devices can be the traditional inductive loop detectors, micro-wave detectors or video detectors. The selection is dependant on the comfort level of the local jurisdiction to be able to install and maintain the devices. In addition to the detectors for RLS operations, CCTV camera may also be used to provide a video link and incident management.

6.2.2 Detection Zones

In arterial RLS installations, detection zones are typically mid-block where they can best monitor traffic speed and density (least affected by upstream or downstream intersections). They should be located in each lane separately to help identify individual lane flows and incidents.

In freeway situations, detection zones are normally set between interchanges, but not more than approximately 500 metres apart. They should also be located in each lane separately to help identify individual lane flows and incidents.

6.3 Reversible Lane System Management

Reversible lane systems need to be planned, designed and operated as a managed lane system. There are components of the system that are standard traffic control devices noted above, and there are more specialized components that are utilized in specific situations to provide information and guidance to the driver. Intelligent transportation systems (ITS) can be utilized in order to improve efficiency and performance of reversible lanes in an urban area by using technology to engage changeable message signs and to automate the reversal process. The RLS can be monitored and controlled within the local traffic management centre (TMC) to provide overall management of the system.

Recommended RLS Operational Considerations for Management & Operations:

Temporary (work zone or special event)
<ul style="list-style-type: none"> ✓ Typically none; ✓ Occasionally TMC
Arterial (at-grade, minor or unrestricted access)
<ul style="list-style-type: none"> ✓ TMC ✓ Traffic control operators
Freeway (limited access)
<ul style="list-style-type: none"> ✓ TMC ✓ Traffic control operators

6.3.1 ITS Architecture for Canada

The ITS architecture for Canada provides a unified framework for integration of different ITS components in a system. Each technology bundle contains a number of services that describe what ITS can do from a user's perspective. For example, one of the services under traffic management bundle is travel demand management which in turn consists of three sub services: (1) high occupancy vehicle lane management, (2) reversible lane management, and (3) predictive demand management. Figure 9 illustrates the same example in a hierarchy diagram.

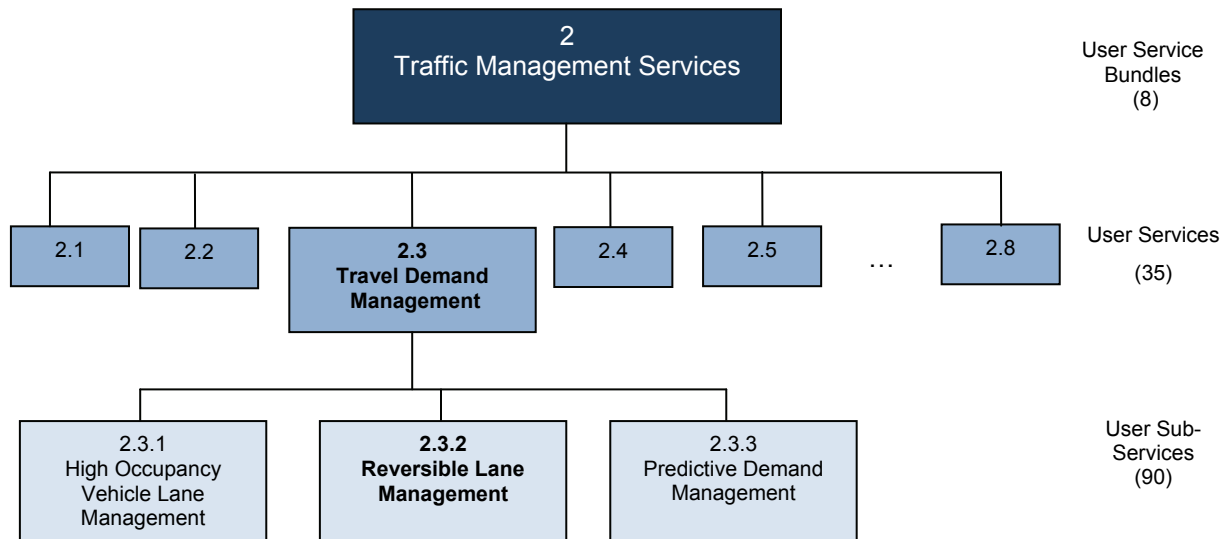


Figure 11: User Service Hierarchy

The reversible lane management is one sub-service within the travel demand management user service group. It provides for the management of reversible lane facilities, including: surveillance capabilities; sensory functions to detect wrong-way vehicles and other special surveillance capabilities that mitigate

safety hazards associated with reversible lanes. The user sub-service includes the field equipment, physical lane access controls, and associated control electronics that manage and control these special lanes. This user sub-service also includes the equipment used to electronically reconfigure intersections and manage right-of-way to address dynamic demand changes and special events.

The reversible lane subsystem includes the equipment distributed on and along the roadway which monitors and controls traffic. Equipment includes highway advisory radio, dynamic message signs, cellular call boxes, CCTV cameras and video image processing systems for incident detection and verification, vehicle detectors, traffic signals, grade crossing warning systems, and freeway ramp metering systems. It provides support for smart work zone deployments through support of portable monitoring and control devices, as well as the capability to have one roadside device (such as a sensor and local processor) control the outputs of another roadside device (such as a portable dynamic message sign). This subsystem also provides the capability for emissions and environmental condition monitoring including weather sensors, pavement icing sensors, fog etc.

6.3.2 RLS Central Control System

A control system can allow centralized operation and control of a reversible lane system. Using a centralized control system, the operators can monitor conditions within the reversible lane system, confirm safe conditions for counter-flow operation, and allow for operator intervention.



Figure 12 - RLS Central Control System, Vancouver, B.C.

(Courtesy of British Columbia Ministry of Transportation and Infrastructure 2009)

Typically, such a system would be located at the traffic management centre, and would consist of

- server
- software interface
- surveillance feeds from live cameras

Software interface for the control system allows for an operator to control the reversible lane system from a centralized operations centre.

Primary software interface features include:

- real time status of field devices and lane states;
- live camera surveillance feed;
- alarms to indicate incorrect operation of field devices; and
- control of devices, allowing manual override or alternate programming

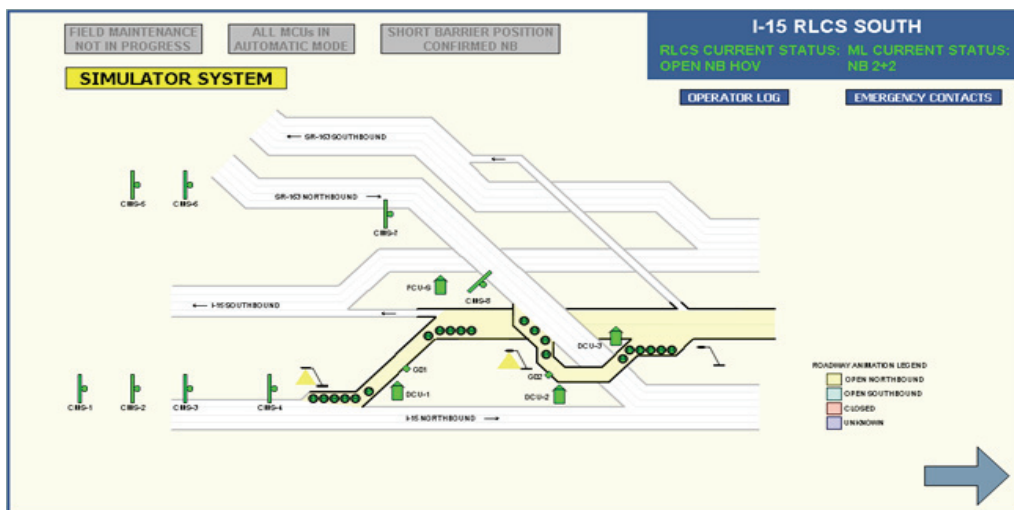


Figure 13 Example of RLS Software Interface, I-15 RLCS, Caltrans D11, San Diego
(Courtesy of ICx360 Surveillance)

The primary purpose of the software is to automate the task of changing the state of field devices, and particularly to confirm that the correct conditions exist before allowing the lane reversal to be implemented. Upon activation of the lane reversal, the software should ask for operator authorization to proceed. During the transition stage, the operator may be asked to visually confirm that traffic has cleared the reversible lane before releasing the contraflow traffic.

The control system should allow the operator to manually override the system; either to initiate an unscheduled lane reversal, or to cancel a lane reversal event.

The RLS central system is used to collect any data, and log incidents such as lane reversal implementation times, incident detection events, and alarms. The control system software should allow for efficient records management of all such events.

The central system should assist in system diagnostics. Alarms should be generated when malfunctions are detected, and for incorrect operation of field devices. The software interface should require that the operator acknowledge the alarm, and correct the problem in the field if required.

An uninterruptible power supply (UPS) is recommended to allow for continuation of RLS management in the event of a temporary power outage.

6.3.3 Incident Management

Much has been documented regarding traffic incident management for general purpose lanes on controlled access highways. Incident management for general purpose lanes and for managed lanes, share many of the same goals; consequently many of the techniques, policies, and procedures are the same for facilities of both categories.

Among the various principles for incident management for general purpose facilities, perhaps the most important is the development, and maintenance, of relationships between key individuals from each of the participating agencies. While it may not be uncommon for the heads of agencies (e.g., law enforcement, local and provincial transportation departments, transit agency, etc.) to meet periodically during the normal course of events, this type of interaction cannot take the place of familiarity and healthy working relationships among operations staff members from these and other critical agencies.

In addition to working relationships, another characteristic of successful incident management programs is the use of various types of agreements, including mutual aid agreements, hold-harmless agreements, wreckage clearance policies, etc.

These and various other elements of incident management programs are common to successfully minimizing non-recurring congestion due to freeway incidents in general purpose lanes. These elements are also common to incident management programs for managed lanes facilities.

The incident response team roles (e.g., police, fire, emergency medical services, traffic operations, etc.) for the managed lanes team are usually filled by the same agencies as for the general-purpose lanes. Multi-agency cooperation is a necessity for effective incident management, and agreements should include mutual aid, and hold-harmless clauses, quick clearance and, abandoned vehicle policies, as well as post-incident briefings and shared information.

Communications to the public regarding the clearance of an incident in the managed lanes should be delivered quickly, just as with messages regarding the beginning of the incident. Incident management for managed lanes should include coordinating statements to the media through a designated incident response team member (e.g., provincial department of transportation public information officer). Depending on the specific financial details of a managed lanes facility, it may be that the cost of pre-positioning tow trucks, or other response vehicles, is offset by the more rapid response to an incident. The consideration of deploying pre-positioned tow trucks is an issue of travel time reliability and the resultant beneficial impact on toll revenues.

Recommended Operational Considerations for Managing Incidents in an RLS:

Temporary (work zone or special event)

- ✓ Site engineer
- ✓ Occasionally TMC

Arterial (at-grade, minor or unrestricted access)

- ✓ TMC with support from emergency services/agencies (fire, police, emergency medical response) and tow truck operators

Freeway (limited access)

- ✓ TMC with support from emergency services/agencies (fire, police, emergency medical response) and tow truck operators

When incident response teams arrive at a scene where one lane incident is sufficiently severe, it may require that a second lane be closed to create a safe work area in which the team can manoeuvre. How this is handled depends on where the incident occurs and the design of the managed lanes facility.

Where managed lanes are separated from general purpose lanes by a barrier, access to an incident, when congestion levels are high and speeds are slow, can be achieved via traveling on the shoulders, if the shoulder is not being used as a travel lane. Where the best route to an incident scene is via the lanes on the opposite side of the barrier from the incident, emergency response vehicles can benefit from the use of emergency access points in the barrier.

A diversion plan should be developed by all the responsive or responding parties, including all the agencies on the incident response team. Typically this team may include personnel from the transportation department, law enforcement, transit authority, incident response team, fire department, hazardous materials team, freeway service patrols, emergency medical services (EMS), local government traffic engineering, towing companies, medical examiner, the designated agency's public information office, etc.

6.3.4 Thresholds for Reversing Lanes

There are three primary options for determining when an RLS is activated:

- Manual activation
- Time of day (TOD)
- Automated activation

Manual activation involves operator judgement, and is often used for work zones, special events, or emergency operations. This may involve physically placing barriers, and signs such as in a construction work zone, or remote activation of an RLS system from a traffic management centre.

Most reversible lane systems in Canada are activated based on time of day (TOD). In the planning stages of an RLS, the appropriate time periods for RLS implementation should be determined based on analysis of typical traffic volume patterns. Typically, RLS implementation corresponds to AM and PM peak hours of traffic. With a TOD operation, driver acceptance of RLS conditions may be improved since they know the reversible lane system will be implemented consistently at specific times of day, and will be able to plan their travel route accordingly.

An RLS may also be activated automatically, based on traffic data such as volume/capacity ratio, queue length, or operating speed.

Recommended RLS Threshold for Changing Lanes:

Temporary (work zone or special event)

- ✓ Manually done (TOD)
- ✓ Manually done (construction staging)

Arterial (at-grade, minor or unrestricted access)

- ✓ TOD
- ✓ Automated based on v/c or queue length

Freeway (limited access)

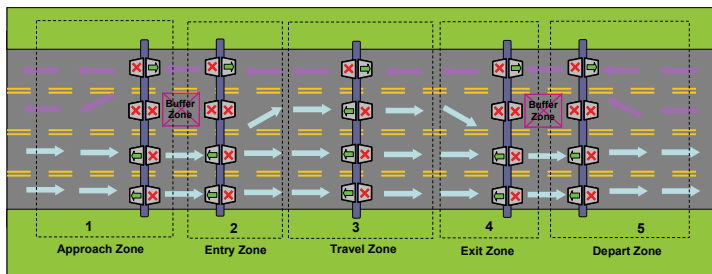
- ✓ TOD
- ✓ Automated based on v/c or operating speed

6.3.5 Transition Times for Reversing Flow

A transition time between directions of traffic flow is generally required to allow the normal traffic flow to clear the reversible lane before the contraflow traffic is released.

In temporary work zones, special events, and emergency operations, this can often be done visually by crews or operators. Sometimes, a pilot vehicle is used to control flow into the reversible lane, under coordination with road crews or operators.

In an urban arterial setting, transition time may be based on a distance speed calculation. One such example of this calculation is as follows; the sum of the length of the entry zone, travel zone, and exit zone (see below) is divided by the speed limit, and the longest signal cycle time (if applicable) along the RLS route is added. Some jurisdictions use a fixed time interval to allow for clearance, followed by visual confirmation that vehicles have cleared the travel zone.



For a freeway RLS, the transition time is calculated as the sum of the length of the entry zone, travel zone, and exit zone (see Section 2.2), divided by the speed limit, adding perception-reaction(PR) time and a safety factor.

Recommended Transition Times for Changing Flows in an RLS:

Temporary (work zone or special event)

- ✓ Manually done
- ✓ Sometimes pilot vehicle

Arterial (at-grade, minor or unrestricted access)

Consider a transition time based on one of the following:

- ✓ (RLS zone 2 + 3 + 4 divided by speed limit) + longest signal cycle time
- ✓ Fixed time interval, followed by a visual confirmation of lane clearance
- ✓ Distance / speed calculation

Freeway (limited access)

- ✓ (RLS zone 2 + 3 + 4 divided by speed limit) + PR time + safety factor

Recommended Operational Considerations for Transit Operations in an RLS:

Arterial (at-grade, minor or unrestricted access)

- ✓ Where transit priority (green extension, early return to green) is in operation, the RLS should not have any negative impact on transit operations
- ✓ The treatment of transit stops within an RLS should be taken into consideration

6.4 Transit Operations

Transit operations may be impacted if facilities are operated as reversible lane facilities and particularly if they are converted to exclusive one-way facilities. Consideration must be given to transit routing and the location of transit stops. A pull-off must be provided for transit stops on a single lane.

The reversal may increase the complexity of weaving for transit vehicles (dependant upon their origin-destination). Transit travel time may be served as a transit related measure of performance for reversible lane systems.

6.5 Monitoring and Enforcement Considerations

An RLS facility requires effective enforcement policies and programs to operate successfully. Visible and effective enforcement promotes fairness and maintains the integrity of the RLS lanes facility to help gain acceptance among users and nonusers.

Successful enforcement of RLS lanes requires appropriate application of available resources. Various enforcement strategies exist concerning the amount of enforcement required to ensure that the RLS maintains the efficiency and safety it was designed for. This ranges from continuous enforcement to the simpler process of self-enforcement. A review of the various enforcement practices across the country indicates that there are multiple variations for the enforcement of RLS lanes with varying levels of success.

Planning for enforcement of RLS lanes is tied to the goals and objectives of the individual project, which determines the operating strategy and user groups. Once an operating strategy for the lanes is defined (i.e., type of RLS lanes facility, allowable user groups, designated access points by user group, etc.), the agencies involved in developing the project can determine what characteristics determine compliance. Enforcement and operations of an RLS facility are intertwined. The role of an RLS enforcement program is to ensure that operating requirements are maintained to protect travel time savings, discourage unauthorized vehicles, and maintain a safe operating environment. Visible and effective enforcement maintains the integrity of the facility and can promote public acceptance.

Traditional enforcement on RLS lanes requires the specific design treatment known as dedicated enforcement areas. These areas are usually located immediately adjacent to the managed lanes facility and allow enforcement personnel to monitor the facility, pursue and apprehend violators to issue appropriate citations.

The role of technology for RLS lanes enforcement is growing at an ever increasing rate. For many years, intelligent transportation system (ITS) technologies have been available for use in monitoring roadways as part of various traffic demand management (TDM) programs. Early detection and quick response times have been vital for incident management and effective use of emergency services. Such advances are the precursor for the use of technology in monitoring and providing enforcement of managed lanes facilities.

The ongoing monitoring of system performance measures will help to justify the system in the long term, and also help to identify when changes are required. If the RLS is a fixed time system based on morning and afternoon weekday peak hours, then ongoing traffic flow monitoring will help identify when the system needs to start and stop. Typical performance measures include:

- 15 minute directional traffic flow counts;
- Peak hour directional level of service; and
- Peak hour directional vehicle (person) delay.

Recommended Operational Considerations for Monitoring and Enforcement of an RLS:

Temporary (work zone or special event)

- ✓ Typically none;
- ✓ Occasionally TMC (smart work zones)

Arterial (at-grade, minor or unrestricted access)

- ✓ TMC

Freeway (limited access)

- ✓ TMC

6.6 Recommended Guidelines for RLS Operational Design

Recommended guidelines for RLS operational design are summarized as follows:

Operational Design Considerations for RLS	Temporary (work zone or special event)	Arterial (at-grade, minor or unrestricted access)	Freeway (limited access)
RLS Signs	<ul style="list-style-type: none"> ✓ MUTCDC (1998) – Temporary conditions ✓ Flaggers should be considered ✓ Needs to be well-signed to provide clarity to drivers ✓ Consider use of portable DMS ✓ Typically reduced speeds 	<ul style="list-style-type: none"> ✓ MUTCDC (1998) ✓ Needs to be well-signed to provide clarity to drivers ✓ Consider use of DMS 	<ul style="list-style-type: none"> ✓ MUTCDC (1998) ✓ Needs to be well-signed to provide clarity to drivers ✓ Consider use of DMS
RLS Signals	<ul style="list-style-type: none"> ✓ Typically implemented without signals (just use of signs and pavement markings) 	<ul style="list-style-type: none"> ✓ Green “down arrow”; flashing red “X”; solid red “X” ✓ Where RLS signals are in close proximity to intersection traffic signals, consideration should be given to turning off the green arrow when a red signal is displayed for that approach 	<ul style="list-style-type: none"> ✓ Green “down arrow”; flashing red “X”; solid red “X”
RLS Signal Spacing		<ul style="list-style-type: none"> ✓ Typically every 75m or to fit situation (mid-block on closely spaced blocks) ✓ Drivers must be able to see at least 2 signal sets at a time ✓ Every attempt should be made to position the RLS signals so that they do not conflict with intersection traffic signals (not within ~35 metres) 	<ul style="list-style-type: none"> ✓ Drivers must be able to see at least 2 signal sets at a time ✓ Where barrier separation, may only need signals in transition zone
Pavement Markings	<ul style="list-style-type: none"> ✓ MUTCDC (1998) [C.2.7.1] - broken double yellow line dividing directional flows for different times of day 	<ul style="list-style-type: none"> ✓ MUTCDC (1998) [C.2.7.1] - broken double yellow line dividing directional flows for different times of day 	<ul style="list-style-type: none"> ✓ Physical separation is preferred over lane markings to separate directional flows in freeway reversible lanes ✓ Where physical separation is impractical, speed restrictions should be considered where used in conjunction with broken double yellow dividing lines as per MUTCDC (1998) [C.2.7.1]
Other TC Devices	<ul style="list-style-type: none"> ✓ MUTCDC (1998) - Temporary conditions ✓ Portable DMS should be considered in approach and transition zones to provide additional driver information ✓ Traffic cones / barrels ✓ Temporary barriers 	<ul style="list-style-type: none"> ✓ Retractable gates can be considered where physical delineation is preferred ✓ Changeable lane designation signs may help to provide additional clarity to drivers at intersections ✓ DMS should be considered in approach and transition zones to provide additional driver information ✓ “Tri-state” guide signs may be considered on the approaches to the RLS to provide better driver comprehension 	<ul style="list-style-type: none"> ✓ Movable barriers can be considered in some freeway/ bridge applications ✓ Retractable gates can be considered where automation is a priority ✓ DMS should be considered in approach and transition zones to provide additional driver information ✓ “Tri-state” guide signs may be considered on the approaches to the RLS to provide better driver comprehension ✓ In-pavement LED markers may be considered to enhance the pavement markings

Operational Design Considerations for RLS	Temporary (work zone or special event)	Arterial (at-grade, minor or unrestricted access)	Freeway (limited access)
Detection Devices	<ul style="list-style-type: none"> ✓ Typically none ✓ CCTV occasionally used for monitoring large construction zones 	<ul style="list-style-type: none"> ✓ Should be used where automation is preferred (volume, speed density) ✓ Should also be considered for arterial incident management applications ✓ Video or loops ✓ CCTV also used for monitoring ✓ Automated incident detection to reduce staffing resource needs 	<ul style="list-style-type: none"> ✓ Should be used where automation is a priority (volume, speed density) ✓ Should also be used for freeway/ bridge/ tunnel incident management applications ✓ Video or loops ✓ CCTV also used for monitoring ✓ Automated incident detection to reduce staffing resource needs
Detection Zones	<ul style="list-style-type: none"> ✓ Typically none 	<ul style="list-style-type: none"> ✓ Mid block in the RLS zone 	<ul style="list-style-type: none"> ✓ Between interchanges or every 500 m
System communications	<ul style="list-style-type: none"> ✓ Typically none; ✓ Occasionally wireless has been used for monitoring purposes 	<ul style="list-style-type: none"> ✓ Copper or fibre to TMC is preferred ✓ Wireless may be used as a redundant system, but is not recommended as a primary means of communications 	<ul style="list-style-type: none"> ✓ Copper or fibre to TMC is preferred ✓ Wireless may be used as a redundant system, but is not recommended as a primary means of communications
RLS Management	<ul style="list-style-type: none"> ✓ Typically none; ✓ Occasionally TMC 	<ul style="list-style-type: none"> ✓ TMC 	<ul style="list-style-type: none"> ✓ TMC
Incident Management, Monitoring & Enforcement	<ul style="list-style-type: none"> ✓ Site engineer ✓ Occasionally TMC 	<ul style="list-style-type: none"> ✓ TMC with support from EMS and tow truck operators 	<ul style="list-style-type: none"> ✓ TMC with support from EMS and tow truck operators
Thresholds for changing RLS lanes	<ul style="list-style-type: none"> ✓ Manually done (TOD) ✓ Manually done (construction staging) 	<ul style="list-style-type: none"> ✓ TOD ✓ Automated based on v/c or queue length 	<ul style="list-style-type: none"> ✓ TOD ✓ Automated based on v/c or operating speed
Transition times to change RLS lanes	<ul style="list-style-type: none"> ✓ Manually done ✓ Sometimes pilot vehicle 	<p>Consider a transition time based on one of the following:</p> <ul style="list-style-type: none"> ✓ (RLS zone 2 + 3 + 4 divided by speed limit) + longest signal cycle time ✓ Fixed time interval, followed by a visual confirmation of lane clearance ✓ Distance / speed calculation 	<ul style="list-style-type: none"> ✓ (RLS zone 2 + 3 + 4 divided by speed limit) + PR time + safety factor
Transit Operations		<ul style="list-style-type: none"> ✓ Where transit priority (green extension, early return to green) is in operation, the RLS should not have any negative impact on transit operations ✓ The treatment of transit stops within an RLS should be taken into consideration 	

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APPENDIX A - Historical Performance Measurement

Despite the concerns with the operations of reversible lane systems, the literature showed relatively few efforts that evaluated performance of reversible segments. 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 collisions.

- The total 3-hour peak period volume, the highest 2-hour period, the highest 1-hour period, and the high 15-min flow during the afternoon and evening peak period travel times were collected at three selected locations along the 1.2 mile segment immediately upstream and downstream of three signalized intersections. The comparison of the results before and after implementation of the reversible lane systems showed that there were 3.5%, 3.4%, 7.1%, and 5.9% increase in total 3-hour peak-period, the highest 2-hour period, the highest 1-hour period, and the high 15-min traffic volumes respectively.
- The comparison of travel time and travel speed also showed improvement over conventional non-reversible operations. The comparison of travel 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%. The comparison travel speeds showed that the average speeds recorded at the three stations within the segment increased by an average of 21.6%.
- Collision frequency dropped by 3.5%, 345 to 335 during the first “after year” period, with a 19% decrease to 279 collisions during the second after year of reversible operation. Although some types of collisions 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 collisions 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 non-use essentially remained unchanged during the study period (TRB 2004).

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 (FHWA 1974 cited in TRB 2004).

Also, on another study done by Kentucky DOT (KDOT) (Agent & Clark, 1980) on a 2.6-mi segment of Nicholasville Road (US-27) in Lexington, Kentucky, it was concluded that reversible operations at that location were a success.

- The KDOT safety study on Nicholasville Road showed no significant increases in collisions 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.
- 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 (TRB 2004).

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

- The study found that drivers appeared to be confused by the overhead signal indications. No significant change has been observed in number of collisions associated with turning movements into the reversible section in comparison to those for a six-lane roadway.
- This study also found that re-striping the convertible lanes from a double yellow 10-ft stripe/30-ft skip to a 10-ft stripe/10-ft skip configuration had little impact on the collision 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”
- Ultimately, the general feeling was that the reversible operation was dangerous and the section of highway would be reconstructed to a divided highway (TRB 2004).

APPENDIX B- Glossary

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. However, tidal facilities are synonymous with reversible roadways as used in Canada and the United States.

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. 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

Off-Centre Operation

“Off-centre” has been used to refer to two different, though related, types of operation. The first, 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.”

Convertible Operations and Facilities

Convertible lanes include those in which traffic operations change on a periodic basis. These operations may include the direction of flow, allowable manoeuvres 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 lanes encompass a variety of operational configurations and strategies. 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.

Reversible Lanes 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.

APPENDIX C - Abbreviations and Acronyms

AASHTO

American Association of State Highway and
Transportation Officials

AHS

Automated Highway System

CBD

Central Business District

CCG

Canadian Capacity Guide of Signalized
Intersections

CMF

Collision Modification Factor

DMS

Dynamic Message Sign

EMS

Emergency Medical Services

FHWA

Federal Highway Administration

HCM

Highway Capacity Manual

HOT

High Occupancy Toll

HOV

High Occupancy Vehicle

ITS

Intelligent Transportation System

LOS

Level of Service

MUTCDC

Manual of Uniform Traffic Control Devices for
Canada

NCHRP

National Cooperative Highway Research Program

RLS

Reversible Lane System

TAC

Transportation Association of Canada

TMD

Traffic Demand Management

TMS

Traffic Management Centre

TOD

Time of Day

UPS

Uninterruptable Power Supply

V/C

Volume Capacity Ratio

VMS

Variable Message Signs