Planning and Operational Practices for Reversible Roadways

REVERSIBLE FLOW IS A TRAFFIC MANAGEMENT TECHNIQUE THAT HAS BEEN USED FOR DECADES TO TEMPORARILY INCREASE THE DIRECTIONAL CAPACITY OF HIGHWAYS AND STREETS WITHOUT REQUIRING THE CONSTRUCTION OF ADDITIONAL LANES. WHEN PROPERLY PLANNED, DESIGNED AND MANAGED, REVERSIBLE LANES AND ROADWAYS CAN YIELD SIGNIFICANT BENEFITS.

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INTRODUCTION

The Institute of Transportation Engineers (ITE) describes the reverse laning of roadways as "potentially one of the most effective methods of increasing rush-hour capacity of existing streets under the proper conditions."[1]

A reversible 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 utility is derived by taking advantage of the unused capacity of the minor flow direction to increase capacity in the major flow direction, negating the need to construct additional lanes.

Reversible roadways most commonly are used for accommodating the directionally imbalanced traffic associated with daily commuter periods. Reversible lanes also have been used regularly in construction work zones, during major events and, more recently, for the evacuation of major metropolitan regions threatened by hurricanes.

The history of reversible lane systems (RLS) dates back more than 75 years and includes applications on all roadway classifications, from local city streets to freeways. Despite the long and diverse history of RLS, it is interesting to note that the practices that guide its application are not nearly as well defined or studied as many other techniques of traffic management.

A review of RLS applications has revealed that the broad, occasionally vague guidelines for reversible roadways actually may be beneficial because they have allowed agencies a wide leeway to apply and adapt practices to fit local roadways.

However, it also is thought that the limited evaluation of the operational and safety benefits and costs of RLS may limit full potential. Some agencies have openly stated their reluctance to implement seemingly unconventional strategies without a quantifiably established record of success.

In recognition of the need for more comprehensive documentation on reversible lane planning, design and management practices, the Transportation Research Board, through National Cooperative Highway Research Program Project 20-5, "Synthesis of Information Related to Highway Problems," sponsored *Synthesis 340—Convertible Roadways and Lanes.*[2]

The goal of the synthesis was to document the historical development of reversible lanes; their application to address various needs; the lessons learned from prior implementation; the costs and benefits associated with their use; and various techniques and successful practices developed over their history.

The synthesis project was conducted over an 18-month period between December 2002 and May 2004 and included a review of more than 50 current and discontinued applications as well as a survey of known and potential users of reversible lanes; prior research and evaluation studies; and informal interviews with representatives of highway agencies that currently use them.

The survey portion of the study was used to gather information on the views of agencies that have used or have contemplated the use of reversible roadways. It included 27 questions focusing on key issues of reversible roadway planning, design, management, control, enforcement and performance assessment and evaluation. The survey questions, along with a complete record of the responses received, can be found in the full synthesis report.[3]

This feature focuses on several key findings of the synthesis and presents an overview of planning, design and control principles that have been developed for reversible lanes as well as many basic guidelines that should be considered by agencies contemplating their use.

The goal of this work is to bring these findings to a wider audience of traffic practitioners for their consideration. It also includes anecdotal information collected from interviews and reviews of scores of field applications, past and present. Several examples are included to illustrate the range of practices and to highlight locally adopted techniques that are particularly effective and/or innovative.

FUNDAMENTALS

The obvious reason for using RLS is to add (or in the case of construction zones, maintain) capacity. It affords the flexibility of changing lane use to fit changing demand patterns and is best suited to routes in which it is not economically practical to add lanes, particularly on bridges and in tunnels. Preferably, capacity gains should be without degrading the operational quality of the opposing direction. This is not always feasible, particularly when full reversals eliminate all opposing traffic lanes.

RLS typically is described using a ratio notation designating of the number lanes flowing in one direction versus the other. For example, a four-lane road used in a conventional 2:2 balanced configuration can be converted to a 3:1 or 4:0 pattern when one or more lanes are reversed.

The most important factor that influences the overall plan of a reversible roadway is its volume characteristics. Ideally, the lane use ratio would match the directional traffic ratio. However, many other factors influence the planning and design of an RLS. These include:

- the cost and the level of complexity and sophistication of traffic control;
- the functional type of roadway on which it is used;
- the purpose and/or intended goals for which it is used; and
- the agency responsible for the planning, design, implementation and management.

Often, these factors are related to one another. For example, urban commuter RLS on freeways is among the most sophisticated and expensive of reversible systems. This is because it frequently requires more robust barrier systems to maintain a safe separation between opposing traffic streams; automated control systems to reduce the demands on field personnel; and greater amounts of traffic control and information to be communicated to drivers.

Many short-term, event-specific RLS applications, particularly those planned and managed by law enforcement agencies, use little more than cones and flares for traffic control and lane separation.

The key spatial elements of a reversible roadway segment include the geometric features such as its overall length, number of lanes and the configuration and length of the inbound and outbound transition. The ways in which these elements are developed within a particular application will be discussed later in more detail.

The primary temporal components of RLS include the frequency and duration of a particular configuration and the time required to transition traffic from one direction to another.

The duration of peak-period commuter RLS applications, for example, typically is about 2 hours (not including set-up, removal and transition time) with a twice-daily frequency. By contrast, an evacuation RLS may be used only once in a decade, although its duration may span a period of days.

REQUIREMENTS AND PRACTICES

Through various resources, organizations such as ITE, the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) have proposed warrant criteria for RLS as well as general practices to help it operate in a positive manner. Although this guidance is relatively consistent in terms of scope and intent, the details are not nearly as specific or consistent as for other long-established forms of traffic management and control.

Although such ambiguity often can cause problems with uniformity of practice, it has been theorized that in the case of reversible roadways, the relatively limited number of established practice standards has allowed many agencies wider latitude to develop and adapt practices to fit specific conditions in local areas.

The following sections summarize some of the established criteria and recommendations for RLS planning, design and management as well several examples of innovative local practices.

Traffic Requirements

The quantity and distribution of traffic volume are the primary parameters for determining the suitability and effectiveness potential of RLS. Reversible operation is best suited to multi-lane roadways in which a directionally unbalanced traffic flow leaves one or more of the minor flow direction lanes underutilized and, in particular, segments with minimal turning and stopping maneuvers.

Prior experience also shows that RLS may be suitable for corridors that suffer from congestion but where, after study, it has been concluded that no other acceptable alternative improvement scenarios exist, including right-of-way limitations that preclude widening an existing facility or constructing a parallel roadway on a separate right-of-way.

Other indicators that suggest a potential significant benefit from reversible operation are traffic congestion patterns that are periodic and predictable, with decreases in average operating speed of at least 25 percent during congested hours, and routes in which adjacent streets do not permit effective parallel one-way operation.

The ratio of directional traffic volumes should be used to allocate the number lanes in each direction as well as to determine the segment length. Generally speaking, a ratio of major to minor traffic volumes of at least 2:1 is recommended, although a ratio of 3:1 is preferable. AASHTO suggests that reversible operations are justified when "65 percent or more of the traffic moves in one direction during peak hours."[4]

Similarly, the *Manual on Uniform Traffic Control Devices* (MUTCD) suggests a "… suitable ratio of directional traffic volumes, with at least 66 to 75 percent in the predominant direction …"[5] Traffic counts should be taken at several locations along the segment to determine the location where additional capacity is no longer needed or where capacity in the minor direction needs to be maintained.

Reversible lanes also are best suited to through routes where intersections and intermediate traffic generators and attractors are minimized, because lane changing and weaving in these areas result in added flow turbulence and friction. Although such maneuvers are a routine feature of conventional roadway operation, the may become more problematic for reversed roadways because drivers entering and exiting from within the segment may be unsure which lanes to enter into or exit from.

A study of a reversible segment of Union Avenue in downtown Memphis, TN, USA, in which mid-segment access points were frequent, showed an increase in the frequency of sideswipe, head-on and angle collisions.[6] These collisions were thought to have resulted from drivers not recognizing active opposing and same-direction travel lanes.

Several agencies have sought to deal with these types of problems by restricting entry turns during periods of reversible operation through the posting of turning lane use signs on approaches of intersecting roads. An example of such a sign on Connecticut Avenue in Washington, DC, USA, is shown in Figure 1. Dual right turn lanes are available during one of the reversal periods.

Representatives from several agencies also have stated that high traffic volumes during reversible operation help minimize crash potential because gap sizes are minimized and the direction of traffic movement in each lane is more obvious to mainline drivers and drivers entering along the segment.

Finally, prior experience strongly suggests the need to maintain a minimum of two lanes in each direction, irrespective of minor-direction flow volume. This is necessary because even at low minor direction volumes, congestion can occur when storage is not provided for turning traffic. The efficiency of single-lane, minor direction operations also can be impacted significantly by the presence of minor incidents and heavy vehicles. The latter has been particularly evident in applications of bus contraflow lanes in urban areas.[7]

TRANSITIONS AND CAPACITY

Adequate terminal capacities also are critical for proper RLS operation. Insufficient entry capacity can prevent a full uti-

Figure 1. Left-turn regulatory sign on Connecticut Avenue in Washington, DC.

lization of the reversed segment. An example of this condition was evident on Interstate 10 near New Orleans, LA, USA, during the September 2004 evacuation for Hurricane Ivan. In that location, a single crossover was used to transition vehicles from the inbound to the outbound lanes.

During the evacuation, the traffic control and police presence at the crossover created a bottleneck resulting in upstream congestion and underutilization of the downstream contraflow lanes, despite the added downstream capacity. This condition was improved significantly less then a year later during the evacuation for Hurricane Katrina—multiple upstream loading points permitted the demand to be spread over a distance of several miles.

Insufficient exit capacity has a similar but opposite effect. Inadequate outflow capacity has the potential to cause congestion within the reversed segment itself. Such conditions are common in lane drop merge configurations that require traffic from the reversed segment to merge into one or fewer lanes at the segment terminus. Although lane drop designs can work when traffic volume decreases sufficiently within the segment, preferable configurations maintain an equivalent number of lanes beyond the terminus or divide traffic into multiple downstream routes.

Transitions also have a temporal component that must be considered. Transition periods occur when traffic is switched from one direction to the other and are necessary to clear the segment and prevent opposing vehicles from conflicting after the conversion. In the simplest applications, the transition needs to minimally include the time required for the last vehicle entering the section to exit. In these applications, the first and last vehicles to enter and exit the segment typically are police or service vehicles, to ensure the full and safe clearance of opposing traffic. In the case of evacuation contraflow, where many segments exceed 100 miles, transition periods may last several hours.

The emergence of more sophisticated signal control systems now permits agencies to shorten transition periods and, in some cases, eliminate the need for physical crossover zones altogether. Two such examples operate in and near Charlotte, NC, USA.

On Tyvola Road, flow conversions are achieved using overhead lane use signals. During the transition period, indications for the modified lane(s) are changed (after a short clearance interval) from green arrows to red Xs in one direction, as shown in Figure 2. In the opposite direction, the signal indication permits drivers to move into adjacent lanes concurrently within different portions of the segment.

Another rapid conversion method observed in construction work zones is the movable barrier. In these applications, a moving vehicle travels at about 15 miles per hour and lifts the median barrier and moves it across a lane. In addition to speed, other advantages of movable barrier systems are that they can be used under traffic and simultaneously open and close opposing lanes of traffic. Movable barrier systems also have been used in permanent reversible installations on bridges and through tunnels.[8,9]

Traffic Control

Traffic control is another key component of RLS. MUTCD contains guidance on the control of reversible roadways, including recommended signs, signals and pavement markings. The review of practice showed, however, many interesting local variations of the MUTCD guidelines. The synthesis survey revealed that, in many cases, local agencies felt that the standard MUTCD control devices were not able to fully communicate relevant information to drivers.

Similar to designs, the level of complexity for RLS traffic control often was found to be a function of the design, functional classification, frequency and type of use. The selection of control devices, especially within transition zones, was related to operating speeds and proximity to opposing traffic. Among the most complex control systems were those used for freeway RLS.

Freeway RLS control systems in use include variable message signs, movable barriers, gates and arrestor mechanisms. Traffic control on low-speed streets is more commonly accomplished using lower cost signs and pavement markings, although on higher volume arterial routes, overhead lane use signalization also has been used. In the case of short-term, temporary, or seasonally used reversals like those for concerts, civic gatherings and sporting events, only minimal traffic control is used. They often involve little more than portable devices like cones and flares in conjunction with traffic police.

The synthesis also revealed the use of many non-standard control devices. Most of these locally developed devices have been adapted from conventional MUTCD designs. For example, for peak period commuter RLS, agencies wanted to include additional information about the hours of reversible operation.

An example observed on Canal Road in Washington, DC, shows the hours of operation and flow direction with an R3-1 DO NOT ENTER sign (see Figure 3). The right photograph shows permitted turning lanes at various times. No significant safety or driver confusion problems have been identified with these signs, but some observers consider them difficult to read, particularly at posted operating speeds.

Another innovative device was observed in Washington, DC, where Connecticut Avenue is converted from a 2:2 balanced operation with on-street parking to a 4:2 reversible operation (without parking) during commute hours. Lane availability, parking restrictions and hours of operation are shown on roadside signs. Diagonal arrow pavement markings are used in the transition zone to guide drivers into the available lanes (see Figure 4).

Figure 2. Overhead lane signals on Tyvola Road in Charlotte, NC.

Figure 3. Reversible lane use regulatory signs on Canal Road in Washington, DC.

Use Policies and Restrictions

The synthesis survey also revealed that a number of agencies have developed local policies and restrictions to enhance the safety and efficiency of reversible segments as well as the roadways adjacent to them. Such policies dictate how the lanes will be used, left-turn prohibitions, on-street parking hours and which vehicles and occupancy rates are eligible during periods of reversible operation.

Although the goal of these policies is to increase the overall effectiveness of the reversible roadway, these benefits can come at a cost to some user groups. Consideration must be given to the movement

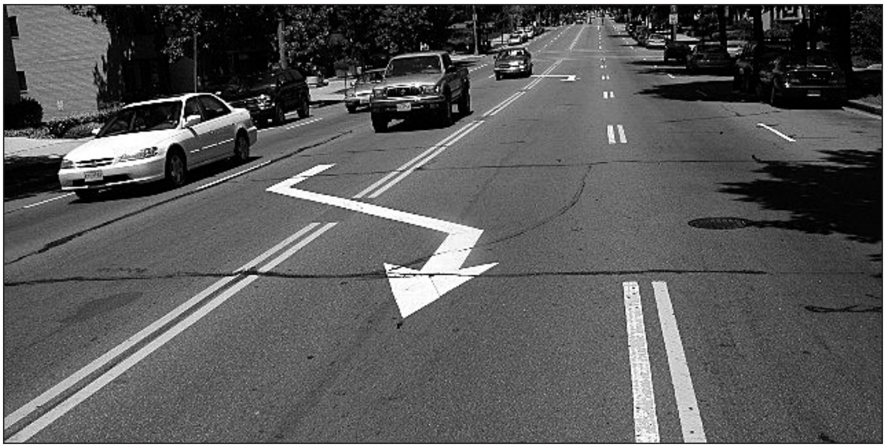

Figure 4. Reversible lane entry pavement markings on Connecticut Avenue in Washington, DC.

of pedestrians across reversible lanes, local businesses and the need to enforce speed limits in areas that may have narrow cross-sections and shoulder areas.

Prohibition of left turns is made primarily to keep through traffic moving. However, it also reduces conflicts for drivers on reversible segments by eliminating lane choice confusion. Left turns also can be a problem at reversible road intersections. Because left turn bays often are added by shifting each outer edge of pavement 6 feet outward to create an additional 12-foot center turn lane, through traffic would straddle a lane line. One way that that this problem has been addressed on reversible segments is by using a continuous center left-turn lane with dynamic overhead lane signals.

The prohibition of on-street parking on reversible roadways in urban areas allows more of the road cross-section to be usable for traffic movement. Depending on the width of the parking lane, an additional lane can be gained in the major and minor flow directions. The obvious advantage this affords is added capacity in the major direction as well as an additional lane in the minor direction for drivers to pass slower and turning traffic.

Another benefit of prohibiting parking is crash reduction. A study conducted on an early reversible road segment in Michigan with parking restrictions showed a significant decrease in all accidents during hours of operation.[10] This was not unexpected because many of the "before" accidents were related to conflicts between through and parking vehicles.

CONCLUSION

The review of reversible lanes and roadways shows that this form of traffic management has had a lengthy and varied history of providing added directional capacity during periods of elevated and unbalanced directional travel demand with varying levels of conformance to suggested practice. Generally speaking, the vast majority of reversible lane applications reviewed were able to achieve their operational objectives with relatively low safety impacts and at surprisingly high levels of public understanding and acceptance.

Although there are few formal analyses of the safety effect of reversible operations, the agencies responsible for their design and management generally regard them as safe and efficient. Most managing agencies interviewed during the review reported little change in accident frequency or severity under reversible operation. In several cases, it was felt that the added capacity and uniform operation on reversible roadways actually contributed to improved safety conditions. This suggests that reversible operations may not be nearly as complicated, controversial, or dangerous as many agencies believe.

The body of empirical evidence gained from prior experience suggests that drivers adapt to reversible flow quite readily. This record is true for both freeway and arterial street applications across all categories of use, including some that have been in operation for more than 10–15 years and in locations where reversible operations were less familiar to local drivers or not well marked.

This is not to suggest that RLS is totally free of problems. One detailed study revealed an abnormally high number of accidents associated with lane reversals.[11] However, after better traffic control devices were added, this problem was reduced. Another concern is mid-block entry points that can result in unauthorized turns and entry into improper lanes. To reduce these problems on Connecticut Avenue, lane use and turning restriction signs have been installed at minor street intersection approaches. In general, many of these problems are reduced during high-volume, minimum-headway conditions when acceptable gaps for turning movements are minimized.

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

When viewed in total, there remains a need for more information on most aspects (design, control, evaluation, etc.) of reversible lanes. The review shows that while some information is available, there are few evaluations of true benefits and costs, particularly the effect on pedestrians and other non-motorized user groups. ■

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