Reversible Lane Operation for Arterial Roadways: The Washington, DC, USA Experience

THIS PAPER DISCUSSES THE OPERATIONS OF REVERSIBLE LANES IN THE DISTRICT OF COLUMBIA. THE OPERATIONS ARE EVALUATED USING THREE CRITERIA—UTILIZATION OF INFRASTRUCTURE CAPACITY, SAFETY, AND ECONOMIC DEVELOPMENT.

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PURPOSE

This paper discusses the operations of reversible lanes on arterial roadways in Washington, DC, USA. The operations of reversible lanes are evaluated using three different criteria:

- Utilization of infrastructure capacity;
- Safety; and
- Land use/economic development impacts.

The discussion takes into account constraints inherent in a built-out urban environment and operational constraints imposed by external stakeholders. The paper discusses the status of continued operations of such facilities and draws some preliminary conclusions.

BACKGROUND

Traffic congestion has become a serious issue in metropolitan areas around the country. The annual cost of traffic congestion is estimated to be $115 billion, consisting of 4.8 billion lost hours and 3.9 billion gallons of fuel wasted.[1] Congestion-related delays are progressively getting worse. Increasing congestion and delay not only has economic and environmental impacts but also has societal impact by affecting quality of life. In major urban areas, a large portion of the population spends more time commuting than vacationing.

Dwindling public resources combined with environmental concerns and lack of opportunities to add new capacity in built-out urban areas have caused the transportation sector to shift its philosophy from "building out of congestion" to "more efficient operations of existing infrastructure." Consequently, jurisdictions have been trying a host of active traffic management strategies aimed at enhancing operational efficiencies. Reversible lanes are a product of this trend.

Reversible lanes on roadways allow transportation agencies to make better use of existing infrastructure by aligning the supply with the demand. This strategy allows agencies to cost-effectively accommodate the temporal changes in traffic patterns during the course of a day. The directional capacities of roadways are adjusted at different times of the day to adapt to changing traffic conditions using reversible lanes. Reversible lanes in an arterial environment can take many forms, from being certain directions during certain time periods to having different lane allocation during different time periods.

OVERVIEW OF WASHINGTON, DC REVERSIBLE LANES

In the District of Columbia, reversible lanes are implemented to improve traffic flow during rush hours in corridors that accommodate predominantly commuter traffic. Some of the reversible lane facilities have been in place for several decades. Reversible lanes have been applied on several roadway segments to accommodate the imbalance in directional traffic (D-factors) associated with peak commuting periods. In addition, reversible lanes are used on an ad hoc basis for emergency evacuations, maintenance of traffic in work zones, and other special events. However, this paper focuses on reversible lanes implemented to address imbalances in peak hour commuter traffic.

Currently, the District of Columbia operates 10 roadway segments with reversible lanes. The total length of these segments is approximately 10.6 miles, which is less than one percent of the District's roadway mileage. Figure 1 shows the reversible lane segments with specifics about starting and ending points, directional lane configuration, and operational hours.

All of these roadways except the Theodore Roosevelt Bridge (which carries I-66 traffic over the Potomac River) are arterial corridors. The reversible lane strategies span the entire spectrum from varying the number of inbound and outbound lanes (on corridors such as Connecticut Avenue, 16th Street, Chain Bridge, Canal Road, and Pennsylvania Avenue, SE) to allowing only one-directional flow during certain time periods (on corridors such as 15th Street, 17th Street, Constitution Avenue, Canal Road, and Waterside Drive).

Information on lane operations during the peak periods is presented to the drivers by the use of pole- and post-mounted static signs and illuminated signs placed on signals and light poles on the side of the road. The illuminated signs are operated by time-of-day schedules that are programmed into nearby traffic signal controllers. The *Manual on Uniform Traffic Control Devices* (MUTCD) recommends the use of ground-mounted reversible-lane control signs only as a supplement to overhead signs or signals.[2] Unfortunately, opposition to mast arms restricts the District's ability to use overhead lane control signs for reversible lanes. Lane control signs are only used in construction projects. The most stringent opposition to mast arms and overhead signs has been the Fine Arts Commission because of its concerns about aesthetics. The District Department of Transportation (DDOT) recently conducted a "pulse check" to determine whether the commission's position in this regard has changed. The response back suggested that it has not. The commission was still concerned about mast arms hindering the "unfettered views towards government buildings and monuments," resulting in "intrusion into City's characteristically open streets." This restriction severely affects the efficient operation of reversible lanes. Insufficient signage increases the possibility of drivers being in the wrong lane at the wrong time, resulting in a higher risk of collisions. In the District, overhead lane control signals are only used in conjunction with a construction project.

The pavement markings for reversible lanes are consistent with MUTCD guidance. On the reversible segments, a normal double broken-yellow line is installed to delineate the edge of a lane in which the direction of travel is reversed from time to time. These double broken-yellow lines serve as the centerline markings of the segments during different operation periods.

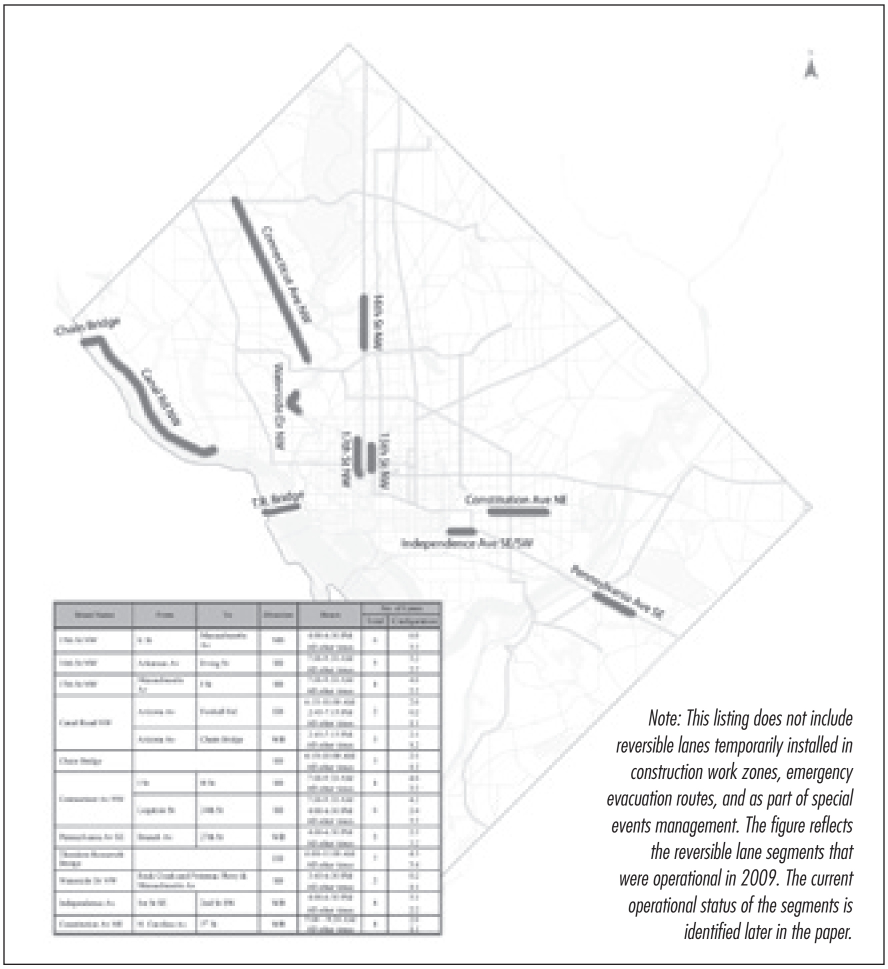


Figure 1. Washington, DC reversible lane segments.

ASSESSMENT OF REVERSIBLE LANES

This paper selects a reversible lane segment on Connecticut Avenue, NW as a sample to evaluate operational and safety impacts of reversible lanes. The reversible lane segment on Connecticut Avenue, NW is approximately 2.7 miles. It runs from 24th Street in the south to Legation Street in the north, as shown in Figure 1. The entire roadway has a six-lane cross section throughout this area.

The reversible lane segment on Connecticut Avenue, NW operates with four inbound (southbound) lanes and two outbound (northbound) lanes during the morning peak hours (7:00 a.m. to 9:30 a.m.). It operates with four outbound and two inbound lanes during the evening peak hours (4:00 p.m. to 6:30 p.m.). Three lanes are open to traffic in each direction at all other times. Curb standing and parking is prohibited on both directions during the reversible lane operations. During off peak hours, the curb lane is used for parking.

For the purpose of the safety evaluation, Massachusetts Avenue, NW and Wisconsin Avenue, NW were selected as a control group (non-reversible lanes) since these two segments share similar traffic patterns, both serving commuting traffic during the peak periods. The segment on Massachusetts Avenue, NW is about 2.5 miles and runs from Edmunds Street in the south to Westmoreland Circle in the north, as shown in Figure 2. The segment of Wisconsin Avenue runs from Edmunds Street in the south to Western Avenue in the north and is 2.6 miles.

UTILIZATION OF INFRASTRUCTURE CAPACITY

Figure 3 shows the daily distribution of traffic on a reversible section of Connecticut Avenue. As expected, the segment shows high peak hour (K) factor ranging from 0.09 to 0.10. Also, the traffic flow is predominantly southbound in the a.m. rush hour and northbound in the p.m. rush hour. The peak direction accounts for 70 percent of the bidirectional traffic volume. Therefore, from a capacity utilization standpoint, the reversible lanes are justified.

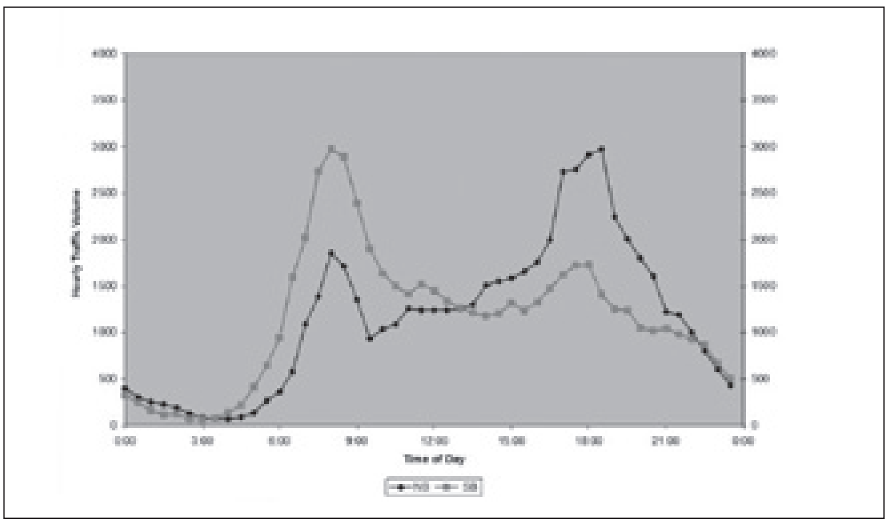
SAFETY ANALYSIS

Table 1 shows the crash history for some selected reversible lane segments. It shows that, depending on the segment, 18 percent to 30 percent of the crashes occur during hours of reversible operations. During the same timeframe, the roadways carry 30 percent to 35 percent of the daily traffic. So anecdotally, there does not appear to be a safety problem on the selected roadway segments during reversible operations.

Table 2 compares six-year crash statistics between the reversible section on Connecticut Avenue and the non-reversible sections of Wisconsin Avenue and Massachusetts Avenue. Compared to its surrogates, Connecticut Avenue seems to have a higher crash rate, even after the crashes are normalized by traffic volumes. The reversible section also has a higher percentage of crashes during the hours of reversible operation in spite of having peaking characteristics (K and D factors) similar to its surrogates. As an example, Connecticut Avenue has three times as many crashes as Massachusetts Avenue, though it carries only 40 percent more traffic. Similarly, 35 percent of the crashes on Connecticut Avenue are during reversible lane operations—a significantly higher percentage than its surrogates. Also, Connecticut Avenue has a higher propensity of head-on and sideswipe crashes than do Massachusetts Avenue and Wisconsin Avenue. These two accident types can be attributed to reversible lane operations.

Table 3 shows the crash history for the reversible section of Connecticut Avenue over a six-year period. The table shows that 35 percent of weekly and 44.3 percent of the weekday crashes happened during the hours of reversible operation. During the reversible operations, Connecticut Avenue carries 32 percent to 46 percent of the traffic. This would seem to indicate that the crash rate is slightly higher than during regular operation. Also the two types of crashes attributable to reversible lane operations, sideswipe and head-on collisions, as a percentage of total crashes, are higher in this segment than the District-wide percentage.

Figure 2. Roadway segments evaluated for safety analysis.



Source: DDOT Data Collection Program

Figure 3. Typical weekday traffic patterns on reversible segment of Connecticut Avenue.

ANALYSIS ON ENCROACHMENTS

The effectiveness of the existing reversible lane information system, with signs and signals mounted on the side of the road, was assessed by evaluating compliance with the signs and signals during the peak periods. The number of violations or encroachments into the reversible lane (vehicles traveling in the opposite direction of the allowed direction of travel) during the peak hour was observed.

The crash data on Connecticut Avenue from Garfield Street to Legation Street were used to determine the critical locations where traffic data should be collected. The key factors from the crash reports used in the analysis were the number of crashes, the number of crashes that occurred during reversible lane operations (7:00 a.m.–9:30 a.m. and 4:00 p.m.–6:30 p.m.), the number of crashes attributable to reversible lane operation (head-on and sideswipes), and the spatial distribution of data collected along

Table 1. Summary of crashes at selected reversible lane sections.

Roadway Segment	Total Crashes	Crashes During Reversible Operations	Percent Crashes During Reversible Operations
17th Street, NW	57	10	18 percent
Canal Road	71	15	21 percent
16th Street, NW	157	36	23 percent
Pennsylvania Avenue, SE	132	40	30 percent

Source: Reference [4]

Table 2. Accidents on comparable segments of corridors.

Safety Metrics	Connecticut Avenue (Reversible Section)	Wisconsin Avenue (Regular)	Massachusetts Avenue (Regular)
Total Crashes	785	460	262
# of Peak Period Crashes	271	130	65
Percent of Peak Period Crashes	35 percent	27 percent	25 percent

Source: Reference [4]

the corridor. The following intersections were the critical locations in the corridor:

- Cathedral Avenue;
- Porter/Quebec Street;
- Tilden Street;
- Yuma Street;
- Nebraska Avenue; and
- Military Road.

Data collected included peak direction traffic (inbound during the a.m. peak period and outbound during the p.m. peak period), non-peak direction traffic, and the number of vehicles encroaching into opposing traffic during the first hour of operations of the reversible lane, 7:00 a.m.–8:00 a.m. and 4:00 p.m.–5:00 p.m. As Table 4 indicates, at three of the locations, Porter/Quebec Streets, Nebraska Avenue, and Military Road, a large percentage of the vehicles traveling in the off-peak direction between 4:00 p.m. and 5:00 p.m. encroach into the reversible lane in the wrong direction of travel. The field observations indicate that some of the violators encroach because they are defiant of traffic regulations and others encroach into the reversible lane because the signs of the reversible lanes do not communicate clearly to them the traffic operations during the peak hours. The violation rate indicates the percentage of vehicles traveling in the off-peak direction that encroach into the reversible lane during the peak hour.

Lane Usage

The reversible lane usage was evaluated at two critical locations (Porter Street and Nebraska Avenue) in the corridor using videotaped data. As Table 4 shows, there is a direct correlation between usage of reversible lanes and violation rates. During the a.m. peak, the number of violations is low at Nebraska Avenue and the reversible lane usage is as high as 82 percent of the adjacent lane volume. At Porter/Quebec Streets there were 18 violations during the a.m. and the reversible lane usage dropped to 48 percent. During, the p.m. peak, however, the reversible lane usage rates at both the locations drop significantly since the violation rates are higher. This pattern indicates that drivers are aware of the violation patterns and stay away from the reversible lane in the sections with large number of violations and use the reversible lane adequately at locations where they know there are few violations. Violations can be reduced significantly with the installation of overhead lane control signals.

LAND USE/ECONOMIC DEVELOPMENT

The focus of reversible lanes is to push traffic "through" the system to an ultimate destination. Therefore, from a land use and economic development standpoint, reversible lanes are not very desirable since they do not cater to the needs of the adjacent businesses and land uses. In addition, local businesses are affected due to operational restrictions such as curbside parking and turn prohibitions.

Reversible lanes are also not very pedestrian friendly. There are a few reasons for this. First, the absence of medians increases pedestrians' exposure to vehicles when crossing the street. Second, reversible lanes make the crossing maneuver somewhat confusing for pedestrians, especially in areas that have large number of unfamiliar pedestrians. With 16.4 million tourists coming to Washington, DC annually this is true in several parts of the District.[5] Third, the lack of medians on reversible sections precludes streetscaping and this reduces the desirability and livability of an area.

Reversible lanes are also being increasingly viewed as pro commuters/anti residents, especially in cases where reversible lanes are being used for one-way operations during certain times of the day.

STATUS OF REVERSIBLE LANES IN THE DISTRICT

The District is in the process of reevaluating its reversible lane system. The status of the reversible lanes are listed below:

- Constitution Avenue, NE: The District eliminated the reversible lane/one-way rush hour operations on Constitution Avenue, NE. Traffic analysis revealed that the conversion will enhance circulation in the area, lower speeds, and enhance network connectivity. It also helps deemphasize the corridor as a major commuter route and enhances the livability of the community.
- Pennsylvania Avenue, SE: The reversible lanes have been eliminated in favor of a planted median. The rationale is that reversible lanes solely served the purpose of added vehicle capacity. They are dangerous for pedestrians in that they introduce a level of unpredictability in knowing from which direction to expect vehicles. They also tend to encourage higher travel speeds in that most drivers are uncertain about them so they stay in the "typical" lanes, leaving the reversible lane free for the more aggressive drivers.
- 15th Street, NW: The reversible lanes were recently eliminated as part of a bike project.
- 16th Street, NW: The District is also

Table 3. Connecticut Avenue crash history.										
Cross Street	Number of Accidents	Number During Rev. Lane Operation	% During Rev. Lane Operation	Volume During Rev. Lane Operation	ADT	% Volume Rev. Lane Operation	Number Head-on	% Head-on	Number Sideswipe	% Sideswipe
Garfield Street	10	6	60%				0		3	30%
Cathedral Avenue	23	10	43%				0	0%	9	39%
Devonshire Place	15	9	60%				0	0%	4	27%
Macomb Street	22	6	27%	16985	38900	44%	0	0%	3	14%
Newark Street	14	3	21%				1	7%	3	21%
Ordway Street	24	7	29%				0	0%	5	21%
Porter/Quebec Street	25	7	28%				1	4%	5	20%
Rodman Street	12	8	67%				0	0%	6	50%
Sedgwick Street	7	3	43%				0	0%	1	14%
Tilden Street	23	5	22%	16000	42700	37%	0	0%	8	35%
Upton Street	15	8	53%				0	0%	5	33%
Van Ness Street	11	4	36%	15403	36000	43%	0	0%	2	18%
Veazey Terrace	7	2	29%	16600	40700	41%	0	0%	1	14%
Yuma Street	17	8	47%	18700	40700	46%	0	0%	4	24%
Albemarle Street	14	5	36%	14900	40700	37%	1	7%	3	21%
Appleton Street	3	2	67%	15500	37600	41%	0	0%	2	67%
Brandywine Street	6	3	50%				0	0%	3	50%
Chesapeake Street	9	3	33%				1	11%	4	44%
Cumberland Street	3	0	0%				0	0%	0	0%
Davenport Street	11	4	36%				0	0%	2	18%
Ellicott Street	7	2	29%				0	0%	3	43%
36th/Everett Street	1	0	0%				0	0%	0	0%
Fessenden Street	16	3	19%				0	0%	4	25%
Nebraska Avenue	34	10	29%				2	6%	5	15%
Chevy Chase Parkway	9	4	44%				0	0%	1	11%
Huntington Street	1	1	100%				0	0%	1	100%
Ingomar Street	4	2	50%				0	0%	2	50%
Jenifer Street	6	4	67%				0	0%	1	17%
Jocelyn Street	1	1	100%				0	0%	0	0%
Kanawha Street	2	0	0%				0	0%	0	0%
Military Road	21	5	24%	10570	32600	32%	0	0%	4	19%
Legation Street	4	3	75%				0	0%	0	0%

Source: Adapted from Reference [3]

assessing the rationale for continuing reversible lanes on 16th Street, NW. The reversible lanes do support the temporal distribution of traffic on this corridor. However, the reversible lanes also restrict operational flexibility in terms of how exclusive turn movements can be handled. Based on recent and historical crash statistics, there are certain locations that could benefit from exclusive left-turn phasing, but this is difficult to implement in a reversible lane situation. While this was primarily a commuter corridor, it has seen significant growth recently. Consequently, there are now heavy turning movements to and from the side streets, especially left-turning movements.

CONCLUSIONS

The District of Columbia has been operating reversible lanes on some of its arterial roadways for several decades. The reversible lanes help optimize system capacity by reallocating transportation supply based on the fluctuating demand. However, a preliminary crash analysis and anecdotal evidence suggest that more crashes are associated with reversible lane operations compared to non-reversible lane segments. The higher crash rate can, at least in part, be attributed to the District's tradition of not using mast arms for overhead reversible lane control signals due to aesthetic reasons. As a popular tourist destination, the District has a large number of unfamiliar drivers, which further magnifies the problem. Reversible lanes can be confusing, especially for unfamiliar drivers, for turning movements, specifically left turns, from and to the side streets. Reversible lanes also restrict the District's ability to provide for protected phasing in areas where such a strategy can have po-

Table 4. Violation rates and reversible lane usage at critical locations.						
First Hour of a.m. Reversible Lane Operations (7:00 a.m.–8:00 a.m.)						
Location	**Peak Direction Volume**	**Off-peak Direction Volume**	**Number of Encroachments**	**Violation Rate (1)**	**Reversible Lane Volume**	**Adjacent Lane Volume in Peak Direction**
Garfield Street	1,626	680	18	2.6 percent		
Porter/Quebec Streets	2,140	852	7	0.8 percent	374 (48 percent)	774
Tilden Street	2,013	884	0	0.0 percent		
Yuma Street	2,210	780	1	0.1 percent		
Nebraska Avenue	1,989	544	0	0.0 percent	476 (82 percent)	582
Military Road	1,991	664	5	0.8 percent		
First Hour of p.m. Reversible Lane Operations (4:00 p.m.–5:00 p.m.)						
Garfield Street	1,193	920	0	0.0 percent		
Porter/Quebec Streets	1,504	948	55	5.8 percent	252 (38 percent)	657
Tilden Street	1,594	956	4	0.4 percent		
Yuma Street	1,688	748	5	0.7 percent		
Nebraska Avenue	1,586	928	60	6.5 percent	132 (25 percent)	521
Military Road	1,481	660	44	6.7 percent		
Source: Based on field data collection						

tential benefits. Despite these operational issues, the biggest drawback of reversible lanes is that, in the District, they are perceived as being too commuter oriented and as deemphasizing the needs and wants of the residents and the communities. It is also less pedestrian friendly and not very conducive to economic revitalization since it focuses on "through traffic" rather than traffic destined to the community. Economic revitalization through infrastructure enhancements and enhancing the walkability and livability are two items high on the District's agenda.

Reversible lanes in an arterial setting should be evaluated on a case-by-case basis. The District Department of Transportation (DDOT) is embarking on a more robust analysis on safety, operational, and land use impacts of reversible lanes. DDOT is also assessing the feasibility of using overhead reversible lane control signals and identifying operational strategies based on best practices that will enhance the safety of reversible lanes.

Given the capacity constrained nature of transportation networks in urban areas, reversible lanes should be an element in a transportation engineer's toolkit. They need to be implemented after properly weighing the pros and cons in the context of the specific situation and the larger environment in which they are implemented.

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