Appendix C

Analysis Details

Contents

To: DDOT-PPSA

From: PB

Date: January 19, 2011

Subject: Rock Creek West II Livability Study (RCW2)
Chevy Chase Circle Traffic Evaluation - Draft

We have completed the traffic analysis of the Chevy Chase Circle partial signalization. The analysis assumes the configuration shown in the plan drawings provided by DDOT, dated 2002. It appears that this configuration, the signalization of the two Western Avenue approaches to the Circle, combined with the existing signal at Connecticut Avenue NW and Oliver Street, has the potential to significantly improve traffic operations compared to the existing configuration.

Background

Chevy Chase Circle, straddling the border of the District of Columbia and Montgomery County, MD, is the hub of seven intersecting roadways: Connecticut Avenue extending to the north and south is a major arterial. Western Avenue, extending to the northeast and southwest along the DC border, Chevy Chase Parkway extending to the east and the west, and Magnolia Avenue, extending to the west. The Circle is located in a primarily residential community.

Connecticut Avenue carries very heavy peak hour traffic flows into and out of the District. Western Avenue carries significant traffic volumes, and the other approaches are relatively low volume. The intersections of these roadways with the Circle are all unsignalized, with traffic within the Circle having the right of way. There is a traffic signal just south of the Circle on Connecticut Avenue, at Oliver Street NW.

At Connecticut Avenue, large islands channelize the intersection. At other approaches, painted pavement markings provide channelization. Three traffic lanes are designated around the Circle. At Connecticut Avenue, all three lanes are permitted to exit the circle.

In 2002, DDOT conducted a preliminary study of signalization of the two Western Avenue approaches to the Circle. Preliminary signal plans were developed, but traffic analysis of this option was either not performed or has not been provided to PB. The analysis discussed in this memorandum reflects this configuration.

Existing Issues

The signage in advance of and along Chevy Chase Circle is insufficient considering the confusing nature of its traffic circulation and yielding. Additionally, because the Circle is unsignalized, there is no priority given to pedestrians while they cross, Connecticut Avenue traffic (the major movement), or Western Avenue traffic (also a large traffic volume).

Due at least in part to these issues, Chevy Chase Circle is the location with the second most traffic collisions between 2007 and 2009 in the RCW2 study area. A total of 56 collisions occurred at this location during the three year period, including two involving a pedestrian. 52 percent of them were property damage only, and 25 percent involved an injury. 45 percent were side-swipes. Other types were rear-end and right angle impact. The types of collisions indicate that weaving movements are primary causes.

Additionally, DDOT received the second most comments (60) out of all study area intersections about Chevy Chase Circle in its June and July 2010 online survey. About half of respondents complained of aggressive driving (failing to yield and speeding). The next biggest complaint was infrastructure deficiencies (such as awkward intersections, missing pedestrian facilities, etc.).

Most legs of the Circle have crosswalks, some high visibility. However, they are unsignalized. There are two locations with high-visibility crosswalks into the center of the Circle, though they are also unsignalized.

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Safer and convenient pedestrian access to and around the Circle is a need today, and into the future.

Data Collection

Spot traffic counts were conducted manually by PB on all approaches to the Circle for 30-minute periods between 8:00 and 8:30 AM, and 5:30 and 6:00 PM. Estimated peak hour volumes were calculated by multiplying the counted volumes by a factor of 2, yielding the numbers below. These estimated counts are generally higher than the peak hour counts conducted in 2002, with the exception of the southbound AM movement on Connecticut Avenue. DDOT 2008 traffic counts show a bi-directional AADT of 28,600 vehicles on the south leg of Connecticut Avenue, and 20,500 vehicles on the west leg of Western Avenue. While it can be difficult to compare daily and hourly traffic volumes, these numbers are generally consistent.

Peak Hour Traffic Volumes

	Intersection	AM Peak Hour			PM Peak Hour		
		Circle		Side	Circle		Side
		Through	Right	Right	Through	Right	Right
A	Connecticut Avenue (North Leg)	890	1172	1918	328	1880	1322
B	Western Avenue (East Leg)	1170	384	892	2152	62	56
C	Chevy Chase Parkway (East Leg)	1322	64	232	1932	870	282
D	Connecticut Avenue (South Leg)	550	1704	836	1130	758	1672
E	Western Avenue (West Leg)	1872	914	382	990	566	898
F	Chevy Chase Parkway (West Leg)	2746	72	40	1540	106	16
G	Magnolia Avenue	2788	20	30	1634	16	12

Note: Peak hour counts factored from 30-minute spot counts 8:00 to 8:30 AM and 5:30 to 6:00 PM (Wednesday, November 17, 2010).

Warrant Analysis
The estimated peak hour traffic volumes were compared to the traffic signal warrant thresholds established in the Manual on Uniform Traffic Control Devices, as shown in the following charts.

Based upon these counts, the peak hour warrant is met as follows:

Intersection		AM Peak	PM Peak
A	Connecticut Avenue (North Leg)	Yes	Yes
B	Western Avenue (East Leg)	Yes	Yes
C	Chevy Chase Parkway (East Leg)	Yes	Yes
D	Connecticut Avenue (South Leg)	Yes	Yes
E	Western Avenue (West Leg)	Yes	No
F	Chevy Chase Parkway (West Leg)	No	No
G	Magnolia Avenue	No	No

Five of the seven legs of the Circle meet the peak hour warrant for signalization. Two legs, Magnolia Avenue and the west leg of Chevy Chase Parkway carry very low traffic volumes. In the analysis, it was assumed that these two approaches would remain unsignalized. Additionally, though they are warranted, the following legs were left unsignalized to simplify operations and implementation: Connecticut Avenue (northern), Chevy Chase Parkway (eastern), and Connecticut Avenue (southern – note that while the approach right at the circle would not be signalized, the existing signal at the nearby Oliver St intersection would remain).

Capacity Analysis

Modeling the circle proved to be relatively complicated. For the existing conditions, the Highway Capacity Manual (HCM) methodology is not calibrated for three-lane approaches under stop control. Accordingly, the SimTraffic module of Synchro was used for this analysis. For signalized analysis, the HCM module of Synchro was utilized for the signalized intersections, while the SimTraffic module was used for the unsignalized intersections.

As shown in the following table, the analysis shows significant delays on some approaches under the existing conditions. In particular, on Western Avenue, peak hour delays of over 160 seconds per vehicle are estimated. This analysis reflects the tendency of drivers on Western Avenue to form two lanes entering the circle, although these approaches are not specifically designated as two lane. . Calibrating the SimTraffic model to reflect weaving behavior around the circle was complex. In particular, SimTraffic does not necessarily reflect the ability of drivers to anticipate lane changes, and move aggressively when merging. Because of these factors, SimTraffic analysis may somewhat overestimate the delays encountered on the unsignalized approaches.

We evaluated signalization of the two Western Avenue approaches to the Circle, as proposed by DDOT in 2002. Our analysis assumed that the existing signal at Connecticut Avenue NW and Oliver Street would be retained. This existing signal primarily serves as a pedestrian crossing and to create gaps and platoons in northbound traffic approaching the circle, to some extent replacing a signal on the Circle at Connecticut Avenue.

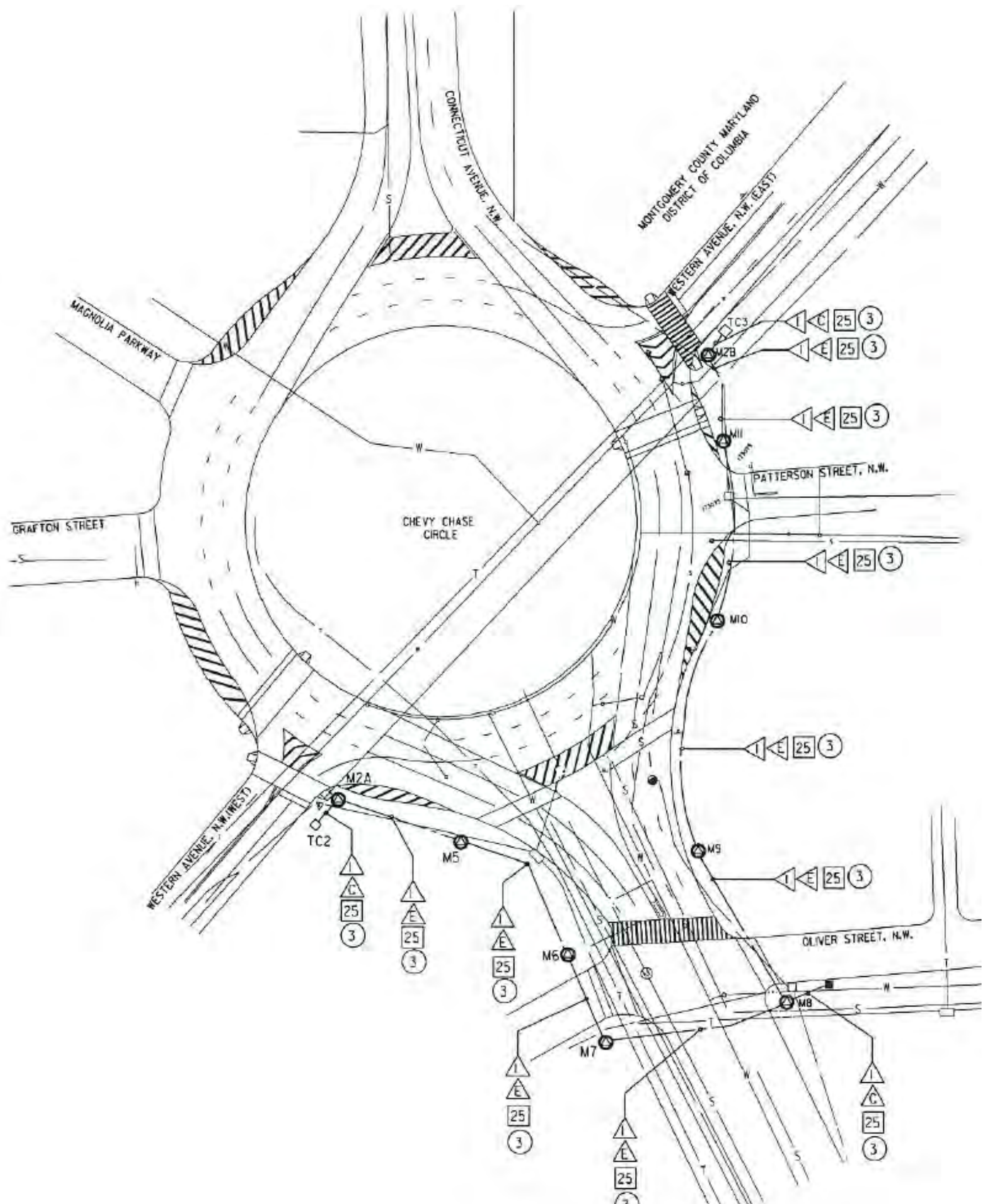


Figure 1: Proposed Circle Configuration (source: Volkert & Associates, P.C.)

Our analysis assumed the lane configuration shown in the figure above. Our analysis assumed that two lanes could be maintained on both Western Avenue approaches to the Circle. Presently, these approaches are striped with a single lane approaching the circle, with peak-period parking restrictions that permit approaching traffic to form two lines. Based upon our analyses, for signalization to be effective, these parking restrictions will need to be rigorously enforced during peak periods to maintain two approaching lanes for at least 200 feet.

With this configuration, signalization appears to be able to provide significant improvement to traffic operation at Chevy Chase Circle.

As shown in the following table, delays on the Western Avenue approaches would drop dramatically, from LOS F to LOS C and D. LOS on southbound Connecticut Avenue would improve somewhat during the AM peak period, although they would remain at LOS F. Levels of service on northbound Connecticut Avenue would remain relatively the same as at present, as would LOS on Chevy Chase Parkway. LOS on Magnolia Avenue (outside the District of Columbia) would degrade to LOS D in the AM peak period, but this is a low-volume movement.

		AM Peak		PM Peak	
Intersection		Unsignalized Scenario[2]	Signalized Scenario[3]	Unsignalized Scenario[2]	Signalized Scenario[3]
A	Connecticut Avenue (North Leg)	164.1 sec.[1] F	116.9 sec.[1] F	3.6 sec. [1] A	3.6 sec. [1] A
B	Western Avenue (East Leg)	151.7 sec.[1] F	22.4 sec. C	50.8 sec. [1] C	26.8 sec. C
C	Chevy Chase Parkway (East Leg)	10.2 sec. [1] B	15.2 sec[1] C	3.7 sec. [1] A	6.1 sec.[1] A
D	Connecticut Avenue (South Leg)	1.8 sec. [1] A	2.8 sec [1] A	18.6 sec. [1] C	7.1 sec. [1] A
E	Western Avenue (West Leg)	100.7 sec[1] F.	40.4 sec D	215.2 sec. [1] F	22.7 sec. C
F	Chevy Chase Parkway (West Leg)	32.9 sec. [1] D	18.8 sec.[1] C	13.9 sec. [1] B	9.0 sec. [1] A
G	Magnolia Avenue	7.9 sec. [1] A	33.8 sec.[1] D	2.5 sec. A	4.7 sec. [1] A

Data tabulated is delay in seconds per vehicle on leg entering the circle.
LOS is based upon delay thresholds defined in HCM. Different thresholds are defined for signalized and unsignalized intersections.

1 Delay for unsignalized intersections calculated using SimTraffic.

2 Unsignalized scenario reflects current operation of Chevy Chase Circle, including traffic signal at the intersection of Connecticut Avenue NW and Oliver Street.

3 Signalized scenario retains existing traffic signal at the intersection of Connecticut Avenue NW and Oliver Street, and adds signalization at both Western Avenue intersections within Chevy Chase Circle. All other approaches to the circle remain unsignalized.

Once traffic enters the Circle, the anticipated lane configuration and the three-phase signal timing maintains an efficient movement of traffic around and out of the Circle.

Conclusion

The peak hour signal warrant is met at five of the seven approaches to Chevy Chase Circle. Signalization of the two Western Avenue approaches would provide for efficient movement of traffic around the Circle. Complex weaving and merging operations would still occur at most legs of the circle, particularly at the Connecticut Avenue approaches, but appropriate signage and pavement markings may mitigate this. In particular, improved advance guidance signs and larger street name signs within the Circle are recommended. Signalization would reduce weaving and merging operations at the two Western Avenue approaches, and would provide the opportunity for protected pedestrian crossings to the center of the Circle at these locations.

The complex traffic patterns at the Circle are difficult to model accurately in Synchro and HCM. Analysis with other programs, such as Vissim, may provide a more exact evaluation but is not likely to change the conclusions. Analysis indicates that the proposed signal operation would substantially reduce delays on all major approaches to the Circle. Delays would increase on some minor approaches, but would remain within acceptable levels.

Memorandum

To: DDOT-PPSA

From: PB

Date: January 13, 2011

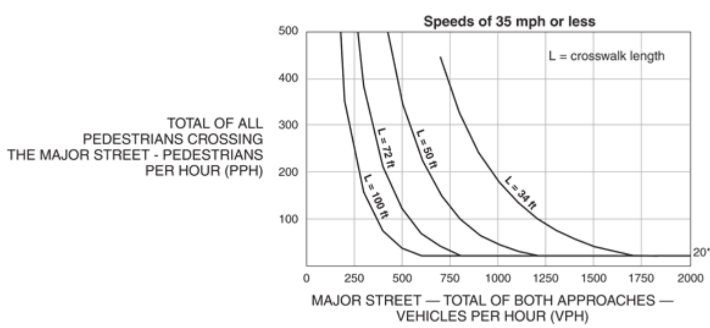
Subject: Rock Creek West II Livability Study
Information for HAWK signal warrant at Connecticut Ave NW & Northampton St NW

The following information supports the installation of a HAWK signal at the intersection of Connecticut Avenue NW and Northampton St NW (southern leg). The HAWK signal, or a pedestrian hybrid beacon, would be placed at the existing high-visibility, unsignalized crosswalk.

- According to the DDOT 2008 Traffic Volumes pap, Connecticut Avenue carries an average of 28,600 vehicles per day in the vicinity of Northampton St NW.
- According to the Connecticut Avenue Transportation Study, Connecticut Avenue NW, near Albemarle St NW, carried 2,237 vehicles during a Saturday peak hour in 2002. It is reasonable to assume that the current Saturday peak hour volume at Northampton St NW is at least 2,237, if not more.
- According to a field count on Saturday, December 4, 2010, from 12:00 to 1:00 PM, 127 pedestrians crossed Connecticut Ave NW at Northampton St NW (southern leg of intersection). This does not include an additional 20 pedestrians that crossed just upstream or downstream of the intersection.
- The crosswalk is approximately 60 feet long.
- Many of the pedestrians included families and small children.
- Illegally parked cars along the western edge of Connecticut Ave NW limit sight distance for pedestrians wanting to cross, and for motorists needing to yield.
- Based on the above information, and the MUTCD guidelines noted below, the intersection meets the warrant for a pedestrian hybrid beacon, or HAWK signal.

Supporting information from MUTCD, 2009 Edition:

Figure 4F-1. Guidelines for the Installation of Pedestrian Hybrid Beacons on Low-Speed Roadways



* Note: 20 pph applies as the lower threshold volume

Table for Figure 4F-1							
Crosswalk length = 34 ft		**Crosswalk length = 50 ft**		**Crosswalk length = 72 ft**		**Crosswalk length = 100 ft**	
VPH on the major street (Total of both approaches)	**PPH for total of all pedestrians crossing the major street**	**VPH on the major street (Total of both approaches)**	**PPH for total of all pedestrians crossing the major street**	**VPH on the major street (Total of both approaches)**	**PPH for total of all pedestrians crossing the major street**	**VPH on the major street (Total of both approaches)**	**PPH for total of all pedestrians crossing the major street**
2000	20*	2000	20*	2000	20*	2000	20*
1750	20*	1750	20*	1750	20*	1750	20*
1500	40	1500	20*	1500	20*	1500	20*
1250	90	1250	20*	1250	20*	1250	20*
1000	190	1000	50	1000	20*	1000	20*
750	40	750	125	750	25	750	20*
500	—	500	350	500	120	500	30
250	—	250	—	250	500	250	250
225	—	225	—	225	—	225	500

* Note: 20 pph applies as the lower threshold volume.

Memorandum

To: DDOT-PPSA

From: PB

Date: December 1, 2010

Subject: Rock Creek West II Livability Study
Ward Circle Traffic Evaluation

This memorandum documents our findings from the evaluation of Ward Circle in Washington, DC, pursuant to the Rock Creek West II (RCW2) Livability Study.

In summary, preliminary analysis using Synchro indicates that conversion of Ward Circle to a traditional traffic circle with signalization at all points of entry will be detrimental to traffic operations at this location. The study methodology and assumptions leading to these findings are described as follows:

Background

Ward Circle is located at the intersection of Massachusetts Avenue and Nebraska Avenue near American University campus in Northwest Washington, DC. The layout of the circle and the approach roadways are as follows:

- Both Massachusetts Avenue and Nebraska Avenue are four-lane roadways with two lanes entering and exiting Ward Circle.
- Marked pedestrian crossings exist across all entry and exit links to Ward Circle.
- Nebraska Avenue continues through the circle, allowing "through" traffic on Nebraska Avenue to bypass the circulatory roadway. The intersections of Nebraska Avenue and Ward Circle are signalized.
- Massachusetts Avenue approaches yield to traffic in the circle. Raised splitter islands separate the entries and exits to/from Massachusetts Avenue, which also serve as pedestrian refuge areas linked to the marked crosswalks.
- The number of lanes within the circle varies from two lanes adjacent to the Massachusetts Avenue entries, three lanes adjacent to the Nebraska Avenue entries, and four lanes (including a dedicated right turn pocket) prior to the exits from the circle onto northbound and southbound Nebraska Avenue.

For purposes of discussion in this study and report, Nebraska Avenue is assumed to be the North-South route and Massachusetts Avenue is assumed to be East-West.

Figure 1 – Ward Circle, Washington, DC

Traffic movements within the circle are intended to be restricted such that left turns from the circle onto the Nebraska Avenue bypass lanes are prohibited, though drivers are frequently observed making such turns. Likewise, left turns from the bypass lanes into the circle are similarly prohibited; drivers seem to adhere to this restriction considering that such turns are in direct conflict with oncoming through traffic from the opposite direction of Nebraska Avenue. Signal operations at the Nebraska Avenue intersections are two-phase, alternating between serving traffic in the circle and Nebraska Avenue.

Existing Issues

As noted in the previous section, motorists make illegal left turns from Ward Circle onto the bypass lanes. Other than basic road signs and a pavement marking indicating through movements only, there is nothing preventing this behavior.

The signage along Ward Circle is insufficient considering the non-traditional and confusing nature of its traffic circulation and yielding. Additionally, there are multiple opportunities for motorists to make short weaving movements within the circle. The weaving, particularly at confusing junctions, causes vehicle conflicts.

Due at least in part to these issues, Ward Circle is the location with the most traffic collisions between 2007 and 2009 in the RCW2 study area. A total of 81 collisions occurred at this location during the three year period, including one involving a pedestrian. 59 percent of them were property damage only, and 21 percent involved an injury. 33 percent were side-swipes, and 29 percent were rear-end impact. The types of collisions indicate that weaving movements and traffic congestion are primary causes.

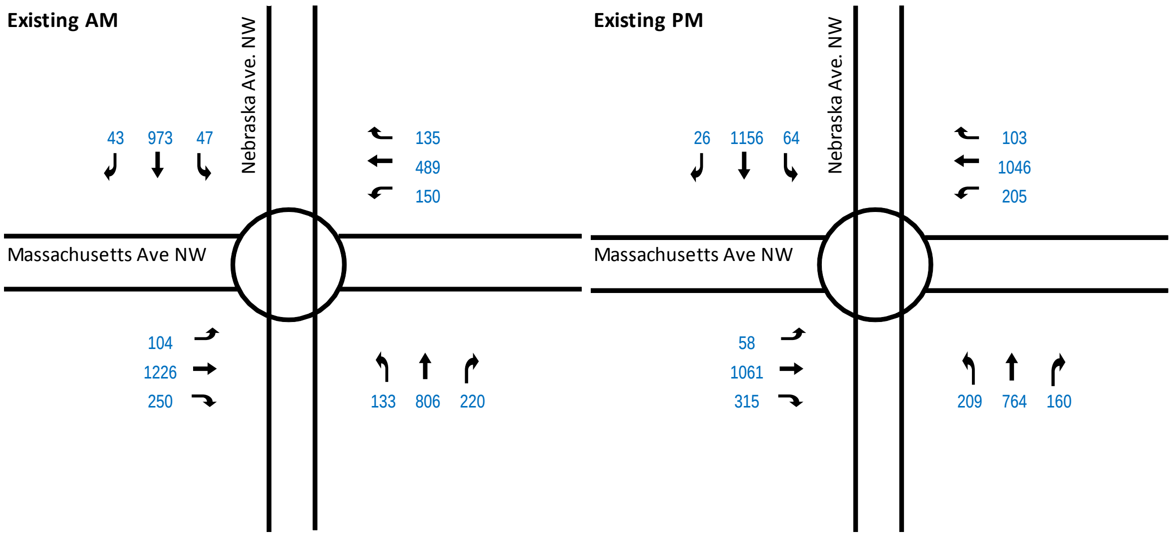
Additionally, DDOT received the most comments (70), out of all study area intersections, about Ward Circle in its June and July 2010 online survey. The most frequent complaint was aggressive driving (failing to yield and speeding), followed by unsafe pedestrian behavior (such as jaywalking) and infrastructure deficiencies (such as awkward intersections, missing pedestrian facilities, etc.).

While each leg of the circle has high-visibility crosswalks, they are unsignalized. There are high pedestrian volumes around the Circle, due to the proximity to American University. In fact, this activity is expected to increase in the future with AU expansion. Therefore, safer and convenient pedestrian access to and around the Circle is a need today, and into the future.

Data Collection

Traffic volumes used for this analysis were obtained from Gorove-Slade in association with their work for American University. These volumes, shown in Figure 2, represent the origin-destination pairs for traffic entering the circle reduced to the topology of a typical four-leg intersection. These volumes were used to estimate the redistribution of traffic for various reconfigurations of the circle. Pedestrian crossing volumes were retained from Synchro models developed by Gorove-Slade in association with their work for the University.

Figure 2 – Existing Peak Hour Traffic Volumes (Macro view)

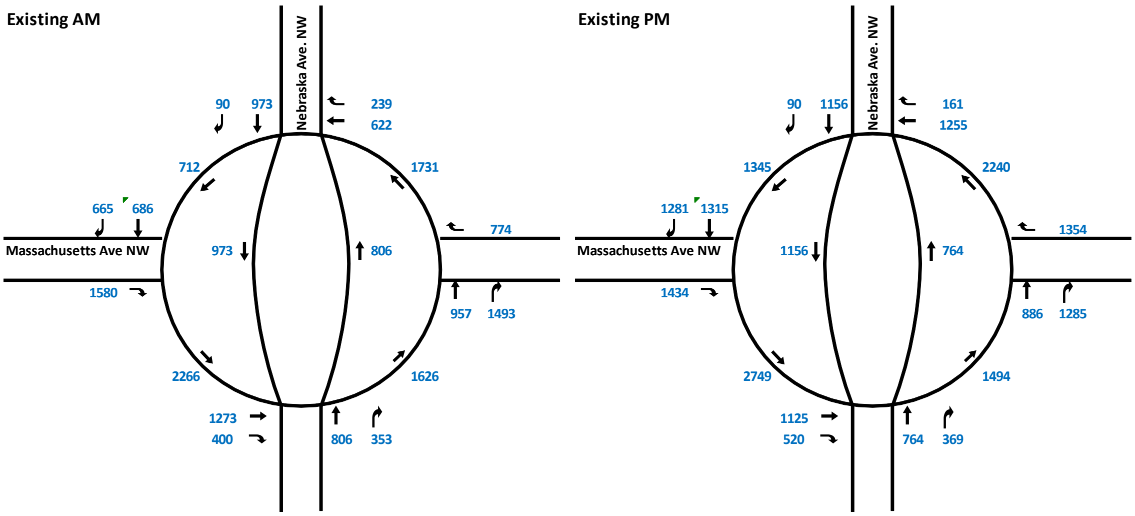


According to these volumes, the heaviest demand is on the through movements through the intersection. Demand is higher to the south and east during the AM peak period, and more balanced in the PM peak period. "Through" demand is generally balanced between Massachusetts Avenue and Nebraska Avenue in the AM (1715 vs. 1779 vph, respectively) and in the PM (2107 vs. 1920). Left turn volumes are generally higher from northbound Nebraska to westbound Massachusetts, and from westbound Massachusetts to southbound Nebraska.

Existing Conditions

Figure 3 presents the distribution of existing AM and PM peak hour volumes throughout the existing configuration of Ward Circle.

Figure 3 – Existing Peak Hour Traffic Volumes (Actual Configuration)



Synchro analysis of Ward Circle, adapted from the Synchro model developed by Gorove-Slade, reports the following for peak hour operations:

Figure 4 – Synchro Results (AM & PM)

Peak Hour	Approach leg to Ward Circle	Operations for Approach		
		Delay (s/veh)	Queue (95th%ile - ft)	LOS
AM	Nebraska Ave (North Leg)	31.4	453(1)	C
	Nebraska Ave (South Leg)	57.8	573	E
	Massachusetts Ave (East Leg)	12.1	57	B
	Massachusetts Ave (West Leg)	32.6	319	D
PM	Nebraska Ave (North Leg)	66.8	594	E
	Nebraska Ave (South Leg)	45.3	518	D
	Massachusetts Ave (East Leg)	41.6	309	E
	Massachusetts Ave (West Leg)	34.2	288	D

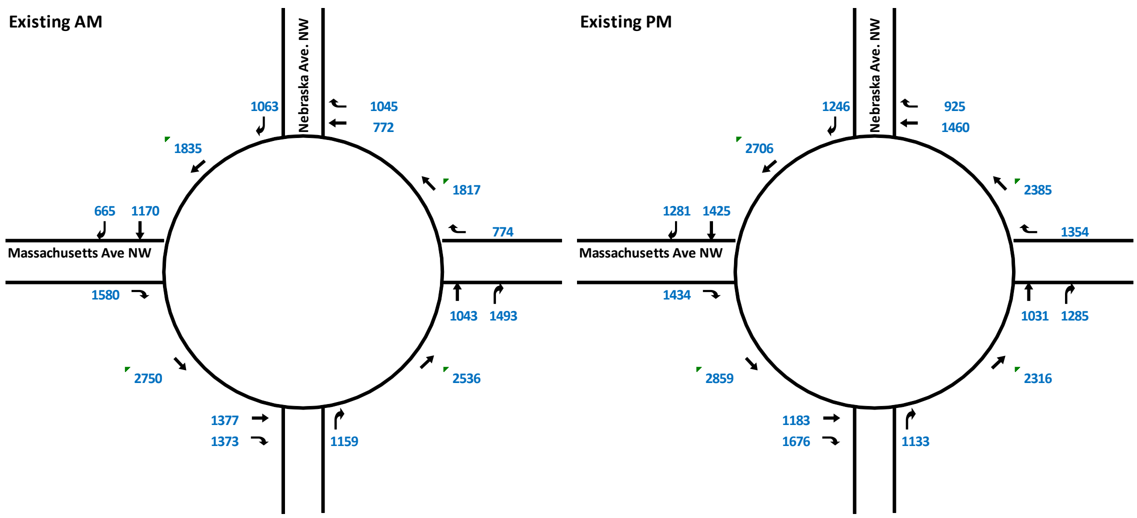
Notes

(1) – Queue limited by metering from upstream intersection

Alternatives Proposed

At the request of DDOT, PB engaged in analysis to evaluate the effect of removing the Nebraska Avenue bypass lanes and reconfiguring Ward Circle as a traditional, signalized traffic rotary. The resultant configuration requires a redistribution of traffic through the circle, as the Nebraska Avenue "through" movements would have to negotiate the circle to complete the movement through the intersection. The resultant traffic volumes arising from this redistribution are shown in Figure 5.

Figure 5 – Existing Peak Hour Traffic Volumes (Circle Configuration)



Warrant Analysis

The currently unsignalized intersections of Massachusetts Avenue and Ward Circle were investigated for warrants for signalization. For this analysis, the entries at the Massachusetts Avenue approaches were treated as three-leg intersections (with Ward Circle as the major street and Massachusetts Avenue as the minor leg) and evaluated against the major and minor street volume thresholds in the 2009 MUTCD.

Though hourly volumes were not available to perform a full analysis in accordance with the MUTCD warrants, an examination of the peak hour volumes provided some insight into the likelihood that the intersections would pass a more comprehensive warrants analysis. The estimated peak hour traffic volumes were compared to the traffic signal warrant thresholds established in the Manual on Uniform Traffic Control Devices, as shown in Figure 6.

According to this analysis, both the AM and PM peak hour volumes exceed Warrants 1 and 2 by significant margins. It is likely that volumes are sustained at a level such that there are eight hours a day that pass Warrant 1 and four continuous hours that pass Warrant 2. As a result of this preliminary analysis, it is assumed that for the circle configuration shown in Figure 5, both intersections of Massachusetts Avenue would meet warrants for signalization.

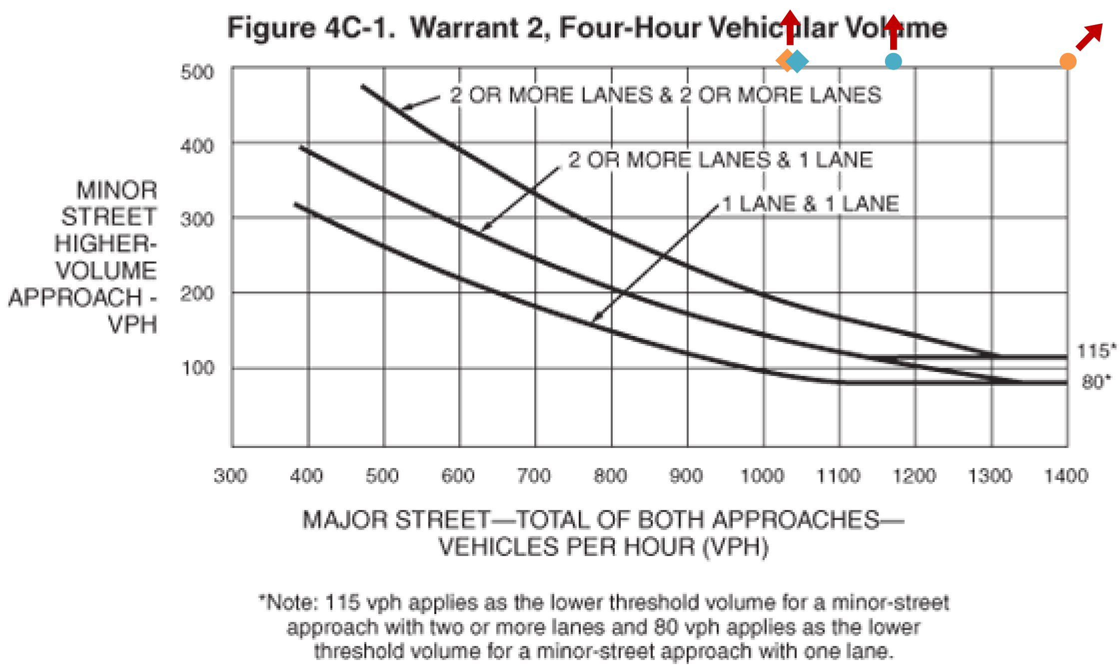
Figure 6 – Signal Warrant Analysis

Warrant 1 – Eight Hour Vehicular Volume

For 2 lane major street and 2 or more lane minor street:
Major street volume > 600 vph
Minor street volume > 200 vph

Peak Hour	Approach leg to Ward Circle	Major Street Volume	Minor Street Volume	Exceeds Warrant 1 thresholds?
AM	Massachusetts Ave (East Leg)	1043	774	Yes
	Massachusetts Ave (West Leg)	1170	1580	Yes
PM	Massachusetts Ave (East Leg)	1031	1354	Yes
	Massachusetts Ave (West Leg)	1425	1434	Yes

Warrant 2 – Four Hour Vehicular Volume



Peak Hour	Approach leg to Ward Circle	Major Street Volume	Minor Street Volume	Exceeds Warrant 2 thresholds?
AM	◆ Massachusetts Ave (East Leg)	1043	774	Yes
	● Massachusetts Ave (West Leg)	1170	1580	Yes
PM	◆ Massachusetts Ave (East Leg)	1031	1354	Yes
	● Massachusetts Ave (West Leg)	1425	1434	Yes

Operational Evaluation as a Traffic Circle

Since the existing traffic models were developed using Synchro, PB developed an adaptation of this model to evaluate the operations at Ward Circle assuming it is reconfigured as a traditional traffic circle as shown in Figure 5.

From multiple trials using alternate lane configurations, it was apparent that the ideal configuration for the traffic circle option involved widening to four lanes throughout the circumference of Ward Circle, providing two "through" lanes and two "exit" lanes at each quadrant approaching the respective exit legs.

Figure 7 – Synchro Results – Traffic Circle Analysis (AM & PM)

Peak Hour	Approach leg to Ward Circle	Operations for Approach		
		Delay (s/veh)	Queue (95th%ile - ft)	LOS
AM	Nebraska Ave (North Leg)	175.5	466	F
	Nebraska Ave (South Leg)	278.7	594	F
	Massachusetts Ave (East Leg)	43.2	314	D
	Massachusetts Ave (West Leg)	452.8	808	F
PM	Nebraska Ave (North Leg)	360.8	647	F
	Nebraska Ave (South Leg)	256.4	572	F
	Massachusetts Ave (East Leg)	345.4	682	F
	Massachusetts Ave (West Leg)	378.3	724	F

Notes
(1) – Queue limited by metering from upstream intersection

As shown in Figure 7, Synchro indicates the introduction of signalization results in significant delays at all points of entry to the circle in both the AM and PM peak periods, representing greater congestion than current conditions and effectively failing LOS for Ward Circle as a whole.

Conclusions and Recommendations

Though the intersections around Ward Circle appear likely to meet MUTCD signal warrants, Synchro analysis does not show signalization of these intersections to have a positive effect on intersection operations. Removal of the Nebraska Avenue bypass lanes has a significant effect on traffic movements within the circle as two lanes appear insufficient to handle the combined circulating volume of Nebraska Avenue and Massachusetts Avenue in a configuration as a fully signalized traffic circle, even with the introduction of double right turns at all exit points from the circle.

With regards to safety, weaving and its associated issues would be less of a problem in the new configuration, because removing the bypass lanes means removing four potential conflict points. However, a circle by nature has weaving movements, and clear signage and pavement markings would be needed to minimize unsafe weaving.

Conversion to a signalized traffic rotary could improve pedestrian safety by providing protected crossings for pedestrians. The crossing of Nebraska Avenue would likely be shorter due to new spitter islands that would act as pedestrian refuges. If desired, protected crossings into the Circle could be added.

Note that Synchro is not the ideal tool for modeling a series of closely spaced intersections with complex traffic routing decisions, such as is the case for Ward Circle. Though this evaluation provides some measure of comparison with the results obtained for the existing conditions models, it is recommended that future analysis at this location utilize a more robust and time-intensive microsimulation tool such as VISSIM.