The Folded Interchange: An Unconventional Design for the Reconstruction of Cloverleaf Interchanges

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I. ABSTRACT

This paper presents the Folded Interchange design and compares its relative advantages and disadvantages between unconventional and conventional interchanges. Proper selection of interchange type must maintain a balance between safety, operations, environmental and right-of-way impacts, and costs.

Many of the existing interchanges that will be reconstructed as the US infrastructure ages are cloverleaf interchanges at the intersection of a freeway and an arterial roadway. The cloverleaf interchange is typically plagued by accident and congestion problems in its weaving sections on both the freeway and arterial roadways. On the arterial roadway, there are typically signalized intersections abutting the interchange, further complicating the weave and merge movements and causing additional accidents and traffic congestion. The Folded Interchange is ideally suited for the reconstruction of failing cloverleaf interchanges between a full-control-of-access freeway and an arterial roadway.

The Folded Interchange combines some of the elements of the diverging diamond and continuous flow interchange elements to optimize operational efficiency while maintaining the basic footprint of the existing cloverleaf interchange to minimize costs and impacts.

This paper is the summary of observations from two case studies involving interchange selection where the Folded Interchange was selected as the preferred alternate. The studies considered traffic and operations analyses, right-of-way and environmental impacts, and construction costs. In each of the case studies, the Folded Interchange offered superior traffic operational performance, with lower costs and fewer right-of-way and environmental impacts compared to other conventional and unconventional interchanges evaluated for freeway-to-arterial intersections.

II. INTRODUCTION

The purpose of this paper is to present the Folded Interchange design and discuss appropriate applications so that it may be added into the transportation engineer's toolbox of ideas. The paper is a result of several interchange studies performed within the State of Maryland wherein this type of intersection was selected by the design team to be the preferred option for the reconstruction of cloverleaf interchanges. This paper is written from the viewpoint of a practitioner, not a researcher, and as such due consideration is given to practical solutions to mitigate transportation problems, and not solely to present another idea. **See page 4 of this paper for plan and typical section views of the Folded Interchange**.

III. BACKGROUND

As the United States' infrastructure ages, traffic congestion is one of the major issues confronting our cities. Vehicle-miles of travel have increased while lane-miles have remained relatively static. Changes in environmental laws and policies, and the continued rise of political action groups have changed the definition of an ideal design from the transportation engineer's perspective. No longer can the transportation engineer recommend improvement options that have considerable right-of-way or property takes, or that do not consider all highway users (cars, trucks, pedestrians, bicycles, etc), or that are fiscally infeasible. The transportation engineer's challenges are great in that we must develop solutions that mitigate existing congestion and serve future traffic demands, safely accommodate all highway users, are within budget and constructable, and increase safety.

The rehabilitation and reconstruction of our interchanges is of paramount importance. Interchanges are generally the source points for the freeway congestion that plagues our nation. Many of the existing interchanges that will be reconstructed are cloverleaf interchanges at the intersection of a freeway and an arterial roadway. The cloverleaf interchange is typically plagued by accident and congestion problems in its weaving sections on both the freeway and arterial roadways. On the arterial roadway, there are typically signalized intersections abutting the interchange, further complicating the weave and merge movements and causing additional accidents and traffic congestion.

IV. INTERCHANGE SELECTION

Proper selection of interchange type must maintain a balance between safety, operations, environmental and right-of-way impacts, and costs. Recent publications on unconventional designs have added many types of interchanges from which to choose. However, most of the unconventional interchanges currently under study are not applicable to arterial-freeway interchanges since they propose a signalized intersection on both crossing roadways (including the freeway). Full and semi directional interchanges are often not feasible or practical from a cost and right-of-way perspective with an intersection with an arterial due to nearby development and adjacent signalized intersections. Thus, for freeway-to-arterial interchanges, the remaining feasible choices are:

- Single Point Urban Interchange (SPUI)
- Diamond or Tight Diamond Interchanges
- Parclo-type Interchanges
- Diverging Diamond Interchange
- Michigan Urban Diamond Interchange
- Roundabout (Single and Double/Teardrop) Interchanges
- Contraflow Left Interchange
- Other options that retain the basic cloverleaf footprint such as collector-distributor roads.

For a complete description of unconventional intersections listed above, see http://attap.umd.edu/uaid.php which is the Applied Technology and Traffic Analysis Program

website supported by the University of Maryland at College Park and the Maryland State Highway Administration Office of Traffic and Safety.

Depending upon the project, many of above choices are not practical given the existing right-of-way and environmental constraints associated with the reconstruction or construction of an interchange. Many agencies are planning on converting their existing cloverleaf interchanges into Single-Point Urban Diamond, Diamond, or Partial Cloverleaf type interchanges. These interchanges are often used because they eliminate the problematic weaving areas, are compact in design thus minimizing impacts and accommodate high left turning volumes.

IV. THE FOLDED INTERCHANGE

A. Description

The Folded Interchange combines some of the elements of the diverging diamond and continuous flow interchange elements to optimize operational efficiency while maintaining the basic footprint of the existing cloverleaf interchange to minimize costs and impacts. The Folded Interchange is ideally suited for the reconstruction of failing cloverleaf or partial-cloverleaf interchanges between a full-control-of-access freeway and an arterial roadway.

Within the Folded Interchange, along the arterial roadway, there are four sets of one-direction traveled ways separated by a physical median or barrier. The two outside traveled ways are the opposing through movements; the inside traveled ways are the left turning movements. The Folded Interchange "folds' or switches the left turning movements on the arterial roadway so that opposing left turns pass on the right, rather than on the left as in a conventional design (conventional for right-hand drive rule). The Folded Interchange maintains all of the directional ramps and two of the loop ramps from the existing cloverleaf interchange, and adds two two-phase traffic signals to control the intersection of the left turning movement traveled way and the opposing through movement. The arterial roadway off-ramp loops (the ramps that move the arterial traffic to the freeway) are removed from the existing cloverleaf interchange so that all four weaving sections from the existing interchange are removed. The two loop ramps that are retained are the ramps from the freeway to the arterial roadway.

Figures 1 and 2 illustrate "wiring diagrams" of an existing Cloverleaf interchange and a Cloverleaf interchange modified into a Folded interchange, respectively. **Figures 3 and 4** illustrated typical sections along the arterial roadway of a cloverleaf and Folded interchange, respectively.

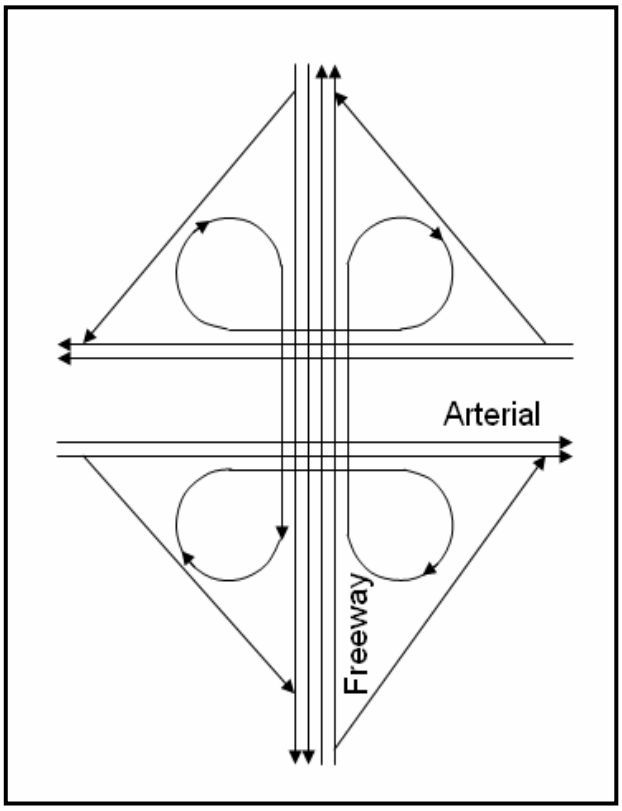

Figure 1. Cloverleaf Interchange

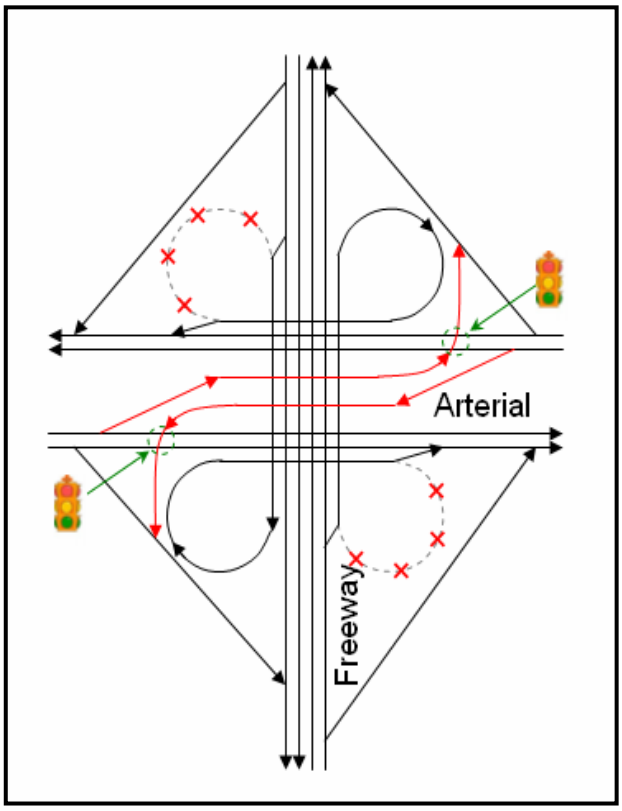

Figure 2. Folded Interchange

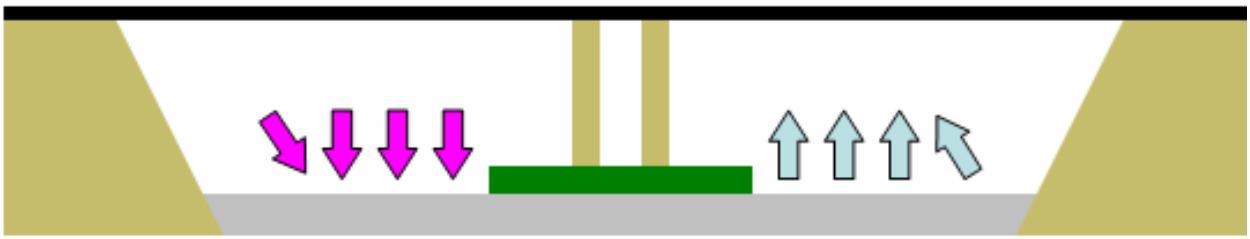

Figure 3. Arterial Roadway Typical Section, Cloverleaf Interchange

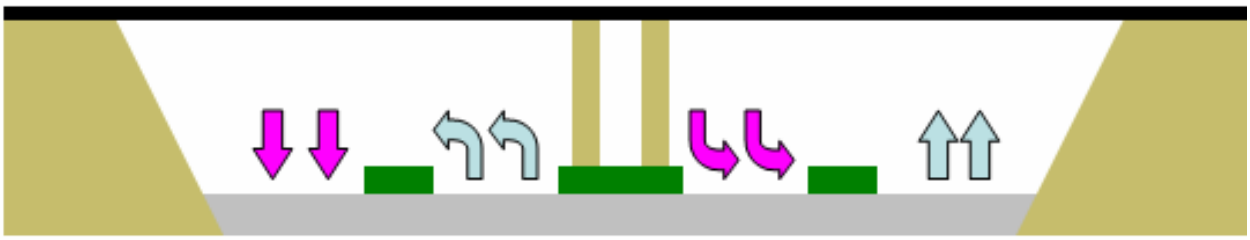

Figure 4. Arterial Roadway Typical Section, Folded Interchange

B. Case Study No. 1: I-695 at US 40 in Baltimore, Maryland

Interstate 695 is a full-control-of-access 8-lane freeway circling the City of Baltimore, Maryland. US 40 is an 8-lane divided principal arterial. The area near the interchange is fully developed. The interchange serves a regional shopping mall, several large communities and business parks, and also serves as access into the northern part of the central business district in the City of Baltimore. The right-of-way lines for the interchange are within 50 feet from the edge of the ramps, and are abutted by a park, residential communities, a shopping mall and a business park. The nearest traffic signals are 500 feet from the terminus of the I-695 off- ramps. The existing interchange was modified from a full-cloverleaf interchange into a partial cloverleaf (Parclo) in 2007-2008 in order to eliminate the problematic weaving sections on US 40 and I-695. The modification was an interim solution. This purpose of this study was to determine the ultimate interchange type that should be carried forward to final design. The final design would have to accommodate future widening of I-695, safely and efficiently accommodate future traffic volumes, could not impact the parkland, homes, or businesses adjacent to the right-of-way lines, and could not add additional lanes on US 40 beyond the limits of the interchange.

Highway Capacity Manual Level of Service (LOS) analyses and corridor simulation analyses were performed for several interchange types as shown in **Table 1**. A semi-direct interchange was initially evaluated and then dropped due to the high number of property acquisitions. Since the PM peak hour is critical, only the PM peak hour analysis is shown. **Figure 5** illustrates the PM peak hour 2025 traffic volume projections. The LOS analysis indicated the Folded and Parclo interchanges were viable options. However, the simulation analysis of the Parclo interchange showed left turning queues into the I-695 ramps spilling out of the turn bays and into the adjacent intersections. Additionally, under the existing Parclo interchange, three through lanes are required on both directions of US 40 in order to provide an acceptable LOS.

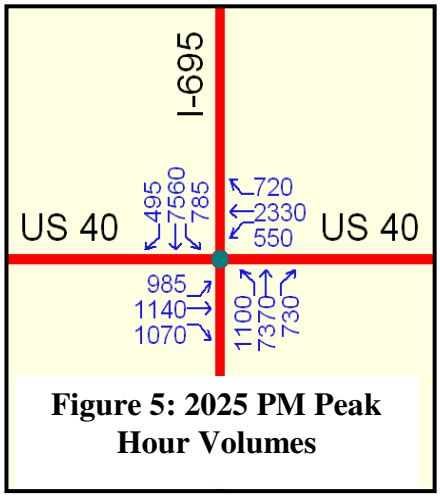

Figure 5: 2025 PM Peak Hour Volumes

TABLE 1. US 40 Traffic Analysis Summaries

Alternative	Signalized Intersection LOS (Avg. Delay per Vehicle)	Arterial LOS (Arterial Travel Time) *interchange and adjacent intersections*	
		Eastbound	Westbound
SPUI	F (82 sec.)	Intersection LOS F, not evaluated	
Michigan Urban Diamond	F (490 sec.) / F (156 sec.)	Intersection LOS F, not evaluated	
Diverging Diamond	E (77 sec.) / E (74 sec.)	E (6.7 min.)	F (14.2 min.)
Folded	B (13 sec.) / C (31 sec.)	D (4.7 min.)	F (10.6 min.)
Parclo (existing)	B (15 sec.) / B (15 sec.)	D (5.1 min.)	F (10.6 min.)
Diamond	E (74 sec.) / F (102 sec.)	Intersection LOS F, not evaluated	

However, under the Folded Interchange, only two through lanes are required to provide the same LOS. Thus, under the Folded interchange, the two I-695 ramps to US 40 would be able to add onto US 40 to complete the 4-lane typical section, whereas under the Parclo interchange, one of the two on-ramps would have to merge onto US 40. The simulation analyses of the Parclo interchange showed queues developing at the ramp merge points and extending along the ramp an onto the interstate highway. Since the I-695 ramps to US 40 under the Folded interchange did not have a merge condition, queues did not develop and thus did not spill back onto the interstate roadway. For these reasons, the Folded interchange was selected as the preferred alternative.

The existing width of US 40 under I-695 consists of 12-lanes and a center median with the I-695 bridge piers. The geometric layout of the Folded interchange consists of the 11-lanes, but with the addition of two extra medians. **Figures 6 and 7** compare the typical sections between the existing Parclo interchange and the proposed Folded interchange. The Folded interchange layout was able to fit within the existing typical section. **Figure 8** illustrates the Folded interchange concept applied to the US 40 at I-695 interchange.

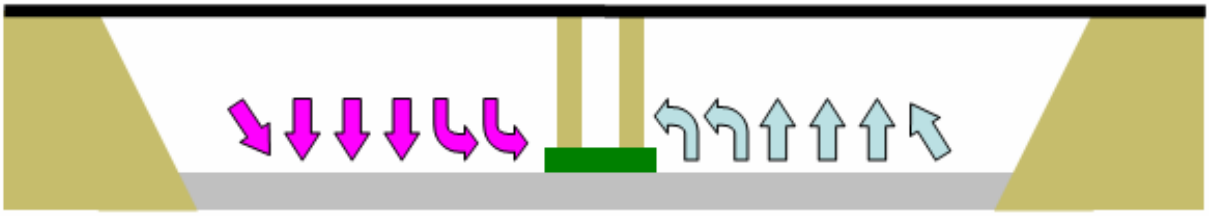

Figure 6. US 40 Existing Parclo Typical Section

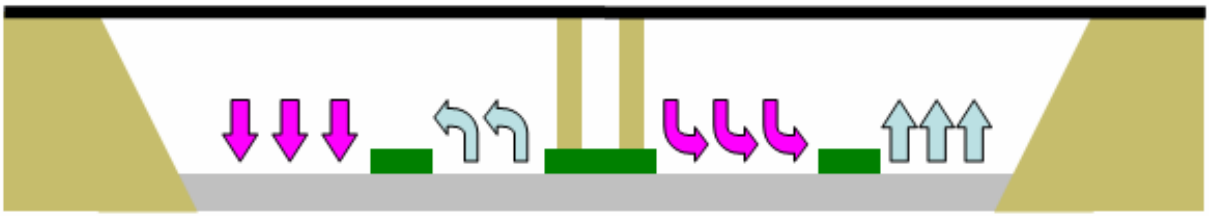

Figure 7. US 40 Folded Typical Section

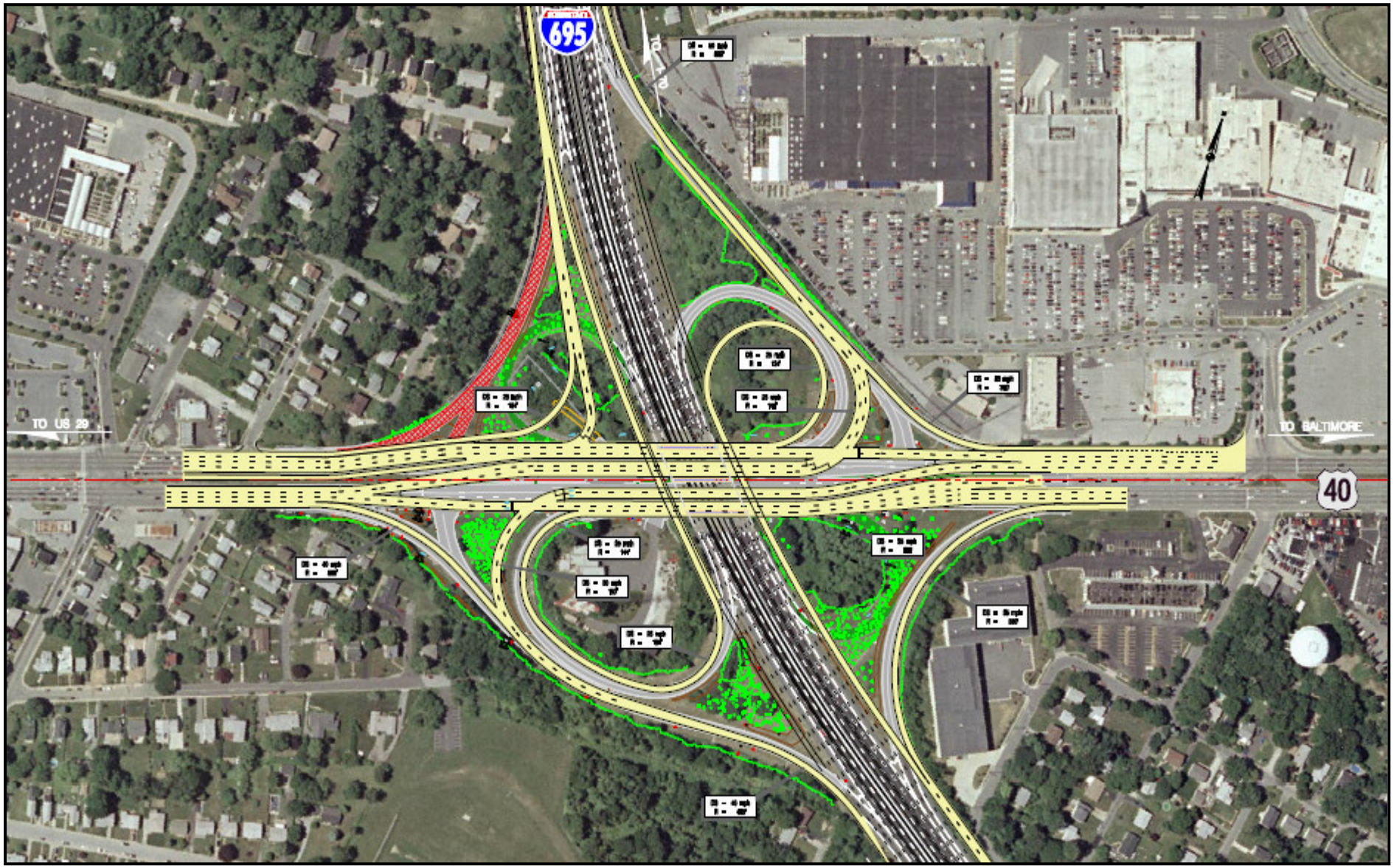

Figure 8. US 40 at I-695 Folded Interchange

C. Case Study No. 2: I-270 at MD 85 in Frederick, Maryland

Interstate 270 is a full-control-of-access freeway and MD 85 is a principal arterial roadway. When this study was performed the interchange was in the planning stages for reconstruction and widening of both I-270 and MD 85, and a preferred alternative was already identified. In the middle of the planning process, the forecasted 2025 traffic volume projections were updated. The planning option was reevaluated under the revised forecasted volumes and the resulting traffic analyses showed that it would not perform acceptably in terms of signalized Level of Service (LOS) and showed that the weaving section along MD 85 would operate poorly and cause queues that would extend into the adjacent signalized intersections on MD 85.

This purpose of this study was to determine the ultimate interchange type to be recommended at the conclusion of the planning study. The key constraints in this study were: 1) the proximity and intensity of development immediately adjacent to the interchange rights-of-way, 2) the fact that the two roadways intersect at a 30-degree skew, and 3) weaving along northbound I-270 between the MD 85 on-ramps and the I-70 interchange to the north. One item that is typically a constraint, but was not for this project, is that additional lanes could be recommended over and above what was initially developed in the planning study – both within the interchange itself and at the signalized intersections immediately adjacent to the interchange – as long as the impacts did not require a total take of the adjacent property.

The existing interchange is bordered by a large business park, a hotel complex, a regional mall, and a shopping center. Since the project planning study proposed widening I-270 from a 4-lane to an 8-lane facility with collector-distributor roadways, some impacts to the parking lots of these facilities were anticipated. However, property impacts were to be minimized and impacts to buildings (or any impacts that would require a total take of the business) were to be avoided. The skew of the interchange also played an important role in determining an acceptable interchange type. Some of the initial concepts proposed retention of existing loop ramps. However, the ramps carry a significant percentage of heavy vehicles (15% or more) and the radius of curvature would not be adequate when modified to accommodate the planned I-270 widening. As a result, flyover ramps were proposed to replace the loop ramps at the acute angles of the interchange.

It should be noted that spur ramps (a diamond interchange type) were evaluated instead of flyovers. However, due to the heavy design traffic volumes, adding a third approach to the signalized intersection would not provide an acceptable Level of Service using the same number of lanes as would the Folded Interchange. In other words, the Folded Interchange operated more efficiently than the Diamond Interchange. Highway Capacity Manual Level of Service (LOS) analyses, Maryland State Highway Administration Critical Lane Volume (CLV) analyses, and corridor simulation analyses were performed for three interchange types as summarized in **Table 2**. Since the PM peak hour was critical in terms of design volumes, and the CLV Method of analysis was used as the primary gauge of intersection performance, Table 2 only presents the PM peak hour CLV LOS analyses. The CLV method of analysis is similar to the Critical Movement Analysis method; the only input data required is approach volumes, lane configurations and signal phasing.

TABLE 2. MD 85 Traffic Analysis Summaries

Alternative	CLV LOS (v/c Ratio)	
	SB Ramps	**NB Ramps**
Planning Option (Parclo / Diamond)	E (1.16)	F (1.42)
Flyover / Diamond	F (0.98)	F (1.07)
Folded	D (1.04)	E (0.92)

The Folded Interchange for I-270 at MD 85 is presented in **Figure 9**. The traffic analysis showed that the Folded Interchange would operate at an acceptable LOS at all intersections in the project area and the simulation showed that it would operate well, without any queuing or blocking problems.

It may be observed that a flyover ramp would be an ideal solution to accommodate the northbound MD 85 movement to northbound I-270, which is projected at 2,067 vehicles per hour. A flyover ramp could not be designed due to the skew of the interchange, the anticipated property impacts, and anticipated weaving problems with the next interchange to the north associated with merging this ramp into I-270 further upstream than the location shown in Figure 11.

Since the Folded interchange provides three sets of medians along the arterial roadway, the bridge piers for the crossing freeway may be placed in each median, resulting in a multiple span bridge with a shorter beam depths and thus lower costs.

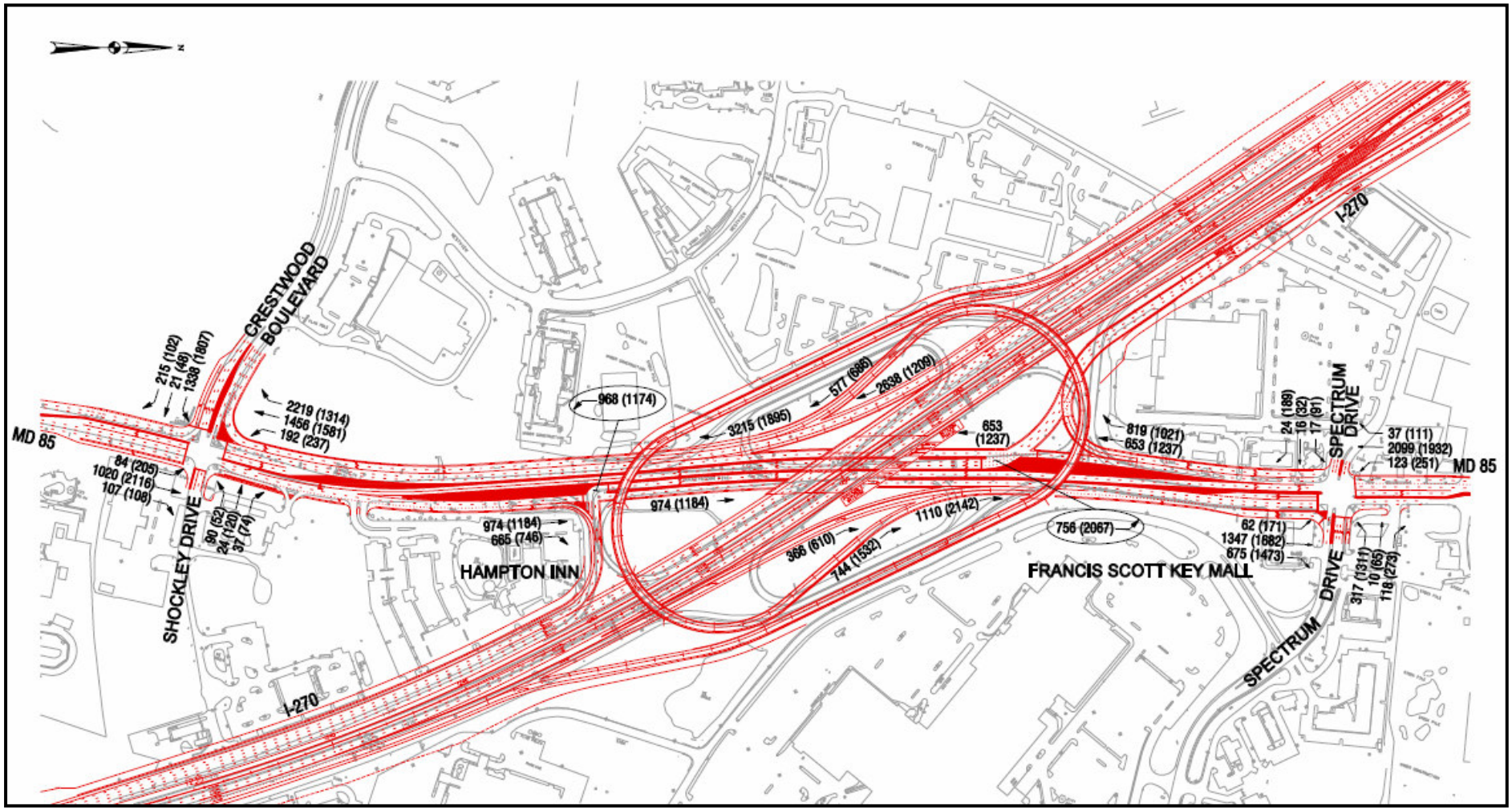

Figure 9. MD 85 at I-270 Folded Interchange

V. CONCLUSIONS

Based upon the two case studies presented above, the following observations are made regarding the applicability of adapting an existing cloverleaf interchange into a Folded interchange:

- The Folded interchange is appropriate for applications along arterials with high left turning volumes onto the freeway. Since the left turning roadways within the interchange should be separated by medians, the width of the traveled way should be at least 22 feet for a single lane to allow passing of a stalled vehicle. The same width could accommodate two travel lanes, and if only used for one travel lane may not provide as efficient design as a SPUI or Diamond interchange.
- When converting from a cloverleaf or partial cloverleaf type interchange, new ramps do not have to be constructed; the existing ramps may be utilized.
- The typical section along the arterial roadway may need to be wider than the existing typical section due to the additional medians required for the Folded interchange. Therefore, the Folded interchange is more easily adapted to locations with wide medians.
- When the arterial roadway crossed under the freeway, the Folded interchange's multiple medians provide opportunities for multiple span bridges. Multiple span bridges generally result in smaller beam depths, which are less expensive to construct.
- The Folded interchange is ideally suited for the reconstruction of failing cloverleaf interchanges between a full-control-of-access freeway and an arterial roadway. It also may be considered in place of SPUI and diamond interchanges. However, the Folded interchange has a larger footprint than the SPUI and Diamond interchanges, which may preclude its use.
- Under the Folded interchange, the number of lanes through the interchange is generally reduced compared to a SPUI or Diamond interchange. Since fewer through lanes are required, high-volume ramps may add lanes to the arterial roadway (rather than merge onto the arterial). Allowing ramps to add lanes may mitigate operational problems with a high-volume ramp merge.
- The Folded interchange is appropriate for application along arterials with signalized intersections close to the interchange with relatively high inbound and outbound flows. The Folded interchange adds two, two-phase signals. Each signal only controls one direction of flow along the arterial roadway, as there are two separate one-way roadways within the interchange. This allows more efficient signal timing and larger bandwidths as the offset at the two-phase signal may be designed to accommodate only one flow direction at a time. One problem observed with the Diverging Diamond in the US 40 case study was associated with the lack of two-way signal coordination; the same problems were not observed with the Folded interchange.

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