Unconventional Arterial Intersection Designs Initiatives

Minseok Kim, Xiaorong Lai, Gang-Len Chang, and Saed Rahwanji

Abstract—**This paper addresses initiative works done in the state of Maryland in order to provide a clearing house for unconventional arterial intersection designs (UAIDs) and apply their concepts to selected locations. As a collaborative research effort among the University of Maryland at College Park, Maryland State Highway Administration (MSHA), and Parsons Brinckerhoff Inc., a knowledge base web interface has been built to help traffic engineers, community planners, and elected officials to consider the UAID as a feasible solution for relieving arterial congestion and to select appropriate unconventional design schemes given actual traffic patterns. A great number of statistics on visits and page views show the beneficial effect of the website. The MSHA has also been active in adopting unconventional design concepts at local intersections that incurred operational or safety problems. This paper summarizes four case studies that have been conducted for those locations and treated relatively new UAID concepts, including: 1) superstreet intersection, 2) continuous flow intersection, 3) center turn overpass, and 4) roundabout at high speed approaches. Results of these case studies indicate that the unconventional intersection designs have promise of enhancing not only operational efficiency but also safety along the arterial.**

I. INTRODUCTION

RISING as a new alternative to relieve arterial congestion, the unconventional arterial intersection design (UAID) concept generally attempts to enhance operational efficiency at major arterial intersections by reducing the negative impacts of turning movements through various innovative intersection designs. General principles of operation and management strategies of the UAID include: 1) an emphasis on through traffic movements along the arterial, 2) a reduction in the number of signal phases (e.g., left-turn arrow phases), and 3) a reduction in the number of intersection conflict points. Although relevant studies are presenting operational benefits of the UAID with the use of traffic simulation, engineers, politicians and the driving public are reluctant to try the UAID that they are not familiar with. To effectively introduce unconventional intersection designs to highway agencies and the traveling public, it is crucial to communicate the range and depth of benefits that unconventional intersections can obtain for motorists, pedestrians, land owners, developers, highway agencies, taxpayers and elected officials [1].

This paper addresses initiative works done in the state of Maryland in order to provide a clearing house for unconventional arterial intersection designs and apply their concepts to selected locations. As a collaborative research effort among the University of Maryland at College Park, Maryland State Highway Administration (MSHA), and Parsons Brinckerhoff Inc., a knowledge base web interface (http://attap.umd.edu/uaid.php) has been built to help traffic engineers, community planners, and elected officials to consider the UAID as a feasible solution for relieving arterial congestion and to select proper unconventional design schemes given actual traffic patterns. Moreover, the MSHA has been active in utilizing unconventional design concepts for local intersections that experienced operational or safety concerns. This paper illustrates four case studies that have been conducted for those locations and adopted relatively new UAID concepts: 1) superstreet intersection, 2) continuous flow intersection, 3) center turn overpass, and 4) roundabout at high speed approaches. The features of those unconventional designs are described in the CASE STUDIES section.

II. LITERATURE REVIEW

A. *Need for Arterial Intersection Innovation*

Most arterial roadways in the United States accommodate direct movements in all directions, i.e., left, through and right, at major intersections. In general, the arterial intersection can be improved by adding turn lanes and/or protected left turn phases for conditions that require treatments due to high through or left turn volume demand or safety issues. While these conventional treatments satisfy public mobility and safety interests at individual intersections, they induce a trade-off in arterial's system performance and mobility [1].

B. *Benefits of Unconventional Arterial Intersections*

Comparing with the conventional design, the potential benefits of adopting the unconventional design have been revealed in many studies based on microscopic simulation experiments [2-9]. Whereas most of selected unconventional designs – the quadrant roadway intersection, median U-turn, superstreet, bowtie, jughandle, split intersection, and continuous flow intersection designs – lead to lower total travel times than the conventional design, the quadrant

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M. Kim is a PhD candidate with the Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742 USA (phone: 301-794-8175; e-mail: minseok@ umd.edu).

X. Lai is a PhD candidate with the Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742 USA (e-mail: xrlai@wam.umd.edu).

G. L. Chang is a professor with the Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742 USA (e-mail: @wam.umd.edu).

S. Rahwanji is a traffic engineering team leader with the Office of Traffic and Safety, Maryland State Highway Administration, 7491 Connelley Dr., Hanover, MD 21076 USA (e-mail: srahwanji@sha.state.md.us).

roadway intersection (QRI) and the median U-turn designs consistently produce the lowest travel times [2]. In particular, the QRI design is shown to reduce system travel time of 22 percent and significantly improve stopped delay. The QRI design performs most favorably under higher volume at saturated intersection conditions. Despite increase in the left-turn travel distance, the QRI design left-turn travel times are not significantly greater than the conventional design [3].

C. *Unconventional Design Implementation*

Planning and operations studies should consider the impacts of the unconventional intersection at various aspects, e.g., safety, capacity, pedestrian movements, air quality, the community, and project costs. Highway agencies and property owners must be convinced that changes to navigation and access will not compromise safety and economic development interests. Established intersections have shown that proper intersection geometric signing, marking, and public awareness campaigns are helpful for safely navigating unconventional intersections [1]. In implementing the split intersection design by converting a conventional cross intersection into two smaller signalized intersections, the distance between the two smaller intersections must be considered with regard to (a) a minimum distance for storage of the left-turn movement and (b) a longer distance to reduce delays and to allow for the simultaneous start of the green time for the through movements in the two intersections [8].

III. KNOWLEDGE BASE WEB INTERFACE

The current version of the knowledge base web interface was designed to facilitate collective information on a total of 22 unconventional arterial intersection types. The 22 unconventional intersection designs consist of a variety of 11 at-grade designs and 11 grade-separated designs. Among those designs, 10 at-grade designs and 8 grade-separated designs include a signalized intersection. Information on each unconventional intersection design is provided with respect to eight categories: 1) design description, 2) visual animation, 3) image library, 4) evolution of design, 5) design and operations, 6) studies and research, 7) lessons learned, and 8) locations found. A technical report of "Unconventional Arterial Intersection Design, Management and Operations Strategies" written by J. D. Reid played a key role in finding the source of collective information. However, VISSIM simulation models were exclusively built and recorded in 3D video files for the visual animation. Those video files are playable and downloadable on the web. Figure 1 shows the design description page of the median U-turn intersection design, which is a type of at-grade and signalized unconventional designs. Being a no.1 webpage in Google search with a key word of the unconventional arterial intersection design, the knowledge base web interface has been a huge success. As shown in Figure 2, the monthly totals of visitors and page views reached about 26,600 and 106,000, respectively in February, 2007.

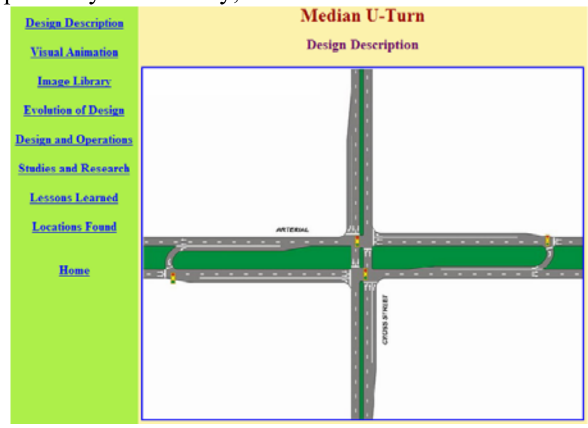
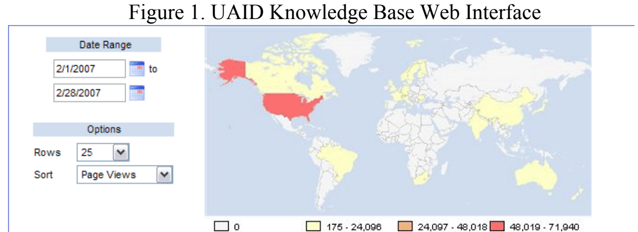


Figure 1. UAID Knowledge Base Web Interface



Rank	Country	Page Views	Visits	Hits
1	United States	71,940	16,920	217,333
2	N/A	15,062	4,199	43,330
3	Canada	3,982	1,068	12,833
4	United Kingdom	2,854	940	8,686
5	Australia	1,501	376	3,899
6	Germany	1,291	290	3,438
7	Netherlands	752	161	2,367
8	France	569	182	1,530
9	Portugal	567	129	1,573
10	Norway	458	85	1,236
11	Sweden	401	160	1,233
12	Spain	383	108	1,189
13	Finland	360	82	1,024
14	Belgium	322	92	949
15	India	283	115	962
16	Switzerland	281	84	812
17	Japan	281	93	690
18	Romania	267	73	776
19	New Zealand	263	53	776
20	Denmark	257	70	750
21	Hong Kong	254	47	1,132
22	Italy	233	73	685
23	China	222	82	591
24	South Africa	182	143	287
25	Brazil	175	46	529
Other Items (79)		2,776	900	8,166
Total(s)		105,916	26,571	316,776
Average(s)		1,018	255	3,045

Figure 2. Visitors to the UAID Web Interface (Feb. 2007)

IV. CASE STUDIES

A. *Superstreet Intersection: Safety*

The superstreet design is similar with the median U-turn design in that it restricts cross street through movements but features directional crossovers that serve left turns from the arterial. In the 1980, at-grade intersections of Frederick County in Maryland began to experience safety and operational problems. To avoid signalization and maintain as much free traffic flow as possible, problem intersections were modified with directional crossovers [10]. Figure 3 shows the satellite image of a superstreet intersection located near by Emmitsburg in Frederick County.

Six locations were studied as the following:

1) *US 15 @ US 15 Business*
- Before period = Sep. 1985 through Aug. 1988
- After period = Oct. 1988 through Sep. 1991
- Truck related accidents were reduced from 4 (in the before period) to 0 (in the after period)
- With no lighting improvements, nighttime accidents

decreased from 4 (before) to 0 (after)

Figure 3. Supersteet Intersection, US 15 @ College Avenue

- No accidents were reported at the U-turn locations in the after period

2) *US 15 @ MD 355/Hayward Road*
   - Before period = Sep. 1989 through Aug. 1992
   - After period = Oct. 1992 through Sep. 1995
   - The number of reported accidents decreased from 12 (before) to 9 (after)
   - Left turn collisions decreased from 8 (before) to 6 (after) 10 injury accidents
   - Injury accidents decreased from 10 (before) to 6 (after)
   - No accidents were reported at the U-turn locations in the after period
3) *US 15 @ Willow Road*
   - Before period = Nov. 1989 through Oct. 1992
   - After period = Dec.1992 through Nov. 1995
   - The number of reported accidents decreased from 6 (before) to 2 (after)
   - Angle collisions decreased from 3 (before) to 1 (after)
   - Left turn collisions decreased from 2 (before) to 0 (after)
4) *US 15 @ US 15A (Biggs Ford Road)*
   - Before period = Nov. 1989 through Oct. 1992
   - After period = Dec. 1992 through Nov. 1995
   - The number of reported accidents decreased from 13 (before) to 4 (after)
   - Angle collisions decreased from 11 (before) to 2 (after)
   - Injury accidents decreased from 8 (before) to 1 (after)
5) *US 15 @ Sundays Lane*
   - Before period = Nov. 1989 through Oct. 1992
   - After period = Dec. 1992 through Nov. 1995
   - Interestingly the number of reported accidents increased from 1 (before) to 5 (after), however, it is not directly related to the crossover modification or the increased volumes of U-turns from the south
   - In the before period, 1 sideswipe collision occurred resulting in a single injury
   - In the after period, 3 left turn collisions and 4 injury accidents occurred
6) *US 15 @ College Avenue*
   - Before period = Aug. 1991 through Jul. 1994
   - After period = Sep. 1994 through Aug. 1997
   - The number of reported accidents decreased from 11 (before) to 1 (after)
   - In the before period, 9 angle collisions and 8 injury accidents occurred
   - In the after period, 1 left turn collision occurred resulting in 2 personal injuries

While traffic volumes have increased at a rate of 7% per year in the last 16 years before this case study, before and after accident evaluations report that significant accident reductions have been achieved, and that the directional crossovers fulfilled their intended purpose of reducing angle accident experience. Thus, the directional crossover should and can be a useful tool on divided highways in situations where traffic signalization should be avoided, and/or where the crossing or left turning movement is a problem. Table I summarizes the average number of reported accidents per year for all six locations.

TABLE I
AVERAGE NUMBER OF REPORTED ACCIDENTS PER YEAR

Location	Before Period	After Period
US 15 @ US 15 Business	4.00	1.67
US 15 @ MD 355/Hayward Rd	4.00	3.00
US 15 @ Willow Rd	2.00	0.67
US 15 @ US 15A (Biggs Ford Rd)	4.33	1.33
US 15 @ Sundays Ln	0.33	1.67
US 15 @ College Ave	3.67	0.33
Average for All Locations	3.055	1.445

Source: Gene Straub, "US 15 Median Treatments (Directional Crossovers)", April 1999

B. *Continuous Flow Intersection: Operational Efficiency*

The main feature of the continuous flow intersection (CFI) is the removal of the left-turn movement by adding a signal-controlled mid-block intersection on the approach about 300 feet from the main intersection. Left turning vehicles enter a left turn lane at this mid-block intersection and cross an oncoming traffic using a protected phase that concurrently runs with the green phase of the cross street through movement at the main intersection.

The CFI design is new in the United States, but many jurisdictions have begun considering it as a feasible solution to congestion at arterial intersections. Only three CFIs are existing in the United States as of March 2006, and one of them is located at the 3-leg intersection of MD 210 and MD 228 in Prince George's County, Maryland. The mid-block intersection was newly added to the northbound approach of MD 228 as shown in Figure 4. By doing this treatment, the westbound left turn traffic from MD 228 approach is required to enter the mid-block in ahead of the main intersection. Figure 5 illustrates the vehicular movements of this CFI intersection in CORSIM simulation environment.

In August, 2005, a comparative study was conducted by building a CORSIM microscopic simulation model. Simulation results indicate that the CFI design can result in significant reductions in delay for through and left turn movements on the arterial, i.e. MD 210. Table 3 presents

Figure 4. Continuous Flow Intersection, MD 210 @ MD 228

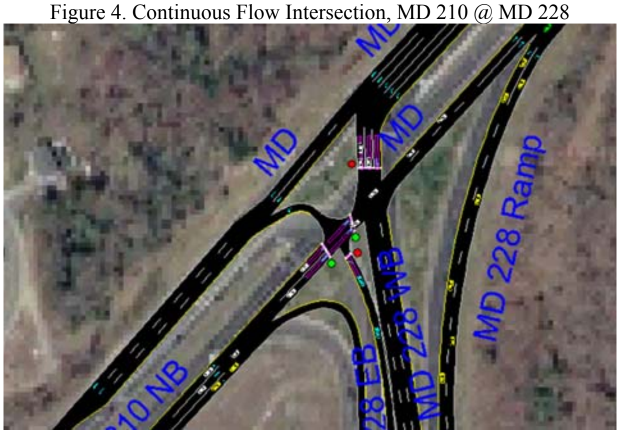


Figure 5. CORSIM Simulation of the CFI, MD 210 @ MD 228

comparing the conventional T-intersection with the CFI T-intersection.

TABLE II
SIMULATED AVERAGE DELAY (SECOND/VEHICLE)

		MD 210		MD 228
		NB Through	SB Left	WB Left
Conventional T-Intersection	AM Peak	41.9	68.5	45.1
	PM Peak	56.9	49.7	68.9
Continuous Flow T-Intersection	AM Peak	12.3	29.7	42.7
	PM Peak	17.6	15.5	71.9
Reduction (%)	AM Peak	70.6	56.6	5.3
	PM Peak	69.1	68.8	-4.4

AM Peak = 6:30 – 7:30, PM Peak = 16:00 – 17:00.

C. *Center Turn Overpass: Operational Efficiency*

The center turn overpass (CTO) is a type of grade-separated and signalized intersection such that left turn traffic is separated from both the arterial and cross street through and right turn movements by elevating all left turns to a separate, elevated intersection, as shown in Figure 6. There is no known application of the CTO design in the United States. In November, 2006, the feasibility of the CTO design was studied for the intersection of US 40 and Rossville Boulevard on east of Baltimore City, Maryland in order to deal with a significant amount of rear-end crashes along the arterial, i.e. US 40. Other alternatives – a bridge for either or both directions on the arterial and the median U-turn – were also considered.

Considering aggressive driving behaviors not tolerating nearly saturated traffic demand conditions as a main cause of the safety problem, the operational efficiency became a primary criterion in selecting a best alternative. The level of service (LOS), volume and capacity ratio (V/C), and maximum queue length were analyzed for each alternative given 2006 peak-hour traffic volumes and optimized signal control strategies. Critical lane volumes (CLVs) were estimated to determine the LOS and V/C. Based on the estimated CLV and cycle length, the average number of vehicles per cycle of a specific movement was calculated using Equation 1. Assuming a vehicle length of 25 feet and a surge factor of 1.4, the maximum queue length was calculated as the product of these two elements and the average number of vehicles per cycle. Table III and Table IV present results from the capacity and queuing analysis, respectively. Although the alternative with a bridge for both directions performed best, the CTO design was selected as the most feasible solution due to its higher cost-effectiveness and comparable efficiency.

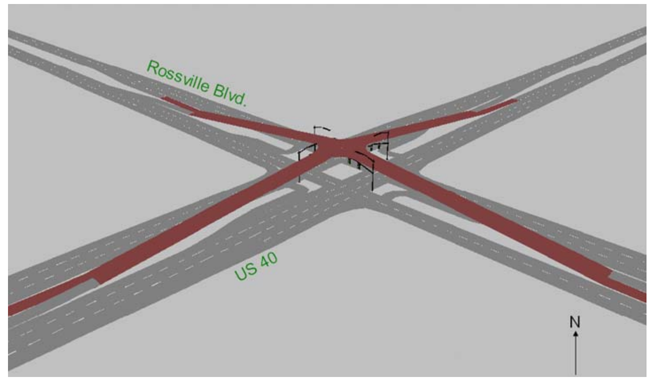


Figure 6. Proposed Center Turn Overpass, US 40 @ Rossville Boulevard

$$Avg\ Veh / Cycle = \frac{CLV\,(veh/hr) \times Cycle\ Length(\text{sec})}{3600} \quad \text{(eq.1)}$$

TABLE III
CAPACITY ANALYSIS RESULTS

Alternatives		AM Peak (LOS, V/C)	PM Peak (LOS, V/C)
Existing (Do Nothing)		E, 0.96	D, 0.86
Bridge for Eastbound(EB)		E, 0.96	D, 0.82
Bridge for Westbound (WB)		A, 0.59	D, 0.86
Bridge for Both Directions		A, 0.59	A, 0.56
CTO	On Bridge	A, 0.50	A, 0.62
	Under Bridge	B, 0.72	A, 0.59
Median U-Turn		E, 0.93	C, 0.79

TABLE IV
QUEUING ANALYSIS RESULTS (FEET)

Alternatives		AM Peak (EB / WB)	PM Peak (EB / WB)
Existing (Do Nothing)		713 / 1,568	1,034 / 945
Bridge for Eastbound (EB)		184 / 1,568	160 / 945
Bridge for Westbound (WB)		475 / 205	1,034 / 407
Bridge for Both Directions		205 / 263	119 / 301
CTO	Under Bridge	318 / 756	583 / 359
Median U-Turn		308 / 1,518	1,121 / 1,062

In implementing the CTO alternative, a compromise must be made between the benefit in operational efficiency and the restriction on accessibility to business areas where located at the intersection. The accessibility analysis that was additionally conducted shows that the negative impact on accessibility to business areas can be mitigated by allowing U-turns at the intersection for all approaches, as previously

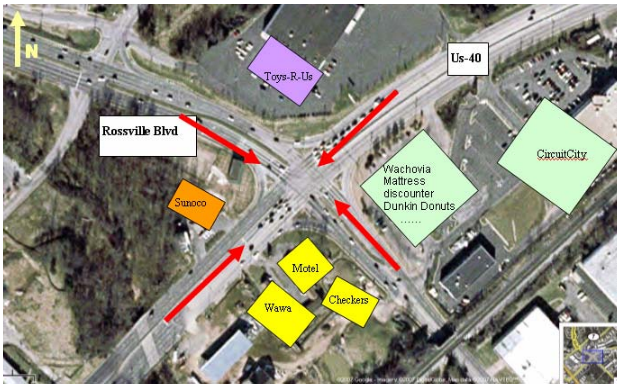


Figure 7. Business Areas, US 40 @ Rossville Blvd

TABLE V. ACCESSIBILITY ANALYSIS RESULTS FOR THE CTO

Business Type	US 40		Rossville Blvd	
	EB	WB	NB	SB
Sunoco	Δ	○	×	○
Motel Wawa Checkers	○	×	Δ	○
Dunkin Donuts Wachovia Mattress Discounter Circuit City	○	Δ	○	×
Toys-R-Us	×	○	○	Δ

○: accessible, ×: inaccessible, Δ: accessible with U-turn

illustrated in Figure 6. The distribution of business areas for the intersection of US 40 and Rossville Boulevard is presented in Figure 7. Results of the accessibility analysis are listed in TABLE V.

D. Roundabouts on High Speed Approaches: Safety

The modern roundabout is a type of circular intersection that features yield control for entering traffic, channelized approaches, and a geometric design for ensuring relatively low travel speeds (e.g. splitter islands). Unlike the modern roundabout concept has been very popular in European countries such as Great Britain, the Netherlands, and France, it is slowly gaining recognition in North America. In particular, the rising need for traffic control strategies in sprawling suburban and rural areas that are usually connected by high speed (45 miles per hour or greater) roadways is raising the question in North America of whether roundabouts are appropriate at intersections with high speed approaches [9].

Within recent five years, the Maryland State Highway Administration (MSHA) has implemented modern roundabouts at high speed rural locations. A report of "Accident Reduction with Roundabouts" published by Edward Myers present the accident data that were reported three years before as well as three years after the roundabouts were installed at those high speed approaches. Five roundabouts were studied as the following:

1) MD 94 / MD 144, Howard County (Lisbon Roundabout)
2) MD 63 / MD 58-MD 494, Washington County (Cearfoss Roundabout)
3) MD 213 / Leads Road- Elk Mills Road, Cecil County (Leads Roundabout)
4) MD 2 / MD 408-MD 422, Anne Arundel County (Lothian Roundabout; see Figure 8)
5) MD 140/ MD 832-Antrim Blvd., Carroll County (Taneytown Roundabout)

Figure 8. Roundabout at High-Speed Approaches, MD 2 @ MD 422

TABLE VI. ROUNDABOUT ACCIDENT FREQUENCY

(a) Before Accidents

Crash Type	Lisbon	Cearfoss	Leads	Lothian	Taneytown
Angle	23	6	8	13	12
Rear-End	0	1	1	2	2
Sideswipe	1	0	0	1	1
Left-Turn	0	1	1	8	1
Opposite Direction	0	0	0	1	1
Single Vehicle	0	1	0	0	2
Overturn	0	0	0	0	0
Avg. Annual Crashes	7.4	3.0	3.9	8.2	5.3
Avg. Injury Crashes	4.3	0.78	0.78	5.4	2.8

(b) After Accidents

Crash Type	Lisbon	Cearfoss	Leads	Lothian	Taneytown
Angle	3	2	2	1	0
Rear-End	1	0	0	8	1
Sideswipe	0	0	1	0	0
Left-Turn	1	0	0	0	0
Opposite Direction	0	0	0	0	0
Single Vehicle	10	0	14	3	2
Overturn	0	0	0	1	0
Avg. Annual Crashes	2.3	0.67	3.2	4.1	1.25
Avg. Injury Crashes	0.53	0.29	0.29	1.25	0.42

Source: Edward Myers, "Accident Reduction with Roundabouts"

Table VI summarizes the before and after accident results by accident type. The table also includes the reported average annual accidents and the injury crash rates three years before and three years after construction of the roundabouts. Table VII provides a summary of the accident severity before and after the roundabouts. Overall, the MHSA has achieved an accident reduction of 59% from an average of 5.56 accidents per year to an average of 2.3 accidents per year. Moreover, the reported injury accidents (including fatalities) have been reduced by 80%. All of the five roundabouts resulted in a reduction in accident frequency as well as accident severity.

TABLE VII. ROUNDABOUT ACCIDENT SEVERITY

Crash Type	Number of Accidents		Total Accident Cost	
Angle	62	8	$7,810,202	$1,007,768
Rear-End	6	10	$481,386	$802,310
Sideswipe	2	1	$121,638	$60,819
Left-Turn	11	1	$1,049,554	$95,414
Opposite Direction	1	0	$307,289	$0
Single Vehicle	3	20	$179,553	$1,197,020
Totals	85	40	$9.949,622	$3,163,331

Source: Edward Myers, “Accident Reduction with Roundabouts”

CONCLUSIONS

This paper addresses initiative contributions made in the state of Maryland to provide collective information on the unconventional arterial intersection design (UAID) and experiment their concepts at arterial intersections. A knowledge base web interface was built with a variety of detailed information on a total of 22 UAIDs, and its reputation has been successfully established in the country as well as in the world. The case studies of existing or newly proposed unconventional intersections in Maryland present revealed or potential benefits of four UAIDs: 1) the superstreet intersection, 2) continuous flow intersection, 3) center turn overpass, and 4) roundabouts at high speed approaches. The study results conclude that those selected UAIDs can achieve significant reductions in accident frequency, accident severity, stopped delay, and queue length.

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