Roundabout Feasibility for Improving a University Campus Intersection, Using Microscopic Traffic Simulation Approaches

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Abstract: This paper introduces a roundabout feasibility study for improving a stop-controlled university campus intersection located at University of South Alabama. The roundabout feasibility is evaluated based on two primary goals: 1) traffic performance, and 2) safety. A microscopic traffic simulation was conducted to assess the traffic performance of the roundabout. The result shows that the intersection improvement with a roundabout significantly upgrades the intersection Level of Service (LOS) and can accommodate forecasted future traffic conditions. In addition, the roundabout can significantly reduce the intersection crash. It is also expected through a cost-benefit analysis that the roundabout would pay for itself in the very near future with continuation of the cost savings for the traffic delay and crash reduction after its implementation.

Key-Words: - Roundabout, Campus Intersection Improvement, Feasibility, Microscopic Simulation

1 Introduction

The University of South Alabama (hereafter called USA) is located in Mobile, Alabama, and is one of the fastest growing universities in Alabama. The university has seen substantial enrollment increases over the last ten years, and has undertaken many new building construction projects on its main campus. However, traffic safety and operation on and around the campus have not been upgraded significantly, causing an increase in traffic crashes and congestion level. Through on-site visits and discussions with many USA employees and students, we have identified many traffic safety and operational issues on campus streets and intersections, particularly at the intersection of USA Drive N. and Health Services Dr. (see **Figure 1**).

1.1 Problem Statement

A frequent traffic overflow is observed around the intersection of USA Drive North and Health Services Drive. This is likely due to new traffic patterns generated from the new Health Science Building and Technology & Research Park, which have a strong AM/PM peak, and feed through the stop-controlled north and south legs of the intersection, conflicting with the uncontrolled east and west legs. The geometry of the intersection compounds this problem, as the north leg approaches the intersection at a 60^{o} angle, and the south leg is offset approximately 30 feet from the intersection. Additionally, heavy traffic mixed with pedestrians in peak hours causes a serious traffic safety problem. Thus, an engineering treatment with a detailed traffic analysis is needed to improve the intersection. Construction of the roundabout may be an effective means of improving operational efficiency of this intersection, since vehicles are not required to stop at the intersection if there is no conflicting traffic present.

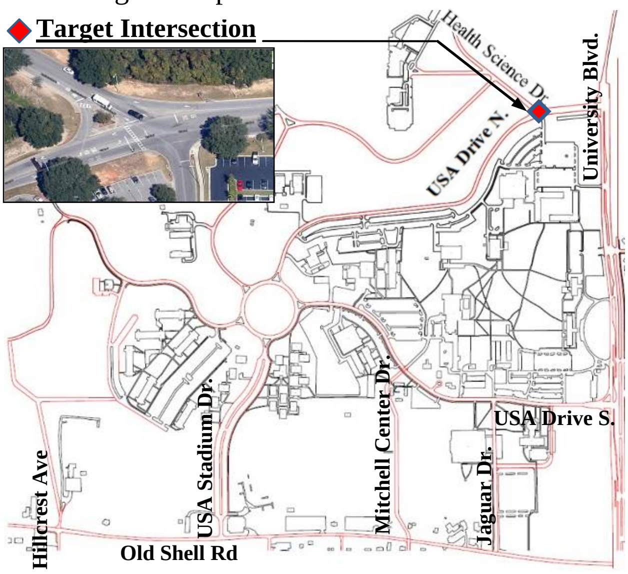

Figure 1: USA Campus Network

A roundabout would also be an effective treatment to improve the intersection safety since it can not only eliminate and/or alter traffic conflict points at the intersection, but also reduce crash severity by guiding drivers to reduce speeds as they proceed into and through the intersection.

1.2 Roundabout

A roundabout is a form of circular intersection in which traffic travels counterclockwise (in the United States and other right-hand traffic countries) around a central island and in which entering traffic must yield to circulating traffic [1]. Circular intersections have been used by the United States since perhaps 1905 when Columbus Circle was designed by William Phelps Eno in New York City. Around that time, many large circular intersections were built in the United States. Unfortunately, most circular intersection designs at that time gave priority to entering vehicles, encouraging high-speed merging and weaving. As a result, congestion and a high crash rate became associated with this type of intersection design, and their use became extremely unpopular. This experience was duplicated across many countries internationally, until the United Kingdom developed the modern roundabout in 1966. This modern roundabout design required entering traffic to yield to circulating traffic, which kept the roundabout from locking up. The new design also achieved better safety by shrinking the size of the required circle, which produced slower entry and circulating speeds.

Roundabouts are not the only type of circular intersection. Other types of circular intersection include rotaries, neighborhood traffic circles, and signalized traffic circles. Rotaries were popular prior to the 1960s, and often have diameters greater than 300 feet. This large diameter is a consequence of the length of the weaving section between the legs of the intersection. Maneuvers within a rotary can be quite challenging, since circulating traffic often must yield to entering traffic and lane changes are typically required for some movements. Neighborhood traffic circles are typically built only at local street intersections for traffic calming or aesthetic reasons. They normally do not include splitter islands to guide the approaching driver onto the traffic circle, and may be either uncontrolled or stop-controlled. Signalized traffic circles use traffic signals rather than yield signs to control entry to and circulation in the circular intersection. They also contain queue storage within the traffic circle, requiring a complicated progression of traffic signals. There are several critical differences between modern roundabouts and other circular intersections such as:

- Modern roundabouts are yield controlled on all entries, which means that the circulatory roadway has no control and traffic can flow unimpeded.
- All vehicles circulate counterclockwise in a modern roundabout, and pass to the right of the central island; some neighborhood traffic circles are too small for large vehicles to make left turns, and require that large vehicles pass to the left of the central island.
- Modern roundabouts with channelization reduce many traffic conflict points that exist in conventional intersections. This is accomplished by using entry flares and splitter islands.
- Parking is not allowed within the circulatory section of a modern roundabout.
- Pedestrian crossings are located only across the legs of the roundabout, separated from the circulatory roadway by at least one vehicle length.

The above critical differences improve safety by lowering driver uncertainty, shortening pedestrian crossing time, and reducing movements and stopping points. Other unconventional intersections such as continuous flow intersections, quadrant intersections, ThrU Turn intersections, and diverging diamond interchanges were also considered, but were not discussed here due to a lack of space.

1.3 Organization of the Paper

After Introduction, this paper will briefly introduce a microscopic traffic simulation method and explain safety benefit of the roundabout. Next, methods used in collecting data and calculating results will be explained. The existing condition of the target intersection will then be analyzed, after which the proposed condition of the intersection will also be analyzed. Finally, this report will conclude with a project summary and possible future research.

2 Research Method

2.1 Synchro Modeling

A microscopic traffic simulation software package (called Synchro 7/SimTraffic) was used to model traffic operation at the target intersection. Synchro 7 uses Highway Capacity Manual 2000 [2] (HCM 2000) methods to model traffic. These methods include a gap-acceptance based procedure for estimating capacity at single lane roundabouts. In a gap-acceptance based procedure, a driver on minor approach scans major traffic stream for an acceptable gap, and when it is found, the driver enters the priority traffic stream. Gap acceptance theory utilizes three characteristics of the traffic stream as follows.

- A gap must be available.
  - This is determined by headway distribution.
- An available gap must be useful.
  - This is determined by typical acceleration characteristics of a design vehicle.
- The rate that drivers fill larger gaps must be determined.
  - This is called follow-up time. Synchro determines these characteristics and uses them to evaluate capacity of a roundabout.

An extension to Synchro called SimTraffic was also used to model traffic operation of the target intersection using microscopic methods as a supplement to the Synchro analysis. SimTraffic uses a stochastic method (car following theory with probabilistic distributions of intersection entering vehicles) to generate traffic which decelerates, queues, and accelerates through traffic movements in a traffic system simulation while the computer records key data that affects delay and traffic count. Synchro and SimTraffic analysis results (for existing, no build, and build conditions) are summarized in **Table 3**.

2.2 Delay

According to a study performed by Eisenman et al. (2005) [3], average delays per entering vehicle of a newly installed roundabout are typically less than half those of the prior control option regardless of what the prior control option was. In traffic engineering, there are many different types of delay as follows:

- Stopped time delay: the length of time a vehicle is stopped while waiting to traverse an intersection
- Travel time delay: the difference between how quickly a driver wants to traverse an intersection and how quickly the driver actually traverses the intersection
- Time-in-queue delay: the time from a vehicle joining the intersection queue to that vehicle being discharged from the queue into the intersection at the stop bar
- Control delay: the delay a motorist experiences that is a direct result of the traffic control and conflicting traffic. This is calculated by adding time-in-queue delay to the amount of time lost decelerating to a stop and accelerating to travel speed at the intersection.

The Synchro software calculates control delay which we will use to assess the intersection LOS.

2.3 Crash Reduction

The results of National Cooperative Highway Research Program (NCHRP) Reports 572 [4] and 672 [1] were referred to evaluate the safety benefit of the roundabout. According to Eisenman et al. (2005) [3], 80% of the 35 intersection sites improved with a modern roundabout showed a reduction in the total number of accidents per year, and 83% of the surveyed sites showed a decrease in injury accidents as well. NCHRP Report 572 [4] later observed crash reduction with a point estimate of 35.4% reduction in total accidents and 75.8% reduction in injury accidents across 55 sites after installation of a modern roundabout as shown in **Table 1**. These compare well with numbers collected internationally as shown in **Table 2** from NCHRP Report 672 [1].

Table 1: US Roundabout Crash Reduction

Control Before	Sites	Setting	Lanes	Crashes recorded in after period		EB estimate of crashes expected without roundabouts		Index of Effectiveness θ (standard error) & Point Estimate of the Percentage Reduction in Crashes	
				All	Injury	All	Injury	All	Injury
All Sites	55	All	All	726	72	1122.0	296.1	0.646 (0.034) 35.4%	0.242 (0.032) 75.8%
Signalized	9	All	All	215	16	410.0	70.0	0.522 (0.049) 47.8%	0.223 (0.060) 77.7%
	4	Suburban	2	98	2	292.2	Too few	0.333 (0.044) 66.7%	Too few to estimate
	5	Urban	All	117	14	117.8	34.6	0.986 (0.120) 1.4%	0.399 (0.116) 60.1%
All-Way Stop	10	All	All	93	17	89.2	12.6	1.033 (0.146) -3.3%	1.282 (0.406) -28.2%
Two-Way Stop	36	All	All	418	39	747.6	213.2	0.558 (0.038) 44.2%	0.182 (0.032) 81.8%
	9	Rural	1	71	16	247.7	124.7	0.285 (0.040) 71.5%	0.127 (0.034) 87.3%
	17	Urban	All	102	6	142.7	31.6	0.710 (0.090) 29.0%	0.188 (0.079) 81.2%
	12		1	58	5	93.7	22.5	0.612 (0.101) 39.8%	0.217 (0.100) 80.3%
	5		2	44	1	48.9	Too few	0.884 (0.174) 11.6%	Too few to estimate
	10	Suburban	All	245	17	357.2	57.0	0.682 (0.067) 31.8%	0.290 (0.083) 71.0%
	4		1	17	5	77.1	21.8	0.218 (0.057) 78.2%	0.224 (0.104) 77.6%
	6		2	228	12	280.1	35.2	0.807 (0.091) 19.3%	0.320 (0.116) 68.0%
	27	Urban/ Suburban	All	347	23	499.9	88.6	0.692 (0.055) 30.8%	0.256 (0.060) 74.4%
	16		1	75	10	162.8	44.3	0.437 (0.060) 56.3%	0.223 (0.074) 77.7%
	11		2	272	13	329.0	44.3	0.821 (0.082) 17.9%	0.282 (0.093) 71.8%

Table 2: International Roundabout Crash Reduction

	Mean Reduction (%)	
Country	All Crashes	Injury Crashes
Australia	41–61%	45–87%
France	-	57–78%
Germany	36%	-
Netherlands	47%	-
United Kingdom	-	25–39%
United States	35%	76%

2.4 Data Collection and Calculation

Data for this study was collected by manual traffic count, using an existing traffic data collection form widely used in traffic studies. After the data collection, the traffic count was entered into an Excel spreadsheet, where the Peak Hour Factor (PHF) was calculated to range from 0.48 to 0.77 using the equation where PHF is equal to the highest hourly volume divided by 4 times the highest fifteen minute volume. Note that the PHF is used to consider the period during which traffic volume is at the highest.

An annual traffic growth factor was determined using campus parking registration information received from USA Parking Services. To calculate the growth factor, the 2006 total enrollments in USA campus parking was subtracted from those in 2012, and this number was divided by the 2006 data. Finally, it was divided by 7 to calculate the annual growth factor of 3% as follows:

$$GF = \frac{A - B}{B} * 100 / 7 \; years \qquad (1)$$

where GF = Traffic growth factor
A = 2012 total campus parking enrollment
B = 2006 total campus parking enrollment

Equation (1) gives the straight line growth between the two points. To verify the estimated traffic growth factor, a regression analysis was also conducted using the referenced parking data and yielded similar results. The 3% traffic growth factor was then used to forecast future traffic flow for the year of 2020. Note that 2013 parking data was not used due to lack of a complete dataset as 2013 fall permit issuances were not yet included. Note that we assume the traffic growth factor applies to all entrances to the USA campus, since traffic was not measured at all campus entrances for comparison.

3 Existing Condition

3.1 Intersection Layout

The geometry of the target intersection is not that of a typical 2-way stop-controlled intersection, and causes additional delay beyond that caused by volume and traffic control. The primary observed issues are as follows:

- The north leg approaches the intersection at a 60^{o}, which makes a driver turn his head at a difficult angle to see east-bound traffic.
- The south leg is offset approximately 30 feet east from the intersection center, which makes a driver swerve through the intersection for the north-bound movement. In addition, it causes driver uncertainty, as the south-bound left movement takes much longer to clear the north-bound lanes than would be expected at a typical intersection.
- There are two receiving west-bound lanes and only one lane in all movements supplying the west leg. This causes driver uncertainty, as south-bound left turn and north-bound right turn vehicles want to turn into the “extra” lane while west-bound through vehicles are making their movement, but no clear traffic device authorizes this movement.

All these issues led to frequent driver uncertainty observed when taking traffic measurements at this intersection.

3.2 Synchro Analysis

A Synchro analysis was conducted to assess the Level of Service (LOS) of the existing 2-way stop-controlled intersection. The analysis shows that the north and south-bound approaches of the intersection are currently operating at or near capacity conditions. More specifically, the LOS for the south-bound left movement is F during the AM and Lunch peaks, while D at the PM peak. Note that the Synchro LOS analysis is based on HCM 2000 [2] delay criteria, and LOSs A, B, and C are considered acceptable for traffic operation at an intersection, while D, E, and F are considered unacceptable due to excess delay. A summary of the Synchro analysis for the existing condition of the intersection is shown in **Table 3**.

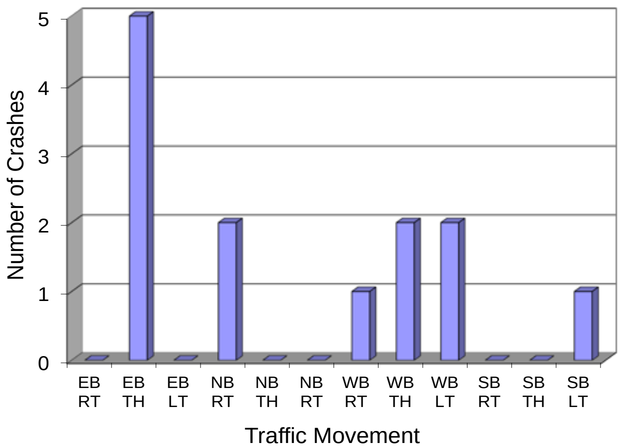

Figure 2: Crash Frequency in an 8-Year Period per Traffic Movement

3.3 Crash Analysis

Ten crashes have occurred at this intersection in the past eight years according to crash data obtained from the USA Police Department. Of those ten

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crashes, none were reported as involving physical injury, and the crash frequency is distributed fairly evenly over the turning movements with the east-bound through movement showing the highest crash frequency. This distribution is shown in **Figure 2**. Note that the statistics for this figure were created by counting a crash involving two separate traffic movements as one crash for each movement. A crash involving only one traffic movement was counted as just one crash. According to the crash narratives, the most frequent cause of these crashes was driver inattention.

4 Proposed Condition with Roundabout

4.1 Roundabout Layout

The roundabout considered in this feasibility study (see **Figure 3**) has several key features as follows:

- A modern single-lane roundabout with a 150 foot outer diameter;
- A 12 foot driving aisle with a 16 foot apron inside the driving aisle to allow access with a WB-67 design vehicle described in AASHTO 2011 [5], which is a typical 18-wheeled interstate semi-trailer;
    - This was the result of analysis with the WB-67 design vehicle using AutoCAD 2013 AutoTurn software [6], which allows the software user to simulate driving the design vehicle through an intersection, while tracking wheel paths.
- Splitter islands on each of the legs to better direct traffic entering and leaving the roundabout;
    - This will eliminate driver indecision at the entrances and exits.
    - This will also improve pedestrian safety by providing a “safe spot” for pedestrians crossing the two lanes of traffic.
- Extra lanes on the western leg are eliminated at the roundabout.
    - This allows for more green space if demolition is the chosen option.
    - Some encroachment will be required on the parking lots to the southwest and southeast, causing a loss of two to four parking spaces, which could be mitigated with the parallel parking above referenced.

Figure 3 shows two conceptual design options for the new roundabout with these features, with consideration given to a tree on the west side of the existing drive. Note that a detailed site survey was not performed, and findings such as grade, underground utility lines, easements, or other similar considerations of a detailed site survey could cause changes to these conceptual design plans.

(a) Option 1: Southern leg places a tree in the splitter island

(b) Option 2: Southern leg keeps the proposed roadway 10 feet from a tree

Figure 3: Roundabout Design Option

4.2 Synchro/SimTraffic Analysis

Synchro/SimTraffic analysis was conducted to assess the LOS of the intersection for future conditions in year 2020 (i.e., No-Build and Roundabout Build conditions as shown in **Table 3**). The analysis indicates that the future No-Build condition using a 3% traffic growth rate will have LOS F for the south-bound left turn at all peaks, as well as LOS F for all other north-bound movements and the south-bound through movement during the AM peak. In addition, north- and south-bound approaches will be operated at (i.e., LOS E) or near capacity (i.e., LOS D or C) conditions during Lunch and PM peaks. With the roundabout, however, the analysis shows that the intersection traffic operation will be dramatically improved; LOS for all intersection approaches, including north- and south-bounds, will become A as shown in **Table 3**. A screenshot of SimTraffic simulation for each of 2020 No-Build and Build conditions is shown in **Figure 4**. Note that there is no significant difference between Options 1 and 2 in terms of the LOS result.

Table 3: LOS Analysis Result for Existing, No-Build, and Roundabout Build Conditions of the Intersection

	Existing Conditions (2013)						No-Build Conditions (2020)						Roundabout Build Conditions (2020)					
	AM Peak		Lunch Peak		PM Peak		AM Peak		Lunch Peak		PM Peak		AM Peak		Lunch Peak		PM Peak	
Movement	Delay s/veh	LOS HCM	Delay s/veh	LOS HCM	Delay s/veh	LOS HCM	Delay s/veh	LOS HCM	Delay s/veh	LOS HCM	Delay s/veh	LOS HCM	Delay s/veh	LOS HCM	Delay s/veh	LOS HCM	Delay s/veh	LOS HCM
EB LT	8	A	8	A	8	A	8	A	8	A	8	A	1	A	2	A	2	A
EB TH	0	A	0	A	0	A	0	A	0	A	0	A	3	A	3	A	3	A
EB RT	0	A	0	A	0	A	0	A	0	A	0	A	2	A	3	A	3	A
WB LT	3	A	2	A	2	A	3	A	2	A	2	A	2	A	2	A	1	A
WB TH	3	A	2	A	2	A	3	A	2	A	2	A	3	A	2	A	2	A
WB RT	0	A	0	A	0	A	0	A	0	A	0	A	2	A	2	A	2	A
NB LT	40	E	24	C	21	C	151	F	50	E	34	D	1	A	3	A	1	A
NB TH	40	E	24	C	21	C	151	F	50	E	34	D	2	A	2	A	3	A
NB RT	40	E	24	C	21	C	151	F	50	E	34	D	5	A	2	A	3	A
SB LT	70	F	55	F	30	D	376	F	230	F	65	F	4	A	3	A	4	A
SB TH	33	D	19	C	20	C	54	F	24	C	25	C	5	A	2	A	1	A
SB RT	11	B	10	A	10	A	11	B	10	A	10	A	2	A	1	A	2	A

4.3 Cost/Saving Analysis

Cost analysis was conducted using RSMeans [7], as shown in **Table 4**. Estimated quantities were obtained using a quantity takeoff of the conceptual roundabout layout Option 2 shown in **Figure 3**. A 15% contingency was added for incidental costs unforeseen in the estimation process, because a detailed site survey was not conducted due to the constraints of time and funds. Nevertheless the initial roundabout construction cost is still underestimated. The reason is that the initial cost does not include other costs required for the project construction, such as landscape architecture cost, traffic sign and pavement marking cost, storm water management facility cost, etc. Taking into account all these considerations, the project cost estimate would be best observed as approximately $150,000 for planning purposes.

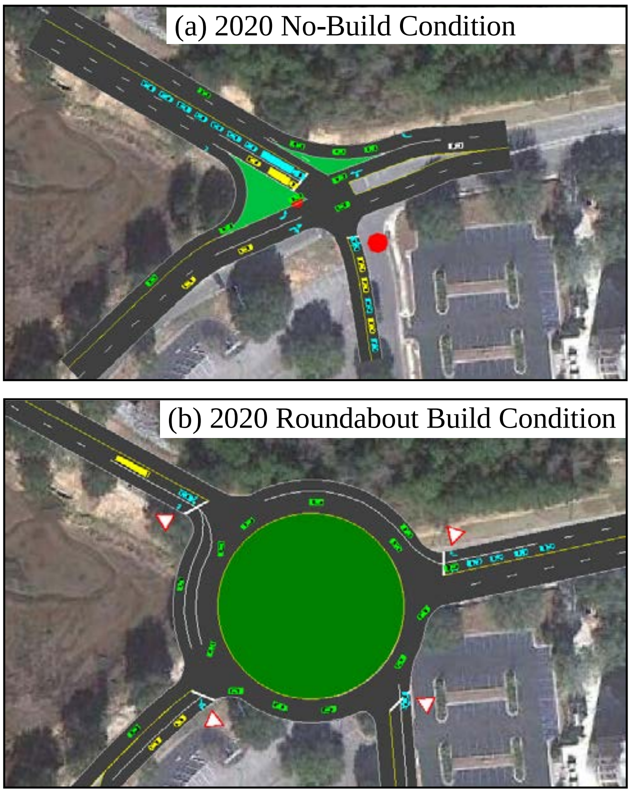

Figure 4: SimTraffic Screenshots for No-Build/Build Conditions

A simple analysis for estimating the benefit of the roundabout implementation was conducted with two main criteria. The first criterion was the change in intersection delay estimated from Synchro multiplied by a weighted average wage of travelers through the intersection. The second factor in the analysis was the reduction in crash frequency, multiplied by the average cost of a crash.

Table 4: Roundabout Construction Cost Estimate

Item	Quantity	Unit	Unit Cost	Extended Cost
Demolish and remove existing asphalt	4014	SY	$5.60	$22,480
Demolish and remove existing concrete	170	SY	$15.20	$2,591
Install 2 inch thick asphalt and 6 inch thick graded aggregate base	2612	SY	$17.25	$45,065
Install curb and gutter	2050	LF	$22.50	$46,125
Install sidewalk	1600	SF	$4.28	$6,848
Install crosswalk striping	96	LF	$0.50	$48
			Subtotal	$123,157
			15% Contingency	$18,474
			Total	**$141,630**

Cost Savings from Delay Reduction:

To establish the weighted average wage, an average faculty and staff wage of $31.18 per hour was obtained from a salary survey company [8], while an average Mobile area student wage of $19.03 per hour was obtained from the Bureau of Labor Statistics [9]. These two wages were then weighted by the distribution of parking permits information received from parking services to produce a weighted average wage of $20.88 per hour per capita. As most of the cars observed travelling through the intersection only contained one person, an assumption of one person per vehicle was made. Delay reduction was calculated by multiplying the existing intersection entering volume by the total intersection control delay estimated from the Synchro analysis. Because the Synchro analysis showed a negligible roundabout delay, the delay for the existing condition was all counted as saved time. The delay time savings was then multiplied by the weighted hourly wage, and converted to a yearly savings using the assumptions of 8 hours of operation per day, 5 hours of operation per week, and 52 weeks of operation per year. Accordingly, the estimated yearly cost savings (for the first year) due to the delay reduction was about $119,870.

Cost Savings from Crash Reduction:
According to Meyer (2008) [10], average cost for an injury crash was $68,170 per injury in 2005 dollars. With consideration of inflation, this crash cost becomes $81,166 per injury in 2013 dollars at a 19.1% cumulative rate of inflation. Average cost for a property damage only crash was $7,910 per crash in 2005 dollars according to FHWA [11]. This becomes $9,418 per crash in 2013 dollars at a 19.1% cumulative rate of inflation.

According to a crash analysis for the target campus intersection, an average of 1.25 crashes (property damage only) occurred per year for the last 8 years. No injury crashes were reported in the same period. Assuming 35.4% crash reduction after the roundabout implementation as suggested by NCHRP Report 572 [4], the estimated yearly cost savings due to the crash reduction was about $4,120. Note that this simple calculation did not consider demand fluctuation over time and regression-to-mean (RTM) bias.

An estimated cost for the roundabout construction is approximately $150,000 for planning purposes, and an estimated yearly saving through the delay and crash reduction is about $124,000. Thus, it is expected that the roundabout would pay for itself in the very near future with continuation of the cost savings for the traffic delay and crash reduction after its implementation.

5. Conclusions and Future Research

Constructing a roundabout at a university campus intersection, which is faced with many traffic accidents and operational issues, would be an effective treatment to improve the facility safety and performance. This study shows the feasibility of a single-lane roundabout at the intersection of Health Services Dr. and USA Drive N. in the University of South Alabama.

The intersection has been identified as having experienced an increase in traffic safety and operational issues due to a substantial student enrollment increases over the last 10 years. Thus, in the present study, the roundabout feasibility is evaluated based on two primary goals: 1) traffic performance, and 2) safety. A microscopic traffic simulation was conducted to evaluate the traffic performance of the roundabout. The result shows that the roundabout significantly upgrades the intersection Level of Service (LOS) and can accommodate forecasted future traffic conditions. In addition, the roundabout can significantly reduce the intersection crash. It is also expected through a cost-benefit analysis that the roundabout would pay for itself in the very near future with continuation of the cost savings for the traffic delay and crash reduction after its implementation. Furthermore, this treatment would also be compatible with the overall feel of the campus, since the USA already utilizes a large roundabout in the center of the main campus.

One possible future direction for continuing this research would be to perform a more detailed break-even analysis to determine how long it would take for savings to equal build cost. This analysis would need to take into consideration traffic growth, inflation, and minimum attractive rate of return.

Another possible future direction for this research would be to complete a Synchro network for the entire USA campus and model roundabouts at other locations with similar traffic issues. This research could coincide well with a full-campus traffic plan. As the university grows, having a full-campus traffic plan will become increasingly important. Some intersections around campus have already been reported as having traffic issues.

A third possible future work would be to track traffic delay and crash reduction after the roundabout installation, and compare the measured value to the estimated value of this research.

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