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Performance Evaluation of Roundabouts for Traffic Delay and Crash Reductions in Oxford, MS

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Principal Investigator

Waheed Uddin, PhD., P.E.
Professor and Director, CAIT
Center for Advanced Infrastructure Technology
Department of Civil Engineering
The University of Mississippi
University, MS 38677-1848
http://www.olemiss.edu/projects/cait/Index.html

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16. Abstract

Due to increased traffic volume, congestion, and capacity limitations, two roundabouts have been constructed on South Lamar Boulevard ramp intersections with MS Highway 6 in Oxford, MS. Roundabouts replaced the existing signalized intersection on the north and stop controlled intersections on the south side of the South Lamar Boulevard and MS Highway 6 Interchange. The overall objective of this study was to assess the performance of the roundabouts in Oxford with respect to traffic flow, capacity, and safety improvements, and to determine the public perception of roundabouts by means of an opinion survey. Detailed post-roundabout traffic movement volume and crash data were collected and compared with the pre-roundabout data to assess the in-service performance of the roundabouts. Traffic flow microsimulation and capacity analysis methods were used to evaluate performance of the roundabouts. The results of the Oxford roundabout study showed significant improvement in traffic flow, crash reduction, and reduction in vehicle emissions. It was found that the conversion of the intersections to roundabouts improved traffic flow by reducing average delay by 24%, idling time by 77%, and fuel wastage by 56%. Overall vehicle emissions from idling were reduced significantly including 56% in CO_2, 80% in VOC, and 77% in CO, NO_x, and PM_{10}.

This conversion of stop-controlled intersections to roundabouts increased the average speed by 67% and improved level of service of both roundabouts. The roundabout conversion increased the mean speed on the South Lamar interchange by 67% and improved level of service for both intersections. The roundabout junctions improved safety performance through a 37.5% reduction in crashes and a 60% reduction in the number of crashes resulting in injury. The reduction in overall crashes in the study area reduced comprehensive cost by 54.4%. Total user cost saving from reductions in travel time, fuel wastage, and crash cost combined is $806,018 annually. These benefits paid off the total cost of construction of the two roundabouts within two years. The resulting B/C ratio is 6.2 over a period from 2009 to 2016. Additionally, significant societal benefits are expected from reductions in vehicle emissions. Also, an anonymous public opinion survey overwhelmingly demonstrated favorable results and provides support to consider more roundabout junctions in place of stop-controlled intersections. The study results indicate that roundabouts are performing well as intended. Some constructive comments suggested by the public, such as flashing lights on signs, can be implemented by the Mississippi DOT to enhance traffic flow and safety.

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DISCLAIMER

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EXECUTIVE SUMMARY

Due to increased traffic volume, congestion, and capacity limitations, two roundabouts have been constructed at the South Lamar Boulevard ramp intersections with MS Highway 6 in Oxford, Mississippi. Roundabouts replaced the existing signalized intersection on the north and stop controlled intersections on the south side of the South Lamar Boulevard and MS Highway 6 Interchange. This study was intended to assist the MDOT Traffic Engineering Division to monitor traffic parameters and to assess the in-service performance of these roundabouts by comparing pre- and post-construction traffic and crash data. Roundabouts have been shown to reduce congestion and crashes if the road users learn to navigate them appropriately. The overall objective of this study was to assess the performance of the roundabouts in Oxford with respect to traffic flow, capacity, and safety improvements, and to determine the public perception of roundabouts by means of an opinion survey.

The project research team collected post-roundabout traffic volume, and crash data for comparison with the pre-roundabout data. Traffic data was collected using traditional onsite manual traffic data collection for all movements and analyzed to assess transportation system performance and impacts of traffic demand on travel time, safety, and vehicle emissions. Detailed post-roundabout traffic movement volume and crash data were collected and compared with the pre-roundabout data to assess the in-service performance of the roundabouts. Traffic flow microsimulation and latest capacity analysis methods were also used to evaluate performance of roundabouts using traffic flow, crash data, and vehicle emissions.

The results of the Oxford roundabout study showed significant improvement in traffic flow, crash reduction, and reduction in vehicle emissions. It was found that the conversion of the intersections to roundabouts improved traffic flow by reducing average delay by 24%, idling time by 77%, and fuel wastage by 56%. Overall vehicle emissions from idling were reduced significantly including CO_2 by 56%, VOC by 80%, and 77% reduction in CO, NO_x, and PM_{10}. The roundabout conversion increased the mean speed on the South Lamar interchange by 67% and improved level of service. The roundabout junctions improved safety performance through a 37.5% reduction in crashes and a 60% reduction in the number of crashes resulting in injury. The reduction in overall crashes in the study area reduced comprehensive cost by 54.4%. Total user cost saving from reductions in travel time, fuel wastage, and crash cost combined is $806,018 annually. These benefits paid off the total cost of construction of the two roundabouts within two years. The resulting B/C ratio is 6.2 over a period from 2009 to 2016. Additionally, significant societal benefits are expected from reductions in vehicle emissions. Also, an anonymous public opinion survey overwhelmingly demonstrated favorable results and provides support to consider more roundabout junctions in place of stop-controlled intersections. The study results indicate that roundabouts are performing well as intended. At this location, roundabouts yield better performance compared to the combination of stop control and signal control. Some constructive comments suggested by the public, such as flashing lights on signs, can be implemented by the Mississippi DOT to enhance traffic flow and safety.

INTRODUCTION

1.1 Background

“Efficient public mobility” and “safe transportation infrastructure assets” are imperative for the distribution of resources and goods, disaster relief, emergency services, and traveling needs of society [1, 2]. Regardless of a region’s characteristics, such as culture, income, or geography, people on average spend a significant amount of their time driving and/or wasting fuel on congested roadways. People in less developed regions spend a great part of their time traveling to and from destinations due to lack of transportation facilities and/or urbanization, while people in more developed countries such as Japan, Western Europe, and the United States spend half of their travel time in leisurely travel and the other half in route [3]. There is a strong connection between a nation’s income and its mobility, as well as a direct association of per capita gross national product (GNP) of a nation with the “paved road density in kilometers per million” [4, 5] and “per capita passenger kilometers traveled” (PKT). The vehicle miles traveled (VMT) increased 148% from 1970 to 2000. In 2008, the total VMT in the United States was about 3 trillion km-traveled [6]. Figure 1 displays the public road mileage, lane miles, and vehicle miles traveled in the United States for 1980 to 2008. It can be seen that the VMT increased drastically over the past three decades, while the number of road mileage increased slightly. Even though this well qualifies the United States to be categorized in the third stage of development, the VMT by Americans well surpasses the capacity of public roads. Cars, pickups, and sport utility vehicles (SUVs) comprise 91.6% of VMT in 2008.

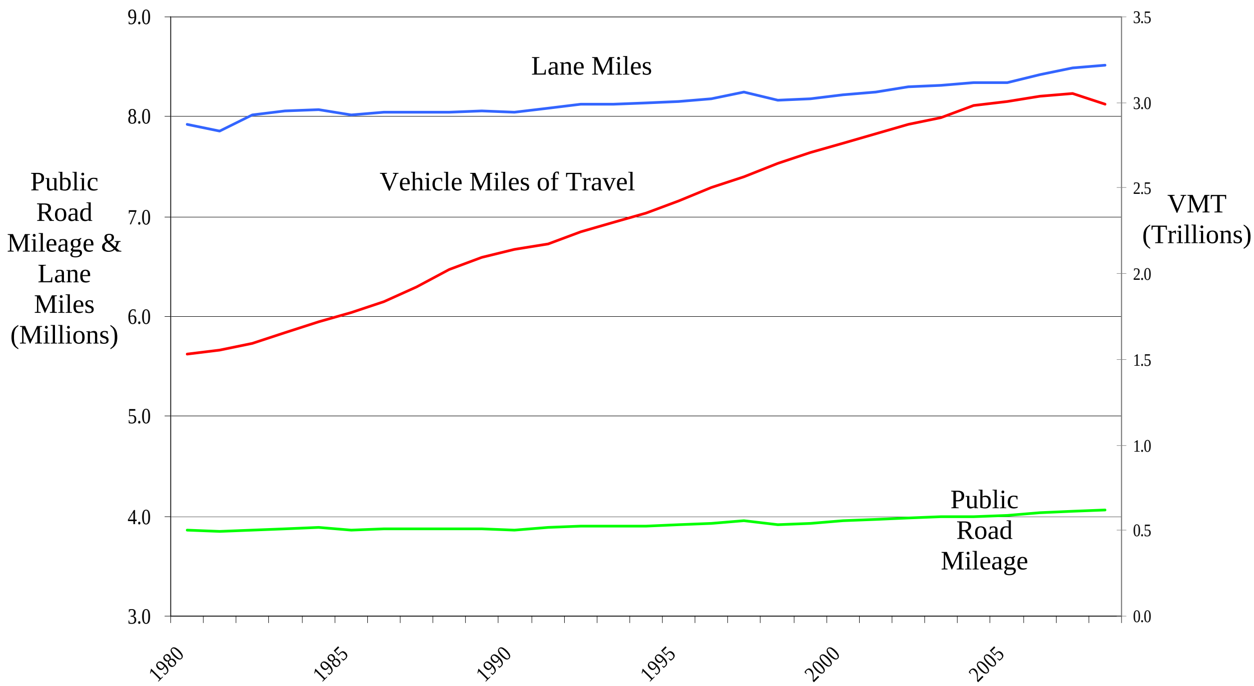
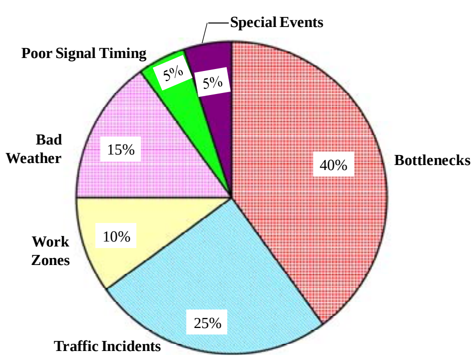


Figure 1. Public road mileage, lane miles, and VMT in the US from 1980 – 2008

The United States leads the world in vehicle ownership with approximately 137 million registered vehicles in 2008, which equates to over 2.2 persons per vehicle (using estimated 2008 United States population) [6, 7]. The annual kilometers per capita traveled per automobile is predicted to increase from 27,400 kilometers in 2005 up to 48,000 kilometers by 2050 in the United States. Despite a growing reliance on high-speed transportation modes, travel patterns will not significantly change in the near future. With this said, Americans are predicted to spend an average of roughly 45 minutes of their day traveling in personal vehicles [3]. Travel demands over the past two decades already surpassed capacity limits of the road infrastructure, not only in America, but also in most urban areas worldwide [1]. Exceeding the road capacity limit results in adverse impacts including, but not limited to, an increase in congestion, greenhouse gas and other vehicle emissions, operating cost, crash related cost, and societal cost, as well as a decrease in productivity, safety, and air quality [4, 8]. As shown in Figure 2, bottlenecks and incidents contribute to 65% of the causes of traffic congestion. On-road vehicles produce 81% of the transportation-related emissions [9]. Each year approximately 40,000 people perish on roads; still the U.S. fatality rate per 10,000 vehicles is comparable to Germany but more than U.K (Figure 3). However, the fatality rate per 100,000 population on Mississippi roads is higher than the U.S. average rate [1]. These road traffic impacts are important to consider for performance evaluation of alternative traffic management strategies including design of road junctions.



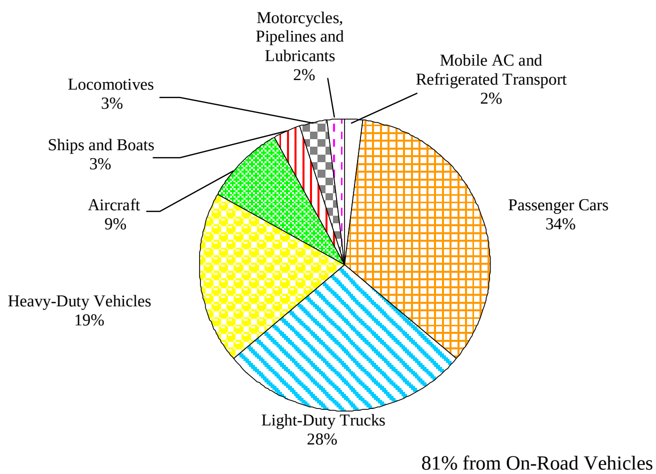


Figure 2. Causes of traffic congestion in the U.S. (left); U.S. Transportation-related emissions, 2004 (right)

With mobile travel continuing to increase globally, the application of congestion reducing strategies must be implemented in order to meet transport infrastructure needs. In the United States several traffic management strategies such as the use of Intelligent Transportation Systems (ITS) and road junction alternatives have been widely implemented in recent years in order to improve traffic flow and reduce traffic congestion. Figure 4 displays ITS video camera locations throughout the rural city of Oxford, Mississippi [10] for traffic management (ITS camera locations are denoted by open circles). At this time there is no video camera surveillance on the study site at MS Highway 6. Many cities employ little to no practices of modern traffic management systems and, therefore, experience longer hours of commute, extreme delays, long travel time, congestion, significant air pollution, and induced societal costs [2].

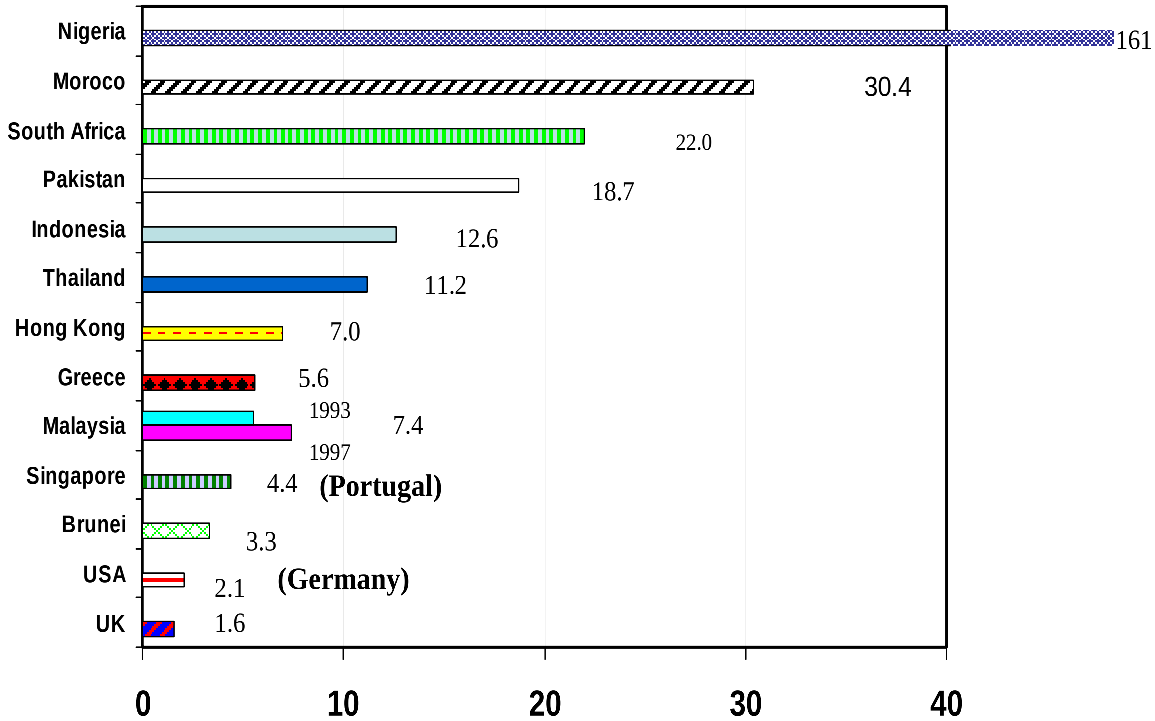


Figure 3. Road fatalities per 10,000 vehicles for selected countries

As a result of the increase in road infrastructure and urbanization, the following attributes of society are affected: "traffic fatalities and injuries, traffic related emissions and air pollution, traffic related noise impacts, built-up area effects on the environment, energy demand and diminishing natural resources, landuse, and societal integration issues" [4, 8]. In order to maintain a sustainable infrastructure these issues must be taken into account when "evaluating alternative strategies for new transportation corridors or capital improvement projects" and should be a "top concern in transportation investment decision making processes" [1].

Roundabouts have been shown to reduce congestion and crashes compared to traditional intersections at road junctions [11, 12] if the road users learn to navigate them appropriately. Due to increased traffic volume and capacity limitations, two roundabouts have been constructed by the Mississippi Department of Transportation (MDOT) on South Lamar Boulevard (Blvd) and MS Highway 6 Interchange. This is an economical solution to improve capacity and safety compared to an unsignalized stop-controlled intersection and a signalized intersection as traffic control devices. The project for Oxford, Mississippi was part of a state study (SS), SS 213, sponsored by the MDOT. This study was intended to assist the MDOT Traffic Engineering Division to monitor traffic parameters and to assess the in-service performance of these roundabouts by comparing pre- and post-construction traffic and crash data.

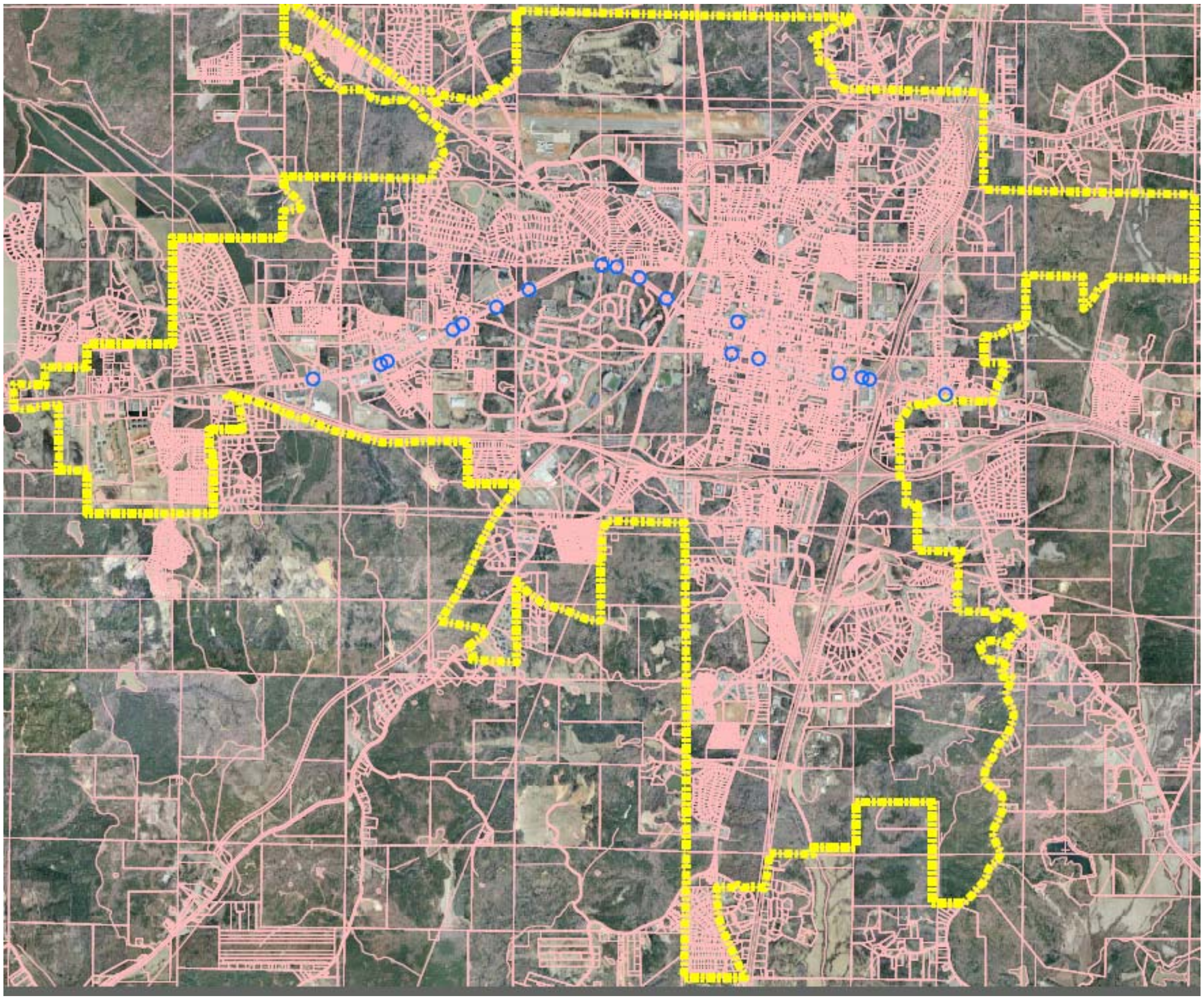


Figure 4. ITS location within Oxford, Mississippi [10]

1.2 Objectives

The overall objective of this study was to assess the performance of roundabouts at the interchange of South Lamar Blvd and MS Highway 6 in Oxford with respect to traffic flow, capacity, and safety improvements, and to determine the public perception of roundabouts by means of an opinion survey. The specific objectives were:

- Create road infrastructure planimetrics and landuse databases for the study area using remote sensing and geospatial technologies.
- Collect daily and hourly traffic data using traditional methods and modern remote sensing and geospatial technologies.
- Evaluate performance of roadway junction alternatives using traffic flow simulation, crash data, and vehicle emissions.
- Address air quality impacts and congestion issues for the selected study site.

The following tasks were performed to accomplish the objectives:

- *Task 1* — *Collect and Review Pre-roundabout Data* (traffic and crash data, design report and plans).
- *Task 2* — *Collect and Analyze Post-roundabout Data* (available traffic data and crash data, on-site traffic data collection and comparison with pre-roundabout data analysis and capacity analuysis).
- *Task 3* — *Conduct Road Users' and Public Survey* (for the effectiveness of roundabouts).
- *Task 4* — *Submit and Present Interim Report* (for feedback from the MDOT's oversight committee).
- *Task 5* — *Finalize Data Collection, Complete Analysis, and Evaluate Results* (for performance of roundabouts with respect to capacity, safety, emissions, benefit/cost analaysis, and public opinion).
- *Task 6* — *Submit and Present Final Report* (submit draft final report including recommendations; make corrections using the MDOT feedback and submit the final report).

1.3 Project Overview

The specific project study site is the South Lamar Blvd and MS Highway 6 interchange in the rural city of Oxford, Mississippi, the United States. Figure 5 displays the study site location before the construction of the roundabouts. A long queue of cars on the bridge traveling north on the overpass bridge indicates long delays and poor level of service (LOS).

(source: http://www.bing.com/maps/ Accessed November 17, 2009)

Figure 5. Pre-construction view of the study site

The project evaluated the performance of the two roundabouts constructed at the junctions of MS Highway 6 (SR 6) and South Lamar Blvd. For the traditional intersections on the study site, conflicting traffic flows were controlled by the stop signs or pre-timed traffic signals. The roundabouts, on the other hand, as alternative junctions facilitate slow moving traffic flow at the current traffic volume. Before the construction of the roundabouts the intersections experienced low LOS, congestion, and extreme delays. The South side of the overpass had a one-way stop sign traffic control. The North side of the overapass had a traffic signal to control traffic flow. The MDOT evaluation of this intersection showed that the northbound traffic turning left on the ramp to MS Highway 6 West was causing long delays and aquired a LOS "F" [13, 14]. In 2006 fifty percent of the movements servicing the interchange experienced a LOS of "D" or worse. With the commercial and residential properties of the area increasing exponentially the intersections would not be able to accommodate the extra traffic flow [13, 14]. Figure 6 shows a satelllite imagery view of the pre-roundabout stop-controlled intersections prior to 2007 construction. Figure 7 shows the plan view of the roundabouts on an aerial imagery.

Figure 6. Pre-construction plan view of the study site on 1-m Ikonos satellite imagery

The roundabouts, constructed at a total cost of over one million dollars, opened in summer of 2007. One roundabout on the north side of the interchange replaced a signalized intersection at the intersection of Highway 6 westbound ramps and South Lamar Blvd. This eye drop roundabout is a noncircular roundabout with four legs. The second roundabout on the south side of the interchange replaced three unsignalized stop controlled intersections, one four- way stop, and two one-way stop. The four-way stop intersection was located at the intersection of MS Highway 6 eastbound ramps and South Lamar Blvd, and the two one-way stop intersections were located at the intersections of South Lamar Blvd and Frontage Road (west), and Access Road (east).

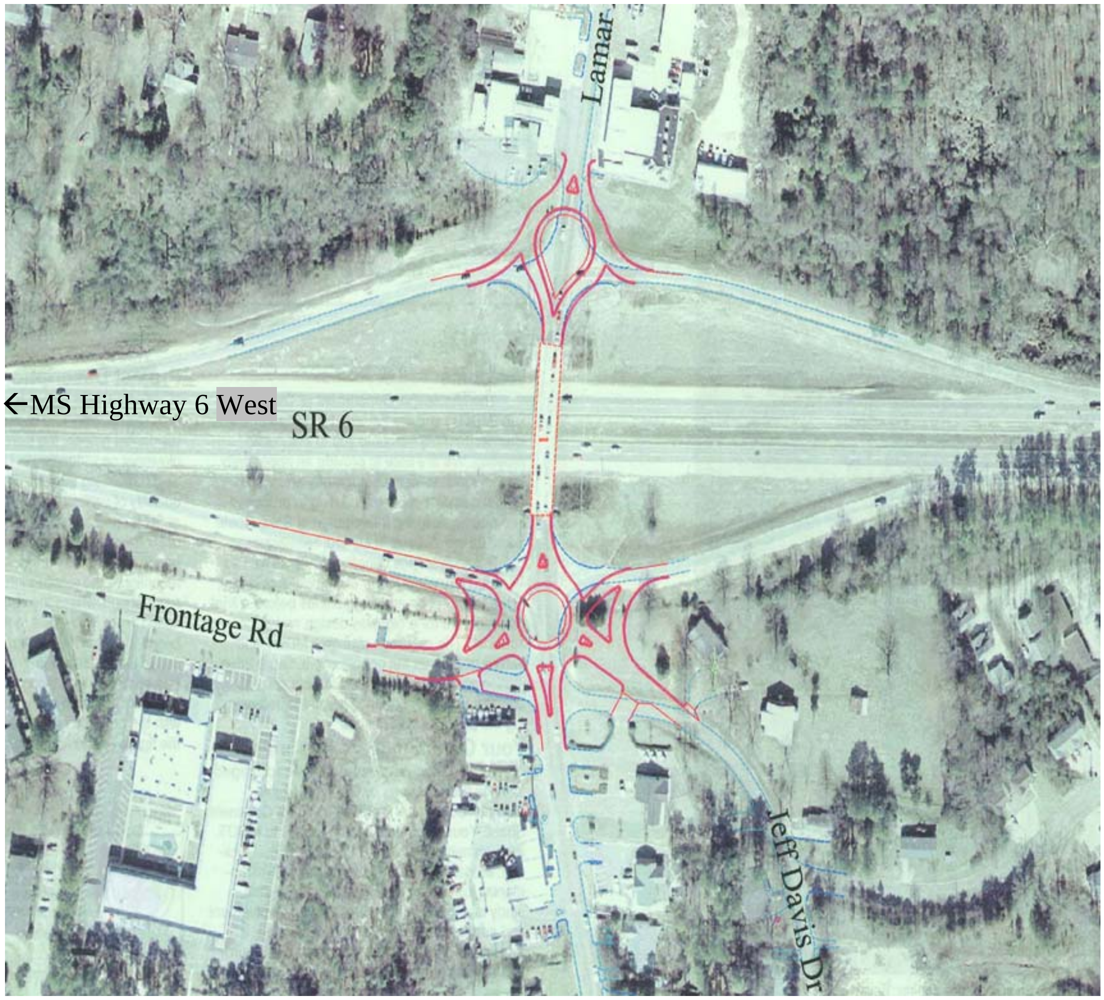


Figure 7. Planned roundabouts on South Lamar Blvd, Oxford
(courtesy of James Sullivan, MDOT)

A consultant report entitled "Exiting vs. Roundabout Conditions for the year 2006 and Forecast 2016 Volumes", prepared for MDOT, was reviewed [14]. Using 2006 and forecasted 2016 traffic volume demands, traffic analysis programs were used to evaluate capacity and level of service of a 'do nothing scenario' and the implication of roundabouts. When the roundabout scenario was simulated using the 2006 traffic demands each movement exhibited a level of service of "B" or better. In order to plan for future growth both scenarios were simulated using forecasted 2016 traffic volumes. From the results of these simulations the 'do nothing scenario' showed evidence of traffic demands exceeding capacity limits, while for the roundabout scenario more than half the movements remained at LOS of "B" or better.

South Lamar Blvd is one of the major arterial roads within Oxford. On the north side of South Lamar Blvd and MS Highway 6 interchange is the town's main area of business and residency, and south of the interchange is the Baptist Memorial Hospital that services the Oxford community and its surrounding areas. The South Lamar Blvd and MS Highway 6 interchange services a large portion of the local traffic, as well as a main route to the hospital. Therefore, the safety of the two junctions on South Lamar Blvd was a primary factor in the planning and redesign considerations. The roundabouts were installed as an economical solution to the capacity problems, low levels of service, and space limitations at the two intersections. The geometrical design of both roundabouts [14, 15] exhibits major departures from common 4-legged roundabouts [11, 12, 16].

1.4 Methodology and Review of Adverse Traffic Impacts

1.4.1 Research Methodology

This study evaluated the roundabouts' ability to improve traffic flow, safety, and air quality of the intersection. The following research methodology was used:

- On-site traffic count data was collected for all movements using traditional manual data collection on both roundabout junctions over a week in the Fall 2009 when the University of Mississippi was open with full attendance.
- Remote sensing and geospatial analysis technologies were used to extract vector maps and create spatial (thematic) maps of annual average daily traffic using traffic volume data from the MDOT web site.
- Newly developed roundabout analysis methods of Highway Capacity Manual were used to analyze traffic capacity and LOS.
- Crash data were collected and statistical analysis was performed to compare traffic crash data from pre- to post- roundabout periods.
- Traffic flow microsimulation software was implemented to analyze traffic capacity, flow, and delay for the peak hour.
- Vehicle emissions of roadway junction alternatives were also calculated using the US Environmental Protection Agency (EPA) models.
- An anonymous public opinion survey form was designed and survey data was collected to evaluate public perception of the roundabouts and favorability to the construction of more roundabouts.

1.4.2 Safety and Air Pollution Impacts of Traffic

Traffic related fatalities are a leading cause of death around the world. Most of the factors that cause traffic crashes, traffic related injuries and fatalities are largely avoidable [1, 4]. The World Health Organization (WHO) and World Bank declared that the quantity of traffic related injuries is unacceptable and are critically affecting public health and development [17]. A road's safety status is based upon its rate of traffic related fatalities. National traffic fatality rates for some countries are shown in Figure 3. The following three terms are used to define a road's traffic safety rating: "fatalities per 10,000 vehicles, fatalities per one million VMT or vehicle-kilometers, or fatalities per 100,000 populations" [17]. Highly motorized countries such as the United States make up 14 % of the world's traffic fatalities. In 2003 the United States average fatality rate was 1.48 fatalities per 100 million VMT. Rural states with a large mileage of two-lane rural roads tend to have higher fatality rates than the national average. In 2003, Mississippi's road fatality rate was more than twice that of the national average at a fatality rate of 3.0 fatalities per 100 million VMT and 30 fatalities per 100,000 inhabitants, making Mississippi's roads the second most dangerous road network in the United States [18].

More than half of all annual traffic fatalities occur on rural two-lane roads in the United States and 22% of all annual traffic fatalities occur at an intersection [19]. Crashes occurring at an intersection make up almost half of all reported traffic crashes. A quarter of all crashes resulting in injuries occur at a traffic signal controlled intersection and two out of every five crashes occurring at an intersection resulting in fatalities occur at a stop sign controlled intersection [19]. Traffic crashes result not only in societal costs, but also have economical consequences related to medical expenses and property damages, particularly traffic crashes that result in injury and fatalities. Traffic related costs are represented in two forms, economic costs and comprehensive costs. The total economic cost from traffic crashes was "$230 billion in year 2000 in the United States [19]. Comprehensive costs are broken down further than economic costs to include all aspects of the accidents such as "pain and suffering and loss of life." The comprehensive cost for all traffic crashes was estimated to be $300 billion in year 2000. The comprehensive cost of crashes occurring at intersections was estimated $97 billion in the United States, making up almost one third of the total comprehensive cost [19].

A second societal and economic factor affected by transportation is air quality. Over time the environment's constant exposure to vehicle emissions can result in adverse effects on air pollution, public health, purity of ambient air, vegetation, visibility, and smog [8]. From 1990 to 2004, vehicle emissions of greenhouse gases (GHG) rose 27 percent across the United States [9]. This increase is a result of constant increases in population and economic growth, travel demand, urban sprawl, popularity of SUVs and light-duty trucks, and congestion. In 2008, transportation activities accounted for 27 percent of U.S. inventory of GHG emissions from transportation related activities. Carbon dioxide (CO_2) from fossil fuel combustion is the largest source of GHG emissions [20]. The measure of the amount of CO_2 released on roads, as well as other vehicle emissions, is dependant on traffic demand, driving patterns, traffic flow, congestion hours, vehicle miles traveled, traffic speeds, and vehicular characteristics [21]. Vehicle emissions other than GHG emissions are described as "ambient air pollutants." The primary EPA criteria pollutants are carbon monoxide (CO), oxides of nitrogen (NO_x), particulate matter ($PM_{2.5,10}$), and hydrocarbons (HC) or volatile organic compounds (VOCs). Tropospheric ozone (O_3), formed by photochemical reaction of NO_x and VOC, is another EPA criteria pollutant. Smog formed by NO_x and O_3 is a major health problem related to respiratory diseases in summer times in most urban areas and cities in the United States [8].

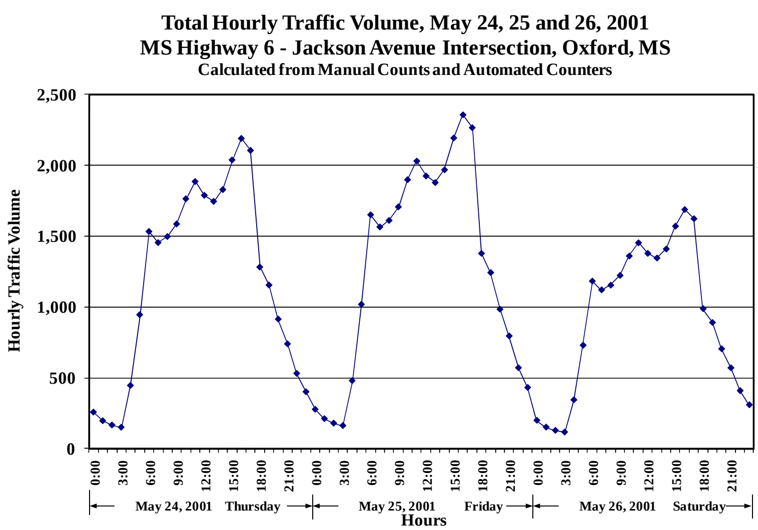
Of these ambient pollutants, only three are linked to vehicle cold start emissions: VOCs, NO_x, and CO, and these three pollutants also vary with vehicle speeds. NO_x, and CO emissions have the potential to increase with an increase in speed, while VOCs may decrease. $PM_{2.5}$, PM_{10}, sulfur oxide (SO_x), and ammonia (NH_3) are not dependent upon vehicle speeds, yet all vehicular emissions increase during vehicle idling hence the dependency on traffic flow and congestion. NO_x and SO_x are the only two pollutants that are not affected by vehicle type. Exhaust emissions of $PM_{2.5}$ and PM_{10} from diesel vehicles and their equipment are the largest direct contributors of transportation related PM emissions [21]. All of these pollutants could potentially have long term effects on air quality and play a critical role in changing the natural balance of the atmospheric air [9]. In urban areas, road traffic is the main source of pollution, and pollutant concentrations in the air are much higher due to the condensed road networks and increased road congestion. Often residential quarters of urban areas are located in close proximity to main road networks resulting in exposure to pollutants at higher concentrations [22]. The level of vehicular emissions is often higher in certain states with no emission testing program and developing countries due to problems in the enforcement of emission regulations on vehicles and environmental standards.

Exposure to these air contaminants is hazardous to public health and the environment. Potential health hazards from air pollutants have a wide range of effects including: respiratory problems, bronchitis, asthma, cardiovascular, and mortality. Public health hazards result in an increase in societal costs [8]. Public health effects account for one third of the total societal cost of transportation in the United States and public health problems from air pollutants make up 30% of the public health costs [23, 24]. In recent studies it has been found that the measurable societal costs related to vehicle emissions is significant enough to justify considerable amounts of time and money spent on air quality improvement and control [8, 25].

2. TRAFFIC VOLUME DEMAND MONITORING AND GEOSPATIAL MAPPING

2.1 Overview of Traffic Data Collection

Daily and hourly traffic volumes are the main data source in travel demand analysis, traffic planning, and roadway design. Traffic volume data are used for most transportation procedures to calculate average speed, flow, capacity, delay, level of service, to forecast trends, and to identify congestion problems. Average Annual Daily Traffic or AADT is the most commonly used form of traffic demand volume data; this is the total count of vehicles in a 24-hour period over a segment of road averaged over one year period. Traffic volumes vary by “month of the year, week of the month, day of the week, hour of the day, and sub-hourly intervals within the hour” [26]. This is shown in Figure 8 for traffic data collected at MS Highway 6 on the west side of the study site [27]. Hence, traffic volumes need to be measured 24 hours a day, 7 days a week, and 365 days a year in order to achieve exact hourly and average annual daily traffic volumes. However, this is neither efficient nor cost-effective, and in most areas not possible. For these reasons the AADT is estimated from traffic data samples collected using manual counts and/or automated counters. Many different ways of collecting traffic data have been implemented in order to reduce cost, but still achieve the most accurate data. Recent modern methods of traffic data collection have included radar method, video surveillance data, and data collection from remote sensing aerial photo or satellite imagery [28, 29]. Manual traffic count data collection method is the most accurate, costly, and labor intensive. Other methods (mechanical and automated counters, ITS video based traffic counts, and noncontact sensors) are less labor intensive; and their accuracy and cost depends on the technology used.



Daily Distribution of Traffic Calculated for Intersection MS Hwy 6 - Jackson Avenue Oxford, MS		
Day	Daily Factor	Daily Volume
Monday	0.1476	26,645
Tuesday	0.1485	26,808
Wednesday	0.1507	27,220
Thursday	0.1584	28,607
Friday	0.1705	30,791
Saturday	0.1221	22,043
Sunday	0.1022	18,460
Total	**1.000**	**180,574**

Figure 8. Hourly and daily distribution of traffic volume data collected for MS Highway 6

An innovative imagery-based geospatial methodology for traffic volume calculation [29] was recently implemented for some sections of MS Highway 6 near the study site. Figure 9 shows the AADT results estimated using the 1-m satellite imagery acquired in March 2007 as shown in GoogleEarth database. Details are not shown here for brevity. The average result showed good accuracy [30] within 15% of the AADT value obtained from the MDOT website [31]. This imagery-based remote sensing method greatly reduces the time and effort spent carrying out traffic counts and the cost associated with them due to the easily available high resolution satellite imagery. This innovative remote sensing imagery-based geospatial methodology is useful where traffic data is not routinely collected or to fill gaps in traffic volume data history efficiently with reasonable accuracy [30]. This methodology could not be applied to the roundabout site because its imagery was not available. Detailed traffic counts for each movement were collected using a manual count method for both roundabouts, as discussed in a later section.

Date	Section	AADT
5-Mar-07	Section 1	35,530
5-Mar-07	Section 2	29,775
5-Mar-07	Section 3	27,494
	Average	30,933

Figure 9. Imagery-based daily traffic volume data extraction for MS Highway 6 in Oxford, Mississippi

2.2 Geospatial Mapping and Visualization of Traffic Volume Data for Oxford

Thematic (spatial) maps are used for visualizing spatial distribution of data on geographical information system (GIS) maps, and making that data easy to interpret. Thematic maps often represent a specific attribute such as population, crash rate, daily traffic volume, or public opinion polls. Thematic maps can be represented in various formats depending on the data type. This section shows some examples of thematic maps in order to display AADT data on roads in Oxford, Mississippi. The AADT data sets for several years were obtained from the GOMDOT website [31]. MDOT uses automated devices in order to collect traffic data. Even though this process of collecting traffic data is widely used, this type of data collection does not account for peak hour or sub hourly traffic volumes. The following are the parameters associated with traffic data collection processes [31]:

- "Traffic is counted for 48 hours at most of the sites.
- One third (1/3) of the traffic sites in a county or city are counted each year.
- Traffic counts for previous 2 years are updated to the current year using a factor based on traffic growth of counted sites statewide.
- The traffic counts shown on the maps are AADT which are computed using factors.

- The 48 hour counts are adjusted to AADT using factors for day-of-week, season, and average percent trucks.
- Factors are derived from Continuous Traffic Recorders (CTR) located across the state on all types of roads.
- Some count locations are assigned to another location due to the similar traffic patterns and will share traffic count data."

Figure 10 shows the AADT map from the MDOT website for the study area of Oxford [31]. Only a few daily traffic volumes are visible in this view, and in order to observe daily traffic volumes for all roads within the study area the map must be zoomed again [32]. Figure 11 displays the first zoom where all the AADT values are visible. Even though the traffic volumes can be seen, most of them cannot be read. Not only do the tabs displaying the daily traffic volumes create clutter on the map, they also make it difficult to decipher which road the traffic volume attributes to. The solution to this is to create a GIS thematic vector map of the Oxford road network. The main purpose of this section is to demonstrate how thematic maps can be used to store and visualize AADT data using GIS.

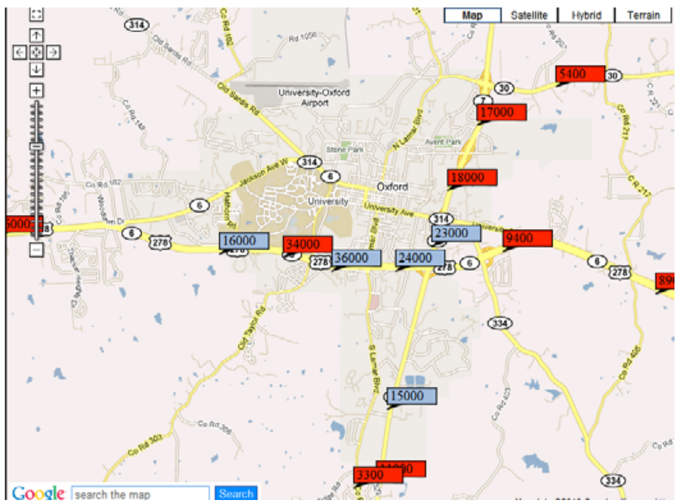


Figure 10. AADT map of Oxford study area

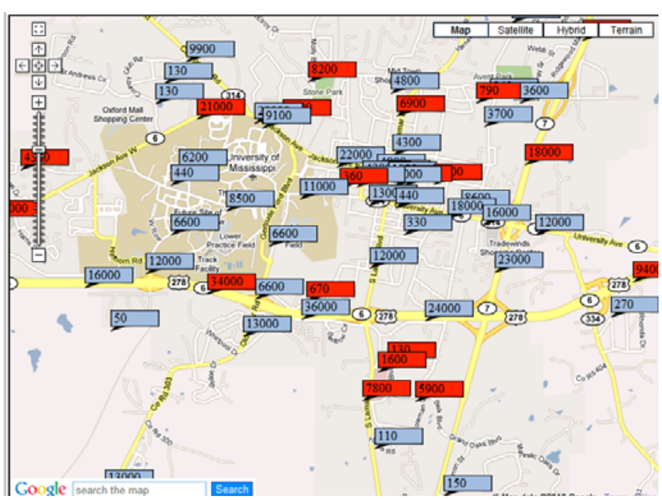


Figure 11. Zoomed-in view of AADT map of Oxford study area

Table 1 displays AADT volume data for all the major roads and highways for the years of 1998 to 2008. This spreadsheet table is easily imported into GeoMediaPro by matching each road section with the road section created in Oxford road vector map and geospatial database [32]. A separate table was also created for the minor roads. Although minor roads account for about 80% of the total road length within Oxford, traffic data is only collected for about 2.33% of the minor roads.

Table 1. AADT data for highways and major roads in Oxford, MS

Road	Intersection	AADT 98	AADT 99	AADT 00	AADT 01	AADT 02	AADT 03	AADT 04	AADT 05	AADT 06	AADT 07	AADT 08
Highway 7	Hwy 7/ Co Rd 101	4700	**5000**	5100	5200	**6100**	**5900**	**6500**	**6100**	**6100**	6200	**5800**
	Sisk Ave/ Hwy 7	**12000**	**13000**	14000	15000	**17000**	17000	17000	17000	18000	18000	**17000**
	Univ Ave/ Sisk Ave	20000	**15000**	16000	17000	17000	17000	17000	**20000**	21000	21000	**18000**
	Univ Ave/ Sisk Ave	20000	**15000**	16000	17000	17000	17000	17000	**20000**	21000	21000	**18000**
	Hwy 6/ Univ Ave	13000	14000	**15000**	16000	16000	**17000**	17000	17000	**22000**	22000	23000
	Hwy 6/ Univ Ave	13000	14000	**15000**	16000	16000	**17000**	17000	17000	**22000**	22000	23000
	Veterans Dr/ Hwy 6	11000	11000	**12000**	12000	12000	**12000**	12000	12000	**15000**	15000	15000
	Veterans Dr/ Hwy 6	11000	11000	**12000**	12000	12000	**12000**	12000	12000	**15000**	15000	15000
	South Lamar/ Veterans Dr	8400	**8300**	8500	8700	**8800**	9000	9200	**9500**	9500	9600	**11000**
Highway 6	Hwy 7/ Univ ave	5100	**5800**	6100	6300	**7600**	7700	7900	**9900**	10000	10000	**9400**
	Hwy 7/ Univ ave	5100	**5800**	6100	6300	**7600**	7700	7900	**9900**	10000	10000	**9400**
	S Lamar Blvd/ Hghwy 7	**15000**	16000	17000	**23000**	23000	23000	**24000**	24000	25000	**27000**	24000
	S Lamar Blvd/ Hghwy 7	**15000**	16000	17000	**23000**	23000	23000	**24000**	24000	25000	**27000**	24000
	Old Taylor Rd/ S Lamar Blvd	18000	19000	**21000**	22000	22000	**17000**	17000	17000	**34000**	35000	36000
	Old Taylor Rd/ S Lamar Blvd	18000	19000	**21000**	22000	22000	**17000**	17000	17000	**34000**	35000	36000
	Coliseum Dr/ Old Taylor Rd	17000	**17000**	18000	19000	**24000**	24000	24000	**35000**	36000	37000	**34000**
	Coliseum Dr/ Old Taylor Rd	17000	**17000**	18000	19000	**24000**	24000	24000	**35000**	36000	37000	**34000**
	Jackson Ave/ Coliseum Dr	15000	**14000**	14000	14000	**16000**	16000	16000	16000	16000	17000	16000
	Jackson Ave/ Coliseum Dr	15000	**14000**	14000	14000	**16000**	16000	16000	16000	16000	17000	16000
	Co RD 313/Jackson Ave	13000	**11000**	11000	11000	**16000**	16000	16000	**22000**	22000	22000	**16000**
	Co RD 313/Jackson Ave	13000	**11000**	11000	11000	**16000**	16000	16000	**22000**	22000	22000	**16000**
University Ave	Hwy 7/ Hwy 6	**9500**	9600	9600	**12000**	12000	12000	**12000**	12000	12000	12000	12000
	Bramlet Blvd/ Hwy 7	18000	18000	**17000**	17000	17000	**16000**	16000	16000	16000	16000	16000
	S Lamar Rd/ Bramlet Blvd	19000	19000	**21000**	21000	21000	**15000**	15000	15000	**19000**	19000	18000
	S 9th St/ S Lamar Rd	**13000**	13000	13000	**16000**	16000	16000	**13000**	13000	13000	**13000**	13000
	Molly Bar Rd/ S 9th St	11000	11000	**11000**	11000	11000	**9900**	10000	10000	**11000**	11000	11000
Lamar Ave (N/S)	Molly Barr Rd/ Co Rd 1032	5800	5900	**6400**	6400	6400	**5100**	5200	5300	**6800**	6800	6800
	Jackson Ave/ Molly Barr Rd				6300	**6300**	6300	6400	**6300**	6300	6300	**6900**
	Hwy 6/ Univ Ave	10000	10000	**11000**	11000	11000	**13000**	13000	13000	**12000**	12000	12000
	Veterans Dr/ Hwy 6	3700	**6100**	6100	6200	**6700**	6700	6800	**7300**	7300	7300	**7800**
	Highway 7/ Veterans Dr	990	**2700**	2700	2700	**1900**	1900	1900	**1400**	1400	1400	**3300**
Old Taylor Rd	Univ Ave/ Molly Bar Rd	6100	5300	5300	5400	5500	7500	7500	6800	6800	6800	6600
	Molly Bar Rd/ Hwy 6	6100	**5300**	5300	5400	**7500**	7500	7500	**6800**	6800	6800	6600
	Hwy 6/ Co Rd 323	8000	8200	9700	9700	9700	12000	12000	12000	14000	14000	13000
Jackson Ave	North Lamar Blvd/ South 9th	5500	5600	5600	**5000**	5000	5000	**4900**	4900	4900	4900	4800
	Molly Barr Rd/ South 9th	17000	17000	16000	16000	16000	12000	12000	12000	22000	22000	22000
	College Hill Rd/ Molly Barr Rd	17000	17000	**16000**	16000	16000	**12000**	12000	12000	**22000**	22000	22000
	Hawthorn Rd/ College Hill Rd	12000	**12000**	12000	12000	**12000**	12000	12000	**14000**	14000	14000	**21000**
	Highway 6/ Hawthorn Rd	12000	12000	12000	12000	**13000**	12000	12000	**17000**	17000	17000	**23000**

By analyzing the MDOT data of AADT (Table 1) over a ten year period in Oxford, Mississippi, it was observed that:

- 5 segments of major roads and highway have had an annual growth of AADT in the negative range of (-5 to -15%);
- 8 segments of major roads and highway have had an annual growth of AADT in the range of 0 to 1.7%;
- 11 segments of major roads and highway have had an annual growth of AADT in the range of 2 to 4%;
- 13 segments of major roads and highway have had an annual growth of AADT in the range of 6 to 10%; and

- 2 segments of major roads and highway have had an annual growth of AADT in the range of 11 to 23%.

Once the AADT tables are imported into GeoMedia Pro, various thematic maps can be made to analyze and display AADT values. In order to identify which years to create AADT maps for, a thematic map of the yearly growth rate was created for the highway daily traffic volumes. In order to find the yearly growth rate an annual compound equation was used for annual growth involving multiple years, and a simple percent difference equation was used for years only involving one year in between the more current year and the later year. The yearly linear growth rate was calculated by applying a functional query. From the yearly growth rate map it was found that there was a significant change in AADT from 1998 to 1999, 2005 to 2006, and 2007 to 2008 [32]. An annual growth 2.5% was estimated for the South Lamar Blvd study site using 2004 base year and used to predict 2016 traffic volume for capacity analysis and microsimulation studies.

Vector maps of Oxford road network were acquired from the cooperation of the City of Oxford and imported into GeoMedia Pro [10]. Thematic maps were created for each year. Figure 12 shows the AADT spatial map for 2008. Bold circles are drawn around the roads with a significant yearly growth rate from one year to the next.

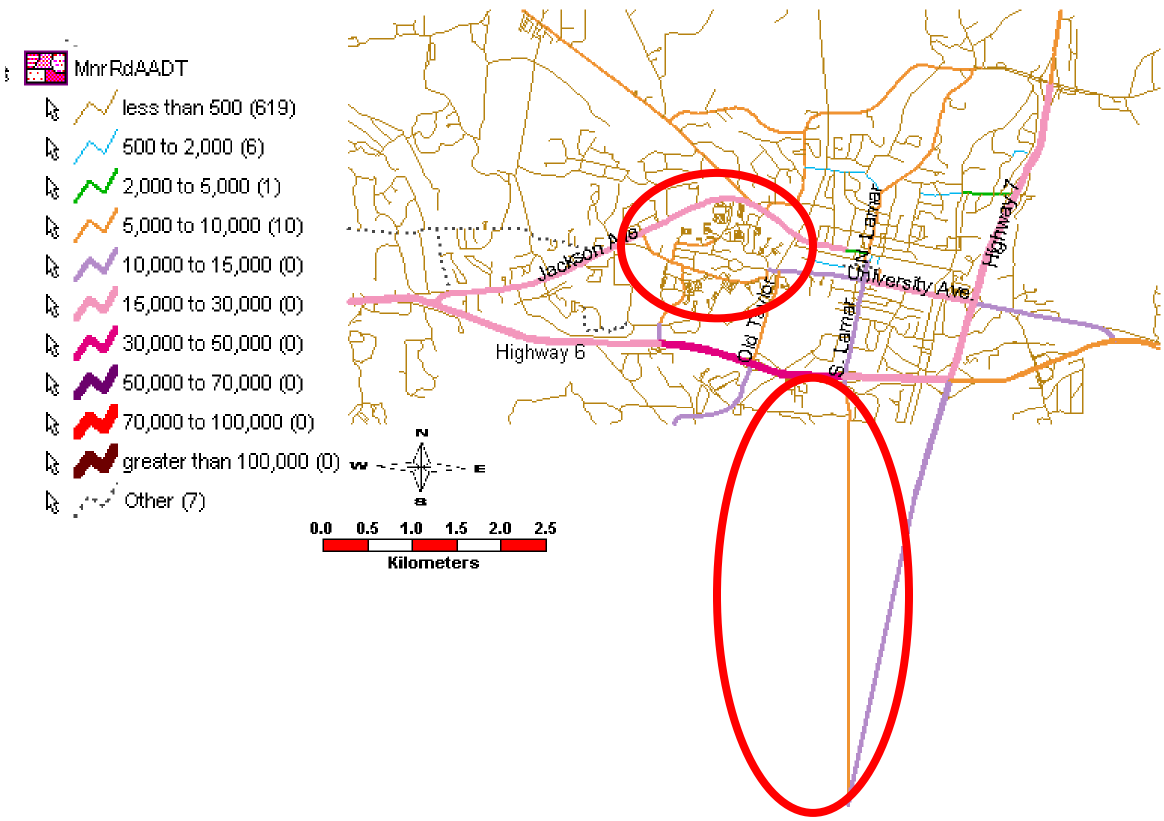


Figure 12. AADT map for 2008

The historical AADT thematic maps reveal:

- From 1998 to 1999 there is a significant increase in daily traffic volume on South Lamar Blvd.
- From 2005 to 2006 there are four road segments with considerable traffic growth. All of these changes occurred within the inner city area. Three of the road segments experienced an increase in traffic volume while one of these road segments, University Avenue from South Lamar Blvd to Bramlet Blvd, experienced a decrease in daily traffic volume. The roads that experienced substantial increases in yearly growth include: MS Highway 6 from Old Taylor to South Lamar Blvd, Jackson Avenue from College Hill Road to Molly Bar Road, and University Avenue from Old Taylor to North Lamar Blvd.
- Lastly from 2007 to 2008, a segment of Highway 7 south of Highway 6, and Jackson Avenue from Rebel Drive to Molly Bar Road experienced considerable traffic growths, while a segment of Molly Bar Road starting from Jackson Avenue heading north experienced a significant decrease in traffic growth.

Figure 13 displays the highway and major road sections where traffic data was collected in 2008. In the MDOT map these road segments are displayed by red and blue fonts. In the thematic vector maps the red line represents the road segments where traffic data was collected for that year, and the road segments traffic data that was not collected are displayed by a gray line. Traffic data was collected on nine highways and major roads, while traffic data was not collected for sixteen road segments.

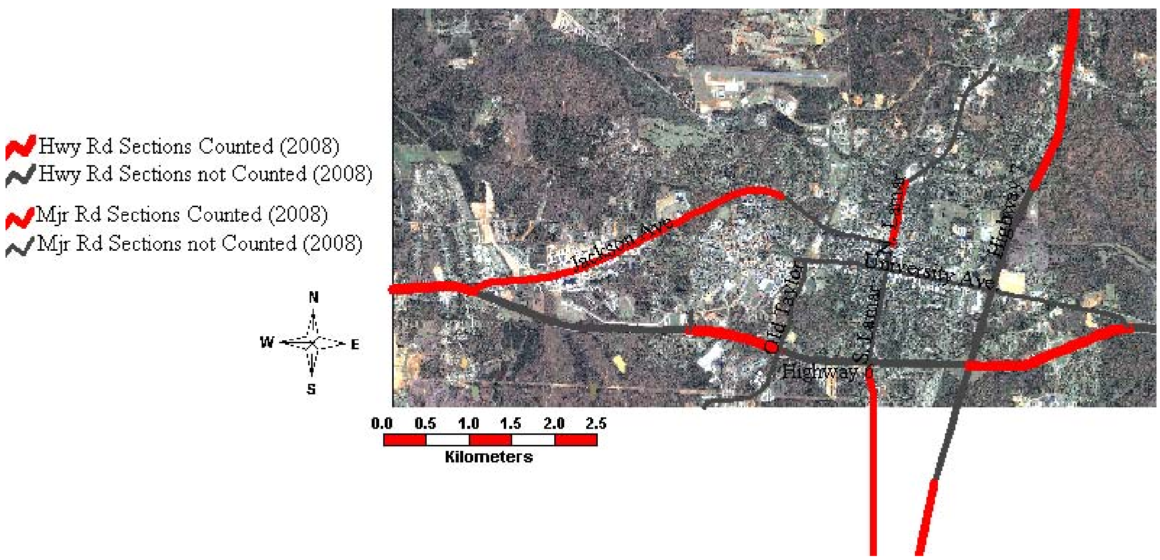


Figure 13. Road sections where traffic data was collected in 2008

The Oxford GIS map did not include the modification of the MS Highway 6 and South Lamar Blvd interchange, and currently there is no available imagery for the roundabouts constructed on the site. Therefore in order to extract the centerlines and pavements for the roundabouts, interactive scanned images of the project design plans [15] were georeferenced by imagery registration into GeoMedia Pro (Figure 14). This allowed for the accurate size as well as location of the roundabouts to be extracted. Step by step procedures of the above image registration and planimetrics processes can be found in Headrick's thesis [32] and the "GeoMedia Professional Course Guide" [33].

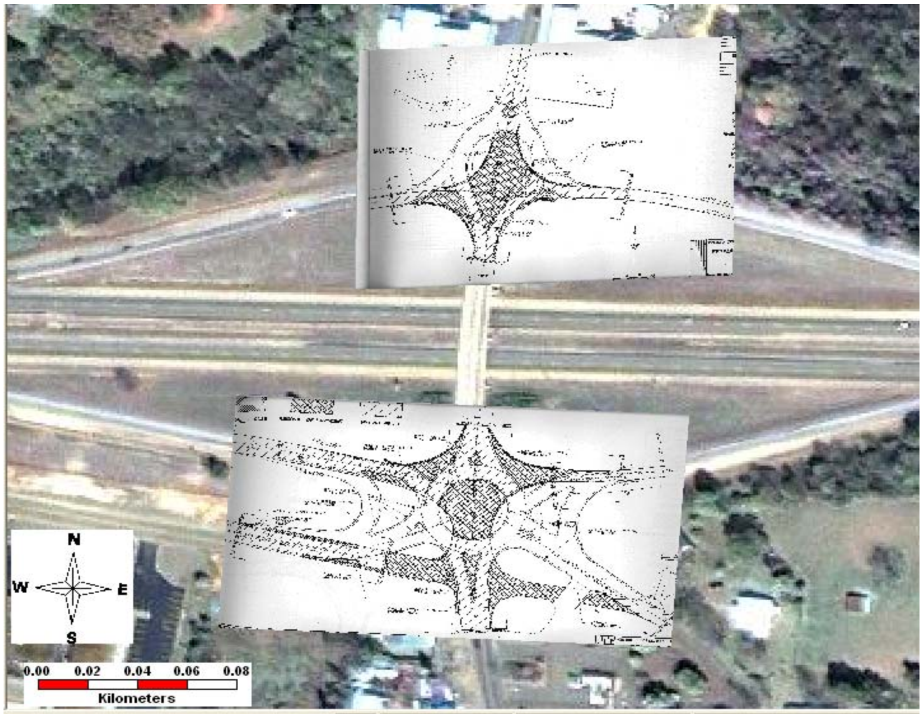


Figure 14. Roundabout design plans georeferenced into GeoMedia Pro

2.3 Traffic Data Analysis from On-site Manual Counts for Oxford and LOS Analysis

On-site traffic data collection is timely and labor intensive but it is the traffic data collection method that achieves the most accurate data. In order to analyze the effectiveness of the roundabout construction on-site traffic counts were conducted for each roundabout. The data was collected in the second week in October 2009 including the days of Monday, October 12 to Saturday, October 17 and counted between the hours of 7:00 am to 7:00 pm, for each day. Actual hour of data collection varied each day due to class schedules and availability of student staff. The data was collected by CAIT faculty and staff, select civil engineering students, and graduate students. A total of 20 undergraduate students and four graduate students participated after a detailed planning meeting and safety briefing by the project director.

After all the data were collected, the data were compiled in Excel spreadsheets for each roundabout by day with the sketch of the roundabout and movement numbers. The data sheets represent a full summary of all the traffic data and information for that date of data collection, as shown in samples included in Appendix. The excel sheets were organized into traffic counts by movement, hour, and total minutes counted for that hour. The sheets also incorporated: the total traffic counts for the daytime hours of data collection, the distribution of vehicle mix (car, truck and motorcycle) over the entire collection hours, hour of maximum volume, maximum hourly volume, the two movements with the maximum volume for the maximum hour, the traffic counts in 15-minute intervals for the two movements with the maximum volume for the maximum hour, and the peak hour factor (PHF) for the two movements with the maximum volume for the maximum hour. Peak hour factor represents the most critical time period of the day, and is used for evaluating lane capacity.

2.3.1 Traffic Data Collection Protocol and Data Collection Form

A comprehensive manual traffic data collection form for each roundabout was designed to count and record traffic for each movement in 15-minute interval for each hour of data collection. The student staff was trained in the office and field and safety briefing was conducted by the project director for each group of traffic counters. Samples of data collection forms are included in Appendix. The traffic was counted manually and recorded on assigned traffic data sheets. The traffic counts were compiled in 15-minute intervals, and a new traffic form was used for each hour and assigned movement(s). The trucks and motorcycles were included in daily traffic, but were also accounted separately by hour. Group leaders were assigned for each day in order to distribute forms and assign movements. Each participant was given a form according to the assigned junction and movements. For the purpose of uniformity the northern roundabout was called North roundabout and the southern roundabout was called South roundabout. The North roundabout, MS Highway 6 westbound ramps, had 6 movements and each participant was assigned 2-3 movements. The South roundabout, MS Highway 6 eastbound ramps, had 12 movements and each participant was assigned 2-4 movements. Sample of data sheets are included in the Appendix. Table 2 lists hour number and corresponding time period of data collection. Figure 15 shows a plan view of the North roundabout and the South roundabout at South Lamar Blvd, as well as photos of data collection from the study site.

Table 2. Hours of manual counts

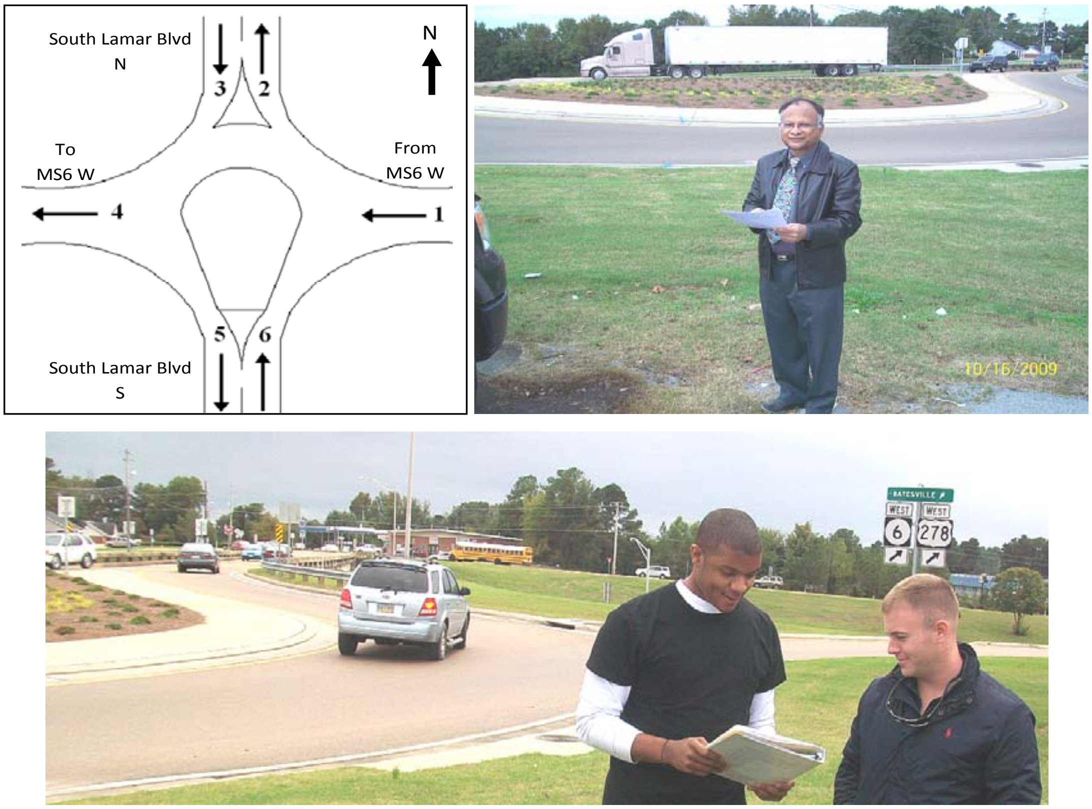
Hours of Manual Count:	#1 7:00-8:00am	#2 8:00-9:00am	
#3 9:00-10:00am	#4 10:00-11:am	#5 11:00-12:00pm	#6 12:00-1:00pm
#7 1:00-2:00pm	#8 2:00-3:00pm	#9 3:00-4:00pm	#10 4:00-5:00pm
#11 5:00-6:00pm	#12 6:00-7:00pm		

Traffic data were collected for 6 days at the North roundabout and for 5 days at the South roundabout. Monday was the day with the lowest peak hour for the North roundabout. Below is an example calculation of PHF from Monday's traffic data:

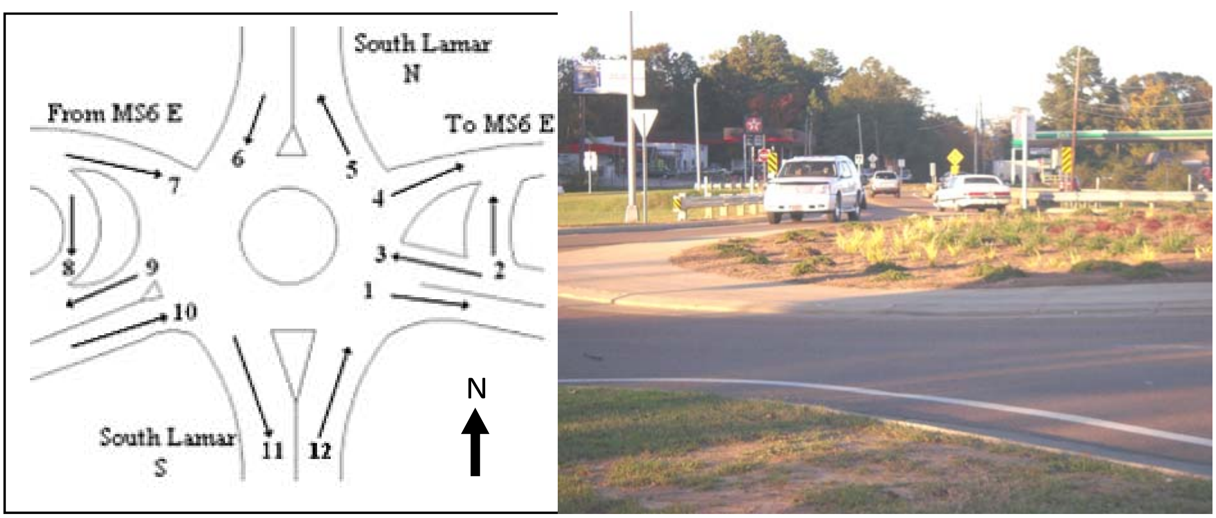
- Peak hourly volume = 2,416 vehicles at Hour # 7 (1:00:00 pm – 2:00:00 pm)
- Peak traffic volumes during the peak hour =
    - 478 at movement 2
    - 651 at movement 6
- Peak quarterly hour traffic for peak movement during the peak hour =
    - Movement 2 = 136
    - Movement 6 = 198
- PHF = peak hourly volume for a given movement during the peak hour/ (4 * peak 15-minute flow for that movement during the peak hour)
    - Movement 2 - PHF = 478 / (4 * 136) = 0.88
    - Movement 6 - PHF = 651 / (4 * 198) = 0.82

2.3.2 Traffic Data Analysis of North Roundabout

The North roundabout was the only roundabout where traffic data was also collected on Saturday. This traffic data was collected for one hour between 11:00 am and 11:59:59 am. The date of collection was on the day of the University of Alabama Birmingham game, which was also The University of Mississippi's homecoming. Traffic data was collected on this day in order to show the difference in traffic in the occurrence of an irregular event when traffic swells several hundred times on game days.



North Roundabout (top right: an 18-wheeler truck trailer driven over the roundabout lane)



South Roundabout (bottom right: looking from south roundabout to the overpass)

Figure 15. Sketch of roundabouts showing traffic movement numbers and site photos

Figure 16 represents the peak hour and the peak hour factor for each day for the North roundabout, the movement of the peak hour is displayed above each bar in the bar graph. The average peak hour factor is 0.92 which is higher than the average rural road PHF [26]. This is a relatively high peak hour for a rural area. Aside from Saturday, Tuesday has the highest peak hour factor for the week. Saturday is disregarded since only one hour of traffic was counted for Saturday. The one 0'clock hour and movement 6 is the most predominant time and movement with peak hour traffic.

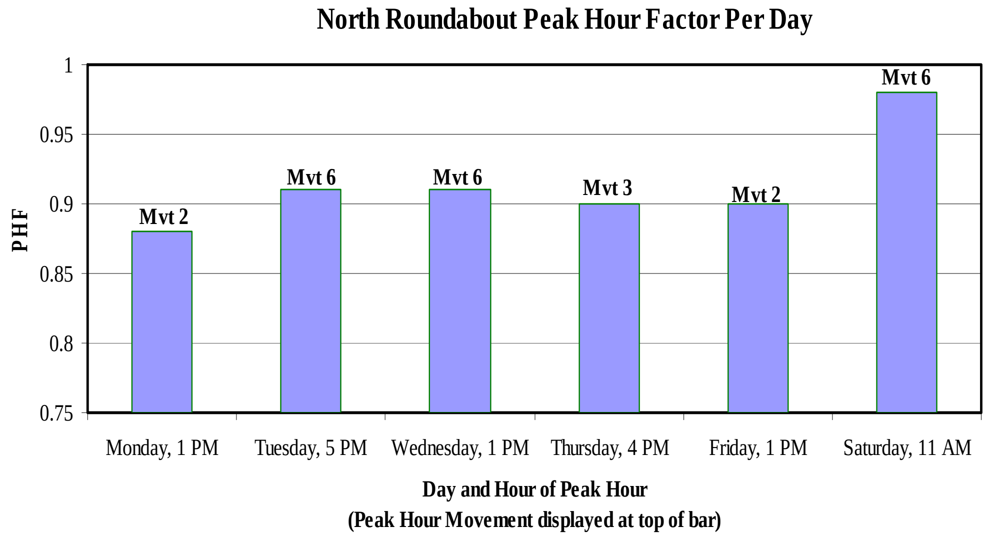


Figure 16. North roundabout peak hour and peak hour factors for each day

The maximum hours counted in one day for the North roundabout was eleven hours; this was counted on Monday, October 12th. The highest daily traffic volume was on Wednesday, October 14, which had a traffic count of 22,818 vehicles. Since different amounts of hours were collected for each day the average traffic volume per hour (vph) was also calculated for each day (Figure 17) for all way traffic.

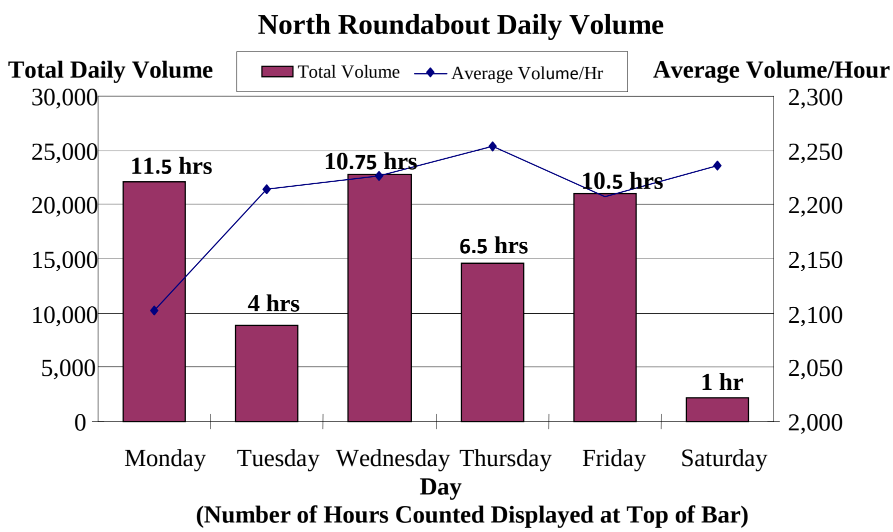


Figure 17. North roundabout daily traffic volume and daily traffic volume per hour, 2009

The average vph was calculated by taking the total volume per daytime data collection and dividing it by the amount of hours accounted for. The total daily traffic volume can be read by reading the graph from left to right, and the average traffic volume per hour can be read by reading the graph from right to left. The total hours of traffic data collected for each day is displayed to the top of each bar. Thursday has the highest traffic volume per hour with a traffic volume of 2,254 vehicles per hour. The average all-way traffic volume per hour for the entire North roundabout for the week of October 12 – 17 was 2,070 vehicles per hour. Figure 18 shows Friday's hourly volumes for each movement at the North roundabout. Average daily traffic volume of 33,928 was estimated considering all way traffic. Note that for capacity analysis entry and exiting volumes were calculated for the peak hour.

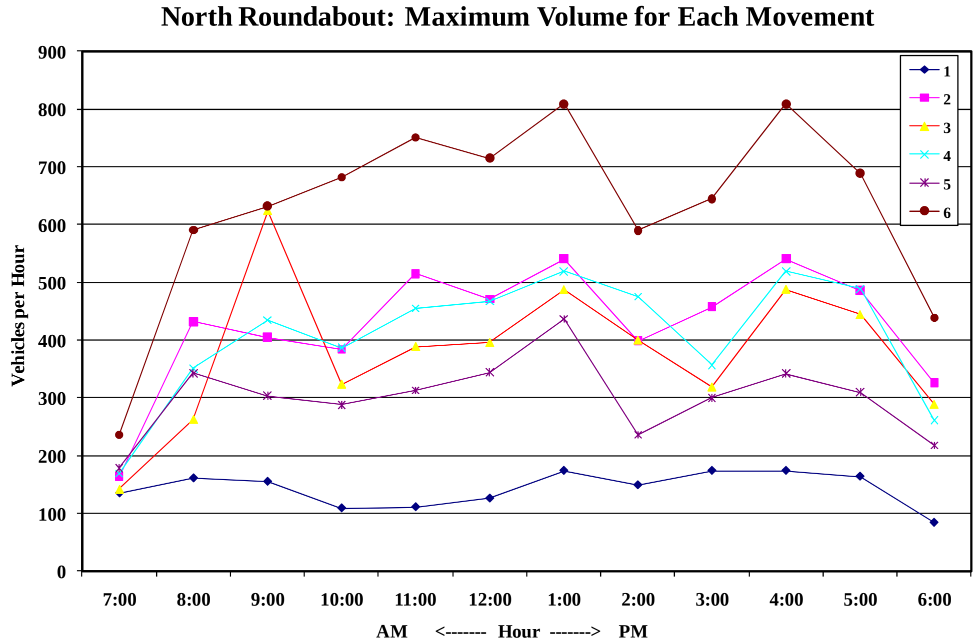


Figure 18. North roundabout hourly traffic volume variations by movement, 2009

2.3.3 Traffic Data Analysis of South Roundabout

The maximum hours were counted on Wednesday for the south roundabout, nine hours and forty-five minutes. Appendix includes a sketch of the traffic movements and complete summary of the traffic data for Wednesday October 14, 2009. Wednesday had the most hours of traffic data collected with a total of 9.75 hours of data collection. The PHF for this day was 0.90. The PHF occurred between the hours of 3:00 pm and 4:00 pm at the second 15-minute subinterval in movement 5. The peak hour factor for the South roundabout was consistent from day to day, with three days having peak hour factor of 0.90 (Figure 19). The peak hour generally occurred around 11 am at movement 12. It was noted that Thursday had an irregularly low peak hour factor of 0.78. The average peak hour factor for the South roundabout was 0.88. Though this value is smaller than the North roundabout, according to the 2000 Highway Capacity Manual this is a normal PHF for a rural road [26]. Figure 20 shows the total daily traffic volume, hours of counts, and average number of vehicles per hour from Monday through Friday for the South Roundabout. Note that for capacity analysis entry and exiting volumes were calculated for the peak hour.

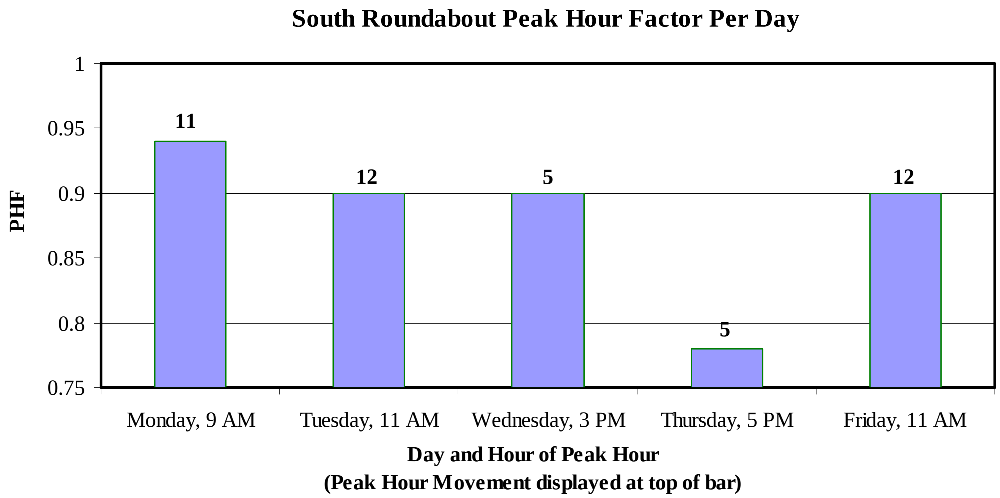


Figure 19. South roundabout daily peak hour and peak hour factor

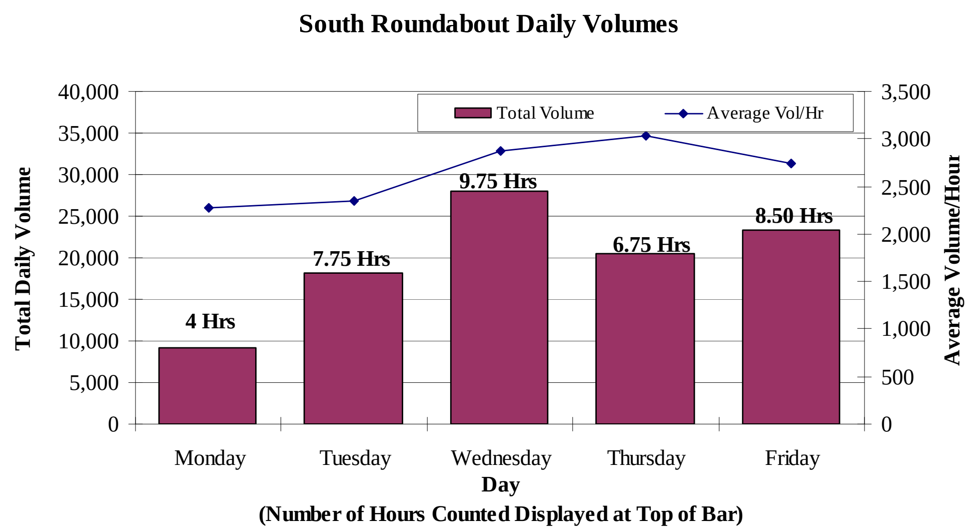


Figure 20. South roundabout total daily traffic volume and average vehicles per hour for all way traffic

Monday had the least amount of traffic data collected, only four hours of traffic data were collected. The highest daily traffic volume was also on Wednesday, October 14, which had a traffic count of 27,952 vehicles. Coinciding with the North roundabout, Thursday had the highest traffic volume per hour with a traffic volume of 3,029 vehicles per hour, and the least hourly traffic volume of 2,281 vehicles per hour was also on Monday (Figure 20). The average traffic volume per hour for the South Roundabout for the week of October 12 – 16 was 2,696 vehicles per hour. Even though the South roundabout has twice as many movements as the North roundabout the average volume per an hour for the entire junction was about 30% higher. This is probably due to the hospital, medical offices, and new communities built in recent years on the south side of MS Highway 6 along South Lamar Blvd, which generate and attract more traffic. However, average daily traffic volume of 35,424 was estimated for 24-hour volume, which is only 4.4% more than the 33,928 vehicles per day (vpd) estimated for the North roundabout.

2.3.4 Traffic Data Summary and Capacity Analysis of the North and South Roundabouts

Figure 21 compares the average hourly volume for all way traffic at each roundabout. The hour of maximum volume in vph is shown on the top of each bar. The maximum hourly volume was measured on Friday for the North roundabout at 2,853 vph and 3,349 on Thursday for the South Roundabout. Entry and exiting volumes were calculated for the peak hour and were used for level of service analysis using the 2010 Highway Capacity Manual (HCM) procedure for roundabouts [16, 34].

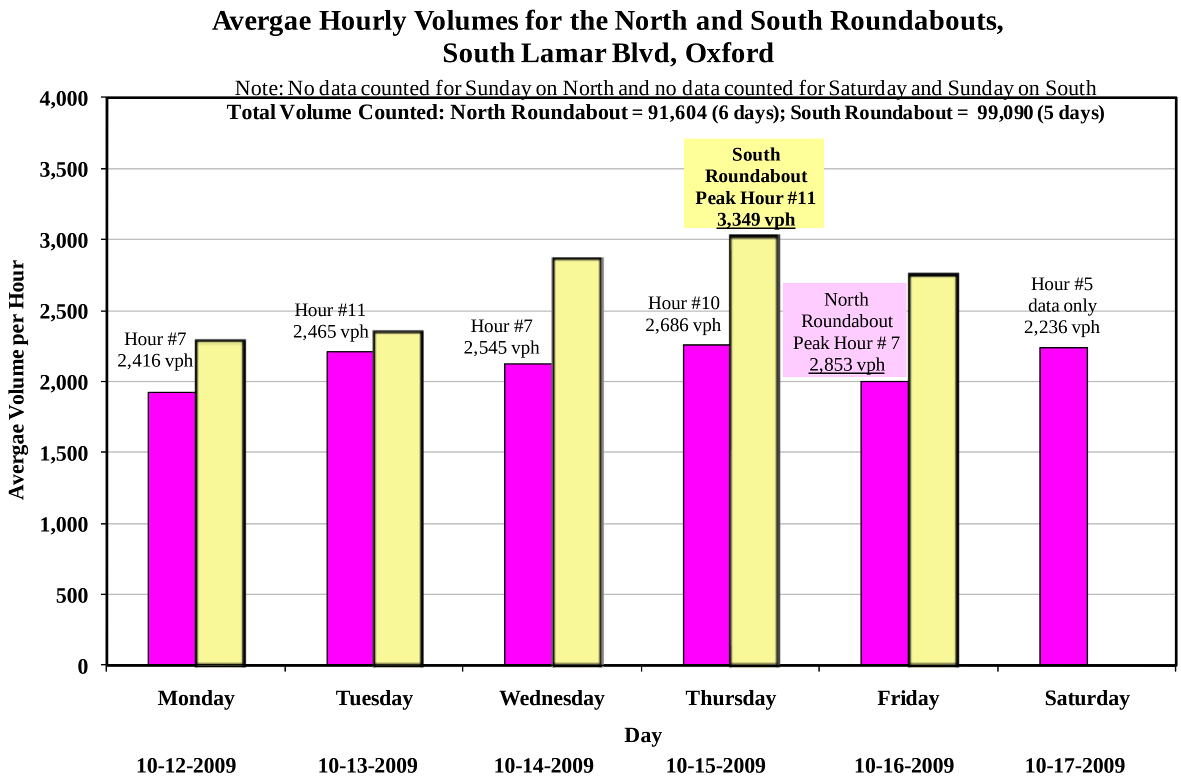


Figure 21. All way hourly volume data comparison for both roundabouts on South Lamar Blvd, 2009

Table 3 lists daily summaries of the total all way traffic counts, number of hours of manual count data collection, estimated 24-hours daily volume in vehicles per day (vpd), and average hourly volume. The average hourly volume for each day was calculated by dividing total counts with number of hours of data collection. The traffic count data collected for daytime hours each day was extrapolated for remaining hours of day and night. The extrapolation was based on hourly factors extracted from a previous study on a nearby section of MS Highway 6 where 24-hour automatic counter data was collected for an entire week [27]. The average daily volume for each roundabout is about 2.9 times the AADT data available from MDOT for year 2008 in Table 1. The 2009 on-site manual traffic data for both roundabouts show maximum daily volume for all way traffic on Wednesday and maximum average hourly volume on Thursday evening peak hours. However, the measured maximum all way hourly volume was on Friday for the North roundabout at 2,853 vph (Figure 21).

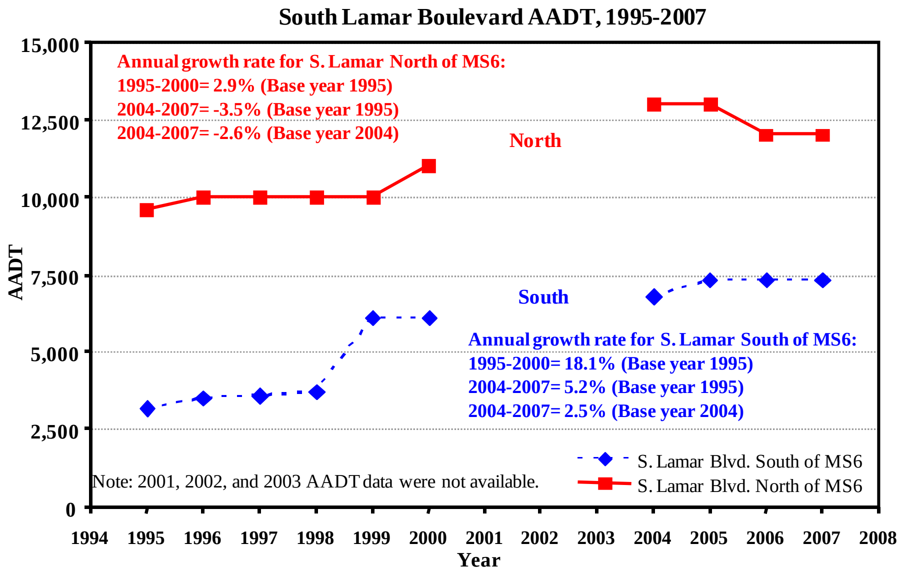
Table 3. Traffic data summaries of manual on-site all way traffic counts collected on site, 2009

		North Roundabout				
(1)	(2)	(3)	(4)	(5)	(6)	
Date	Day	Total Counts	Number of Hours	24-Hours Volume (Est.)	Volume/Hour (vph)	
12-Oct-09	Monday	22,076	11.5	33,825	1,920	
13-Oct-09	Tuesday	8,859	4.0	34,320	2,215	
14-Oct-09	Wednesday	**22,818**	10.75	36,433	2,123	
15-Oct-09	Thursday	14,650	6.5	34,699	**2,254**	
16-Oct-09	Friday	20,965	10.5	30,405	1,997	
17-Oct-09	Saturday	2,236	1.0	33,889	2,236	
		91,604	44.25	203,571	Total for 6 days	
				33,928	Average per day	
				2,070	Average per hour	

		South Roundabout				
(1)	(2)	(3)	(4)	(5)	(6)	
Date	Day	Total Counts	Number of Hours	24-Hours Volume (Est.)	Volume/Hour (vph)	
12-Oct-09	Monday	9,125	4.0	36,249	2,281	
13-Oct-09	Tuesday	18,221	7.75	31,325	2,351	
14-Oct-09	Wednesday	**27,952**	9.75	40,538	2,867	
15-Oct-09	Thursday	20,447	6.75	35,152	**3,029**	
16-Oct-09	Friday	23,345	8.5	33,857	2,746	
		99,090	36.75	177,121	Total for 5 days	
				35,424	Average per day	
				2,696	Average per hour	
				(30% more than North Roundabout)		

			Weekly Volume	
		North Roundabout	226,752	Total for 7 days
		South Roundabout	228,337	Total for 7 days
	South Roundabout is higher by:		0.7%	for weekly volume

Figure 22 shows the published AADT data for South Lamar Blvd [31] from 1995-2007. The year 2008 AADT is 12,000 vpd. A decline in AADT is observed in north of MS Highway 6 whereas an increase in AADT is seen in the south. This general trend is also confirmed from the 2009 manual count data summarized in Figure 21 and Table 3. Linear annual growth rate in AADT is also shown in Figure 22. For the purpose of this study, a linear annual growth rate of 2.5% (assuming base year 2004 AADT) is calculated for the southern section of South Lamar Blvd as well as used for the northern section.



Data Source: Traffic Volume Map, Oxford, MS, Prepared by MDOT's Intermodal Planning Division, Accessed June 10, 2008.
http://www.gomdot.com/Divisions/IntermodalPlanning/Resources/Maps/TrafficVolumeMaps.aspx

Figure 22. The published AADT data for South Lamar Blvd from 1995-2007

The capacity analysis and LOS calculation for road junctions (intersections and roundabouts) are based on the analysis of peak hour data for traffic flow entry and exiting movements. Table 4 summarizes the 2009 peak hour data for both roundabouts by movement and 2016 predictions using 2.5% annual growth. These peak movement data were used for conducting LOS analysis for the most critical movements in the peak hour using the 2010 HCM capacity analysis procedure for single lane roundabouts (Eq. 1) and control delay equation [16, 34].

$$C = 1130\, e^{(-0.001)(V_c)} \qquad \text{Eq. 1}$$

where ,

C = capacity of subject approach, vph

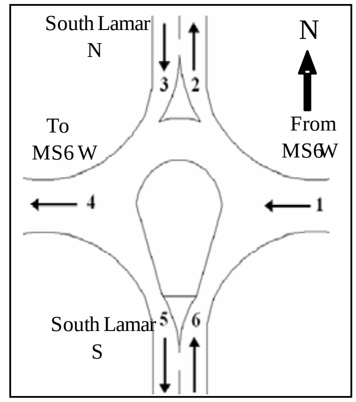
V_c = volume of all conflicting movements, vph

Table 5 shows the capacity and LOS calculations using HCM procedure for single lane roundabout and results for both roundabouts. In year 2009, the roundabouts were performing as intended by their design with LOS equal to C or B for critical approaches. As shown in Table 5, there is no congestion problem if the traffic volume does not increase over these years. However, with assumed 2.5% annual growth in peak hour traffic volume, the LOS in year 2016 remains C for most entry flows but it deteriorates to E for the southbound traffic on South Lamar Blvd (Movement 3) entering the North roundabout (Table 5) during Friday's peak hour. For Thursday's peak hour the LOS worsens to F due to higher conflicting flow. Therefore, it is recommended to install MDOT's video surveillance camera for monitoring traffic flow and collect annual traffic data at the study site. This will help to plan timely mitigation strategies if the traffic grows as projected or even at a different rate. For example, a bypass right-side lane at Movement 3 will improve the LOS for southbound traffic at the North roundabout. According to

Headrick about 36% of this traffic flow is estimated to turn right onto the MS Highway 6 west on-ramp [32]. Therefore, this is a viable strategy considering the availability of land and distribution of traffic flow.

Table 4. Peak hour traffic volume by movement for years 2009 and 2016

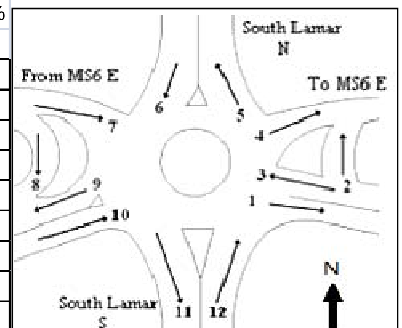
10/16/2009 Friday Peak Hour #7 (1:00 - 2:00 pm)				Assuming annual growth =			2.5%
North Roundabout Entry/Exit Counts, 2009				North Roundabout Entry/Exit Counts, 2016			
Entry		Exit		Entry		Exit	
Movement Number	Vehicle Count	Movement Number	Vehicle Count	Movement Number	Vehicle Count	Movement Number	Vehicle Count
1	174	2	541	1	207	2	643
3	487	4	519	3	579	4	617
6	809	5	323	6	962	5	384
M		M		M		M	
Total =	*1,470*	*Total =*	*1,383*	*Total =*	*1,748*	*Total =*	*1,644*
Total Both Directions=		2,853		Total Both Directions=		3,392	
		(Entry and Exit)				(Entry and Exit)	



South Roundabout

10/15/2009 Thursday Peak Hour #11 (5:00-6:00 pm)				Assuming annual growth =			2.5%
South Roundabout Entry/Exit Counts, 2009				South Roundabout Entry/Exit Counts, 2016			
Entry		Exit		Entry		Exit	
Movement Number	Vehicle Count	Movement Number	Vehicle Count	Movement Number	Vehicle Count	Movement Number	Vehicle Count
12	428	1	107	12	509	1	127
3	95	4	119	3	113	4	141
6	356	5	776	6	423	5	922
7	712	9	111	7	846	9	132
10	92	11	491	10	109	11	584
M		M		M		M	
Total =	*1,683*	*Total =*	*1,604*	*Total =*	*2,001*	*Total =*	*1,906*
Total Both Directions=		3,287		Total Both Directions=		3,907	
		(Entry and Exit)				(Entry and Exit)	

Note: Movements 2 and 8 are excluded which are right turn lanes and do not enter/exit the roundabout.



North Roundabout

Table 5. Results of LOS analysis for years 2009 and 2016 for both roundabouts

North Roundabout		Year 2009	Year 2016
Peak volume (V) at M 6, vph	=	809	962
Conflicting flow (Vc) at M 6	=	0	0
Entry capacity (C) for entry 6, vph =Ce,6 =		1,130	1,130
V / C (for Movement 6)		0.72	0.85
Delay on subject approach, sec/veh	=	14.7	24.5
LOS (for Movement 6)	=	B	C
		Delay >10 - 15	Delay >15 - 25
Peak volume (V) at M 3, vph	=	487	579
Vc at M 3 = M1 + M6 - M2	=	442	525
Entry capacity for entry 3, vph = Ce,3	=	719	660
V / C (for Movement 3)	=	0.68	0.88
Delay on subject approach, sec/veh	=	18.7	43.5
LOS (for Movement 3)	=	C	E
		Delay >15 - 25	Delay >35-50

South Roundabout		Year 2009	Year 2016
Peak volume (V) at M 12, vph	=	428	509
Vc at M 12 = M6 + M7 + M10 - M9 -M11 =		558	663
Entry capacity (C) for entry 12, vph =Ce,12 =		639	574
V / C (for Movement 12)		0.67	0.89
Delay on subject approach, sec/veh	=	20.2	22.1
LOS (for Movement 12)	=	C	C
		Delay >15 - 25	Delay >15 - 25
Peak volume (V) at M 7, vph	=	712	846
Vc at M 7 = M12 + M3 + M6-M1-M4-M5=		0	0
Entry capacity for entry 7, vph = Ce,7	=	1,130	1,130
V / C (for Movement 7)	=	0.63	0.75
Delay on subject approach, sec/veh	=	11.7	16.2
LOS (for Movement 7)	=	B	C
Vc set to zero at M7 due to negative values.		Delay >10 - 15	Delay >15 - 25

The HCM method of capacity and LOS analysis was developed for traditional 4-leg roundabouts and may not be applicable in this case of an eye-drop non-circulating North roundabout and 6-legged South roundabout. Traffic microsimulation is an alternative approach to model queuing and delay as discussed in the next chapter.

2.4 Traffic Data Processing for Microsimulation Studies

2.4.1 Synchronizing Different Traffic Data Sets for Comparison

A consulting report was presented to the Mississippi Department of Transportation, MDOT, in February 2006 [14]. The consultant's report evaluated the effectiveness of installing roundabouts in place of a signalized intersection in the north of the overpass and three stop-controlled intersections in the south. The report used 'Synchro 6 and aaSIDRA 2.1 software programs' to analyze LOS and queue lengths for predicted 2006 and 2016 traffic on the MS Highway 6 and South Lamar Blvd junctions. The traffic data was predicted using a 2.5% yearly growth rate from on-site traffic data collected on Wednesday, January 28, 2003 [14]. This consultant report was provided by courtesy of MDOT for review in this study. The data from this report were used for comparison with the on-site traffic data collected for this study. Using the same annual growth rate of 2.5%, 2009 traffic count was predicted using the original traffic data collected for MDOT in 2003. This predicted 2009 traffic count was used for comparison with the on-site traffic data collected in 2009. Since each set of traffic volume data was collected using a different method, a full 12-hour day of traffic counts and coinciding traffic movements were needed in order to summarize the two traffic data sets into parallel formats. This allowed for a more efficient and accurate comparison.

First a full 12 – hour day of traffic counts was estimated for the 2009 field traffic data for comparison with the consultant report's predicted 2009 traffic data. Since most of the data collectors were university students it was not possible to collect every hour of traffic for every movement at both roundabouts for the entire week. Out of a possible 72 hours of data collection per roundabout at 12 hours per day for six days, 44 hours of traffic counts were collected for the North roundabout and 37 hours were collected for the South roundabout. Thursday was considered for the North roundabout because of the high traffic volume per hour, but lacked the amount of total hours counted. Wednesday traffic data was chosen as the day to compare the traffic counts for both the North and the South roundabouts because of the relatively high traffic volume per hour, and the amount of hours counted for both roundabouts. For the North roundabout, Wednesday lacked a total of one hour and forty five minutes of traffic data, 7:00:00 am to 8:00:00 am, 2:30:00 pm to 3:00:00 pm, and 6:45:00 pm to 7:00:00 pm. Since the only day traffic was collected for 7:00:00 am to 7:59:59 am was on Monday, the Monday traffic counts for this hour were used. The South roundabout data on Wednesday was missing two hours and fifteen minutes of traffic data, 7:00:00 am to 8:00:00 am, 10:00:00 am to 10:14:59 am, 2:00:00 pm to 3:00:00 pm, and 6:30:00 pm to 7:00:00 pm. Same as the north roundabout, the only day that accounted for traffic between 7:00:00 am to 7:59:59 am was on Monday. The intervals of missing traffic data were extrapolated from the trend of that hour using the following equation [26, 32]:

- V' = V * CF
- $CF = \dfrac{CP}{CP - SB}$

Where,

CF = count expansion factor
CP = counting period, minutes
SB = short break, minutes
V’ = adjusted count, vehicles
V = actual count, vehicles

Secondly, the traffic data summary in the MDOT consultant’s report was prepared based on the original road intersection layout prior to the roundabouts. The construction of the roundabouts reduced the total number of movements at each junction, therefore, altering the way the traffic data was defined in the traffic data report. The reduction of movements occurs because of the reduction of turning lanes. Each lane approaching a roundabout enters in the same direction, whereas in a simple at-grade intersection vehicles enter the intersection in the direction the vehicle is traveling. This results in the traffic data collection and entry differing for each type of road design. The MDOT consultant’s report counts the traffic entering the intersection based on the direction the traffic is traveling. In a roundabout design all the vehicles enter in the same direction and travel around the roundabout in the same direction, therefore, there is no way to know the exact road destination of every vehicle, consequently the roundabout traffic data is collected for each entry and exit movement. In order for the MDOT traffic data summary to be compared with the roundabout field traffic data the original traffic design movements needed to coincide with the roundabout movements.

The MS Highway 6 westbound and South Lamar Blvd intersection originally had 7 movements entering the intersection; the placement of the North roundabout reduced the entering movements to 3 [32]. Figure 23 represents the intersection prior to the construction of the roundabout and the intersection’s movements. The movements are lettered from A to J started at the MS Highway 6 off ramp and lettering the movements counterclockwise. The entering movements are represented by white arrows and the outgoing movements are represented in grey. The numbers at the beginning and end of the movement arrows correspond with the roundabout movements displayed in Figure 24. The circled numbers at the beginning of the arrows correspond with the entering movements of the North roundabout. The light italicized not circled numbers at the end of the arrows correspond with the outgoing (exiting) roundabout movements.

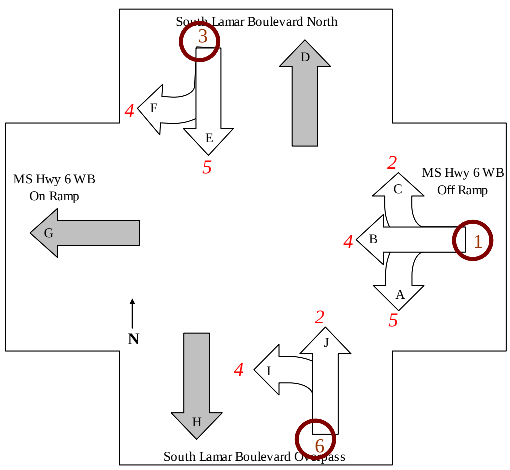


Figure 23. MS Highway 6 westbound and South Lamar Blvd intersection prior to the construction of the roundabouts

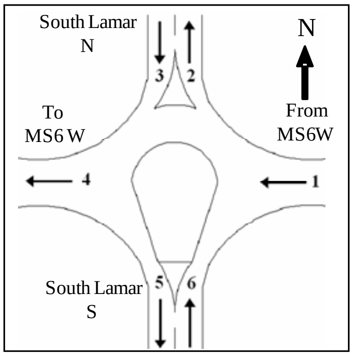


Figure 24. North Roundabout with each movement designation

The South roundabout required more analysis since the south roundabout is a combination of three intersections: MS Highway 6 eastbound ramp/ South Lamar Blvd, Frontage Road/ South Lamar Blvd, and Access Road/ South Lamar Blvd. The construction of the South roundabout in place of these three intersections reduced the number of movements entering the intersection from 19 to 5. Figure 25 represents the road design prior to the construction of the roundabout.

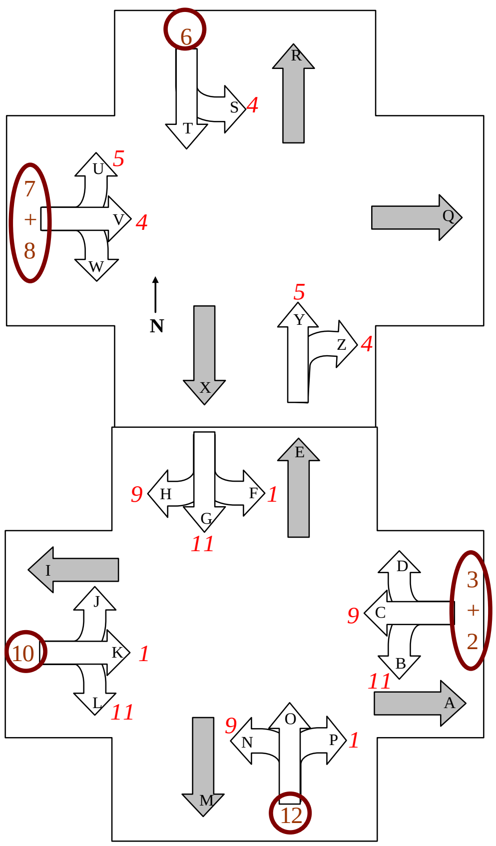


Figure 25. MS Highway 6 eastbound and South Lamar Blvd intersection prior to the construction of the South roundabout

The intersection of Access Road and Frontage Road with South Lamar Blvd are represented as one intersection because the consultant report traffic counts represent this condition. The movements are lettered from A to Z starting with Access Road and lettering the movements counterclockwise. The numbers 1-12 are the movement numbers that correspond with the South roundabout movements represented in Figure 26. The arrow and number fonts depict the same movement types (entering, exiting) as the MS Highway 6 westbound ramp and South Lamar Blvd intersection drawing. Note that at the end of the arrows not all are designated with numbers as they were in the North roundabout. These movements are either repeated traffic counts and are not needed, or they are only partially used in order to calculate other movements.

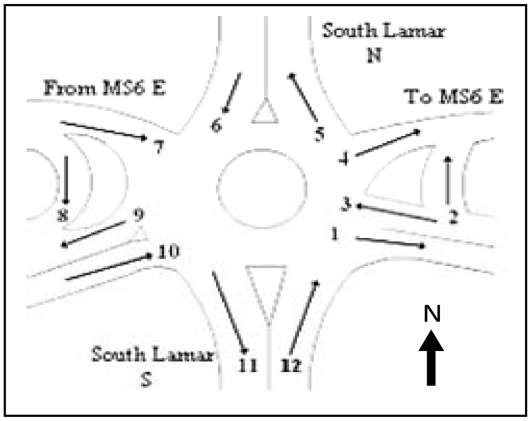


Figure 26. South roundabout with each movement designated

Since there were so many movement changes from the original road design to the roundabout design, some extra calculations were made to account for all the roundabout movements. There are two entering movements that are the summation of two of the roundabout movements. This is because in the roundabout road design, two side streets were constructed separate from the roundabout to prevent unnecessary traffic from entering the roundabout.

One of the side streets is movement 2. This road allows for traffic traveling from Access Road to MS Highway 6 eastbound to access the on-ramp without entering the roundabout. In Figure 27 the path movement 2 through the original roadway design is displayed in red. Movement E remains shaded because it is an exit movement and was not individually counted by the consultant report. The traffic demand for movement 2 from the consultant report would ideally be calculated by the following formula where each letter represents the traffic demand for that movement from the consultant report: $\text{movement}\,2 = \frac{D}{E} * Z$. Using this equation though is assuming that E = D + O + J =Y + Z. Since realistically this is not the case the equation had to be altered so that $\text{movement}\,2 = \frac{D}{D+O+J} * Z$. The second side street is movement 8. Movement 8 allows vehicles approaching the intersection from MS Highway 6 westbound ramp to travel onto Frontage Road without entering the roundabout. The same concept as movement 2 applies for movement 8. The ideal equation for $\text{movement}\,8 = \frac{W}{X} * H$, but the realistic equation becomes movement $8 = \frac{W}{T+W} * H$. A representative diagram of movement 8 through the original road design is displayed in Figure 28. The variables used in the above equation are defined in Figures 25 - 28.

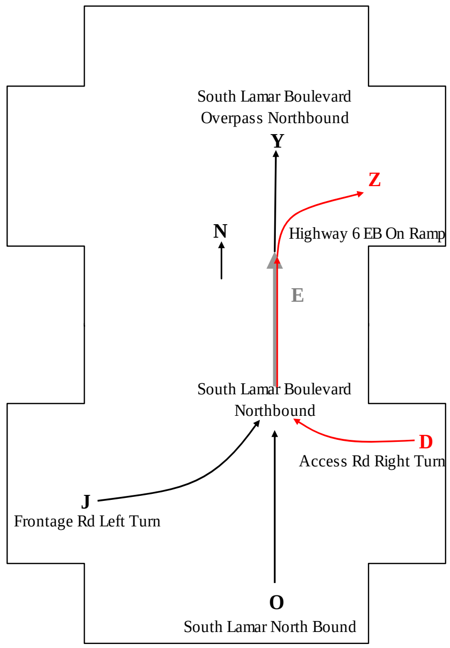


Figure 27. Path of movement 2 through the original roadway

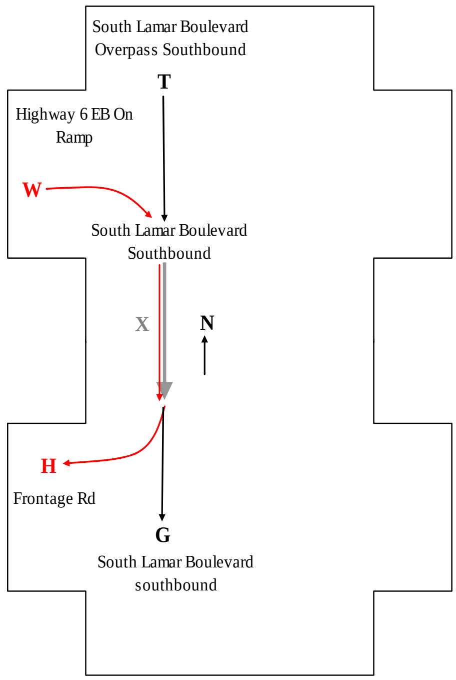


Figure 28. Path of movement 8 through the original roadway

The previous steps were completed and compiled into standardized traffic data tables for the following sets of traffic data listed by date, collection method, and intersection:

- Scenario 1A: Wednesday October 14, 2009, on-site, MS Highway 6 westbound and South Lamar Blvd (North)
- Scenario 1B: Wednesday October 14, 2009, on-site, MS Highway 6 eastbound and South Lamar Blvd (South)
- Scenario 2A: 2016, predicted from 2009 on-site using 2.5% yearly growth rate, MS Highway 6 westbound and South Lamar Blvd (North)
- Scenario 2B: 2016, predicted from 2009 on-site using 2.5% yearly growth rate, MS Highway 6 eastbound and South Lamar Blvd (South)
- Scenario 3A: 2009, predicted from MDOT consultant report using 2.5% yearly growth rate, MS Highway 6 westbound and South Lamar Blvd (North)
- Scenario 3B: 2009, predicted from MDOT consultant report using 2.5% yearly growth rate, MS Highway 6 eastbound and South Lamar Blvd (South)
- Scenario 4A: 2016, predicted by Neel-Schaffer from 2003 on-site using 2.5% yearly growth rate, MS Highway 6 eastbound and South Lamar Blvd (North)
- Scenario 4B: 2016, predicted by Neel-Schaffer from 2003 on-site using 2.5% yearly growth rate, MS Highway 6 westbound and South Lamar Blvd (South)

The traffic data sets may be referred to by their scenario types. Table 6 (a) represents scenario 1B for October 14, 2009, on-site, MS Highway 6 eastbound and South Lamar Blvd (South).

Table 6 (a). Standardized traffic data summary table for scenario 1B

Time	Movements												Total In	Total Out	Total
	1	2	3	4	5	6	7	8	9	10	11	12	3, 6, 7, 10, 12	1, 4, 5, 9, 11	
	F + K + P	D/(D+O+J)*Z	B + C + D - 2	S + V + Z	U + Y	S + T	U + V + W - 8	W/(T+W)*H	C + H + N	J + K + L	B + G + L	N + O + P	B:D,S:W,J:L, N:P	All others	Total
7:00 AM	**114**	**4**	**50**	**58**	**492**	**392**	**424**	**10**	**30**	**82**	**550**	**344**	1,292	1,244	2,550
8:00 AM	52	3	47	53	592	254	477	19	27	88	518	410	1,276	1,242	2,540
9:00 AM	47	5	59	43	582	250	375	13	46	80	443	455	1,219	1,161	2,398
10:00 AM	**44**	**9**	**43**	**44**	**603**	**268**	**407**	**24**	**64**	**69**	**420**	**469**	1,256	1,175	2,464
11:00 AM	56	17	78	48	786	291	432	24	53	73	445	590	1,464	1,388	2,893
12:00 PM	63	12	87	78	760	339	548	47	63	117	516	553	1,644	1,480	3,183
1:00 PM	49	10	50	59	603	343	488	31	65	92	589	473	1,446	1,365	2,852
2:00 PM	**58**	**10**	**82**	**90**	**672**	**398**	**438**	**32**	**80**	**96**	**576**	**488**	1,502	1,476	3,020
3:00 PM	72	36	98	118	886	398	431	17	91	105	618	410	1,442	1,785	3,280
4:00 PM	92	21	105	110	840	574	473	21	100	85	308	303	1,540	1,450	3,032
5:00 PM	69	28	103	133	584	310	622	33	114	106	520	559	1,700	1,420	3,181
6:00 PM	**42**	**6**	**56**	**72**	**454**	**246**	**520**	**22**	**130**	**84**	**406**	**432**	1,338	1,104	2,470
Total	758	161	858	906	7,854	4,063	5,635	293	863	1,077	5,909	5,486	17,119	16,290	33,863

The adjusted traffic counts for the on-site data are displayed in bold font. Table 6 (b) represents scenario 3B (2009, predicted from MDOT consultant report using 2.5% yearly growth rate, MS Highway 6 eastbound and southbound South Lamar Blvd). For both sets of traffic data the exiting traffic is shaded in grey. Movements 2 and 8 are not included in either the total in or the total out. This is because the movements never actually enter the intersection, and could be considered in or out. They are included in the total traffic count though.

Table 6 (b). Standardized traffic data summary table for scenario 2B

Time	Movements												Total In	Total Out	Total
	1	2	3	4	5	6	7	8	9	10	11	12	3, 6, 7, 10, 12	1, 4, 5, 9, 11	
	F + K + P	D/(D+O+J)*Z	B + C + D - 2	S + V + Z - 2	U + Y	S + T	U + V + W - 8	W/(T+W)*H	C + H + N - 8	J + K + L	B + G + L	N + O + P	B:D,S:W,J:L, N:P	All others	Total
7:00 AM	86	3	43	65	612	425	481	12	31	79	645	432	1,477	1,439	2,916
8:00 AM	49	4	43	91	478	323	325	16	41	86	459	472	1,249	1,119	2,388
9:00 AM	48	4	51	79	667	329	405	15	38	75	537	506	1,366	1,369	2,754
10:00 AM	52	5	69	57	641	297	352	17	45	65	485	490	1,273	1,280	2,575
11:00 AM	52	4	40	111	646	356	388	24	75	67	502	553	1,405	1,386	2,819
12:00 PM	87	5	68	97	742	458	468	22	67	111	669	585	1,690	1,662	3,378
1:00 PM	67	3	46	96	650	460	459	19	56	83	660	498	1,545	1,529	3,097
2:00 PM	70	5	52	112	743	489	485	25	59	67	697	607	1,700	1,682	3,412
3:00 PM	65	7	58	213	908	499	508	35	74	71	707	858	1,994	1,967	4,002
4:00 PM	79	6	64	182	846	449	561	30	90	81	698	754	1,909	1,895	3,840
5:00 PM	75	7	53	236	781	506	494	38	105	80	637	702	1,835	1,834	3,714
6:00 PM	36	2	25	123	600	340	414	38	91	80	483	474	1,332	1,333	2,705
Total	767	54	613	1,463	8,312	4,931	5,340	290	774	946	7,178	6,931	18,776	18,494	37,600

2.4.2 Comparison of MDOT Report Data with Roundabout Traffic Data in this Study

Figure 29 is a comparison of all four sets of scenarios for North roundabout (A), and South roundabout (B) categorized by their junction type. The first two bars for intersection type A and B represent the traffic data from the on-site traffic counts and the second two bars for each intersection type represent the traffic data from the consultant report. The percent change from the on-site traffic counts compared to the consultant report is displayed in a text box above the histogram bars. It is observed that the traffic counts predicted from the MDOT consultant report are higher for both intersections than the on-site traffic counts. For the North junction the MDOT consultant traffic counts are 24% higher than the on-site traffic counts, and 10% higher for the South junction.

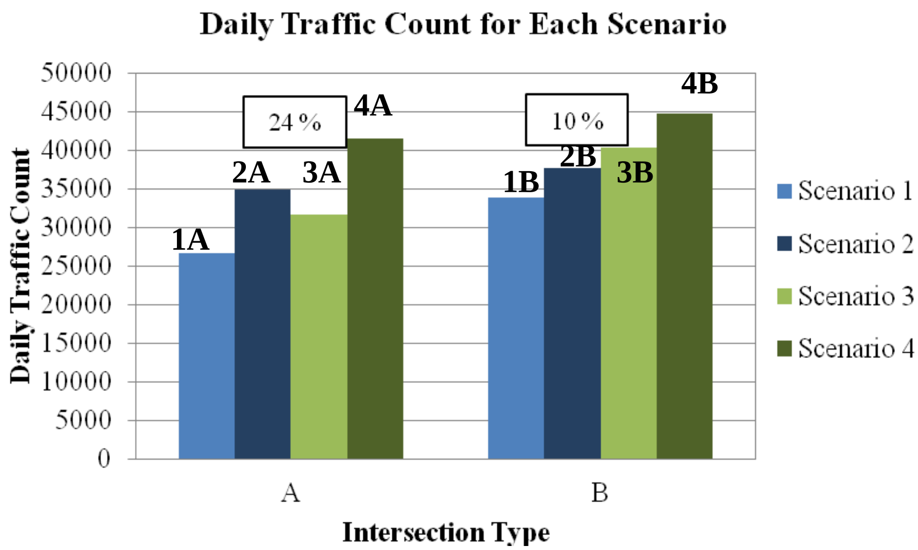


Figure 29. Daily traffic counts for each scenario at each intersection

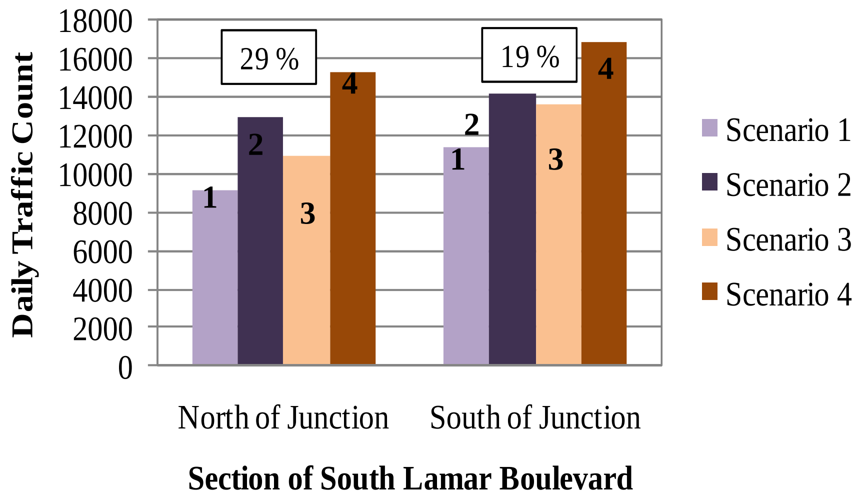


Figure 30. Twelve hour traffic count of each scenario

The traffic trends of South Lamar Blvd were also observed. Figure 30 displays the total 12 hour traffic volume of each scenario for sections of South Lamar Blvd before and after the roundabout junction. For the road section north of the junction this is the combination of the total 12 hour traffic counts of movements 2 and 3 from the North roundabout, and for the road section south of the junction this is the combination of the total 12 hour traffic counts of movements 11 and 12 from the South roundabout. This exhibits an increase in traffic of 29% for the North roundabout and 19% for the roundabout from the on-site traffic counts compared to the predicted traffic counts from the MDOT Consultant's report.

In order to further observe a possible explanation for the large discrepancy a third source was used. Both sets of data were compared with automated AADT counts collected by MDOT for South Lamar Blvd [31]. The MDOT AADT was collected over a ten year period for sections of South Lamar Blvd, north and south of the intersection from the MDOT website (Table 7) [31]. As stated earlier the MDOT automated counts are only collected every three years. If the year's data is not collected the AADT is assumed. In Table 7 the years that AADT was collected are represented in bold font, and the years of assumed AADT are in italics. The AADT North of the junction was collected between Old Taylor and Grant Street. Since a small percentage of South Lamar Blvd traffic enters and exits South Lamar Blvd between Grant and the intersection of MS Highway 6 westbound and the South Lamar Blvd intersection this traffic data is fairly representative of the traffic data entering and exiting the North roundabout to and from South Lamar Blvd.

Table 7. AADT over ten year period for sections of road north and south of the MS Highway 6 and South Lamar Blvd junction (Collected by MDOT)

Year	North		South	
	AADT	**Percent Increase**	**AADT**	**Percent Increase**
99	*10,000*		**6,100**	
00	**11,000**	10.0%	*6,100*	0.0%
01	*11,000*	0.0%	*6,200*	1.6%
02	*11,000*	0.0%	**6,700**	8.1%
03	**13,000**	18.2%	*6,700*	0.0%
04	*13,000*	0.0%	*6,800*	1.5%
05	*13,000*	0.0%	**7,300**	7.4%
06	**12,000**	-7.7%	*7,300*	0.0%
07	*12,000*	0.0%	*7,300*	0.0%
08	*12,000*	0.0%	**7,800**	6.8%
Average	2.3%		2.8%	

Although an assumption of an average 2.5% yearly growth rate over a ten year period is a practical assumption, the linear yearly growth rate from 2003 to 2008 for the section of South Lamar Blvd north of the intersection was calculated to be -1.6% yearly growth rate. Using the yearly growth rate of -1.6% traffic volumes in 2009 for the north roundabout were predicted from the MDOT 2003 traffic counts for the North roundabout. A difference of 2.7% was calculated between the predicted 2009 traffic counts using a -1.6% increase and the on-site traffic counts, compared to the previous 24% increase using a yearly growth rate of 2.5% over 6 years. Figures 31 and 32 display the 2009 traffic distribution per hour over a 12 hour period for the maximum two movements, 2 and 6 respectively. These two histograms compare the on-site traffic counts counted on Wednesday October 14, 2009, predicted traffic counts from the MDOT consultant report using -1.6% yearly growth increase, and predicted traffic counts from the MDOT consultant report using a 2.5% yearly growth rate. It can be observed that the predicted traffic counts using a -1.6% yearly growth increase are more representative of the on-site traffic counts, than the predicted traffic counts using a 2.5% increase.

The MS Highway 6 eastbound and South Lamar Blvd intersection only had a 10 % difference from the on-site traffic counts compared to the predicted MDOT traffic counts using a 2.5%

yearly growth rate. The AADT reported in the MDOT consultant report on the section of South Lamar was collected north of the Baptist Memorial Hospital, where a large percentage of the traffic enters and exits South Lamar Blvd. Therefore the AADT yearly growth calculated in the MDOT report may not be representative of the yearly growth rate of this particular intersection, and was not used for comparison.

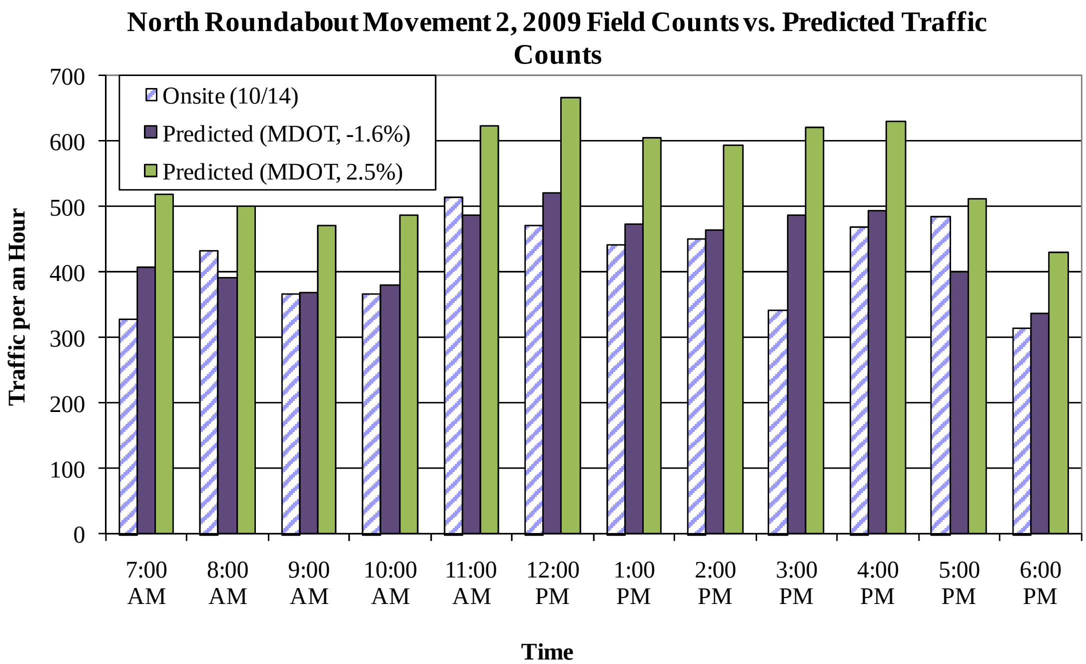


Figure 31. North roundabout movement 2, 2009 field counts vs. predicted traffic counts

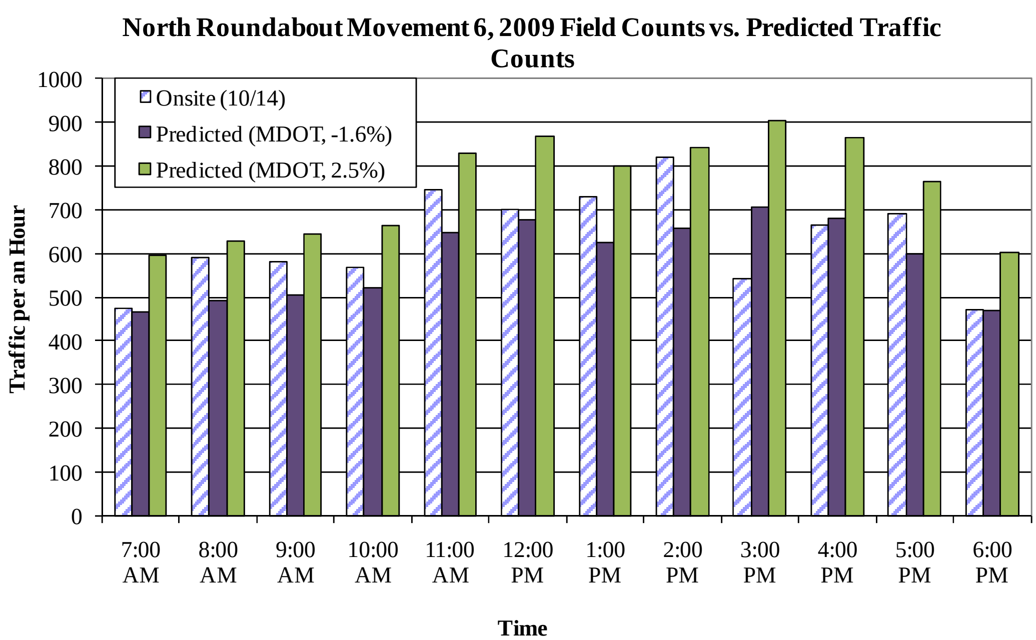


Figure 32. North roundabout movement 6, 2009 field counts vs. predicted traffic counts

Figure 33 compares the hourly distribution of the 2009 on-site traffic data collected on October 14 with the 2009 predicated traffic from the MDOT consultant report using a 2.5% yearly growth rate over a 12 hour period for the maximum two movements, 5 and 11. The hourly distribution of the on-site traffic data and the predicted traffic data is generally comparable. The only hours that demonstrate a significant difference are eleven o'clock for movement 5, and four o'clock for movement 11. This discrepancy could be a result of many different outside factors such as the time of year, the hour of workers lunch breaks, or weather.

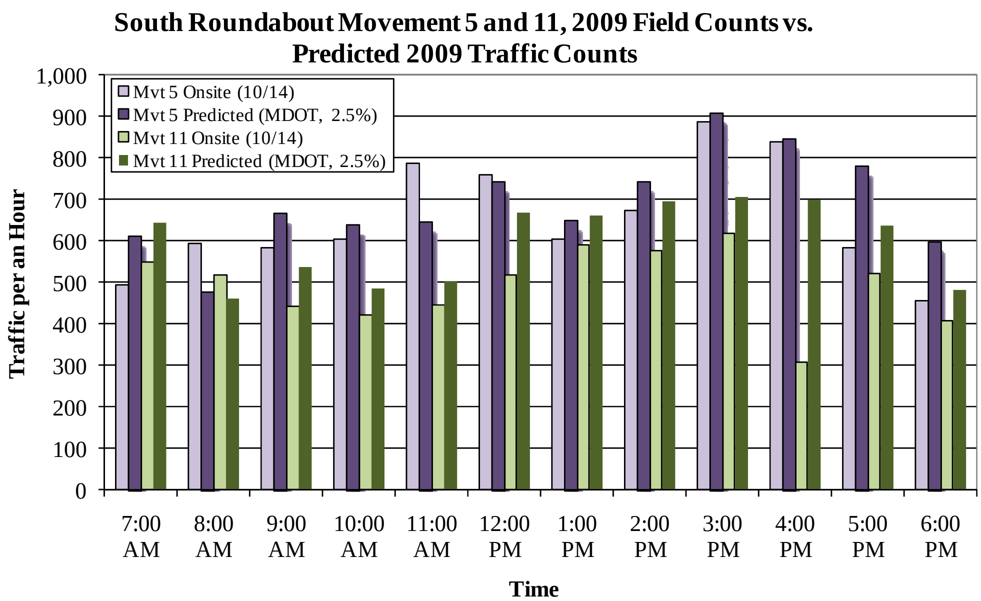


Figure 33. South Roundabout movements 5 and 11, 2009 field counts vs. predicted 2009 traffic counts

As a result of this evaluation it is concluded that the on-site traffic counts collected on Wednesday October 14, 2009 would be a more appropriate set of traffic counts to use for microsimulation studies of these two junctions. The on-site traffic counts completed in 2009 provide a more accurate and up to date traffic record for both road junctions. Since the average yearly growth rate over a ten year period for South Lamar Blvd was about 2.4 %, a 2.5 percent yearly growth rate (calculated earlier) was used in order to predict the 2016 traffic data from the on-site traffic data collected on October 14, 2009.

2.4.3 Traffic Destination for Each Movement

Since all traffic enters and travels around a roundabout in the same direction it is impossible to know the destination of every vehicle. Therefore, a vehicle destination distribution factor needs to be calculated for each entering movement. Since the MDOT consultant report [14] recorded the destination of all the entering movements it is suggested this information be used in order to determine distribution factors for each entering movement. In order to examine the accuracy of using the MDOT consultant report's destination distributions the vehicle distributions are observed over the entire intersection for both roundabouts. Figure 34 shows the daily volume distribution of each movement at the North roundabout for both the predicted traffic counts and the on-site traffic counts. Although movement 3 from the on-site traffic data demonstrated a minor decrease compared to the MDOT predicted traffic data, the traffic distribution is consistent from the on-site counts compared to the consultant report for each movement. Figure 35 compares the total 12-hour daily traffic volume for all four scenarios for the South roundabout. The traffic distribution over each movement follows the same pattern for all four of the scenarios. This concludes that the 2009 on-site traffic counts follow the same pattern as the MDOT traffic counts. Therefore, the vehicle path distribution for each movement was calculated from the factors developed in the MDOT consultant report.

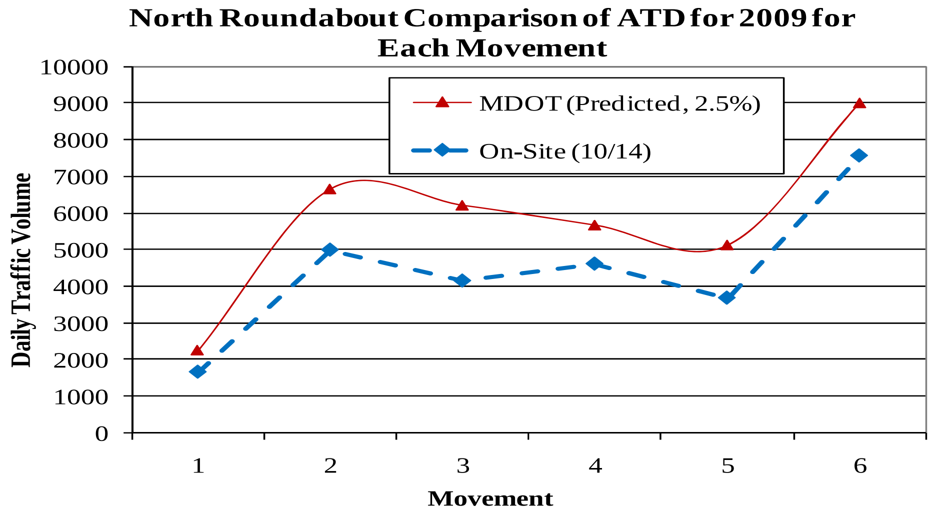


Figure 34. North roundabout comparison of AATD for 2009 for each movement

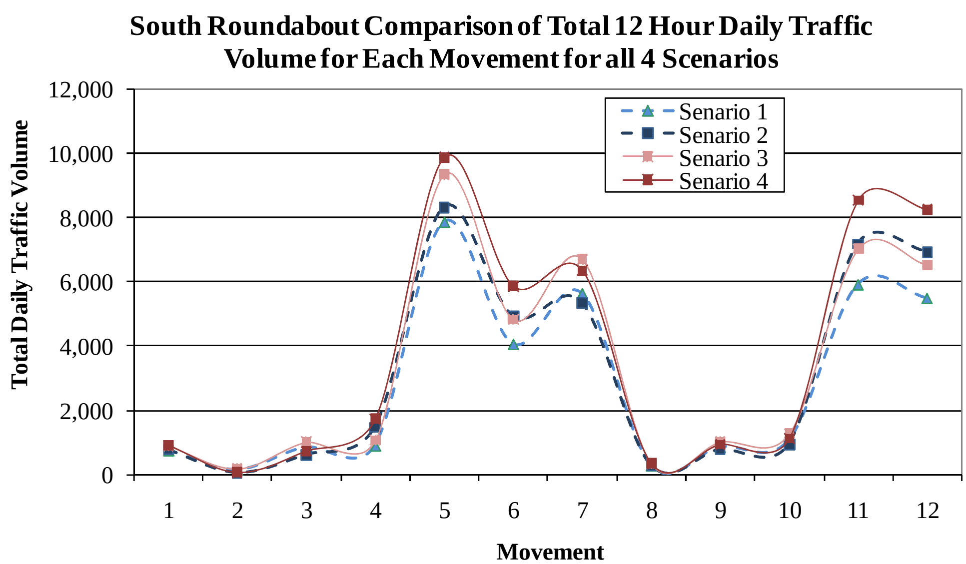


Figure 35. South roundabout comparison of total 12 hour daily traffic volumes for each movement for all 4 scenarios

For the North roundabout the vehicle destination distribution is calculated by dividing the number of vehicles traveling in each direction by the total amount of entering vehicles of that movement. This is calculated for each entering movement, movement 1, 3, and 6. An example of this is completed for movement 1:

- total vehicles entering: 2093
- total vehicles turning left: 1092; percent distribution: 1902/2093 = 52.17%
- total vehicles traveling straight: 11; percent distribution: 11/2093 = 0.53 %
- total vehicles turning right: 990; percent distribution: 990/2093 = 47.30 %

Using these percentages calculated from the MDOT consultant report vehicle destinations for each entering movement on the roundabout can be calculated. This is computed by multiplying the total amount of vehicles entering the roundabout for each movement by the percent distribution for each direction traveled. Continuing the previous example from movement 1:

- total vehicles entering: 1652
- percent distribution: 52.17 %; total vehicles traveling from movement 1 to movement 5: 52.17% * 1652 = 862
- percent distribution: 0.53 %; total vehicles traveling from movement 1 to movement 4: 0.53% * 1652 = 9
- percent distribution: 47.30 %; total vehicles traveling from movement 1 to movement 2: 0.53% * 1652 = 781

Table 8 shows the vehicle directional distribution for each entering movement for the North roundabout. The traffic volumes displayed are for 2009 daily traffic and peak hour traffic, and 2016 daily traffic and peak hour traffic.

Table 8. Percent distribution for North roundabout

Road	South Lamar Blvd Southbound				MS WB off ramp Westbound				South Lamar Blvd Northbound				Total Daily Traffic Counts
Direction Pre-Roundabout	Left	Straight	Right	Total Counts	Left	Straight	Right	Total Counts	Left	Straight	Right	Total Counts	
MDOT Daily Traffic	0	3670	2091	5761	1092	11	990	2093	3165	5193	0	8358	16212
MDOT percent distribution	0.00%	63.70%	36.30%	35.54%	52.17%	0.53%	47.30%	12.91%	37.87%	62.13%	0.00%	51.55%	100.00%
Movement	3 to 1	3 to 5	3 to 4	3	1 to 5	1 to 4	1 to 2	1	6 to 4	6 to 2	6 to 1	6	Total
Onsite 2009 Daily Traffic	0	2641	1505	4146	862	9	781	1652	2865	4701	0	7566	13364
Onsite 2009 Peak Hour	0	285	163	448	50	1	45	96	311	509	0	820	1364
Predicted 2016 Daily Traffic	0	3140	1789	4928	1025	10	929	1964	3409	5594	0	9003	15895
Predicted 2016 Peak Hour	0	340	193	533	59	1	54	114	370	606	0	976	1623
Movement	3 to 1	3 to 5	3 to 4	3	1 to 5	1 to 4	1 to 2	1	6 to 4	6 to 2	6 to 1	6	Total

For the South roundabout calculating the percent of vehicles traveling in each direction was more complicated since the MDOT consultant report separated the intersection into two separate intersections. In order to know the direction vehicles traveled from one intersection to another the vehicle distribution of the intermediate section of road between the intersections was calculated (Table 9). By knowing the vehicle distribution of the intermediary the allocation of the vehicles traveling between two intersections could be calculated.

Table 9. Percent distribution of the intermediate section of road

Street	South Lamar Boulevard Northbound			South Lamar/MS 6 (bypass) Southbound			
Direction	Straight	Right	Total	Left	Straight	Right	Total
MDOT Daily	6,033	700	6,733	598	6,227	577	7,402
MDOT percent distribution	89.60%	10.40%	100.00%	8.08%	84.13%	7.80%	100.00%

Figure 36 illustrates a vehicle's path traveling through the south end of the interchange on South Lamar Blvd, from the overpass to the south end of the intersection. The path from the original road design in presented by a dashed light pink line, and the path of the roundabout road design is displayed by a dark red solid line. The vehicle path of the original road design travels south from the overpass then road branches off once, then continues south through the median between the intersections, and then branches off two more times, as the vehicle travels through the intersections. The vehicle path of the roundabout enters the roundabout intersection and the vehicles branch off in their designated direction as the vehicles travel around the roundabout. The purpose of this figure is to show the change in vehicle path from two stop controlled intersections to a roundabout junction. The final directional distribution for the south roundabout is given in Table 10.

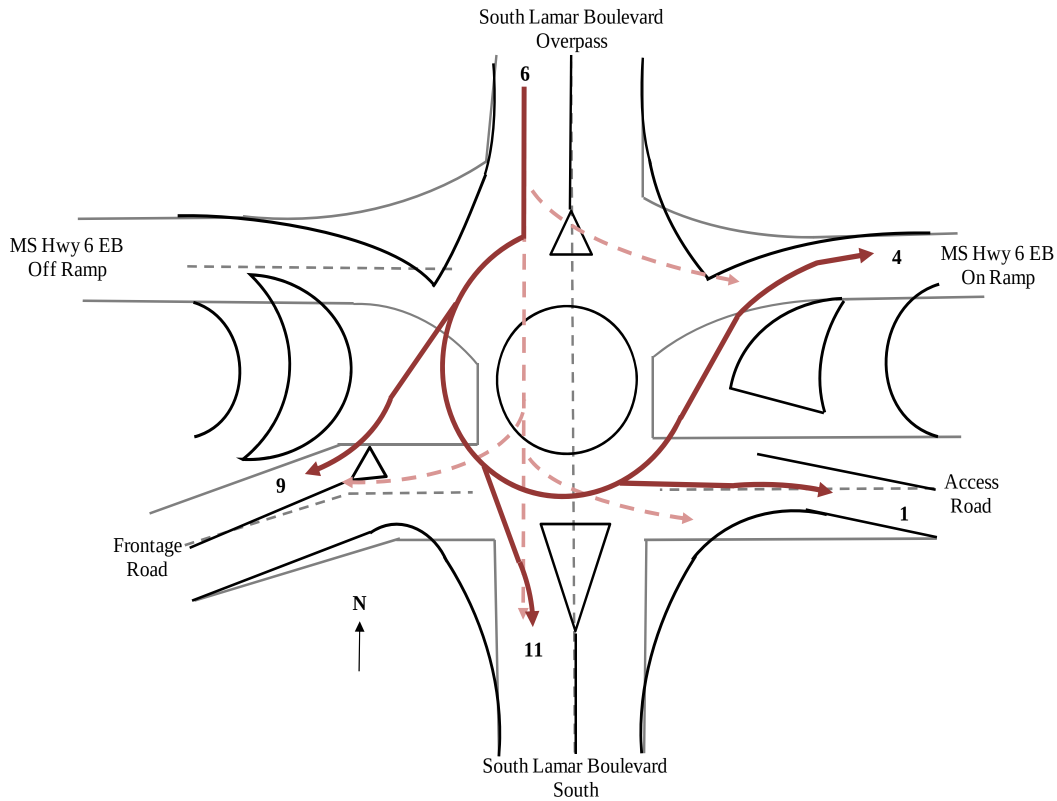


Figure 36. Diagram of vehicle path from the South Lamar Blvd South through both road designs

Table 10. Percent distribution of the South roundabout

Road	Access Rd Eastbound					Lamar Blv Southbound				
Direction of Part Intersection	Left	Straight	Right		Total Counts	Left	Stright			Total Counts
Direction of Whole Intersection			Straight	Right			Left	Straight	Right	
MDOT Daily Traffic	35	40	542		617	611	3968			4579
MDOT % Distribution Part Intersection	5.7%	6.5%	87.8%		3.5%	13.3%	86.7%			25.8%
MDOT % Distribution Whole Intersection			78.7%	9.1%	100.0%		7.0%	72.9%	6.8%	100.0%
Movement	3 to 11	3 to 9	3 to 5	2	3	6 to 4	6 to 1	6 to 11	6 to 9	6
Onsite 2009 Daily Traffic	49	56	675	161	858	542	284	2962	274	4063
Onsite 2009 Peak Hour	6	6	77	36	98	53	28	290	27	398
Predicted 2016 Daily Traffic	58	66	802	192	1019	644	338	3521	326	4830
Predicted 2016 Peak Hour	7	8	91	43	116	63	33	345	32	473
Movement	3 to 11	3 to 9	3 to 5	2	3	6 to 4	6 to 1	6 to 11	6 to 9	6

Road	MS 6 EB Off Ramp Eastbound					Frontage Rd Westbound				
Direction of Part Intersection	Left	Straight	Right		Total Counts	Left		Straight	Right	Total Counts
Direction of Whole Intersection			Straight	Right		Straight	Right			
MDOT Daily Traffic	1688	99	3440		5227	423		55	399	877
MDOT % Distribution Part Intersection	32.3%	1.9%	65.8%		29.5%	48.2%		6.3%	45.5%	4.9%
MDOT % Distribution Whole Intersection			59.0%	6.8%	100.0%	43.2%	5.0%			100.0%
Movement	7 to 5	7 to 4	7 to 11	8	7	10 to 4	10 to4	10 to 1	10 to 11	10
Onsite 2009 Daily Traffic	1820	107	3323	386	5635	466	54	68	490	1077
Onsite 2009 Peak Hour	139	8	254	29	431	45	5	7	48	105
Predicted 2016 Daily Traffic	2163	127	3950	458	6698	554	64	80	583	1281
Predicted 2016 Peak Hour	165	10	302	35	512	54	6	8	57	125
Movement	7 to 5	7 to 4	7 to 11	8	7	10 to 4	10 to 11	10 to 5	10 to 1	10

Road	Lamar/MS 7 (bypass) Northbound					Total Daily Traffic Counts
Direction of Part Intersection	Left	Straight		Right	Total Counts	
Direction of Whole Intersection		Straight	Right			
MDOT Daily Traffic	366	6008		59	6433	17733
MDOT % Distribution Part Intersection	5.7%	93.4%		0.9%	36.3%	100.0%
MDOT % Distribution Whole Intersection		83.7%	9.7%		100.0%	
Movement	12 to 9	12 to 5	12 to 4	12 to 1	12	Total
Onsite 2009 Daily Traffic	312	4591	533	50	5486	17666
Onsite 2009 Peak Hour	23	343	40	4	410	1507
Predicted 2016 Daily Traffic	371	5458	633	60	6522	21000
Predicted 2016 Peak Hour	28	408	47	4	487	1791
Movement	12 to 9	12 to 5	12 to 4	12 to 1	12	Total

2.4.4 Estimating Daily Traffic Volumes from Peak Hourly Traffic Volumes

In order to convert hourly traffic volume to daily traffic volume, the hourly volume is divided by the k-factor approximated for urban and rural areas [26]. The k-factor is defined as the 30th highest hour of the year and is the traditional design factor used to calculate AADT from peak hourly volumes or design peak hour volume from AADT. The k-factor is provided by the Highway Capacity Manual [26] in the absence of field data (Table 11). These are gross factors based on past studies and may not represent site specific peak hour conditions. However in the absence of 24 hour counts, this is a reasonable approach to estimate AADT from mean peak hour data. Recall, a site-specific approach was used to develop daily traffic volume from the 2009 traffic data as shown in Table 3.

Since the North roundabout's average PHF was equal to that for an urban area (0.92), and the North roundabout experiences higher traffic volumes than typical rural roads, the urban k-factor of 0.09 was used for the north roundabout. On the other hand both PHF and peak hourly volumes at South Roundabout are less. As a result, the south roundabout tends to be more representative of a rural road. Therefore the k-factor of 0.1 was used for the South roundabout. The directional traffic for each movement was calculated from the total daily traffic count based on each movement's original distribution within the hour. Maximum hourly data was calculated for 2009 traffic data sheets for each movement, shown in the right column of Tables 12 and 13. The left column displays the estimated daily traffic volumes for both the north and the south roundabouts respectively. The difference in the daily volume compared to the site-specific approach (Table 3) is within 5%. Figure 37 displays a thematic map of the daily traffic volumes for each movement for the Oxford study site.

Table 11. PHF, and k- values for urban and rural areas

Factor	**Area**	
	Urban	**Rural**
PHF	0.92	0.88
K	0.09	0.1

Table 12. North roundabout daily traffic counts, Friday, October 16, 2009

North Roundabout Movement	Hourly Traffic Count	Daily Traffic Count
1	174	1,933
2	541	6,011
3	487	5,411
4	519	5,767
5	323	3,589
6	809	8,989
2+3	1,028	11,422
5+6	1,132	12,578
Total Entering	1,470	16,333
Total Exiting	1,383	15,367
Total Volume	2,853	31,700

Table 13. South roundabout daily traffic counts, Thursday, October 15, 2009

South Roundabout Movement	Hourly Traffic Count	Daily Traffic Count
1	107	1,070
2	25	250
3	95	950
4	119	1,190
5	776	7,760
6	356	3,560
7	712	7,120
8	37	370
9	111	1,110
10	92	920
11	491	4,910
12	428	4,280
1+3	202	2,020
5+6	1,132	11,320
9+10	203	2,030
11+12	919	9,190
Total Entering	1,683	16,830
Total Exiting	1,604	16,040
Total Volume	3,349	33,490

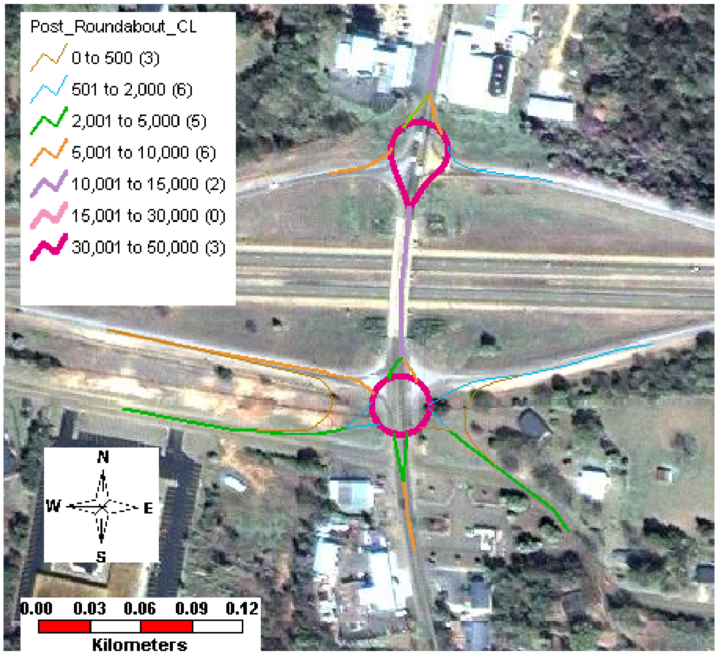


Figure 37. Thematic map of post roundabout daily traffic volumes, South Lamar Blvd, Oxford

3. TRAFFIC FLOW MICROSIMULATION STUDIES

3.1 Overview of Traffic Flow Simulation

3.1.1 Introduction

Traffic problems are characterized by the interaction of many transport systems components. The "reliability and accuracy" of conventional traffic models are dependent upon the exactness of these components and/or entities. Unfortunately the precision of these components are limited to sources, costs, availability, and amount of data. Planning authorities often only collect the minimal amount of data due to traffic, economical and environmental restrictions creating insufficient sets of data. Traditional traffic models then analyze this data using "complex processes that cannot be described readily in analytical terms [35]." Many of these models are developed using measurements in the field and fitting the data through statistical modeling methods or using theoretical models calibrated by field data to express traffic flow relationships. These conventional models include the HCM models for roundabout capacity analysis. These are gross modeling approach and may not simulate actual traffic flow process in presence of site-specific constraints. A computer simulation approach is now an accepted traffic modeling tool to assess the benefits of road traffic management improvements. Simulation models "predict performance by stepping through time and across space, tracking events as the system unfolds" [36].

In the last decade many simulation programs have been developed and released. Traffic simulation models focus on the dynamic of traffic flow by representing either a single component of a facility or an entire road network. They have the ability to take all aspects of the transportation system into account when analyzing traffic systems and flow such as: vehicle headways, origin-destination flow patterns, saturation flow rates, capacity and delay relationships, and signal timing controls. Simulation models are categorized into three groups: microscopic, mesoscopic, or macroscopic. Microsimulation traffic flow models work by following each individual vehicle in its path in a road network at sub-second time intervals and as the vehicle interacts with the other vehicles under pre-defined traffic rules and road geometry. This research applied a microsimulation approach to analyze the traffic flow on the study site.

In microsimulation modeling traffic flow is analyzed through Graphical User Interface (GUI) and guided by traffic control rules, signals, imposed constraints, interaction with other vehicles, and geometric layout [35, 36]. GUI is the concept of providing user friendly computer interface screens with the simulation program. Microsimulation is different from animation software in that microsimulation derives information for every vehicle based upon "its physical capabilities, its desire to reach a certain destination, and its interaction with other vehicles in the system." However, animation considers the vehicles and the road network as two separate entities and does not take their interactions into consideration [36].

3.1.2 Overview of S-Paramics

The S-Paramics microsimulation software was used in order to assess the road networks in this study recognizing the program's comprehensive and efficient capabilities. S-Paramics abilities include [37]: alternative drive options, capability to handle large intricate road networks, various road junction options, different vehicle mixes, congestion scenarios, transit use, lane change behavior, route costs, vehicular emissions, three-dimensional (3-D) outputs, traffic signal control, and traffic flow analysis. S-Paramics also exports data directly to a user friendly data analysis program for easy access and interpretation of results.

Each base microsimulation model in this study was created in S-Paramics [37] following the same general procedures. The following step-by-step procedures are used to create a base simulation model:

Step 1: Creating an overlay of a road network

In order to recreate the road network in S-Paramics an overlay for each site is created. Overlays are used as a guide so that the simulation model can depict reality as closely as possible, for this reason the overlay must be as accurate as possible. The overlay for each road network is created as planimetric features in GeoMedia Pro from satellite imagery. This is to ensure correct size and makeup of the road network. The road networks created in GeoMedia Pro are imported into AutoCad in order to (1) create a file format compatible with S-Paramics and (2) to add additional attributes to the road network such as centerline and stop lines. Then the road network is exported from AutoCad as a drawing exchange format (DXF) file.

Step 2: Creating a new simulation model

When the model is created the option of a left-hand drive or a right-hand drive is given. Right hand drive is the driving pattern used in the United States; left hand drives are used in countries such as England. For the purposes of the two simulations created for Oxford, Mississippi the right hand drive was chosen. Once the model is created and named, the DXF file can be imported into the model. Again, the DXF file is an overlay, and is used only as a guide for recreating the network.

Step 3: Adding traffic volume demands

Traffic volume demands are added through zone to zone routing. Zones are polygon shapes placed at locations within the network where vehicles either originate or arrive at destination. Once these zones are put in place vehicles demands can be added from an origin zone to a destination zone. Zones are used for adding traffic demands so vehicles may inherently choose the shortest path to their destination.

Step 4: Creating a road network

Road networks in traffic flow simulation models are comprised of nodes and links. Nodes are used to denote an intersection, end of a roadway, change in a roads characteristic, or for vehicle designation. Each node is connected by links. Links represent road segments and are used to define a road's characteristics, such as lane number and size, speed, road type and cost factor. Figure 38 displays an example of a link's characteristics. "Flags" can also be added to links (Figure 39). Flags represent specific attributes of a road segment such as: "one way", "buses only", "lane closed", "wide start", "wide end", and "ext". "Wide starts" represents a lane drop after the beginning of a road segment, and "wide end" represents a gain at the end of a road (this feature is used for a majority of the road segments in the pre-roundabout road network design, and it is described further in the corresponding study site section.) Curb alignments and stop lines can also be adjusted in order for the road network model to resemble reality as much as possible. Note: Attributes unique to each specific site are described in their corresponding sections.

Step 5: Creating a roundabout junction

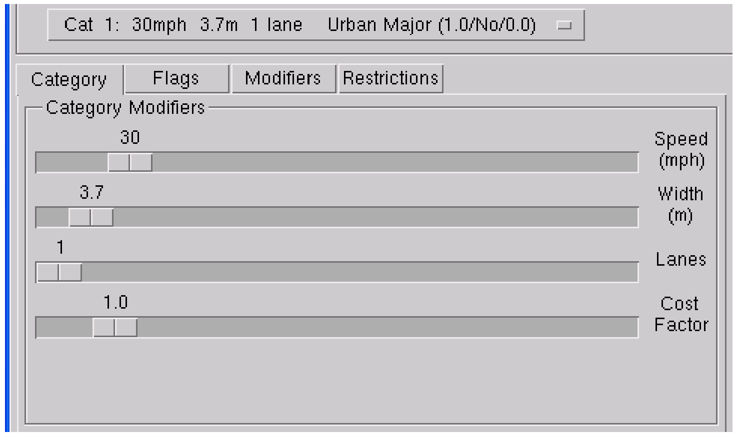


Figure 38. Link characteristics used to define a road section

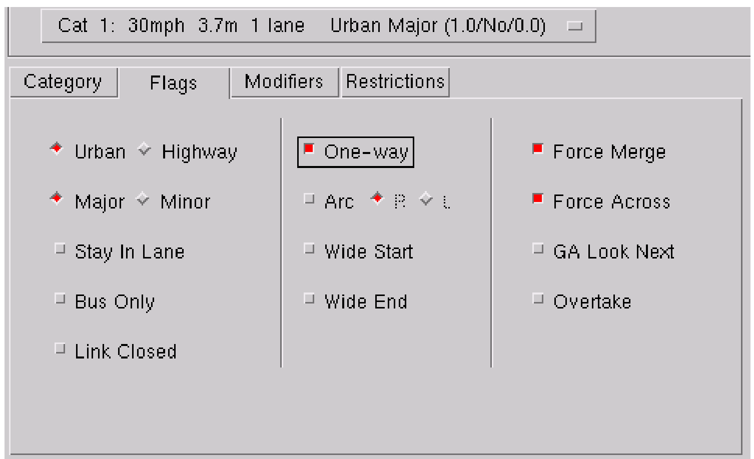


Figure 39. Link flags used to define traffic characteristics applied to a road section

3.1.3 Objective and Output for Traffic Flow Simulations of the Study Site

Two microsimulation models were created using the S-Paramics procedures for the study site in Oxford, Mississippi using the forecasted 2016 traffic peak hour volume demand. Each of the road junction layouts differ, and further characteristics of each simulation model are described in the section pertaining to that model. Since microsimulation evaluates the actions of each vehicle individually, each simulation run may produce slightly different outcomes. Therefore, three simulation runs were completed for each simulation model and an average of the three runs was taken. Analysis of the simulation output data was completed depending on the simulations relevance to this thesis.

The main objective of these simulations is to obtain mean delay time, mean speed, and mean idling time for the purpose of performance evaluations of the roundabouts. Table 14 describes and defines each of the values obtained from the simulation runs. Detailed instructions for creating simulation models and other simulation terms and definitions can be found in the S-

Paramics reference manual [37]. All the simulation run data can be found in Headrick's MS thesis [32].

Table 14. Descriptions and definitions of output values from simulation

Value	Description	Definition
Mean Delay	Cumulative time (sec/veh)	Aggregate time spent in the network for all vehicles that have traveled through the network
Mean Speed	Cumulative average (mph)	Average speed of all vehicles that have traveled through the network over the entire time of simulation
Mean Idling Time	Cumulative stationary time (minutes)	Aggregate time spent at a stationary position in the network for all vehicles that have traveled through the network

3.2 Traffic Flow Microsimulation of Stop-Controlled Intersections

3.2.1 Microsimulation Model

The intersection traffic simulation model created for the South Lamar Blvd study site in Oxford, Mississippi is representative of the interchange at MS Highway 6 before the construction of the roundabouts. The road junction is represented by one signalized intersection at the north end and two two-way stop intersections at the south end of the overpass bridge. The following procedures expand on the procedures from the previous section pertaining to this study site:

Step 1: Creating an overlay of the road network

For the model overlay vector maps were created for the road pavements within a 0.25 km radius of the study site. The road pavement planimetrics were extracted from the 1-m satellite imagery using GeoMedia Pro. The DXF file was exported to AutoCad and centerlines and stop lines for the interchange were added in AutoCad (Figure 40).

Step 2: Creating a new microsimulation model

A new model was created using the right-hand drive option, and importing the DXF file of the road pavement and centerlines.

Step 3: Creating a road network

Nodes were placed at the intersection of each road. At the beginning of the two MS Highway 6 on ramps a wide start was applied. This is added because the on ramps give way to vehicles entering from all three directions and after a few feet the on ramps drops to one lane. Wide ends were added to the two MS Highway 6 off ramps. This is because at the intersection of the off ramps and South Lamar Blvd the vehicles are able to travel in more than one direction, or the road section gains lane(s).

South Lamar Blvd was categorized as a "30 mph, 12 foot wide lane, 2 lane, Urban Major" road, while all the other roads were categorized as "30 mph, 12 foot wide, 1 lane, Urban Minor" roads. All the roads that intersected with South Lamar were also flagged to "force merge and force across." This flag allows vehicles to enter the roadway if there is an available open gap between traveling vehicles. All four MS Highway 6 ramps were flagged as one-way roads.

Step 4: Adding travel demands

The peak hour travel demands, estimated in the preceding chapter, were applied to origin and destination zones.

Step 5: Creating a roundabout junction

In the traffic simulation a signal was placed in the north end at the intersection of South Lamar Blvd and MS Highway 6 westbound. Since the exact timing of the original signal is unknown fixed time signals were used. The signal timings are added in phases denoted by letters where each letter represents a different signal phase. Letters A through D are used to represent the signal phases for the South Lamar Blvd and Hwy 6 westbound intersection. The timings are then categorized into stages represented by numbers. Only two stages are needed for this intersection. Stage 1 represents letters A-C. Letter A gives way to traffic approaching the intersection from the north. Letter B gives way to vehicles continuing north on South Lamar Blvd from the south end of the intersection, and letter C gives way to vehicles turning left onto the MS Highway 6 on ramp from South Lamar Blvd. Stage 2 represents letter D and gives way to traffic traveling from the MS Highway 6 off ramp. The arrows with filled in heads denote the major movements, and the unfilled heads denote the minor movements. The major movements have longer signal times, and the signal times are correlated within each stage. The traffic signal timing stages and phases within each stage can be seen in Figure 41.

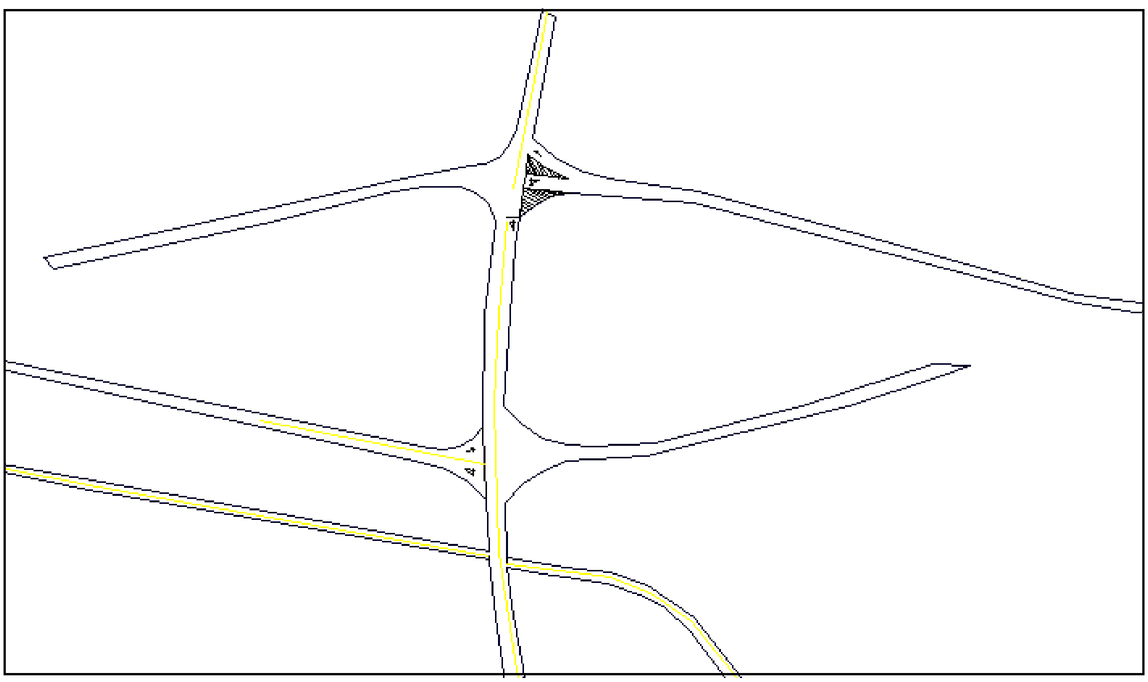


Figure 40. AutoCad drawing of South Lamar Blvd and MS Highway 6 pre roundabout intersection

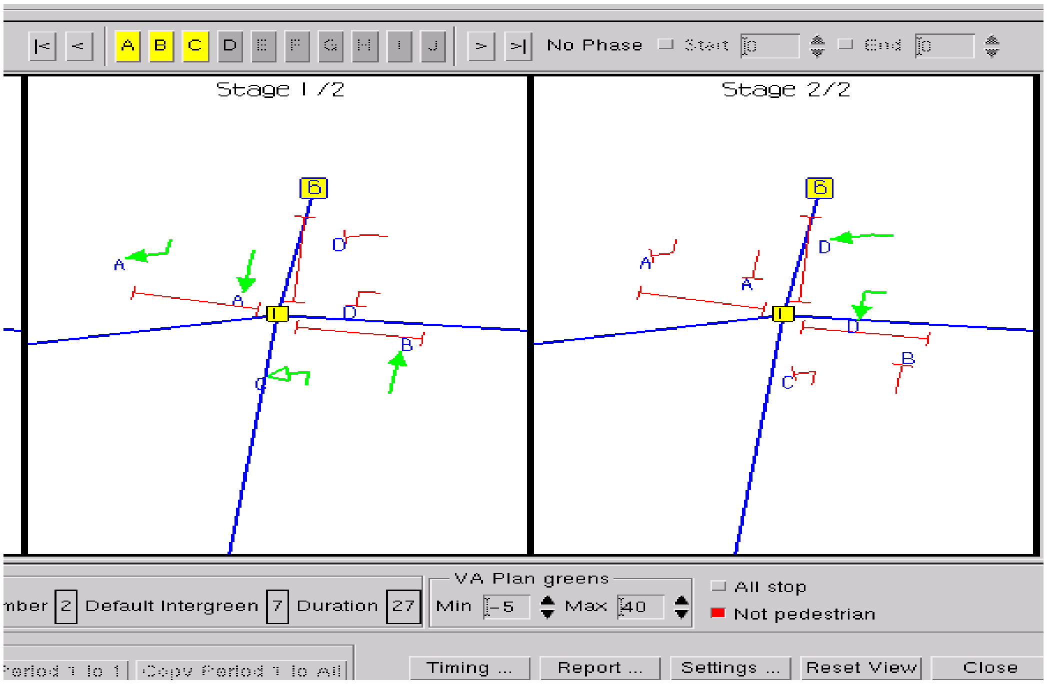


Figure 41. Signal timings for the North roundabout

3.2.2 Results of Traffic Flow Microsimulation for Stop-Controlled Intersections

Table 15 shows the outcome of the three simulation runs and their average results. The mean speed of the network should be noted. The design speed of the network is 30 miles per hour, but the average speed vehicles are traveling in the network is 10 miles per hour, less than half the design speed. From the table it can also be seen that each run produces slightly different results, particularly the third run. This is most likely due to the signalized intersection. A traffic signal does not permit traffic to travel the same speed each time it enters the intersection.
In the third run the mean delay and idling time are less than the first two runs. When the mean delay decreases the mean speed of the network increases allowing for more vehicles to travel though the network in a given hour. If such a reduction in delay is applied to a peak hour this could result in an increase in production. For example in the morning when people are traveling to work they would spend less time traveling to work and arrive at the work place in a more timely fashion.

Table 15. Simulation results for stop-controlled intersection

Condition	Run Number	Mean Delay	Total Distance (m)	Total Number Vehicles	Mean Speed (mph)	Mean Idle Time
Stop Controlled Intersection	**Run 1**	45	307423	1635	9	14
	Run 2	46	308435	1636	9	14
	Run 3	36	310065	1657	12	10
	Average	42	308641	1643	10	13

3.3 Traffic Flow Microsimulation of Roundabout Junctions

3.3.1 Microsimulation Model

The next traffic simulation model created for the Oxford study site was representative of the junction after the construction of the roundabouts. The junction was represented by one non-circular roundabout at the north end of the overpass and one circular roundabout at the south end of the overpass. The procedures for creating the simulation model were similar to those used in the previous section. The following procedure was followed to create a traffic flow microsimulation model for roundabout junctions:

Step 1: Creating an overlay of the road network

Vector maps were created for the road pavements within a 0.25 km radius of the study site were created for the model overlay. The planimetrics of road pavements were extracted from the project plans georeferenced into GeoMedia and exported to AutoCad. The centerlines and stop lines for the interchange were added in AutoCad (Figure 42).

Step 2 - 4: Same as discussed in the previous section.

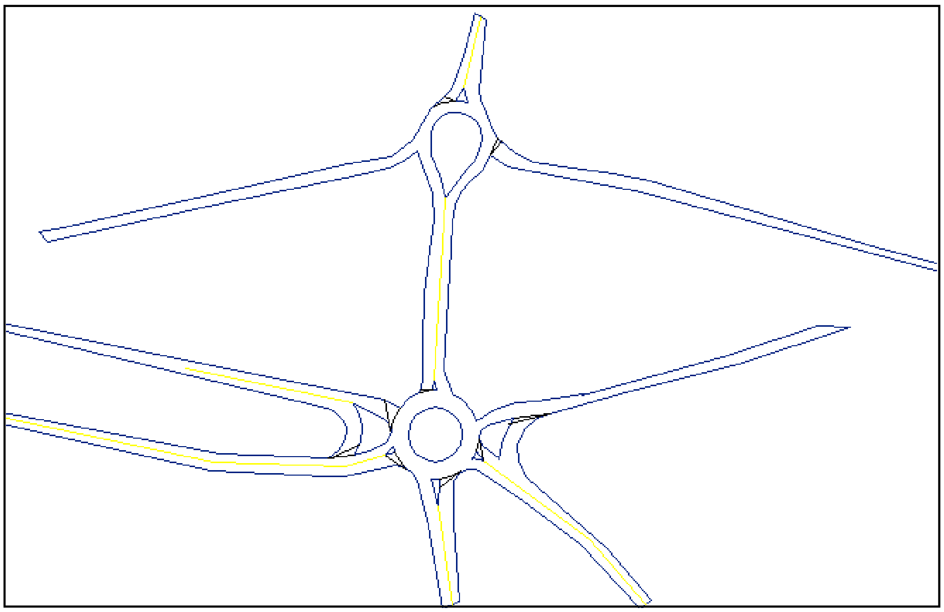


Figure 42. AutoCad layout of South Lamar Blvd MS Highway 6 intersection post-roundabout

Step 5: Creating a roundabout junction

The North roundabout is a noncircular roundabout therefore links and nodes are created as they normally would around the path of the roundabout (Figure 43). The characteristics of the nodes in the circulating part of the roundabout (the northern end) are coded from "normal intersection" to "roundabout junction." This automatically flags the path circulating the junction as a one way, and makes the approaching traffic yield to the circulating traffic.

The South roundabout is a circular roundabout; therefore it is coded differently than the north roundabout. First, each leg of the roundabout is joined at a node in the middle of the junction. Using the "Node Attribute Modifier" function in S-Paramics the node is categorized as a roundabout and the diameter of the roundabout it specified. The diameter of 17.6 meters was used for this roundabout. This diameter was found using spatial analysis in GeoMedia Pro of the design plans. Once this is completed the roundabout will expand to the specified diameter and the characteristics of the roundabout will automatically be applied: one circulating direction and approaching traffic must yield to circulating traffic (Figure 44). The two one way side streets were added as well connecting the appropriate roadways. The posted speed of 15 mph was applied to both roundabouts.

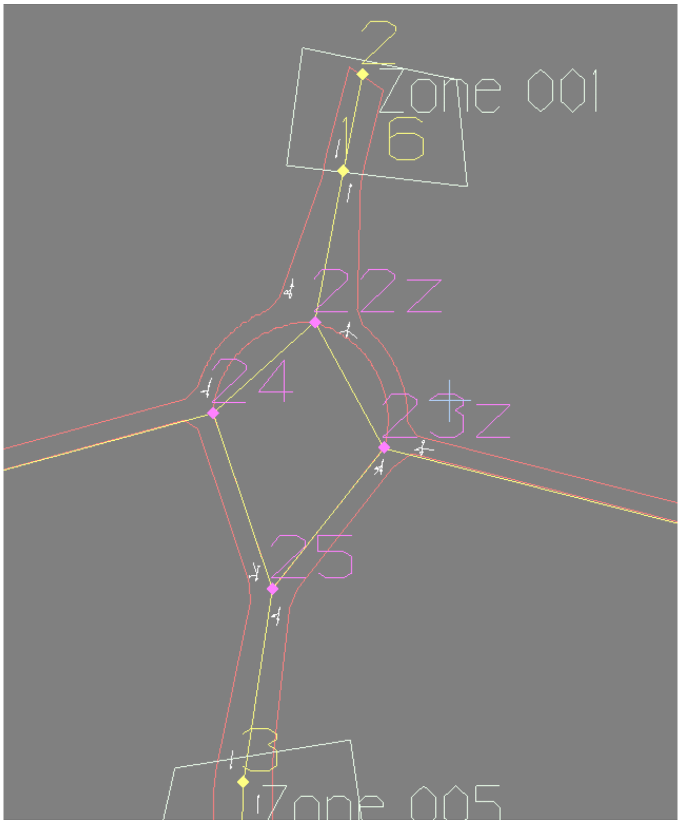


Figure 43. North noncircular roundabout with links and nodes

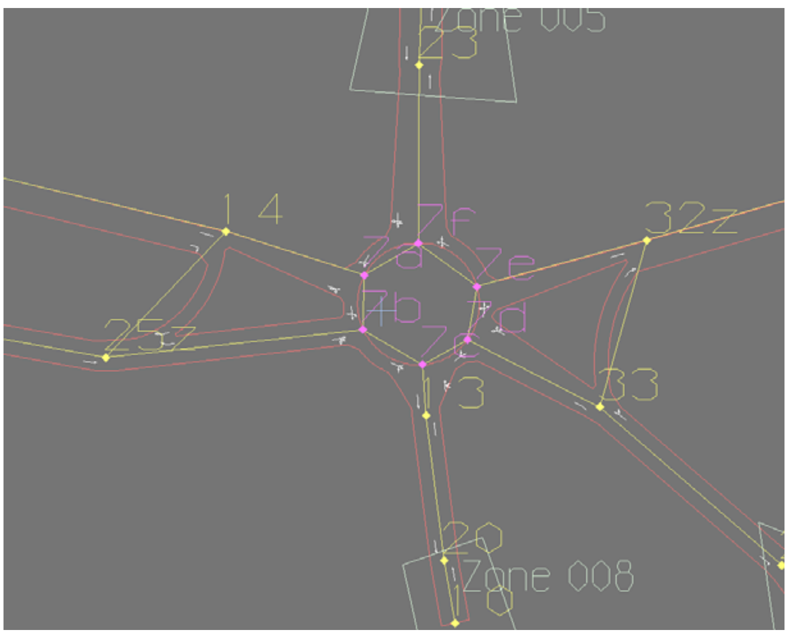


Figure 44. South circular roundabout with links and nodes

3.3.2 Results of Traffic Flow Microsimulation for Roundabout Junctions

Table 16 shows the output for the three simulation runs for the roundabouts. The runs from the roundabouts are more consistent than the runs from the signalized intersection. This is most likely due to the absence of the signalized intersection. Also, the mean speed of the roundabout junction is consistently 15 mph, which is the design speed of the interchange with the roundabouts. Mean delay is 35 seconds per vehicle for the entire interchange.

Table 16. Simulation results for roundabout junction

Condition	Run Number	Mean Delay	Total Distance (m)	Total Number Vehicles	Mean Speed (mph)	Mean Idle Time
Roundabout Junction	Run 1	35	377826	1657	15	3
	Run 2	35	375330	1647	15	3
	Run 3	35	377010	1652	15	3
	Average	35	376722	1652	15	3

3.4 Results of Microsimulation and Emission Studies

3.4.1 Comparison of Microsimulation Results

Traffic flow simulations completed in S-Paramics are used to analyze the performance of a stop controlled intersection compared to a roundabout junction, as well as verify the validity of the consultant report's queuing and LOS predictions. The output mean delay, queuing time, and speed values from simulation runs are used to compare the junction alternatives. Therefore, three simulation runs were completed for each junction alternative. The data set used for comparison is based on the worst case scenario of the three outputs (Run 1, Run 2, Run 3) for each junction type.

The output data from Run 2 was used for the stop controlled intersection or the 'do nothing' scenario. Out of the three simulation runs, Run 2 produced the highest delay and therefore represented the worst case scenario of the three runs. In order to find the simulation that represented the worst case scenario for the roundabout junction a different approach had to be taken. Because traffic flow in a roundabout junction is uninterrupted by stop signs or traffic signals the roundabout simulations produce more consistent results than the stop controlled intersection. The delay and queuing times were the same for all three runs of the roundabout simulation. Therefore the simulation run that had the least number of vehicles traveling through the intersection in the given hour was used as the worst case scenario for the roundabout junction. This was also Run 2. By observing the stop controlled simulations, it is known that the number of vehicles that pass through an interchange in a given period of time is directly associated with the delay of the intersection; the longer the delay of the intersection the fewer the number of vehicles that are able to travel through the interchange.

Delay in transportation is defined in units of second per vehicle (s/veh), which represents the amount of time in seconds that each vehicle travels at speeds slower than the network design speed. This value is usually represented as an average, or mean, within a given time frame over a particular road section or intersection. Delay values are very representative of the performance of an intersection, and when calculated using the HCM method [16, 26, 34] the value is used to define the LOS of road junctions (Table 17). The total mean delay (averaged over a one-minute period) for the peak hour over the entire interchange from simulation is represented in Figure 45.

The mean delay for the stop controlled intersection in the worst scenario (Run 2) during the peak hour is 46 s/veh (LOS of E) , and the mean delay for the roundabout junction during the peak hour is 35 s/veh (LOS of D). This results in a 23.9% decrease in delay during peak hours over the entire interchange of South Lamar Blvd and MS Highway 6 when stop controlled intersections are replaced with roundabouts. The overall LOS improves from E to D. Recall the delay calculated from the 2010 HCM equations for 2016 peak hour traffic on the roundabout junction shows most approaches at B and C except one approach (Movement 3 entering southbound to the North roundabout) at LOS of E. The result of the simulation is more representative of the roundabout layout in the field with overall LOS of D for the roundabout junctions. The LOS is acceptable for the 2016 projected peak hour traffic volume

Table 17. Level of service criteria used for intersections and roundabouts

LOS	**Average Control Delay (s/veh)**
A	< 10
B	>10 - 15
C	>15 - 25
D	>25 - 35
E	>35 - 50
F	>50

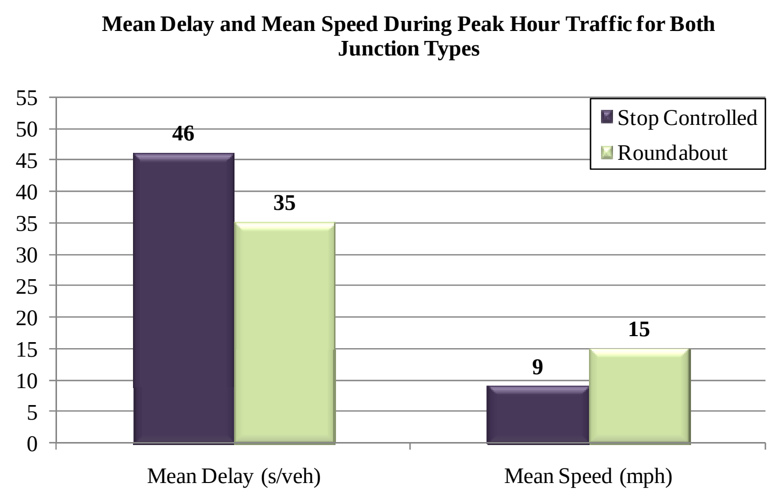


Figure 45. Comparison of mean delay and mean speed during peak hour traffic for both junction alternatives

The mean speed of each junction type over the peak hour is also represented in Figure 45. An intersection's ability to perform at its full capacity is reflected most directly by the speed of the intersection. The speed of an intersection is affected by congestion, delay, flow, and incidents. The mean speed for the stop controlled intersection is 9 mph, compared with the roundabout mean speed of 15 miles per hour. The design speed of the entire stop controlled intersection is 30 miles per hour, thus during peak hours traffic is traveling through the intersection at less than one third the design speed of the intersection. The design speed of the road sections connected to the roundabout is 30 mph; however, the design speed for the traffic traveling around the roundabout junctions is 15 mph. The traffic approaching the junction must yield to the circulating traffic; therefore, traffic traveling at an average speed of 15 mph during the peak hour is a very reasonable speed. This shows about 66.7% improvement in average speed of vehicles traveling on the road junction. The idling time is also reduced by 76.9% from 14 to 3 min.

Figure 46 represents the aggregate mean queuing time over the peak hour period. The queuing times were averaged and recorded over minute periods, and are cumulative over the hour. The mean queuing time is the average amount of time vehicles spend either at speeds less than 4.55 mph or at distances of 20.0 meters or less from one vehicle to the next over all for the vehicles in the network. These speeds, for an extent of time, are generally generated when a vehicle is either slightly rolling due to congestion or stopped at a stop sign or stop light. For the purpose of this report these speeds define when a vehicle is idling within the network. In Figure 46 it can be seen that vehicles spend a much larger amount of time queuing in a stop controlled intersection compared to a roundabout junction. The roundabout queuing times are represented by a thin green line. From the graph it can be seen that the queuing times for the roundabout interchange remain consistently between 2 and 4 minutes throughout the hour. Since the queuing times are cumulative throughout the hour this means that there is little to no time spent idling during peak hours. Comparing this to the stop controlled intersection, represented by a thick red line, the time spent queuing in a roundabout is more than a quarter less over a one hour period than the time spent queuing at a stop controlled intersection. It can also be seen by the positive linearity of the graph that when the interchange is controlled by stop signs and signals vehicles are more frequently halted in queue during peak hours. Note the jump in the graph during the first two minutes of the simulation represents the simulation becoming active.

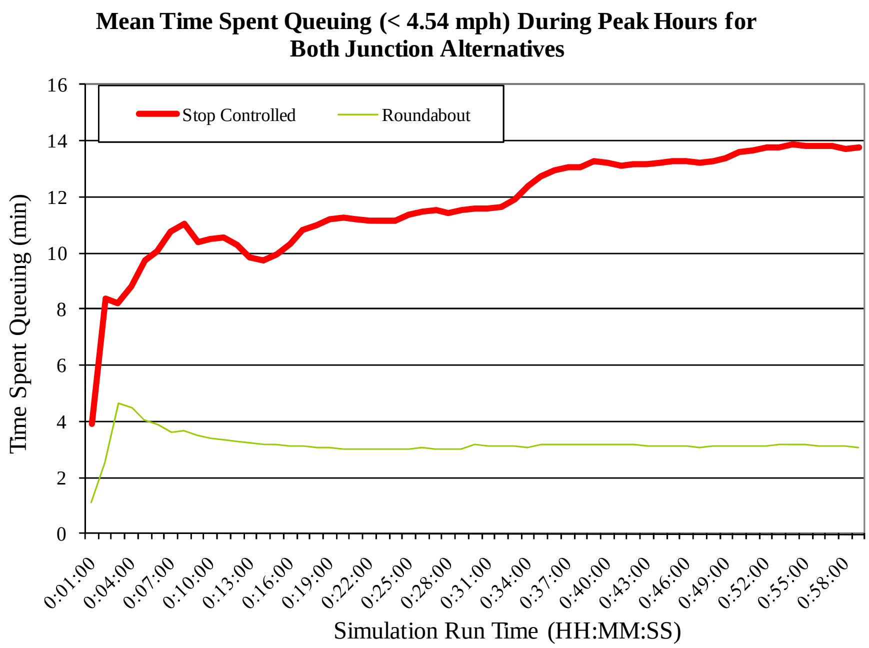


Figure 46. Mean time vehicles spent in speeds less than 4.54 mph during the peak hour for both junction alternatives

3.4.2 Vehicle Emission Analysis

Reductions in mean speed and delay on roundabout junction layout result in reduced vehicle emissions as well. Additionally, there is a significant reduction in GHG emissions. Table 18 shows CO_2 calculations for pre- and post-roundabout scenarios for 2016 peak hour traffic flow using the EPA models [9, 38]. The average speed and average delay are for the worst scenario (simulation Run 2) and the average idle time represents the average value of all three runs. A reduction of 56.1% in CO_2 emission is attained considering combined peak hour traffic volume at both junctions and assuming that vehicles travel an average 300m distance.

Table 18. Reduction in CO_2 emissions during peak hour traffic, 2016

CO_2 Calculations		2016 Peak Hour Traffic Flow = 3,391 (North); 3,981 (South)					
		2016 Total Peak Hour Volume, vph =			7,372		
98.0% cars & other gasoline		20.3	mpg	19.4	lb/gallon of CO_2 emission		
2.0% trucks (diesel)		5.9	mpg	22.2	lb/gallon of CO_2 emission		
Vehicle Emission Scenario per peak hour	Average Speed, mph	Average Idle Time, min.	Length of Interchange, miles	Effective Distance, miles	Gas per Car, Gallons	Total CO_2 Emission g/hour	Total CO_2 Emission kg/hour
Stop-controlled	9	13	0.188	2.138	0.105	7,231,896	7,232
Roundabout	15	3	0.188	0.938	0.046	3,171,884	3,172
Reduction in CO_2 due to coversion of the intersections to roundabouts =							56.1%
Note: Effective distance = (Length of Interchange + Distance covered during idle time)							

The average idle time reduction calculated from traffic flow simulations for pre- and post-roundabout junction were used to estimate other vehicle emissions (VOC, CO, NO_x, PM_{10}). This is discussed further in the next chapter.

4. PERFORMANCE EVALUATION OF ROUNDABOUTS IN OXFORD, MS

4.1 Overview of Roundabout Design and Implementation

4.1.1 Background

The first intersection resembling a roundabout design in the United States was constructed in New York City in 1905 [39]. The installment of the one-way rotary design was discontinued in the 1950's because these junctions were deemed inefficient and unsafe for high speed automobile traffic. The junctions were constructed with design speeds of 25 miles per hour (mph) and traffic speeds generally exceeded 35 mph [11]. The one-way rotary design was reconstructed in the 1960's in the United Kingdom to address the problems of the one-way rotary design. The new design improved traffic safety and flow by enforcing two main limitations: (1) the incoming traffic enters the junction tangentially to the roundabout, therefore, making incoming traffic yield to traffic traveling around the junction and (2) the geometric design is curved with the intent of slowing vehicles entering and traveling around the roundabout. In order to distinguish between the two one-way rotary designs, the old junction design is referred to as 'traffic circles', while the new design is referred to as a 'modern roundabout' or just a roundabout [12].

The construction of roundabouts was re-introduced in the United States in 1990, and has rapidly grown since. In 2003 there were reportedly 310 roundabouts in the United States, over half of which were constructed after 1995 [12]. The western half of the United States contained 68% of these roundabouts, and only eight percent of the roundabouts were present in the northeastern region of the United States (forty of which are located in the state of Maryland). Majority of these roundabouts are designed with four legs and were constructed to replace an existing traditional stop-controlled intersection [12]. Roundabout junctions are economical intersectional interchange alternatives to improve traffic flow, increase intersection capacity, decrease vehicular emissions, and reduce intersection crashes [40]. Roundabouts are able to increase the flow of traffic and decrease delay of the overall junction by not requiring traffic to stop unnecessarily. Approaching traffic must yield to circulating traffic, but if no traffic is present or there is a safe gap between circulating vehicles, approaching vehicles may continue to their path without ever coming to a complete stop. An increase in flow and a decrease in delay result in a decrease in congestion, queuing lengths, queuing times, and vehicle emissions.

A recent informational guide on roundabouts [16] defines three categories with detailed discussions on design issues mostly for a 4-legged junction: *mini-roundabouts*, *single-lane roundabouts*, and *multilane roundabouts*. The geometric design of roundabouts also controls traffic speeds, which allow for a safer more efficient junction. Even though many studies have been conducted to confirm these benefits of a standard roundabout, the roundabout design varies depending on the site's location and needs. This chapter evaluates performance of the two roundabout junctions constructed to replace stop-controlled intersections on South Lamar Blvd and MS Highway 6 interchange in the city of Oxford, Mississippi.

4.1.2 Overview of Roundabouts in Oxford, MS

Ten percent of modern roundabouts in the United States are located in the southeastern region. Of these 310 roundabouts only one roundabout was located in Mississippi in 2003 in the state capital city, Jackson. The construction of the first roundabout in Oxford, Mississippi began and was opened to traffic in 2005. This mini-roundabout is located at the intersection of Gertrude

Ford Road and Old Taylor Road. In 2006 two new roundabouts were proposed for construction in Oxford at the MS Highway 6 and South Lamar Blvd interchange. The interchange was experiencing high traffic volumes, long delays, and poor LOS. The roundabouts were considered to be a safe and economical solution to the intersection's existing and forecasted capacity limitations [13]. The MDOT's consultant report on roundabouts [14] found that the construction of the roundabout would significantly increase LOS, and increase the capacities to meet traffic demands.

The signalized intersection of South Lamar Blvd and MS Highway 6 westbound was replaced with a four leg non-circular roundabout with one circulating lane. Figure 15 shows the layout and traffic movements of both North roundabout and South roundabout. The South roundabout replaced three stop-controlled intersections. South Lamar Blvd and MS Highway 6 eastbound replaced three separate two-way stop-controlled intersections: South Lamar Blvd and MS Highway 6 eastbound, South Lamar Blvd and Frontage Road, and South Lamar Blvd and Access Road. The design of the South roundabout has a very intricate layout with five entering movements, five exiting movements, one circulating movement, and two side streets. The side streets are designed to reduce unnecessary traffic from the circulating junction. The side street to the west of the roundabout allows incoming traffic from MS Highway 6 eastbound traveling to Frontage Road to exit without entering the intersection. The side street to the east of the roundabout designates traffic traveling from Access Road to MS Highway 6 eastbound without circulating the inner circle. The design of the intersections at the interchange before the construction of the roundabouts can be seen in Figure 47 (planimetric overlay on 1-m satellite imagery). The design of the current roundabout junction is shown in Figure 48.

Figure 47. South Lamar Blvd and MS Highway 6 interchange prior to the construction of the roundabouts

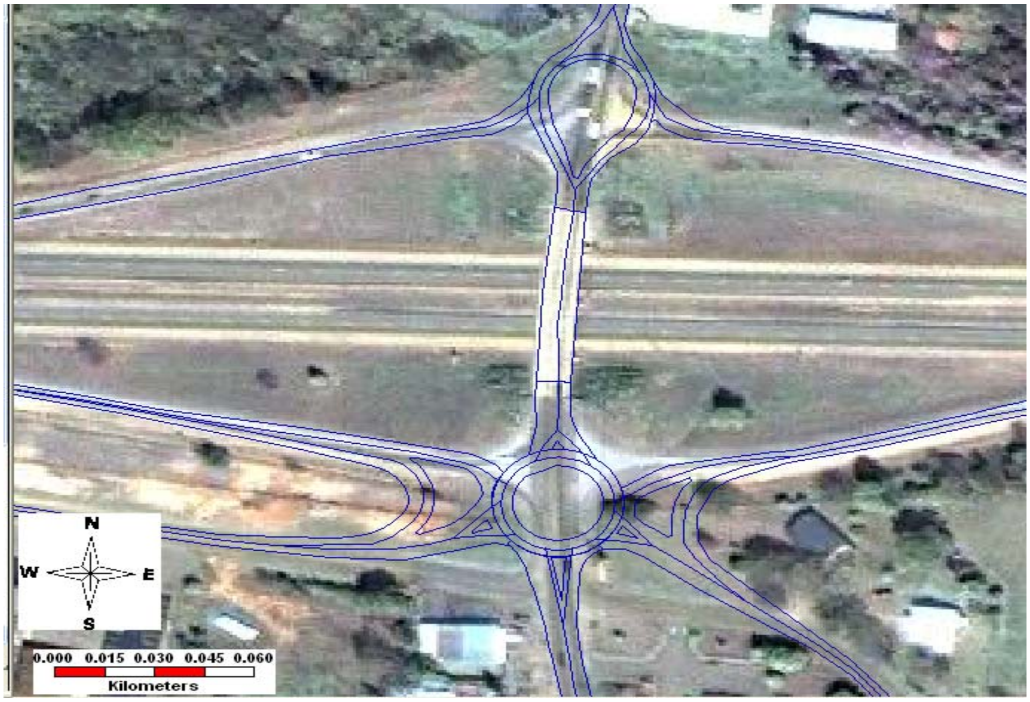


Figure 48. South Lamar Blvd and MS Highway 6 interchange after the construction of the roundabouts

4.2 Traffic Flow, Capacity, and Vehicle Emission Improvements

4.2.1 Highlights of MDOT Consultant's Report

When the consultant report [14] on roundabout analysis and design was prepared for MDOT in 2006 it was found that 50% of the movements in the stop-controlled interchange of MS Highway 6 and South Lamar Blvd experienced LOS of E or F, with F being the worst possible LOS. Table 17 defines the LOS scale based on delay in s/veh ranges. When the interchange was converted to roundabout junctions using traffic simulation programs, the junctions showed a LOS of B and better for all movements. In order to analyze the performance of the roundabout junction both a 'no change' scenario and a roundabout scenario were analyzed and simulated using forecasted 2016 volumes predicted by the consultant from 2003 on-site traffic counts [14]. When the forecasted 2016 traffic volumes were applied to the stop-controlled intersections all the road lanes/movements that were experiencing LOS of F in 2006 remained at a LOS of F and the road section experiencing LOS of E decreased to a LOS of F, resulting in half of the movements in the interchange section of South Lamar Blvd having a LOS of F. When the forecasted 2016 traffic volumes were applied to the roundabout junction the movements displayed LOS of A through D, with over 60% of the sections having a LOS of B or better.

Two of the roundabout movements presented concerns though: (1) the MS Highway 6 eastbound off ramp northbound, and (2) the MS Highway 6 westbound off ramp southbound. These two movements showed a decline in LOS from the stop-controlled interchange to the roundabout junction. The MS Highway 6 eastbound off ramp heading north was a free flowing one way-stop-controlled intersection, and had its own lane so the LOS of this movement remained an A, where as with the construction of the roundabouts vehicles traveling northbound from the MS Highway 6 eastbound off ramp are now required to enter the junction before traveling north.

Traffic coming from the MS Highway 6 westbound off ramp heading southbound previously had its own designated lane at this signalized intersection. With the construction of the roundabout this lane was given priority to traffic traveling to northbound South Lamar, and the traffic heading southbound is now required to enter the roundabout junction in order to travel south. Both parties (MDOT and Consultant) agreed that the superior LOS for the other movements outweighed these two discrepancies. The above results showed that delay, which directly affects LOS assignments, is reduced by 24% when a stop-controlled intersection is converted to a roundabout, thus indicating that although the two movements show a decline in LOS the overall delay of the junction traffic flow is improved.

When the 2016 traffic volumes were applied the stop-controlled intersections would exceed capacity limits. The MS Highway 6 eastbound off ramp is 850 feet whereas the queuing length of the vehicles heading in the east direction is 994 feet exceeding the length of the off ramp. The above results displayed that the queuing times are much higher for the ‘do nothing’ scenario than the roundabout scenario. The higher the queuing times the longer the queue length therefore it is reasonable to assume that the roundabouts would better accommodate capacity limits than a stop-controlled intersection. In this study traffic capacity analysis was conducted using the updated 2016 forecast based on the 2009 on-site traffic volume for each movement and peak hour counts.

4.2.2 Comparison of LOS and Microsimulation Results

The first step to analyzing the performance of an intersection is to observe the intersection’s traffic pattern such as traffic flow, delay, LOS, congestion, capacity, and queuing lengths and times. Typically the HCM method of the American Association of State Highway and Transportation Officials (AASHTO) [16, 34] are used for these calculations in traffic planning and design practice. This analysis using 2010 procedure for capacity and control delay was conducted with assumed 2.5% annual growth in peak hour traffic volume from 2009 to 2016, as discussed in detail in Chapter 2. The LOS in year 2016 was C for most entry flows but it deteriorated to E for the southbound traffic during Friday’s peak hour on South Lamar Blvd (Movement 3) entering in the North roundabout. For Thursday’s peak hour the LOS of this movement worsens to F due to higher conflicting flow.

The HCM computations of capacity and LOS are necessary for planning and design but not adequate for the purpose of detailed in-service traffic flow analysis and performance evaluation. Therefore, traffic flow simulations were used to facilitate the comparison of the two junction alternatives. The S-Paramics traffic flow microsimulation software [37] was used to analyze the performance of stop-controlled intersections and compare it to that of roundabout junctions. Additionally, microsimulation results were used to verify the consultant report’s queuing and LOS predictions. The simulation processes, inputs, and output results are presented and discussed earlier in Chapter 3. The output mean delay, queuing time, and speed values from S-Paramics simulation runs described in the preceding chapter are used to compare the performance of the junction alternatives. Three simulation runs were completed for each junction alternative. The data set used for comparison was based on the worst case scenario of the three outputs for each junction type. By observing the stop-controlled simulations, it is known that the number of vehicles that pass through an interchange in a given period of time is directly associated with the delay of the intersection; the longer the delay of the intersection, the fewer the number of vehicles that are able to travel through the interchange.

Delay in transportation and traffic engineering is defined in units of s/veh, which represents the amount of time in seconds that each vehicle travels at speeds slower than the network design speed. This value is usually represented as an average, or mean, within a given time frame over a particular road section or intersection. The total mean delay (averaged over a one-minute period) for the 2016 peak hour traffic flow from simulation over the entire interchange (including both junctions at South Lamar) is represented in Figure 45. An intersection's ability to perform at its full capacity is reflected most directly by the mean speed of the intersection. The mean speed of an intersection is affected by congestion, delay, and flow. The mean speed of each junction type over the peak hour is also represented in Figure 45. The key simulation results are:

- The mean delay for the stop-controlled intersection during the peak hour is 46 s/veh, and the mean delay for the roundabout junction during the peak hour is 35 s/veh. This results in a 24% reduction in delay during peak hours over the entire interchange of South Lamar Blvd and MS Highway 6 when the stop-controlled intersections were replaced with roundabouts.
- The calculated delays from simulation runs indicate that the overall LOS of the roundabout junctions improved to D from E (for the stop-controlled intersections). This is more representative of the in-service traffic flow where actual geometry was modeled in simulation runs.
- The mean speed for the stop-controlled intersection interchange was 9 mph, compared with the roundabout mean speed of 15 mph. The design speed of the entire South Lamar segment with both signalized and stop-controlled intersections is 30 miles per hour, thus during peak hours traffic is traveling through the segment at less than one third the design speed of the intersection. Though the design speed of the road sections connected to the roundabout are 30 mph, the design speed for the traffic traveling around the roundabout junctions is 15 mph, and traffic approaching the intersection must yield to the circulating traffic, therefore traffic traveling at an average speed of 15 mph during peak hours is a very reasonable speed and a significant improvement over the stop-controlled intersection junctions.
- The plot of the aggregate mean queuing time over the peak hour period (Figure 46) reveals that vehicles spend a much larger amount of time queuing in a stop-controlled intersection compared to a roundabout junction. When the interchange is controlled by stop signs and signals vehicles are constantly spent in queue during peak hours. The queuing times for the roundabout interchange remain consistently between 2 and 4 minutes throughout the hour. Since the queuing times are cumulative throughout the hour this means that there is little to no time spent idling during peak hours. This will result in reductions of vehicle emissions, road user travel time, and wastage of fuel.

4.2.3 Vehicle Idling Emission and GHG Reductions

The FHWA states that vehicle emissions are shown to reduce if transportation planning strategies employ one or more of the following: "reducing vehicle miles traveled and or vehicle trips, reducing vehicle idling time, shifting travel times, improving traffic speeds or traffic flow, or altering vehicle fleet characteristics [21]." Table 19 shows various transportation system management (TSM) strategies and the approaches they employ in order to reduce vehicle emissions. TSM strategies focus primarily on altering the transportation system in order to improve traffic flow and delay. A reduction in idling time is often a result of changing the operation of a transportation system to increase traffic flow. The strategies listed are limited to either reducing idling and/or changing vehicle speeds. The right side of the table displays the strategy's effects on pollution emissions, whether the emissions are decreased (↓), increased (↑), vary (↓/↑), or are not effected (N). The results of this table are based on reference documents and case studies [21]. From the table it can be seen that all strategies that reduce vehicle idling will generally reduce all vehicle emissions, while strategies that focus on altering vehicle speeds will not effect PM, SO_x, or NH_3, and CO, NO_x. Also, VOC emissions may increase or decrease depending on the extent of the vehicle speeds and the vehicle accelerations and decelerations.

Table 19. General emissions impacts of TSM strategies [21]

Strategy	Category of Primary Effect						General Pollutant Effect						
	Reduce VMT	**Reduce vehicle trips**	**Shift travel time**	**Reduce idling**	**Change speeds**	**Change vehicle stock**	**PM-2.5**	**PM-10**	**CO**	**NOx**	**VOCs**	**SOx**	**NH_3**
Signal Synchronization/ Intersection Improvements	-	-		√	√		↓/N	↓/N	↓/↑	↓/↑	↓*	↓/N	↓/N
Incident Management/Traveler Information	+			√	√		↓/N	↓/N	↓/↑	↓/↑	↓*	↓/N	↓/N
Speed Control					√		N	N	↓/↑	↓/↑	↓/↑	N	N
Shifting/Separating Freight Movements					√		N	N	↓/↑	↓/↑	↓*	N	N
Vehicle Idling Restrictions/Programs				√			↓	↓	↓	↓	↓	↓	↓

Based on MS Highway 6 study of vehicle emissions [41], Figure 49 shows the correlation between vehicle speed and the following air pollutants: VOC, NO_x, and CO. It can be seen from this figure that when vehicle speeds drop below about 4 km per hour (kmph) the rate of release of vehicle emission increases exponentially. When vehicle speeds increase from 4 kmph to 16 kmph the level of emissions begin to decrease and when vehicle speeds are between 16 kmph to 64 kmph the vehicles emissions start to level off. The range of vehicle speeds when emissions are the lowest are from 16 to 64 kmph. When vehicle speeds reach higher than 64 kmph the level of emissions begin to increase. Roundabouts generally keep traffic speeds within a range of 10-35 mph (16-56 kmph) and reduce time spent idling. Roundabouts are intended to increase traffic flow by keeping vehicles in constant movement for transportation planning and modeling. In roundabout junctions vehicles are only required to yield to traffic circulating the roundabout. This traffic pattern prevents vehicles from making unnecessary stops and reducing traveler delay, which will both effectively reduce idling times. The geometric design of roundabouts is also planned with the intent to controlling traffic speeds. The reduction in vehicle stops, idling times, and excessive vehicle speeds ultimately results in a reduction in vehicular emissions.

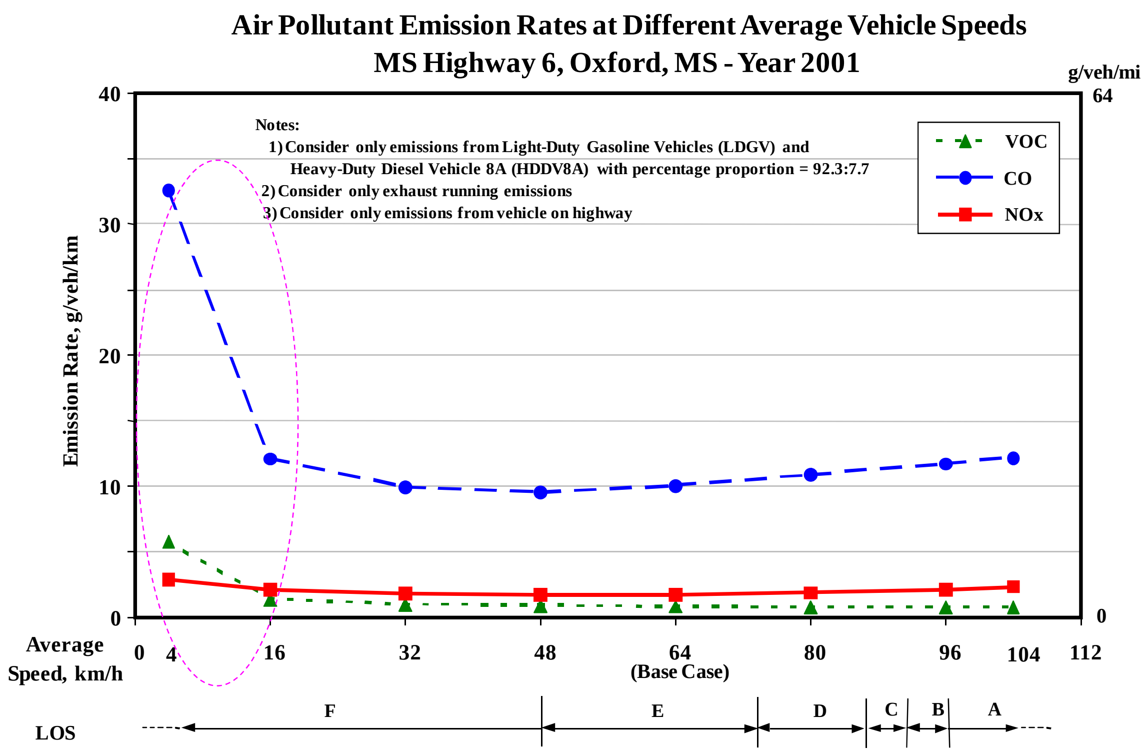


Figure 49. Emissions factors by vehicle speed for vehicle mix on MS Highway 6, Oxford, MS

Observing the correlation between speed and vehicle emissions in Figure 49, the mean speed of the roundabouts (15 mph or 24 kmph) emits fewer emissions than the mean speed of the stop-controlled intersection (9 mph or 14.4 kmph). Many site studies have been conducted in order to verify that roundabouts reduce vehicular emissions. The following studies have found that by replacing stop-controlled intersections with roundabouts vehicle emissions and fuel consumptions are reduced:

- Kansas and Nevada, 21 - 42% reduction in CO, 16 - 59% reduction in CO_2, 20-48% reduction in NO_x, and 17 – 65% reduction in HC were reported [42]
- Sweden, CO emissions were reduced by 29%, NO_x by 21%, and fuel consumption by 28% [43].

The previous section demonstrated that the intersection improvement at the South Lamar Blvd and MS Highway 6 interchange from a stop-controlled intersection to a roundabout reduced traveler delay, improved vehicle speeds, and reduced vehicle idling times. This section uses these results to analyze the reduction of vehicular emissions from vehicular idling. The following pollutants are the primary focus of this study: VOC, CO, NO_x, and PM_{10}. All of these EPA criteria pollutants' concentrations increase significantly during vehicle idling for all vehicle types except PM emissions whose concentration is distinctly from heavy duty diesel vehicles. The level of vehicle idling emission is dependant on vehicle and engine type. For this reason the vehicle mix distribution was estimated for South Lamar Blvd. The vehicle distributions of light duty vehicles, heavy duty vehicles, and motorcycles were estimated from the on-site traffic counts completed in Oxford in October, 2009. Figure 50 shows the vehicle mix percentages from the on-site manual traffic counts using the highest percentages for trucks, buses, and motorcycles over the traffic count week. From the on-site traffic counts heavy duty traffic and buses accounted for 1.70% of the total vehicle mix, while motorcycles accounted for 0.72%, and passenger vehicles accounted for the remainder 97.58% of the vehicle distributions.

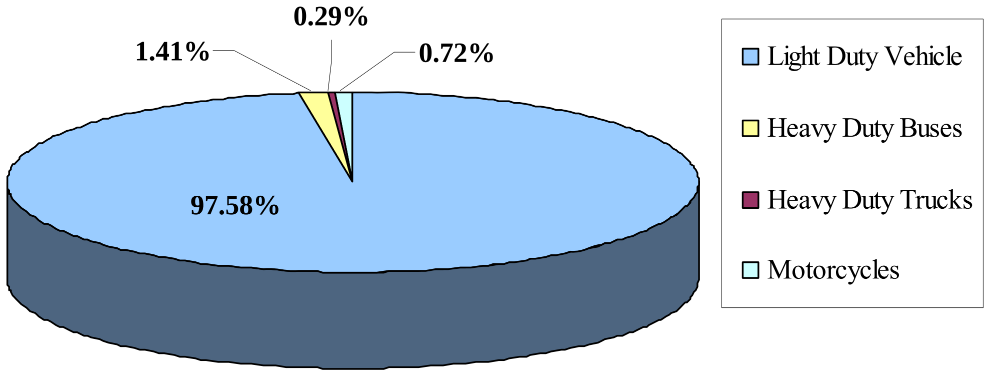


Figure 50. Vehicle distribution from 2009 on-site traffic counts

This on-site traffic counts did not account for SUVs and light duty trucks, or diesel engines. The vehicle distribution of light duty trucks (including SUVs and minivans) can be estimated from state or national averages [44]. For the purpose of this site-specific emission analysis the following vehicle mix was assumed:

- Light-duty gasoline-fueled vehicles (LDGV): 98.0% (cars, pick-ups, and SUVs)
- Light-duty gasoline-fueled trucks (LDGT): 0.0%
- Heavy-duty gasoline-fueled vehicles (HDGV): 0.0%
- Light-duty diesel vehicles (LDDV): 0.0%
- Light-duty diesel trucks (LDDT): 0.0%
- Heavy-duty diesel vehicles (HDDV): 2.0% (1.0% HDDV trucks and 1.0% HDDV buses)
- Motorcycles (MC): (0.72%, included in LDGV)

Table 20 displays the EPA's vehicle idling emission factors for CO, VOC, and NO_x for each vehicle type (when ambient temperatures are 75˚) [45]. For these pollutants heavy duty trucks and buses are considered to have the same idling emission factors. Table 21 also shows the PM_{10} idling emission factors for heavy-duty diesel trucks and buses (particulate matter emissions are not significantly affected by air temperatures) [45]. Using these vehicle idling emissions factors the amount of vehicle emissions from idling time (simulation results) were calculated for both the stop-controlled intersection scenario and the roundabout junction scenario over the peak hour based on the mean time spent idling in a queue. Table 20 and Figure 51 display the estimated vehicle idling emissions over the peak hour for both interchange scenarios. It should be noted that the level of pollutant emissions only takes into account the vehicle idling emissions since this is known to be the largest contributor to emissions from vehicles for these pollutants. Table 20 (right column) also shows peak hour emission reductions for roundabouts, as follows:

- CO reduced by 76.9%
- VOC reduced by 80.3%
- NO_x reduced by 76.9%
- PM_{10} reduced by 76.9%

Furthermore, CO_2 reduction considering the peak hour traffic was calculated in Chapter 3, as follows:

- CO_2 reduced by 56.1%

Table 20. Vehicle idling emissions factors per vehicle type and total peak hour emissions

Average Idle Time		2016 Peak Hour Traffic Flow = 3,391 (North); 3,981 (South)								
(from simulations)			2016 Average Peak Hour Volume, vph =					7,372		
Stop-controlled, min =	13		cars & other gasoline vehicles =				98.0%	(LDGV)		
Roundabout , min =	3		trucks (diesel) =				2.0%	(HDDV)		
Idling Vehicle	Vehicle Type							Total Emission, g/hour		Emission
Emission Factors	LDGV	LDGT	LDDV	LDDT	HDGV	HDDV	MC	Stop-controlled	Round-abouts	Reduction, %
CO, g/min	6.190	8.120	0.190	1.580	11.400	0.168	6.470	581,682	134,234	76.9%
VOC, g/min	0.352	0.512	0.080	0.211	0.734	0.061	0.335	38,789	7,656	80.3%
NO_x, g/min	0.103	0.125	0.115	0.945	0.196	0.111	0.042	9,886	2,281	76.9%
PM_{10}, g/min	HDDV (Buses) =		0.042	HDDV (Trucks) =		0.043		81	19	76.9%

Light-duty gasoline-fueled vehicles (LDGV) including cars; Light-duty gasoline-fueled trucks (LDGT);
Light-duty diesel vehicles (LDDV); Light-duty diesel trucks (LDDT);
Heavy-duty gasoline-fueled vehicles (HDGV); Heavy-duty diesel vehicles (HDDV); Motorcycles (MC)

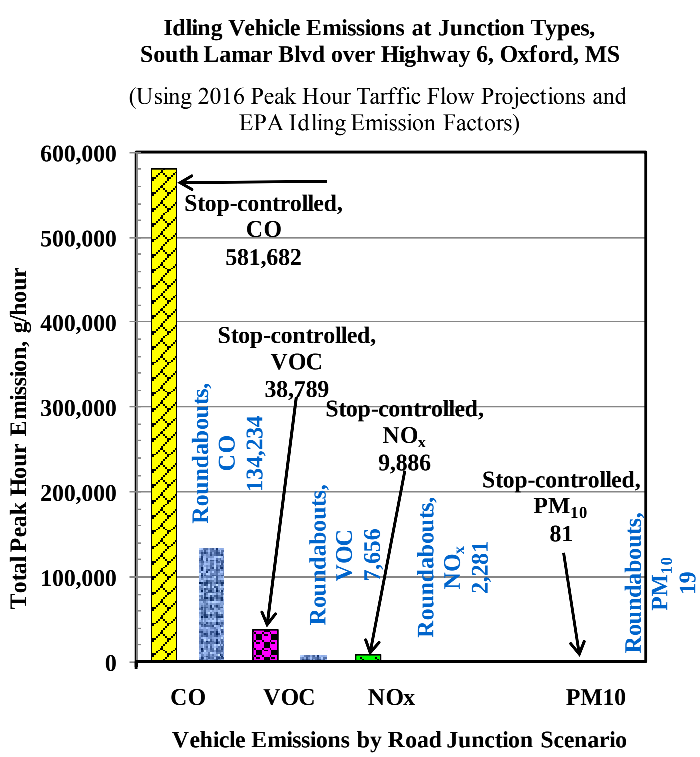


Figure 51. Vehicle idling emissions before (stop-controlled) and after roundabout construction

Reduction in tropospheric O_3 due to improved traffic flow at a roundabout junction is not estimated due to the facts that it is produced in summer days. Moreover, the precursors (VOC and NO_x) are also generated by other contributors such as industrial and commercial emitters, built-up environment, and consumption of fossil fuels for electricity generation.

4.3 Safety Performance Evaluation and Benefit/Cost Analysis

4.3.1 Literature Review of Safety Improvement from Roundabout Junction

Studies conducted in the United States, Australia, and the Netherlands's have proven roundabouts to be a safe solution to stop-controlled intersections. From a study of 23 roundabouts in the United States it was estimated that by converting a stop-controlled intersection to a roundabout, total crashes would be reduced by 40%, crashes resulting in injury would be reduced by 80%, and fatalities would be reduced by an estimated 90% [46]. In Australia injury crashes were reduced by 74% upon the conversion of a stop-controlled intersection to a roundabout [47]. The largest study was conducted on 181 Dutch roundabouts. The construction of roundabouts to replace stop sign and signalized intersections reduced crashes by 47% and injuries by 71% [48]. With a reduction in crashes comes a reduction in crash related costs. Crashes at intersections controlled by stop signs make up 38% of intersection crashes resulting in fatalities, and half of the total costs from injury related crashes that occur at intersections are at stop sign controlled intersections. Also, crashes that occur at stop controlled intersections are statistically more severe than crashes that occur on road sections. Thirty three percent of comprehensive costs of crashes occur at intersections totaling at 97 billion dollars in 2000 [19]. If roundabouts were prevalently used as junction alternative these costs could be significantly reduced. This section describes crash data in order to analyze the ability of roundabouts in Oxford, MS to reduce crashes and crashes resulting in injury. This section also conducts a comprehensive cost and benefit analysis from the reduction in crashes and injuries.

4.3.2 Safety Improvements in Geometrics of South Lamar Blvd Roundabout Design

Roundabouts are able to reduce intersection crashes and crashes resulting in injury by reducing traffic speeds, and limiting the number of contact or conflict points. Conflict points are reduced from 32 a standard 4-legged intersection to 8 at a typical single lane roundabout. Contact points are points within the interchange where vehicles from opposing directions have a possibility of intersecting. Figures 52 (a) and 52 (b) display the number of contact points for the South roundabout before and after conversion of the interchange, respectively. It can be seen from these figures there is a significant reduction in number of contact points from the stop-controlled intersection (25 points of contact) to the roundabout junction (7 points of contact). The type of contact points in the stop-controlled intersection also are more obtrusive then contact points in a roundabout junction since the vehicles approach each other at a perpendicular position and have the possibility of involving multiple vehicles. The geometry of roundabouts forces vehicles to enter the circle at a tangential position, therefore reducing speeds and the severity of vehicle contact.

4.3.3 Overview and Statistical Analysis of Crash Data of the Study Area, Oxford

The crashes and injury crashes over the current and past years were examined in order to analyze the effectiveness of the roundabouts on South Lamar Blvd in reducing crashes. The crash data for the city of Oxford, Mississippi was requested and provided by courtesy of the Mississippi Department of Public Safety for the years of 2004 through 2009 [49]. The crash data included the following information for each crash: date, time, number vehicles, number fatalities, number injuries, street, highway, intersecting street, distance, direction, city, longitude, and latitude. The information is filled out on a crash form by the on-site police officer for each crash, and then recorded into the state's Safety Analysis Management System (SAMS) database by a local state employee. Not all the information from the SAMS database for each crash is accessible to the public such as age, influences (drinking/drugs), or injury rate. Therefore, these data were not available for use in this study. Figure 53 shows that number of crashes in daytime exceed number of crashes at nighttime, which is obviously attributed to higher traffic volume in the daytime.

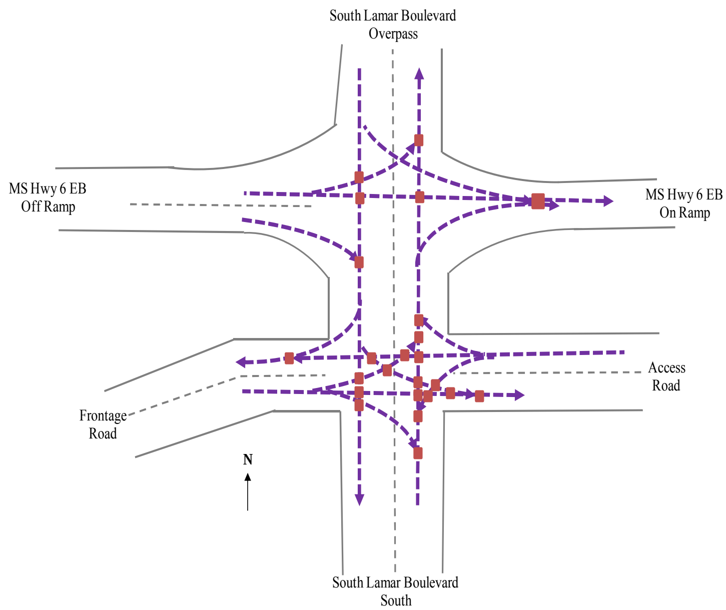


Figure 52 (a). Contact points at south end of South Lamar Blvd and MS Highway 6 interchange as stop-controlled intersections

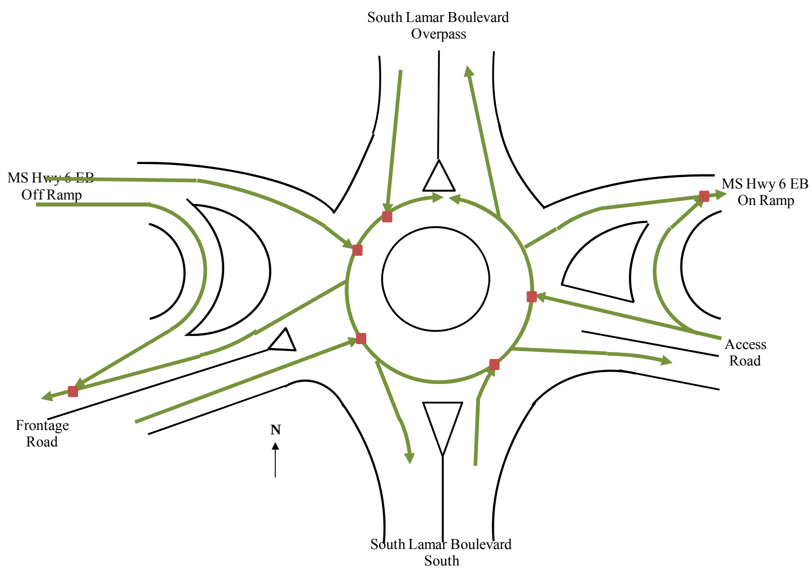


Figure 52 (b). Contact points at south end of South Lamar Blvd and MS Highway 6 interchange as roundabout junction

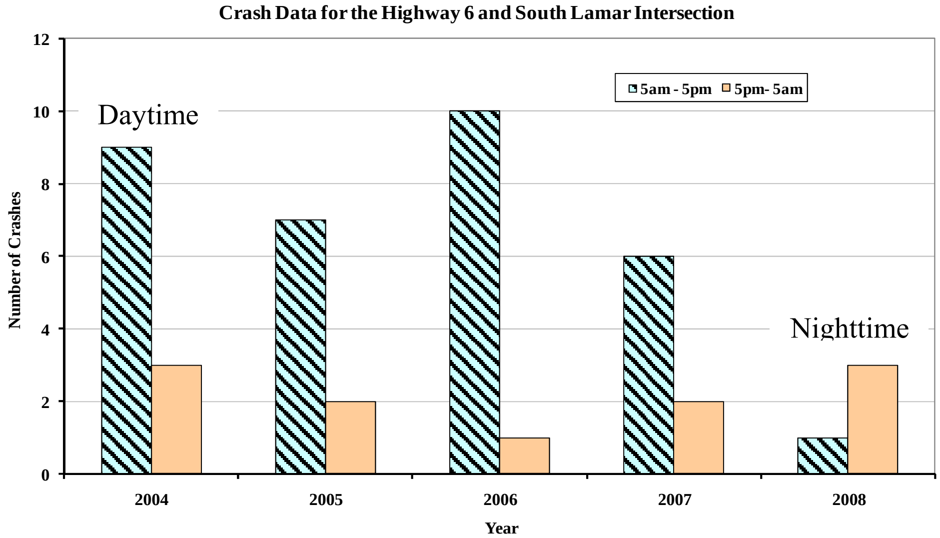


Figure 53. Comparison of number of crashes at daytime vs. nighttime in the study area

The crash data for the study area was filtered from the entire database using the street and intersecting street names, as well as their geographic coordinates (crashes that occurred on sections of MS Highway 6 only were excluded from the study). Figure 54 displays the crash study area (within 0.16 mile or 0.25 km radius of the study site) and the outer most coordinates of the crash study area. The radius and coordinates of the crash study area were found using geospatial analysis in GeoMedia Pro. Statistical analysis and Empirical Bayes approach before and after the roundabout were used in order to analyze the crash data.

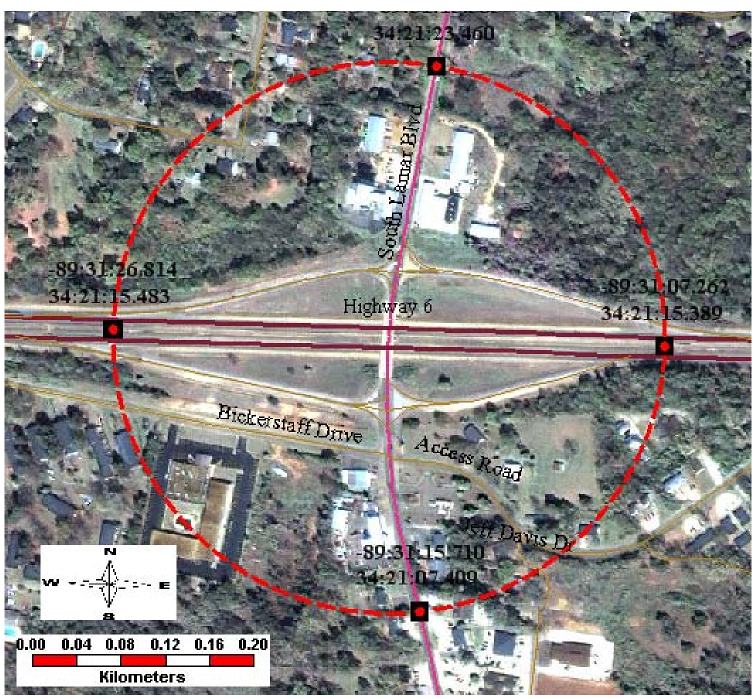


Figure 54. South Lamar Blvd study site for crash data, Oxford, MS

Statistical analysis was used to provide statistically significant evidence of a roundabout junction's ability to reduce the number of vehicle crashes. A t-test was conducted to compare the means of number of crashes before and after the construction of the roundabouts. Statistical t-tests compare the means of two distinct sets of data in order to provide statistical evidence of a significant difference between the two means. The crash database for Oxford was filtered for crash data for South Lamar Blvd study site, summed in 6 month periods, and split into two sets of data (pre-roundabout and post-roundabout). For each set of data the total number of crashes that occurred in the study area and the number of crashes that occurred at an intersection within the study area was summed for each six month period (Table 21). The crash data for 2004 was not used in order to analyze data only based on the new crash report form starting in 2005. This also provides equal sample size for pre and post crash data.

Table 21. Crash data for South Lamar Blvd and MS Highway 6 interchange, Oxford

Time Period	Pre/Post	Total Number Crashes	Number Crashes at Intersection
1/2005 - 6/2005	Pre	16	11
6/2005 - 12/2005	Pre	19	10
1/2006 - 6/2006	Pre	23	9
6/2006 - 12/2006	Pre	29	11
1/2007 - 6/2007	Pre	22	8
6/2007 - 12/2007	*Post*	*11*	*5*
1/2008 - 6/2008	*Post*	*19*	*6*
6/2008 - 12/2008	*Post*	*14*	*4*
1/2009 - 6/2009	*Post*	*12*	*9*
6/2009 - 12/2009	*Post*	*13*	*5*

The total number of crashes in the area includes all the crashes that occur at both intersections within the study area and other sections of roads that are connected to the study area within a 0.16 mile or 0.25 km radius. The overall performance of the roundabout is explored by the relevance of knowing whether the reduction in total number of crashes over the entire study area is reduced. The t-test analysis [50] completed for the total number of crashes within the study area tests the following:

- Dependant Variable: Total number of crashes within the study area per 6-month period
- Independent Variable: Pre or post roundabout construction
- Hypothesis:
  - H_0: $\mu_1 = \mu_2$
  - H_1: $\mu_1 \neq \mu_2$
    - Where μ_1 and μ_2 are the mean total number of crashes for pre and post roundabout construction, respectively
- Level of significance $\alpha = 0.05$
- Test hypothesis:
  - If sig. (2-tailed) value < α. reject H_0
  - If sig. (2-tailed) value > α. fail to reject H_0

From the t-test results a significance (2-tailed) value = 0.015 < α was found. Thus, H_0 is rejected at 0.05 α level. The result concludes that the number of crashes is significant to whether the intersection is a roundabout or a stop-controlled intersection at a significance level of 0.05. Table 22 shows the results of the t-test.

Table 22. Results of t-test for the total number of crashes on the study area roads

<table>
<tr><th></th><th></th><th colspan="2">Levene's Test for Equality of Variances</th><th colspan="2">t-test for Equality of Means</th><th colspan="3">t-test for Equality of Means</th><th colspan="2">t-test for Equality of Means (95% Confidence Interval of the Difference)</th></tr>
<tr><td rowspan="3">Crash Count</td><td>Equal variance:</td><td>F</td><td>Sig.</td><td>t</td><td>df</td><td>Sig. (2-tailed)</td><td>Mean Difference</td><td>Std. Error Difference</td><td>Lower</td><td>Upper</td></tr>
<tr><td>assumed</td><td>0.641</td><td>0.446</td><td>3.095</td><td>8</td><td>0.015</td><td>8</td><td>2.58457</td><td>2.03997</td><td>13.96003</td></tr>
<tr><td>not assumed</td><td></td><td></td><td>3.095</td><td>6.804</td><td>0.018</td><td>8</td><td>2.58457</td><td>1.85268</td><td>14.14732</td></tr>
</table>

In order to analyze the spread of the crash data the descriptive statistics, frequency of crashes, central tendency and dispersion of the crashes are observed. Table 23 displays the descriptive statistics for pre and post roundabout construction. In this table it is shown that all the descriptive statistics show lower values for the roundabout junction compared to the stop-controlled intersection. When observing the stop-controlled intersection against the roundabout junction it can be seen that the mean number of crashes over the 5 periods is reduced by 36%, the median value (middle value) of the stop-controlled intersection compared to the roundabout junction is almost double, and the variance and standard error are significantly lower showing that the crashes that occur at the roundabout have a more consistent trend. Figures 55 and 56 display the frequency distribution for the total number of crashes on the study area roads before the construction of the roundabouts and after the roundabout construction, respectively. These figures show the number of times a crash or group of crashes occurs. It can be seen from these figures that after the construction of the roundabout fewer crashes occurred at lower frequencies than before the construction of the roundabouts.

Table 23. Descriptive statistics of the total number of crashes pre- and post-roundabout construction

<table>
<tr><th colspan="2">Statistic</th><th>Pre-</th><th>Post-</th></tr>
<tr><td colspan="2">Mean</td><td>21.8</td><td>13.8</td></tr>
<tr><td rowspan="2">95% Confidence Interval for Mean</td><td>Lower Bound</td><td>15.7553</td><td>9.9329</td></tr>
<tr><td>Upper Bound</td><td>27.8447</td><td>17.6671</td></tr>
<tr><td colspan="2">5% Trimmed Mean</td><td>21.7222</td><td>13.6667</td></tr>
<tr><td colspan="2">Median</td><td>22</td><td>13</td></tr>
<tr><td colspan="2">Variance</td><td>23.7</td><td>9.7</td></tr>
<tr><td colspan="2">Std. Deviation</td><td>4.86826</td><td>3.11448</td></tr>
<tr><td colspan="2">Std. Error Mean</td><td>2.17715</td><td>1.39284</td></tr>
<tr><td colspan="2">Minimum</td><td>16</td><td>11</td></tr>
<tr><td colspan="2">Maximum</td><td>29</td><td>19</td></tr>
<tr><td colspan="2">Range</td><td>13</td><td>8</td></tr>
</table>

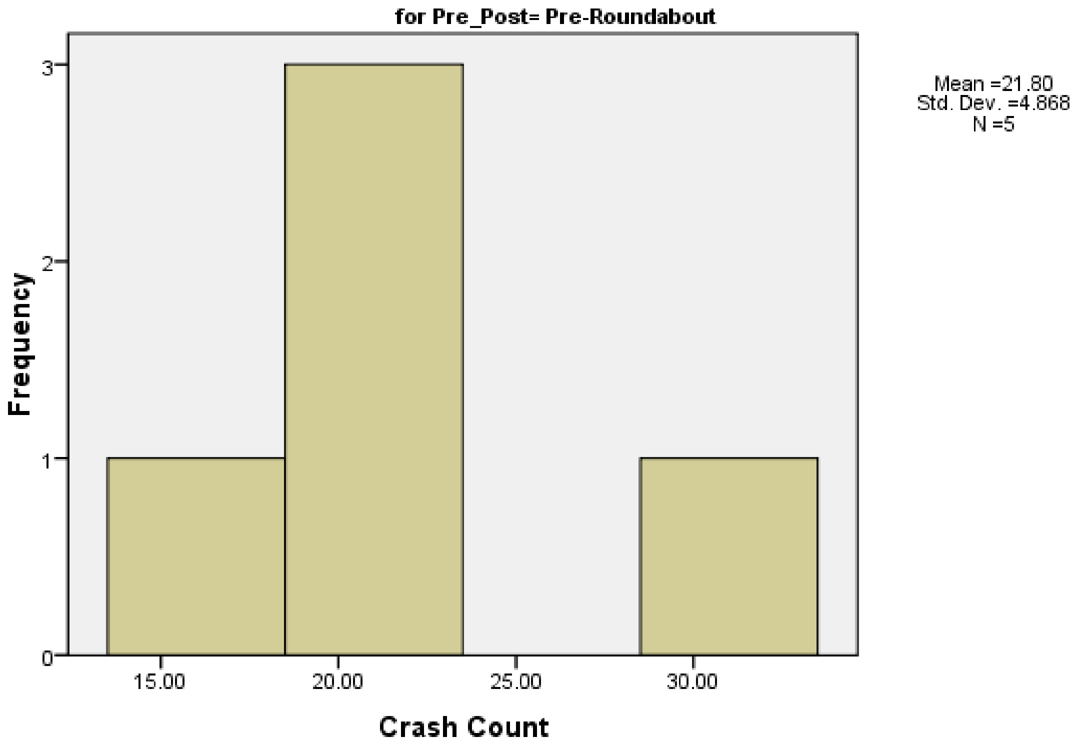


Figure 55. Frequency distribution of total crash counts for pre-roundabout construction

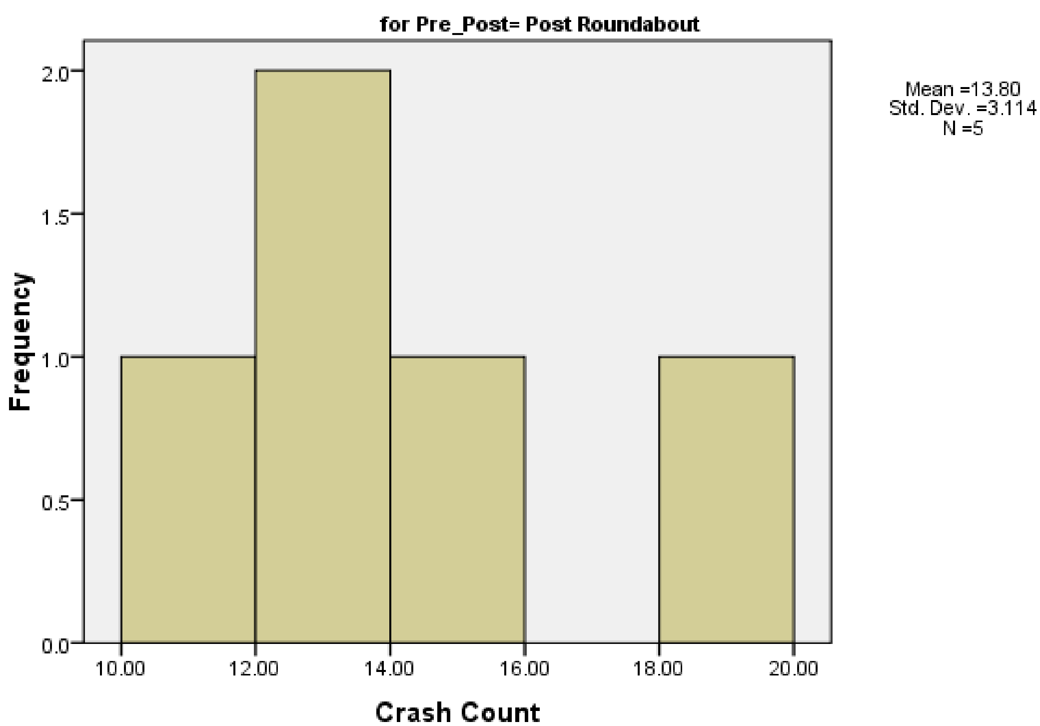


Figure 56. Frequency distribution of total crash counts for post-roundabout construction

Figure 57 displays a box plot of the total number of crashes on the area roads for both before the construction of the roundabout and after the construction of the roundabout. This figure displays the central tendencies and the dispersion of the crashes. The line through the middle of the box displays the measure of central tendency, or the median value for each set of data. The measure of dispersion is illustrated by the length of the box; this represents the interquartile range of the crashes [50]. The vertical end points of the graph represent the minimum and maximum values. From this graph is can be seen that the median value of the crashes is much larger for the stop-controlled intersection compared to the roundabout junction. Also the crashes that occurred before the construction of the roundabout were much more dispersed. The point labeled '7' above the box plot for the post roundabout condition represents an outlier. An outlier is a data point within the data set that is distant from the trend of the data.

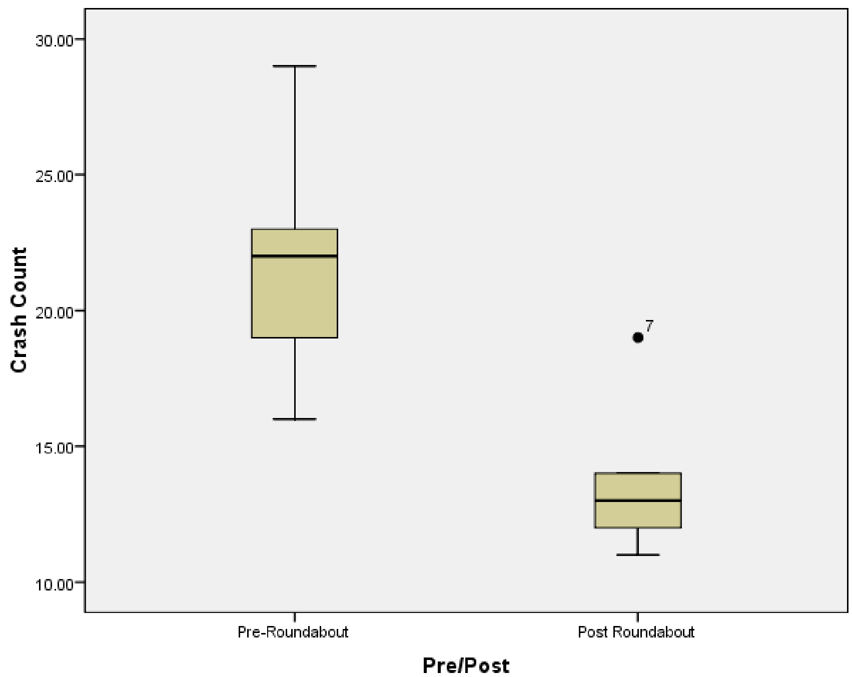


Figure 57. Box plot of total number of crashes for pre- and post-roundabout construction

The original intention of roundabout construction at the study site was to improve the performance of intersections. Intersection crashes account for almost half of the crashes that result in injury, with traffic signal controlled intersection accounting for half of these crashes and stop sign controlled intersections accounting for 25%. Also, crashes that occur at intersections are statistically more severe than crashes that occur on road sections [19]. Therefore knowing if the conversion of a stop-controlled intersection to a roundabout has a statistically significant effect on the reduction of crashes at intersections is desirable. The total number of crashes that occur at intersections within the study area includes all the crashes that occur at both intersections of South Lamar Blvd and MS Highway 6 interchange within the study area and intersections on other roads that connected to the study area within a 0.25 km radius. The overall performance of the roundabout is explored to determine whether the total number of crashes that occur at intersections within the entire study area is reduced. The t-test analysis completed for the total number of crashes that occur at an intersection within the study area tests the following:

- Dependant Variable: Number of crashes at intersections within the study area
- Independent Variable: Pre or post roundabout construction
- Hypothesis:
  - H_0: $\mu_1 = \mu_2$
  - H_1: $\mu_1 \neq \mu_2$
    - Where μ_1 and μ_2 are the mean total number of crashes that occur at intersections for pre and post roundabout construction, respectively
- Level of significance $\alpha = 0.05$
- Test hypothesis:
  - If sig. (2-tailed) value < α. reject H_0
  - If sig. (2-tailed) value > α. fail to reject H_0

From the t-test the significance (2-tailed) value = 0.005 < α was found. Thus, H_0 is rejected. This concludes that the number of crashes is significant to whether the intersection is a roundabout or a stop-controlled intersection at a significance level of 0.05. Table 24 shows the results of the t-test including the significance values.

Table 24. Results of t-test for the number of crashes that occur at intersections

		Levene's Test for Equality of Variances		t-test for Equality of Means		t-test for Equality of Means			t-test for Equality of Means (95% Confidence Interval of the Difference)	
Crash Count	Equal variance:	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
	assumed	0.295	0.602	3.849	8	0.005	4	1.03923	1.60353	6.39647
	not assumed			3.849	7.035	0.006	4	1.03923	1.54509	6.45491

The descriptive statistics for the number of crashes that occur at an intersection points for both the stop-controlled intersection and the roundabout junction are displayed in Table 25. As observed previously from the total number of crashes, the intersection change from a stop-controlled intersection to a roundabout junction reduces the mean number of crashes that occur at intersections from 9.8 to 5.8, a 41% reduction. The variance and standard error are actually higher for the roundabout junction compared to the stop-controlled intersection. This is most likely because both sets of data are more defined, therefore having less variables.

Figure 58 displays the number of crashes and the number of times they occur. In this figure it can easily be seen that the number of crashes is much less for the roundabout junction than the stop-controlled intersection. There is only one sample set for the roundabout junction that intertwines with the stop-controlled intersection. This sample set occurred within the first six months of 2009. Even the data of this sample set is at the lower end of the stop-controlled intersection crash data. Figure 59 displays a box plot of the total number of crashes that occur at intersection points for both before the construction of the roundabout and after the construction of the roundabouts. From this graph is can be seen that the median value of the crashes for the stop-controlled intersection is double that of the roundabout junction. For the roundabout junction the dispersion of the crashes are higher than the median value. This is most likely because of the sample set that occurred at the beginning of 2009. The number of crashes that occurs at each sample set for the roundabout junction is within one value of the other except this sample set which accounted for a total of nine crashes. This value is represented by the point above the post roundabout box plot and is referred to as an outlier.

Table 25. Descriptive statistics of the total number of crashes occurring at intersections, pre- and post-roundabout construction

Statistic		Pre-	Post-
Mean		9.8	5.8
95% Confidence Interval for Mean	Lower Bound	8.1811	3.4116
	Upper Bound	11.4189	8.1884
5% Trimmed Mean		9.8333	5.7222
Median		10	5
Variance		1.7	3.7
Std. Deviation		1.30384	1.92354
Std. Error Mean		0.5831	0.86023
Minimum		8	4
Maximum		11	9
Range		3	5

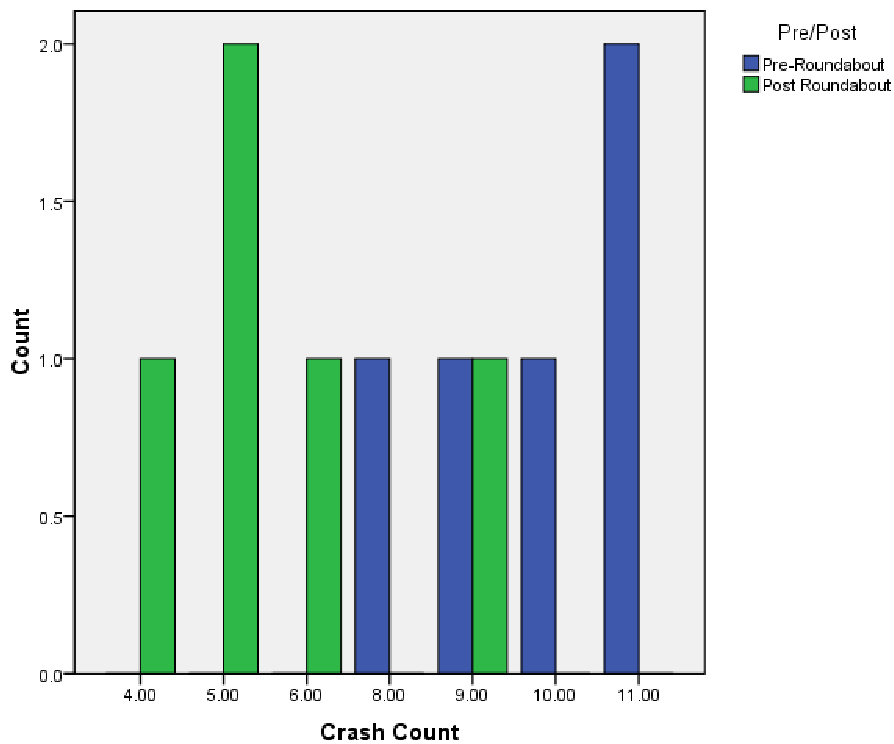


Figure 58. Number of crashes occurring at intersections for post and post roundabout construction

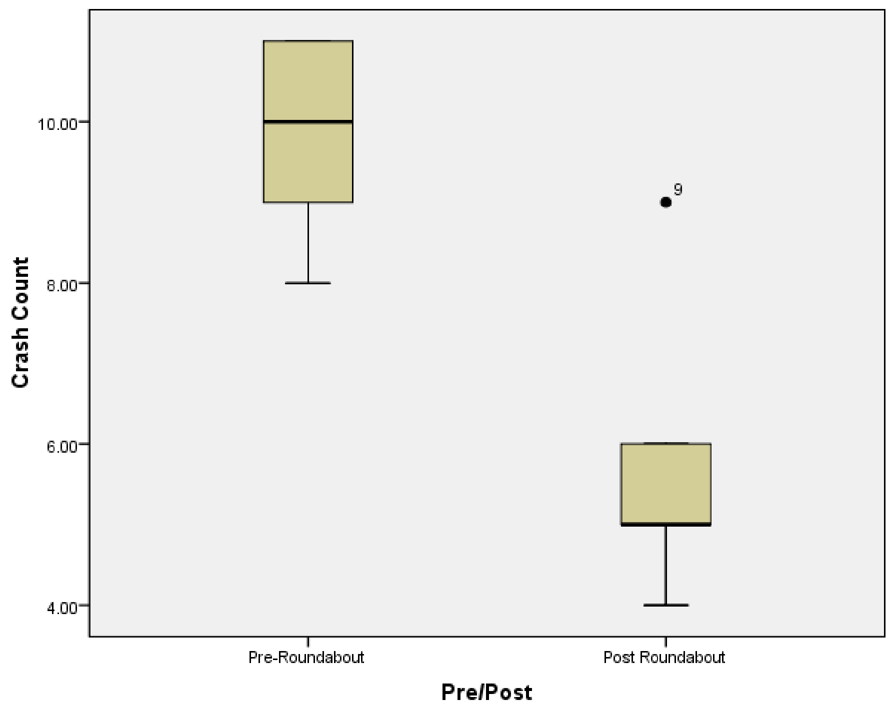


Figure 59. Box plot of crashes occurring at intersection for pre- and post-roundabout construction

4.3.4 Empirical Bayes Before – After Analysis

The previous section provided statistical proof that the conversion of a stop-controlled intersection to roundabout junction reduced the total number of crashes as well as the crashes that occurred at intersections. In order to achieve numerical results of the reduction in crashes from the stop-controlled intersection to the roundabout junction for cost and benefit analysis an Empirical Bayes (EB) before-after approach is recommended, which is described in the NCHRP Report 572 entitled "Roundabouts in the United States" [12]. The Empirical Bayes before-after approach predicts the number of accidents had the road modification not taken place and compares this with the actual number of accidents with the road modification. The predicted safety of the road without modification is based on two factors:

- "accident history of that entity, and
- what is known about the safety of other entities with similar traits"

Employing this approach "accounts for the regression-to-mean while normalizing," gives a more precise estimate, accounts for differences in traffic volumes, and allows estimation for the entire time series [12, 51].

In the NCHRP Report 572 [12] this approach was applied to roundabouts and intersections in the United States in order to estimate the safety benefits of installing roundabouts. In the report safety performance functions (SPF) were developed for various intersections types and roundabouts calibrated by junctions with similar characteristics and traffic volumes. In order to develop a SPF for an intersection type at least 10 intersections with at least 60 crashes is required for an accurate model. The following attributes are taken into account for each SPF [12]:

- Traffic volumes
- Type of control before
- Crash history
- Number of legs
- Single lane or multiple lane design
- Setting (urban versus rural)

The traffic volumes calculated in Chapter 2 and the appropriate SPF for each intersection was used to predict the number of crashes for the South Lamar Blvd and MS Highway 6 interchange had the roundabouts not been constructed. Since roundabouts are a form of intersection improvement the focus of the crash study area is reduced to crashes occurring at intersections within the study area. The following NCHRP Report 572 procedures were used in this study to predict the number of crashes and injury crashes in the study area [12, 32]:

Step 1: Assembling the data

The following data was collected for each intersection in order to apply to correct SPF and calculate the predicted number of crashes.

- Setting (urban versus rural)
- Previous control
- Number of legs
- Years of observed crash data = *n*
- Total number of crashes = x_c
- Total number of injury crashes = x_i
- Average total entering AADT during years of observed crash data = $\text{AADT}_{\text{before}}$
- Average total entering AADT for the year of calculation = $\text{AADT}_{\text{after}}$

Step 2: Applying the correct base safety performance function

The SPF is found for each intersection based on the intersection's setting, previous control, and number of legs.

Step 3: Calculating the predicted annual number of crashes by severity

Using the SPF for each intersection type and the AADT for the years of observed crashes calculate 'P' for both total crashes and injury crashes, where P is the prediction of annual number of crashes using for intersection with similar characteristics. Next weights estimated from the mean, w_1, and variance, w_2, from the regression analysis are calculated for both total crashes and injury crashes using P, k, and *n*. The variables k and *n* represent the dispersion parameters estimated for each SPF and the number of years the crashes account for, respectively. Then the predicted annual number of crashes, *m*, is calculated for the total number of crashes and injury crashes using the weights, *w*, the total number of crashes observed, *x*, and P. The following is the calculations for the predicted number or crashes in the year in question, *m,* and *w,* respectively.

- $m = w_1x + w_2P$
  - w_1 = weights estimated from the mean of the regression model
    - $$w_1 = \frac{P}{\frac{1}{k} + nP}$$
  - w_2 = weights estimated from the variance of the regression model

- $w_2 = \dfrac{\frac{1}{k}}{\frac{1}{k} + nP}$

  - x = crash count in the n years before the conversion
  - P = prediction of annual crashes using SPF for intersections with similar characteristics

Step 5: Adjusting for change in AADT

Since AADT does have an effect on the number of crashes that occur within an intersection an adjustment for the change in AADT must be made. This is multiplied times *m* calculated in the previous step to find the final predicted number of crashes. The adjustment for AADT is calculated using the following calculation:

- $\dfrac{(AADT_{after})^{0.220}}{(AADT_{before})^{0.220}}$

The previous steps were applied to the South Lamar Blvd and MS Highway 6 interchange using the follow factors and SPF [32]:

- Setting = Rural
- Number of legs = 4
- Control Before = signalized
- Years of observed data = 3 = n
- Total Crashes observed = 22 = x_c
- Injury Crashes observed = 8 = x_i
- Average total entering AADT over the years observed = 16,730
- Current AADT = 16,333
- SPF = $\begin{matrix} acc/yr = e^{-12.972}(AADT)^{1.465}, k = 0.50 \\ Inj/yr = e^{-15.032}(AADT)^{1.493}, k = 1.67 \end{matrix}$

Table 26 displays the results of the EB model used for the North roundabout. These results show that overall crashes were reduced by 37.5%, while crashes resulting in injury were reduced by 60%. This EB analysis could not be applied to the 6-legged South roundabout because there is no SPF model that exists for roundabouts with more than 5 legs [32].

Table 26. Crash reduction from Empirical Bayes model for North roundabout

Comparison of Before - After Crash Results			
Junction Control Type	Stop - Controlled	Roundabout	Percent Change
Total Number of Crashes	8	5	37.5%
Number of Injury Crashes	5	2	60%

It is also recommended that the south roundabout be used as part of a future study to create a SPF model for 6 legged roundabouts since currently there is no model that exists for roundabouts with more than 5 legs. Also the EB safety performance models developed for rural areas that have converted stop-controlled intersections to roundabout junctions are very limited and have a minimal amount of available sources and are therefore very site specific. A continuation of studies in rural areas with similar traits for the purpose of expanding the SPF models should be conducted.

4.3.5 Crash-related Cost and Benefit Analysis

The comprehensive costs are the total cost of a crash including the cost of property damage, pain and suffering from injuries and fatalities. In 2003 the annual comprehensive cost from crashes occurring at intersection areas was a total of $97 billion US dollars, which accounted for 32.33% of the total estimated comprehensive cost from crashes [19]. Crashes that occurred at stop-controlled intersections (signalized and stop sign) accounted for 71% of the annual comprehensive cost of crashes that occurred at intersections. Because there has not been a recorded crash resulting in a fatality at the interchange of MS Highway 6 and South Lamar Blvd in the past 6 years the comprehensive costs from fatalities are disregarded for the purpose of this cost analysis. The comprehensive costs from injury crashes are based on injury levels measured by the Maximum Abbreviated Injury Scale (MAIS) of injury severity rating [19]. The MAIS injury levels range from 0 – 5, with 0 being uninjured and 5 being injuries resulting in extended hospital stay. Due to limited sources the level of injury for each injury crash was not known, therefore the national distribution of injury crashes occurring at intersections by MAIS injury type was used (Figure 60). This distribution is based on an average over three years, 2001 to 2003, from nationwide crashes resulting in injuries in the crashworthiness data system (CDS). The percentages are only from crashes that result in injury; property damage only (PDO) crashes are not included. The percentage of MAIS-0 is from secondary occupants that were not injured [19].

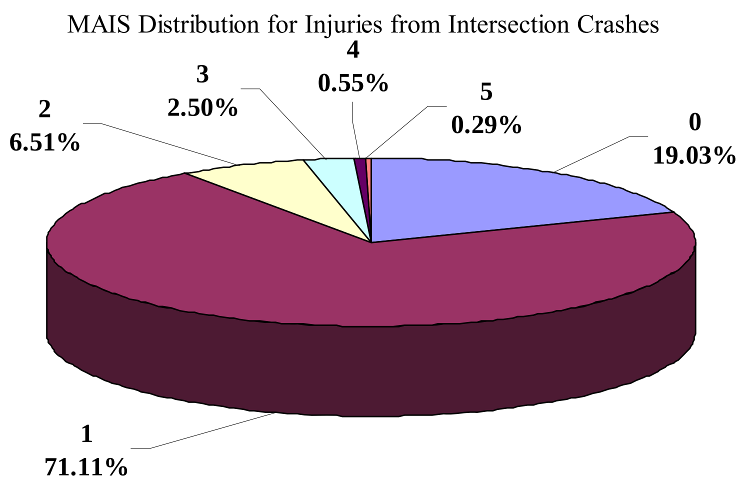


Figure 60. Distribution of injury crashes at intersection by injury type [19]

In order to calculate the comprehensive cost for each intersection type the total number of crashes minus the crashes that resulted in injury was multiplied by the PDO cost, and the crashes that resulted in injury were distributed by injury type then multiplied by the corresponding unit cost for each injury type. The unit costs for PDO vehicles and injury type and fatal crashes can be seen in Table 27. The conversion of a stop-controlled intersection to a roundabout junction results in an annual savings (a user benefit) of $86,008.33 U.S. dollar ($158,219.71 – $72,211.38). This amounts to 54.4% reduction in annual crash related cost. This cost reduction only takes into account the savings from crash and injury reduction for one roundabout. There is also a large benefit from a reduction in maintenance related to signs and traffic signals.

Table 27. Comprehensive unit costs of crash injury and fatality used in the study

Category	Unit Cost
PDO Vehicle	$2,532
MAIS - 0	$1,962
MAIS -1	$15,017
MAIS - 2	$157,985
MAIS - 3	$314,204
MAIS - 4	$731,580
MAIS - 5	$2,402,997
Fatalities	$3,366,388

4.4 Public Opinion Survey Results

4.4.1 Literature Review

One problem that arises in making decisions about roundabout implementation is the general public's unfamiliarity of roundabouts. This is especially true for the southeastern region of the United States where only 10% of the roundabouts are located. In order to evaluate people's perception of the roundabouts a survey questionnaire is recommended. The questionnaire is designed to assess the public's perception, knowledge, and familiarity with roundabouts, specifically in reference to the roundabouts constructed on South Lamar Blvd. The public opinion survey questionnaire form is based on previously conducted opinion surveys of roundabouts [40]. In 2002 a report examining the public opinion of three modern roundabouts was published [40]. This report examined the percent of people that had previously driven on roundabouts before the construction of the roundabout in their area, drivers opinion of roundabouts before and after the roundabout construction, as well as examined the overall effectiveness of the roundabouts at reducing traffic delay, and increasing flow. The opinion surveys were conducted by telephone and on-site in three states (Kansas, Maryland, and Nevada). From these surveys it was found that before the construction of the roundabouts 55% of drivers opposed the conversion of the intersection to a roundabout junction. After the construction of the roundabouts the percentage of drivers that opposed the roundabouts decreased from 55% to 28%, and the percentage of drivers in favor of the roundabouts increased from 31% to 63%. It was also found that the roundabouts decreased delay up to 57% and increased traffic flow up to 42% [40].

Though these surveys served as a guide for the survey questions regarding the South Lamar Blvd roundabouts, the results of these published surveys are not recommended to be compared with the results from the South Lamar Blvd survey conducted in this study. This is because the roundabouts constructed in these three communities were mainly constructed for the purpose of convenience. Unlike the South Lamar Blvd roundabouts, the traffic volumes traveling the interchanges in the reviewed study were moderately low and the intersections probably would have functioned sufficiently without the intersection conversion to roundabout.

4.4.2 Survey Questionnaire Form for Oxford Study

A roundabout performance evaluation survey questionnaire form for the South Lamar Blvd roundabouts was developed for this study [32] in cooperation with the MDOT project oversight committee. The survey form was approved by the University of Mississippi – Office of Research and Sponsored Program's Division of Research Integrity and Compliance – Institutional Review Board (IRB) as this survey involved human subjects. The following explanation block was provided on the survey form and briefly explained verbally to the surveyed individuals.

Information on the Survey Study

Investigator: Dr. Waheed Uddin, Professor of Civil Engineering, University of Mississippi
Voice 662-915-5363 cvuddin@olemiss.edu

Study Sponsor: Mississippi Department of Transportation (MDOT) / University of Mississippi – CAIT

Purpose of Survey: The survey is in response to the study sponsor's desire for learning overall public perception about the traffic flow performance of roundabouts which were constructed in place of traditional stop-controlled intersections at the described location. Statistical summary of the survey results will be provided to the sponsors and the final report, published after MDOT approval, will be available through MDOT.

(Note: The results of technical data analysis, computer modeling and simulation, and statistical analysis of roundabout traffic data vs pre-roundabout conditions show: improved performance with respect to queue length, reduced overall travel time through the interchange, reduced crashes and better road safety in the study area, and improved air quality.)

Conduct of Survey: This is an anonymous public opinion survey where no names, personal data, or physical contact info are asked. The survey should be completed within 5 minutes and the info on gender and age is solely for the purpose of identifying the mix of drivers in the study area. There is no payment and any material benefit for helping us in this study. We are seeking volunteer participation to learn public opinion so that we can inform MDOT about public perception concerning roundabout applications as road junctions.

Dr. Uddin can be reached by e-mail to answer any queries. We thank you for your time and feedback.

The survey form is displayed in Figure 61 in its final version.

- The first two questions in the questionnaire are designed to observe the subject's former and current familiarity with the interchange in question.
- Questions 3-7 are questions regarding the public's opinion of the South Lamar Blvd interchange's effectives before and after construction, general opinion of roundabouts before and after the construction of the roundabouts on South Lamar Blvd, and public view on the construction of future roundabouts as a traffic solution in Oxford.
- Question 8 addresses the driver's previous experience with roundabouts.
- The last questions, 9-11, are personal information about the person responding to the survey which may be taken into account if it is found that a particular group of people have a weighted opinion.
- Question 12 field is for comments by subjects.

The University of Mississippi
Center for Advanced Infrastructure Technology
Mississippi DOT State Study 213

South Lamar Roundabout Performance Evaluation (at South Lamar/MS Highway 6 Interchange, Oxford)

Survey Questionnaire

1. About how many times did you drive through the South Lamar/ Highway 6 intersection prior to construction of roundabouts? 1 – 4 times (circle only <u>one</u>):
   a. Month or year   b. Week   c. Day   d. Never
2. About how many times do you currently drive through the South Lamar/ Highway 6 roundabouts? 1 – 4 times (circle only <u>one</u>):
   a. Month or year   b. Week   c. Day   d. Never

<u>On a scale 1 – 5 (as defined below) rate the following questions 3 – 7:</u>

5	4	3	2	1
most favorable (most agree)	**somewhat favorable** (somewhat agree)	**Neutral** (no opinion)	**less favorable** (somewhat disagree)	**not favorable** (disagree)

3. Did you think the South Lamar/ Highway 6 intersection needed improvement prior to the construction of the roundabouts? (circle only <u>one</u>)
   5   4   3   2   1
4. Before the construction of the South Lamar Roundabouts, did you have a more or less favorable view of roundabouts? (circle only <u>one</u>)
   5   4   3   2   1
5. Do you think the roundabouts have been an effective solution to the congestion, delay, and safety problems at this intersection? (circle only <u>one</u>)
   5   4   3   2   1
6. As a result of this project, do you view roundabouts more favorably or less favorably? (circle only <u>one</u>)
   5   4   3   2   1
7. Do you think more roundabouts should be constructed throughout Oxford as a solution to traffic problems at other intersections? (circle only <u>one</u>)
   5   4   3   2   1
8. Which of the following best describes your experience with roundabouts (circle only <u>one</u>):
   a. The S. Lamar / Hwy 6 roundabouts are the first ones I've driven through
   b. I've driven through a few other roundabouts in the southeastern region
   c. I've driven through many other roundabouts throughout the US
   d. I've driven through many other roundabouts in other countries
   e. I've driven through many other roundabouts in the US and other countries
9. Gender (circle only <u>one</u>):
   a. Male   b. Female
10. Age Range (circle only <u>one</u>):
   a. 18 – 30   b. 31 – 65   c. 65+
11. Please circle <u>one</u> that applies to you:
   a. University of Mississippi student   b. University of Mississippi faculty or staff
   c. Other resident of Oxford/ Lafayette County
   d. Resident from Mississippi   e. Non-resident from other state
12. Please provide any additional comments here and continue on back:

Figure 61. Questionnaire survey form for South Lamar Blvd roundabouts

4.4.3 Survey Methodology and Results

The anonymous survey was conducted in early May on site and through telephone contacts. The on-site surveys were conducted in the premises of two gas stations located on the north side of the North roundabout intersection (with permission of property owners). Additionally, telephone and e-mail surveys were conducted by reaching out to the Oxford community. The results of 80 random survey responders were processed. On a scale of 1 (unfavorable/disagree) to 5 (most favorable/most agree), the average results show that all responders agree with Questions 3 – 7. There are multiple aspects of the questionnaire that may affect people's opinion, such as gender and age. About one-third responders were female drivers (Question 9). Answers to Question 10 about driver's age group revealed: (a) 59% younger drivers (less than 30 years age), (b) 37% middle age group (31 to 65 years age), and (c) 4% seniors (more than 65 years age). Figure 62 shows some key results. The survey results show overwhelming approval of the roundabouts and support construction of more roundabouts. Some respondents commented about older drivers who may get confused at roundabouts and recommended to install improved signage including flashing lights and additional pavement markings, especially at the South roundabout.

AVG.			4.1	3.4	4.2	4.1	4.0		F=27 (34.2%)		
Std. Dev.			1.1	1.0	1.1	1.1	1.4		M=52 (65.8%)		
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11

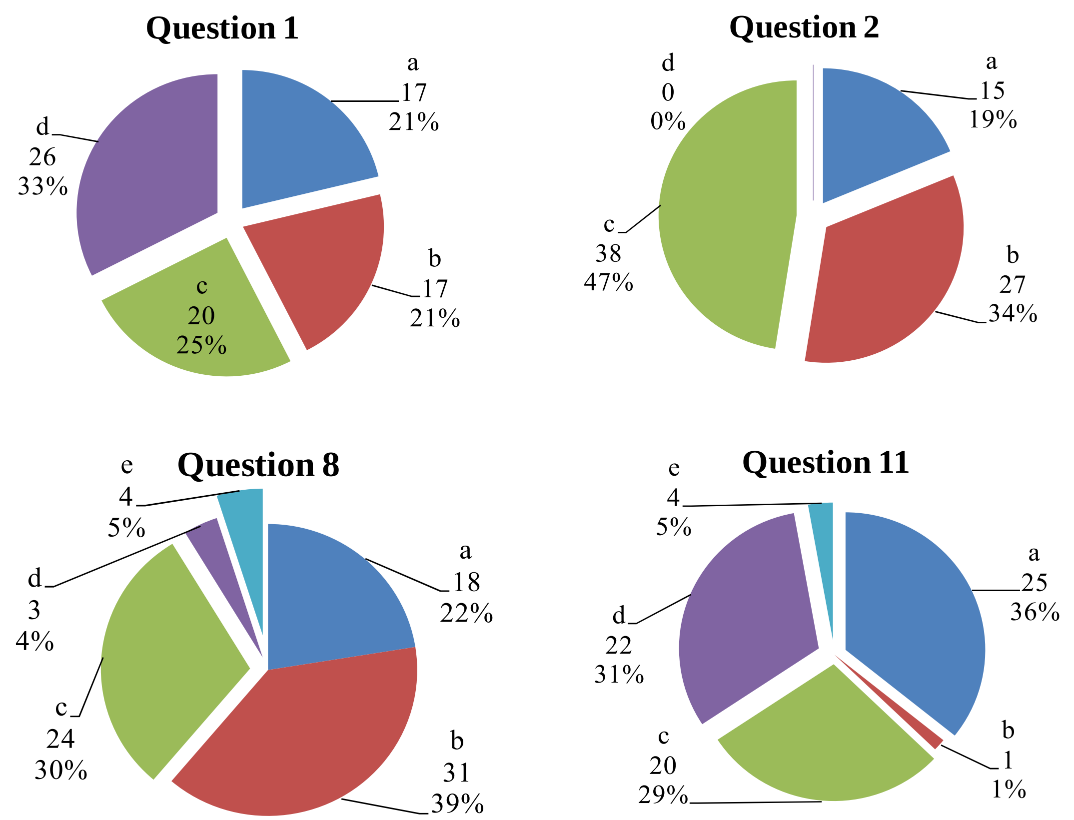


Figure 62. Summary statistics and key results of public opinion survey about South Lamar roundabouts

The following written comments were provided by the survey respondents:

Lives on Lamar and is pleased with traffic flow
Needs improved sign on South Roundabout
Old women do not navigate the roundabout in a timely manner
Confusing for older generation and a hazard to the EMS personnel, fire, and police
Roundabouts = Awesome
Nice Survey
Put roundabouts on Taylor Road. Widen Highway 7.
Roundabouts are excellent traffic flow and control devices and can easily have 6 entrances and two lanes of traffic
Like Oxford a lot, keep going good like it is
Like larger Roundabouts on Old Agency Exit I-55 Ridgeland, MS
Bigger roundabouts in Florida; Florida has wider and larger roundabouts

The public opinion survey shows good public perception of the roundabouts on the South Lamar Blvd and MS Highway 6 interchange and clear support to build more roundabouts. It is recommended that MDOT may wish to follow some of the recommendations provided by the public to improve navigation of traffic through the roundabout especially older drivers.

4.5 Summary for South Lamar Roundabouts and Recommendations

4.5.1 Summary of Performance Evaluation and Benefit/Cost Results

From the detailed performance evaluation of the roundabouts it can be seen that roundabouts are a beneficial interchange alternative to a stop-controlled intersection. Table 28 shows a summary of the roundabout performance evaluation and benefit/cost results comparing the previous stop-controlled intersection with the roundabout junction. It can be seen that as a result of the construction of the roundabouts there is shorter delays, controlled speeds, reduction in queue times, improved traffic safety, reduction in vehicle emission, less air pollution, and crash cost savings. The additional benefits also include a reduction in annual maintenance, calmer traffic, and an aesthetically pleasing junction. Key results supporting better performance of roundabouts for 2016 peak hour traffic demand volume projected from 2009 traffic counts include:

- 66.7% increase in mean speed; improved LOS
- 23.9% less delay; 76.9% less idling time; 56.1% less fuel wastage
- 77.1% reduced overall vehicle emissions (80.3% less VOC, 76.9% less CO, 76.9% less NO_x, 76.9% less PM_{10}, 56.1% less CO_2)
- 37.5% reduction in total crashes; 60.0% reduction in injury-related crashes (fatal crashes are unlikely due to slow speed)
- Significant benefits in terms of annual savings
    - $391,186 annual saving to road users (due to 56.1% less wastage of fuel)
    - $328,824 annual saving of user travel time (due to higher speed and less delay)
    - $86,008 annual saving from crash reduction (54.4% less comprehensive cost)
- $806,018 total annual total benefit (from the above savings)
- The roundabouts paid all costs within 2 years (roundabouts built at a total cost of $1,165,095 including $95,000 design cost); cost data courtesy of Bob Mabry, MDOT Roadway Design Division

- 6.2 Benefit/Cost (B/C) ratio (over 9 years from 2007 to 2016; considering 0% discount rate and ignoring inflation)
  B/C may slightly reduce to 6.1 if $100,000 is required to improve signage and pavement marking and considering routine maintenance cost.
- Additional cost avoidance and societal benefits include: less annual maintenance cost for signals, improvement in air quality and significant reductions in emissions (56% in CO_2 and 77-80% in other vehicle emissions), and reduced public health costs.

Table 28. Summary of performance evaluation of roundabouts of South Lamar Blvd

(a) Reduction in vehicle emissions and crashes

Performance Comparison Summary	Total CO_2 Emission kg/hour	Total VOC Emission kg/hour	Total CO Emission kg/hour	Total NO_x Emission kg/hour	Total PM_{10} Emission g/hour	Total Emission kg/hour	Total Crash Cost	Total Crashes	Injury Crashes
Stop-controlled	7,232	38.8	582	9.9	81	**Reduced**	$158,220	8	5
Roundabout	3,172	7.7	134	2.3	19		$72,211	5	2
Improvement by Roundabout	-4,060	-31	-447	-8	-63	-486	-$86,008	-3	-3
	-56.1%	-80.3%	-76.9%	-76.9%	-76.9%	-77.1%	-54.4%	-37.5%	-60.0%
Savings	less CO_2	less VOC	less CO	less NO_x	less PM_{10}	less	saving	less	less injury

(b) Summary of user benefits and costs

Note: Average speed and average delay are based on the worst scenario (microsimulation Run 2) and average idle time is an average of all three microsimulation runs.

Performance Comparison Summary	Average Speed, mph	Average Delay s/veh	Average Idle Time, min.	Gas per Car, Gallons	Diesel per Truck, Gallons	Total Crash Cost
Stop-controlled	9	46	13	0.105	0.362	$158,220
Roundabout	15	35	3	0.046	0.159	$72,211
Improvement by Roundabout	6	-11	-10	-0.059113	-0.20339	-$86,008
	66.7%	-23.9%	-76.9%	-56.1%	-56.1%	-54.4%
Savings	more speed	less delay	less idle	less vehicle fuel		saving
Benefits/Savings	*$6,324*			*$7,523*		
for Peak Hour Flow	less time (average volume)			less fuel (total volume)		
(assume one day per week)	$16.00			$3.50	$4.00	
	per hour			per gallon	per gallon	
Annual User Savings	*$328,824*			*$391,186*		
Annual Benefits	*$720,010*	(no crash cost)		*$806,018*	(with crash cost saving)	
Cost of roundabout construction=		$1,165,095		(including Design $95,000)		

Lastly, roundabouts do not require electricity to run, therefore they eliminate need for electric power and reduce maintenance costs for the city. This means the roundabout will continue to function properly with power outages as well. While the advantages of roundabouts greatly outweigh the disadvantages, a couple of disadvantages include: improper uses of the roundabouts and collisions causing a damper to the traffic flow of the whole roundabout; and sometime roundabouts taking up more space than normal interchanges.

4.5.2 Recommendations

Since roundabouts are still being incorporated into society they are unfamiliar to a majority of the public, especially in Mississippi. People tend to steer away from an unfamiliar situation, therefore negative public opinion and opposition of roundabout construction has often led some transportation entities to choose other alternatives. The lack of knowledge of and unfamiliarity with roundabouts and their functionalities can have negative effects on the efficiency of roundabouts. During Fall 2009 semester, junior students of CE481-Transportation Engineering I at the University of Mississippi were assigned group term projects to collect traffic data manually on each roundabout, analyze travel demand by movement, and suggest any needed improvements in the field to improve traffic flow. The public opinion survey shows good public perception of the roundabouts on the South Blvd and MS Highway 6 interchange. The roundabouts are well performing well as intended in the design and construction phase, and no major changes are recommended. The following recommendations to enhance traffic flow and safety through the South Lamar Blvd roundabouts are based on the results of this performance evaluation study, public opinion survey, and students' research and term project reports:

1. Install improved signage and pavement markings, especially at the South roundabout to improve navigation of traffic through the roundabout especially for older drivers.
    - For example placing low mounted one way directional signs in the island (facing each approach lane) and flashing light on yield signs for circulating traffic can help the driver to know the yield-at-entry-rule (the most important characteristic of a roundabout). This rule means that entering traffic must yield the right-of-way to the circulating traffic already in the circle.
    - Also, additional signs and marking will help the traffic on eastbound Highway 6 of ramp going to frontage road.
    - The bold pavement marking and solar powered flashing light on speed/stop signs would benefit all of the drivers by letting them know what lane they need to be in and where it will take them. Problems involving driver fatigue, impairment and sensory overload could also be partially alleviated with the introduction of the reflective directional arrows on the road.
2. Add rumble strips leading into the junction will help to lower speed and raise awareness. With this safety device in place it would greatly lower the risk of having traffic incidents within the roundabout that would cause major delays for all entering/approaching roads.
3. Monitor traffic volume demand and driving patterns to evaluate any negative impacts on LOS.
4. Consider adding a right-side bypass lane in future (5-6 years from 2010) for traffic flow entering from South Lamar Blvd to the North roundabout for merging onto the MS Highway 6 westbound on ramp.
5. Work with the Department of Public Safety, driving schools, and high schools to implement awareness of roundabouts and roundabout use as part of driver's education courses.
6. Construct more roundabouts in Oxford, the state and nationally as an intersection improvement alternative. The more common roundabouts become in communities, the more familiar they will become to the public.

7. Conduct a future study using the South roundabout to create a SPF model for 6-legged roundabouts since currently there is no model that exists for roundabouts with more than 5 legs. Also the EB safety performance models developed for rural areas that have converted stop-controlled intersections to roundabout junctions are very limited and have a minimal amount of available sources and are therefore very site specific. A continuation of studies in rural areas with similar traits for the purpose of expanding the SPF models can be persuaded as a joint pool fund study in cooperation with other neighboring states.

4.6 Roundabout Application to Future Site

The Old Taylor Road and MS Highway 6 interchange in Oxford is currently experiencing the same concerns that the South Lamar Blvd interchange faced in 2006. Though Old Taylor Road currently experiences lower traffic volumes than South Lamar Blvd, the intersection experiences long delay times and low safety levels. In order to analyze the effectiveness of replacing the current two-way stop-controlled intersections with roundabout junction a safety and cost analysis is performed. Figure 63 displays the 0.25 km (0.16 mile) radius around the study area created using GeoMedia Pro.

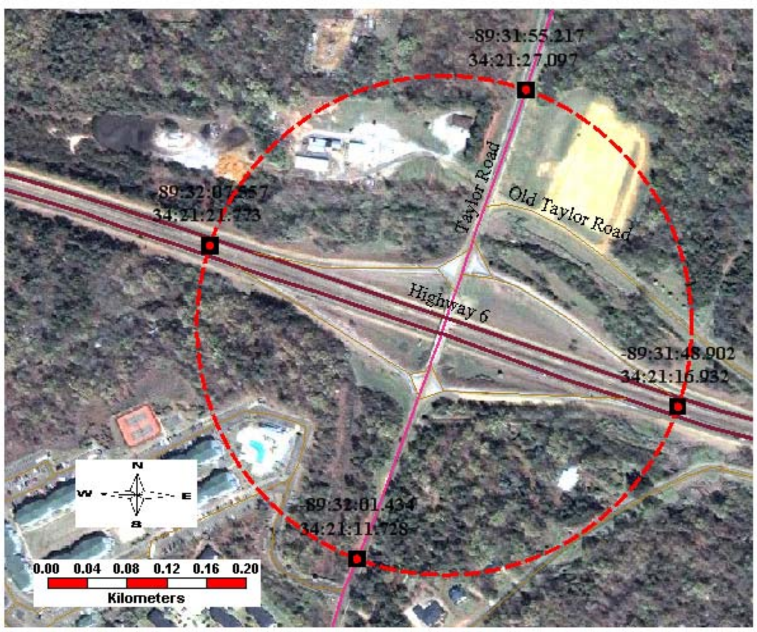


Figure 63. Old Taylor Road study site for crash data, Oxford, MS

The design and construction of roundabouts to replace the two-way stop intersections are being considered at Old Taylor Road interchange with MS Highway 6. In order to analyze the safety and cost/benefit of a roundabout to replace the existing intersection at Old Taylor Road similar procedures were followed as those described in section 4.3. Thus, the total number of crashes and injury crashes must be predicted for both the construction of a roundabout and for the current stop-controlled design. The procedures for predicting the crashes with the roundabout and the two-way stop sign intersection follow the same EB procedures using the corresponding SPF as used for South Lamar Blvd roundabouts [12, 51]. The analysis covered crashes for one side of the MS Highway 6 and Old Taylor interchange over a 4 year period from 2006-2009. The

AADT values were obtained from the MDOT website for 2006 - 2008 and estimated for 2011 using a 2% yearly growth rate, as this was the observed yearly growth rate over a three year period for the road.

Factors:

- Setting = Rural
- Number of legs = 4
- Control Before = two-way stop
- Years of observed data = 4
- Total Crashes observed = 59
- Injury Crashes observed = 7
- Average total entering AADT over the years observed = 18,000
- Current AADT = 19,102
- SPF roundabout = $\begin{array}{l} acc/yr = 0.0023(AADT)^{0.7490}, k = 0.89686 \\ Inj/yr = 0.0013(AADT)^{0.5923}, k = 0.9459 \end{array}$
- SPF two-way stop = $\begin{array}{l} acc/yr = e^{-8.6267}(AADT)^{0.952}, k = 0.77 \\ Inj/yr = e^{-8.733}(AADT)^{0.795}, k = 1.25 \end{array}$

Table 29 displays the predicted results from the above analysis. The results show that the construction of a roundabout to replace one of the two-way stop-controlled intersections on Old Taylor Road has the possibility of increasing overall crashes by 8%, but may decrease crashes resulting in injury by 23%. Therefore, though the overall crashes may increase they will not be as severe. Using these crash values an estimated cost savings analysis was completed. Even with an 8% increase in crashes from the stop-controlled intersection to the roundabout junction, the decrease in injury crashes results in a comprehensive saving (benefit) of $32,025.84 US dollars per year if the intersection is changed to a roundabout (Table 30). Moreover maintenance cost of a roundabout is very small compared to the maintenance of a signalized intersection.

Table 29. Crash reduction from Empirical Bayes model for Old Taylor Road future site study

Comparison of Before - After Crash Results			
Control Type	**Stop - Contolled**	**Roundabout**	**Percent Change**
Number of Crashes	13.15	14.16	-8%
Injury Crashes	4.94	3.78	23%

Table 30. Comprehensive cost analysis of crash and injury reduction for Old Taylor Road future site study

Category	**Per**	**Unit Cost**	**Percentage**	**Cost Stop-Controlled Intersection**	**Cost Roundabout**
No Injury	**PDO Vehicle**	$2,532.00	100.00%	$20,803.99	$26,293.19
Injury Type	**MAIS - 0**	$1,962.00	20.00%	$1,937.69	$1,482.04
	MAIS - 1	$15,017.00	72.00%	$53,391.37	$40,836.41
	MAIS - 2	$157,958.00	5.50%	$42,900.23	$32,812.26
	MAIS - 3	$314,204.00	1.70%	$26,376.43	$20,174.02
	MAIS - 4	$731,580.00	0.31%	$11,198.99	$8,565.55
	MAIS - 5	$2,402,997.00	0.20%	$23,732.23	$18,151.61
Total	***Injury***	*$3,623,718.00*	*100%*	*$180,340.93*	*$148,315.09*

5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The primary objective of the state study (SS), SS 213, sponsored by the Mississippi Department of Transportation, was to evaluate the performance of two roundabouts at the junction of MS Highway 6 and South Lamar Blvd in Oxford, Mississippi. The study reviewed and analyzed pre- and post-roundabout traffic flow, capacity and level of service, and crash data. The performance evaluation results indicate that the roundabouts are performing better than the stop-controlled intersections.

5.1 Summary

Oxford, Mississippi was used as a case study for analyzing intersection alternatives. Oxford is a rural city in Mississippi and is home to The University of Mississippi's main campus. The two intersections in Oxford were experiencing low levels of service, congestion, and extreme delays. With the continuing increase in commercial and residential development, the intersections would not be able to accommodate the increasing traffic demand. The roundabouts were constructed to provide a safe and economical solution to the interchange's capacity limitations.

A road infrastructure database was created for the city of Oxford from remote sensing and geospatial technologies using GeoMedia Pro. The road vector maps were created from 1-m IKONOS satellite imagery acquired on March 27, 2000. Since the date of imagery acquisition, new roads and road improvements had been made within the city. A shapefile of Lafayette county road network was used in order to accommodate for the road network changes in Oxford from 2000 – 2009. However, it did not include the roundabout planimetrics.

Currently no GIS sources are available to account for the construction of the roundabouts on South Lamar Blvd; therefore, original project design plans of the two roundabouts were georeferenced into GeoMedia Pro and used to create spatial maps of the new site of roundabouts. These vector maps were also used for traffic microsimulation studies. Thematic spatial maps of Oxford's AADT were created for the years of 1998-2008 using GeoMedia Pro. These maps were created from automated traffic counts posted on a web site by the MDOT. The traffic counts are counted over a 48 hour period and adjusted using factors in order to achieve the AADT of the road. The traffic volumes for each segment of road are collected every three years.

On-site manual traffic data was collected at both roundabouts for the South Lamar Blvd and MS Highway 6 interchange in mid-October, 2009. The on-site traffic counts were compared with the 2009 predicted traffic volume demand in a consultant's report prepared in 2006 for the MDOT. The 2009 on-site traffic counts were used to calculate daily traffic volumes of the interchange. The traffic data from the on-site counts was also used in traffic flow microsimulation to conduct a performance analysis of junction alternatives.

Traffic flow microsimulation was completed in S-Paramics using the on-site traffic counts. Traffic flow microsimulation software analyzes traffic flow behavior within a particular transportation system over a given time period by evaluating the actions of every vehicle in the road network at a sub-second time interval. The results from the traffic flow simulation were used to compare the roundabout junctions to the previous stop-controlled intersections on South Lamar Blvd.

A performance analysis of roadway junction alternatives for the South Lamar Blvd and MS Highway 6 interchange was conducted using the results from microsimulation. Capacity, delay, level of service, speed, queuing lengths, and queuing times obtained from microsimulation results were used to compare the two interchange alternatives at South Lamar Blvd and MS Highway 6. A vehicle emission analysis was completed for both junction alternatives using average vehicle idling times and speeds obtained from microsimulation results.

A t-test for statistical significance analysis was completed to compare the total number of crashes within the study area and the total number of crashes at intersections within the study area for the stop-controlled intersections compared to the roundabout junctions at the South Lamar Blvd and MS Highway 6 interchange. An Empirical Bayes approach was used to predict the number of crashes and injury crashes at the north end of the South Lamar Blvd and MS Highway 6 interchange that would have occurred in 2009 if the interchange had remained a signalized intersection. The results from the Empirical Bayes analysis was compared with the actual number of crashes and injury crashes that occurred at the roundabout interchange in 2009. The number of crashes and injury crashes were used to perform a crash cost analysis for both types of junction alternatives.

A public opinion survey was conducted for the South Lamar Blvd roundabouts in order to complete the performance analysis of the roundabouts. The public opinion survey addressed people's opinion of roundabouts, specifically the roundabouts on South Lamar Blvd, as well as the public's experience and knowledge of roundabouts. Finally, a benefit/cost analysis was performed where benefits were calculated from user savings of travel time, decrease in vehicle fuel wastage, and crash cost reduction. A cost analysis from crashes and injury crashes was applied to a future site study where a roundabout is planned to replace an intersection.

5.2 Conclusions

- Using remote sensing and geospatial technologies in order to create road and landuse vector maps is an easy and effective way of acquiring infrastructure databases.
- Thematic maps are a beneficial way of visualizing the built environment and spatial distribution of daily traffic volumes. Thematic maps were created using on-site AADT from the MDOT maps.
- By analyzing the MDOT data of AADT over a ten year period from 1998-2008 in Oxford, Mississippi, it was observed that:
  - 5 segments of major roads and highway have had an annual growth of AADT in the negative range of (-5 to -15%);
  - 8 segments of major roads and highway have had an annual growth of AADT in the range of 0 to 1.7%;
  - 11 segments of major roads and highway have had an annual growth of AADT in the range of 2 to 4%;
  - 13 segments of major roads and highway have had an annual growth of AADT in the range of 6 to 10%; and
  - 2 segments of major roads and highway have had an annual growth of AADT in the range of 11 to 23%.

- An annual growth 2.5% was estimated for the South Lamar Blvd study site using 2004 base year and used to predict 2016 traffic volume for capacity analysis and microsimulation studies.
- From on-site manual traffic counts completed in Oxford, Mississippi for the MS Highway 6 interchange with South Lamar Blvd the following attributes of the intersection were calculated:
  - PHF range from 0.88 – 0.98 for the North Roundabout, with Saturday having the highest PHF of 0.98
  - PHF range from 0.78 – 0.94 for the South Roundabout, with Monday having the highest PHF of 0.94
  - North roundabout traffic counts: peak hour 2,853; daily 31,700; Friday
  - South roundabout traffic counts: peak hour 3,349; daily 33,490; Thursday
- Traffic flow microsimulation of the South Lamar Blvd and MS Highway 6 junction was conducted to compare pre and post roundabout conditions. It was found that the conversion of the intersections to roundabouts improved traffic flow by:
  - Reducing delay by 24%
  - Reducing idling time by 77%
  - Reducing fuel wastage by 56%
  - Increasing average speed by 67% and improving LOS
- Roundabouts are able to manage the average speed of traffic traveling through the interchange better than a signalized or unsignalized stop-controlled intersection.
- Overall vehicle emissions from idling are reduced by 77% when the two stop-controlled intersections were converted to roundabout junctions. Thus air quality is improved by:
  - Reducing VOC by 80%
  - Reducing CO by 77%
  - Reducing NO_x by 77%
  - Reducing PM_{10} by 77%
  - Reducing CO_2 by 56%
- Statistical evidence was found that the change of a one signalized intersection to a four leg (noncircular) roundabout and one four-way stop and two two-way stop intersections to a six leg roundabout intersection reduces overall crashes in the interchange area, and crashes that occur at intersections.
- The Empirical Bayes base safety performance model described in the NCHRP report 572 for before-after analysis of modern roundabouts was used to predict the number of crashes in 2009 if the intersection of South Lamar Blvd and MS Highway 6 westbound was still a signalized intersection. The results of the predicted number of crashes were compared to the actual number of crashes in 2009 that occurred at the North roundabout. This approach takes into account changes in AADT. The results for the conversion of the MS Highway 6 westbound and South Lamar Blvd junction from a signalized intersection to a four leg roundabout showed the junction improved performance through:
  - a reduction in crashes by 37.5%
  - a reduction in crashes resulting in injury by 60%
- The results show 54.4% reduction in crashes and crashes resulting in injury (due to higher speed and less delay time) and an annual comprehensive cost saving of $86,008 U.S. dollars.

- The user cost saving from travel time reduction is $328,824 annually and from reduction in fuel wastage is $391,186 annually (due to less idling time).
- Total user cost saving and crash cost reduction combined is $806,018 annually.
- B/C ratio is 6.2 over 9 years from 2009 to 2016 considering 0% discount rate and ignoring inflation. Additionally, significant societal benefits are expected from reductions in vehicle emissions.
- The result of an anonymous public opinion survey confirms good public perception of the roundabouts and provides support to build future roundabouts. Some constructive suggestions provided by the public can be implemented by MDOT to enhance traffic flow and safety.
- The roundabouts at the interchange of South Lamar Blvd and MS Highway 6 are performing well as intended. The roundabout proved to be a beneficial junction alternative by increasing traffic flow, improving capacity of the intersection, decreasing delay, reducing number of crashes and number of injury crashes, and significantly reducing vehicle emissions.
- Old Taylor Road is under consideration as a future site for roundabout construction. The Empirical Bayes approach and cost analysis used for South Lamar Blvd was applied to this site. The number of crashes and injury crashes for 2011 was predicted for the current stop-controlled intersections and a roundabout junction.

5.3 Recommendations

- Install additional signs and markings where needed to enhance traffic flow and help unfamiliar and older drivers, such as: low-mounted reflective one directional arrow signs on the island (facing each approach lane), solar powered flashing lights on yield signs to circulating vehicles and speed/stop signs, rumble strips on approach lanes where drivers may tend to speed, and bold reflective pavement markings on lanes approaching circular lanes.
- Continue to monitor traffic flow and peak hour volume at the South Lamar Blvd and MS Highway 6 interchange and crash data in the study area.
- Develop and apply the Empirical Bayes approach to the South roundabout in order to calculate the change in crashes and crashes resulting in injury.
- Continue to study rural areas that have been converted from a stop-controlled intersection to a roundabout junction in order to expand the range of SPF models
- Create a safety model based upon Empirical Bayes formulation for the all-way stop intersection converted to a 6 or more leg modern roundabout in rural area.
- Continue study of Old Taylor Road intersection with MS Highway 6 in Oxford, MS for possible future site of a roundabout.

6. REFERENCES

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APPENDIX

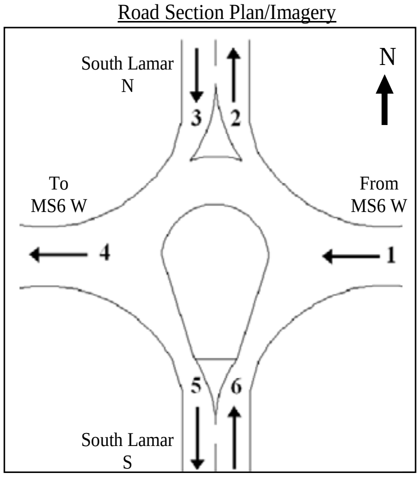
North Roundabout Traffic Data Collection Form Front

THE UNIVERSITY OF MISSISSIPPI
DEPARTMENT OF CIVIL ENGINEERING
CENTER FOR ADVANCED INFRASTRUCTURE TECHNOLOGY (CAIT)
TRAFFIC DATA COLLECTION FROM MANUAL COUNTS

Road Section Information	Section Plan/Imagery Information	Manual Data Collection Information
City: Oxford, Mississippi	Source: Sketch	Data Location: North Roundabout
Road Classification: Major	Date: Sep. 30, 2009	Date Collected:
Road Name: South Lamar Blvd (North Roundabout), North of MS Hwy 6 overpass	Time: N/A	Collected by:
	Entered by: Annie Chapman	Checked by:

Location: North Roundabout   Section Length: 0.06 km   End GPS Coordinates: 89°31'16.21"W, 34°21'17.13"N

Road Section Plan/Imagery



Notes/Remarks

Assigned Movement Number ________ for traffic counts

Assigned by: ______________   Counted by: ________________

Total Number of Trucks =

Total Number of Buses =

Total Number of Motorcycles =

Additional Remarks:

Date of Manual Count __________________________

Time Started ___________AM/PM   Time Completed ____________AM/PM   Total Time Counted _______minutes

Traffic Counts: (Record all vehicle counts for each time interval)

0-15 minutes Movement No. ____S/L/R	15-30 minutes Movement No. ____S/L/R	30-45 minutes Movement No. ____S/L/R	45-60 minutes Movement No. ____S/L/R
1) Total Vehicles Counted:	2) Total Vehicles Counted:	3) Total Vehicles Counted:	4) Total Vehicles Counted:
		Total Vehicles Counted (sum of 1, 2, 3, 4):	

North Roundabout Traffic Data Collection Form Back

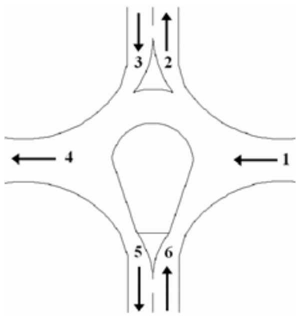
0-15 minutes Movement No. ____S/L/R	15-30 minutes Movement No. ____S/L/R	30-45 minutes Movement No. ____S/L/R	45-60 minutes Movement No. ____S/L/R
1) Total Vehicles Counted:	2) Total Vehicles Counted:	3) Total Vehicles Counted:	4) Total Vehicles Counted:

North Roundabout Table Processed for Friday, October 16, 2009

THE UNIVERSITY OF MISSISSIPPI
DEPARTMENT OF CIVIL ENGINEERING
CENTER FOR ADVANCED INFRASTRUCTURE TECHNOLOGY (CAIT)
TRAFFIC DATA COLLECTION FROM MANUAL COUNTS

Road Section Information	Section Plan/Imagery Information	Manual Data Collection Info.	Computer Data Entry
City: Oxford, Mississippi	Source: Sketch	Data Location: North	Date: 11/16/09
Road Classification: Major	Date: Sep. 30, 2009	Roundabout	By: Mamun
Road Name: South Lamar Blvd (North	Time: N/A	Date Summarized: 10/28/09	
Roundabout), North of MS Hwy 6 overpass	Entered by: Annie Chapman	Summarized by: Annie	

Location: North Roundabout Section Length: 0.06 km End GPS Coordinates: 89°31'16.21"W, 34°21'17.13"N



Field Data Group Leader (s): Annie
Field Staff Names (who recorded vehicle counts): Chamar, Peyton, Cole, Mamun, Brooks

Remarks: none weather: Overcast Other: H#1 not counted, H#6,8,12 < 60m
Date of Manual Count: 10/16/09 Day: Friday
(one summary sheet per day)

Hours of Manual Count: #1 #2 8:00-9:00am
#3 9:00-10:00am #4 10:00-11:00am #5 11:00-12:00pm #6 12:00-1:00pm
#7 1:00-2:00pm #8 2:00-2:30pm #9 3:30-4:00pm #10 4:00-5:00pm
#11 5:00-6:00pm #12 6:00-6:30pm

Type S/L/R	#1 Hour	#2 Hours	#3 Hour	#4 Hour	#5 Hour	#6 Hour	#7 Hour	#8 Hour	#9 Hour	#10 Hour	#11 Hour	#12 Hour	Total Minutes
Minutes		60	60	60	60	30	60	60	30	60	60	30	570
Movement No./type	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Total Counts
1		78	100	109	109	81	174	149	59	174	149	59	1,241
2		180	405	384	496	287	**541**	399	184	541	399	184	4,000
3		147	299	324	389	219	487	400	156	487	400	156	3,464
4		204	350	380	455	243	519	475	143	519	475	143	3,906
5		126	304	281	313	169	323	225	93	323	225	93	2,475
6		294	541	607	730	443	**809**	590	233	809	590	233	5,879
7													0
8													0
9													0
10													0
11													0
12													0
Total Counts	0	1,029	1,999	2,085	2,492	1,442	**2,853**	2,238	868	2,853	2,238	868	20,965
	Hour of	*#7*	*max volume*		*2,853*								

Checked by:		Hours Counted	Total Volume	Cars, etc	Trucks	Buses	Motor-cycles	*Hour of max vol*	*0-15 min*	*15-30 min*	*30-45 min*	*45-60 min*	*PHF*
								2 *541*	150	**150**	113	128	**0.90**
Date:		11	20,965	20,740 98.93%	152 0.73%	41 0.20%	32 0.15%	*6* *809*	**243**	223	175	168	0.83

Hours	#1 Mins	#2 Mins	#3 Mins	#4 Mins	#5 Mins	#6 Mins	#7 Mins	#8 Mins	#9 Mins	#10 Mins	#11 Mins	#12 Mins	Total Vehicles
Trucks		29	28	21	22	14	12	6	2	12	6	0	152
Buses		3	7	7	10	2	4	2	0	4	2	0	41
Motorcycles		6	0	1	0	1	6	2	4	6	2	4	32
Total Car	0	991	1,964	2,056	2,460	1,425	2,831	2,228	862	2,831	2,228	864	20,740

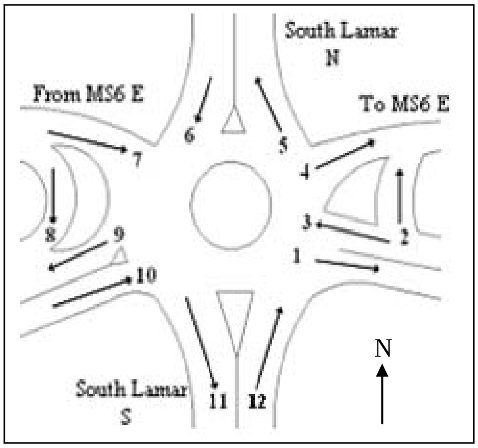
South Roundabout Traffic Data Collection Form Front

THE UNIVERSITY OF MISSISSIPPI
DEPARTMENT OF CIVIL ENGINEERING
CENTER FOR ADVANCED INFRASTRUCTURE TECHNOLOGY (CAIT)
TRAFFIC DATA COLLECTION FROM MANUAL COUNTS

Road Section Information	Section Plan/Imagery Information	Manual Data Collection Information
City: Oxford, Mississippi	Source: Sketch	Data Location: South Roundabout
Road Classification: Major	Date: Sep. 30, 2009	Date Collected:
Road Name: South Lamar Blvd (South Roundabout), South of MS Hwy 6 overpass	Time: N/A	Collected by:
	Entered by: Annie Chapman	Checked by:

Location: South Roundabout   Section Length: 0.06 km   End GPS Coordinates: 89°31'16.45"W, 34°21'13.12"N

Road Section Plan/Imagery



Notes/Remarks

Assigned Movement Number ________ for traffic counts

Assigned by: _________________ Counted by: ________________

Total Number of Trucks =

Total Number of Buses =

Total Number of Motorcycles =

Additional Remarks:

Date of Manual Count __________________________

Time Started ___________AM/PM   Time Completed ____________AM/PM   Time Counted ____________minutes

Traffic Counts: (Record all vehicle counts for each time interval)

0-15 minutes Movement No. ____S/L/R	15-30 minutes Movement No. ____S/L/R	30-45 minutes Movement No. ____S/L/R	45-60 minutes Movement No. ____S/L/R
1) Total Vehicles Counted:	2) Total Vehicles Counted:	3) Total Vehicles Counted:	4) Total Vehicles Counted:
		Total Vehicles Counted (sum of 1, 2, 3, 4):	

South Roundabout Traffic Data Collection Form Back

0-15 minutes Movement No. ____S/L/R	15-30 minutes Movement No. ____S/L/R	30-45 minutes Movement No. ____S/L/R	45-60 minutes Movement No. ____S/L/R
1) Total Vehicles Counted:	2) Total Vehicles Counted:	3) Total Vehicles Counted:	4) Total Vehicles Counted:

South Roundabout Table Processed for Thursday, October 15, 2009

THE UNIVERSITY OF MISSISSIPPI
DEPARTMENT OF CIVIL ENGINEERING
CENTER FOR ADVANCED INFRASTRUCTURE TECHNOLOGY (CAIT)
TRAFFIC DATA COLLECTION FROM MANUAL COUNTS

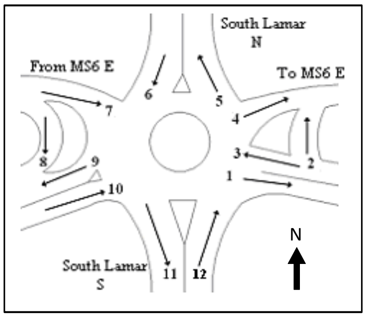
Road Section Information
City: Oxford, Mississippi
Road Classification: Major
Road Name: South Lamar Blvd (North Roundabout), North of MS Hwy 6 overpass

Section Plan/Imagery Information
Source: Sketch
Date: Sep. 30, 2009
Time: N/A
Entered by: Annie Chapman

Manual Data Collection Info.
Data Location: South Roundabout
Date Summarized: 11/13/2009
Summarized by: Christine Checked by:

Computer Data Entry
Date: 11/05/09
By: Christine

Location: South Roundabout
Section Length: 0.06 km
End GPS Coordinates: 89°31'16.21"W, 34°21'17.13"N



Field Data Group Leader (s): Ryan, Jessica
Field Staff Names (who recorded vehicle counts):
Ryan, Brittany, James, Brent, Cherrelle, Jessica, Mamun, Peyton

Remarks: none weather: overcast,rainy Other: compiled without missing data movements 5 and 6 for Hr #7
Date of Manual Count: 10/15/09 Day: Thursday
(one summary sheet per day)

Hours of Manual Count: #4 10:30-11:00am #5 11:00-12:00pm
#6 12:00-1:00pm #7 1:00-2:00pm #8 2:00-3:00pm
#9 3:00-3:30pm #10 4:15-5:00pm #11 5:00-6:00pm

Type S/L/R	#1 Hour	#2 Hours	#3 Hour	#4 Hour	#5 Hour	#6 Hour	#7 Hour	#8 Hour	#9 Hour	#10 Hour	#11 Hour	#12 Hour	Total Minutes
Minutes	0	0	0	30	60	60	60	60	30	45	60	0	405
Movement No./ type	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Counts	Total Counts
1				16	43	54	68	81	45	66	107		480
2				10	14	6	3	14	57	22	25		151
3				36	99	68	51	73	5	70	95		497
4				41	69	59	62	95	53	103	119		601
5				276	752	733		635	661	653	**776**		4,486
6				141	300	352		329	362	285	356		2,125
7				219	400	580	325	606	522	438	712		3802
8				10	23	28	16	37	20	18	37		189
9				24	91	82	32	71	94	81	111		586
10				55	65	78	26	103	112	70	92		601
11				216	355	571	268	537	333	459	**491**		3230
12				277	589	658	300	582	251	614	428		3699
Total Counts	0	0	0	1,321	2,800	3,269	1,151	3,163	2,515	2,879	**3,349**	0	20,447
	Hour of	# 11	*max volume*		*3,349*								

							Hour of max vol	*0-15 min*	*15-30 min*	*30-45 min*	*45-60 min*	*PHF*
Checked by:		Hours Conted	Total Volume	Cars, etc	Trucks	Buses	Motor-cycles	*5* *776*	**250**	213	177	136	0.78
Christine/Waheed		5	20,447	20,266	122	43	16	***11***	156	**161**	98	76	
Date:	11/23/2009			99.11%	0.60%	0.21%	0.08%	*491*					0.76

Hours	#1 Mins	#2 Mins	#3 Mins	#4 Mins	#5 Mins	#6 Mins	#7 Mins	#8 Mins	#9 Mins	#10 Mins	#11 Mins	#12 Mins	Total Vehicles
Trucks	0	0	0	22	21	22	16	22	12	9	8	0	132
Buses	0	0	0	1	7	5	3	6	10	7	4	0	43
Motorcycles	0	0	0	0	0	1	2	0	1	6	6	0	16
Total Car	0	0	0	1,298	2,772	3,241	1,130	3,135	2,492	2,857	3,331	0	20,256