Mississippi Department of Transportation

State Study 213

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

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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.

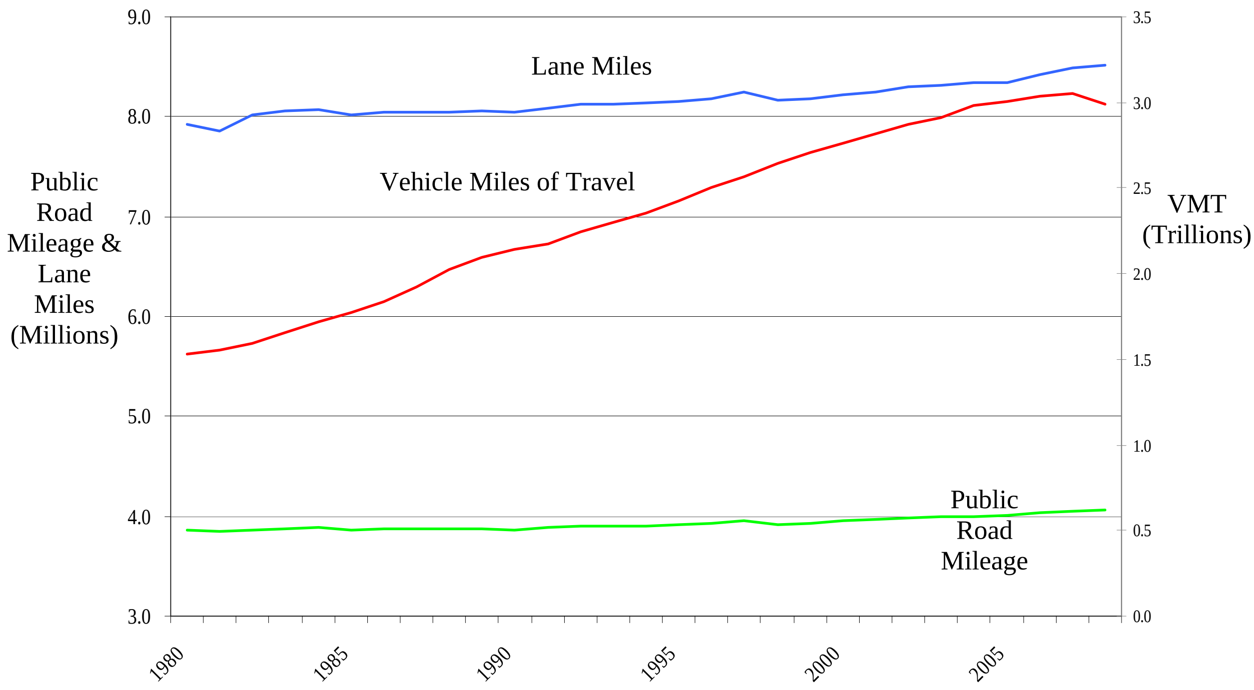

Figure 1. Public road mileage, lane miles, and VMT in the US from 1980 – 2008

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.

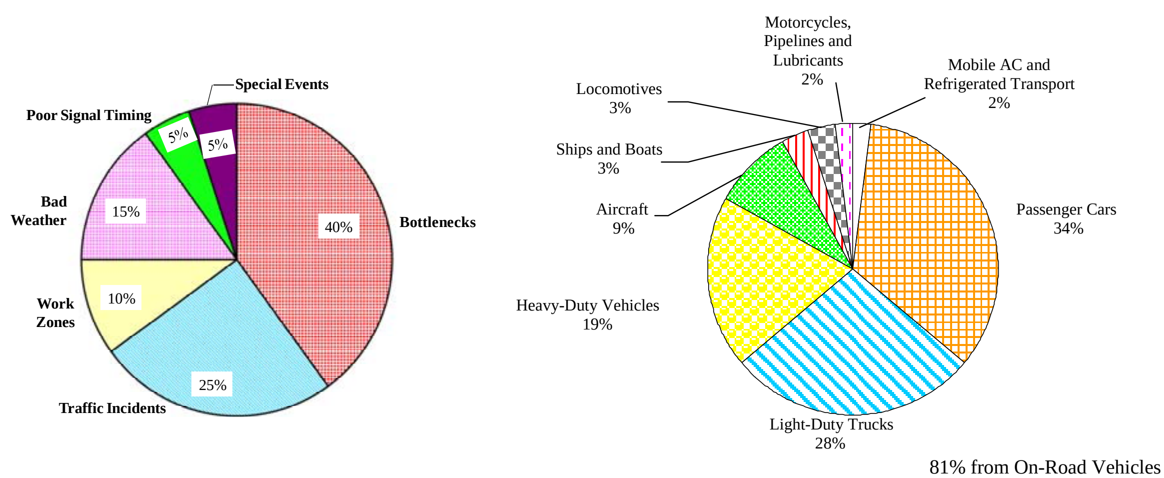

Figure 2. Causes of traffic congestion in the U.S. (left); U.S. Transportation-related emissions, 2004 (right)

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].

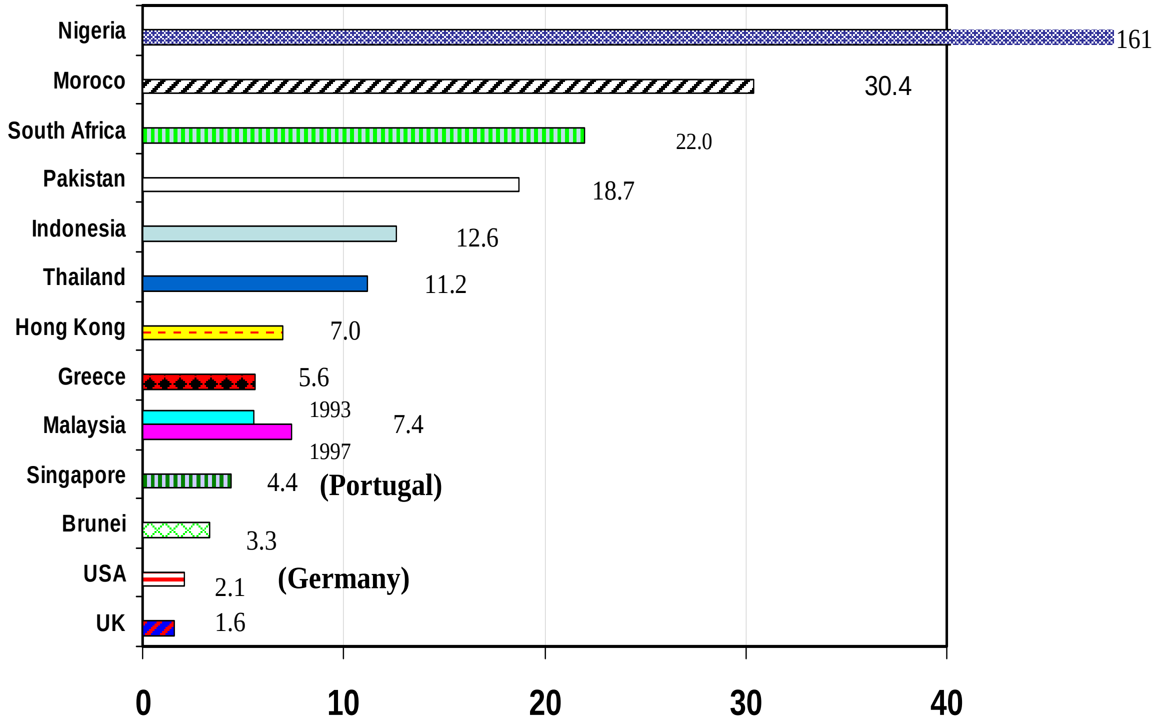

Figure 3. Road fatalities per 10,000 vehicles for selected countries

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.

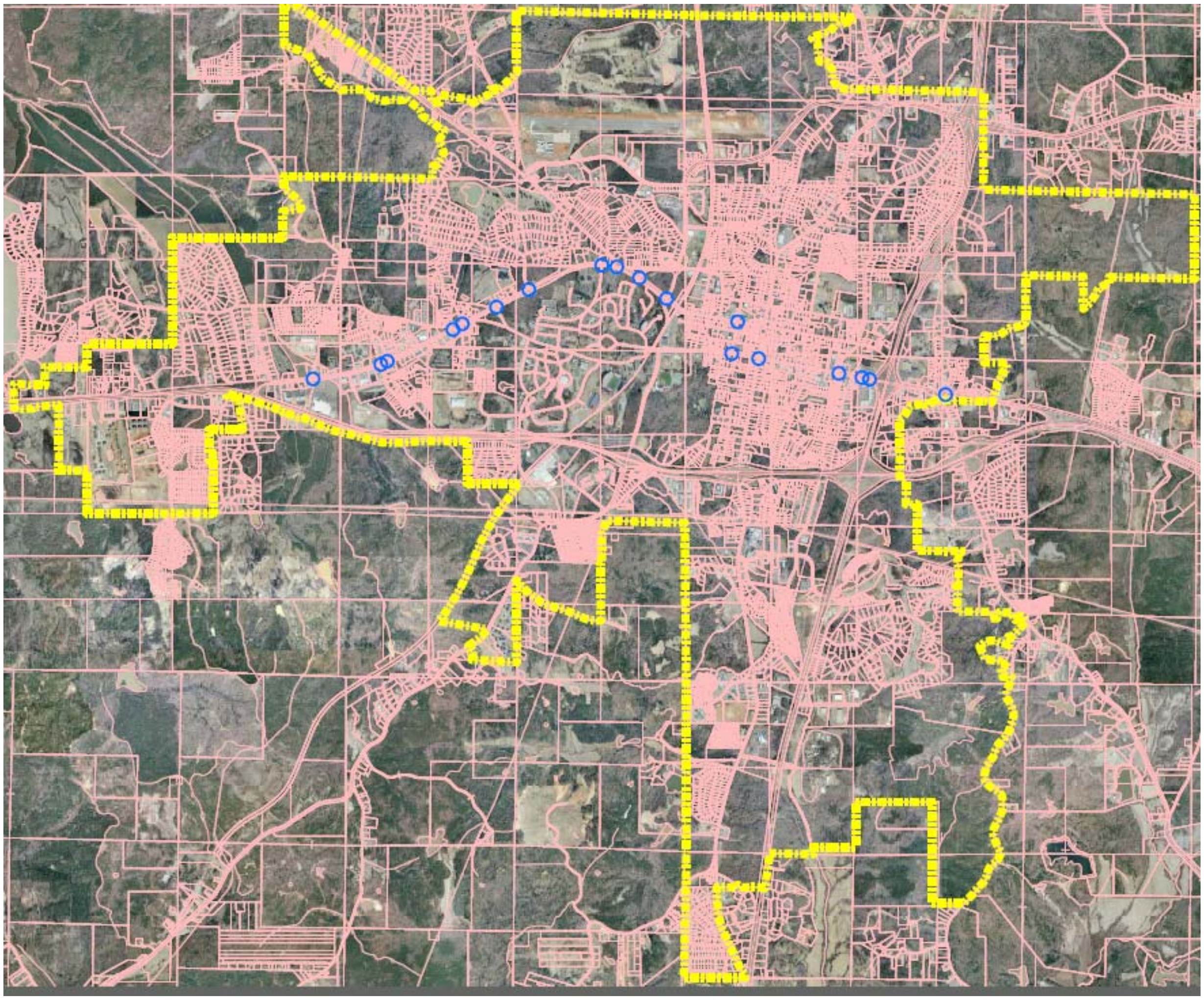

Figure 4. ITS location within Oxford, Mississippi [10]

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).

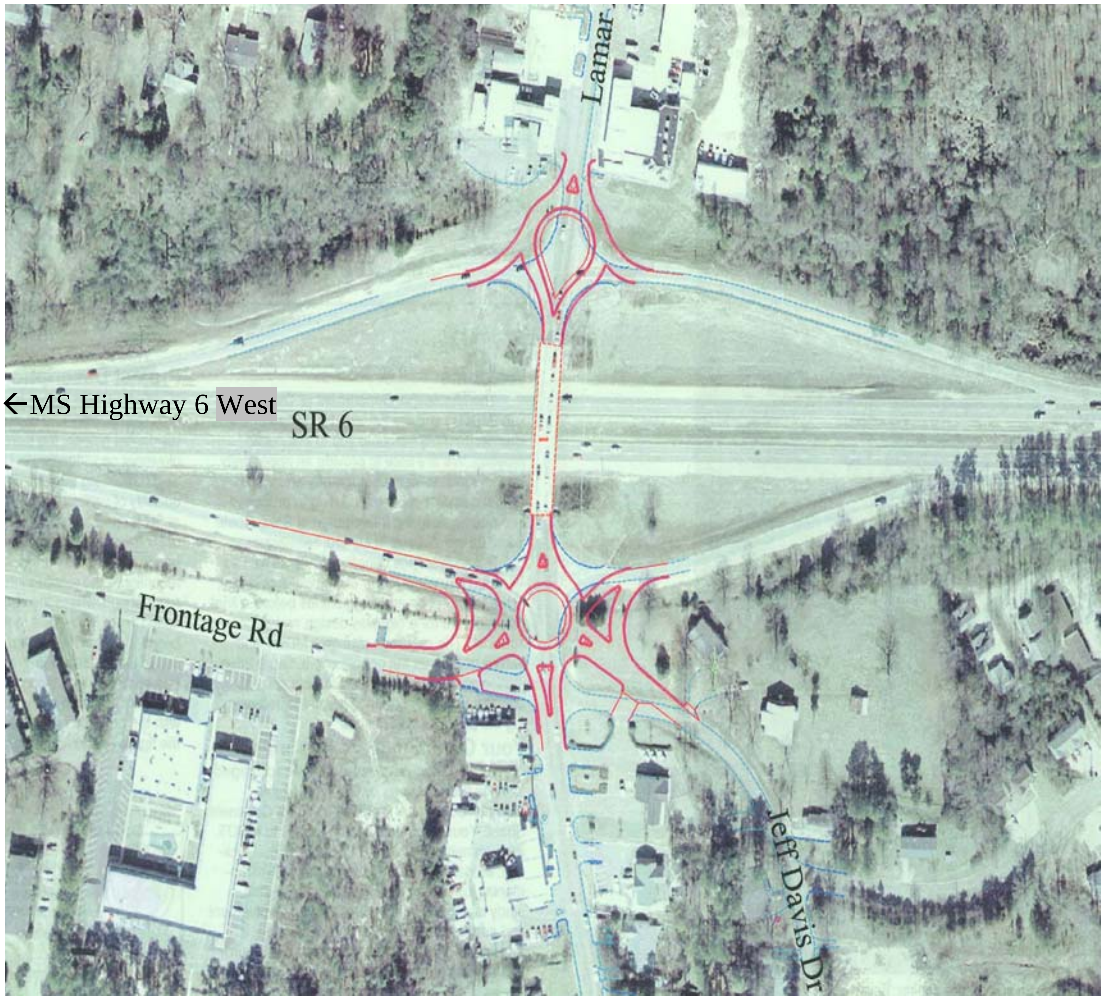

Figure 7. Planned roundabouts on South Lamar Blvd, Oxford
(courtesy of James Sullivan, MDOT)

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].