Appendix L
Roundabout Feasibility Report
ROUNDABOUT FEASIBILITY REPORT

LANCASTER BOULEVARD / 10TH STREET WEST

Prepared For:
City of Lancaster, California

Prepared By:
Scott Ritchie, P.E.
Roundabouts & Traffic Engineering

August 6, 2007
LANCASTER BOULEVARD / 10TH STREET WEST
ROUNDABOUT FEASIBILITY REPORT

FOR:
CITY OF LANCASTER

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EXECUTIVE SUMMARY

Roundabouts & Traffic Engineering (RTE) has been retained by the City of Lancaster to perform a Roundabout Feasibility Study at the intersection of Lancaster Boulevard / 10th Street West for a modern roundabout project in Lancaster. The purpose of this study is to provide the feasibility of a modern roundabout as well as a comparative analysis of the operational performance of a modern roundabout versus a traffic signal at the identified intersection with a final recommendation. Comparisons between each alternative in terms of capacity and safety have been analyzed and documented for the future design year of 2030. The project site is located within the City’s right of way at an existing signalized intersection. However, the City of Lancaster desires further investigation and consideration of a modern roundabout at this location for their known safety, capacity, and aesthetical benefits. The general conclusions of the feasibility study are provided below:

CONCLUSIONS

1. A modern roundabout is a feasible and appropriate traffic control device for this intersection.
2. The roundabout provides superior capacity over the signal alternative with respect to the overall operations, level of service, delay, and queue lengths for the intersection.
3. The “before” and “after” safety statistics conducted in the United States and worldwide provide substantiating evidence of the superior safety performance of modern roundabouts versus traffic signals and other intersection types for both vehicles and pedestrians.
4. The operational characteristics of the roundabout are superior to the traffic signal. This includes adjacent access operations and emergency vehicle operations.
5. The roundabout and proposed signal will both require additional right-of-way in future conditions in order to maintain City thresholds of LOS D and the additional roadway width for the signal’s required turn lane lengths.
6. The roundabout would reduce air pollutants / vehicle emissions.
7. The roundabout would enhance the character of the City of Lancaster at and near the Lancaster Blvd / 10th St West intersection with added landscaping and potential ornamental features for public appeal.

It was determined by all the contributing factors within the study that the roundabout is the identified alternative recommended for this intersection. Please refer to Chapter VII for additional conclusions and recommendations.
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I. INTRODUCTION

BACKGROUND

The City of Lancaster has an existing traffic signal at the intersection of Lancaster Boulevard / 10th Street West located in the central western area of Lancaster. Roundabouts & Traffic Engineering (RTE) has been retained by the City of Lancaster to perform a Roundabout Feasibility Study at the intersection for this new potential roundabout project. The intersection will either need to remain signalized or be controlled by a modern roundabout. The City of Lancaster desires further investigation and consideration of a modern roundabout at this location for their known safety and capacity benefits. The City has also requested general information on roundabouts and supporting evidence of the safety comparisons of traffic signals and modern roundabouts. The proposed roundabout location is shown in Figure 1 in an aerial photograph of the existing area.

PURPOSE

The purpose of this study is to provide a comparative analysis of the operational performance of a modern roundabout versus a traffic signal at the identified intersection with a final recommendation. A comparison between each alternative in terms of capacity and safety has been analyzed and documented for the future design year of 2030. In addition, this report will determine if the proposed intersection is a viable location for a modern roundabout, depending on the information provided by the City of Lancaster, with a provided conceptual roundabout design. This report documents the existing and future traffic conditions and a recommended alternative for the intersection.

ORGANIZATION

This Roundabout Feasibility Report is organized into the following chapters:

I. Introduction
II. Existing Site Conditions
III. Traffic Volumes & Future Assumptions
IV. Capacity Analyses & Conceptual Roundabout Design Alternative
V. Capacity Comparisons
VI. Safety Comparisons
VII. Conclusions & Recommendations
VIII. Appendix
The report begins with the identification of the existing site conditions for the intersection. The next chapter of the report identifies the future conditions and assumptions used to determine the design volumes in the analyses of the report. Next, the report examines the future capacity and delay requirements for a roundabout and a signal (existing) at the intersection location. The following chapter discusses the safety parameters and statistics of signals versus roundabouts. Finally, the feasibility study provides conclusions based on the results of the comparative analyses conducted for the intersection and recommendations for the selected alternative.

Figure 1: Project Area (Aerial Photo)
II. EXISTING SITE CONDITIONS

SURROUNDING AREA CONDITIONS

There is a need for a higher-level traffic control device at the intersection of Lancaster Boulevard / 10th Street West due to capacity concerns in 2030. Since the identified intersection is considered a high visibility or “gateway” location for the City, the key element of the area is this existing intersection that should be incorporated into a consistent theme for the corridors in the area. The proposed project includes constructing a modern roundabout at the intersection as an alternative to a traffic signal.

The land uses surrounding the intersection area are currently a mix of residential and commercial establishments as well as City owned land. A review was performed of the most recent site plans and roadway alignment information as well as a review of the intersections’ volumes. The proposed roadway’s surrounding topography, centerlines, curb faces, edge of pavement, environmental, and right of way constraints were also reviewed from the information provided.

The existing intersection is a relatively old intersection that provides a primary access point to the City of Lancaster. The image below shows the existing lane configuration and surrounding area conditions for the intersection (Figure 2).

![Figure 2: Existing Lane Configuration](image-url)
III. TRAFFIC VOLUMES

FUTURE TRAFFIC ASSUMPTIONS & DESIGN VOLUMES

The future turning movement volumes were originally provided to RTE in late 2006. RTE found these preliminary files to contain left and through movement volumes only. After analyzing the available traffic data, RTE questioned the validity of the data and requested the City of Lancaster to re-evaluate the accuracy of the data and provide additional turning movement volumes. During late 2006 and early 2007, the City was also undertaking other studies on the subject corridors in which the traffic volumes were also being updated.

In mid-2007 the City provided RTE with a spreadsheet of revised turning movement volumes for the intersection. RTE analyzed the revised volumes and inquired what year the “Existing Plus Ambient Growth Plus Project” turning movement volumes were estimated (i.e. 2020, 2025, 2030, etc.). The City of Lancaster then provided RTE with a final set of turning movement volumes identified as “Future 2030” turning movement volumes. RTE reviewed and compared all sets of volume data submitted and found the data to be consistent in nature with no apparent anomalies. Hence, RTE again analyzed the final future 2030 AM and PM peak hour turning movement traffic volumes for the intersection based on data provided by the City of Lancaster, which are the volumes included in this report.

The final 2030 AM and PM peak hour traffic volumes provided by the City are shown in Figure 3. Figures 4 and 5 show the AM and PM volumes graphically.

According to the City of Lancaster, the design vehicle was identified as a WB-50 for all turning movements, similar to the illustration provided in Figure 6.

The heavy truck percentages for the intersection were assumed to be a conservative percentage of 2% for all legs of the intersection. RTE also reviewed other local data and confirmed that a 2% value for heavy trucks is appropriate and was used in the analyses of this report. A 2% volume of trucks for all traffic at the intersection is considered very low in traffic terms. Hence, the roundabout will be designed primarily for passenger car, local bus traffic, and the design vehicle.
Figure 3: AM and PM Peak Hour Traffic Volumes

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PM Peak Hour Turn Volumes

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Figure 4: 2030 AM Peak Hour Traffic Volumes (Graphically)
Figure 5: 2030 PM Peak Hour Traffic Volumes (Graphically)
IV. CAPACITY ANALYSES & CONCEPTUAL DESIGN ALTERNATIVES

Following RTE’s review of the relevant site plan files and traffic volumes of the proposed project locations and roadways, capacity analyses were commenced for both the traffic signal and modern roundabout design alternatives. The information in this chapter set the initial parameters for the capacity calculations of the proposed roundabout location, geometry, and how they will function as a system with the proposed roadway network. No nearby access locations were identified to incorporate into the design with the exception of the existing curb cuts in the northwest and southwest quadrants of the intersection.

GENERAL CAPACITY METHODOLOGY

Both the traffic signal and the modern roundabout capacity analyses are based on the general principles and performance measuring criteria identified in the Highway Capacity Manual. The Highway Capacity Manual\(^1\) evaluates intersections based on vehicular delay as well as their Level of Service.

Traffic operations are assessed in terms of Level of Service (LOS) and delay. The level of service for an intersection is determined by the amount of delay experienced at the intersection. Delay is measured as the average time from when a vehicle stops at the end of the queue until the vehicle departs from the stop or yield line. The numerical value of delay per vehicle (typically in seconds or minutes) of a turning movement, approach, or total intersection is quantified with an assigned letter value or “grade” of measurement called LOS. The LOS is determined from the length of the average delay experienced at the intersection during the peak hour.

LOS is a concept that was developed by transportation engineers to quantify the level of operation of intersections and roadway segments. The LOS for most jurisdictions at intersections is classified in grades “A” through “F.” These grades of LOS are the quantified terms that relate to the average delay per vehicle. A LOS “A” reflects full freedom of operation for a driver, while a LOS “F” represents very long delays of operation for a driver, forcing the driver to wait for adequate gaps in conflicting traffic. Under the HCM methodology, an intersection operating at LOS “F” is considered to have failed. The City of Lancaster’s current traffic threshold policy is to maintain LOS D.

\(^1\) Highway Capacity Manual, Transportation Research Board, 2000
SIGNAL CAPACITY ANALYSES

After obtaining and reviewing all of the pertinent information regarding the roadways, site, and traffic volumes, an analysis of the existing signal at the intersection using the software program Traffix For Windows was conducted to analyze the capacity requirements of the signalized intersection for the design year of 2030. Traffix is based upon the HCM 2000 methodologies described above. The AM and PM peak hours were analyzed to ensure adequate signal operations during both future peak conditions.

Signal Capacity Methodology: For signalized intersections under the Highway Capacity methodology, LOS is primarily measured in terms of average delay. The Volume to Capacity ratio (V/C) is used as an additional measure for quantifying the capacity utilization/design adequacy of the intersection. Typically, an intersection with a v/c ratio over 0.85 indicates the potential need for additional capacity on the approach. However, recent research has indicated that an intersection can operate at an acceptable level of service even though the V/C ratio exceeds 1. Therefore, a signalized intersection can operate at an acceptable LOS even if entering traffic volumes at that intersection exceed its theoretical capacity. Such situations occur primarily when unbalanced heavy demands occur on one or two approaches.

Based on the established design criteria for the signalized intersection analyses, the Traffix software program and engineering analyses produced the following results, as shown in Figures 7 and 8. Please note that the lane configurations match the existing signal layout. The figures below provide the following results for the 2030 design year:

- Lane Configurations
- Anticipated Queue Lengths of Each Lane
- Peak Hour Signal Timing
- Peak Hour Cycle Lengths
- LOS Results for AM and PM Peak Hours

As shown in the figures below, the signalized intersection operates at a LOS D with 35.5 seconds of delay in the AM and a LOS F with 98.3 seconds of delay in the PM peak hours of 2030. However, please note that these results assume additional capacity amenities within the signal system such as overlap right turn phasing (right turns have green arrows during selected phases - requires special signal heads) and protected/permitted phasing for the eastbound and westbound legs (left turn green arrows during selected phases with permitted
Figure 7: Lancaster Boulevard / 10 Street W Capacity Analyses – 2030 AM Peak Hour
Figure 8: Lancaster Boulevard / 10th Street W Capacity Analyses – 2030 PM Peak Hour
left turns against opposing traffic – requires special signal heads). This type of phasing may not be desired for safety purposes as protected / permitted phasing can result in serious t-bone accidents, however, the LOS continues to degrade with other types of phasing analyzed. The existing lane configurations for each approach of the intersection are also shown in the figures above.

It should be noted (as shown above) the capacity analyses for the signal reflect significant turn lane lengths for most of the lanes at the intersection in 2030 (e.g. 650 feet for the westbound left lane). The extension of the turn lanes will require significant roadway widening and right-of-way for the required improvements. In addition, this may have a detrimental impact on adjacent properties for future use and development opportunities. This is particularly relevant to commercial land uses since the City may consider the corner parcels and adjacent parcels as essential redevelopment sites for the downtown area. The capacity results are documented in Table 1 as well as in the comparison analyses between the signals and roundabouts at the end of the next chapter following the roundabout capacity analyses.

<table>
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<th>Table 1: Signalized Intersection Capacity Summary</th>
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<td>DELAY (in seconds)</td>
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<tr>
<td>LOS</td>
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<td>AVG QUEUE (ft / lane)</td>
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Note 1: Signal Requires Signal Head and Phasing Modifications to Achieve Results Reported
Note 2: LOS D Can Be Achieved with Additional Lanes On ALL Approaches
Source: RTE

However, in order to bring the signalized intersection up to City of Lancaster LOS threshold requirements, additional lanes would be required. Since only the PM peak hour fell below a LOS D, the intersection was reanalyzed with the lane
configuration required to achieve a LOS D or better. The results are shown below in Figure 9. As shown, the southbound approach would require an additional through lane and double left turn lanes. The eastbound and westbound approaches would also require double left turn lanes. This essentially creates an eight (8) lane roadway on the north side, eight lanes on the south side, and 6 lanes on the east and west sides of the intersection. Figure 10 on the next page illustrates these improvements as a rough sketch only.

Figure 9: Lancaster Blvd / 10 St W MITIGATED Capacity Analyses – 2030 PM Peak
Figure 10: Conceptual Traffic Signal Exhibit

- Existing Face of Curb
- Proposed Face of Curb
- Dual Left Turn Lanes Required / Six Total Travel Lanes Required
- Dual Left Turn Lanes & Three Through Lanes Required / Eight Total Travel Lanes Required
- Seven Travel Lanes Required / Eight Lanes Due to Offset Alignments
ROUNDABOUT CAPACITY ANALYSES

After obtaining and reviewing all of the pertinent information regarding the roadways, site, and traffic volumes, a geometric analysis of the proposed roundabout using the roundabout design software tool called RODEL was conducted.

The RODEL calculations provided the initial lane geometry and capacity requirements for the roundabout design alternative based on the design year traffic volumes. RODEL is based on empirical equations (observed and checked from field data) developed by the United Kingdom and utilizes specific geometric relationships to determine the capacity requirements of a roundabout. A further discussion on RODEL software and the geometric factors affecting roundabout capacity is provided in the next section of this report (RODEL Software and Roundabout Geometric Parameters). In general, RODEL (roundabout delay) calculates the required geometry for the roundabout to function within the desired capacity or, alternatively, to determine if the existing/planned geometry will be adequate with respect to capacity and delay. Since both the AM and PM peak hour volumes are part of the intersection design, separate RODEL calculations were completed for the intersection location to ensure the roundabout will operate appropriately under both peak hour traffic conditions. Since multiple sets of volumes (AM and PM) were requested as part of this design, separate RODEL calculations were completed for the design alternative to arrive upon the recommended configuration of the roundabout to ensure it will operate appropriately under both AM and PM 2030 traffic conditions.

In addition, separate RODEL calculations were also performed under the peak minutes of the peak hour at an 85th percentile confidence level to ensure the proposed design would function adequately under the recommended geometric recommendations provided herein during the peak minutes of the peak hour. Nearly all software programs that analyze traffic volumes with respect to operations and level of service are reported at a 50th percentile confidence level. RODEL allows for a “design check” at an 85th percentile confidence level to determine if the roundabout has been sized / designed adequately. This ensures adequate capacity of the roundabout during the peak hour.

Roundabout Capacity Methodology: The predominant consideration in roundabout capacity analyses is the volume of the circulating traffic and the volume of the entering traffic on an approach. Traffic entering a roundabout will look for gaps in the circulating traffic in order to enter the roundabout. This behavior is called gap seeking. In addition to gap seeking, the geometric design of the roundabout affects the speeds and comfort level at which...
drivers will negotiate the roundabout. This also affects the capacity and safety of roundabouts.

The Highway Capacity Manual\(^2\) evaluates roundabouts based on their volume to capacity ratios as well as their level of service. The volume to capacity (v/c) ratio describes the volume of traffic entering the circulating roadway from one approach as compared to the capacity of that approach. The capacity of an approach is dependent on the traffic volume within the circulating roadway at each specific approach. As the traffic within the circulating roadway goes up, the capacity of an approach would be reduced. Because of this, traffic engineers prefer to leave a “reserve capacity” for an approach. Typically, an intersection with a v/c ratio over 0.85 indicates the potential need for additional capacity on the approach. However, too much reserve capacity results in an unsafe (too fast or “too loose”) roundabout design. Hence, careful and specific balance is needed in the design of roundabouts for safety and operational capacity purposes.

**Roundabout Geometry Parameters / RODEL Software:** Empirical studies in England have shown that the following six (6) dimensions collectively control traffic speed, capacity, and safety at a roundabout (see Figure 11 below):

1. Inscribed Circle Diameter (ICD): the diameter of the outside curb of the circulating roadway. The ICD is established based on the tracking characteristics of the vehicle the roundabout is to accommodate, and the number of circulating lanes required to accommodate the projected traffic volumes. Increasing or decreasing this parameter (and thus increasing or decreasing the central island diameter) has minor effects on the safety of the roundabout (theoretically). However, it can be demonstrated that changing the size (ICD) of the roundabout can substantially change the safety of a roundabout design.

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\(^2\) Highway Capacity Manual, Transportation Research Board, 2000
2. Half Width (V): the width of the approach roadway. This dimension is typically known before the roundabout design process has begun, as it is an element of the upstream roadway cross section. The half width has a significant impact on the capacity of the roundabout and some impact on travel speeds and safety of the roundabout.

3. Entry Width (E): the width of the entering roadway at the point of its intersection with the outside curb of the circulating roadway. Increasing or decreasing the entry width can have large impacts on the safety and capacity of the roundabout.

4. Flare Length (L’): the average effective length of flare from the transition between the point where the half width ends and the yield line. Flare length is accident neutral. As the flare gets longer the capacity of the roundabout increases. However, the entry speed increases and the roundabout’s deflection decreases. Hence, flare length and entry width are related. If the approaches to the roundabout were parallel, the half width is equal to the entry width, and the flare length is zero (not recommended in modern roundabout designs and proven to increase accidents).

5. Entry Angle (∅) – the mean angle tangential between the direction of entry into the roundabout and tangential to the direction of the adjacent exit (or circulating traffic, depending on the size of the roundabout). The figure above shows the entry angle as half the angle formed by the junction of the tangent line (a-b) projected from the entry and the tangent line (c-d) projected from the adjacent exit. If all other dimensions remain constant, reducing the entry angle will increase the speed at which the roundabout can be entered which, in turn, tends to reduce the safety of the roundabout.

6. Entry Radius (R) – The radius of the outside curb of the entering roadway at its point of intersection with the outside curb of the circulating roadway. The entry radius is a critical component in roundabout design that determines many factors such as entry speed and entry deflection.

After inputting the future traffic turning movement volumes into RODEL for the peak hours, the roundabout was analyzed to verify the appropriate number of lanes at each entry or approach of the roundabout. Specifically, the recommended geometric requirements for the roundabout were analyzed to verify that the entering approach widths, average effective flare lengths, entry angles, entry radii, and roundabout diameter are adequate for the proposed
traffic volumes. The results of the RODEL analyses are shown in the following RODEL output in Figures 12 and 13:

**Figure 12: AM RODEL ANALYSES: 50th Percentile**

![Figure 12: AM RODEL ANALYSES: 50th Percentile](image1)

**Figure 13: PM RODEL ANALYSES: 50th Percentile**

![Figure 13: PM RODEL ANALYSES: 50th Percentile](image2)
Based on the established design criteria for the roundabout analyses, the RODEL software program and engineering analyses produced the preliminary results above. The analyses provide the following results for the 2030 design year:

- Required Lane Configurations
- Anticipated Queue Lengths of Each Approach
- Roundabout Geometry (E, L’, R, Phi, D)
- LOS Results for AM and PM Peak Hours

As shown in Figures 12 and 13, the intersection operates at a LOS A with 4.3 seconds of delay in the AM and LOS A with 5.4 seconds of delay in the PM peak hours of 2030. The recommended roundabout diameter is 164-200 feet. Also shown, the required lane configurations of each approach of the intersection are based on the turning movement conflicts and the approaching existing roadway configuration. The roundabout design only requires 2 lanes per approach. In addition, relatively insignificant stopped queue lengths develop at the intersection. This is documented in Table 2 below as well as in the comparison analyses between the signals and roundabouts at the end of the next chapter following these capacity analyses.

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<td><strong>AM PEAK HOUR</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DELAY (in seconds)</td>
<td>4.2</td>
<td>4.2</td>
</tr>
<tr>
<td>LOS</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>AVG QUEUE (ft / lane)</td>
<td>25’</td>
<td>25’</td>
</tr>
</tbody>
</table>

| **PM PEAK HOUR** | | | | | |
| DELAY (in seconds) | 6.6 | 4.8 | 4.2 | 6.0 | 5.4 |
| LOS | A | A | A | A | A |
| AVG QUEUE (ft / lane) | 50’ | 25’ | 25’ | 50’ | 50’ |

Source: RTE Lancaster Feasibility Tables.xls

Figure 14 below graphically represents a rough conceptual sketch of the modern roundabout at the intersection. Specific fastest path entry design speeds (prior to yield line) at approximately 25 miles per hour have been preliminarily incorporated into the roundabout design for proper deflection and safety.
Figure 14: Conceptual Roundabout Exhibit

- Two Lane Approaches Required For All Approaches / Four Lanes Total
- Multiuse 10-Foot Ped/Bike Path Detached By 2 Foot Planter Strip Area
- 170 Ft ICD Two-Lane Roundabout
- Protected Ped Crossing Refuge
- 8 Ft Multiuse Ped/Bike Path
- Two Lanes Each Direction
- North
It should be noted that Figure 14 is an illustration or conceptual roundabout exhibit at a 15% level of detail that was developed for the intersection for preliminary discussion purposes. The sketch simply demonstrates the recommended design lane configurations and initial geometry recommendations. Regardless, the image shown in Figure 14 provides an idea of what the modern roundabout could look like incorporated into the existing area.

Following this report, a full roundabout design with proper geometrics, signing, striping, lighting, grading, and landscaping design plans will need to be developed by a qualified roundabout specialist if the roundabout alternative is selected by the City of Lancaster. The provided conceptual roundabout design exhibit will require further modifications for final PS&E plans.
V. CAPACITY COMPARISONS

This chapter compares the proposed roundabout alternative to the proposed signal alternative with respect to a various number of capacity related issues such as the calculated delay and level of service, lane geometry, right of way, and the average queuing for the design year of 2030.

.signals vs. roundabouts

Capacity (Delay & LOS): Table 3 illustrates the 2030 capacity comparisons of the traffic signal and the modern roundabouts for each intersection. The actual Traffix and RODEL output was shown in the previous chapter of this report. As shown in the tables below, the modern roundabout’s level of service operates significantly superior to the signalized intersection.

<table>
<thead>
<tr>
<th>Table 3: Capacity Comparison</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lancaster Blvd / 10th Street W</td>
<td>AM and PM Peak Hour Results - 2030</td>
</tr>
<tr>
<td>Intersection</td>
<td>Roundabout</td>
</tr>
<tr>
<td></td>
<td>AM</td>
</tr>
<tr>
<td>DELAY (in seconds)</td>
<td>4.3</td>
</tr>
<tr>
<td>LOS</td>
<td>A</td>
</tr>
</tbody>
</table>

Note 1: Signal Requires Signal Head and Phasing Modifications to Achieve Results Reported
Note 2: LOS D Can Be Achieved with Additional Lanes On All Approaches
Source: RTE Lancaster Feasibility Tables.xls

Lane Geometry: In addition, the required lane geometry should also be compared in order to show the improvements necessary prior to the intersection. The required lane geometry was described in the previous sections of this report. The following major differences between the roundabout and signal for the intersection are as follows:

- The roundabout requires two lanes per approach on all legs for a LOS A. The signal would operate at a LOS F under the existing lane configuration. In order to bring the signal operation up to a LOS D or better, per City of Lancaster requirements, significant lane additions would be required as discussed in the previous sections.
The signal would operate with protected (stopped) phases, whereas the roundabout would operate with yield conditions on all approaches with relatively continuous traffic flow.

The roundabout provides safer pedestrian crossings with only two lanes of one-way traffic to cross at the largest distance with slow or yielding traffic speeds. The signal requires a pedestrian to cross six to eight lanes of two-way traffic while several phases of traffic remain stopped.

As a result, the required lane geometry for the roundabout has fewer number of required approach lanes, less storage lengths required, less lane changing prior to the intersection, and a smaller amount of turning movement conflicts when compared to the either the existing signal or proposed signal at the intersection.

**Right-of-Way:** The modern roundabout would require at least a 164-foot outside diameter (up to approximately 200 feet). As shown in the conceptual roundabout exhibit (Figure 14), the northwest and southeast quadrants of the intersection will require minor right of way acquisition assuming the southwest quadrant of the intersection is City owned property. Assuming traffic signal head changes and phasing alterations with the existing traffic signal, the operations still fail at LOS F during the PM peak hour, but no right of way would be required. In order to raise the operating conditions of the traffic signal to a LOS D or better, the traffic signal would require significant right of way acquisition along Lancaster Boulevard as well as 10th Street West for at least 800-1000 feet to the north, 500-1000 feet to the south, and about 500 feet in the east and west directions due to the required additional lanes and storage lengths.

**Queue Lengths:** A comparison can also be made between the queue lengths formed from the traffic signal and the modern roundabout for the 2030 design year conditions. Typically, roundabouts have significantly less queue buildup than traffic signals since roundabouts provide a relatively continuous traffic flow pattern. The RODEL output show the average and maximum peak hour queue lengths (in vehicles). Based on the capacity calculations in the previous chapter of this report, the following average queue length summary information can be provided for the roundabout and signal analyses.

As shown in Table 4 below, the queue lengths are negligible or quite short for the roundabout compared to the traffic signal (without lane improvements) with the same traffic volumes. The roundabout requires less vehicular stacking at the intersection, which will improve the operations of nearby private and public accesses. The roundabout will also improve driver behavioral characteristics, roadway level of service, environmental impacts, and aesthetical effects to the area.
However, despite the traffic control device chosen, as the traffic volumes increase and the surrounding area experiences additional growth, the intersections should be re-evaluated for proper changes in the projected turning movement volumes. Although not anticipated in the near future, geometric modifications, signal timing changes, or the addition of lanes may be needed if the traffic volumes change significantly from the assumed analysis design year volumes.

**Capacity Summary:** In summary, there are demonstrated capacity benefits for the modern roundabout operations versus maintaining the signalized alternative. This can mostly be explained by the basic operational characteristics of a signal versus a roundabout. A signal requires traffic flows to stop and wait for the permission of the traffic signal to move forward, whereas the roundabout has continuously flowing traffic with yield conditions to approaching vehicles. The approaching traffic flow is only required to search for an available gap in the traffic stream of the roundabout’s circulating roadway, which will occur quite frequently with the yielding approaches and since the traffic flows have separate turning movements. Since the decision making for the driver to enter the roundabout is based on driver judgment, similar to a four-way stop controlled intersection, for only a right turn movement, the natural driver behavioral instinct occurs at the yield line, which is different for every type of driver (aggressive, passive, etcetera). Hence, adequate gaps for conflicting traffic movements automatically form in the roundabout and all traffic continues to flow with minimal delay, relatively slow vehicular speeds, and a high amount of safety. In most studied cases, slowing all traffic at an intersection with continuous flow has been proven to provide faster travel times for a corridor than stopping selected phases.

### Table 4: Queuing Comparison

<table>
<thead>
<tr>
<th>Intersection</th>
<th>NB</th>
<th>SB</th>
<th>EB</th>
<th>WB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AM PEAK HOUR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal¹</td>
<td>275'</td>
<td>325'</td>
<td>375'</td>
<td>250'</td>
</tr>
<tr>
<td>Roundabout</td>
<td>25'</td>
<td>25'</td>
<td>25'</td>
<td>25'</td>
</tr>
<tr>
<td><strong>PM PEAK HOUR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal¹</td>
<td>825'</td>
<td>650'</td>
<td>950'</td>
<td>345'</td>
</tr>
<tr>
<td>Roundabout</td>
<td>50'</td>
<td>25'</td>
<td>25'</td>
<td>50'</td>
</tr>
</tbody>
</table>

Note 1: Shorter Queues Can Be Achieved with Additional Lanes On ALL Approaches

Source: RTE Lancaster Feasibility Tables.xls
VI. SAFETY COMPARISONS

The previous chapters analyzed the capacity requirements of both a traffic signal and a modern roundabout at the intersection and provided conceptual design illustrations. The previous section demonstrated the capacity comparisons between the two alternatives. This chapter discusses the safety considerations and comparisons between roundabouts and signalized intersections as well as the adjacent lane use operations.

GENERAL ROUNDABOUT INFORMATION

Modern roundabouts are a type of circular intersection with specific design and traffic control features to control driver behavior. Figure 15 identifies key modern roundabout features required in roundabout design. Some of these features include yield control for entering traffic, channelized approaches, and a geometric design that ensures travel speeds are relatively low and safe. Modern roundabouts are unique from other circular intersections in that they use splitter islands (or curved medians) and physical geometry (raised concrete curb) to control and slow the speeds of vehicles entering the roundabout and traveling

Figure 15: Typical Roundabout Features

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through the roundabout. The splitter islands help control speeds, guides drivers into the roundabout, physically separate entering and exiting traffic streams, significantly increases intersection safety, deters wrong-way movements, and provides safe pedestrian crossings. Modern roundabouts are designed and sized to accommodate specific design speeds, traffic flows, and large design vehicles.

Roundabouts improve the safety of an intersection through the introduction of a raised island in the center of the intersection and the conversion of all movements through the intersection to right turns thus eliminating vehicle-to-vehicle crossing conflicts.

The horizontal and vertical geometry of a roundabout is crucial to the operation and safety of the roundabout. Since the capacity of a roundabout is dependent on the turning movement volumes at each approach, the capacity or RODEL analyses completed above identified the required lane geometry and the number of entries required for the design. As depicted in the RODEL analyses, the correct geometric design is identified only with respect to the entry lane capacity. The safety factors of each design’s geometry now become the primary concerns for the operational adequacy of the roundabout. The “body language” of the roundabout directly relates how comfortable and safe drivers will use the roundabout. The body language of the roundabout must adequately communicate to the driver in order to avoid accident problems.

The geometric analysis of a roundabout evaluates the geometric parameters that affect roundabout capacity and safety. However, for the purposes of this feasibility study, the capacity and safety of the roundabout have been divided into separate sections for ease of reader comprehension. The geometric safety design includes the design of fast path speeds and speed consistency within the roundabout design. The roundabout designs also consider other safety parameters such as vehicle deflection into the roundabout, splitter island design, crosswalk locations and the ability of the design vehicle to negotiate the roundabout.

In addition, a large part of roundabout design involves specific non-geometric details such as the roundabout’s signing, striping, and lighting of the roundabout. This intersection location has not progressed to this level of detail yet. However, many other proposed roundabout features were analyzed during the roundabout design.

The design of roundabout entries and exits is an intricate and complicated procedure that involves numerous variables that need to be addressed to ensure a safe design and adequate capacity. Some of these variables include the following design components:
SAFETY COMPARISONS (RESEARCH FACTS & STATISTICS)

The best method of comparing traffic signals to roundabouts is through “before” and “after” case study results with respect to roundabouts compared to other types of stop controlled and signalized intersections. The Insurance Institute for Highway Safety (IIHS) performed a study titled Crash Reductions Following Installation of Roundabouts in the United States in 2000 on 24 U.S. intersections that had converted both signalized intersections and stop-controlled intersections to modern roundabouts. Similarly, the Institute of Transportation Engineers (ITE) also completed a related study in 2002. The US Department of Transportation, Federal Highway Administration (FHWA) also produced Roundabouts: An Information Guide in 2000 with safety statistics contained. All of these studies revealed very consistent “before” and “after” results with respect to the safety of modern roundabouts compared to other types of stop controlled and signalized intersections. The following is a brief summary of these results with regard to the extent to which modern roundabout conversions improved the accident safety of the intersections:

- 38 - 40% average reduction in all crash types
- 74 - 78% average decrease in injury accidents
- 90% average decrease in fatalities or incapacitating injuries
- 30 - 40% average decrease in pedestrian accidents (depending on the roundabout location and existing pedestrian volumes)
- As much as a 75% reduction in delay where roundabouts replaced traffic signals

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4 IIHS, Status Report, 5/13/2000
5 ITE Journal, September 2002
The FHWA informational guide on roundabouts states that accident frequency and severity is less for a roundabout than a traffic signal. These study results replicate the results of numerous other studies conducted on roundabouts in Europe and Australia and provide quantitative evidence that the selection of a roundabout over the more conventional intersection geometrics and traffic control can have significantly positive traffic safety implications. Studies completed in England have revealed that the total number of pedestrian accidents with vehicles at roundabouts is lower than that of other intersection types by 33 to 54 percent. Norway has also indicated in several studies over the years that roundabouts have provided a 73 percent reduction in pedestrian crashes at intersections converted to roundabouts.

The unaware person typically asks why roundabouts are safer than traffic signals. The following bulleted list of items provides these answers as well as further discussions and illustrations below:

- Roundabouts have fewer conflict points for vehicles, pedestrians, and cyclists. The potential for many hazardous conflicts, such as right-angle accidents and conflicting left turn head-on crashes, are eliminated with modern roundabouts.
- Speeds at roundabouts are significantly lower (average of 22 mph) than other types of crossings, which allows drivers more time to react to potential conflicts.
- There is a lower speed differential between the users of roundabouts (e.g. vehicles to pedestrians to cyclists) since the road users travel at similar speeds through the roundabout.
- Lower speeds and speed differentials between users of roundabouts significantly reduces the accident severity if an accident occurs.
- Pedestrian crossings at roundabouts are much shorter in distance and entails interruption in only one direction of the traffic stream at a time. Since conflicting vehicles arrive in one direction only to the pedestrians, the pedestrians need only to check to their left for conflicting vehicles. In addition, the speed of the vehicles in the roundabout at entry and exit are reduced with a proper roundabout design.

The following are some facts on traffic signals, red light running, and roundabouts:

1. In 2002, more than 1.8 million intersection crashes occurred throughout the nation. Of those crashes, about 219,000 are due to red light running; resulting in about 1,000 deaths and 181,000 injuries. *(Insurance Institute for Highway Safety, IIHS, and Federal Highway Administration, FHWA, 2003)*
2. A study conducted by the Insurance Institute for Highway Safety (IIHS) in 2003 found that at a busy intersection in Virginia, a motorist ran a red light every 20 minutes. During peak commuting times red light running was more frequent.

3. Researchers at the IIHS studied police reports of crashes on public roads in four urban areas. Of thirteen crash types identified, violating traffic control devices accounted for 22 percent of all crashes. Of those, 24 percent were attributed to red-light-running.

4. According to a survey conducted by the U.S. Department of Transportation and the American Trauma Society, two out of three Americans see someone running a red light at least a few times a week and, at most, once a day. (1998)

5. One in three Americans knows someone who has been injured or killed in a red light running crash. (FHWA, 2002)

6. Research from the IIHS illustrates far fewer crashes occur at intersections with roundabouts than at intersections with signals or stop signs. Modern roundabouts are substantially safer than intersections controlled by stop signs, traffic signals or traffic circles.

7. Compared to the former traffic circle or rotary, the majority of modern roundabouts have excellent safety performance mostly due to their small diameter, slower circulating speeds, flared approach, deflection, and yield control entrances. Studies from around the world have shown modern roundabouts typically reduce crashes by 40 to 60 percent compared to stop signs and traffic signals. They also typically reduce injury crashes by 35 to 80 percent and almost completely eliminate fatal and incapacitating crashes.

Roundabouts are self-regulating traffic control devices that automatically control driver speeds. Lower speeds at roundabouts, compared to traffic signals, directly relates to intersection safety. To elaborate on this concept, lower speeds on a roadway or at an intersection equate to shorter braking distances. The following bar chart (Figure 16) demonstrates a comparison of traffic signals to roundabouts based on braking distance and driver perception/reaction distances for braking.
As mentioned above, since the speeds at roundabouts are significantly lower with a lower speed differential between the users of roundabouts, this significantly reduces the accident severity of collisions at roundabouts. Figure 17 illustrates the accident severity of collisions at roundabouts versus traffic signals based upon vehicle speeds. As shown in the chart below, roundabouts will have a lower accident severity rate than that of traffic signals. Hence, there will be less injuries and fatalities at roundabouts than signals as well as other types of intersections. The statistics discussed above or the “before” and “after” field studies verify this reality.
Another reason why roundabouts are safer types of intersections are the reduced number of conflict points at a roundabout versus a signal. The following illustrations (Figures 18 and 19) show the number of vehicle-to-vehicle (black dots) and vehicle-to-pedestrian (white dots) conflicts at a roundabout and signal.

As shown above, there are more vehicular and pedestrian points of conflicts at a signalized intersection than a roundabout. This solves the question in a very basic way of why roundabouts are safer than a signalized intersection.

In addition to a significant reduction in traffic accidents, roundabout installation can generate reductions in delays and associated air emissions, improve intersection capacity and pedestrian travel, reduce intersection improvement costs and associated operation and maintenance costs, and can be a key element in improving the visual quality of roadway corridors and town centers.

In general, if roundabouts are designed by a qualified roundabout specialist, the modern roundabout will function as a self-regulating traffic control device that offers numerous capacity, safety, aesthetic, and often cost benefits to a community and/or public jurisdiction.
ACCESS OPERATIONS

Only the roundabout alternative would maintain all ingress and egress accesses to all adjacent properties assuming the southeast quadrant’s access closest to the intersection on both Lancaster Blvd and 10th Street are eliminated. The traffic signal not only eliminates more accesses than these two, but issues arise with vehicles blocking these driveways with the traffic signal as more traffic congestion occurs during the peak hours and in the future. The signal’s queue lengths far exceed the access points to many driveways along all four approaches/roadways. Further information is required to analyze all access points near the roundabout and signal. Hence, one primary difference between the traffic signal and the modern roundabout is the operational characteristics of the two intersections and the benefits the roundabout provides for access operations.

EMERGENCY VEHICLE OPERATIONS

With respect to emergency vehicle operations, the traffic signal would need to be equipped with an emergency detection system, which actuates the signal in favor of the emergency vehicle, in order to have adequate response times. However, the sirens, lights, and horn of the emergency vehicle should be sufficient warning if the detection system is too expensive to install. Although is also required by law for vehicles to yield to emergency vehicles as well as stop at all red lights (despite the statistics showing 24% of all accidents at signals are red light runners), the significant queues forming at the traffic signal may force emergency vehicles to use the opposing travel lanes. Safety concerns arise with this method of passing through the intersection.

The roundabout would not require any special phasing, pedestrian or design modifications, or special traffic control features at the intersection. All traffic and drivers are already anticipating to yield to circulating traffic in the roundabout and thus are anticipating a reduced speed if not a brief stop condition at the intersection. Similar to the signal, the emergency vehicle would sound its sirens, horn, and lights while entering the roundabout’s circulating roadway. By law, all approaching traffic at the roundabout must yield to vehicles in the roundabout (circulating). However, unlike the signal, the geometry of the roundabout (right curb faces, splitter islands, and the central island) enforces and forces the speed for all traffic to slow down at the intersection to a maximum of about 25 miles per hour at entry and about 18 miles per hour circulating the roundabout. This significantly decreases the likelihood of accidents with vehicles and any entering emergency vehicles.
The only conflicting movements with the emergency vehicle are any remaining traffic in the circulating roadway, with a driver choice to either exit the roundabout and pull over or pull over immediately within the roundabout (not common). All approaching traffic to the roundabout would be required to yield to the emergency vehicle now in the circulating roadway. The emergency vehicle could enter the roundabout with the same movements as normal traffic using the intersection and proceed around the roundabout (counterclockwise) to whichever exit or direction the emergency requires.

The roundabout would operate safer than the signal with respect to the emergency vehicle making the same anticipated movements as a vehicle using the intersection. This reduces driver confusion and allows traffic to proceed around the roundabout as normal. The addition of sirens and lights increases traffic safety with a stopped/yielded condition of other traffic at the yield line and nearly guarantees emptying of the roundabout.

In the event of traffic stopping or an accident occurring within the circulating roadway of the roundabout, the emergency vehicle may also use the truck apron of the roundabout to bypass any stopped traffic or incident. This can be shown in video clips taken by RTE in the field. Vehicular traffic is relatively undisturbed with little driver frustration once the emergency vehicle passes and can continue to operate normally. The emergency vehicle has access anywhere to any direction, including u-turn options within the roundabout.

Emergency vehicle response times are also worth noting. Discussions with fire department and police department chiefs in jurisdictions throughout the nation where RTE has roundabouts constructed or where modern roundabouts have replaced traffic signals or stop control have reported either a decrease in emergency response times or no reported problems with roundabouts implemented. RTE has observed and videotaped the traffic behavior of emergency vehicles in route to an incident where little to no hindrances to the emergency vehicle were experienced. In general, traffic moves to the curb near or within the roundabout or exits the roundabout before pulling over. Emergency officials state that drivers infrequently pull over in a manner that does not permit the emergency vehicle to proceed through the intersection. In these infrequent cases where vehicles block the circulating roadway, the emergency vehicle utilizes the truck apron or the adjacent exit to bypass traffic. This ease of emergency response and reduced response times is due to the continuous traffic flows, wider entry lanes at roundabouts, and wide circulating lanes for large trucks to maneuver in the roundabout, which provides enough room for an emergency vehicle to pass by passenger vehicles.
VII. CONCLUSIONS & RECOMMENDATIONS

CONCLUSIONS

The preceding sections of this report analyzed the feasibility of a modern roundabout at the intersection of Lancaster Boulevard / 10th Street West as well as compared the capacity and safety of either a modern roundabout or a traffic signal alternative. The following summarizes the analysis sections of this report.

- A modern roundabout is a feasible and appropriate traffic control device for this intersection if small amounts of right-of-way is available.

- The roundabout provides superior capacity over the signal alternative with respect to the overall operations, level of service, delay, and queue lengths for the intersection.

- The “before” and “after” safety statistics conducted in the United States and worldwide provide substantiating evidence of the superior safety performance of roundabouts versus signals and other intersection types for both vehicles and pedestrians. The roundabout provides self-enforcing geometry and forces traffic speeds to be slow for the entire intersection. This significantly decreases the likelihood of accidents with vehicles as well as with emergency vehicles.

- The operational characteristics of the roundabout are superior to the traffic signal. This includes adjacent access operations and emergency vehicle operations.

- The roundabout and signal will both require additional right-of-way in future conditions in order to maintain City thresholds of LOS D and the additional roadway width for the signal’s required lanes and turn lane lengths.

- The roundabout would reduce vehicle emissions (see Appendix).

- The roundabout would enhance the character of the City of Lancaster at and near the Lancaster Boulevard / 10th Street West intersection with added landscaping and potential ornamental features for public appeal.

In addition to the feasibility, capacity, and safety of each alternative, the importance of a proper functioning traffic control device that increases
aesthetical beauty and community character for the City of Lancaster is also significant. Therefore, it can be unanimously determined by all the contributing factors within this feasibility study that the modern roundabout is recommended for this intersection.

Although this report provides information and comparisons primarily focusing on the feasibility, capacity requirements, and safety analyses of each alternative, a number of other comparisons could also be made between the two alternatives for the intersection. However, this report does not provide additional comparisons or explanation on these additional issues such as aesthetics, driver behavioral characteristics, benefit-to-cost ratios, predicted accident safety costs, predicted societal accident costs, life-cycle maintenance costs, and delay costs to road users. However, a simplified comparison matrix is provided below that accounts for decision-making factors between the signal and roundabout alternative.

**Comparison Matrix:** The Comparison Matrix is designed for the internal use for the project development team and the City of Lancaster. It assists in a comparative analysis that measures and weighs a various number of major design decision options. RTE has compiled the results of a variety of comparison factors into a matrix that includes key decision measures, assigned percentages, and weighted values based on the capacity, safety, and other results completed in this feasibility study. The comparison matrix merely provides a tool for the design team to aid in the selection of a preferred alternative. Table 5 provides the items considered and the summary results of the analyses.

### Table 5: Decision Matrix

**Comparison of Key Elements of Alternatives**

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Delay / LOS</th>
<th>Vehicle Safety</th>
<th>Const. Costs</th>
<th>EMS &amp; Ped Safety</th>
<th>0 &amp; M Costs</th>
<th>Aesthetics</th>
<th>Total Score: Higher is Better</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>30%</td>
<td>30%</td>
<td>10%</td>
<td>15%</td>
<td>5%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Signalized Intersection</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.80</td>
</tr>
<tr>
<td>Modern Roundabout</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4.75</td>
</tr>
</tbody>
</table>

Legend: 0=Very Poor, 1=Poor, 2=Below Avg, 3=Average, 4=Above Avg, 5=Excellent

Source: RTE
It is understood that each jurisdiction has slightly differing weights and factors included for each design project, however, the intent of the comparison matrix is to provide a general insight and basic rational behind the conclusions of this report. The results of each numeric factor are based on the results of this report, available averages, nationwide statistics, and RTE’s professional judgment for this particular project. The provided weights of each key element or factor is a derivative and average of public decision makers with similar roundabout versus signal projects RTE has dealt with throughout North America. As shown in the comparison matrix, the total score for the roundabout alternative is much better than the score of the signal alternative.

Cost Comments: Although the City of Lancaster has postponed the costs of the roundabout and signal improvements and are not addressed in this feasibility report, it should be noted that a traffic signal requires ongoing maintenance costs for the signal poles, controller cabinet, loop or video detectors, signal heads, or the like. These costs typically add up to an annual average range of $5,000 to $30,000 per year depending on the signal. A roundabout does not incur such maintenance costs unless annual flowers or foliage need replacement or upkeep in the central island or outside the roundabout. The required obstructions in the roundabout design can usually be accommodated with perennial foliage, statues, or rocks that requires little to no maintenance. Other costs, such as curb and gutter, drainage maintenance, pavement repair, and lighting maintenance are similar between the two alternatives.

Other Comments: Air emissions and construction traffic impacts are additional topics that could be discussed at great length where roundabouts provide positive results over traffic signals. With respect to the reduction of air emissions, a recent report published by Gene Russell with Kansas State University is attached to this report (see Appendix) for additional vehicle emission reduction information from roundabouts. Essentially, the report documents through several case studies, “The research concludes that modern roundabout can be used as a viable alternative to cut down vehicular emissions and thereby making intersections more environmentally friendly”. In addition, the aesthetic benefit of roundabouts is understated in most instances. As a civic feature, roundabouts provide a gateway to a town entry or city focal point. The local environment at the intersections could be significantly improved with proper landscaping.

RECOMMENDATIONS

The key points this study established were that the roundabout alternative provides the most amounts of capacity and operational safety for this project location. This was demonstrated in the capacity analyses, the safety discussions,
the proposed roundabout conceptual design, and the comparative analyses between the signal and the roundabout. As determined in the conclusions, the roundabout alternative is recommended for this intersection location.

It is recommended to proceed with the final geometric layout of the roundabout, including geometric design modifications and details still to complete, all of the non-geometric essentials (such as signing, lighting, striping, and landscaping), and the remaining civil components of the design plans including grading, utilities, drainage, and staking information. It is recommended that the geometric layout of the roundabout design be revised by a qualified roundabout expert in order to ensure proper design safety and capacity.

As stated in the introduction of the report, the modern roundabout, coupled with good design practices and additional geometric and non-geometric design measures such as proper signing and landscaping, are the traffic control devices of choice for intersections in most countries. The self-regulating traffic control device creates an environment controlled by roadway and intersection geometric layouts with roadway widths, curves, medians, lighting, signing, striping, and landscaping to regulate traffic speeds.

As shown in the conceptual roundabout design (Figure 14), the entries are visible to drivers from a safe stopping distance, safe design speeds corresponding to the fastest paths can exist to promote yielding at entry with slow entry and circulating speeds, the splitter islands have been designed properly, ADA and bike lane appurtenances will be present, as well as many other design features in final design.

**Additional Implementation Recommendations:** The following additional items not shown in the conceptual roundabout design are also recommended:

- A four-inch rolled curb is recommended for the roundabout’s truck apron.
- Provide at least a 3-5% slope on the truck apron sloping downward towards the circulating roadway with textured or stamped concrete. The concrete should be constructed with color (preferably red/brown or black/white) with chevrons (as separate sections).
- Provide highly visible and obstructing landscaping in the central island according to sight distance requirements for each entry and circulating points within the roundabout.
- Provide obstructing landscaping in the planter areas outside the roundabout to reduce driver–pedestrian side friction.
➢ Provide post mounted maptype signs as shown in the *Roundabout Signing Guide, A Recommended Practice, 1st Edition*, for driver comprehension of destination and repeated display and understanding of a roundabout ahead.

➢ Provide an internally illuminated bollard (MUTCD compliant) on the splitter islands of all approaches to assist in nighttime visibility of the roadway geometry ahead. RTE has an MUTCD compliant sample of the product available for illustration and discussion.

➢ Provide roadway, approach, and exit lighting at the roundabouts at least 200 feet prior to the yield line for all approaches. RTE can identify the specific locations for proper positive contrast lighting at the roundabout.

➢ Provide detached sidewalks with landscaping between the back of curb and face of walk to provide a tunnel effect or constrained environment for the driver to slow down prior to entry. A five-foot detached sidewalk with a minimum of a ten-foot multiuse path should be designed in the final plans. However, these dimensions could be reduced to a two-foot planter and an eight-foot multiuse path if necessary (as shown in Figure 14).

➢ If possible, the use of internally illuminated exit signs is a highly visible method of displaying an intersection with a roundabout. RTE has illustrations of the internally illuminated signs used in Vail, Colorado.

➢ General conformance to the recommendations found in the *Roundabout Signing Guide, A Recommended Practice* such as the arrow shaped exit signs are recommended for all approaches at both roundabouts.

➢ Conformance to the DRAFT 2008 MUTCD manual is recommended. Scott Ritchie is a member of the board for the new MUTCD 2008 manual on signing and striping at roundabouts and can provide recommendations on the latest federal and ADA recommendations.

➢ Provide highly visible crosswalks with the use of thermoplastic in an international style stripe design (a.k.a. “ladder” stripes) or a stamped and colored concrete for high visibility.

➢ Provide proper advanced and intersection signing and markings to advise of the appropriate speed and lane for approaching drivers.

Advance signage combined with a visible driving situation with appropriate landscaping and a well-illuminated intersection all contribute to the good safety performance currently being observed at roundabout sites. The consequences of an inconspicuous central island and/or splitter islands is mainly loss of control crashes as motorists unfamiliar with the roundabout are not given sufficient visual information to elicit a change in speed and path.

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APPENDIX
Impact of Modern Roundabouts on Vehicular Emissions

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ABSTRACT

Vehicular emissions have increased considerably over the years with the increase in traffic. Modern roundabouts can improve traffic flow as well as cut down vehicular emissions and fuel consumption by reducing the vehicle idle time at intersections and thereby creating a positive impact on the environment.

The primary focus of this research is to study the impact of modern roundabouts in cutting down vehicular emissions. Six sites with different traffic volume ranges, where a modern roundabout has replaced Stop controlled intersection, have been chosen for the study. The operation of the roadways at the intersection was videotaped and the traffic flow data was extracted from these tapes and analyzed using Signalized and Unsignalized Intersection Design and Research Aid (SIDRA) software. The version used is a.a. SIDRA 2.0. The software produces many measures of effectiveness (MOEs) of which five were chosen for analyzing the environmental impact of roundabouts. The chosen five outputs give rate of emission of HC, CO, NOX, and CO2 in (kg/hr).

All the MOEs were statistically compared to determine which intersection control performed better. After comparing all the MOEs at all locations for the before and after traffic volumes, it was found that the modern roundabout performed better than the existing intersection control (i.e., stop signs) in cutting down vehicular emissions thereby creating a positive impact on the environment. The research concludes that a modern roundabout can be used, as a viable alternative to cut down vehicular emissions and thereby making intersections more environment friendly.

Key words: modern roundabouts—reducing air pollution—vehicular emissions
INTRODUCTION

With the increase in traffic over the years, one of the major threats to clean air in many of the developed countries like the U.S. is vehicular emissions. Problems posed by the environmental impact of traffic are growing and are a challenge for traffic engineers. Vehicular emissions are dependent on the total amount of traffic, intersection control type, driving patterns and vehicular characteristics.

Vehicular emissions contain a wide variety of pollutants, principally carbon monoxide (CO), carbon dioxide (CO₂), oxides of nitrogen (NOₓ), particulate matter (PM₁₀) and hydrocarbons (HC) or volatile organic compounds (VOCs) which have a major long term impact on air quality. These emissions vary with the engine design, the air-to-fuel ratio, and vehicle operating characteristics. With increasing vehicle speed there is an increase in NOₓ emissions and decrease in CO, PM₁₀ and HC or VOC emissions. The emissions of (CO₂) and oxides of sulfur (SOₓ) vary directly with fuel consumption and for any given vehicle and fuel combination, aggregate emission levels vary according to the distance traveled and the driving patterns (I).

Road and street intersections force vehicular traffic to slow down and stop in varying patterns of interruption of ideal, constant traffic flow at an ideal speed. The longer the stops, the more fuel that is consumed and vehicular emissions increase. With the vehicular emissions problems worsening, it has become prudent to choose effective traffic control devices (TCDs) that can improve traffic flow on the roads and reduce emissions per vehicle kilometer traveled while enhancing mobility.

Modern roundabouts in the U.S., which are functioning as one of the safest and most efficient forms of intersection control (4, 14, 15) and improving traffic flow at intersections, have the additional advantage of cutting down vehicular emissions and fuel consumption by reducing vehicle idling time at the intersections and thereby having a positive affect on the environment.

The primary focus of this research is to study the impact of modern roundabouts in cutting down vehicular emissions at intersections. This research focuses on six sites with different traffic volume ranges where a modern roundabout has replaced stop-controlled intersection. The emissions at the intersections were compared for the before (stop controlled) and after (modern roundabout) conditions to assess the impact of a modern roundabout at these intersections.

LITERATURE REVIEW

Vehicle exhaust fumes played a major role in the deterioration of air quality in urban areas since 1950s and as a result the Clean Air Act (CAA) was passed in 1970. The CAA gives the Environmental Protection Agency (EPA) the authority to set limits on emission standards. The EPA estimates that over 5,000 tons of VOCs from transportation sources were emitted in 1999 and that approximately 62 million people living in areas that do not meet health based standards. EPA also estimated that in 1999 the transportation sector, including on-road and non-road vehicles, contributed to 47 percent of hydrocarbon (HC) emissions, 55 percent of nitrogen oxides (NOₓ) emissions, 77 percent of carbon monoxide (CO) emissions, and 25 percent of particulate matter (PM) emissions (2).

Roundabouts are being implemented throughout the U.S. in a variety of situations. Many states and cities are considering roundabouts as a viable alternative to other TCD’s, and, in some cases, complex freeway interchanges. Modern roundabouts are becoming popular in the US for more than just safety reasons. As stated in an article by the Insurance Institute for Highway Safety (IIHS) they reduce fuel consumption and vehicular emissions by reducing stopping at intersections, and also reduce noise levels by making the traffic flow orderly. Modern roundabouts can enhance the aesthetics of the place and create visual
gateways to communities or neighborhoods. In commercial areas they can improve access to adjacent properties (3).

Vehicles stopping at traffic signals and stop signs emit more carbon dioxide ($CO_2$) when compared to roundabouts as the delay and queuing are greater. Even if the delays are similar to that of roundabout, traffic signals always queue traffic at a red light and hence emissions are usually greater. The average delays at roundabouts have to be significantly larger than at traffic signals for the emissions to be equal. When traffic volumes are low, traffic rarely stops at a roundabout and the emissions are very small (5, 6).

When roundabouts become very congested with large queues, the emissions equal those at traffic signals. During off-peak hours roundabouts do not experience long queues and delays and the emissions are low. Traffic signals and stop signs stop vehicles even during off-peak hours and thereby experience higher delays and emissions. United Kingdom (UK) engineers believe that traffic signals have lower emissions only in exceptional cases (5, 6).

As stated by Barry Crown, a roundabout expert from the UK: “When vehicles are idle in a queue they emit about 7 times as much carbon monoxide (CO) as vehicles traveling at 10 mph. The emissions from a stopped vehicle are about 4.5 times greater than a vehicle moving at 5 MPH” (5).

The Bärenkreuzung/Zollikofen project undertaken in Bern, Switzerland, replaced two important signalized intersections by roundabouts and the result was a reduction of emissions and fuel savings by about 17 percent. The roundabouts also steadied the driving patterns (7).

On a microscale there have been studies conducted on the effect that different traffic flows have on emissions at an intersection. Of the studies that reported quantitative results, roundabouts reduced vehicle emissions for hydrocarbons (HC) in 5 studies by an average of 33 percent, carbon monoxide (CO) in 6 studies by an average of 36 percent, and nitric oxides (NOx) in 6 studies by an average of 21 percent. The regional scale air quality benefits of roundabouts would depend on their percent contribution to regional mobile source emissions (8, 9).

In a study conducted by Mustafa et.al (1993), the authors concluded that there exists a direct relationship between vehicle emissions and traffic volumes at urban intersections regardless of traffic control. Their simulation results showed that traffic signals generate more emissions (almost 50 percent higher) than a roundabout. In case of higher traffic volumes the HC generated by traffic signals is twice as high as that generated at roundabouts (10).

In another study conducted by Varhelyi in Sweden, he found that replacing a signalized intersection with a roundabout resulted in an average decrease in CO emissions by 29 percent and NOx emissions by 21 percent and fuel consumption by 28 percent per car within the influence of the junction (11).

Results of a study conducted by Jarkko Niittymaki show fuel consumption reductions of 30 percent in an intersection designed as a roundabout instead of using traffic signals and environmentally optimized traffic control systems have proved an energy saving potential of 10 percent to 20 percent in different cases (12).
METHODOLOGY

Description of Study Sites

Six study sites were selected for this research. Five of the sites are in Kansas and one in Nevada. Of the sites studied in Kansas two were in Olathe, one in Lawrence, one in Hutchinson, and one in Paola. Data from these sites was available from previous roundabout studies at Kansas State University (KSU) (4, 14, 15).

The sites in Olathe are (1) the intersection of the Ridgeview Road and Sheridan Avenue and (2) the intersection of Rogers Road and Sheridan Avenue. Sheridan Avenue runs in the East-West direction while the Ridgeview and Rogers Roads run in the North-South direction, roughly parallel to Interstate 35 (I-35).

The site in Lawrence is the T-intersection of the Harvard Road and Monterey Way. Harvard Road runs in the east-west direction while and ends at Monterey Way, which runs in the north-south direction.

The site in Hutchinson is the intersection of 23rd Street and Severance Avenue. Severance Avenue runs in the north-south direction and 23rd Street runs in the east-west direction.

The site in Paola is the intersection of the Old KC Road, State Route K68, and Hedge Lane. The Old KC Road runs in the north-south direction. The K68 runs in the east-west direction. Hedge Lane runs in Southeast- northwest direction, and intersects K68 just east of the K-68 and Old KC Road intersection.

The site in Nevada is the intersection of the Wedekind Road and ClearAcre Lane. Wedekind Road runs in the east-west direction while ClearAcre Lane runs in the north-south direction.

All the sites except Hutchinson and Nevada (which had a two-way stop control, TWSC) were controlled by stop signs on all approaches (all-way stop control, AWSC) prior to the installation of the modern roundabout. The major drawback of AWSC is that the presence of vehicles on all the approaches of the intersection will result in longer departure headways and longer driver decision times that reduce the capacity of the intersection. The major drawback of TWSC is that congestion on the minor street caused by a demand that exceeds capacity, and queues that form on the major street because of inadequate capacity for left turning vehicles yielding to opposing traffic. In the after condition a single-lane modern roundabout was built at all sites. The Paola roundabout is different from the others because it has five legs, and is an intersection on the state highway (4). See Table 1 for the intersection hourly traffic volume ranges and the percentage of left turn for the intersections studied.
### TABLE 1. Intersection Hourly Traffic Volume Ranges and Percentages of Left Turns

<table>
<thead>
<tr>
<th></th>
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<td>PM (AWSC)</td>
<td>PM (Roundabout)</td>
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<td></td>
<td>257-594 (veh/hr)</td>
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<td>192-690 (veh/hr)</td>
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<td>40% left turns</td>
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<td>AM (Roundabout)</td>
<td>PM (AWSC)</td>
<td>PM (Roundabout)</td>
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<tr>
<td></td>
<td>227-536 (veh/hr)</td>
<td>263-447 (veh/hr)</td>
<td>412-733 (veh/hr)</td>
<td>442-692 (veh/hr)</td>
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<tr>
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<td>30% left turns</td>
<td>17% left turns</td>
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<td>1220-1994 (veh/hr)</td>
<td>1244-2024 (veh/hr)</td>
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<td>PM (AWSC)</td>
<td>PM (Roundabout)</td>
</tr>
<tr>
<td></td>
<td>708-1110 (veh/hr)</td>
<td>776-1124 (veh/hr)</td>
<td>1140-1626 (veh/hr)</td>
<td>1119-1784 (veh/hr)</td>
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<td>PM (Roundabout)</td>
</tr>
<tr>
<td></td>
<td>449-983 (veh/hr)</td>
<td>415-864 (veh/hr)</td>
<td>514-1204 (veh/hr)</td>
<td>501-1110 (veh/hr)</td>
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<td>AM (Roundabout)</td>
<td>PM (TWSC)</td>
<td>PM (Roundabout)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>423-718 (veh/hr)</td>
<td>372-691 (veh/hr)</td>
<td>619-893 (veh/hr)</td>
<td>547-881 (veh/hr)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>31% left turns</td>
<td>32% left turns</td>
<td>28% left turns</td>
<td>27% left turns</td>
<td></td>
</tr>
</tbody>
</table>

### Data Collection

The available data had been collected in two phases. The first phase was videotaping intersection traffic movements with a video camera and the second phase was obtaining traffic counts visually from the videotapes (4, 14, 15).

#### Phase 1: Video Data Collection

The benefit of using this method for data collection is that all the data is recorded on videotapes and can be accessed and retrieved at a later time. In this method, all the information recorded on the tapes can be accessed for evaluation at any time and serves as a permanent record for re-verification of data, or reuse for other purposes. A specially designed 360-degree omni directional, video camera and videocassette recorder were used for data collection at each location. The camera was designed to provide a full 360 degrees view when mounted above the intersection. The camera was placed near the intersection to see the traffic flow coming toward and leaving the intersection. The camera was installed on existing poles and mounted perpendicular to the ground. The perpendicular mounting allowed the video image to be relatively distortion free to the horizon in all directions. The camera was mounted approximately 6 meters (20 feet) above the ground. This mounting height provides a focal plane of approximately 40.5 meters by 54.0 meters (133 feet by 177 feet). The camera feed went in to a TV/VCR unit placed in a recycled traffic signal controller cabinet. All the equipment was mounted on a single pole. The video images were recorded on standard VHS videotapes. See Figure 1 for details (13, 14). The traffic counts from the
intersection were video taped for two six-hour sessions from 7:00 AM to 1:00 PM and from 1:00 PM to 7:00 PM on normal week days for the before and after conditions. A normal day in this study refers to a day with no adverse environmental/weather or any external factor(s), such as special events in the nearby locality of the study intersection that would impact the flow of traffic through the study intersection.

**FIGURE 1. Camera and TV/VCR Units Used in Data Collection**

*Phase 2: Visual Data Collection*

In this phase the data was visually collected from the videotapes. All the videotapes were studied visually to extract the traffic volumes and turning movements for the analysis. Various graduate student research assistants in the Department of Civil Engineering at KSU did the data extraction from the videotapes. Every vehicle coming from all the approaches for a period of 15 minutes was recorded on pre-prepared data collection sheets. Hourly counts were used as input data for analysis using the computer program Signalized and Unsignalized Intersection Design and Research Aid (aaSIDRA) (15).

*Software Selection*

The software used for data analysis is aaSIDRA, Version 2.0. The Australian Road Research Board (ARRB), Transport Research Ltd., originally developed the SIDRA package as an aid for design and evaluation of intersections such as signalized intersections; roundabouts, two-way stop control, and yield-sign control intersections. SIDRA was taken over by a private company that now supports the software. aaSIDRA 2.0 is the latest version.

In evaluating and computing the performance of intersection controls there are some advantages that the SIDRA model has over any other software model. The SIDRA method emphasizes the consistency of capacity and performance analysis methods for roundabouts, sign-controlled, and signalized intersections through the use of an integrated modeling framework. Another strength of SIDRA is that it is based on the *U.S. Highway Capacity Manual* as well as Australian Road Research Board research results. (16)

The input to the software includes the road geometry, traffic counts, turning movements, and speed of the vehicles. The SIDRA software analyzes the data and the output provides measures of effectiveness from which the performance of the roadway can be determined. There are 19 measures of effectiveness given in SIDRA output but only four of them were considered relevant to the project. The four measures of effectiveness (MOEs) used in evaluating the performance are as follows:
SIDRA uses a four-mode elemental model for estimating fuel consumption, operating cost and pollutant emissions for all types of traffic facilities. This helps with estimation of air quality, energy and cost implications of alternative intersection design. For this purpose, a unique vehicle drive-cycle model (acceleration, deceleration, idling, cruise) is used. See Figure 2 for details (17).

![Graphical Representation of Drive-Cycle Model Used by SIDRA](image)

**FIGURE 2. Graphical Representation of Drive-Cycle Model Used by SIDRA**

Fuel consumption and emission rates are calculated from a set of equations which use such vehicle parameters as mass and fuel emission efficiency rates, as well as road grade and relevant speeds (cruise, initial, final).

**Data Analysis**

The data collected from videotapes for the AM and PM periods was recorded manually in 15-minute periods, and hourly data was then input to the SIDRA software for analysis. All the MOEs were statistically compared using standard statistical procedures. Minitab 13 was the software used to perform the statistical tests. The data analysis was done separately for the AM and PM hourly volumes but the procedure followed was the same for both sets of data. This was done to see whether the results differed due to the differences in before and after traffic volumes for both AM and PM traffic counts, as there was more traffic during the PM period than during the AM period.

**RESULTS**

The statistical analysis of the MOEs helps determine if and how the Stop controlled Intersections and the Roundabout controlled Intersections differed in cutting down vehicular emissions. The analysis provides information to assess characteristics of the Stop Controls and the Roundabout. The statistical testing was done separately for the AM and PM periods for all the locations in order to evaluate the operation of the intersection during these separate periods. The results obtained for each site are then averaged and the overall results are given in Table 2.
TABLE 2. Overall Emissions Results

<table>
<thead>
<tr>
<th>Measures Of Effectiveness</th>
<th>SC</th>
<th>R.A</th>
<th>% Diff.</th>
<th>Statistically Different</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Monoxide (CO) Kg/Hr</td>
<td>9.77</td>
<td>7.67</td>
<td>-21%</td>
<td>Yes</td>
</tr>
<tr>
<td>Carbon Dioxide (CO2) Kg/Hr</td>
<td>138.91</td>
<td>117.18</td>
<td>-16%</td>
<td>Yes</td>
</tr>
<tr>
<td>Oxides Of Nitrogen (NOX) Kg/Hr</td>
<td>0.31</td>
<td>0.25</td>
<td>-20%</td>
<td>Yes</td>
</tr>
<tr>
<td>HydroCarbons (HC) Kg/Hr</td>
<td>0.23</td>
<td>0.19</td>
<td>-18%</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Note: SC: AWSC or TWSC, RA: Roundabout

- The average Carbon Monoxide (CO) emissions (Kg/hr) for the intersection locations studied are 21 percent and 42 percent less for the AM period and PM periods respectively for the case of a modern roundabout. Statistical tests showed that the decrease in CO emissions after a roundabout was installed is statistically different from the emissions that occurred in case of AWSC for both AM and PM conditions.

- The average Carbon Dioxide (CO2) emissions (Kg/hr) for the intersection locations studied are 16 percent and 59 percent less for the AM period and PM periods respectively for the case of a modern roundabout. Statistical tests showed that the decrease in CO2 emissions after a roundabout was installed is statistically different from the emissions that occurred in case of AWSC for both AM and PM conditions.

- The average Oxides of Nitrogen (Nox) emissions (Kg/hr) for the intersection locations studied are 20 percent and 48 percent less for the AM period and PM periods respectively for the case of a modern roundabout. Statistical tests showed that the decrease in NOx emissions after a roundabout was installed is statistically different from the emissions that occurred in case of AWSC for both AM and PM conditions.

- The average Hydrocarbons (HC) emissions (Kg/hr) for the intersection locations studied are 18 percent and 65 percent less for the AM period and PM periods respectively for the case of a modern roundabout. Statistical tests showed that the decrease in HC emissions after a roundabout was installed is statistically different from the emissions that occurred in case of AWSC for both AM and PM conditions.

- The results from SIDRA analysis also showed that there was a statistically significant decrease in delay, queuing and stopping after the modern roundabout was installed when compared to the before (AWSC/TWSC) because, as previous studies have concluded, the modern roundabouts have less delay, queuing and stopping than an AWSC/TWSC. This is reflected in the decrease in vehicular emissions shown above.

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CONCLUSIONS

- The modern roundabouts in Kansas operated more effectively than the before intersection control (AWSC/TWSC) in reducing vehicular emissions at all locations studied.
- There was a (21 percent to 42 percent) decrease in the Carbon Monoxide (CO) emissions (Kg/hr) for the AM and PM periods after the installation of modern roundabout. The decrease was observed to be statistically significant for both periods.
- There was a (16 percent to 59 percent) decrease in the Carbon Dioxide (CO₂) emissions (Kg/hr) for the AM and PM periods after the installation of modern roundabout. The decrease was observed to be statistically significant for both periods.
- There was a (20 percent to 48 percent) decrease in the Oxides of Nitrogen (NOx) emissions (Kg/hr) for the AM and PM periods after the installation of modern roundabout. The decrease was observed to be statistically significant for both periods.
- There was a (18 percent to 65 percent) decrease in the Hydrocarbons (HC) emissions (Kg/hr) for the AM and PM periods after the installation of modern roundabout. The decrease was observed to be statistically significant for both periods.
- Reduction in delays, queues and proportion of vehicle stopped at the intersection in the case of roundabouts suggest that roundabouts enhanced the operational performance of the intersections and account for the reduction in vehicular emissions.
- Since all the locations had a range of different traffic conditions, it is reasonable to suggest that a modern roundabout may be the best intersection alternative to reduce vehicular emissions for several other locations in Kansas with similar ranges of traffic volumes.

Overall Conclusion

Considering the above summary, it is concluded that at the intersections studied the modern roundabouts studied significantly reduced the vehicular emissions of the intersections studied by making the traffic flow orderly.

Further Study

Further studies should be conducted in other locations in United States with different traffic conditions, particularly those where volumes are high enough that a multi-lane roundabout is required, in order to get a much clearer picture. Also, field studies should be conducted using emissions detection equipment to further verify the results obtained from SIDRA.

REFERENCES


