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KTC-99-55
Conversion of New Circle Road
to a Limited Access Highway

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Research Report
KTC-99-55

CONVERSION OF NEW CIRCLE ROAD TO A LIMITED ACCESS HIGHWAY
(KYSPR-99-108)

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16. Abstract
The objectives of this study were to first evaluate the existing traffic conditions along the NE part of New Circle Road and investigate the use of unconventional left turn treatments, as well as other access restrictions to improve the operating conditions of New Circle Road. The alternatives examined include a do-nothing alternative, the addition of one through lane per direction, the use of median U-turns at various locations, and combinations of them. Restrictive left turn strategies proved to be a more successful tool for traffic management on New Circle Road than simply adding a lane in each direction. Using median U-turns, significant improvements were observed in all operating measures of the arterial. One of the main advantages to the improvements recommended in this study is that they can be constructed quickly and provide immediate improvement to arterial operating conditions without requiring any new right of way acquisition.

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EXECUTIVE SUMMARY

According to the Kentucky Transportation Cabinet, New Circle Road is classified as an urban arterial, but in its current state of operation it does not function as such due to a variety of reasons including a large number of traffic signals, several access points, and increased traffic volumes. To restore the operation of New Circle Road to its intended function as a primary arterial and to benefit the movement of traffic in the area major changes and access restrictions are required.

The focus of this report is to investigate the use of unconventional left turn treatments, as well as other access restrictions to improve the operating conditions of New Circle Road. It is expected that the elimination and rerouting of left turns at signalized intersections, in coordination with other access restrictions, will produce significant gains in the operational characteristics of the arterial without further road expansion. The study area was limited to the 5.6 miles of the unlimited access roadway which carries a volume well above its design volumes established in the 1950's.

Existing traffic data were utilized to simulate the level of operation of the existing conditions and establish the baseline for comparing the alternatives. This was accomplished through the use of a microscopic simulation model called CORSIM. The model was validated with field travel time studies and several measures of effectiveness were selected for the evaluation of the alternatives. Based on the existing right-of-way and geometries, it was decided that the best alternative to accommodate indirect left turns from New Circle Road is the use of median U-turns. These turns are placed 500 feet from the intersections, have one, 150-foot storage lane, and have a median opening of 60 feet.

The alternatives examined include a do-nothing alternative, the addition of one through lane per direction, the use of median U-turns at various locations (alternative 3: Palumbo Drive, Liberty Road, Eastland Drive, and Meadow Lane; alternative 4: alternative 3 plus at Bryan Station Road; alternative 5: alternative 4 plus at N. Limestone Street), and the use of additional lanes after implementing alternative 5.

Restrictive left turn strategies proved to be a more successful tool for traffic management on New Circle Road than simply adding a lane in each direction. The widening of New Circle Road to three lanes in each direction did not produce results that were more favorable than any of the other design alternatives that would implement median left turns. Using median U-turns, significant improvements were observed in all operating measures of the arterial. Average delay was the measure that improved the most at all intersections. The improvements were most notable at intersections where the median left turn design was placed. These intersections showed an improvement in operating conditions by as much as 60 percent. All intersections were not altered mainly due to either low left turn volumes which did not justify the cost of construction, or extremely high left turn volumes that could not be accommodated by a median left turn. At intersections with high left turn volumes, dual left turns were currently in place.

Based on the results of this study, alternative 5 is recommended for implementation. This design provides the greatest benefit to the arterial at the lowest cost. The traffic network showed a tremendous improvement in operating conditions with several of the selected measures of effectiveness showing an improvement of over 100 percent. As a minimum, we recommend the implementation of alternative 3 (median left turns at the intersections of Meadow Lane, Bryan Station Road, N. Limestone Street, and Palumbo Drive) to provide relief to the arterial. This alternative would not require a significant amount of construction and would be an excellent alternative to provide short-term improvement in arterial operating conditions. To fully evaluate costs of implementation, it is recommended that a more detailed analysis of the necessary construction be conducted. Other items, such as traffic control plans during construction and heavy vehicle traffic could affect the final recommendations for design.

One of the main advantages to the improvements recommended in this study is that they can be constructed quickly and provide immediate improvement to arterial operating conditions. In addition, the requirement for new right of way acquisition is minimal. The roadway is highly developed and the purchase of new right of way could be extremely expensive and require a significant amount of time for completion.

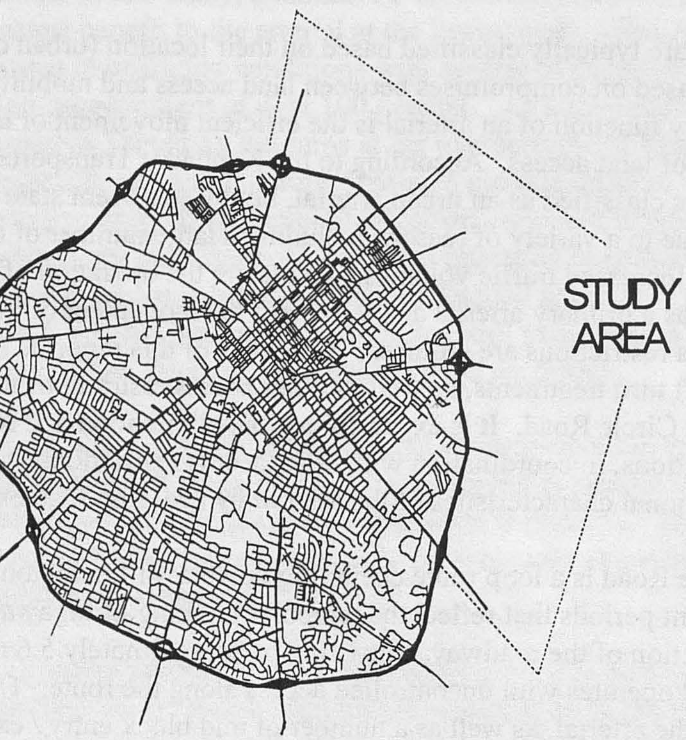
In conclusion, the use of restrictive left turn designs proved to be a successful method of traffic control for use on New Circle Road. The results evaluated from the traffic simulation model indicated that these designs improved a number of the measures of effectiveness selected to measure the performance of the network. Instead of initiating a costly construction program, traffic can be controlled in an innovative manner that makes better use of the existing infrastructure.

1.0 INTRODUCTION

Roadways are typically classified based on their location (urban or rural) and the function they accomplish based on compromises between land access and mobility (arterial, collector, or local). The primary function of an arterial is the efficient movement of traffic, while maintaining a reasonable level of land access. According to the Kentucky Transportation Cabinet (KyTC), New Circle Road is classified as an urban arterial, but in its current state of operation does not function as such due to a variety of reasons including a large number of traffic signals, several access points, and increased traffic volumes. To restore the operation of New Circle Road to its intended function as a primary arterial and to benefit the movement of traffic in the area major changes and access restrictions are required. The focus of this report is to investigate the use of unconventional left turn treatments, as well as other access restrictions to improve the operating conditions of New Circle Road. It is expected that the elimination and rerouting of left turns at signalized intersections, in coordination with other access restrictions, will produce significant gains in the operational characteristics of the arterial by avoiding road expansion.

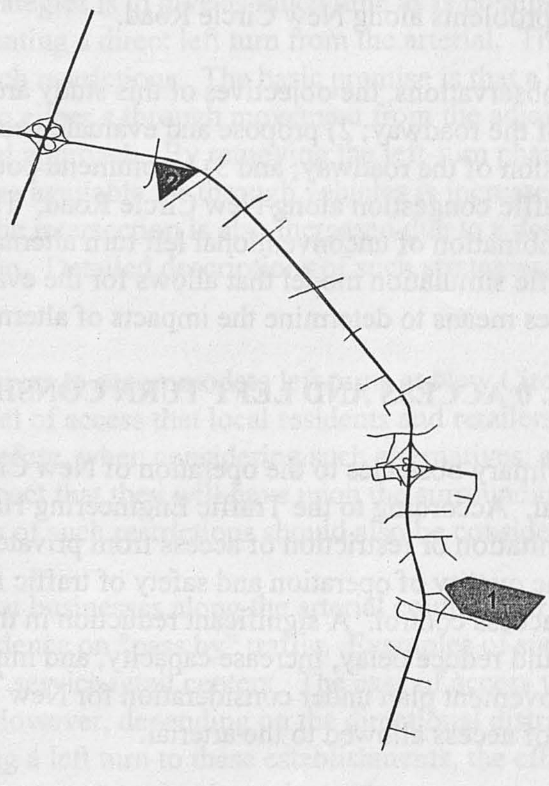
New Circle Road is a loop route encircling downtown Lexington. It was constructed during two different periods that reflect the temporal thinking of highway design used at the time. The first section of the roadway, consisting of approximately 5.6 miles, was constructed in the late 1950's and operates with uncontrolled access along the route. There are 19 traffic signals along this part of the arterial, as well as a number of mid block entry / exit points. This portion of the road was designed as a four-lane, two-way divided arterial with a median and exclusive turning lanes at all signalized intersections. The remainder of the roadway, approximately 13.7 miles long, was completed in the 1970's as a limited access roadway and was designed as a four-lane freeway with variable median width. Traffic volumes using the roadway today are almost twice as high as the original design volumes. Based on 1996 traffic counts, the average daily traffic was approximately 54,000 vehicles. Such high traffic volumes create significant traffic congestion and often influence the entire traffic network surrounding New Circle Road and require an extensive amount of time to be dissipated. The effects of traffic congestion are likely to be most severe on the unlimited access portion of this roadway due to interrupted flow conditions. The primary focus of the study will be the improvement of the operating conditions of the uncontrolled access portion of the roadway. A map showing the study area is shown in Figure 1. It should be noted here that from this point forward, all references to New Circle Road will refer to this part of the road.

Figure 1. Project study area



There are a number of recent developments in the area that will likely place an additional strain on the operating conditions of New Circle Road. One of the more intensive areas of housing development in Lexington at present is along Liberty Road, a roadway that intersects New Circle Road (Figure 2, Area 1). Upon completion, there will be a large amount of new traffic that will use New Circle Road to access other points in the area. Additionally, in the vicinity of the intersection of Russell Cave and New Circle Road, Wal-Mart is presently building a new retail facility that will significantly impact the volume of traffic using New Circle Road (Figure2, Area 2). The traffic generated by comparable Wal-Mart stores (~120,000 ft^2 of retail space) is approximately 6,829 vehicles per hour in the PM peak period (1). Even though many of these trips would be pass by trips (i.e. already existing on the network but making an intermediate stop at the development), a significant portion of them are expected to be new. In addition, it has been suggested that delay on urban freeways will increase as much as 1,000% from 1985 to 2005 in urban areas with population less than 1 million (2). While it is outside the scope of this study to fully evaluate the effects of such developments, it is important to consider the broader implication that they will have upon the operating conditions of New Circle Road.

Figure 2. New Circle Road future traffic generators



One of the primary obstacles facing the operation of New Circle Road is the conflict of operating conditions along the roadway. Previous studies conducted in the spring of 1996 by seniors in the Civil Engineering Department indicated that there are numerous intersections that disrupt the continuous flow of the through traffic along this portion of the arterial (3). In addition, there are a number of mid-block entry / exit points that disrupt traffic flow and result in an increased propensity for accidents along the route (4). The operation of the arterial could be improved by increasing the flow of the through traffic by examining and designing alternatives that would facilitate these movements, such as limiting, diverting, or eliminating direct access to the arterial. However, the primary concern for such designs would be to maintain existing levels of access or provide alternative ways to access the existing retail centers. It is clearly understood that limiting access to existing establishments would only create negative impacts to the acceptance of any plans by both the retailers and the public. Thus, the primary goal of this study is to produce alternative designs that would meet the needs of the general population as well as retailers, while improving traffic flow.

The residents of Lexington have long been calling for some type of improvement along New Circle Road to enhance the quality of travel options available for their use. In addition, this is the only route that provides any type of continuous loop around the city. However, under current operating conditions, there are severe delays to the through movement of traffic around the city. Through the use of innovative design measures, alternatives that present a significant improvement to travel conditions, without exhaustive construction costs, were developed to alleviate congestion problems along New Circle Road.

Given these observations, the objectives of this study are to 1) document and evaluate the existing operations of the roadway; 2) propose and evaluate geometric changes throughout the unlimited access portion of the roadway; and 3) recommend potential solutions to alleviate current and future traffic congestion along New Circle Road. These objectives will be achieved with the use of a combination of unconventional left turn alternatives and evaluated with the use of a microscopic traffic simulation model that allows for the evaluation of such urban traffic networks and provides means to determine the impacts of alternatives.

2. 0 ACCESS AND LEFT TURN CONSIDERATIONS

One of the primary obstacles to the operation of New Circle Road is the level of access allowed to the arterial. According to the Traffic Engineering Handbook, the control of access refers to the legal limitation or restriction of access from private properties to public highway right-of-way (5). The quality of operation and safety of traffic flow is greatly affected by the type and manner of access control. A significant reduction in the number of access points on New Circle Road could reduce delay, increase capacity, and improve the safety of the roadway. Therefore, any improvement plan under consideration for New Circle Road should consider changes to the level of access allowed to the arterial.

It has long been recognized that sound land use and development planning are essential to provide efficient and safe operation of an arterial. Coordinating roadway needs and zoning will significantly impact roadway congestion. A report recently completed indicates that a combination of measures could be used to improve flow along arterial streets including median U-turns, limiting median openings, and providing frontage roads (6). Restricting access from median openings other than at major intersections could significantly enhance the operation and safety of the arterial. For example, an arterial approximately 0.25 miles in length, with full median openings every 400 feet and two major intersections at both ends will have approximately 190 conflicts points. Limiting access to left turns only from the arterial, the same section will have 108 conflict points, while providing only for one median U-turn there will be only 85 conflict points. This is a typical length and frequency of access points along New Circle Road and similar gains in safety could be achieved applying these techniques.

Studies have also shown that such techniques improve flow, decrease delays, and increase capacity. The provision of median U-turns with reduced access could increase the capacity of intersections without left-turn lanes by 14 to 20 percent over intersection with dual left-turn lanes (7). Most of these gains are a result of a simpler phasing plan and reduced lost times at the signalized intersections. Benefits associated with cost reductions due to reduced right-of-way requirements and construction material could also be significant.

The second element of this study is the investigation of the use of restrictive left-turn strategies. The goal of such strategies is to give as much time as is possible to the through movement of vehicles by preventing a direct left turn from the arterial. There are a number of possible methods to achieve such restrictions. The basic premise is that a left turn from the arterial approach is converted to either a through movement from the adjoining side street or a right turn at the opposite arterial approach. By removing the left-turn phase from the signalized intersections, the amount of time available for through vehicles is increased appropriately. In addition, the overall safety of the intersection is also increased due to a decrease in the number of conflict points at the intersection. Detailed descriptions of such strategies under consideration are discussed later.

The use of such alternatives to accommodate left turns at New Circle Road may present special problems due to the level of access that local residents and retailers have been accustomed to receiving. Therefore, when considering such alternatives, a primary consideration is to consider the economic impact that they will have upon the surrounding businesses. In addition, any legal implications of such restrictions should also be considered.

There is a possibility that businesses along the arterial could suffer depending on the category of retail and its dependence on "pass by" traffic. Examples of such retail establishments are gas stations and other "fast" service retail centers. The ease of access will have an effect on the volume of such business. However, depending on the directional distribution of the traffic and present delays when making a left turn to these establishments, the effect may be minimal. Retail centers that primarily rely upon "destination oriented" customers may see a positive increase in their business volume. The decrease in delay of traveling to these establishments may entice customers who would not normally travel into the area to conduct business at these establishments. Typical examples of such retailers are grocery stores and other large retailers such as Sam's Club. The customers of such establishments have specific trip purposes in mind when traveling to their destination. As a result, access would not be an important factor in the customers' decision to frequent the retailer.

Attempts to quantify the effects of these restrictions in previous studies have achieved mixed results. Previous studies indicated a relationship between the loss of access to pass by traffic and business sales (8). However, due to the limitations of the present study it is difficult to examine such relationships. Overall, the conclusions reached on the effects of left-turn restrictions have shown wide variation. Some businesses were unaffected, some experienced gains, and some experienced losses. The variety of circumstances surrounding such projects make it very difficult to make any type of generalized inferences from previous studies. Political opinions, neighborhood support, and other variables that widely vary among communities have a significant effect on the perceived successes of such access restrictions.

In addition to the economic effects of these restrictions, there may also be legal concerns regarding their use. There are two main legal premises that apply to this situation. The first is the power of eminent domain, which is granted by statute to the state for various public purposes.

The basic concept is that states may take what land is necessary for a construction project, provided that just compensation is given to the landowner. This doctrine is commonly applied in the realm of highway construction. However, it is hoped that no additional right-of-way will be needed for any proposed improvements, but in such cases, the state may have to exercise its power of eminent domain. Many states also are allowed to exercise police power, which is the authority to regulate activities for the public's health, safety, and welfare. Proper exercise of police power does not require the payment of compensation to private parties. Some states have had great success in the use of this doctrine in situations regarding the implementation of access restrictions (9). If it is shown that the limitation of access results in a significant improvement to the safety of the roadway, the state should be justified in its actions.

In summary, the use of restrictive left-turn strategies has been gaining popularity across this country. Because of the tremendous growth in traffic volumes that communities experience, the capacity of our infrastructure has been stretched to its limits. Some individuals are of the opinion that we can simply build our way out of the crisis. However, massive construction is not the best alternative under the current condition of our transportation system. Such alternatives should be considered only after the evaluation of other less costly and less intrusive traffic control methods have been evaluated.

3.0 INNOVATIVE LEFT-TURN TREATMENTS

The purpose of restrictive left-turn designs is to provide an alternative method for vehicles to perform a left turn from an arterial. At most intersections, the left-turning movement is a significant contributor to delay at the intersection, as well as the source of several traffic accidents. An alternative to direct left turns at the intersection are U-turns, either in advance or after the intersection, which is an alternative that could improve safety and operational efficiency. Implementation of such movements allows for the prohibition of left turns either from the major street onto the minor or vice versa and offers the opportunity to eliminate unnecessary traffic signals or simplify existing signal phasing. At a typical four-leg intersection there are 32 conflict points and elimination of left turns along one direction could reduce the conflict points to 20. By prohibiting left turns at a signalized intersection, a simpler phasing plan can be used that would allow for longer green times for the through movements and thus more efficient operation. By prohibiting left turns at driveways, all such movements are routed to a major intersection and thus could be completed in a safer manner.

Several designs for U-turns have been developed and the appropriate one should be selected base on the traffic volumes and available space for its geometry. A brief description of each alternative design with its advantages and disadvantages is presented in the following.

3.1 Median U-turn

The median U-turn is a common restrictive left-turn strategy that has been used by some states for quite some time. The Michigan Department of Transportation (MDOT) has been using median U-turns for over 30 years, and has approximately 1,000 miles in service (7). Most recently, the state of Florida has implemented these strategies in a number of arterial improvement projects.

The median U-turn requires left turns to and from the arterial to use directional median crossovers (Figure 3). Left turns from the arterial pass through the intersection and enter into a storage lane that is constructed in the median. The vehicle is able to remain in this lane until there is a sufficient gap in arterial traffic to make a U-turn. The vehicle then makes a right turn at the intersection to access the desired side street. Left turns onto the arterial from the minor street make a right turn and then a U-turn at the median crossover to travel in the desired direction on the arterial. The directional crossovers may be signalized depending upon arterial volumes. The spacing of the crossover from the main intersection varies depending upon the volume of left turns; some agencies have found that a distance of 600 feet works best (6). Modifications of this design may be necessary depending upon the operating conditions of the intersection. Median crossovers (U-turn) may be placed on the minor street, as opposed to the arterial to reduce right of way requirements along the arterial (Figure 4). Additionally, the U-turns may be placed on both the arterial and the minor street to increase left turn capacity. The feasibility of either of these adaptations is highly dependent upon arterial left turn volumes, minor street traffic volumes, and geometric conditions at the intersection.

Figure 3. Median U-turn on arterial

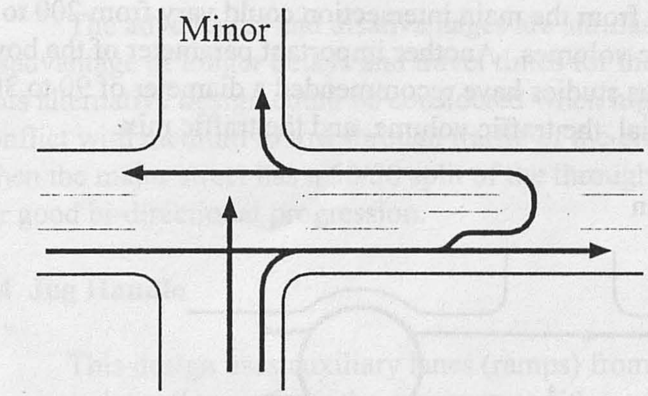
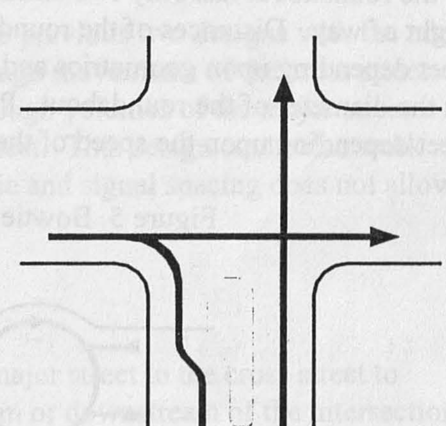


Figure 4. Median U-turn on cross street



The restriction of left turns at intersections offers advantages in a number of operational measures of the arterial. By eliminating left turns to and from the arterial, the major street is accommodated by one-phase of the signal. There is also a reduction in start up lost time associated with phase changes. This results in reduced delay to through arterial traffic, easier progression for through arterial traffic, fewer threats to crossing pedestrians, and fewer conflict points at the intersection.

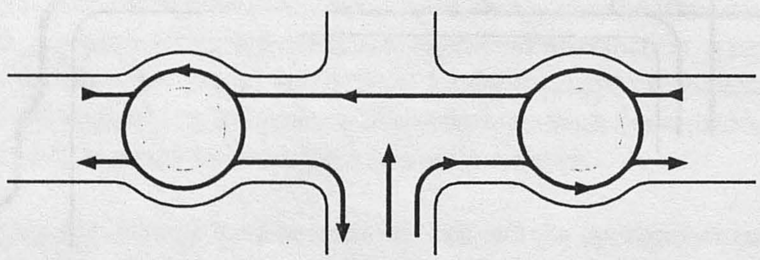
The median U-turn is most applicable where high arterial through volume conflicts with moderate or low left-turn volumes and any cross street through volumes. On arterials with high volumes of left turns, the increased delay and travel distance for left turns may outweigh the potential benefits to the through movement.

There are also disadvantages that can be attributed to left turn restrictions. Delay may increase for left turns, drivers may be confused initially, left-turn prohibitions may be disregarded, and travel distances for left turns may increase. While these disadvantages are acknowledged, it is felt that the benefits to the through movement will outweigh the negative affects to left turns. Moreover, since the primary function of an arterial is to service the through traffic, these disadvantages may be considered minor.

3.2 Bowtie

The bowtie is a variation of the median U-turn with the median and directional crossovers on the cross street. The bow tie is a new design that was first conceived at the University of North Carolina in 1992 (10) and has seen limited use across the country. The bowtie design (Figure 5) uses roundabouts rather than median crossovers to accommodate left-turning movements from the arterial. In order to perform a left-turn movement, vehicles will make a right turn onto the minor street, proceed around the roundabout and then proceed through the main intersection to complete the maneuver. Vehicles entering the roundabout must yield to traffic in the circle, but if the roundabout has only two entrances, the traffic entering from the main street will have the right of way. Distances of the roundabout from the main intersection could vary from 200 to 600 feet depending upon geometrics and traffic volumes. Another important parameter of the bowtie is the diameter of the roundabout. Previous studies have recommended a diameter of 90 to 300 feet depending upon the speed of the arterial, the traffic volume, and the traffic mix.

Figure 5. Bowtie design

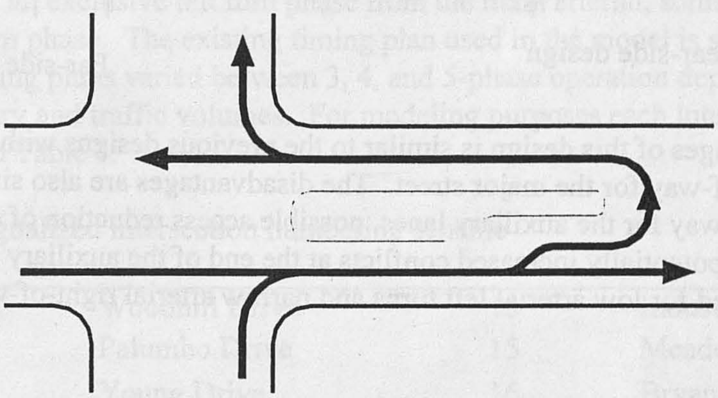


The advantages and disadvantages are similar to those of median U-turns with the added disadvantages of additional travel distance for some movements (U-turns from a street) and significant larger right-of-way for the cross street. This design works well when high arterial through volumes interact with low left-turn volumes from the arterial and low to medium through volumes form the cross street.

3.3 Super-street

This design is an extension of the median U-turn, where the though movements from the cross street and the left turns to and from the major street are completed through the median crossovers (Figure 6). This design allows for the creation of two independent three leg intersections that could be timed independently from each other and thus allow for better progression in both directions of traffic. Even though this design is promising, no agency has implemented it completely, but it has been used in one direction only.

Figure 6. Super-street design

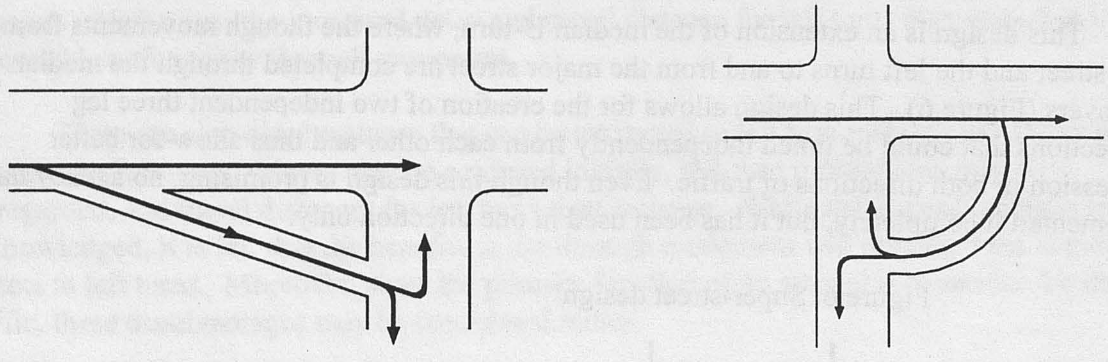


The advantages and disadvantages are similar to the previous two designs with the added disadvantage of longer delays and travel times for the through movements of the cross street. This alternative design could be considered when high through volumes of the major street conflict with medium to low through traffic of the cross street. This design could also work when the major street has a 50/50 split of the through traffic and signal spacing does not allow for good bi-directional progression.

3.4 Jug Handle

This design uses auxiliary lanes (ramps) from the major street to the cross street to accommodate all turns from the major street either upstream or downstream of the intersection (Figure 7). Left turns from the major street turn right at the auxiliary lane and then turn left at the intersection of the lane with the cross street. The terminals of the auxiliary lanes are usually stop controlled or could be yield controlled with channelization.

Figure 7. Jug handle design



The advantages of this design is similar to the previous designs with the added advantage of narrower right-of-way for the major street. The disadvantages are also similar but include the additional right-of-way for the auxiliary lanes, possible access reduction of developments close to these lanes, and potentially increased conflicts at the end of the auxiliary lane. This design should be considered for low arterial left turns and narrow arterial right-of-way.

3.5 Summary

There are several alternative designs for accommodating indirect left turns from arterial streets. All produce similar benefits, reduced delays and increased safety, but they have different right-of-way requirements. For streets with existing medians of approximately 12 to 15 feet, the median U-turns could be the preferred solutions with respect to space requirements. The super street design could also be accommodated on such streets. The bowtie design is the one that requires the most space and the benefits that could be materialized from the indirect left turns could be offset by the longer delays of these movements while completing their left turn. Finally, the jug-handle design may increase the efficiency of the movements but may also simply shift the conflict points at the end of the ramps.

Given all these considerations and the existing geometric layout of New Circle Road, it was concluded that the most appropriate design that would minimize construction time and costs, limit right-of-way acquisition, and efficiently use the existing facility was the median U-turn.

4.0 METHODOLOGY

4.1 Data Sources

The primary sources of data used in this study were the Lexington Fayette Urban County Government (LFUCG) and the Kentucky Transportation Cabinet.

The LFUCG provided traffic counts and signal timing plans for the weekday a.m., mid-day, and p.m. peak periods. The most recent traffic counts available were conducted during the early months of 1998. Each count was performed for a period of two hours. Traffic volumes used in the model were calculated using the four highest consecutive 15-minute intervals during the course of each two-hour count. After analyzing all traffic volumes, it was determined that the PM peak period experienced the largest amount of traffic. For that reason, the PM peak traffic counts were used in the model. Due to the difficulties of accurately predicting future traffic volumes, only existing traffic was used in the evaluation of each alternative.

The traffic signals currently have a 155-second cycle length. At every signalized intersection there is an exclusive left turn phase from the main arterial, some side roads also had an exclusive left turn phase. The existing timing plan used in the model is shown in Appendix A. Intersection timing plans varied between 3, 4, and 5-phase operation depending on the intersection geometry and traffic volumes. For modeling purposes each intersection was given a number as shown in Table 1.

Table 1. Signalized intersection numbering scheme

2	Woodhill Drive	13	Industry Drive
3	Palumbo Drive	15	Meadow Lane
4	Young Drive	16	Bryan Station Road
6	Liberty Road	17	N. Limestone Street
8	Family Circle	18	N. Broadway Road
9	Trade Center Drive	19	Russell Cave Road
10	Jingle Bell Lane	20	Boardwalk Road
12	Eastland Drive		

In addition to the data mentioned above, the LFUCG ArcView GIS coverage was also utilized to obtain distances between intersections in the network. While the accuracy of the files used in ArcView was a concern, the research team decided that they would be sufficient for the purposes of this study.

The KyTC provided plans from the original construction of New Circle Road. An attempt was made to obtain more recent images and plans of the area. However, the most recent collection of data available was found on Microfiche at the Lexington District Office of the KyTC. The plans were used to aid in the identification of openings in the median, turning bay lengths, and intersection geometries. All observations from the plans were investigated in the field and adjusted in the model as necessary. In addition, the Microsoft terra-server was also used to view aerial photographs of the area. The aerial photographs were taken in 1993, so there were many deviations observed in comparison to the current conditions.

4.2 Simulation Model

Traffic simulation has evolved into a valuable tool for evaluating potential improvements to the transportation system. Using simulation, engineers are able to provide valuable evaluations of infrastructure improvements so that cost efficient designs providing significant operational benefits can be identified prior to construction. Benefits of traffic simulation over traditional field studies include:

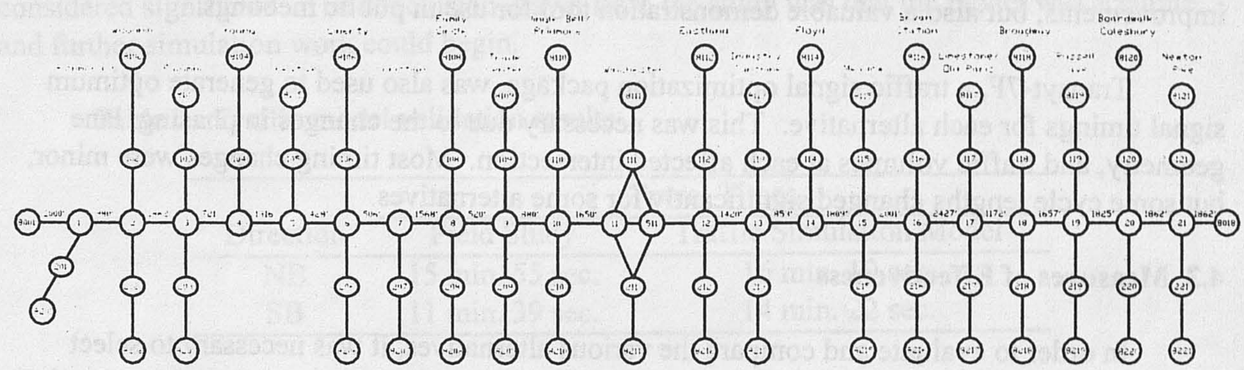
- Reduced costs;
- Short time for obtaining results;
- Generation of several measures of effectiveness that cannot be easily obtained from field studies;
- Avoidance of disruption to traffic operations, which often accompanies field experiments;
- Evaluation of designs requiring significant physical changes to the facility; and
- Evaluation of the operational impact of future traffic demand.

The traffic simulation software predominantly used for this project was the Traffic Software Integrated System (TSIS). The TSIS simulation package was developed by the Federal Highway Administration (FHWA) for a variety of functions associated with traffic simulation. The component of the software package used for this project is CORridor SIMulation or CORSIM. This model is actually the combination of two simulation components, NETSIM and FRESIM. NETSIM is a stochastic, microscopic simulation model for urban traffic network analysis, and FRESIM is a stochastic, microscopic simulation model for the modeling of freeway traffic operations. CORSIM simulates traffic conditions in a user defined traffic network for a specified period of time. It tracks individual vehicles throughout the simulation period and collects statistics used in the generation of Measures of Effectiveness (MOE) that allow for network evaluation.

The data entry required for CORSIM is fairly intensive. The parameters that must be entered into the model include the following:

- Topology of the roadway system in the form of a link-node diagram (Existing network is shown in Figure 8);
- Geometrics of each roadway component;
- Channelization of traffic (left, through, right, etc.. .);
- Motorist behavior that determines the operational performance of vehicles in the system (acceleration, deceleration, gap acceptance, and yellow light response);
- Traffic control devices (stop, yield, and signal timing);
- Traffic volumes entering the network;
- Turn movements in the form of percentages or turning counts;
- Traffic mix (cars, carpools, trucks, and buses).

Figure 8. Link-node diagram for CORSIM



The data structure for CORSIM is in the form of a text file with a number of record types, or card types. Each entry is assigned a record type and has assigned column positions for various network parameters. There are currently graphical interfaces that can be used to create CORSIM data sets. However, at the onset of the study no such software package was available.

To ensure that the vehicles utilizing the median U-turn are turning right at the major intersection, i.e. simulate the actual vehicle path, a special feature of CORSIM was implemented that is called a conditional turn movement. This process allows the user to determine the exact path of these vehicles and thus guarantee that they would follow the desired path and not become a through vehicle at the next intersection. By utilizing this feature, vehicle operations were customized so that the simulation matches the real life scenario and the MOE collected represent the actual field operations.

Since CORSIM is a stochastic simulation program, results can vary significantly depending upon the random number seeds used to assign driver and vehicle behavior. For this reason, different sets of random numbers were used for each alternative to generate a set of five simulation runs. Results were then averaged to obtain MOE that were deemed characteristic of the alternatives under evaluation. There were a total of 35 simulation runs for the final product of alternatives. Each simulation was conducted for one hour of traffic operations. To ensure that the network has reached equilibrium at the beginning of each simulation an initialization period of 15 minutes was used. The equilibrium condition ensures that a sufficient number of vehicles are circulating through the network prior to the commencement of the simulation and collection of MOE.

Another important component of the TSIS simulation package is TRAFVU. TRAFVU is an animation processor for viewing simulation results generated with CORSIM and provides an intuitive view of traffic conditions. It provides an interface similar to a VCR that allows the user to view the entire simulation and move forward and reverse at any point in time. The user is able to view vehicles in the network, signal operations, and can control the level of detail on the screen. TRAFVU also has a built in graphing tool that allows the user to view statistics generated by the simulation. This is not only a useful tool for the user in the evaluation of traffic improvements, but also a valuable demonstration tool for use in public meetings.

Transyt-7F, a traffic signal optimization package, was also used to generate optimum signal timings for each alternative. This was necessary due to the changes in phasing, lane geometry, and traffic volumes at each affected intersection. Most timing changes were minor, but some cycle lengths changed significantly for some alternatives.

4.3 Measures of Effectiveness

In order to evaluate and compare the various alternatives, it was necessary to select measures of effectiveness generated by CORSIM. Several such measures were selected and are described here along with the rationale for their selection.

- *Move / Total Time Ratio*: this is the ratio of move time to total time for vehicles traveling through the network. This ratio provides a valuable evaluation of operating conditions in the network because it shows the proportion of time that a vehicle is moving when in the study area.
- *Total Delay*: this is defined as the difference between actual travel time and the travel time if a vehicle were constantly moving at the free flow speed.
- *Average Delay*: this is the total delay divided by the total number of trips through a link or through the network. It is a measure of how much time a vehicle is delayed when traveling in the network.
- *System Speed*: this is the average speed at which vehicles in the network are traveling in the network. It is a good measure of the overall operating conditions of the network.

All of the previously defined MOE are easily understood, show the quality of traffic flow through the network, and can be used to determine areas where improvements may be needed. In addition to these measures, other descriptive statistics, such as queue times, stopped delay, number of failed cycles, and vehicles in queue, were viewed as deemed necessary to identify and remedy any special problems in the network.

4.4 Field Study

Field studies were conducted to obtain lane geometries, speed limits, type of intersection control, lane markings, and turning pocket lengths. In addition, travel time studies were conducted to calibrate the traffic simulation model. During the hours of 4:00 to 6:00 p.m, individuals traveled through the entire length of the study area to observe traffic operations and record travel times. Two passes were made in each direction and total travel times were recorded. The results were then averaged and compared to travel times that were predicted by the simulation model of the existing conditions. It was found that the travel times predicted by the model were in very close agreement with those observed in the field. Table 2 shows the field study results and the results obtained from the model. The larger variation was in the SB travel times. However, when the field studies were conducted there was also large variation noted in the travel times that were measured in this direction. Therefore, this discrepancy was not considered significant. The conclusion drawn from the study was that the model was accurate and further simulation work could begin.

Table 2. Traffic model validation results

	Travel Times	
Direction	Field Study	Traffic Simulation Model
NB	15 min. 55 sec.	16 min. 19 sec.
SB	11 min. 39 sec.	14 min. 22 sec.

5.0 EXISTING CONDITIONS

The existing conditions of New Circle Road were evaluated using data from the sources discussed above. The simulation results indicate that system wide performance was less than desirable. The overall system speed was 15.4 mph, which is approximately 1/3 of the free flow speed of the route. In addition, the move to total time ratio was 0.35, which indicates that vehicles in the network were stopped approximately 65% of the time they were in the network. The average trip delay was significantly high (3.4 minutes/trip) and the total delay was also high (854.72 veh-hr). Table 3 shows a summary of these MOE at each intersection in the network. Since the primary focus of this project is the main arterial, New Circle Road, only links associated with the major intersection approaches were evaluated for the existing conditions and other alternatives evaluated.

Table 3. Intersection performance measures for existing conditions

Intersection number	Total delay (veh-min)	Average delay (sec/veh)	Move / Total time	Speed (mph)
2	1076.86	39.01	0.43	19.23
3	579.07	24.29	0.42	19.10
4	144.38	5.31	0.73	32.88
6	1382.21	47.86	0.14	6.18
8	640.43	20.25	0.51	22.78
9	477.99	16.35	0.39	17.57
10	206.63	7.43	0.63	28.53
12	1566.43	58.34	0.16	7.40
13	331.76	13.19	0.58	26.01
15	987.40	37.79	0.46	20.57
16	1230.08	51.28	0.42	18.89
17	1557.12	64.82	0.30	13.57
18	1086.05	45.76	0.32	14.52
19	1175.69	48.64	0.36	16.00
20	887.07	35.44	0.52	23.59

The individual intersection performance measures showed that there are significant delays at intersections 2, 3, 6, 12, 15, 16, 17, 18, 19, and 20. These results were used to identify areas where improvements might be of greater benefit to the arterial.

6.0 DESIGN ALTERNATIVES

Upon the completion of the evaluation of existing conditions, problem areas were identified and control strategies were implemented as deemed necessary. The first design alternative that was evaluated did not make use of any innovative left-turn designs and it was simply a new timing plan to accommodate the existing volumes (alternative 1). To establish early in the process the impact of the addition of a third lane in each direction this alternative design was examined next (alternative 2).

Additional design alternatives used innovative left-turn treatments in the form of median left turns. Initially, a number of innovative left-turn designs were considered for implementation. However, after field observations it was determined that other alternatives would require considerable right of way acquisition and therefore, make other designs prohibitively expensive. Therefore, the median left turn was the only design that was evaluated using the simulation model. All median left turns are designed with a median opening 500 feet from the intersection with a 150-foot storage bay, stop controlled access, and a 1-lane approach.

If an intersection had a significantly low volume of left turns, the potential benefits would not justify the costs associated with the construction of the proposed left-turn restriction. Therefore, intersections were considered for left-turn restriction based on left turn volumes and the potential benefits that might be gained by diverting left turns from the intersection. Intersections that had at least 150 left turning vehicles per hour were considered for modification. Such a volume of left turns required a significant portion of the cycle length to carry out the movement. Moreover. based on prevailing cycle lengths for New Circle Road, a volume of approximately 60 vehicles can be accommodated during the yellow interval and do not require an additional phase. Therefore, the elimination of left turns would return the left-turn portion of the cycle length to the through movement, thus decreasing delays and increasing the number of through vehicles that can be moved through the network. In addition, the ease of installation and the cost of construction for median left turns was considered.

The data shown in the following tables are only for the approaches around New Circle Road. Since the primary objective of the study is to evaluate the impacts along this road it was considered essential to isolate the possible positive or negative effects of the side streets. The impact of such alternatives on the entire network is demonstrated later.

6.1 Alternative 1

The first step in the analysis was to optimize the timing of all intersections along the arterial. Using Transyt-7F, an optimized timing plan was obtained for each intersection. In addition to signal timings, offsets were also optimized by the program. The timing plan appears in Appendix A.

The network wide measures of performance showed that there was an increase in various MOE when compared to the existing simulation results: the system speed was increased by 0.74 mph, the average (3.22 min/trip) and total (841.67 veh-hr) delay were slightly reduced, and the move / total time ratio remained almost unchanged (0.36). All of these measures indicate a slight improvement in overall network performance, but these gains were almost insignificant. The individual intersection MOE for the optimized timings appear in Table 4. The individual intersection performance measures revealed mixed results. Liberty Road exhibited significant gains in operating efficiency. Most other intersections saw a slight improvement, or deterioration of operating conditions.

Table 4. Intersection performance measures for alternative 1

Intersection number	Total delay (veh-min)	Average delay (sec/veh)	Move / Total time	Speed (mph)
2	928.05	33.35	0.46	20.92
3	636.63	26.84	0.40	18.03
4	145.99	5.34	0.73	32.73
6	988.67	33.72	0.19	8.55
8	565.84	17.77	0.54	24.08
9	408.90	13.88	0.43	19.34
10	232.72	8.20	0.61	27.43
12	3173.54	128.99	0.09	4.15
13	585.25	38.58	0.47	21.26
15	1035.99	38.58	0.44	19.94
16	2377.49	61.06	0.38	17.31
17	1530.22	60.41	0.32	14.19
18	1447.32	60.34	0.27	12.24
19	1421.19	57.12	0.32	14.40
20	777.94	30.40	0.56	25.20

6.2 Alternative 2

The addition of a through lane in each direction was evaluated prior to the use of any restrictive left turn strategies. This would make New Circle Road a six-lane roadway, with three lanes in each direction. Since the addition of lanes is the most common method used to increase roadway capacity, this alternative was evaluated for comparison purposes with other alternatives. The system wide performance measures compared to the existing conditions showed a significant improvement. The system speed increased to 17.8 mph, the average delay decreased (2.65 min/trip), the total delay decreased (703.02 veh-hr), and the move / total time ratio increased to 0.41.

Table 5 shows the intersection performance measures for the addition of a through lane in each direction. The intersections of Liberty Road, Family Circle, Industry Drive, Meadow Lane, N. Limestone Street, Russell Cave Road and Boardwalk showed the greatest improvement. Reduction in average delay ranged from 15 to 70 % of delays that exist under current operating conditions. These results will be discussed in more detail later after presenting all the other improvements to the arterial.

Table 5. Intersection performance measures for alternative 2

Intersection number	Total delay (veh-min)	Average delay (sec/veh)	Move / Total time	Speed (mph)
2	988.60	34.77	0.46	20.54
3	814.29	32.86	0.36	15.92
4	143.77	5.07	0.74	33.17
6	782.38	26.18	0.23	10.28
8	195.00	6.10	0.72	32.40
9	749.29	24.23	0.30	13.60
10	295.92	10.32	0.59	26.41
12	1608.69	53.90	0.19	8.51
13	152.39	5.89	0.74	33.55
15	625.23	23.56	0.56	24.94
16	1215.55	48.02	0.41	18.47
17	992.70	38.82	0.40	18.15
18	1743.79	68.27	0.24	10.68
19	1062.71	40.38	0.41	18.26
20	776.53	30.07	0.56	25.31

6.3 Alternative 3

Design alternative 3 is the placement of median left turns at the intersections of Palumbo Drive, Meadow Lane, Bryan Station Road, and N. Limestone Street. These intersections were selected because of high delays due to the left turns that were identified by evaluating the existing conditions. The intersections of Meadow Lane, Bryan Station Road, and N. Limestone Street are spaced in succession along the route. Observations in the field and from the computer simulation of the existing conditions indicated that these intersections were a significant source of congestion. These observations indicated that traffic, prior to entering this group of intersections, appeared to flow fairly smoothly. In an effort to alleviate this congestion, these intersections were considered together. Similar conditions were observed at the intersection of Palumbo Drive: traffic volumes entering the intersection were fairly heavy and this intersection did not provide adequate capacity to accommodate the through traffic. In addition, this intersection appeared to have similar levels of delay associated with its left turns as the other three intersections. Finally, these intersections appeared to require the smallest amount of construction for implementation of the designs. The three intersection group will require the least amount of construction due to the presence of suitable median openings near the intersections. However, some modification may be required to complete the geometric requirements for the turning lanes.

The system wide performance measures showed significant improvement in the operation of the network as compared to the current operating conditions. The system speed increased by 2.6 mph, the average and total delay times decreased by approximately 20 percent (2.45 min/trip and 646.71 veh-hr, respectively), and the move / total time ratio increased to 0.41. These measures indicate that the network is operating more efficiently compared to its current operating conditions. The intersection performance measures are shown below in Table 6. The intersections that were directly affected by the changes appear in bold italics.

Table 6. Intersection performance measures for alternative 3

Intersection number	Total delay (veh-min)	Average delay (sec/veh)	Move / Total time	Speed (mph)
2	1216.60	29.51	0.41	18.48
3	***181.56***	***3.87***	***0.71***	***31.74***
4	111.70	3.33	0.76	34.10
6	1101.02	42.12	0.14	6.48
8	266.43	9.60	0.59	26.55
9	356.05	13.60	0.44	19.73
10	320.23	12.57	0.50	22.71
12	1346.50	54.26	0.18	8.15
13	172.12	8.02	0.68	30.47
15	***335.00***	***5.97***	***0.66***	***29.56***
16	***598.49***	***8.43***	***0.58***	***26.30***
17	***441.62***	***7.65***	***0.57***	***25.63***
18	1097.49	37.20	0.30	13.68
19	928.03	40.07	0.40	17.80
20	815.08	33.13	0.54	24.35

6.4 Alternative 4

Design alternative 4 built upon alternative 3 by adding a median left turn lane at the intersection of Liberty Rd. This intersection was selected due to high delays and low link speeds that persisted after alternative 3 was implemented. The system performance measures were further improved compared to alternative 3: a noticeable increase in the system speed (18.06 mph), a small reduction in delays (2.37 min/trip average and 625.56 veh-hr total), and a slight increase in the move / total time ratio (0.42). Compared to the existing conditions, the system speed increased by 2.7 mph, the move / total time ratio increased by 18 percent, and the total and average delay were decreased by 27 and 30 percent, respectively.

The individual intersection performance measures are shown in Table 7. The simulated operating conditions of Liberty Road showed significant improvement with the implementation of the median left turn lane. The results for this intersection compared to the existing conditions, shown in bold, indicated that total delay was reduced by 57 percent, average delay decreased by over 30 seconds per vehicle, and the move / total time ratio increased 84 percent. In summary, this design produced overwhelming improvements in the operation of the intersection of Liberty Road, and therefore, improved the operation of the entire system.

Table 7. Intersection performance measures for alternative 4

Intersection number	Total delay (veh-min)	Average delay (sec/veh)	Move / Total time	Speed (mph)
2	992.97	25.89	0.45	20.22
3	236.67	5.11	0.63	28.50
4	306.20	6.34	0.58	25.88
6	***591.38***	***15.49***	***0.25***	***11.25***
8	372.94	13.15	0.57	25.62
9	377.21	14.48	0.42	18.98
10	279.69	11.42	0.55	24.93
12	1231.79	49.20	0.20	8.71
13	192.19	8.79	0.65	29.37
15	772.26	13.46	0.47	21.07
16	541.16	7.40	0.60	27.20
17	496.80	8.20	0.56	25.05
18	1115.68	37.89	0.30	13.74
19	985.58	41.58	0.39	17.43
20	693.89	27.47	0.59	26.54

One potential problem that may exist for the implementation of this alternative is the presence of an entrance to the arterial just south of the intersection. However, this entrance is from a relatively small cluster of business offices. The most desirable modification would be to make this entrance right in / right out. The vehicles that previously made a left turn at this exit would now need to use the main intersection. This is not viewed as a major problem since the sequence of vehicle movements is very similar for either treatment.

6.5 Alternative 5

An additional median left turn lane was installed at the intersection of Eastland Dr. for this design alternative in addition to those presented in alternative 4. This intersection exhibited extremely poor operating conditions in the analysis of the existing conditions. This alternative also showed significant improvements in the network-wide operating conditions. Compared to the existing conditions, the system speed increased by 3.6 mph, the move / total time ratio increased by 24 percent (0.44), the average delay was decreased by 36 percent (2.19 min/trip), and the total delay was also decreased by 32 percent (582.78 veh-hr).

The individual intersection performance measures are shown in Table 8. The intersection performance measures for Eastland Drive showed significant improvement from previous results. The results for this intersection compared to the existing conditions, shown in bold, indicated that total delay was reduced by 58 percent, average delay decreased by over 40 seconds per vehicle, and the move / total time ratio increased by 95 percent.

Table 8. Intersection performance measures for alternative 5

Intersection number	Total delay (veh-min)	Average delay (sec/veh)	Move / Total time	Speed (mph)
2	1212.25	29.75	0.41	18.42
3	275.65	5.78	0.60	26.86
86	116.91	2.33	0.75	33.72
6	746.83	19.37	0.21	9.60
8	295.77	10.53	0.57	25.60
9	318.06	11.70	0.47	21.37
10	279.69	11.42	0.55	24.93
12	***625.91***	***18.02***	***0.32***	***14.51***
13	245.43	6.82	0.63	28.39
15	685.37	12.01	0.50	22.55
16	539.31	7.47	0.60	27.03
17	457.71	7.71	0.57	25.87
18	1007.65	33.50	0.32	14.41
19	908.55	38.03	0.41	18.47
20	645.13	25.57	0.61	27.39

6.6 Alternative 6

For this design alternative, all of the previous median left turns were included and a through lane was added in each direction along the entire length of arterial. The system-wide performance measures showed a considerable improvement compared to the existing conditions. The system speed increased by 5.36 mph, the move / total time ratio increased 35 percent, and the total and average delay were decreased by 42 and 46 percent, respectively.

Table 9 shows the individual intersection performance measures. As is indicated by these measures, all intersections showed dramatic improvement. The operating conditions improved the most at intersections where median left turns were used in conjunction with the widening of the roadway. However, the intersections of Woodhill Drive, Broadway, and Russell Cave, which were not modified previously, also exhibited significant improvement in their operating conditions.

Table 9. Intersection performance measures for alternative 6

Intersection number	Total delay (veh-min)	Average delay (sec/veh)	Move / Total time	Speed (mph)
2	1088.57	28.00	0.43	19.33
3	259.47	5.46	0.63	28.29
4	158.33	3.11	0.69	31.24
6	588.32	15.19	0.26	11.68
8	194.78	6.85	0.69	31.10
9	323.81	11.68	0.47	21.10
10	267.69	10.01	0.56	25.29
12	616.83	16.78	0.33	14.92
13	182.92	4.63	0.72	32.20
15	694.29	12.10	0.50	22.28
16	414.32	5.66	0.66	29.90
17	426.75	7.10	0.59	26.56
18	856.69	27.84	0.36	16.00
19	892.70	38.16	0.41	18.36
20	635.35	26.08	0.60	26.91

6.7 Summary and Discussion of Alternatives

Table 10 shows a summary of the percentage changes in system-wide performance measures for each alternative. These percentage gains are in respect to the existing conditions.

Table 10. Summary of percentage changes in network-wide operating MOE

	Move /Total time	System speed (mph)	Total delay (veh-hr)	Average delay (min / veh-trip)	Composite Rating
Alternative 1	2.82	2.47	(-) 1.52	(-) 5.18	12.00
Alternative 2	15.82	15.89	(-) 17.75	(-) 22.18	71.64
Alternative 3	15.25	14.58	(-) 24.34	(-) 27.88	82.05
Alternative 4	18.08	17.58	(-) 26.81	(-) 30.18	92.65
Alternative 5	24.29	23.44	(-) 31.82	(-) 35.71	115.26
Alternative 6	35.03	34.90	(-) 41.77	(-) 45.76	157.46

Notes: 1. Note that the total delay and average delay actually decreased, which indicates positive results, but the percentages are represented as positive numbers for comparison purposes.
2. The composite rating is calculated by summing all percentage gains / losses in operating measures for the specific design alternative.

The data in Table 10 indicate that the network efficiency improved with each design scenario. Alternative 6 produced the greatest gains in operating efficiency with a composite rating of 157.46, but it is also the most expensive alternative to construct. It is also of interest to note that alternative 2, which widened New Circle Rd. to three lanes in each direction did not produce results that were more favorable than any of the other design alternatives that implemented median left turns. Alternative 3 has a composite rating of 82.05, which is 10 points higher than alternative 2. In addition, the construction and implementation costs for alternative 3 are significantly lower in comparison to those of alternative 2. These data indicate that the installation of median left turns would provide significant benefits to the operation of the traffic network compared to existing conditions.

For further insight into the performance of the median left turn, a single intersection will be analyzed to show the benefits that the median left turn provides. Intersection 16, the intersection of New Circle Road with Bryan Station Road is used in this analysis to show the effects of the design scenarios at individual intersections. A median left turn was implemented at this intersection in alternative 3. Table 11 shows the existing traffic volumes which indicate significant left-turn volumes from New Circle Road (SB and NB approach) and moderately heavy traffic on Bryan Station Road.

Table 11. Traffic volumes at Bryan Station Road

Movement	SB	WB	NB	EB
Left	325	223	150	90
Through	1,115	145	1,110	223
Right	95	200	133	125
Total	1,535	568	1,393	454

Table 12 shows the improvement in intersection operating measures with the implementation of each design alternative. The existing conditions performance measures are shown as the actual number and the design alternatives are shown as the percentage gain / loss.

Table 12. Percentage improvement in intersection performance measures for intersection 16

	Move /Total time	System speed (mph)	Total delay (min / mile)	Average delay (veh-min)	Composite Rating
Existing conditions	1230.08	51.28	0.42	18.89	----------
Alternative 1	-93.28	-19.07	-8.81	-8.36	-129.52
Alternative 2	1.18	6.36	-1.90	-2.22	3.41
Alternative 3	51.35	83.57	39.14	39.22	213.28
Alternative 4	56.01	85.57	43.89	43.97	229.43
Alternative 5	56.16	85.42	43.04	43.11	227.73
Alternative 6	66.32	88.96	58.18	58.26	271.72

For this intersection, alternative 1 actually had a negative effect and alternative 2 produced a very small increase in performance measures with a composite rating of 3.41. The implementation of the median left turn showed a tremendous increase in performance for this intersection. The composite rating jumped to 213.28. This indicates that the intersection performance measures increased by over 200 percent. The intersection operation was further improved with the implementation of the other design alternatives. The individual evaluation of this intersection shows the positive benefits of the median left turn.

An obvious concern that has not been addressed is the effect that the median left turn has on the side street approaches of the intersection. This intersection also provides valuable insight as to the magnitude of these effects because the side street volumes (WB and EB in Table 10) are quite significant. Table 13 shows the improvement in performance measures for the side street approaches at intersection

Table 13. Percentage improvement in intersection performance measures for side streets at intersection 16

	Move /Total time	System speed (mph)	Total delay (min / mile)	Average delay (veh-min)	Composite Rating
Existing conditions	1378.85	213.55	0.044	1.55	-----------
Alternative 1	32.44	44.38	95.45	90.32	262.60
Alternative 2	56.92	66.33	190.91	187.10	501.25
Alternative 3	50.08	60.49	156.82	154.19	421.58
Alternative 4	39.62	51.52	115.91	112.26	319.31
Alternative 5	53.77	63.75	179.55	176.13	473.19
Alternative 6	62.33	70.70	222.73	218.71	574.47

Table 13 shows that side street operations were not adversely affected by the implementation of median left turns. In fact, the side street MOE actually showed a dramatic increase with composite ratings ranging from 262.6 to 574.47. This is easily explained by considering the process followed for median left turn implementation. The time allowed for the side street traffic was not decreased at the intersections. The additional time for the main arterial was provided by eliminating the left turn phase. Increased times for the through movement, and a more effective coordination of timing offsets resulted in a successful balance of arterial and side street traffic. Therefore, with a small adjustment in timing plans and the construction of median left turn lanes, intersection 16 showed a tremendous improvement in performance without extremely expensive construction costs.

Analysis for the other intersections affected by median left turns revealed similar results. From an operational standpoint, the median left turns performed remarkably. Average delay showed the greatest improvement at most intersections. Appendix B includes a chart for each intersection that shows the average delay for each design alternative. In all intersections where a median left turn was placed, there was a dramatic decrease in delay for the intersection directly affected after implementation.

One initial concern was the spillback of left turning traffic into the travel lane. However, the simulation results as well as visual observations of the TRAFVU simulation did not indicate that a significant problem existed. There were a few instances where the turning traffic spilled over into the travel lane, but these were infrequent and very short in duration. These problems could be corrected by lengthening the median left turn lane at the affected intersections.

Another issue that was mentioned earlier in the report was heavy vehicle traffic. A heavy vehicle requires a larger turning radius to complete a turn from the median left turn lane. The current AASHTO standards require a median opening of 18 m (60 feet) to accommodate a WB-15 (WB-50) design vehicle. This distance could be reduced to 15 m (50 feet) by providing areas on the shoulder for the truck to complete the turn. Analysis of the routes seemed to indicate that most freight traffic could access their delivery point without making a left turn from the arterial. However, if an excessive number of heavy vehicles were making left turns from the affected intersections, the advantages of the median left turn could be diminished. In order to evaluate this component of the traffic mix, another study may be necessary that would address the demands of heavy vehicles.

One intersection experiencing high delays that was not improved was Woodhill Drive. It was decided that the presence of traffic entering New Circle Road from the Richmond Road on ramp could be a potential safety hazard for vehicles making a U-turn from the median. One possibility that was considered was the placement of roundabouts on the minor streets. However, due to high traffic volumes and the lack of sufficient right-of-way this alternative was not considered further. The most significant source of delay at this intersection is the WB side street approach. Some type of improvement is needed at this intersection and due to geometric constraints it would most likely require significant construction. However, this was not within the scope of this study.

7.0 CONCLUSIONS / RECOMMENDATION

New Circle Road is a major arterial serving the metropolitan area of Lexington. Increasing traffic volumes and increased development have dramatically altered this area of Lexington since the road was originally constructed in the late 1950's. There have been very few improvements made to the arterial since its construction. The North area of Lexington is now an area that is experiencing a large amount of development and as a result the operating conditions along this roadway have diminished. Additionally, this is the only route that provides a continuous loop around the city. However, in its current operating condition motorists experience significant delays due the presence of many traffic signals and access points along the arterial.

The tremendous growth in traffic volumes throughout the nation require transportation professionals to seek innovative solutions to traffic problems. Simply adding an extra travel lane will not always provide a significant improvement in operating conditions. This situation can be observed here in Lexington on Nicholasville Road near Fayette Mall. A few years ago this route was widened to provide an extra travel lane in each direction. While this did provide some improvement to the operating conditions of the roadway, significant delays to motorists continue to persist. In order to correct these problems, innovative traffic control methods must be used in conjunction with traditional methods of capacity improvement.

Restrictive left turn strategies proved to be a successful tool for traffic management on New Circle Road. Through the use of CORSIM, a traffic simulation tool, these strategies were tested and their effects were documented. Significant improvements were observed in all operating measures of the arterial. Average delay was the measure that improved the most at all intersections. The improvements were most notable at intersections where the median left turn design was placed. These intersections showed an improvement in operating conditions by as much as 60%. All intersections were not altered mainly due to either low left turn volumes which did not justify the cost of construction, or extremely high left turn volumes that could not be accommodated by a median left turn. At intersections with high left turn volumes, dual left turns were currently in place.

The analysis presented here indicated that the median left turn proved to be a viable alternative to increase the level of performance of this traffic network. Based on the results of this study, alternative 5 is recommended for implementation. Alternative 5 involved the construction of median left turns at the intersections of Palumbo Drive, Liberty Road, Eastland Drive, Meadow Lane, Bryan Station Road, and N. Limestone Street. This design provides the greatest benefit to the arterial at the lowest cost. The traffic network showed a tremendous improvement in operating conditions with a composite rating of 115.26. This indicates that the selected MOE showed an improvement of over 100%. Alternative 6 actually showed a greater improvement in network operations than alternative 5. However, the benefit to cost ratio for alternative 6 would be much lower than that of alternative 5.

As a minimum, we recommend the implementation of alternative 3 (median left turns at the intersections of Meadow Lane, Bryan Station Road, N. Limestone Street, and Palumbo Drive) to provide relief to the arterial. This alternative would not require a significant amount of construction and would be an excellent alternative to provide short-term improvement in arterial operating conditions. To fully evaluate costs of implementation, it is recommended that a more detailed analysis of the necessary construction be conducted. Other items, such as traffic control plans during construction and heavy vehicle traffic could affect the final recommendations for design.

One of the main advantages to the improvements recommended in this study is that they can be constructed quickly and provide immediate improvement to arterial operating conditions. In addition, the requirement for new right of way acquisition is minimal. The roadway is highly developed and the purchase of new right of way could be extremely expensive and require a significant amount of time for completion.

Driver education is essential to the success of the restrictive left turn design. Initial installation could be very confusing to the driving public. In order to ensure that drivers are familiar with the new traffic control, education and proper signage should be used. One possibility is the use of variable message signs to alert drivers of the change. Additionally, if these designs gain in popularity some type of discussion should appear in the driver's manual used to educate new drivers. In time, the public should know this information and drivers will be aware of the proper methods to navigate the network.

In conclusion, the use of restrictive left turn designs proved to be a successful method of traffic control for use on New Circle Road. The results evaluated from the traffic simulation model indicated that these designs improved a number of the measures of effectiveness selected to measure the performance of the network. These designs provide a means by which the city of Lexington can take steps to enter into a new era of transportation design. Instead of initiating a costly construction program, traffic can be controlled in an innovative manner that makes better use of the existing infrastructure. Designs such as this will become a necessity as the volumes of traffic using our roadways increase further and the commodity of land becomes an even scarcer resource.

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APPENDIX A

TRAFFIC SIGNAL TIMING PLANS

Table A.1. Existing conditions, Cycle 150 sec

Intersection Number	Interval number 1	2	3	4	5	6	7	8	9	10	Offset
2	72	5	21	4	14	4	26	4			72
3	79	5	29	5	11	4	13	4			64
4	110	5	15	4	12	4					43
6	71	5	16	4	29	5	16	4			29
8	110	5	14	5	12	4					125
9	95	5	25	5	16	4					128
10	105	5	19	5	12	4					118
12	75	5	21	4	15	5	21	4			68
13	96	5	29	5	11	4					48
15	95	5	25	5	16	4					15
16	65	5	11	4	20	5	11	4	21	4	125
17	63	5	20	4	29	5	20	4			79
18	57	5	21	4	25	5	16	4	9	4	61
19	64	5	16	4	30	5	22	4			30
20	85	5	16	4	16	4	16	4			0

Table A.2. Alternative 1, Cycle 150 sec

Intersection Number	Interval number 1	2	3	4	5	6	7	8	9	10	Offset
2	75	5	21	4	11	4	21	4			25
3	71	5	29	5	21	4	6	4			37
4	108	5	18	4	6	4					25
6	78	5	10	4	25	5	14	4			3
8	108	5	11	5	12	4					3
9	99	5	18	5	14	4					3
10	101	5	21	5	9	4					3
12	62	5	16	4	25	5	24	4			29
13	105	5	19	5	7	4					38
15	84	5	33	5	14	4					135
16	51	5	19	4	22	5	16	4	15	4	6
17	54	5	20	4	31	5	22	4			49
18	47	5	28	4	31	5	8	4	9	4	61
19	54	5	22	4	31	5	20	4			25
20	90	5	20	4	7	4	11	4			0

Table A.3. Alternative 2, Cycle 145 sec

Intersection	Interval number										
Number	1	2	3	4	5	6	7	8	9	10	Offset
2	63	5	26	4	13	4	26	4			111
3	43	5	38	5	21	4	25	4			126
4	109	5	15	4	8	4					3
6	68	5	10	4	37	5	12	4			13
8	107	5	11	5	13	4					0
9	87	5	22	5	22	4					142
10	100	5	22	5	9	4					3
12	56	5	22	4	24	5	25	4			18
13	109	5	16	5	6	4					6
15	86	5	33	5	12	4					96
16	42	5	23	4	23	5	17	4	18	4	111
17	49	5	20	4	33	5	25	4			139
18	31	5	29	4	41	5	10	4	12	4	6
19	54	5	20	4	33	5	20	4			13
20	87	5	21	4	9	4	11	4			0

Table A.4. Alternative 3, Cycle 160 sec

Intersection	Interval number										
Number	1	2	3	4	5	6	7	8	9	10	Offset
2	82	5	24	5	12	5	22	5			130
3	105	5	45	5							133
4	117	5	16	5	12	5					133
6	98	5	13	5	34	5					112
8	118	5	17	5	10	5					115
9	106	5	23	5	16	5					112
10	112	5	23	5	10	5					112
12	71	5	18	5	25	5	26	5			133
13	117	5	18	5	10	5					139
15	118	5	32	5							85
16	96	5	24	5	25	5					103
17	90	5	21	5	34	5					103
18	52	5	31	5	37	5	9	5	6	5	100
19	54	5	21	5	27	5	38	5			21
20	98	5	22	5	8	5	12	5			0

Table A.5. Alternative 4, Cycle 160 sec

Intersection	Interval number										
Number	1	2	3	4	5	6	7	8	9	10	Offset
2	82	5	25	4	13	4	23	4			130
3	105	5	45	5							133
4	118	5	17	4	12	4					133
6	101	5	15	4	30	5					112
8	118	5	17	5	11	4					115
9	106	5	23	5	17	4					112
10	112	5	23	5	11	4					112
12	72	5	19	4	25	5	26	4			133
13	117	5	18	5	11	4					139
15	118	5	32	5							85
16	96	5	25	4	25	5					103
17	90	5	22	4	34	5					103
18	52	5	32	4	37	5	9	5	6	5	100
19	70	5	22	4	27	5	23	4			21
20	98	5	23	4	9	4	13	4			0

Table A.6. Alternative 5, Cycle 145 sec

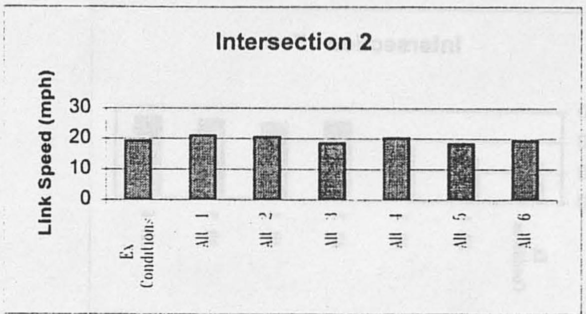
Intersection Number	Interval number										Offset
	1	2	3	4	5	6	7	8	9	10	
2	73	5	21	5	11	5	20	5			117
3	94	5	41	5							120
4	110	5	15	5	5	5					120
6	85	5	11	5	34	5					98
8	104	5	14	5	12	5					98
9	95	5	18	5	17	5					98
10	101	5	20	5	9	5					95
12	86	5	17	5	27	5					104
13	104	5	19	5	7	5					101
15	95	5	40	5							67
16	85	5	21	5	24	5					92
17	79	5	19	5	32	5					95
18	41	5	27	5	36	5	8	5	8	5	92
19	48	5	16	5	27	5	34	5			17
20	87	5	20	5	7	5	11	5			0

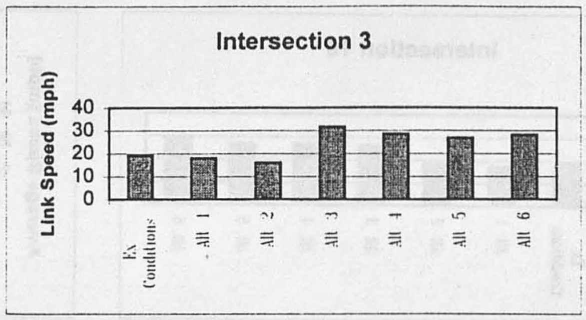
Table A.7. Alternative 6, Cycle135 sec

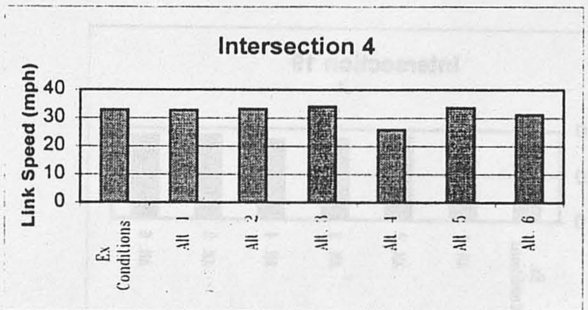
Intersection	Interval number										
Number	1	2	3	4	5	6	7	8	9	10	Offset
2	57	5	22	5	12	5	24	5			123
3	80	5	45	5							115
4	88	5	17	5	15	5					107
6	76	5	10	5	34	5					89
8	103	5	9	5	8	5					75
9	92	5	15	5	13	5					79
10	94	5	17	5	9	5					83
12	74	5	22	5	24	5					77
13	99	5	15	5	6	5					87
15	74	5	51	5							49
16	78	5	19	5	23	5					77
17	73	5	19	5	28	5					77
18	32	5	26	5	34	5	11	5	7	5	77
19	32	5	22	5	26	5	35	5			20
20	73	5	25	5	8	5	9	5			0

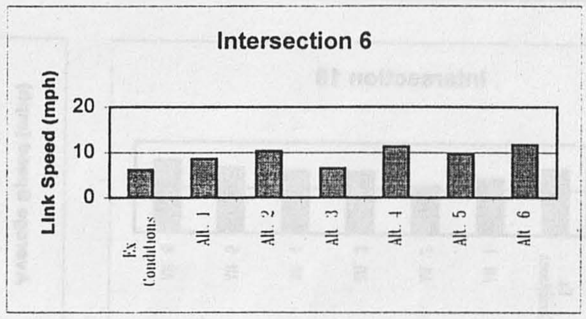
APPENDIX B

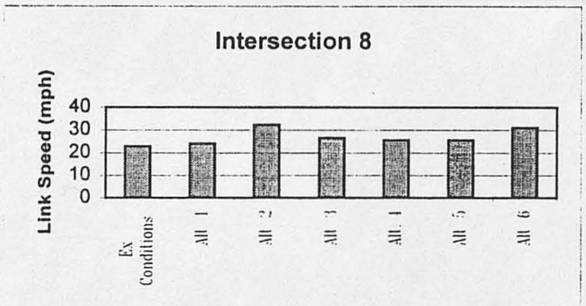
INTERSECTION PERFORMANCE FOR EACH ALTERNATIVE

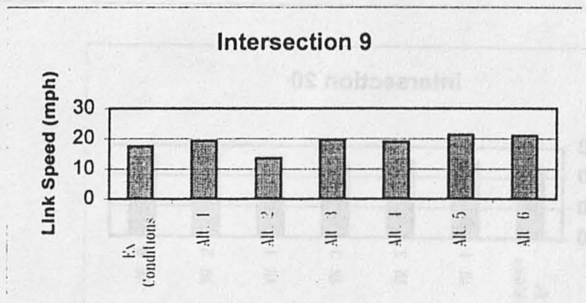

Intersection 2
Link Speed (mph)
30
20
10
0
Ex Conditions
Alt 1
Alt 2
Alt 3
Alt 4
Alt 5
Alt 6

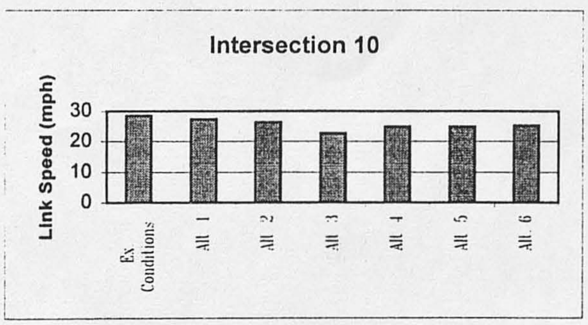

Intersection 3
Link Speed (mph)
40
30
20
10
0
Ex Conditions
Alt 1
Alt 2
Alt 3
Alt 4
Alt 5
Alt 6

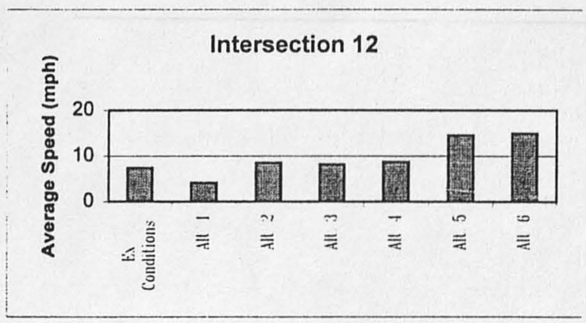

Intersection 4
Link Speed (mph)
40
30
20
10
0
Ex Conditions
Alt 1
Alt 2
Alt 3
Alt 4
Alt 5
Alt 6

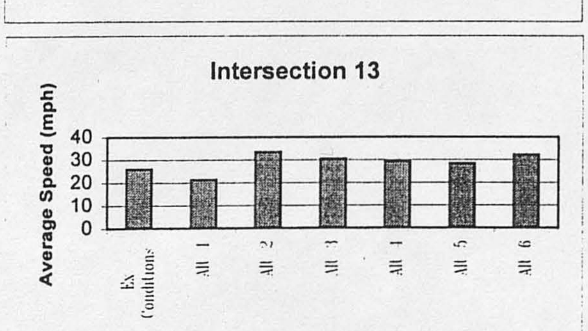

Intersection 6
Link Speed (mph)
20
10
0
Ex Conditions
Alt 1
Alt 2
Alt 3
Alt 4
Alt 5
Alt 6

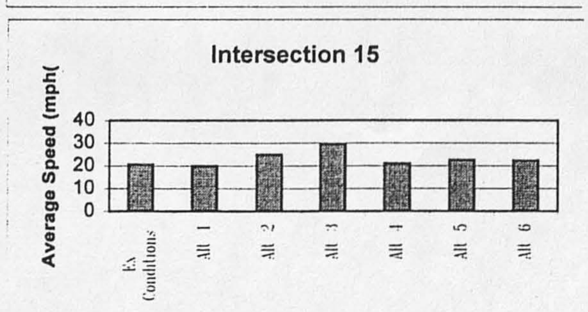

Intersection 8
Link Speed (mph)
40
30
20
10
0
Ex Conditions
Alt 1
Alt 2
Alt 3
Alt 4
Alt 5
Alt 6

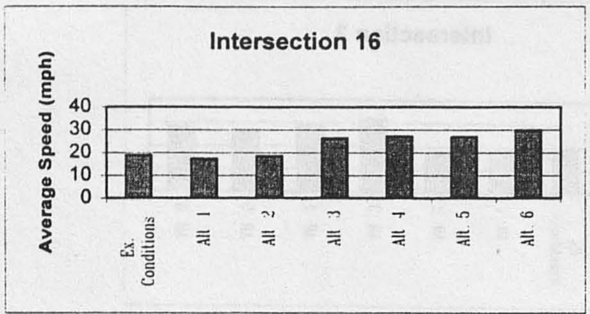

Intersection 9
Link Speed (mph)
30
20
10
0
Ex Conditions
Alt 1
Alt 2
Alt 3
Alt 4
Alt 5
Alt 6

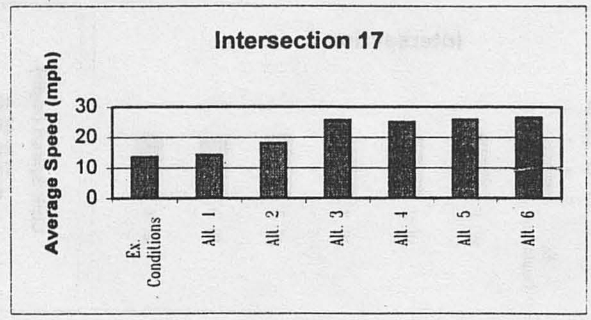

Intersection 10
Link Speed (mph)
30
20
10
0
Ex Conditions
Alt 1
Alt 2
Alt 3
Alt 4
Alt 5
Alt 6

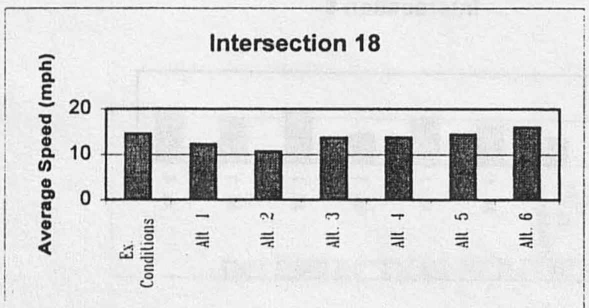

Intersection 12
Average Speed (mph)
20
10
0
Ex Conditions
Alt 1
Alt 2
Alt 3
Alt 4
Alt 5
Alt 6

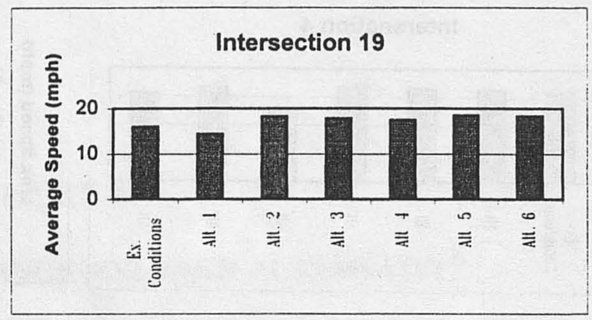

Intersection 13
Average Speed (mph)
40
30
20
10
0
Ex Conditions
Alt 1
Alt 2
Alt 3
Alt 4
Alt 5
Alt 6

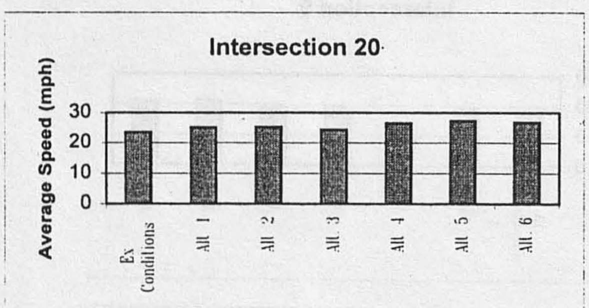

Intersection 15
Average Speed (mph(
40
30
20
10
0
Ex Conditions
Alt 1
Alt 2
Alt 3
Alt 4
Alt 5
Alt 6


Intersection 16
Average Speed (mph)
40
30
20
10
0
Ex. Conditions
Alt. 1
Alt. 2
Alt. 3
Alt. 4
Alt. 5
Alt. 6


Intersection 17
Average Speed (mph)
30
20
10
0
Ex. Conditions
Alt. 1
Alt. 2
Alt. 3
Alt. 4
Alt. 5
Alt. 6


Intersection 18
Average Speed (mph)
20
10
0
Ex. Conditions
Alt. 1
Alt. 2
Alt. 3
Alt. 4
Alt. 5
Alt. 6


Intersection 19
Average Speed (mph)
20
10
0
Ex. Conditions
Alt. 1
Alt. 2
Alt. 3
Alt. 4
Alt. 5
Alt. 6


Intersection 20
Average Speed (mph)
30
20
10
0
Ex Conditions
Alt. 1
Alt. 2
Alt. 3
Alt. 4
Alt. 5
Alt. 6