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Kentucky Transportation Center

College of Engineering

U-TURNS AT SIGNALIZED INTERSECTIONS

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16. Abstract

The objectives of the study were to examine the safety consequences from the installation of U-turns at signalized intersections in Kentucky and to develop a set of guidelines for using this alternative in the future. The literature review indicated that the use of U-turns is very effective in reducing delays as well as crash rates. The most efficient configuration is that of stop-controlled median U-turns. An analysis of the crash data shows that the U-turn design in the Kentucky locations did not result in a large number of crashes involving U-turning vehicles. Also, at the Somerset location where the design eliminated median crossovers between intersections, there was a decrease in total crashes. Potential factors that could affect the implementation of U-turns at intersections were examined. Using delay time as a measure of effectiveness, it was concluded that the presence of the U-turn enhances the operation of the corridor most likely due to the more efficient processing of vehicles at the downstream intersection. The study recommends that U-turns should be considered for corridors with peak volumes greater than 1,500 vph or for cases where the expected total turn volume is greater than 20 percent of the total approach volume.

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U-TURNS AT SIGNALIZED INTERSCETIONS

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EXECUTIVE SUMMARY

The objectives of the study were to examine the safety consequences from the installation of U-turns at signalized intersections in Kentucky and to develop a set of guidelines for using this alternative in the future. To complete the objectives of the study, a literature review was completed, followed by a safety study of the current applications and a simulation analysis for developing guidelines based on volumes and delays. A questionnaire was also administered at one of the Kentucky sites (Somerset) to determine the opinions of business owners related to the effect of the design on their business as well as the safety impacts.

The literature that was reviewed indicate that the use of median U-turns is very effective in reducing crash rates as well as delay when placed on high volume arterials intersecting with low to moderate volume cross streets. The most efficient configuration is that of stop-controlled median U-turns. This has been shown to increase intersection capacity by 20 to 50 percent while decreasing the rate of crashes by up to 30 percent. Median openings placed only on the arterial also work well. Allowing U-turns at the intersection is not advised due to the conflicts the U-turning vehicles encounter with right-on-red vehicles from the cross street. However, if the number of these conflicts is low or non-existent, this method may be considered. Median U-turns are a relatively low cost means of improving traffic flow and have already been employed extensively in Florida and Michigan with much success.

An analysis of the crash data shows that the U-turn design did not result in a large number of crashes involving U-turning vehicles. Also, at the Somerset location where the design eliminated median crossovers between intersections, there was a decrease in total crashes. The total crash rates at Lexington and Somerset were higher than the statewide rates but the rates were not associated with U-turn crashes.

The survey found that there is a perception by about one-third of the businesses that there has been a negative economic impact while about one-fourth felt there was positive effect of their business. However, this perception may be due to other factors, such as the general economy trends, and thus not directly attributed to the current design. A more thorough economic study would be necessary to determine whether there is an economic impact due to the U-turns. There was a general perception that the design had a positive effect on safety. The most common negative comment about safety dealt with drivers disregarding the red indication.

Potential factors that could affect the implementation of U-turns at intersections were examined. The research provided an opportunity to confirm some of the established relationships between corridor volume and the performance of traffic with or without a U-turn. Using delay time as a measure of effectiveness, it was concluded that the presence of the U-turn enhances the operation of the corridor most likely due to the more efficient processing of vehicles at the downstream intersection. These delay gains increased for higher percentages of U-turns. For cases where the total percent of turns was the same, the cases with the higher U-turn percent reduced delays more than those with the higher left-turn percent. For higher arterial volumes, direct left turns or median openings allowing left turns should be replaced with a directional opening allowing only left turn egress movements.

Based on these findings, the following recommendations are made:

- U-turns should be considered for corridors with approach peak volumes greater than 1,500 vph. A full evaluation of the operation with and without the U-turn should be conducted.
- U-turns should be considered in cases where the expected total turn (left and U-turns) is greater than 20 percent of the total approach volume. This volume should be estimated as the total amount of left turns and through movements that would have been processed at the upstream intersection and the left turns at this intersection.
- Consideration should be given to prohibiting right turns on red at signalized intersections when U-turns are allowed. This would enhance both operational and safety performance of the installation. If the U-turn is completed in a permitted phase, an alternative to prohibiting right turns on red is to place a "U-turn yield to right turn" sign (R10-16 in the Manual of Uniform traffic Control Devices) near the left-turn signal face. Another sign that could be used to avoid prohibiting right turn on red is "Right turn on red yield to U-turn".

The installation of a U-turn could be considered when either of the two first recommendations is satisfied. Approval should also be sought and obtained to allow a "combination left turn arrow/U-turn" indication in a signal lenses which should be considered at these locations.

It is recommended that further research be conducted in this area especially if it is desired to further refine the guidelines for future use of this design.

1. INTRODUCTION

The increase in population is accompanied by a larger number of vehicles and drivers on U.S. roadways (1). The increased number of vehicles leads to congestion that in turn impacts the safety and operational characteristics of roadways. Issues such as these have led to the development of the access management concept. As defined by AASHTO, "access management involves providing (or managing) access to land development while simultaneously preserving the flow of traffic on the surrounding road system in terms of safety, capacity, and speed" (2). The major advantages of using access management techniques are improvement of the safety level and operational efficiency of the roadway.

A significant part of the access management techniques focuses on the treatment of left turns along a roadway. Approaches used to achieve control of left turns include separation of the left turns in exclusive left-turning lanes, use of U-turns either at or after the intersection, and consolidation of median openings. The concept of U-turns as an alternative to direct left turn movements is a relatively new approach and has recently been implemented in several locations. Depending on the design, this eliminates either all the left turn movements at an intersection or only left turns onto arterials from cross-streets. The safety gain from such a design is due to the decrease in the number of conflicting points at the intersections. The advantages of U-turn movements over left turn movements are as follows:

- Shorter travel times, reduced delay times and an enhancement in the roadway capacity are some of the important benefits of U-turn movements over left turn movements. For distances of less than 0.5 mile the provision of a U-turn will be more effective, as the travel times of the vehicles in this case will be comparable with the travel times obtained by providing direct left turns (3). This is especially true for heavy arterial volumes.
- High left turn volumes at a signalized intersection require left turn phases with long green times which may affect the intersection capacity and increase the delays of the through movements. The provision of U-turns in these cases will improve the traffic flow condition by enhancing the vehicle travel time (4).
- Studies indicate that there has been a tremendous decrease in the crash rates when direct lanes are replaced by directional left turns/ U-turns. For example, on Grand River Avenue in Detroit, four median openings allowing left turns were replaced with U-turns and the results showed that crashes can be reduced by using U-turns (4). The reductions ranged from 96 percent for angle crashes to 17 percent for rear end crashes with an overall crash reduction of 61 percent.

There are three ways that a U-turn movement can be completed: 1) in advance of the intersection; 2) at the intersection; and 3) after the intersection. The current applications in Kentucky involve U-turns at the intersection so this is the type of U-turn that is examined in this report. Moreover, this treatment is associated with median closures and completion of all turns at a signalized intersection. This treatment requires a protected left-turn phase to accommodate left and U-turns at the same time. Concerns related to the use of U-turns at signalized intersections include safety and operational concerns as well as what effect the design may have on adjacent businesses.

This study was initiated to address these concerns and evaluate the current applications in Kentucky. The objectives of the study were to examine the safety consequences from the installation of U-turns at signalized intersections in Kentucky and to develop a set of guidelines for using this alternative in the future. To complete the objectives of the study, a literature review was completed, followed by a safety study of the current applications and a simulation analysis for developing guidelines based on volumes and delays. A questionnaire was also administered at one of the Kentucky sites (Somerset) to determine the opinions of business owners related to the effect of the design on their business as well as the safety impacts.

2. LITERATURE REVIEW

Most of the available literature deals with median U-turns, which involves the use of median openings before or after the intersection. Even though this type is not the focal point of this study, it was considered appropriate to discuss it in this report to demonstrate the relative operational and safety improvements of this design over conventional left-turn treatments.

2.1. Design

The median U-turn design removes left turns at the main intersection by diverting left turning vehicles onto one-way crossovers placed in the median on both sides of the intersection. Vehicles wishing to turn left from the side street must first make a right turn, and then make a U-turn at the provided upstream median opening (5). The most efficient design is the one shown in Figure 1. In this design, drivers wishing to make a left turn onto a side street from the major road pass through the main intersection until they come to the median opening where they can make the a U-turn. Then, the vehicles can proceed back to the main intersection where they make a right turn to complete the movement. If adequate space is provided, an additional lane may be added to the right side of the other direction with a jughandle to accommodate large U-turning vehicles. If space allows, the U-turning traffic is also provided with an acceleration lane on the right side of the crossroad (6). This design has been widely used in Michigan, and has been found to reduce travel time and delay at various volume combinations when compared to conventional intersection designs (6). The median openings may be signalized or controlled by stop signs. However, signal coordination is important along the corridor and the prior intersection so drivers must stop no more than once (7).

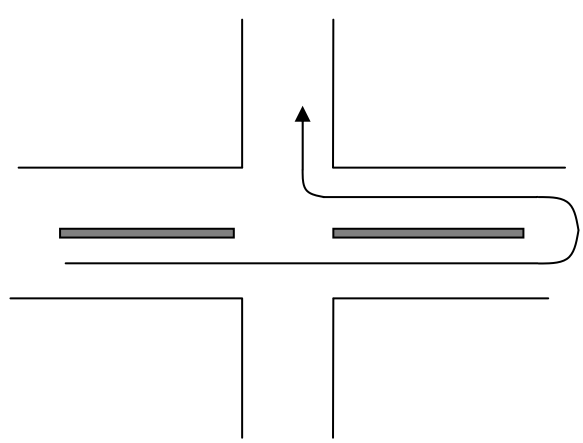

Figure 1. Median U-turn layout

2.2. Performance

Median U-turns can reduce travel times on major arterials by reducing the number of conflicts between left turning vehicles, in some cases by more that 30 percent (6). The reduction in the number of conflicts also improves the safety of the highway by reducing the number of crashes. This decrease in crashes is most significant on 6-lane and 8-lane highways. A study completed in Florida showed that the use of the median U-turn concept on 6-lane arterials over direct left turns reduced the total number of crashes by 26 percent and the injury/fatality crash rate was lowered by 32 percent (8). Though the reduction in non-injury crashes was not considered statistically significant, the reduction in injury accidents was considered significant (8). This trend was also similar for 8-lane highways; however, 4-lane arterials involve another factor when considering the use of median U-turns. The narrow receiving bay of 4-lane arterials presents a problem for trucks trying to negotiate a U-turn. In the same study, it was found that median U-turns actually increase the crash rate when truck volumes were high, so it is not advised to employ this concept in such conditions.

In another study conducted on a six-lane highway in Pinellas County, Florida, a full median opening was transformed into a directional median opening. This change implied that left turn egress from driveways was restricted. Left-turning vehicles were forced to make a right turn followed by a downstream U-turn to complete their desired movement. The safety effects of this conversion were studied by counting the number of potential conflicts before and after the median openings were changed. A traffic conflict was defined as an event involving two or more road users where the action of one vehicle caused another to make an evasive maneuver to avoid a crash (9). After installing the directional median opening, the average number of daily conflicts was reduced by 46 percent (10). The average number of conflicts per hour was also reduced by 30 percent (10). Another interesting fact noted in this study was that the conflict rate of right-turn U-turn vehicles during peak hours was 8 percent lower than during non-peak hours (10). This may indicate that drivers are more cautious in performing the U-turn movement when opposing traffic volumes are very high. A different study performed on the same highway found similar results. When comparing the number of conflicts per hour between vehicles performing direct left turns from driveways and indirect left turns by way of median U-turns, the number of conflicts for the indirect left turning vehicles were lower by 50 percent, 22 percent and 34 percent, during peak, off-peak and total time periods respectively (11).

2.3. Delay Issues

The primary objective of using median U-turns is to reduce travel time of through vehicles on major arterials. When placed in highway corridors with proper volume combinations, this alternative can have significant effects on the net traffic flow through that corridor. Qualitatively, median U-turns are most applicable when high volume arterials have low to moderate left turn volumes (approximately 10 to 15 percent of entering volume), and cross streets have low to moderate volumes (12). Past research indicated that for arterial volumes greater than 400 vehicles per hour per lane, the use of U-turn will reduce delays as compared to conventional left-turn treatments (13). Simulations were performed by Reid and Hummer on a high-volume arterial in Detroit, Michigan. The arterial had six through lanes with an ADT of

52,000 to 60,000 and a speed limit of 50 mph. The conclusion of the study was that the median U-turn was superior to the two-way left-turning lane (TWLTL) in mean vehicle speed and total system time in peak periods, while still remaining roughly equal during non-peak periods (7). The U-turn treatment used in Michigan, which prohibited left turns, provided 20 to 50 percent capacity gains at intersections (14). More specifically, the benefits from using median U-turns increased rapidly as the total incoming flow (sum of all approaches) to the intersection increased beyond 6,000 vph with 10 percent left-turning flow (6). When the left-turning flow was increased to 20 percent, a drastic reduction in delay was realized at volumes as low as 4,500 vph (6).

A different study performed on Michigan's boulevard design also demonstrated the pronounced reduction in delay from using the median U-turn over direct left turns. Simulations showed that when the percent saturation of each leg entering the intersection increased beyond 70 percent, the use of direct left turns is rendered totally inefficient, while the U-turn design remained effective (15). The trend continued as the percent of left turns was increased from 10 percent to 25 percent during the simulation. This suggests that median U-turns can be much more efficient than direct left turns when an intersection is at 70 percent of saturation or higher.

In some cases, it may be difficult for U-turning vehicles to find adequate gaps in traffic to perform their desired movement. For this situation, median openings can be placed on both the arterial and cross streets to provide relief. Then, some of the left turning vehicles on the arterial can make a right turn onto the cross street, followed by a U-turn on the minor street. A simulation performed by Hummer and Thompson attempted to compare the efficiency of intersections with four U-turns to those with two U-turns (16). In addition, stop-controlled median openings were compared to signalized openings for both alternatives. They found that the intersection with four stop-controlled U-turns created the least delay of any intersection alternative studied. On average, it led to a savings of eight to fifteen seconds per vehicle for both left-turning and through vehicles (16). Placing U-turns on both intersecting highways also increases the left turn capacity when left turn volumes are very high (17). Another alternative is to place the median openings only on the cross streets, which appears to work well when through arterial volumes are too high to provide an acceptable number of gaps for the U-turning vehicles. This configuration allows the U-turns to be made into less oncoming traffic providing longer and more frequent gaps. Placing the U-turns on cross streets will also conform to restrictions of right of way on the arterial, assuming this is not a problem on the side street.

In the Pinellas County, Florida study, the delay for the left turning vehicles was observed to evaluate the assumption that median U-turns only provide relief for the through arterial vehicles, while increasing delay for those making left turns. Researchers compared the weighted average total delay and the weighted average travel time of both situations to compare the delay before and after the directional median opening was installed. Though there was no significant effect on the travel time due to the conversion, the travel delay was reduced by 15 percent during peak hours, and 22 percent during non-peak hours (10). This suggests that the use of directional median U-turn opening decreases delay for both through vehicles and left turning vehicles.

Before placing median openings on arterials, the speed of vehicles on the highway must be considered in conjunction with the traffic volume. Both of these factors affect the available gaps for vehicles to complete the U-turn movement. A study performed on ten highways in Tampa, Florida found that this critical gap ranged from 5.8 to 7.4 seconds with an average of about 6.8 seconds (18). The study also noted two other important facts. First, when traffic volumes are higher, vehicles will make U-turns into smaller gaps than when volumes are lower. This may be attributed to drivers' impatience when waiting for long periods of time in the U-turn lane. Secondly, it was found that at higher speeds, drivers required considerably larger time headways to complete the U-turn movement because drivers are less able to judge gaps at the higher speeds. Critical gaps are a difficult element to study because of the higher number of lanes on arterials. Some people are willing to make a U-turn when only the nearest lane is clear while others are not. However, all these issues should be considered when deciding whether to place the median opening on the arterial, and/or the cross street, or not to implement the U-turn.

2.4. Kentucky Case Study

The use of median U-turns has been simulated and studied on the portion of New Circle Road (KY 4) in Lexington with no access control. It was desired to limit the access on this highway to decrease the travel time of through vehicles since congestion had become a major problem. With strict limitations on time, space, and money, it was decided that placing median U-turns in high access areas would best serve the needs of New Circle Road (19). In these simulations, engineers decided to place the median openings 600 feet from the intersection. This distance has been found to be the optimum distance for median U-turn openings because it allows for adequate weaving space for the U-turning vehicles, yet it is short enough to not deter drivers from performing the right-turn U-turn movement. If the median opening is located too far from the intersection, it will cause too much delay for those desiring to make a left turn and defeat its purpose. Once the design was coded and simulated at various points on New Circle road, the average speed was increased by 2.7 mph. Average delay was decreased by 20 to 30 percent in various systems and, in some cases, up to 60 percent. In areas where the U-turns were placed in multiple intersection systems, the benefit was even more pronounced. These results only reinforce the idea that median U-turns have the ability to reduce through traffic delay, while still providing access to neighboring driveways. There was some concern that, upon implementation, drivers may be confused when using the new system or that there may be an increase in delay for the left turning vehicles; however neither appeared to pose a significant problem.

2.5. "No U-turn" Guidelines

There are some situations where median U-turns should not be constructed. Limiting factors related to roadway geometry must be satisfied before median U-turns can be safe and effective. General scenarios for avoiding U-turns include the following:

- Arterials with narrow medians and no prospects of gaining extra right-of-way are generally poor candidates for the median U-turn, unless the crossovers can be built on the cross street.
- U-turns where the receiving roadway width is less than 24 feet should be avoided (20). Any width less than 24 feet would make it difficult for larger vehicles to make a U-turn movement.
- A median width of 60 feet on a four-lane highway is recommended by AASHTO for a large semi-trailer vehicle; however, a narrower median is possible on six- or eight-lane arterials (21).

- U-turns at intersections should not be used when the protected left-turn phase on the mainline overlaps a right turn on the side street (20). Furthermore, any movement that may involve the unexpected crossing of paths during green or yellow intervals must be prohibited (20).
- Another important factor to consider when implementing median U-turns is sight distance. Many state DOT's restrict U-turns on any curve or near the crest of a grade where approaching vehicles cannot be seen within 500 feet by U-turning drivers (20). In addition, U-turns that do not meet the minimum AASHTO requirements for sight distance must be prohibited (20).
- An accident history threshold of 5 or more U-turn related crashes over any 12-month period has also been recommended when prohibiting U-turns (20).

2.6. Summary of Literature Review

The literature that was reviewed indicate that the use of median U-turns is very effective in reducing crash rates as well as delay when placed on high volume arterials intersecting with low to moderate volume cross streets. The most efficient configuration is that of stop-controlled median U-turns. This has been shown to increase intersection capacity by 20 to 50 percent while decreasing the rate of crashes by up to 30 percent. Median openings placed only on the arterial also work well. Allowing U-turns at the intersection is not advised due to the conflicts the U-turning vehicles encounter with right-on-red vehicles from the cross street. However, if the number of these conflicts is low or non-existent, this method may be considered. Median U-turns are a relatively low cost means of improving traffic flow and have already been employed extensively in Florida and Michigan with much success.

3. KENTUCKY INSTALLATIONS

This section reviews the current installations of U-turns in Kentucky. It should be noted that these U-turn locations are at signalized intersections with the U-turns made during the protected left turn phase. Results from an analysis of crashes before and after implementation of the U-turn design and from the questionnaire sent to businesses at the Somerset location are also presented.

There have been three sites where U-turns at signalized intersections have been installed in Kentucky. At each of these locations, there are separate left turn lanes with the U-turns made during the protected left turn phasing. There were three opposing lanes which allowed a substantial turning radius.

The first installation was in Somerset along US 27 from Boat Dock Road (MP 11.374 and signal 29) to KY 80 Business (MP 16.782 and signal 4). The length of the roadway is approximately 5.4 miles with U-turns made at 26 intersections. This project was completed in 1998. The weighted average daily traffic at this location is about 31,000.

The second installation was in Lexington along New Circle Road (KY 4) from Industry Road (MP 12.245) to Trade Center Drive (MP 13.195). The length of the roadway is 0.95 miles and there are three intersections with U-turns. This project was completed in 2000. The weighted average daily traffic at this location is about 38,500.

The newest installation is in Pikeville along US 23 from KY 3227 (MP 27.378) to KY 2061 (MP 29.464). The length of the roadway is approximately 2.1 miles with U-turns with seven signals in this section. This installation was started in 2003 with completion in 2004. The weighted average daily traffic is about 33,000.

3.1. Crash History

The crash history for each site was examined to determine whether there were any safety consequences from the U-turn design (Table 1). The Somerset location has been constructed for the longest time with a large number of signalized intersections so the data at this location would provide the best evaluation of the effects of the U-turn design on traffic safety. The Somerset data showed a 16 reduction in total crashes in the 5.4-mile section in five years after construction compared to two years prior to construction. This reduction could be attributed to a reduction in non-intersection crashes, since crashes at intersections showed an increase (19 percent). However, the increase in crashes at intersections would not be directly attributed or related to the U-turn crashes since there were less than two U-turn crashes per year (approximately 1 percent of all intersection crashes). There were eight U-turn crashes in the five years of 1999 through 2003. Six of the eight crashes involved another driver disregarding the red indication as a driver was making a U-turn on a green arrow (five of the six were the driver of a vehicle in the opposing direction with one on the side street). The other two crashes involved a bus and a single unit truck and were related to the turn radius of these vehicles. The eight U-turn crashes occurred at six intersections with these intersections scattered along the route. There was no more than two U-turn crashes at any intersection during the five-year after period.

There was an increase in the total number of crashes in the after period at the Lexington location with no change in the injury crashes and a reduction in crashes at intersections. There was only one crash in the three-year after period which involved a vehicle making a left turn. In this crash, the vehicle making the U-turn was hit in the rear by a left turning vehicle when the driver slowed for a vehicle turning right from the side street.

The Pikeville location was not completed so a before and after comparison could not be made. A review of the crash data found one crash during construction involving a U-turning vehicle where the vehicle making the U-turn was hit in the side by a vehicle turning right from the side street. When this crash occurred there was construction in the third lane with impact in the middle lane.

An analysis of the crash data shows that the U-turn design did not result in a large number of crashes involving U-turning vehicles. Also, at the Somerset location where the design eliminated median crossovers between intersections, there was a decrease in total crashes.

Table 1. Crash history at U-turn locations

Location	Year	Total	Injury	Fatal	U-Turn	Intersection
Somerset	1995[1]	310	67	1	-	109
	1996[1]	324	71	0	-	127
	1997	313	66	0	-	129
	1998	265	49	0	0	102
	1999[2]	250	49	0	2	101
	2000[2]	243	64	1	4	127
	2001[2]	280	50	0	1	152
	2002[2]	250	40	0	1	147
	2003[2]	311	51	0	0	171
Lexington	1998[1]	66	17	0	1	27
	1999[1]	92	26	0	0	39
	2000	105	30	0	0	26
	2001[2]	96	17	0	0	21
	2002[2]	103	25	0	0	27
	2003[2]	83	21	1	1	24
Pikeville	1998[1]	33	13	2	2	7
	1999[1]	29	7	0	0	12
	2000[1]	46	14	0	0	15
	2001[1]	52	23	0	0	11
	2002[1]	60	21	1	0	18
	2003	82	21	0	1	13

Notes: 1. Before construction data; 2. After construction data

Crash rates were also computed for each site and compared to the statewide averages for similar roads (Table 2). The Somerset and Lexington data show that these facilities have greater crash rates in comparisons to the statewide averages but these rates were not associated with U-turn crashes. The high fatal rate at the Lexington location in the after period resulted from one fatal crash that was not related to the U-turn design. The reduction in the rate at the Somerset location should be noted.

Table 2. Crash rates (100MVM)

Location	Total	Injury	Fatal
4-lane Divided (statewide)	295	75	0.9
Somerset-Before	480	96	0.0
Somerset-After	436	83	0.3
Lexington-Before	592	161	0.0
Lexington-After	704	157	2.5
Pikeville	214	68	0.8

3.2. Opinion Survey

Of interest to this study was also an understanding of the public acceptance of U-turn installation and a documentation of potential economic and other impacts on the properties along these corridors. A questionnaire was developed that was distributed to a large number of the businesses along the Somerset location (Appendix A). Since the U-turn design has been in place for over five years at this location, any long-term effect should be established.

The questionnaire asked the respondents to identify their type of business and provide comments regarding the U-turn installation and perceived problems or benefits as a result of the new design. A prepaid envelope was included for the respondents to return their questionnaire. A total of 200 questionnaires were mailed and 73 responses were received (36.5 percent response rate).

A summary of the response is as follows:

- 24 respondents (33 percent) thought the design had a negative impact on their business. All of these made a comment with the most common complaint related to a limit of access (14 comments). 16 respondents (23 percent) felt the design had a positive effect on their business while 42 percent felt the design had no effect on their business.
- 24 respondents (33 percent) thought they had noticed a problem with drivers understanding the design although most of the comments were more general in nature. The most common response stated that non-local drivers were confused (6 responses). Other comments were that the signals caused confusion and drivers disregarded the red signal (4 responses each).
- 18 respondents (25 percent) thought the design had a negative effect on safety. All these respondents provided a comment with the most common relating to running red lights (9 responses) and no emergency lanes (4 responses). 31 respondents (44 percent) felt the design had a positive effect on safety while 18 percent did not observe any effect on safety.
- About two-thirds of the respondents were located on the east side of US 27.
- The highest number of respondents' businesses were located between signals 4 and 5 (9 respondents) followed by 7 respondents between signals 24 and 25.
- The most common business type was retail (19 businesses) followed by 6 fast food restaurants.
- The respondents located on the east and west sides of US 27 gave similar results concerning any negative effect on their business (30 percent on the east side noted a negative effect compared to 36 percent on the west side). However, there was a large difference between businesses located on the north end of the project (signals 4 through 19) compared to south section (signals 20 through 29). The results showed that 41 percent of businesses on the north end noted a negative effect compared to 25 percent on the south end.
- There was no substantial difference for businesses on the east or west side or north or south end concerning their opinion about drivers understanding the design or safety effects.

These data indicate that there is a perception by about one-third of the businesses that there has been a negative economic impact while about one-fourth felt there was a positive effect on their business. However, this perception may be due to other factors, such as the general economy trends, and thus not directly attributed to the current design. A more thorough economic study would be necessary to determine whether there is an economic impact due to the U-turns. There was a general perception that the design had a positive effect on safety. The most common negative comment about safety dealt with drivers disregarding the red indication.

4. OPERATIONAL GUIDELINES

The main objective of this section is to present the experimental approach followed in attempting to identify the possible conditions under which the provision of a U-turn for replacing a direct left turn is preferred at a signalized intersection. The analysis focused on determining the effect of arterial volume, and left turning and U-turning vehicle percentages on the appropriateness of selecting the U-turn option.

4.1. Methodology

The objective of this task was to determine the potential influence of various factors on the performance of a corridor with and without the U-turns at signalized intersections. To achieve this objective, simulation of a basic corridor was utilized. The corridor volume and the left- and U-turning volume percentages were varied to examine their influence on the operation of the corridor under both conditions. The results were then analyzed to examine the relative changes in the performance of the corridor and used in developing a set of conditions that could be used in identifying cases where the use of U-turns should be considered as an alternative option.

4.2. Network

A basic network was developed that was used as the basis for the simulation (Figure 2). The network consisted of five intersections. Three of the intersections are signalized (intersection numbers1, 3, and 5) with actuated signals and the other two are unsignalized. The intersection of interest is intersection 3 which is the intersection where U-turns were allowed. In this scheme, the original east- and west-bound left turns at intersections 2 and 4 proceed through and become U-turns at intersection 3. Similarly, the north-bound through and left turns at intersection 2 and south-bound through and left turns at intersection 4 turn right and become a U-turn at intersection 3. Therefore, the middle three intersections (intersections 2, 3, and 4) are the intersections of interest and they were used in the analysis. Even though U-turns could be completed at intersections 1 and 5, this scenario was not examined, since the intention of the study was to examine the impact of the U-turn movements at an intersection as opposed to the performance of the entire corridor.

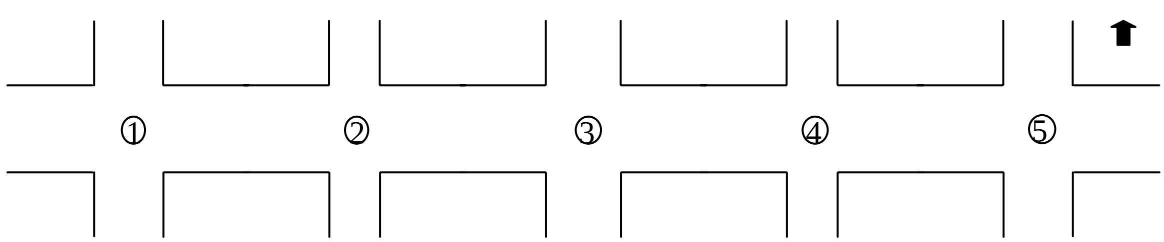

Figure 2. Network diagram

The corridor (east-west direction) has a five-lane cross section with a continuous two-way left-turn lane. The cross streets have two lanes per approach. For all turning movements a 250-foot turning bay is provided. The distance between intersections is 1,000 ft. The network is developed in such a way that similar roadway and traffic conditions exist in both directions on the arterial, thus being able to use each direction as a separate network model for the data analysis. The directional volumes for the corridor and the cross streets were also identified and kept constant throughout the study. This allowed for comparisons among different conditions without introducing any differences due to directional volume variations. The simulation model considers these as percentages of the entire traffic entering the intersection with these splits shown in Table 3.

Table 3. Directional traffic splits

		Intersections 1, 3, and 5				Intersections 2 and 4		
Case	Direction	U	L	T	R	L	T	R
Base	North/South	-	10	80	10	15	10	75
	East/West	-	5	85	10	10	70	20
U-turn	North/South	-	10	80	10	0	0	100
	East/West	15	5	70	10	0	80	20

The final step in establishing the network was the determination of the volumes to be used for the various tests. The network was examined for five different directional corridor volumes. The volumes examined were 1,000 vehicles per hour (vph), 1,250 vph, 1,500 vph, 1,750 vph, and 2,000 vph per direction. These volumes were considered to be representative of the arterial conditions in Kentucky and seemed appropriate to be used in this network study. The network also examined different volumes of left- and U-turning vehicles at intersection 3. Two different percentages of left turning vehicles, 5 and 10 percent, were used as well as three different percentages of U-turning vehicles, 15, 20, and 25 percent. Thus, in each of the base and U-turn conditions, this experimental approach provided 30 combinations (five arterial volumes, two left turn movements and three U-turn movements) to be studied.

For each corridor volume, a signal optimization was performed to determine the required background cycle for the signals at intersections 1, 3, and 5. The phasing plan provided for protected only phases for the left and U-turns. Green extension and count type detectors were located in the left turning and through lanes at intersections 1, 3, and 5. All the detectors had a length of 25 feet and a delay time of three seconds.

4.3. Traffic Simulation

TSIS (Traffic Software Integrated System) was used to simulate each of the 30 networks with different combinations of arterial volumes and left- and U-turning volumes. TSIS is a collection of software tools that allows for traffic analyses using microscopic traffic simulation (22). The TSIS package provides a realistic simulation of the traffic conditions. A wide range of measures of effectiveness and performance, such as delay times, travel times, queue lengths, vehicle speeds and queue times for a simulated network can be obtained using this simulation package. These properties and capabilities of the TSIS package make it a very powerful tool and allow for the evaluation of different traffic conditions and operations on a traffic network.

4.4. Measures of Effectiveness

Delay time was used as a measure of effectiveness in the present study. The total delay time of the vehicles through an approach is a collected measure of the network and was used in this analysis. Since the comparison between the two scenarios, base and U-turn condition, involved more than a single movement, it was necessary to identify the appropriate movements to be used (Figure 3). For example, the affected movements from the base condition in the east-bound direction are the east-bound through and left-turning movements at intersection 2, the north-bound traffic at intersection 2, and the east-bound left turns at intersection 3. These movements should be compared to the east-bound through at intersection 2, the north-bound right turns at intersection 2 and the left- and U-turns at intersection 3. For each of these movements, the total delay was obtained from the TSIS output along with the number of vehicles that completed the movement and a weighted average delay is computed for the affected movements for each condition. These figures were then compared to determine the impact of the U-turn on the operation of the corridor.

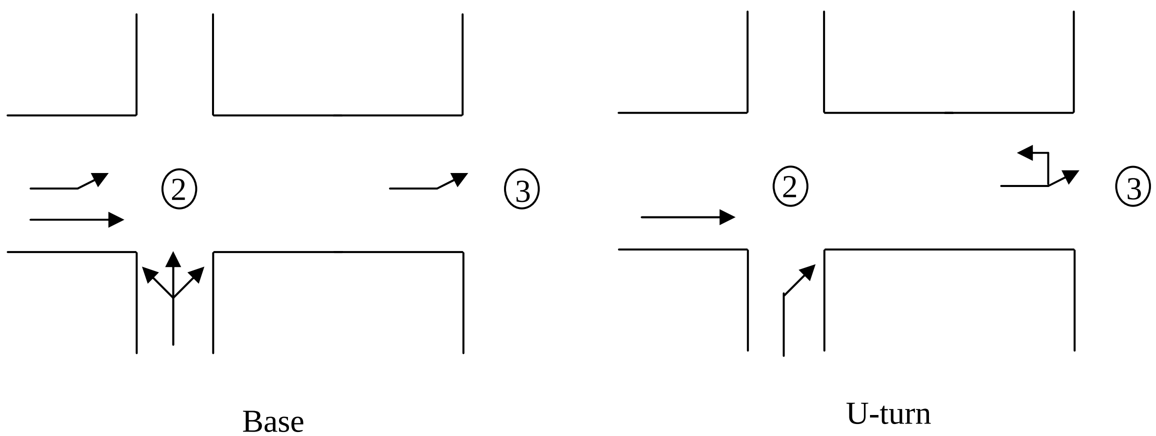

Figure 3. Movements for weighted average delay estimates

Each of the 30 different simulated networks was run for a 60-minute period. Four different runs were simulated using different random seeds for each of the 30 simulations in both base and U-turn conditions. Also, the network was set in such a way that similar roadway and traffic conditions were present in both directions of the arterial. Thus, each direction was used as a separate delay estimate. A total of eight delay observations were obtained for each of the simulations in both conditions. The average value of these eight delay observations was calculated and taken as the representative average delay for each particular simulation model.

4.5. Results

The first variable examined was the corridor volume for each combination of left- and U-turn percentages. An example of the relationship between corridor volume and the two conditions is shown in Figure 4, which is the l0 percent left turns and 25 percent U-turns scenario. As expected, the average delays of the movements increased as the corridor volumes increased. The movements in the Base condition experience higher average delays than the corresponding movements in the U-turn condition. Moreover, the difference between the average delays for both conditions increased as the corridor volumes increased. For all six combinations of left and U-turns, similar patterns were observed. An additional observation for these graphs is an increase in the difference between the delays of the two conditions as the percent of U-turns increases. Thus, the benefits of U-turn in terms of the total delay time of the vehicles increases with the increasing percentage of the U-turning vehicles. The figures for the remaining combinations are presented in Appendix B.

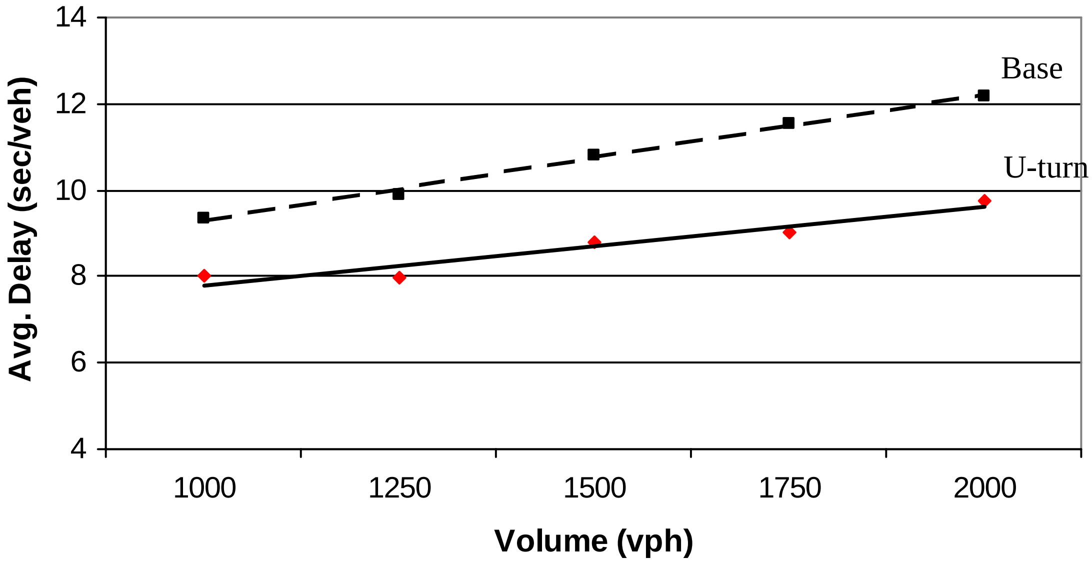

Figure 4. Average delay, 10 percent left turns and 25 percent U-turns

The trend lines observed in these graphs indicate that there is an overall improvement in delays with the installation of the U-turns. However, the question was whether these trends were statistically significant. There are two tests that should be conducted to allow for concluding whether these differences are significant. First, the slope of each line was tested to determine whether it is not zero. This test determines whether the variation observed in delays is due solely to random fluctuations about the line (case when the slope is zero) or some of the variation can be explained by the influence of the corridor volume (case when the slope is different than zero). The second test compares the slopes of the two lines for each pair of Base and U-turn models to determine whether their observed differences are statistically significant.

All statistical tests indicated that the slopes were statistically significant (Table 4). The slopes for the average delay models indicate a significant difference between the Base and U-turn models. There is an inverse relationship between the slope magnitude and U-turn percentage indicating higher reductions in delays with an increasing percentage of U-turns. As the percent of U-turning vehicles increases, a reverse condition is observed for the Base model. The higher slopes with the increasing U-turn percentage indicate an increase in delays. The statistical analysis showed that this was significant for all cases except those with 15 percent U-turns. Therefore, it can be concluded that, at least for the volume ranges examined, there are delay reductions when direct left turns are replaced with U-turns.

Table 4. Regression slopes for average delay models

Turn type (%)		Base		U-turn		Base/U-turn different?
Left	U	Slope	P-value	Slope	P-value	
5	15	0.0022	0.005	0.0024	0.007	No
	20	0.0024	0.002	0.0014	0.003	Yes
	25	0.0027	0.001	0.0014	0.005	Yes
10	15	0.0025	0.002	0.0020	0.017	No
	20	0.0029	0.004	0.0019	0.020	Yes
	25	0.0030	0.000	0.0018	0.010	Yes

To examine the effect of the U-turning volumes on delays, the values for each corridor volume were compared to determine the relative increase of the delay differences between the Base and U-turn models (Figures 5 and 6). The data indicate that for low volumes, less than 1,250 vph, these differences were small and not statistically significant. For larger volumes these differences increased. This was more pronounced for the greater percentages of left- and U-turns. Therefore, it can be concluded that for higher corridor volumes, the U-turn alternative is more desirable.

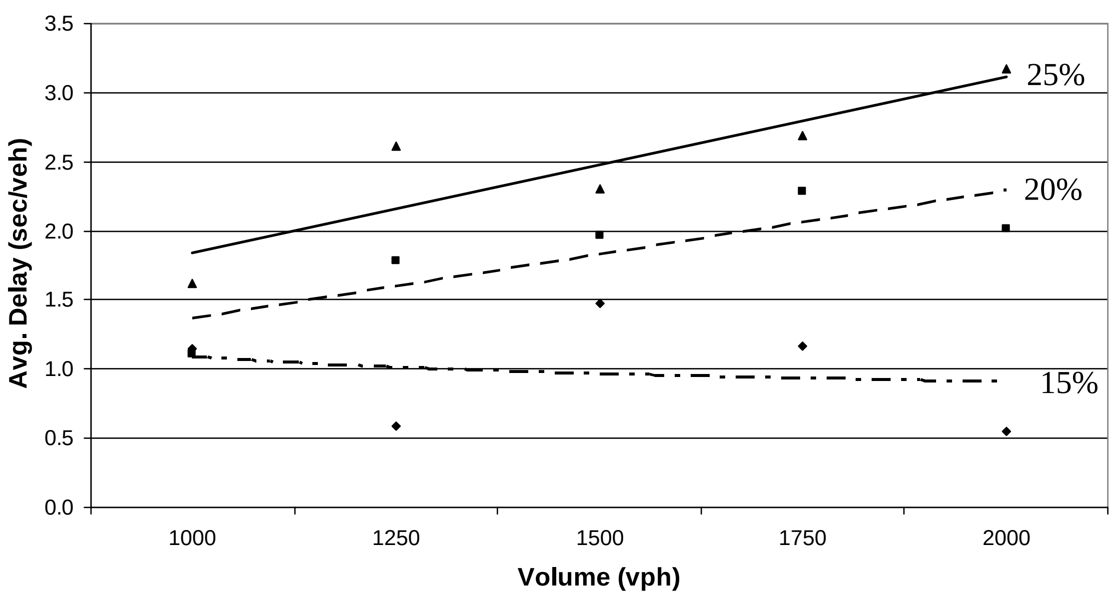

Figure 5. Delay differences between Base and U-turn scenarios, 5 percent left turns

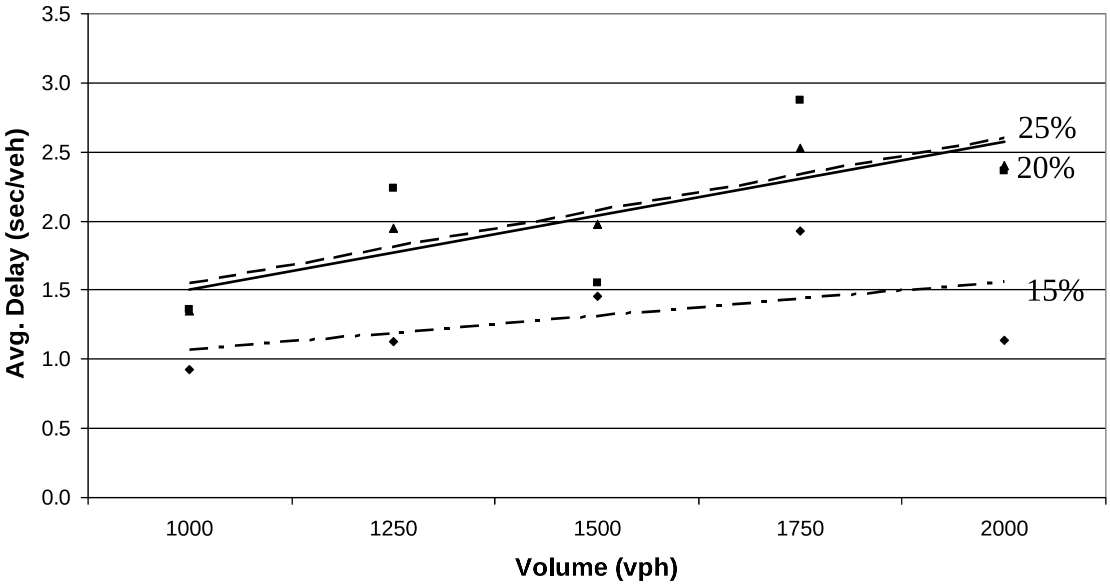

Figure 6. Delay differences between Base and U-turn scenarios, 10 percent left turns

To examine the effect of the left turning percentage on the difference in delays, the points corresponding to a given arterial and left turning volumes were compared. For 15 and 20 percent U-turns, the delay time differences for the 10 percent left turns are greater than those of the 5 percent indicating that greater gains in delays are obtained for higher left turn values. However, the values for the 25 percent U-turns do not conform to this trend indicating that the U-turns are a more controlling factor than the left-turn percentage. The statistical tests performed to examine whether there was any significant difference in the delay times with the increase in the left turning volume indicate that there is a statistically significant difference only for the case of 25 percent U-turns which confirms the observations noted above.

Apart from the major results mentioned above, two other results of lesser significance can be confirmed from the analysis of this experimental approach. First, it can be clearly noted from the graphs (Figures 2 through 6 and Appendix B) that for any percentage of left- and U-turning vehicles, the weighted average delay increases with the increase in the corridor volume. This result was expected because, as the arterial volume increases, the interaction among vehicles increases and results in increased vehicle delay.

The second observation relates to the effect of the percentage of the U-turning vehicles on the overall average delay. The data in the graphs presented in Appendix B indicate that the average delay time of the U-turn scenario decreases with the increase in the percentage of the U-turning vehicles. This is true for both let-turn percentages and is indicative that the system of the two intersections will perform more efficiently with the U-turn alternative. These gains also increase with higher percentages of U-turn vehicles because they can be processed more efficiently at intersection 3.

This observation is further supported by an examination of the cases where the total turning percentages are the same (Figure 7). This occurs for 25 percent total turns (5 left and 20 U-turns or 10 left and 15 U-turns) and the 30 percent total turns (5 left and 25 U-turns or 10 left and 20 U-turns). The comparison of the differences in average delays between the Base and U-turn scenarios shows an increasing trend (higher slope) for the cases with the larger U-turn percentages. This indicates that for similar total turning percentages, U-turns will prove to be more efficient in terms of delay times than when they are not implemented.

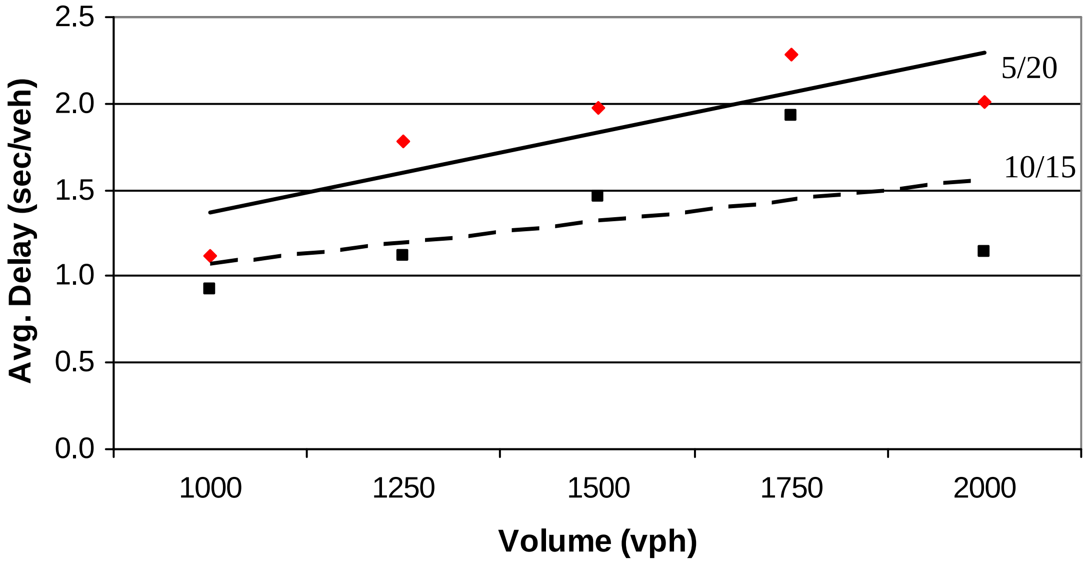

Figure 7. Delay differences between Base and U-turn models, 25 percent total turns

5. CONCLUSIONS

U-turns placed at median openings have shown much promise in reducing crash rates as well as delay when they are located on high volume arterials that intersect with low and moderate volume cross streets. These median U-turns are most effective when stop-controlled U-turns are placed on all four legs of the intersection. However, if constructing four median openings is not feasible, the simpler configuration placing median openings only on the arterial, performs almost as well.

The safety analysis indicates that the installation of the U-turns at signalized intersections did not have negative safety consequences based on the crash history of the corridors. The total crash rates at Lexington and Somerset were higher than the statewide rates but the rates were not associated with U-turn crashes. Total crashes decreased at the Somerset location which has the longest evaluation period. A couple of the crashes were due to the interaction of the U-turn and right turns on red and could be alleviated by prohibiting the right turn on red at those locations. A complementary benefit of a U-turn installation is the elimination of direct left turns onto a corridor from side streets and consolidation of these turns at one point. This reduces the number of conflict points along the corridor and thus improves safety.

Potential factors that could affect the implementation of U-turns at intersections were examined. The research provided an opportunity to confirm some of the established relationships between corridor volume and the performance of traffic with or without a U-turn. Using delay time as a measure of effectiveness, it was concluded that the presence of the U-turn enhances the operation of the corridor most likely due to the more efficient processing of vehicles at the downstream intersection. These delay gains increased for higher percentages of U-turns. For cases where the total percent of turns was the same, the cases with the higher U-turn percent reduced delays more than those with the higher left-turn percent. For higher arterial volumes, direct left turns or median openings allowing left turns should be replaced with a directional opening allowing only left turn egress movements.

Based on these findings, the following recommendations are made:

- U-turns should be considered for corridors with approach peak volumes greater than 1,500 vph. A full evaluation of the operation with and without the U-turn should be conducted.
- U-turns should be considered in cases where the expected total turn (left and U-turns) is greater than 20 percent of the total approach volume. This volume should be estimated as the total amount of left turns and through movements that would have been processed at the upstream intersection and the left turns at this intersection.
- Consideration should be given to prohibiting right turns on red at signalized intersections when U-turns are allowed. This could enhance both operational and safety performance of the installation. . If the U-turn is completed in a permitted phase, an alternative to prohibiting right turns on red is to place a “U-turn yield to right turn” sign (R10-16 in the Manual of Uniform traffic Control Devices) near the left-turn signal face. Another sign that could be used to avoid prohibiting right turn on red is “Right turn on red yield to U-turn”.

The installation of a U-turn could be considered when either of the two first recommendations is satisfied. Approval should also be sought and obtained to allow a “combination left turn arrow/U-turn” indication in a signal lenses which should be considered at these locations.

It is recommended that further research be conducted in this area especially if it is desired to further refine the guidelines for future use of this design. The additional research should focus in examining the impact of operating speeds and geometric configurations such as number of lanes and median presence.

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APPENDIX A

OPINION SURVEY

April 5, 2004

The Transportation Center at the University of Kentucky has been requested by the Kentucky Transportation Cabinet to evaluate the results of the reconstruction of US 27 in Somerset. This reconstruction included a unique design where left turns are made only at signalized intersections or by making U-turns at these intersections. As part of the evaluation process a survey of the businesses along US 27 is being conducted to determine their opinion of the effectiveness of this design.

Your business is located on the section of US 27 that was reconstructed in 1998. Part of the reconstruction involved changing the access to businesses along the corridor in order to reduce congestion. Previous to the reconstruction, this section of US 27 was a four lane divided highway with median crossovers and full shoulders. The road was reconstructed to a seven-lane roadway with a divided median. Left turn lanes are provided only at the signalized intersections. Motorists entering the roadway from various access points between the signalized intersections who desire to turn left are required to make a right turn onto US 27, travel to the next signal, and make a U-turn using a protected left turn phase.

Your opinion on this design is greatly appreciated and valued. Attached is a very short survey in which you are asked to give your opinion of this design and estimate what impacts there may have been on your business and the safety on US 27 from this design. We would appreciate it if you would complete this survey and use the enclosed, postage paid envelope to return the survey to the Center by April 19, 2004.

We thank you for assisting us in this evaluation.

Sincerely,

Kenneth R. Agent
Research Engineer

Attachment

SOMERSET US27 U-TURN SURVEY

The following questions relate to the current intersection design on US 27 in which U-turns are permitted at signalized intersections with no left turns between intersections.

1. Please identify the location of your business
2. Between intersection numbers ☐ and ☐ on the ☐ east ☐ west side of the road
3. Please mark the box that applies to your type of business

Gas station			Restaurant-Sit down	
Bank			Restaurant-Fast food	
Convenience store			Office Supplies	
Grocery store			Marine equipment	
Hotel			Medical	
Automobile dealer			Commercial; other	
Retail			Other: .	

4. Did the design have any effect on your business?
   ☐ No ☐ Yes, Positive ☐ Yes, Negative

Explain the basis of this opinion. ____

____

5. Have you noticed any problem with drivers understanding this design?
   ☐ Yes ☐ No

If yes, explain. ____

____

6. In your opinion, have there been any safety effects on US 27 from this design?
   ☐ No ☐ Yes, Positive ☐ Yes, Negative

Explain the basis of this opinion. ____

____

7. Please note any comments concerning your experience with this design.

____

____

____

Thank you very much for your cooperation and input.

APPENDIX B

TRAFFIC SIMULATION

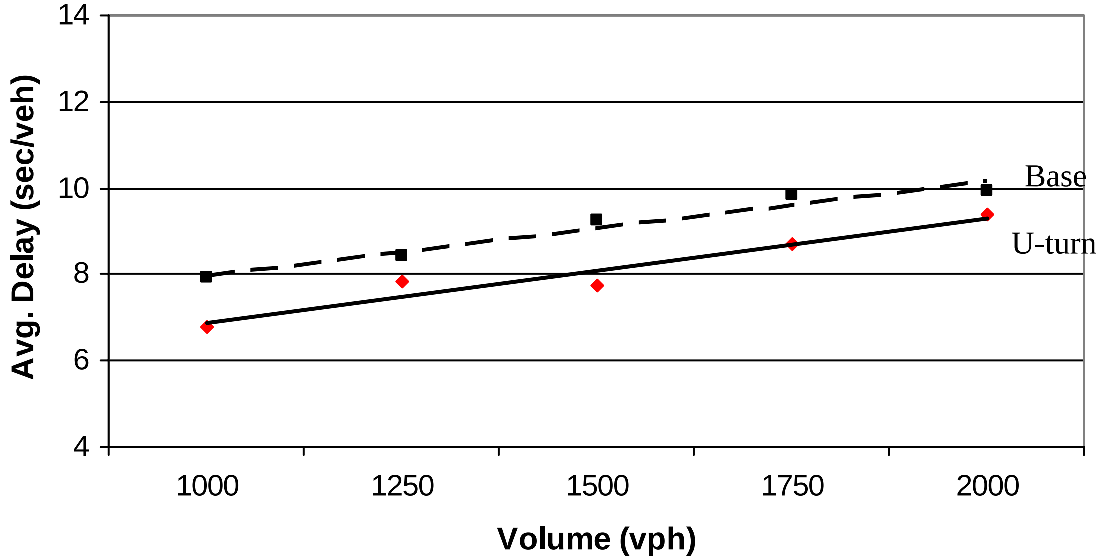

Figure B-1. Average delays, 5 percent left turns and 15 percent U-turns

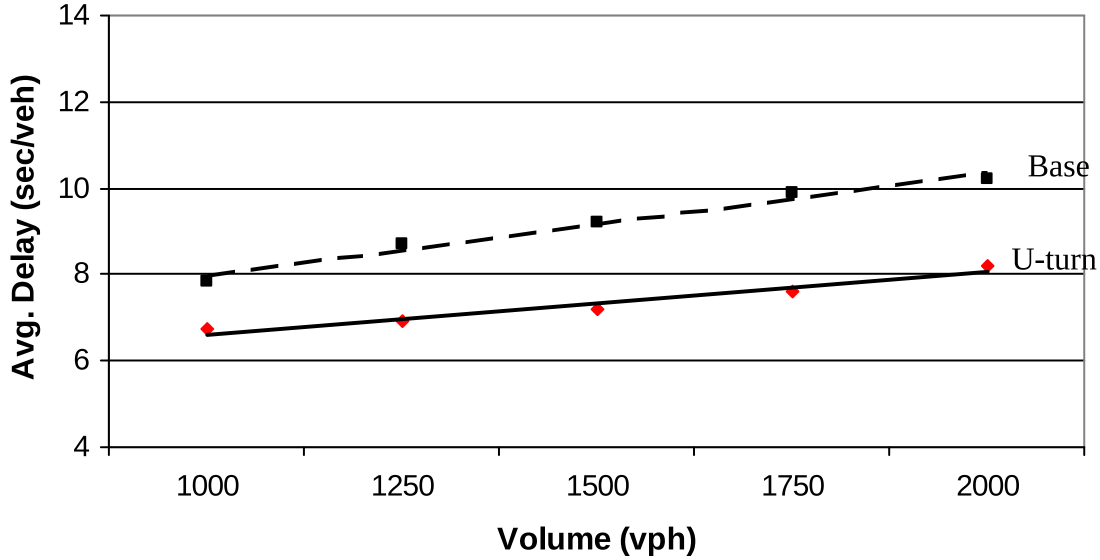

Figure B-2. Average delays, 5 percent left turns and 20 percent U-turns

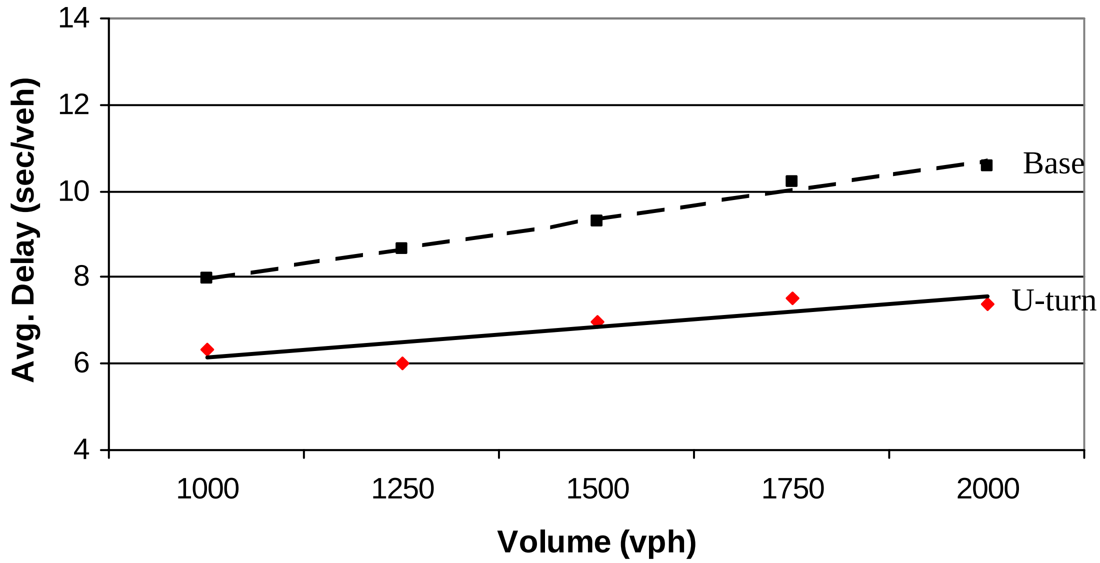

Figure B-3. Average delays, 5 percent left turns and 25 percent U-turns

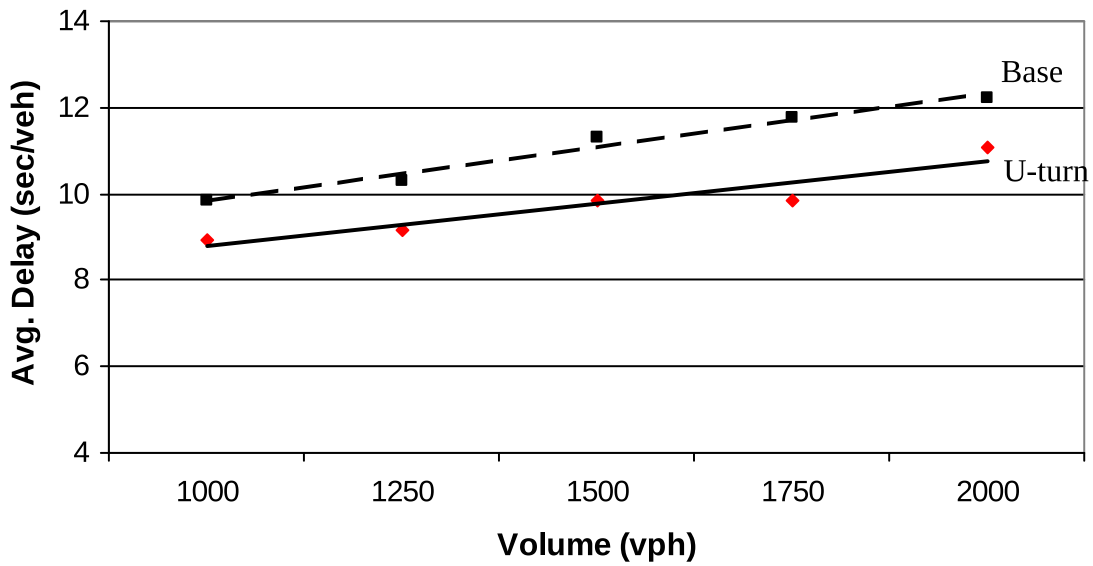

Figure B-4. Average delays, 10 percent left turns and 15 percent U-turns

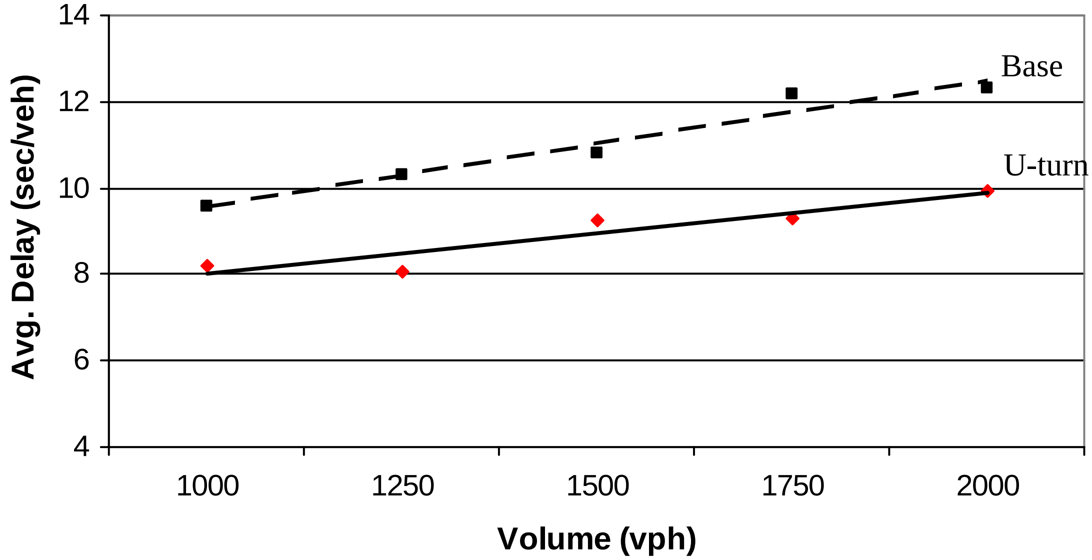

Figure B-5. Average delays, 10 percent left turns and 20 percent U-turns