

## CONTRIBUTION TO THE U-TURN DESIGN AT MEDIAN OPENINGS IN IRAQ: AI-NAJAF CITY AS A CASE STUDY

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#### Abstract

Field observations indicate that left turning vehicles at U-turn sections lead to a significantly bottleneck (congestion) at both origin and destination (opposing) roads. The bottlenecks have been observed in several U-turns such as Kufa –Najaf U-turn sections, Najaf –Karbala U-turn sections. It was found that left turn flow from U-turn leads to high congestion on both origin and destination roads. Therefore, field improvements have been done by the traffic policemen who create a temporary barrier from traffic plastic signs in order to protect left turning vehicles from through traffic in opposing direction. This study introduces new design for U-turn in order to protect both turning and through traffic to increase the level of performance. This design has been tested by using simulation model. The developed model (S-Paramics) has been calibrated using field data collected from Al-Najaf city. Then, the validation for the developed model has been implemented using another set of field data. Finally, the simulation model has been adopted to test the new design for U-turn. It was found that the new design gives higher capacity than the current design.

#### Keywords: U-Turn Capacity, Median Openings.

# المساهمة في تصميم الاستدارات نوع U في العراق : مدينة النجف كحالة دراسية

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## الخلاصة

بينت المشاهدات الموقعية بان المركبات المستدير ويسارا في مقطع الاستدار (U-turn) تقود الى اختناقات مفاجئه للطريق المنطلقة منه الرحله وللطريق بالاتجاه المعاكس. الاختناقات المروريه قد شو هدت في العديد من الاستدارات على طريق نجف-كربلاء وطريق كوفه نجف. لقد وجد بان المركبات المستديرة يسارا تؤدي الى از دحام عالي على كلا الطريقين المنطلقة منه المركبات والذاهبه اليه. لذلك اجريت تحسينات من قبل شرطة المرور وذلك من خلال وضع سياج مؤقت من العلامات المروريه البلاستيكيه لحماية المركبات المستديرة من شرطة المرور وذلك من خلال وضع سياج تصميم جديد للاستدارات لحماية المركبات المستديرة من المرور بالاتجاه المعاكس. الدر اسة الحاليه تقدم باستخدام نموذج المحاكاة. لقد تم معايرة المركبات المستديرة من المرور بالاتجاه المعاكس. الدر اسة الحاليه تقدم باستخدام نموذج المحاكاة. لقد تم معايرة البر نامج الحالي باستخدام بيانات حقلية تم جمعها خلال هذه الدراسة من مدينة النجف. التأكد من تمثيل النموذج لواقع الحال تم باستخدام بيانات حقلية الحرى. ثم بعد ذلك تم اعتماد النموذج المطور لدر اسة التحصميم المورية المركبات المستديرة من المرور الأخر ولزيادة مستوى الاداء. هذا الدراسة من مدينة

الكلمات الدالة: سعة الاستدارة U-turn , فتحات الجزرات الوسطية

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## 1.Background

During the past years, more state departments of transportation and local transportation agencies have started installing non-traversable medians and directional median openings on multilane highways (Liu,2006). Since 1993, the Florida Department of Transportation mandated that all new or reconstructed multilane arterials with design speeds over 40 mph be designed with restrictive medians (Liu, 2006). By installing non-traversable medians and replacing full-median openings with directional median openings at various locations, Florida is limiting median openings to left-turns from the major arterials. Hence, drivers desiring to make Direct Left-Turn egress (DLT) maneuvers from a driveway or a side street onto major arterials would need to turn right onto the major-street and then make U-turns (RTUT) at a downstream median opening or a signalized intersection, as shown in Figure 1(Liu,2006). Moreover, Mauga (2010) mentions other types of U-turns as shown in Figure 2.



Fig. 1: Three Different Driveway Left-turn Alternatives (Liu, 2006).



Fig.2: Types of Median openings (Mauga, 2010).



The purpose of using non-traversable and directional median openings is to eliminate problems associated with left-turns and crossing movements on multilane highways (Liu, 2006). As a result of this design decision, drivers desiring to make direct left-turns at a driveway will be relocated to a downstream U-turn bay to make U-turns. Therefore, replacing a full median opening with a directional median opening will reduce conflict points from 32 to 8, as shown in Figure 3. Thus, it will simplify driving tasks and could significantly reduce crash rate (Vargas and Gautam, 1989).



Fig.3: Conflict Points at a Conventional Full Median Opening Versus a Directional Median Opening (TRB, 2003).

Previous studies have demonstrated that the use of non-traversable medians and directional median openings have little or no overall adverse impacts on roadside business activities (Eisele et al., 1999, Rees et al., 2000, Williams, 2000, Levinson and Gluck, 2000, Patrick et al., 2002); and the increased numbers of U-turns at median openings and signalized intersections will not constitute major safety concerns (Kach, 1992; Levinson et al., 2000; Maki, 1996; Cluck et al., 1999; Lu et al., 2001; Lu et al. 2001, Potts et al., 2004; Carter et al., 2005).

#### 2. Spacing between median openings

The process of replacing direct left turn movement by right-plus U-turn has been studied by **Yang (2001)** under specific traffic conditions. The author found that at 200vph of left turning traffic from major streets, delay for direct left turn is always bigger than of right-plus U-turns for all through traffic conditions. The study also reported that when left turn volume between 6000 and 7000 vph the right-plus U-turn is the best over direct left turn. Whereas, there is no benefit from right-plus U-turn in case of weaving distance are very long (i.e. more than 210 m). **Pirinccioglu (2007)** conducted a study similar to Liu's study but the recommended separation distances for his study are higher as shown in **Table 1 and 2**, respectively.

No procedures or guidelines have been determined optimal location of U-turn median openings as reported by Zhou et al. (2003). They also added that if spacing is long, travel time for diverted left turning traffic increases and if short there may be safety problems.



They reported that restricting vehicles from directly turning left onto major roads reduces delay of diverted traffic and improves safety by 68%.

No. of lanes	Location of U-turn Bay	Critical separation distance (m)	Recommended distances(m)
4	Median opening	102	105
4	Signalized intersections	152	150
6 to 8	Median opening	137	135
6 to 8	Signalized intersections	232	225

## Table 1: Recommended Minimum Separation Distances (Liu, 2006).

Table 2: Recommended Separation Distance Values (Pirinccioglu, 2007).

Location of U-turn Bay	No. of lanes	Critical separation distance (m)	Recommended separation distances(m)
Median opening	4	126	120
Median opening	6 to 8	206	210
Signalized intersections	4	184	180
Signalized intersections	6 to 8	302	300

Due to the lack of regulations and guides for minimum and optimal separations between upstream driveways and downstream U-turn median openings, Liu (2006) used 50<sup>th</sup> percentile crash rate to determine the minimum separations. The results of this study are summarized in Table 1. However, Liu did not clarify why the 50<sup>th</sup> percentile was taken as the threshold value instead of lower percentiles which correspond to lower crash rates.

Then, the left-turn will be changed to right turn plus U-turn as reported by Pirdavani et al. (2011). The authors have applied this management to unconventional arterial intersections. The results showed that replacing Direct Left Turn (DLT) by Right Turn plus U-turn (RTUT) lead to reduce delay and travel time for intersections. Pirdavani et al. (2011) reported that DLT vehicles would suffer longer delays than RTUT vehicles when the vehicles on the major road are relatively high and the DLT volume exceeds 50vph.

The operational effects of U-turns as alternatives to direct left turns from driveways were studied by Zhou et al, (2003). They conducted their study on eight sites in the Tampa and Clearwater areas of Florida (urban and sub urban areas) to compare the operational effects of the direct left turn (DLT) and right turn plus U-turn (RTUT). Field data collection including delay, travel time models of DLT and RTUT were developed to estimate how many drivers would prefer to make a RTUT rather than DLT under certain traffic flow conditions. These



operational models were used to measure system performance of a full median opening versus a directional median opening.

## 3. Median and roadway width to facilitate U-turns

The minimum median and roadway width required to facilitate U-turning vehicles are key factors in determining whether U-turn movements can be permitted at a median opening or a signalized intersection. The AASHTO Green Book (A Policy on Geometric Design of Highways and Streets) contains some guidelines on the relationship between median width and U-turn maneuvers. As indicated in the AASHTO Green Book, medians of 5.0 m and 15 m or wider are needed to permit passenger car and single-unit truck traffic, respectively, to turn from the inner lane (next to the median) on one roadway to the outer lane of a two-lane opposing roadway. Also, a median left-turn lane is highly desirable in advance of the U-turn opening to eliminate stopping on the through lane. This scheme would increase the median width by approximately 3.6 m (AASHTO, 2001). The minimum widths of medians to accommodate U-turns by different design vehicles turning from the lane adjacent to the median are shown in Figure 4.



Fig. 4: Minimum Median Widths to Accommodate U-Turns (AASHTO, 2001).

A median width that can accommodate normal left-turns and passenger U-turns should be supplied for a new design divided highway. Therefore, there is a need for adequate median width that can accommodate U-turns, and then add extra pavement width, through use of a taper, a flare or on the shoulder for example should be considered (Potts et al., 2004).

Another treatment to facilitate the larger turning path of U-turning vehicles along narrow medians is the use of loons. As defined in the NCHRP Report 524, a loon is an expanded paved apron on the shoulder opposite a median crossover, as shown in **Figure 5** (Potts et al.,



**2004).** The purpose of installing loons is to provide additional space for larger vehicles (particularly trucks) to negotiate U-turns, and thus, to allow the installation of conventional or directional median openings along narrow medians. The provision of loons is to serve U-turns by large vehicles. This is a new technique that formalizes past use of paved shoulders for the same purpose (**Potts et al., 2004**).

**Sisiopiku and Aylsworth-Bonzelet (2003)** evaluated the operations, placement, and safety of existing loons at directional crossovers in Michigan. It was found that loons provide commercial vehicles with the extra pavement necessary to complete the U-turn maneuver; and the consistent placement of advance warning signs preceding the indirect crossover and associated loon assists in driver behavior. The research team of that study investigated crash data analysis at 7 crossovers installed with loons and indicated that directional crossovers with loons experienced a high percentage of fixed-object and sideswipe crashes. As a result of that study, the researchers developed the guidelines for the design and placement of loons using computer simulation.



Fig.5: Conventional Median Opening with Left-Turn Lanes and Loons at Three-Leg Intersection (Potts et al., 2004).

## 4. Capacity of U-Turn

Left turn movements have been proved by different methods (HCM 1994 and HCM 2000) to be one of the most impacts on the level of service (LOS) and performance of unsignalized and signalized intersections. As left turn demand increases at signalized intersections, the phase for this left turn changes from permitted to protected phase. Moreover, one of iterations to improve the performance of intersections is by diverting left turning flow from crossing through traffic the main intersection. This will reduce the number of signal phases (Liu, 2006).

Generally, studying the effects of U-turn could be classified as one focuses on its influence on the capacity of signalized and un-signalized intersections. Second, studies focus on U-turn at median openings such as Al-Masaedi (1999). The author developed an empirical model to estimate the capacity and average delay of U-turn at median openings. This study concerns the capacity of U-turn movement at un-signalized intersections. In Al-Masaeid's study, regression models were developed to estimate the capacity and delay of U-turn movement at median openings and to investigate the effect of different relevant factors that might affect the estimated capacity and delay.



Al-Masaeid also estimated the critical gap and move-up time for U-turns and used them to calculate capacity on the basis of the 1994 edition of the Highway Capacity Manual. The author compared the results of gap acceptance model and regression model and 23 concluded that the gap acceptance model provided reasonable results for estimating the capacity of U-turns. Al-Masaeid's study provided very useful information about the capacity of U-turn movement at un-signalized intersections. However, the author did not explain the procedures for estimating the critical gap and follow-up time for U-turns. In addition, Al-Masaeid's study was conducted in Jordan; the results may not reflect the behaviors of motor vehicle drivers in the United States.

In terms of Highway Capacity Manual 2000, the U-turning movement is treated as left turn for estimating the saturation flow rate. Saturation flow rate is one of the most critical and important factor in evaluating the capacity of a lane or a lane group at a signalized intersection. However, based on the field data and real situation, the operational impacts of U-turns are different from which of left turns. From the field data, it is easily to find that the turning speed of U-turns and the turning speed of left turns are different. Thus, the saturation headway will be interrupted if the U-turning vehicles mix in the left lane. Due to the U-turn speed is lower than the left turn speed, the capacity of the lane will be reduced. According to the field data review and analysis, it is found that U-turning movement will increase the delay of the approach. As the control delay is the criteria for evaluating the Level of Service of a signalized intersection, thereby the U-turning movements have an adverse effect on Level of Service. At present, there is no widely accepted theory or method for estimating the effects on capacity caused by U-turning movements. It is necessary to analyze the feature of U-turns and find out a method to estimate the effects of U-turning vehicles on capacity at a signalized intersection (Wang, 2008). Pirdayani et al. (2011) reported that simulation models were adopted to test different scenarios of using unconventional intersections using RTUT. These studies have concluded that unconventional intersections are better than signalized intersections in terms of reducing delay and conflicting points.

**Kim et al, (2006)** performed some simulation studies for three different cases of superstreet which is similar to median U-turn. In the first case one left turn lane and two through lanes on the major road was considered, the second case considered one left turn lane and three through lanes on the major road. For each case microscopic traffic simulations were conducted for various traffic volumes and their performance was compared to the conventional design option. The first case was simulated for high, medium and low traffic scenarios and the remaining two cases were studied for high volumes as their application was mainly intended for sites operating under heavy traffic conditions. A 400 ft offset was assumed in the superstreet design. The traffic signal required only two phases instead of four or more phases. Phase one allowed the major road through movement and phase two allowed the major road left turn movement and the minor road through and left movements. The Simulation Surrogate Safety Assessment tool was used to perform some safety evaluations.

Unconventional intersection designs have been discussed for urban and suburban arterials by different researchers such as Hummer (1998) and Liu et al. (2007). They found that these alternatives serve increasing through capacity and reducing conflict point and delay.



Shihan and Mohammed (2009) studied the effect of some factors on the performance of Uturns such as gap acceptance, opposing flow, and U-trun flow using U-SIM simulation model in Baghdad city. However, the effect of speed of opposing flow was neglected and no obvious procedure of collecting field data.

**Al-Taei** (2010) conducted empirical study on eight U-turn locations in Iraq under different flow and speed conditions. He found that these locations were characterized by high delay and accident rates. The author also investigated the gap acceptance for left turning vehicles. However, this study has several limitations such as absence of clear methodology of collecting field data and the information of these data.

**Pirdayani et al.** (2011) proposed some crucial differences to the other types of median openings. These developed U-turn facilities are built on main roads, both sides of the intersection, and used as a complete replacement of signalized intersections. It means that all the movements on the intersection will be one by U-turn and the signalized intersection is fully blocked; while all types of U-turn facilities reviewed in the literature were used just for left turns. This type of U-turn is geometrically designed as shown in Figure 6, has channelizing and splitting islands and provides protected U-turn movements. Channelizing island with a convex section helps drivers to keep track on their desired trajectories even if they want to use the U-turn facility or go straight on the main road. This convex section affords an opportunity for a through driver to pass to the right of a slower moving or stopped vehicle on the deceleration lane preparing to use the U-turn. By the use of a splitting island, a safe divergence at the entrance of U-turn facility and a safe and protected convergence operation at the exit of U-turn are provided. An acceleration lane is also provided for a safe merging of U-turn vehicles with through movement of the main road. Different parts of Uturn as defined: A: Channelizing island, B: Deceleration lane, C: U-turn raised island and D: Acceleration lane.



Figure 6 Protected U-turn (RTUT design) (Pirdavani et al., 2011).

## 5. Data Collection

#### **5.1 Field Observations**

Most of U-turns in Al-Najaf city suffer from congested traffic especially in peak period. Therefore, the traffic policemen exist in these locations in order to mitigate the congestion by putting plastic signs to create a channelization. This channelization helps in separating traffic and providing enough refuge area for turning vehicles. This temporary management has been observed in several locations such as U-turn close to Al-Tarbia Building on Kufa-Najaf road, U-turn opposing the main entrance of University of Kufa also on Kufa –Najaf road and other U-turn on Najaf-Kerbalaa road and Al-Askan road. In



these locations, the queue length on both origin and destination roads has been observed. One of the main reasons for that queue in the destination road is the reduction of number of lanes.

In this study, the U-turn in front of the gate of the University of Kufa has been selected in this survey. Three observers for the opposing traffic and two observers for the U-turning vehicles have been assigned for the task of collecting data. On the other hand, a video camera has been installed over the bridge foot in order to capture the traffic on both directions at the upstream traffic and for u-turning vehicles. It was found that the percentage of trucks around 5 as average, whereas the percentage of minibus is about 25. The high percentage of minibus reflects that this road (Najaf-Kufa) serves a lot of facilities such as educational institutions, health centers and other facilities. **Figure 7** indicates the flow for both u-turning and opposing traffic.

It has been observed that long queue of vehicles up to 1km at the upstream of the location of u-turn. This long queue of vehicles waits to be served by this u-turn (wait to turn). The waited vehicles block one of the three lanes for Najaf-Kufa road. Therefore, this segment of that road suffers from high congestion which lasts for more than one-hour (7:40-8:40). On the other hand, the queue in the opposite direction (opposing traffic) extends to the Al-Najaf Hospital intersection (T-intersection) causing blocking this intersection as indicated in **Figure 8**.







Fig.8: Long Queues due to U-Turn Vehicles.



It was also observed that the traffic policemen put a plastic signs to increase the area used for turning vehicle as shown in **Figure 9.** Accordingly, the new type of protected u-turn has been suggested later on in this study.

The above behavior is not only in Najaf but also in other Iraqi cities. For example in Duhok City, eight locations on U-turn median openings were studied by Al-Taei (2010). He concluded from this empirical study that these eight sections suffered from long delay and dangerous accidents. Moreover, the author indicated that the traffic officers were at these locations in order to manage traffic there.



Fig. 9: Traffic Barrier using Plastic Signs for Traffic Separation.

## **5.2 Spacing Distances**

The spacing between ten U-turns and their access roads were measured by this study as shown in **Table 3**. It has been observed that about 90% of these U-turns are not satisfied with standards mentioned in **Tables 1 and 2**. Moreover, a short distance leads to more accidents and congestion. This is due to absence of enough weaving length. The average speed of all roads, where the U-turn faculties are located, is 80 km/hr except the last case as shown in **Table 3**.

Type of road	The distance from u-turn and access point	
Minor arterial (Al-Askan road)	46m (right –hand)	
Minor arterial (Al-Askan road)	31m (right-hand)	
Minor arterial (Al-Askan road)	90m (left -hand)	
Al-Gadeer street (minor arterial)	34m (right-hand)	
Al-Gadeer street (minor arterial)	101m (right-hand)	
Al-Gadeer street (minor arterial)	75m (left-hand)	
Al-Gadeer street (minor arterial)	50m (left-hand)	
Al-hazam Al-Akader (minor arterial )close to Al-Mulahak Al-gadeer	45m	
Al-hazam Al-Akader (minor arterial ) (Al-Adaab road)	32m	
Al-Adaab road with its subway	47m	

### Table 3: The Distance between Access Point and the U-Turn at Different Locations.



From the safety point, it was noted that a lot of accidents occurred frequently on the existing U-turns in Al-Najaf City. However, there is no accurate documentation for these accidents. Consequently, absence of actual accident rate may lead to inaccurate information about how the effect of existence of U-turn on traffic safety.

## **6. Simulation Model (S-Paramics)**

A well-know microscopic simulation model (S-Paramics) has been used to represent the case of U-turn. After getting the license of this package, the model has been built using the nodes and links as shown in **Figure 10**. Moreover, the simulation model could provide the user with the three-dimensional views as shown in **Figure 13**.



Fig. 10: S-Paramics Simulated Model for Normal U-Turn Case (Two-Dimensional).



Fig.11: S-Paramics Simulated Model for Normal U-Turn Case (Three-Dimensional).

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Then field data has been used for calibration the simulation model as shown in **Figure 12**. The opposing traffic from simulation model shows very close behavior with observed data. Whereas, a bit of difference between the simulated and observed turning vehicles. This could be attributed to managing the turning vehicles especially during the peak hour.



Fig.12 ; Calibration Simulation Model with Field Data.



Fig.13; Validation of the Simulated Data with Field Observations.

After calibrating the developed S-Paramics, published field data were used for validating the developed model. These data were collected from Jordan by Al-Masaedi (1999). These published data represent the effect of opposing traffic stream on the turning traffic stream. Then, the S-Paramics model has been used to model the same characteristics of geometric design (number of lanes for U-turn and other roads) and traffic



characteristics (flow for U-turning and other vehicles). A graphical test for the validation process indicates a good behavior of the simulation model as shown in Figure 13.

In the light of the above, the S-Paramics shows a good ability to represent the reality of the traffic stream for U-turning and opposing traffic streams.

### 7. New Management

After the calibration and validation processes, the simulated model could represent the driver behavior in the U-turning section. The model now is ready to test different scenarios (managements). The first scenario is the protected U-turn. This section consists of protected U-turn and widening the whole area of U-turn as shown in Figure 14.

The second design for U-turn is indicated by **Figure15**. This design is similar to the previous suggested design in providing refuge for the turning vehicles. However, this design allows the vehicles turning in large turning radius. This will facilitate the turning for heavy vehicles but increase the possibility of accident.

The suggested two designs for U-turn by this study increase the capacity by more than two times the normal case. The above two suggestions were tested by the simulation model (S-Paramics).The simulated results demonstrate that no queuing vehicles on any side.This attributes to continued movement for both U-turning and opposing traffic.



Fig.14 : Proposed Design for U-Turn Section.



Fig. 15: Second Suggested New Design for U-Turn.



## 8. Conclusions and recommendations

The main conclusions of this study could be summarized by the following points:

- 1. Simulation models are from the best tools to solve the traffic congestion problems such as U-turns at the median. Field data has been collected in order to calibrate and validate the S-Paramics model.
- 2. The suggested design for U-turn which has been mentioned by previous studies has been tested by the simulation model (S-Paramics). The results show that design is more efficient than conventional design.
- 3. The new design suggested by this study shows encouraged results by increasing the capacity of the U-turn.
- 4. The spacing between the access points (driveways, roads) and U-turns may be less than the critical spacing (default values). This should be improved by changing the location of U-turn in order to reduce the number of accidents and increase the capacity of both through and turning vehicles.

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