

SAFETY AND OPERATIONAL ANALYSIS FOR MEDIAN U-TURN INTERSECTIONS IN THAILAND

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ABSTRACT: At major conventional uncontrolled intersections along high-speed divided highways, road users experience serious accident risks and long travel delay. Specifically, vehicles from minor roads at unsignalized intersections have to make a direct crossing at the main intersection. To solve safety and mobility problems at such conventional intersections, a median U-turn intersection design has recently proposed among highway authorities in Thailand. This design removes the median opening at the main intersection, restricts vehicles from making a direct crossing, guides them to make a U-turn at the downstream median U-turn opening, and returns to the main intersection. For such design, the distance between the median U-turn opening downstream and the main intersection (called a median U-turn offset) is the most important design parameter that influences the safety and operating efficiency. Too short median U-turn offset will result in harsh lane-change conflict for minor-road traffic, while too long median U-turn offset will increase vehicle travel time. This paper proposes the framework to rationally recommend the median U-turn offsets of such design. The microscopic traffic simulation models are developed to estimate vehicle travel time, and the crash surrogates are used to estimate the number of vehicles involved in conflicts. The median U-turn offsets that balance the operating and safety efficiencies are recommended. It is found that the recommended median U-turn offsets are sensitive to volumes on major and minor roads, vehicle speed, and vehicle composition. The proposed framework is then applied to the real-world highway improvement projects.

Keywords: Safety, Surrogate safety assessment, Traffic simulation, Intersection, Median u-turn

1. INTRODUCTION

Managing traffic mobility and safety at intersections is one of the most challenging tasks for highway engineers. At major intersections, road users often experience travel delay during peak periods and suffer serious accident risks. To solve such problems, various alternative intersection designs have recently been proposed among highway authorities, such as roundabouts, restricted-crossing U-turn intersections [1]. The basic premise of such designs is to separate different traffic movements, provide more uninterrupted flow, and minimize severe traffic conflicts.

In Thailand, road users experience severe far-side angle accident risks and long travel delay at a conventional unsignalized intersection where a minor road intersects a high-speed multilane road. To improve safety and mobility at an intersection, a median U-turn intersection design is gaining acceptance. This design prohibits vehicles from a

minor road to directly cross the main intersection but guides them to make a U-turn at the downstream median U-turn opening and return to the intersection [1,2]. The design features of conventional unsignalized and median U-turn intersection designs considered in this study are shown in Fig. 1.

For this type of intersection design, the distance between the median U-turn opening and the main intersection, called median U-turn offset (L) shown in Fig.1(b) is the most important design parameter that influences the operating and safety efficiency. Too far median U-turn offset will increase vehicle travel time, while too short offset will result in harsh lane-change conflicts for minor-road traffic. The objectives of this study are (i) to propose the model framework that can rationally recommend the median U-turn offsets for median U-turn intersection designs; and (ii) to apply it to determine the U-turn openings for a real-world highway intersection improvement project.

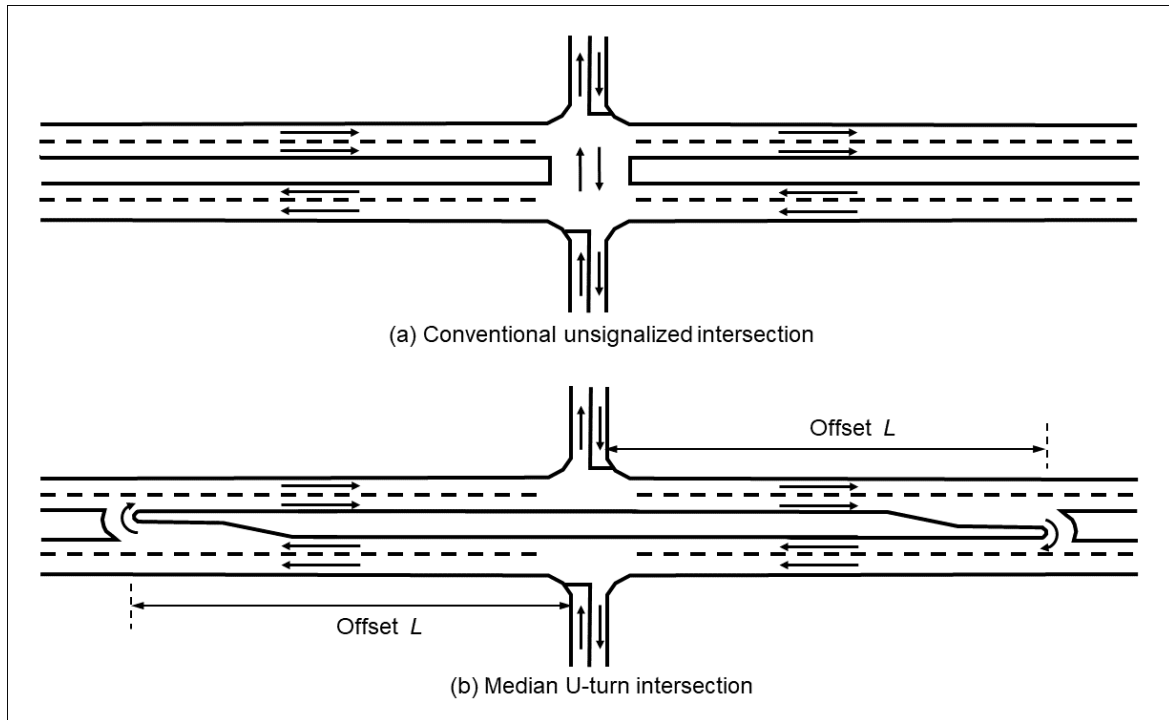


Fig. 1 Intersection configurations

2. BACKGROUND STUDY

2.1 Median U-Turn Intersection Design

A median U-turn treatment is an alternative low-cost at-grade intersection design that offers the potential to improve safety and mobility of conventional intersections along multi-lane divided highways. The median U-turn intersection design restricts some or all of the direct turn movements at the main intersection and provides the median U-turn downstream to make a turn [3]. Past studies on this subject mainly focused on determining the operational or safety benefits of the alternative designs. For the operational benefits, such design performs better than the conventional design in terms of travel delay, queue length, and vehicle throughputs [4,5]. For the safety benefits, such design theoretically reduces the number of conflicts by half. The before-and-after studies also showed the reduction in numbers of crashes [5-7].

There are a number of factors affecting the safety and efficiency of median U-turn intersection designs, such as the number of traveled lanes, the vehicle operating speed on major and minor roads, the presence of acceleration lane, the configuration of U-turn opening, and the median U-turn offsets.

In practice, the median U-turn offset are varied. For unsignalized types, the median U-turn offsets

range from 100 to 900 m. [2,9]. For signalized types, the median U-turn openings are relatively short. The openings are located closer to the main intersection, typically 100 to 180 m based on signal timing [8].

2.2 Microscopic Traffic Simulation Model

A microscopic traffic simulation is a powerful tool that can analyze the complex traffic flow and represent traffic movement under various scenarios. It is used to simulate and replicate several driving behaviors. In highway and traffic engineering applications, a microscopic traffic simulation is widely accepted and used as a reliable decision tool. In general, the development of microscopic traffic simulation model involves network coding, model calibration, and model validation [9].

2.3 Surrogate Safety Assessment Model

The surrogate safety assessment model (SSAM) is an analytical tool to identify conflict events. The basic premise of surrogate safety assessment is that all collisions will be preceded by conflicts. The frequency of conflict events (or traffic crash avoidance) in a road network can be recorded using vehicle trajectories in a microscopic traffic simulation and can be measured by various surrogate safety measures including both temporal

and spatial proximal indicators. [10] Two frequently used indicators in surrogate safety assessment are

- Time to Collision (TTC) is defined as the time until a collision between two vehicles would occur if they continued on their course at their present rate.
- Post-Encroachment Time (PET) is defined as the time between the moment that a vehicle leaves the area of potential collision and the other vehicle arrives collision area.

Typically, three categories of conflict events can be identified: rear-end, lane-change, and path-crossing conflict events [11].

3. METHODOLOGY

3.1 Model Framework

The study presents the model framework to analyze the safety and operational performance of median U-turn intersection designs as shown in Fig. 2. The details are as follows.

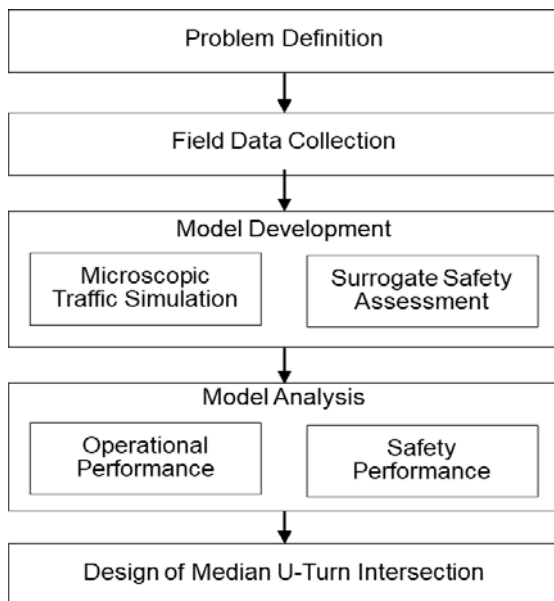


Fig. 2 Model framework

3.2 Data Collection

This research focuses on the analysis of median U-turn intersections located on a 4-lane divided major road intersecting with a 2-lane minor road. Although the scope of the research is limited to this intersection configuration, the proposed model framework can be further applicable to other intersection configurations.

The parameters required to develop traffic simulation models were first identified. These parameters include road network geometry, input traffic on major and minor road, turning movements on all intersection approaches, traffic compositions, desired vehicle speed, and gap acceptance for all types of vehicle and movement to merge the flow.

Data from two sources were gathered. Field data were collected from the intersections on a high-speed corridor. They are road geometry (i.e. the configuration of intersection and U-turn openings) and traffic data (i.e. traffic volume, speed, traffic composition, gap acceptance). Data on socio-economic characteristics (i.e. value of time, unit cost of accident) were obtained from national reports.

3.3 Model Development

The typical models of conventional intersection and median U-turn intersection were developed using the microscopic traffic simulation package and surrogate safety assessment model (SSAM) for evaluating operational and safety performances, respectively [11]. The basic parameters used in model development are as shown in Table 1.

Table 1 Parameters used in simulation models

Parameter	Value
<i>Microscopic Traffic Simulation</i>	
Traffic volume	100 to 600 veh/hr/lane
Turning movement	Left-turn 20% Through 60% Right-turn 20%
Median U-turn offset	100 m to 1,000 m
Traffic composition	Motorcycle 40 to 50% Car 40 to 50% Truck 5 to 20%
Accepted gap	Motorcycle 2.5 sec Car 4 sec Truck 6 sec
Desired speed	Motorcycle 50 km/h Car 70 km/h Truck 50 km/h
Simulation time	7,200 sec
Simulation runs	10 runs
<i>Surrogate Safety Assessment Model</i>	
Time-to-Collision	1.5 sec
Post-Encroachment Time (PET)	5 sec

The simulation models were developed for different combinations of input parameters to cover the variation of input parameters. The total number of 3,960 simulation tests were performed: 360 tests for conventional intersections (36 sets of traffic volumes, and 10 simulation runs); and 3,600 tests for median U-turn intersections (36 sets of traffic volumes, 10 offsets, and 10 simulation runs).

3.4 Model Analysis

The recommended median U-Turn offsets were determined by minimizing the marginal user costs at an intersection. The marginal user costs represent the operational and safety effects of traffic flows at an intersection.

3.4.1 Operational Analysis

The operational performance is analyzed by the excess travel time cost. Using a microscopic traffic simulation, travel times that all vehicles used to maneuver through the intersection for both conventional and proposed intersection designs were recorded. The excess travel time cost is calculated by the difference of travel times between two designs, and it is then converted to the annual costs by taking into consideration the annual traffic and value of time.

3.4.2 Safety Analysis

The safety performance is analyzed by the accident cost saving. Using a surrogate safety assessment model, the reduction in number of conflicts that vehicles encountered when making a U-turn compared with the direct turn at the intersection. The accident cost saving is then calculated by converting the number of conflicts by taking into consideration the accident to conflict ratio and the unit cost of accident.

3.5 Design of Median U-Turn Intersection

The median U-turn offsets are then determined based on the minimum total (marginal) user cost concept as shown in Fig. 3. The marginal user cost is the sum of the excess travel time costs accrued by road users traveling longer to make a U-turn, and the excess accident costs accrued by road users experiencing risks of accident to weave for U-turn movement. The recommended offset is the location of median U-turn where the total user cost is minimized.

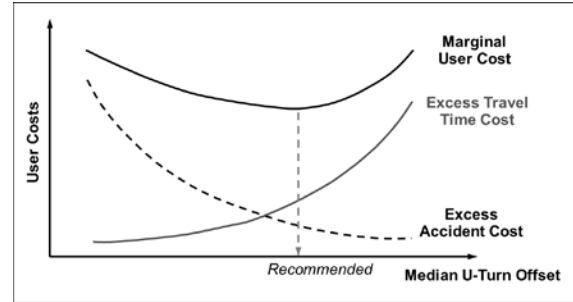


Fig. 3 Minimum user cost concept

4. RESULTS AND DISCUSSION

4.1 Operational Performance

Using a microscopic traffic simulation model, travel time associated with conventional and proposed design were measured, and then travel time costs were calculated. The result shows that travel time cost increases with the increase in median U-turn offset for any given major- and minor-road traffic volumes as shown in Fig. 4. The figure also shows that the travel time costs increase significantly when the median U-turn offset increase greater than 500 m.

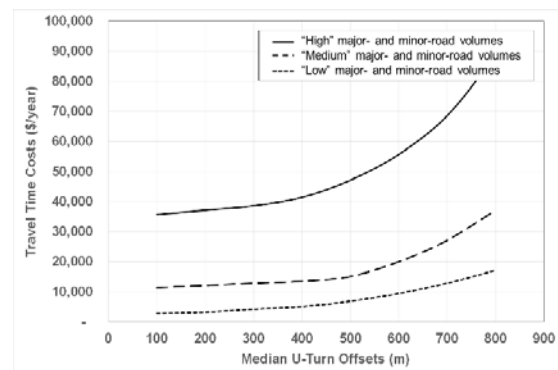


Fig. 4 Operational performance with respect to different median U-turn offsets

4.2 Safety Performance

Using a surrogate safety assessment model, the conflict points associated with a given intersection design can be measured. Fig. 5 shows the example of a road network in a simulation model platform, and its associated conflict points obtained from a surrogate safety assessment model. Three conflict types were marked by different colors: red is for crossing conflict, green is for lane-change conflict, and yellow is for rear-end conflict.

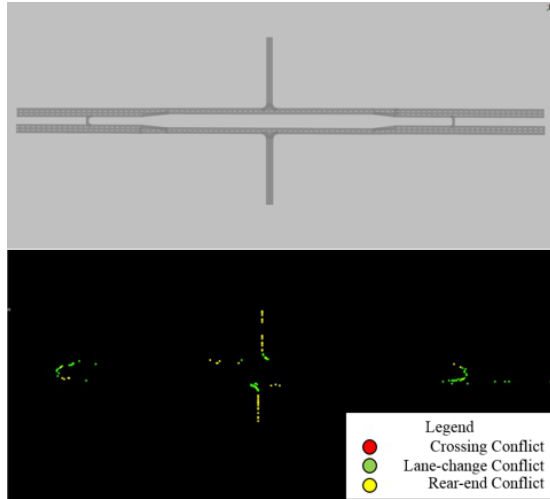


Fig. 5 Conflict points on a simulated road network

The result intuitively shows that accident costs decrease with the increase in median U-turn offsets for any given major-road and minor-road traffic volumes (low, medium, and high traffic volumes) as shown in Fig. 6. This figure presents that the long median U-turn offsets can reduce the loss of accident.

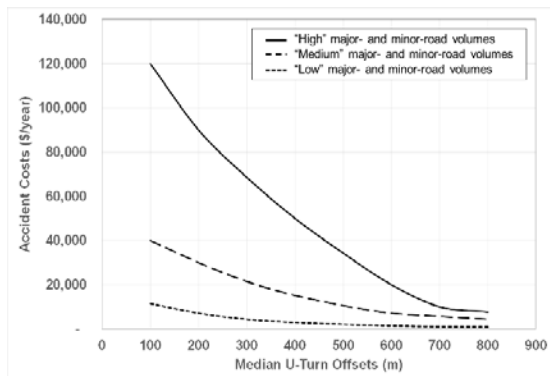


Fig. 6 Safety performance with respect to different median U-turn offsets

4.3 Recommended Design

For a given traffic condition and design setup, the median U-turn offset can be determined by minimizing the total user cost (which combines travel time costs and accident costs.) Fig. 7 illustrates the relationship of total user costs and median U-turn offsets. The results show that for a given traffic volume, there is an optimal value of median U-turn offset. Too short offset may cause low travel time cost with very high accident cost,

while too long offset may cause very high travel time cost with low accident cost.

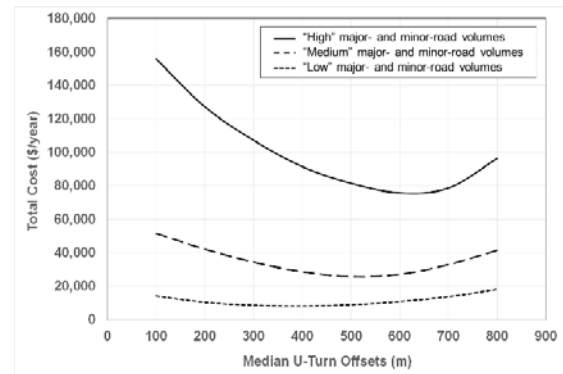


Fig. 7 Recommended median U-turn offsets based on minimum costs

Fig. 8 plots the recommended offsets for different combination of major-road and minor-road traffic volumes. The higher traffic volumes, the longer median U-turn offsets are.

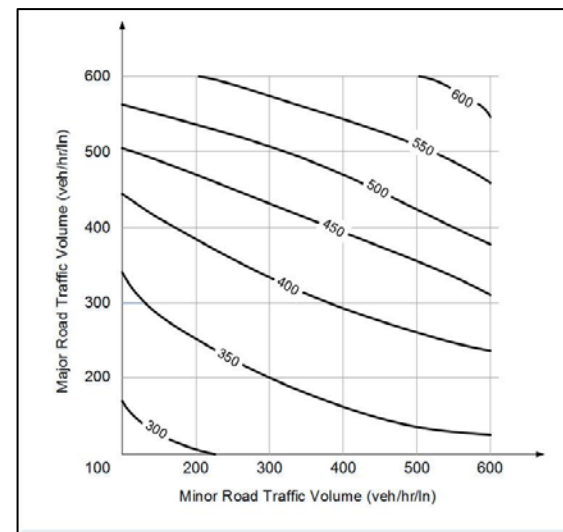


Fig. 8 Look-up chart on recommended median U-turn offsets for different traffic volumes

Table 2 presents the set of recommended median U-turn offsets in meters for different traffic volumes on major and minor roads (100 to 600 vehicles per hour per lane).

Fig. 8 and Table 2 are complementary; the former shows in specific values, while the latter is a look-up chart for practitioners. The recommended offsets can be determined if traffic volume on a major- and a minor road are given.

Table 2 Recommended median U-turn offsets for different traffic volumes

Traffic Volume on Major Road (veh/hr/ln)	Traffic Volume on Minor Road (veh/hr)					
	100	200	300	400	500	600
100	270	295	310	330	340	345
200	310	330	347	360	370	380
300	345	370	390	410	430	445
400	390	420	435	470	495	520
500	445	475	495	520	550	570
600	535	550	565	580	595	630

4.4 Sensitivity Analysis

The study performs the sensitivity analyses to determine which parameters are significant and should be taken into account to the proposed model. The effects of some parameters on the median U-turn offsets are discussed below.

- Effect of heavy vehicles. The heavy vehicles require longer gap to merge the traffic and change lanes than other vehicles. The proposed model suggests the need to consider the percentage of heavy vehicles. The median U-turn offset should be longer than what is proposed in Fig. 8 by 15-20% for every 5% increase of heavy vehicles.
- Effect of vehicle operating speed. The operating speed on a major road significantly affect the median U-turn offset. The higher operating speed on a major road creates difficulties for vehicles to enter the major road, and at the same time force them to the risky situation.
- Effect of socio-economic factors. The economic factors that used to convert operational and safety performance to single comparable performance have insignificant effect on the optimal median U-turn offsets. For example, the value of time and unit of accident cost will proportionally shift the total costs, but not the recommended median U-turn offsets.

4.5 Application to Intersection Design

The study applied the model framework and the simulation models to search for the optimal median U-turn offsets in the real-world situations. Although the real-world cases are varied from the typical model, the proposed framework can be applied together with the simulation model of the entire corridor when multiple intersections are considered.

A real-world highway improvement project in Chiang Mai, Thailand as shown in Fig. 9 was used

as a case study. The existing corridor is a 12-kilometer 4-lane divided high-speed road in a suburban area. There are many intersections and U-turn openings along this corridor as shown in Fig. 10; and as a result, there are many road crashes at these locations. The goal of the improvement project is to relocate the median U-turn openings by introducing median U-turn intersection design concept along this corridor.

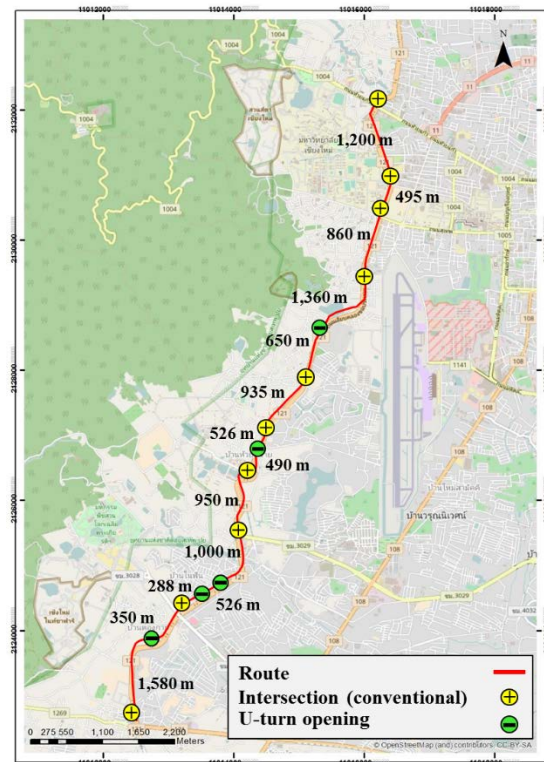


Fig. 9 The existing corridor of 4-lane divided high-speed road

Fig. 10 illustrates the snapshot of microscopic traffic simulation model developed for evaluating the operational and safety performance of the intersections in the case study.



Fig. 10 Snapshot of simulation model

Fig. 11 presents the locations of the median U-turns proposed for the highway improvement project in the application. Some existing intersections were eliminated and some were converted to RCUT intersections, while the optimal locations of median U-turn openings were proposed along the corridor.

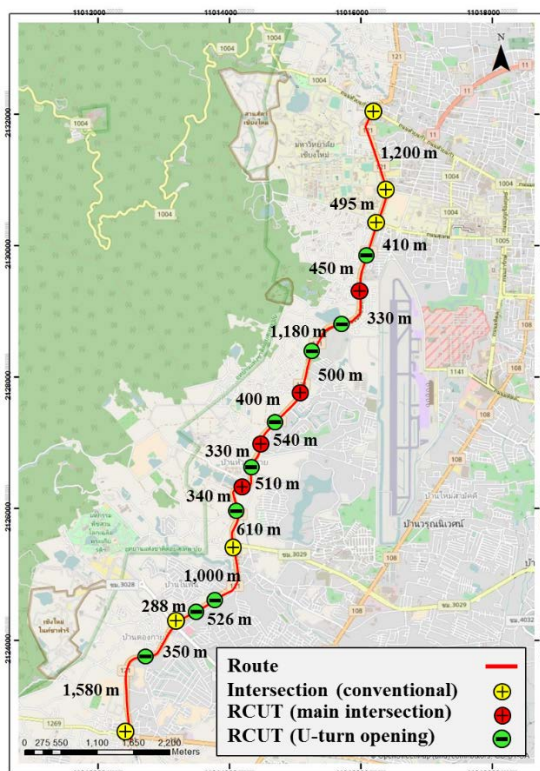


Fig. 11 Proposed median U-turn intersections and their median U-turn offsets in a case study

5. CONCLUSIONS

A median U-turn intersection is an alternative design that helps improve safety and mobility at major at-grade intersections by eliminating the median opening at the main intersection and converting severe crossing conflicts into merging

and weaving conflicts. For its design, the distance between the main intersection and the downstream U-turn opening (or median U-turn offset) is the critical design parameter influencing efficiency and safety of the intersection.

This paper develops a model framework for determining the median U-turn offsets of median U-turn intersection design using simulation analysis. The analysis considers the trade-off between the increase of travel time required to make a U-turn downstream and the reduction of potential accident risks due to fewer number of conflicts. The study recommends the median U-turn offsets for a given traffic condition which minimizes the cost of road users including the travel time cost and accident cost. The results also note that the median U-turn offsets are sensitive to the major-road and minor-road traffic volumes, vehicle composition, and vehicle operating speed.

The proposed model framework and the exhibits allow the engineers to examine the proper locations of median U-turns for median U-turn intersection design. Therefore, the model framework is useful for both practitioners and researchers in real-world highway improvement projects.

6. ACKNOWLEDGMENTS

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