Safe U-Turn Management Model Based on Area: A Case Study of Nakhon Ratchasima

Yotsawat Kamol[1,*], Sajjakaj Jomnonkwao[1], and Onanong Sangphong[2]

[1]Institute of Engineering, Transportation Engineering, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand
[2]Department of Construction Technology, Faculty of Industrial Technology, Nakhon Ratchasima Rajabhat University, Nakhon Ratchasima 30000, Thailand
Email: attapol.km88@gmail.com (Y.K.); sajjakaj@g.sut.ac.th (S.J.); onanong.s@nrru.ac.th (Q.S.)
*Corresponding author
Manuscript received December 6, 2023; revised January 12, 2024; accepted February 23, 2024; published June 13, 2024

Abstract—**The appropriate U-turn area management is one of the methods of leveling safe roads. The objective of this research is to study and assess the consistency of physical characteristics of the U-turns with the current traffic flow. The research team has studied 14 U-turn points in Nakhon Ratchasima Province from the survey of physical characteristics, traffic volume, and traffic flow speed. When assessing the effectiveness of U-turns compared to the standard of the length of the awaiting section, in terms of the speed, traffic volume of the conflicting point of the traffic flow, and the standard width of the road medians, it was found that the U-turn point with the length of the awaiting section is sufficient for the current traffic volume, accounting for 35.71%. The road median width is wide enough to allow cars to safely make a U-turn in the innermost lane accounting for 28.57%. Thus, the current data of this study potentially reflect the suitability of U-turns and reality, such as the traffic lane length to reduce speed, areas for waiting queues, U-turn types, etc., by designing a prototype for managing a safe U-turn to propose as a guideline for further development to reduce future accidents all over the place of that U-turn.**

Keywords—**U-turn, auxiliary lanes, conflict point, capacity**

I. Introduction

The road accident death situation remains a major problem in Thailand [1]. Its economic growth, resulting in the expansion of road networks and an increasing number of drivers and vehicles on the road, contributes to a significant increase in road accidents each year [2]. According to the World Health Organization's Road Safety Situation Report [3] in B.E. 2563, Thailand had approximately 15,757 fatalities, representing a road accident death rate of 32.7 people per 100,000 populations. From land accident data in the Department of Highways responsibility, from B.E. 2556 to B.E. 2563, it accounted for 19% of the whole country [4].

Road accidents at U-turns, which are another area on the highways, cause a high number of accidents. When compared to the physical road characteristics at intersections, the number of accidents was more than doubled compared to other ones. According to the statistics of the Department of Highways accidents in B.E. 2563, there were 1,096 accidents at the median opening for U-turns per year, resulting in 129 deaths among all accident occurrences. The U-turn at the road median opening point has been considered prone to accidents and most accident severities. The presence of a U-turn on a straight road and the absence of warning lights are major contributors to recurrent accidents. Therefore, safety measures during road design, regular road safety assessments, and instantaneous road improvement are very important to be taken into account. Thus, an important approach for benefiting road users' safety and reducing road accident problems [5] is a safe system to cover human errors.

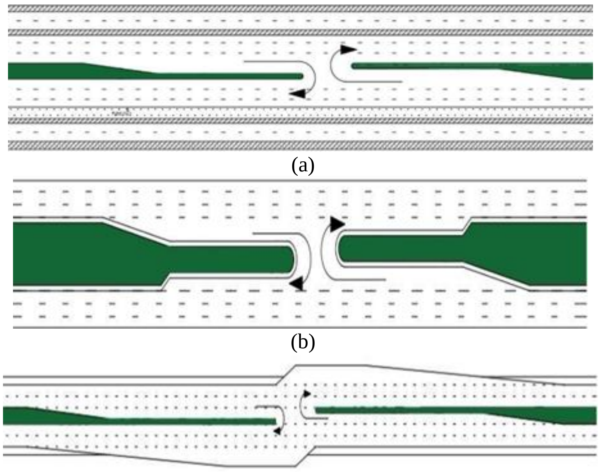
The U-turn point is built to solve the problems of cars entering and exiting the alley as well as their obligatory change of traffic direction on the main road. A common problem around U-turns is accidents between the vehicles on the main road and the vehicles making the U-turn, especially during heavy traffic on the main road [6]. This study investigated the U-turn points of the Nakhon Ratchasima Province area. As when considering the accident statistics of the Northeastern region, Nakhon Ratchasima Province has the highest number of accidents, two to three times higher than Khon Kaen Province which is ranked the second in the country, reflecting the significance of solving the problems in the area. Thus, this study investigated safe U-turn management in the context of Nakorn Ratchasima Province, based on various accident statistics, traffic volumes, and standards of U-turn points as important elements to assess the conformity of the physical characteristics of the U-turn points with the current traffic flow. As urban development road network development results in the change from the time of the earlier period of design and construction of U-turn points in driving behavior, traffic volume, and speed, collecting the current data could reflect their suitability and reality in those areas.

II. Function of U-Turns

A. Flat Level U-turn with the Median Opening

Flat level U-turn with the median opening: this U-turn is designed for small cars to large trucks, but is more suitable for small cars. All three types, including Wide Median, Median "Bulb–Out" and Flare–Out (Jug Handles) will be designated to have a stopping point waiting for making a U-turn. The U-turns are designed in several types based on the intended use of traffic lanes and areas. The wide medians have a waiting lane to make a U-turn to separate the traffic flow from the main lane. For the "Bulb–Out" median, after a U-Turn, the accelerate lane is required to allow the vehicles to speed and potentially combine with the vehicles in a straight line, and Flare–Out (Jug Handles) median requires a zone beyond conventional design standards. However, the location may be designed at the public area because it can invade outside the zone area, as shown in Fig. 1 [7].

DOI: 10.7763/IJET.2024.V16.1266

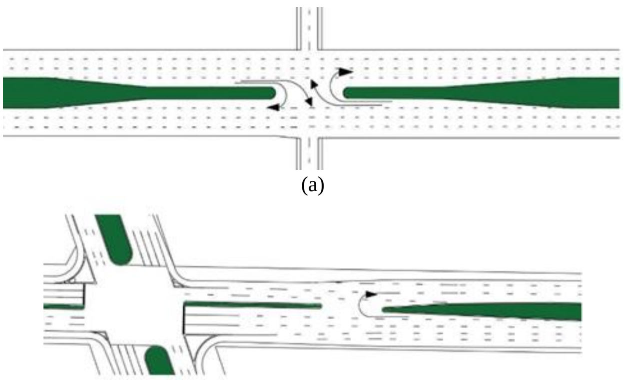


(a) (b) (c)

Fig. 1. (a) Wide Median, (b) Median "Bulb–Out", (c) Flare–Out (Jug Handles).

B. Flat Level U-Turn with the Median Opening

U-turn at the intersection: In the position where the road median has enough space to turn right for 2 traffic lanes, this feature can be used to make a U-turn according to the light signal system as shown in Fig. 2(a). The U-turn at the intersection with signal lights. For the median opening to make a U-turn before reaching the junction, there is a problem with the service level (LOS) at the intersection with the high traffic volume of the cars turning right [8] as shown in Fig. 2(b): Making a U-turn before or after reaching a junction with traffic lights.



(a) (b)

Fig. 2. (a) U-turn at the intersection with signal lights; (b) U-turn before or after reaching a junction with traffic lights.

III. Method and Analysis

A. Survey Design

This research selected 5 types of flat-level U-turns, including Wide Median, Median "Bulb–Out", Flare–Out (Jug Handles), U-turns at the intersection, and the U-turn points before or after the intersection with signal lights in the area of Mueang Nakhon Ratchasima District, Pak Chong District, Pak Thong Chai District, Phimai District, and Sung Noen District, Nakhon Ratchasima Province, totaling 14 points. The location coordinates of each point are shown on the map. The blue dots are wide median U-turns, the red dots are median "Bulb–Out" U-turns, the orange dot is a Flare-Out (Jug Handles) U-turn, the green dot is a separating U-turn with signal lights, and the purple dot is a U-turn point before/after an intersection with signal lights. Details are shown in Fig. 3.

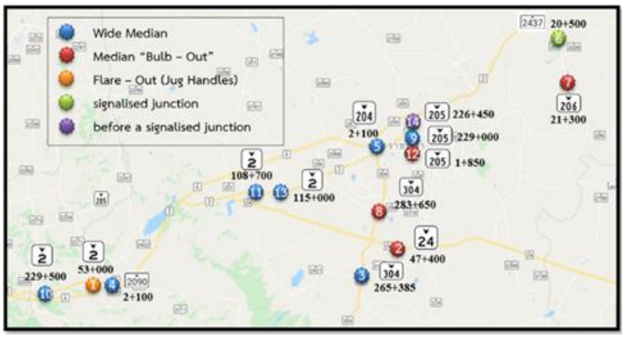


Fig. 3. U-turn points in the study area of Nakhon Ratchasima Province.

For the details of the traffic volume data collection, to potentially visualize throughout the study area, a video camera was used and installed at the point where the state of affairs, as well as the U-turn behavior, could be seen in the distance used for the analysis of the U-turn, such as being installed on an overpass or a road shoulder. The duration of data collection was 7 days. The staff responsible for collecting traffic data divided them by vehicle type and direction, and the survey team went into the areas to collect traffic speed data divided by direction, and physical data, as shown in Figs. 4 and 5.

Fig. 4. Illustration Example of the study area, HWY 2 (Km. 53+000).

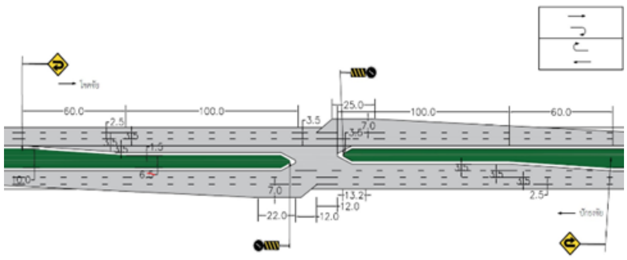


Fig. 5. Example of physical data collection HWY 24 (Km. 47+400).

B. Analysis for Finding Solutions to Problems by Design Criteria Consideration

The traffic data obtained from the survey is used in the data analysis to describe the characteristics of traffic conditions in each surveyed type of the studied U-turn areas. The standard design analysis was compared with the traffic volume and patterns of the study area, collected from straight traffic volume, U-turn points, and speed, in order to analyze the design criteria for the U-turn points in terms of traffic lane capacity, service flow level, waiting lane length for U-turn, and whether the current design criteria for U-turn traffic lanes are sufficient for the amount of traffic at the U-turn point or not. Therefore, in order to solve the traffic problems in the study area, the study was divided into the following types:

Traffic data analysis: The traffic volume was analyzed in each vehicle type (Vehicle: number of vehicles). It was used to convert the number of vehicles into PCU Factor and EU Factor due to the different sizes and performance of vehicles. Therefore, it is necessary to initially convert those vehicles into passenger car-equivalent units and then combine them. Passenger car equivalent unit traveling in the normal direction is PCU and passenger car equivalent unit of U-turn vehicle is EU.

1) Traffic lane capacity and level of service flow: For city streets, the appropriate capacity values are determined using standard planning criteria and a comprehensive city plan (revised B.E. 2544) of the Department of Public Works and Town & Country Planning to find the relationship between capacity and influencing factors to help estimate highway capacity with similar physical characteristics for Thailand.
2) Design criteria for U-turn lanes: The design criteria for U-turn lanes result from analyzing and finding a solution to the problem by using the conflict point of traffic flow as a variable, informing the number of conflicts in moving the car according to the traveler's purpose. The number of conflicting points of traffic flow obtained from surveying around the U-turn point is taken into consideration for the standard of a safe U-turn waiting lane [9] as shown in Table I. Eqs. (1) and (2) depict the critical quantification analysis.

$$T = \frac{S_{PL} - S_E}{2a_c} + 2 \times \delta \tag{1}$$

where S_E is the speed of the traffic flow incoming from the loop (Q_E), measured in m/s. S_{PL} is the speed of the traffic flow in conflict with the flow Q_E, traveling in the left lane of the main road (Q_{PL}). δ denotes temporal safety distance between two consecutive vehicles on the main road. Generally, it is fixed at 1s, and a_c is longitudinal average acceleration. It is fixed at 1.2 m/s^2.

$$L_{EN} = (k-1) \times \lambda^{-1} \times S_E \tag{2}$$

where k is the number of events (occurrences of vehicles traveling in the left lane of the main road) corresponding to the value of the design probability. $1/\lambda$ is the temporal duration of each single event(s). And S_E defines the traffic flow speed at the entrance of the loop (Q_E), expressed in m/s;

From the given information, the probability value of the waiting section length for a design equal to 70% contradicts the vehicles waiting for a safe U-turn by using three reference values of the actual traffic speed (70 km/h, 60 km/h, and 50 km/h).

3) Design criteria for U-turn traffic lanes: To achieve a standard U-turn median, the width is taken into consideration for the design standard of the U-turn points in Thailand. According to inquiries from the design office, the design is based on the AASHTO standard and adapted for the suitability [10], relying on considering the standard narrow median width for use in U-turn design to prevent accident occurrences.

IV. Results

The study assessing the conformity of the physical characteristics at the U-turns with the current traffic volume has examined 14 U-turn points in Nakhon Ratchasima Province from a survey of physical characteristics, traffic volume, and speed of traffic flow. When analyzing and evaluating the effectiveness of the U-turn points compared to the design standards regarding traffic volume per traffic lane, speed, traffic volume at conflict points, and speed of traffic flow per the U-turn waiting lane length and the standard median width, the study results are shown in Table 1.

From the table of the analysis results of the effectiveness of U-turn points and the current traffic volume data, it summarizes the study areas that did not pass the three types of analysis assessment criteria as the dots shown on the map. The purple dot is the traffic capacity criterion, the orange dot is the U-turn waiting lane effectiveness criterion, and the orange dot is the median width criterion per study area, as shown in Fig. 6.

Table 1. Volume of conflicting traffic flows compared to standards in the U-turn survey area

U-turn point/direction (heading)		Conflicting traffic flows of vehicles compared to standards									
		PCU (v/h)	**EU (v/h)**	**Conflicting flow rate (v/h)**	**Straight average speed**	**U-turn average speed**	**Median size**	**U-turn length**	**Traffic capacity**	**Effectiveness of waiting section length**	**Median width /area**
HWY.2 (53+000) (1)	Inbound	2,013	73	2,083	78.73	38.90	5.5	115	X	X	✓
	Outbound	2,194	145	2,339	91.16	33.23	5.5	115	X	X	✓
HWY.24 (47+400) (2)	Inbound	560	27	587	100.85	43.55	6.5	160	✓	✓	✓
	Outbound	778	27	805	105.5	45.84	6.5	160	✓	✓	✓
HWY.304 (265+385) (3)	Inbound	1,117	35	1,152	80.6	37.69	10	150	✓	✓	✓
	Outbound	1,020	17	1,037	88.98	39.79	7	-	✓	X	✓
HWY.2029 (2+100) (4)	Inbound	924	160	1,084	79.56	51.80	-	-	X	X	X
	Outbound	900	-	-	82	-	3.4	-	X	X	X
HWY.204 (2+100) (5)	Inbound	1,636	121	1,757	91.68	34.29	6	160	✓	X	✓
	Outbound	1,914	51	1,965	90.41	39.47	5.3	163.5	✓	X	✓
HWY.2437 (20+500) (6)	Inbound	244	70	314	63.29	34.26	4.5	93	✓	✓	✓
	Outbound	156	14	170	48.66	43.87	4.5	92.6	✓	✓	✓
HWY.206 (21+300) (7)	Inbound	190	33	223	70.39	33.78	1.1	150.6	✓	✓	✓
	Outbound	170	23	193	84	25.2	1.1	150.6	✓	✓	✓
HWY.304 (283+650) (8)	Inbound	1,004	54	1,058	105.09	47.19	10	100	✓	X	✓
	Outbound	1,200	73	1,273	98.99	44.89	10	94.5	✓	X	✓

U-turn point/direction (heading)		Conflicting traffic flows of vehicles compared to standards									
		PCU (v/h)	EU (v/h)	Conflicting flow rate (v/h)	Straight average speed	U-turn average speed	Median size	U-turn length	Traffic capacity	Effectiveness of waiting section length	Median width /area
HWY.205 (229+000) (9)	Inbound	1,927	131	2,058	89.62	49.13	9.5	160.5	X	X	✓
	Outbound	1,628	173	1,801	77.01	47.56	9.5	160.5	X	X	✓
HWY.2 (229+500) (10)	Inbound	2,109	-	-	-	-	0.8	-	X	-	✓
	Outbound	3,643	104	3,747	94.21	38.76	-	160.5	X	X	✓
HWY.2 (108+700) (11)	Inbound	1,273	87	1,360	106.29	47.49	3.6	105	✓	X	✓
	Outbound	1,168	51	1,219	105.23	40.04	3.6	105	✓	X	✓
HWY.226 (1+850) (12)	Inbound	1,613	358	1,9171	100.7	57.72	1.6	120	X	✓	X
	Outbound	1,159	153	1,312	72.74	39.7	1.6	162	X	✓	X
HWY.2 (115+000) (13)	Inbound	1,245	74	1,319	104.2	39.90	3.6	105	✓	X	✓
	Outbound	1,145	64	1,209	103.32	38.57	3.6	105	✓	X	✓
HWY.205 (226+450) (14)	Inbound	1,653	173	1,826	61.84	42.39	8.5	164	✓	✓	✓
	Outbound	1,131	40	1,171	81.69	47.61	8.5	101	✓	X	✓

Fig. 6. The analysis results of the effectiveness of the U-turn points with the current traffic volume data.

V. Conclusions

The analysis results of the U-turn point capacity and the current traffic volume data, in terms of traffic lane capacity, waiting traffic lane length, and the road median width, From the study area of 14 U-turn points, the capacity assessment of the U-turn points can be summarized as follows:

The capacity to support the traffic volume of the road section found that the traffic volume was higher than the capacity of the traffic lanes. To increase the service flow of traffic in the area, more expansive traffic lanes should be considered at 5 U-turn points, namely, U-turn Point No. 1 HWY 2 (Km. 53+000), U-turn Point No. 4, HWY 2029 (Km. 2+100), U-turn Point No. 9, HWY 205 (Km. 229+000), U-turn Point No. 10, HWY 2 (Km. 229+500), and U-turn Point No. 12, HWY 226 (Km. 1+850).

The effectiveness of auxiliary lanes is determined by the speed and volume of traffic at the point of conflict in traffic flow. It was found that there were 6 U-turn points with sufficient distance from the auxiliary lanes to match the current traffic volume, accounting for 42.86%, namely U-turn No.2, HWY 24 (Km. 47+400), U-turn No.3, HWY 304 (Km. 265+385), U-turn No.6, HWY 2437 (Km. 20+500), U-turn No.7, HWY 206 (Km. 21+300), U-turn No.12, HWY 226 (Km. 1+850) and U-turn No.14, HWY 205 (Km. 226+450), which are the U-turn points on minor roads where the traffic volume is not very high. This indicates that when the traffic volume increases from the former standard design, there should be some revisions to accommodate the current traffic volume in the U-turn points that do not pass the turnover performance benchmark of awaiting section.

The minimum road median width: the turning point that can make a safe U-turn by potentially turning the car into the innermost lane accounted for 29%, making a U-turn outside the lane 42%, and making a U-turn on the road shoulder, 29%. If considered, the point most prone to danger is the U-turn point, which has a narrow median width as it is required to turn onto the road shoulder. Thus, there should be a traffic lane on the shoulder to support the vehicles. However, there are no shoulder lanes available at 2 U-turns, including U-turn No. 4 HWY 2029 (Km. 2+1) and U-turn No. 12 HWY 226 (Km. 1+850), causing traffic difficulties and safety problems in those areas.

The points that should fix the capacity to support the traffic volume of the road section and the effectiveness of the auxiliary lanes are 3 U-turn points. The U-turn point that should fix the problems in all 3 case studies is the U-turn point HWY 2029 (Km. 2+2090).

VI. Recommendations

This research proposes solutions to the problem of the U-turn points by considering the results obtained by collecting data from the study areas and the traffic data to compare with the appropriateness according to the design standards of the U-turns in various aspects. An additional suggestion is that the results of the study can be used to build a traffic condition model to compare the results with the analysis results of the safe U-turns in a number of aspects. This study potentially leads to the more effective design of the U-turn points and assists in decision-making for an optimal solution. This is the reason why it is necessary to adopt design solutions which expect a complete reorganization of the road section affected by the insertion of U-turns [9].

Acknowledgment

The organizing committee would like to thank the National Research Office (NRCT) for supporting research grants from the National Research Office for the fiscal year 2020 for conducting research projects. Thank you to Highway Districts 1, 2, and 3 for providing information and giving advice and suggestions. Thank you to the Department of Construction Engineering Faculty of Industrial Technology, Nakhon Ratchasima Rajabhat University Transport Engineering, Suranaree University of Technology, the research team, research assistants, survey team, and all students that support places, equipment, and tools, as well as their cooperation and dedication in carrying out various activities to achieve the objectives and goals of this research

project in all respects.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Yotsawat Kamol conducted the data collection, methodology, formal analysis, and writing—original draft. Sajjakaj Jomnonkwao conducted the conceptualization, validation, writing—review & editing. Onanong Sangphong conducted validation, visualization, and supervision. All authors had approved the final version.

References

[1] World Health Organization, *Global Status Report on Road Safety 2018*, Geneva, Switzerland, 2018.

[2] I. P. Meel, U. Brannolte, D. Satirasetthavee, and K. Kanitpong, "Safety impact of application of auxiliary lanes at downstream locations of Thai U-turns," *IATSS Research*, vol. 41, pp. 1–11, April 2017.

[3] World Health Organization, *Global Status Report on Road Safety 2013: Supporting a Decade of Action*, Geneva, Switzerland, 2013.

[4] ThaiRSC, *Accident Information Center to Strengthen Road Safety Culture*. [Online]. Available: http:// https://www.thairsc.com/

[5] World Health Organization, *Global Status Report on Road Safety 2015*, Geneva, Switzerland, 2015.

[6] T. Kumphan and R. Pueboobpaphan, "A study of U-turn behavior at unsignalized U-turn," *SWU Engineering Journal*, vol. 8, pp. 1–9, January 2013.

[7] Department of Highways, *Design Guideline-Road Medians and Road Widening*, Bureau of Surveying and Design, 2007.

[8] Department of Highways, *Design Guideline-Intersection Design*, Bureau of Surveying and Design, 2011.

[9] N. Distefano and S. Leonardi, "U-turn lanes in narrow-width median openings: Design criteria for asafe and efficient project," *Archives of Civil Engineering*, vol. 63, pp. 1–14, 2016.

[10] American Association of State Highway and Transportation Officials (AASHTO), *A Policy on the Geometric Design of Highways and Streets*, Washington, DC: AASHTO, 2011.