Estimating the Length of Right-Turn and U-Turn Pocket Lane Using Binomial Distribution

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Abstract
Delays at U-turns and signalized intersections often occur due to insufficient right turns and U-turn pockets. It is significant to assess and determine the lengths of the pocket lane for right turns and U-turns to improve vehicle efficiency in the area. The right-turn and U-turn pocket designs are based on a binomial distribution and comply with the standards of the DOH of Thailand. Research demonstrates that the flow becomes congested and optimized of right-turn and U-turn pockets, which vary with the volume of turning vehicles. Once the lane does not lack the capacity of a pocket lane, the flow rate of vehicles in both directions decreases, but the flow for right turns and U-turns increases. Therefore, determining the appropriate turn pocket can boost the flow rate and reduce travel delays in those areas.
Keywords: Binomial distribution, Right turn pocket, U-turn pocket and Queue.

1. Introduction

Designing sufficient routes and traffic lanes for highway movement needs, which ensures safety, convenience, and reduced travel time, can help alleviate traffic congestion and potential highway accidents. Certain areas of arterial roads often encounter deficiencies due to various causes, especially in U-turn areas and intersections without traffic signals. These locations, where the traffic volume requiring right turns or U-turns is high, tend to create bottlenecks in the traffic flow. This issue arises when the number of vehicles waiting to turn exceeds the capacity of the pocket lane. Hence, the appropriate length of the turning lane impacts the traffic conditions in the same and opposite directions. Studying the physical factors affecting the saturation flow rate in U-turn areas, accessible from interference from opposing traffic, shows the highest values when traffic officers control the movement [1]. Many provinces in Thailand experience high traffic volumes and several problematic U-turn areas. Therefore, evaluating and proposing solutions and designing turning lanes in these areas is crucial. This research applies binomial distribution to analyze and predict the opportunity of events where the number of vehicles waiting to turn exceeds the pocket lane capacity, obstructing the main traffic flow. The objective is to determine the appropriate length of the right-turn lane for the specific traffic volume. The study references the U-turn standards the Department of Highways (DOH) set in Thailand. Field surveys and data collection include physical characteristics, peak-hour traffic volumes, and saturation flow in U-turn areas and signalized intersections. The study focuses on case study areas on significant roads in Chiang Mai province, Thailand, selecting three U-turn areas and three signalized intersections. These areas were chosen and analyzed based on projected increases in future traffic volumes. The results of this study serve as guidelines for designing and improving solutions to address high-traffic density issues in certain areas.

2. Materials and Methods

2.1 Traffic

Traffic consists of three main components [2].

Road Users: This is the most important aspect of traffic, encompassing drivers, passengers, and pedestrians. Their road usage behavior varies according to different factors.

Vehicles: Key characteristics for design include size, type, and power. The design often considers the most significant vehicles that frequently use the road or have specific features.

Road: Safety principles and design rely on data from surveys and statistics. Important data include traffic information, physical characteristics, and socio-economic factors.

2.2 Saturation flow

The measurement of the performance or capacity of an intersection or a specific direction of movement is a systematic process. It is the highest stable traffic volume passing through a designated reference line [2]. Data collection, which requires at least eight vehicles in the queue and a minimum of 15 cycles, is carried out with a systematic approach to ensure the reliability of the results. The measurement of saturation flow begins when the front wheel or reference part of the fourth vehicle in the queue passes the designated reference line and continues until the front wheel or reference part of the last vehicle passes the designated reference line during the effective period. The value can be calculated using Equation (1).

$$S=\frac{3,600}{H_s} \qquad (1)$$

Where: S = Saturation flow rate (veh/hr)
H_s = Average headway during saturation flow (Seconds)

2.3 Median

A median is used on roads with four or more lanes to separate traffic directions, especially in urban areas [3]. It serves various purposes, such as providing space for turning lanes, U-turn exits at intersections, or deceleration lanes before entering straight paths. Medians also offer waiting areas for pedestrians, space for installing safety equipment, and underground utilities, and can act as a base for elevated roads or pedestrian overpasses. Additionally, they reserve space for future lane expansions. There are four types of medians: Flush and Painted medians, Raised medians, Depressed medians, and Barrier medians.

2.4 U-turn area standards

U-turn areas are a crucial component of the road systm. The standards set by the relevant highway authorities in Thailand are based on the standard drawing for highway design and construction 2015 revision (Edition 2018) [4]. These standards, which include a minimum requirement for deceleration, vehicle storage, and U-turn opening of 70, 100, and 24 meters, respectively.

2.5 Binomial distribution

The binomial distribution is a probability distribution of random, denoted by X, the number of successes in a sequence of n (≥ 1) independent trials of an experiment, and assumes that each trial results in a success or a failure with respective probabilities p ($0 < p < 1$) and $q = 1-p$. The random variable X is said to have the binomial distribution with parameters n and p, denoted by B (n, p). The variable P is probability of X. The probability mass function f(x) of X is given by equation (2) [5].

$$f(x)=P(X=x)=\binom{n}{x}p^x q^{n-x}, \quad x=0,1,2,\ldots,n, \qquad (2)$$

Where $\binom{n}{x}=\frac{n!}{x!(n-x)!}$ for $0 \le x \le n$ and 0 otherwise.

Consider a scenario in which a set contains 100 jobs, comprising 80 high-quality jobs and 20 defective jobs. When selecting a sample, there exists a probability of drawing both high-quality and defective jobs. Additionally, there is a possibility of selecting only high-quality jobs or only defective jobs, depending on the sampling process from 1 to n.

2.6 Related research

Use the Markov process to analyze the lane-changing behavior of vehicles approaching U-turns and median openings. It presents field data on vehicular distribution, probabilities of lane changing, and the application of probability matrices to predict lane-changing patterns. The study finds that lane-changing behavior varies with U-turn volumes and traffic conditions, with the Markov process accurately predicting these behaviors compared to field observations [6]. Studying the U-turn area and intersections has resulted in a probabilistic modeling approach to estimate the capacity of signalized intersections with short right-turn lanes. Factors such as the number of vehicles in the right-turn lane, the proportion of through vehicles, and the average number of vehicles in the lane are considered in the model. The capacity calculations are based on discharge rates of queues in different lane sections. The study validates the model using traffic simulation and highlights the benefits of short right-turn lanes in enhancing intersection capacity compared to shared through/right lanes [7]. The study evaluated traffic simulation models' accuracy and time cost for estimating left-turn queue storage lengths at intersections. SimTraffic was identified as the most accurate model for left-turn queue length estimation, while VISSIM was not recommended due to lower accuracy and longer simulation time. Recommendations were made to use SimTraffic for accurate estimates and to avoid VISSIM for this purpose. A simulation-based method was developed for left-turn deceleration length estimation, aligning with TxDOT guidelines. The study aimed to provide a procedure for estimating the total design length of left-turn lanes based on peak and off-peak traffic conditions [8]. The study analyzed traffic dynamics at a U-turn section on an urban arterial road during morning and evening peak hours. It found that traffic capacity and speed decreased during breakdown events, with morning peak observations experiencing a more significant drop than evening peak observations. The study suggested adding a 50m pocket lane as a potential solution to improve traffic flow, with simulation models showing promising results in reducing delays and increasing speed [9].

Thailand has a study on U-turn traffic in the right lane at traffic light intersections. Using the equivalent value of a personal car, analyze the position of the waiting line that affects the average departure time of the vehicles. The relationship between the ratio of turns and the average departure time The time away from the vehicle is saturated from starting at the intersection, and the equivalent value is that a private car turns right [10]. Factors affecting U-turn behavior: There is a non-signalized area when waiting for the U-turn area. It was found that the size of the gap between the vehicle on the main road and the position of the oncoming lane affected the driving style, but the waiting time did not affect the U-turn [11]. The flow is saturated in the reversing area with different physical characteristics, which is the most free from interference from the opposing vehicle when there is a controlling officer [1]. Research discusses assessing road safety at U-turn locations on highways in Thailand. Various conflicts, severity indicators, and safety measures were analyzed to understand and improve road safety. The studies emphasized the importance of consistent design characteristics of road infrastructure and the use of objective methods for measuring conflict severity to enhance safety at U-turn locations [12].

Various studies and reports on road safety and traffic accidents in Sub-Saharan Africa reveal several essential factors. These include road usage behavior, the positioning and use of child restraints, statistical modeling of traffic accidents, regional economic conditions, the impact of post-crash care on road mortality, and the effects of road speed and curvature on traffic casualties. The studies delve into the influence of factors such as GDP per capita, demographic variables, safe driving behavior, health infrastructure, and road network size on traffic fatalities in Sub-Saharan African countries from 2001 to 2010. The recommendations stemming from these findings include enhancing the enforcement of seat belt laws, introducing random breath testing, improving access to medical care, and launching road safety campaigns to curb road accidents in the region [13]. Various advanced statistical models are used to predict traffic crash severity and vehicle damage at intersections and highway locations. Researchers compared the Multivariate Poisson-Lognormal model and the Joint Negative Binomial- Generalized Ordered Probit Fractional Split model to improve crash prediction accuracy. A result is that considering correlations among crash severity levels and using vehicle damage as an alternative to injury severity can enhance the reliability of crash prediction models [14]. Conducted in Tainan, Taiwan, urban areas, focused on analyzing pedestrian-vehicle collision incidents using binomial distribution models. Factors such as land use, traffic conditions, and pedestrian-vehicle interactions were considered in the analysis. The results highlighted the impact of variables like road infrastructure, retail activities, and commercial activities on the frequency of pedestrian-vehicle encounters, with arterial roads posing higher risks despite having fewer incidents [15].

2.7 Research Methods

This study gathered physical data on the saturation flow of right-turn pocket lanes at U-turn and signalized intersection locations and vehicle volumes during peak hours. Binomial distribution was utilized to forecast instances where the number of vehicles in the queue exceeded the capacity of the right-turn pocket lane, leading to obstruction of the

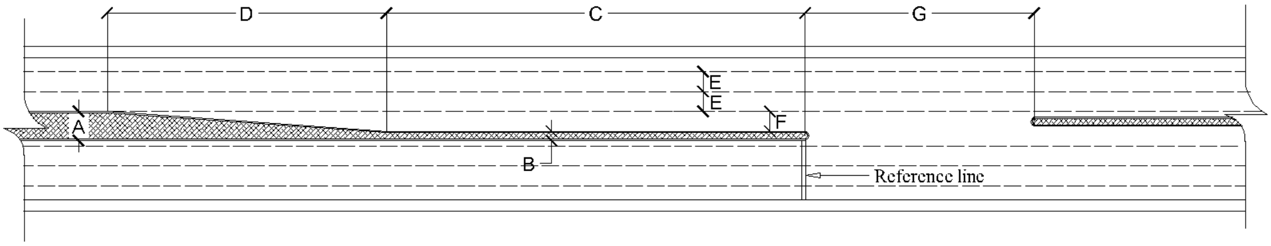

Figure 1 Data collection of physical characteristics of the right turn and U-turn area

main traffic flow. The selection criteria for data collection areas included U-turn points and signalized intersections with vehicle volumes that surpassed the capacity of the right-turn waiting lane. The study obtained data from three U-turn points and three signalized intersections, totaling six areas. The physical characteristics data are presented in Figure 1. Saturation flow and traffic volume data Were collected during peak traffic periods: 6 hours daily, from 7:00 am to 10:00 am and 3:00 pm to 6:00 pm on regular working days.

The measurement of saturation flow starts when a vehicle begins moving from the U-turn area to the designated reference line. Data collection requires at least eight vehicles in the queue for one survey cycle. The reference line is shown in Figure 1. During each cycle, the number of vehicles exceeding the capacity of the right-turn pocket lane is counted. Motorcycles are not considered due to their unpredictable movement and minimal impact on the length of the waiting lane.

2.8 Application of Binomial distribution

The analysis of U-turn areas and signalized intersections, applying binomial distribution, is a comprehensive approach to predicting traffic conditions and determining the appropriate length of right-turn and U-turn pocket lanes. We calculated the volume of vehicles making U-turns as a percentage of the total vehicle volume passing through the surveyed area, and recorded the maximum number of vehicles in the queue. If the probability of the event occurring exceeded 5%, the length of the right-turn and U-turn pocket lanes should be increased. The probability of VEPOM - the vehicles exceeding the capacity of the turning lane and obstructing the traffic flow in the through lane is X in equation (2)- was calculated, considering the volume of vehicles in the queue and the proportion of vehicles needing to turn right or make U-turns. The analysis aimed to match the cumulative percentage as closely as possible to the most significant considered percentage without exceeding it, ensuring a thorough understanding of the traffic conditions. The results, presented in charts and tables, are comprehensive guidelines for designing the length of future right-turn and U-turn waiting lanes. Data analysis used current and future vehicle volumes to estimate OVEPOM- the opportunity for vehicles to exceed the capacity of the turning lane (distance C in Figure 1), obstructing the traffic flow in the through lane-. The results were compared with the Department of Highways (DOH) standards in Thailand to ensure consistency with local traffic volumes. To determine the length of a pocket lane using the binomial distribution, follow these general steps:

1. Define the Variables:

n = Maximum number of vehicles in the queue (based on survey data).

p = Proportion of vehicles turning right or making U-turns.

Capacity = Maximum number of vehicles that can fit in the waiting lane.

2. Calculate the expected overflow: Use the binomial distribution formula to estimate the probability of overflow. The binomial distribution is defined as equation (2).

Where: X = Number of vehicles exceeding the pocket lane capacity.

x = Number of vehicles exceeding the capacity.

$\binom{n}{x}$ = Binomial coefficient.

3. Determine the probability of overflow: To find the probability that the number of vehicles exceeds the pocket lane capacity, sum the probabilities of having x vehicles exceeding the capacity for different values of x, equation (3).

$$P(X \geq \text{Capacity}) = \sum_{x=\text{Capacity}}^{n} P(X = x) \quad (3)$$

4. Calculate the length of the waiting lane: Adjust the length of the pocket lane to ensure that the probability of exceeding its capacity is within an acceptable range (e.g., less than 5%).

Use the following approach:

- Estimate the required length based on the proportion p and the maximum number n.
- Ensure that the length can accommodate the maximum number of vehicles expected to queue.

Example calculation, assume:

- Maximum number of vehicles in the queue (n) = 10 vehicles
- Proportion of vehicles turning right or making U-turns (p) = 0.10
- Desired capacity of pocket lane = 3 vehicles
  – Calculate the probability of having more than 3 vehicles in the queue, equation (4).

$$P(X \geq 3) = \sum_{x=3}^{10} \binom{10}{x} (0.10)^x (0.90)^{10-x} \quad (4)$$

  – Adjust the length of the pocket lane so that this probability is less than or equal to 5%.

This approach allows you to estimate the length required for the pocket lane to handle the expected vehicle volumes and ensure effective traffic flow.

3. Results and Discussion

This section presents the survey results from case study areas, consisting of three straight U-turn areas and three signalized intersections. The aim was to determine the saturation flow rates, the volume of vehicles making U-turns or right turns, and the total volume of vehicles through the survey areas from a maximum of one direction. The data was used to evaluate the appropriate length of pocket lanes. The binomial distribution was applied to estimate the OVEPOM of the right-turn or U-turn pocket lanes. The study also considered various proportions of turning traffic compared to the total traffic volume through the survey areas.

3.1 Physical characteristics

The location areas of the physical characteristics and traffic surveys for U-turn points and signalized intersections are as follows:

U-Turn Area 1: On Chiang Mai-Doi Saket Road (outbound), Mueang District, Chiang Mai (at coordinate 18°48'22.1"N, 99°01'18.2"E).

U-Turn Area 2: No Chiang Mai-Doi Saket Road (inbound), Mueang District, Chiang Mai (at coordinate 18°48'22.1"N, 99°01'18.2"E).

U-Turn Area 3: On Mahidol Road, Mueang District, Chiang Mai (at coordinate 18°46'19.0" N, 98°58'10.9"E).

Signalized Intersection 1: On Chiang Mai-Doi Saket Road, San Sai District, Chiang Mai (at coordinate 18°48'40.2"N, 99°01'42.7"E).

Signalized Intersection 2: On Chiang Mai-Hang Dong Road, Hang Dong District, Chiang Mai (at coordinate 18°45'34.8"N, 98°58'15.6"E).

Signalized Intersection 3: On Chotana Road, Mueang District, Chiang Mai (at coordinate 18°49'03.3"N, 98°58'55.1"E).

The results of the survey collecting data on the physical characteristics of the U-turn or right-turn areas at U-turn points and signalized intersections, which are used as the research area for this study, are presented in Table 1.

Table 1 Physical characteristics of the U-turn area and signalized intersection.

Physical characteristics		U-tarns			Signalized intersections		
		1	2	3	1	2	3
Medium size, m	(A)	4.2	4.0	3.6	2.5	3.6	3.0
	(B)	1.0	0.9	0.5	1.1	1.0	1.0
Turning area size, m	(C)	80	68	32	80	32	58
	(D)	44	58	24	24	58	44
	(E)	3.5	3.5	3.5	3.5	3.5	3.5
	(F)	3.5	3.5	3.5	3.5	3.5	3.5
Opening size, m	(G)	38	38	-	40	32	32
Number of lane in one direction, lanes		4	4	2	4	3	3

Remark: The U-turn 3 area does not have an opening because the U-turn area has one side. There is no U-turn area on the other side.

In table 1, length C has a maximum value of 80 meters. When comparing the pocket length with the DOH standard value, it was found that all U-turn points, straight and intersection U-turns, had a length less than the DOH standard, which recommends that the pocket length should not be less than 100 meters [4]. This discrepancy could potentially disrupt the smooth flow of traffic.

3.2 Traffic data

The maximum number of vehicles, the traffic data on the straight and turning right or U-turning, the maximum number of vehicles in the queue on the pocket lane, and the number of VEPOM are shown in Table 2.

Table 2 Traffic volume in U-turn areas and Signalized intersections.

Traffic information in one direction		U-tarns			Signalized intersections		
		1	2	3	1	2	3
The maximum traffic volume, veh/hr	Mid-Block	3,628	3,808	2,340	2,216	2,340	1,316
	U-turn and turn right	348	412	444	232	208	432
	Total	3,976	4,220	2,784	2,448	2,548	1,748
Percentage of vehicles that U-turn or turn right, %		9.59	9.77	15.59	9.48	8.17	24.72
Maximum vehicle in queue, veh		11	10	8	11	8	11
VEPOM, veh		1	4	4	2	2	5

In the survey, Table 2 illustrates that the proportion of vehicles turning right or making U-turns is approximately 10% for U-turn areas 1 and 2. In comparison, U-turn area 3 has a proportion of around 16%. In all of the signalized intersection surveys, the proportion of vehicles turning right or making U-turns is approximately 8-10% for intersections 1 and 2, while intersection 3 has a proportion of about 25%. Part of VEPOM has several vehicles for 1-5 vehicles. The saturation flow rate is the maximum traffic volume that can pass a reference line during the effective period, as shown in Table 3.

Table 3 Saturated flow rate at the turning area and intersection.

Information	U-tarns			Signalized intersections		
	1	2	3	1	2	3
Average time headway, Seconds	3.74	3.84	4.06	2.14	2.23	2.17
Saturated flow rate, veh/hr	963	938	887	1,683	1,615	1,659

The survey of traffic data revealed that right-turning vehicles at intersections experience shorter waiting times than those in U-turn areas. The differences in physical characteristics and the number of traffic lanes have a significant impact on vehicle movement in the sample areas. The time gap between vehicles in the three U-turn areas is similar, but there are notable differences in the saturation flow rates between U-turn areas and intersections. Table 3 illustrates the average time headway of vehicles at U-turn points to be 3.88 seconds and at intersections with traffic signals to be 2.18 seconds, with the corresponding saturation flow rates of 928 veh/hr and 1,652 veh/hr, respectively. The intersection with traffic signals boasts a saturation flow rate 56.17% higher than the U-turn point. Despite Table 3. showing that the proportions of right-turning and U-turning vehicles are similar in both areas, this may be due to the precise control of movements at intersections, which results in a higher flow rate in this direction compared to U-turn points. However, it's important to note that at U-turn points, where vehicles must rely on safe gaps to make a right turn or U-turn, the flow rate varies significantly according to the driving behavior of each driver, highlighting the need for more comprehensive traffic management strategies.

3.3 Application of binomial distribution to evaluate U-turn areas and signalized intersections.

To determine the appropriate length of the waiting lane, the percentage of U-turn vehicles and the maximum number of vehicles in the queue are considered. Table 2, used where "n" represents the maximum number of vehicles in the queue. The results of the analysis are shown in Table. 4. The cumulative percentage probability of vehicles determines the number of VEPOM. The calculation stops if this value is greater than or equal to 95%.

Table 4 Application of binomial distribution to U-turn areas and signalized intersections.

Number of VEPOM, veh	Percentage of OVEPOM, (%)					
	U-tarns			unsignalized intersections		
	1	2	3	1	2	3
0	33	37	25	33	51	4
1	38	39	38	39	36	16
2	20	18	25	20	11	26
3	6	5	10	6	-	26
4	-	-	-	-	-	17
5	-	-	-	-	-	8
SUM	97	99	98	98	98	97

When analyzing the overflow of vehicles using a binomial distribution to assess VEPOM, according to Table 4, all U-tarn areas and unsignalized intersection 1 had excess vehicle counts of 3 vehicles. Then, at unsignalized intersections 2 and 3, the excess vehicle counts were found to be 3 to 5 vehicles, respectively. These values are close to the survey data with a confidence level of 95%.

3.4 Finding the length of the waiting compartment by Binomial distribution.

Using the binomial distribution, various parameters are defined to illustrate vehicle trends under different scenarios and facilitate practical application. From the survey data of U-turns and intersection areas, the proportion of vehicles making U-turns or turning ranges from 8.17% - 24.72%. Therefore, the selected proportions of vehicles making U-turns or turning right "p" that might exceed the pocket lane capacity range from 5% - 40%, with increments of 5%. The maximum number of vehicles in the queue observed is 11. Thus, "n" values are chosen from 3 to 15 vehicles to account for potential increases in the future. Proportions "P" from 2% - 20% are used with increments of 2% to examine the trends in changes in the number of VEPOM in each scenario, as shown in Figure 2 - 11.

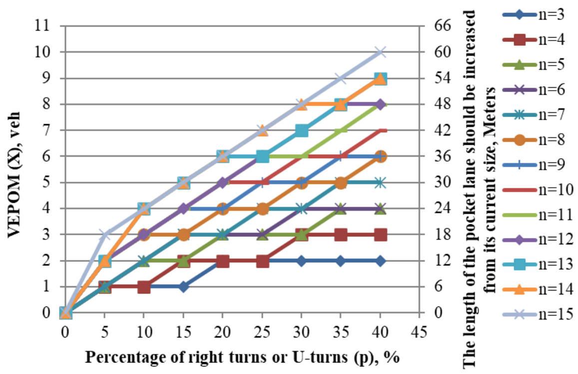

Figure 2 OVEPOM (P), 2%

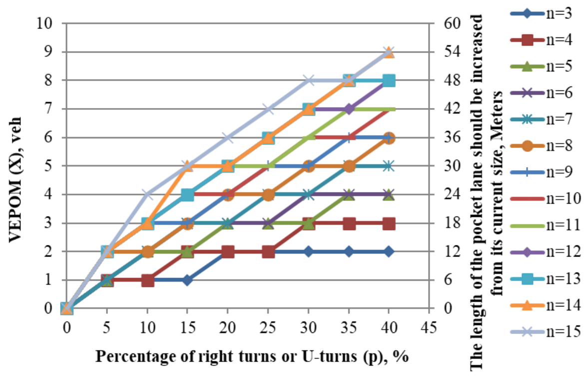

Figure 3 OVEPOM (P), 4%

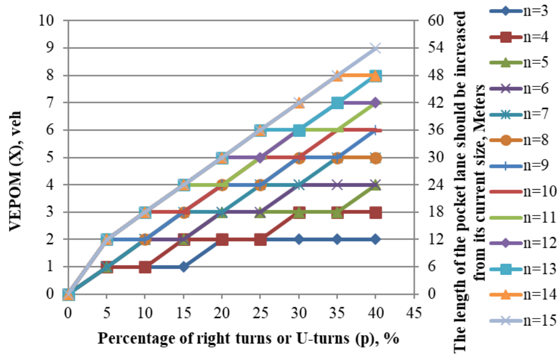

Figure 4 OVEPOM (P), 6%

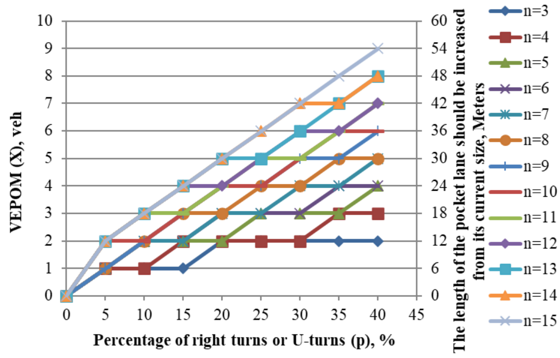

Figure 5 OVEPOM (P), 8%

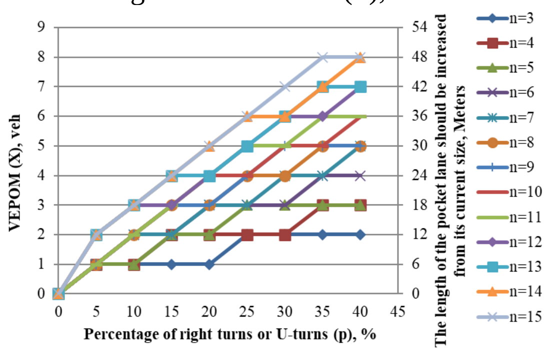

Figure 6 OVEPOM (P), 10%

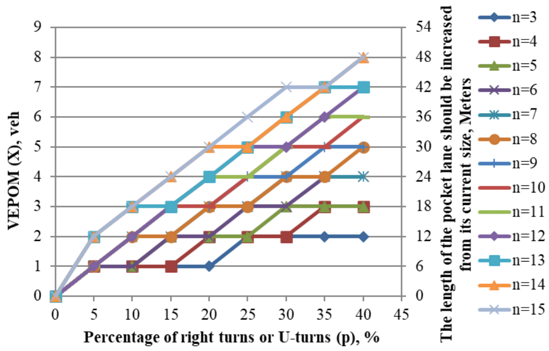

Figure 7 OVEPOM (P), 12%

The study defines the total length of vehicles and the minimum distance between the front and rear bumpers of vehicles that make a U-turn or right turn, averaging 6 meters. Figures 2-11 represent the required length of the pocket lane, determined solely by the number of vehicles exceeding the pocket lane's capacity.

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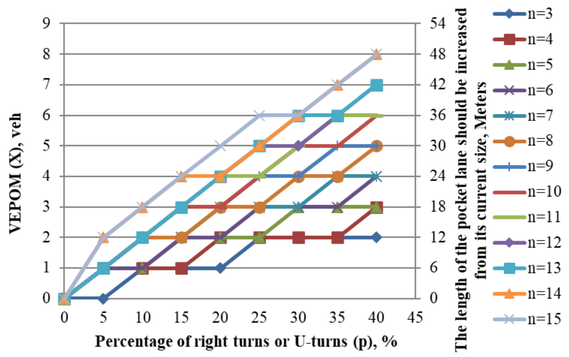

Figure 8 OVEPOM (P), 14%

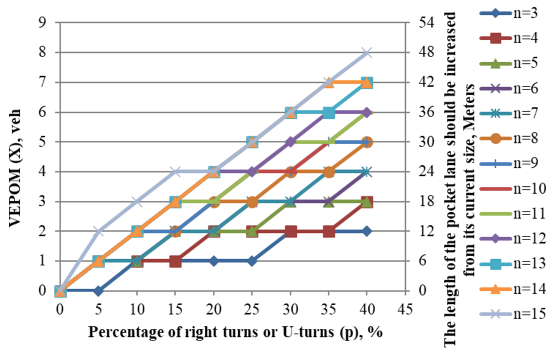

Figure 9 OVEPOM (P), 16%

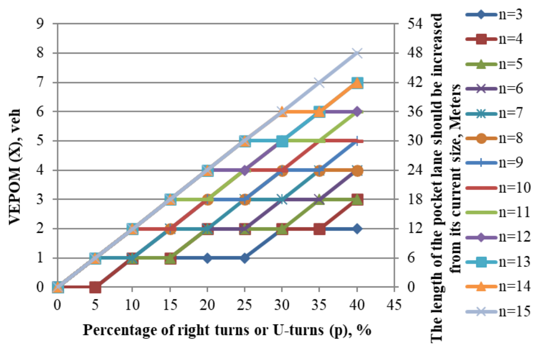

Figure 10 OVEPOM (P), 18%

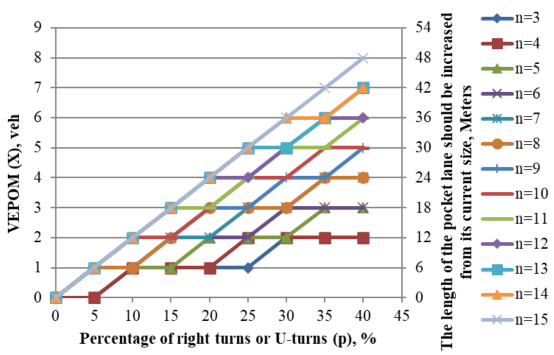

Figure 11 OVEPOM (P), 20%

Figure 2-11 illustrate the relationship between the VEPOM (on the left side of the chart) and the varying proportions of right-turning or U-turning vehicles compared to the total number of vehicles from the same traffic direction (at the bottom of the chart). These figures help determine the appropriate length that should be added to the area's existing length (on the chart's right side). The opportunity to overturn the right-turn lane's capacity to the main road for 2 to 20 % is a critical factor in this determination. For instance, if the existing area has a length of 50 meters and the value read from the figure is 20 meters, this indicates that after the improvement, the suitable total length of the turning lane will be 70 meters. This consideration is based on the number of vehicles of interest, n. Table 5. It can be used to simplify the decision-making process. It provides a range of percentages based on the desired length of the pocket lane for the right turn and U-turn. The appropriate lane length can be determined by matching the desired length with the corresponding percentage.

Table 5 provides crucial data for designing the pocket lane length for vehicles making a right turn or U-turn. The following guidelines and examples can be applied in real-world scenarios:

- It is essential to select data based on assumptions or surveys. This will help determine the percentage of vehicles making a U-turn or right turn from traffic volume in one direction (e.g., selecting 20% from row 2 of Table 5).

- Choose the desired or relevant OVEPOM value to calculate the required pocket lane length (e.g., select OVEPOM = 10%).

- Select the number of vehicles in the queue by assumptions or survey data (e.g., select 5 vehicles).

- Refer to Table 5 based on the above inputs (e.g., the minimum required length is 42 meters, as shown by the red dashed line).

The appropriate pocket lane length is determined with precision from the example above. The number of vehicles in the queue, which equals 5 vehicles, combined with the VEPOM obtained from a binomial distribution analysis equals 2 vehicles (as shown in Figure 6). Therefore, the total number of vehicles turning right or making a U-turn is seven. Based on the previously mentioned vehicle spacing, the required pocket lane length can be calculated as 7 x 6 = 42 meters.

Table 5 The appropriate length of pocket lanes for turning, when considering the opportunity to make right turns and U-turns per all traffic volume in the same direction.

	Percentage of right turns or U-turns (p), %																							
	5	10	15	20	25	30	35	40	5	10	15	20	25	30	35	40	5	10	15	20	25	30	35	40
	The length of the pocket lane should be increased from its current size, Meters																							
Number of vehicles in queue. (n), Veh.	OVEPOM (X), 2%								OVEPOM (X), 4%								OVEPOM (X), 6%							
3	24	24	24	30	30	30	30	30	24	24	24	30	30	30	30	30	24	24	24	30	30	30	30	30
4	30	30	36	36	36	42	42	42	30	30	36	36	36	42	42	42	30	30	36	36	36	42	42	42
5	36	42	42	48	48	48	54	54	36	42	42	48	48	48	54	54	36	42	42	48	48	48	48	54
6	42	48	54	54	54	60	60	60	42	48	54	54	54	60	60	60	42	48	48	54	54	60	60	60
7	48	54	60	60	66	66	72	72	48	54	60	60	66	66	72	72	48	54	60	60	66	66	72	72
8	60	66	66	72	72	78	78	84	60	60	66	72	72	78	78	84	60	60	66	72	72	78	78	78
9	66	72	78	78	84	84	90	90	66	72	72	78	84	84	90	90	66	66	72	78	78	84	84	90
10	72	78	84	90	90	96	96	102	72	78	84	84	90	96	96	102	72	78	78	84	90	90	96	96
11	78	84	90	96	102	102	108	114	78	84	90	96	96	102	108	108	78	84	90	90	96	102	102	108
12	84	90	96	102	108	114	120	120	84	90	96	102	108	114	114	120	84	90	96	102	102	108	114	114
13	90	102	108	114	114	120	126	132	90	96	102	108	114	120	126	126	90	96	102	108	114	114	120	126
14	96	108	114	120	126	132	132	138	96	102	114	114	120	126	132	138	96	102	108	114	120	126	132	132
15	108	114	120	126	132	138	144	150	102	114	120	126	132	138	138	144	102	108	114	120	126	132	138	144
Number of vehicles in queue. (n), Veh.	OVEPOM (X), 8%								OVEPOM (X), 10%								OVEPOM (X), 12%							
3	24	24	24	30	30	30	30	30	24	24	24	24	30	30	30	30	24	24	24	24	30	30	30	30
4	30	30	36	36	36	36	42	42	30	30	36	36	36	36	42	42	30	30	30	36	36	36	42	42
5	36	42	42	42	48	48	48	54	36	36	42	42	48	48	48	48	36	36	42	42	42	48	48	48
6	42	48	48	54	54	54	60	60	42	48	48	54	54	54	60	60	42	42	48	48	54	54	60	60
7	48	54	54	60	60	66	66	72	48	54	54	60	60	66	66	72	48	54	54	60	60	66	66	66
8	54	60	66	66	72	72	78	78	54	60	66	66	72	72	78	78	54	60	60	66	66	72	72	78
9	60	66	72	78	78	84	84	90	60	66	72	72	78	84	84	84	60	66	72	72	78	78	84	84
10	72	72	78	84	84	90	96	96	66	72	78	84	84	90	90	96	66	72	78	78	84	90	90	96
11	78	84	84	90	96	96	102	108	72	78	84	90	96	96	102	102	72	78	84	90	90	96	102	102
12	84	90	96	96	102	108	108	114	84	90	90	96	102	108	108	114	78	84	90	96	102	102	108	114
13	90	96	102	108	108	114	120	126	90	96	102	102	108	114	120	120	90	96	96	102	108	114	120	120
14	96	102	108	114	120	126	126	132	96	102	108	114	120	120	126	132	96	102	108	114	114	120	126	132
15	102	108	114	120	126	132	138	144	102	108	114	120	126	132	138	138	102	108	114	120	126	132	132	138
Number of vehicles in queue. (n), Veh.	OVEPOM (X), 14%								OVEPOM (X), 16%								OVEPOM (X), 18%							
3	18	24	24	24	30	30	30	30	18	24	24	24	24	30	30	30	18	24	24	24	24	30	30	30
4	30	30	30	36	36	36	36	42	30	30	30	36	36	36	36	42	24	30	30	36	36	36	36	42
5	36	36	42	42	42	48	48	48	36	36	42	42	42	48	48	48	36	36	36	42	42	42	48	48
6	42	42	48	48	54	54	54	60	42	42	48	48	54	54	54	60	42	42	48	48	48	54	54	60
7	48	54	54	60	60	60	66	66	48	48	54	54	60	60	66	66	48	48	54	54	60	60	66	66
8	54	60	60	66	66	72	72	78	54	60	60	66	66	72	72	78	54	60	60	66	66	72	72	72
9	60	66	72	72	78	78	84	84	60	66	66	72	78	78	84	84	60	66	66	72	72	78	78	84
10	66	72	78	78	84	90	90	96	66	72	78	78	84	84	90	96	66	72	72	78	84	84	90	90
11	72	78	84	90	90	96	102	102	72	78	84	84	90	96	96	102	72	78	84	84	90	96	96	102
12	78	84	90	96	102	102	108	114	78	84	90	96	96	102	108	108	78	84	90	96	96	102	108	108
13	84	90	96	102	108	114	114	120	84	90	96	102	108	114	114	120	84	90	96	102	108	108	114	120
14	96	102	108	108	114	120	126	132	90	96	102	108	114	120	126	126	90	96	102	108	114	120	120	126
15	102	108	114	120	126	126	132	138	102	108	114	114	120	126	132	138	96	102	108	114	120	126	132	138
Number of vehicles in queue. (n), Veh.	OVEPOM (X), 20%																							
3	18	24	24	24	24	30	30	30																
4	24	30	30	30	36	36	36	36																
5	36	36	36	42	42	42	48	48																
6	42	42	48	48	48	54	54	54																
7	48	48	54	54	60	60	66	66																
8	54	54	60	66	66	66	72	72																
9	60	66	66	72	72	78	78	84																
10	66	72	72	78	84	84	90	90																
11	72	78	84	84	90	96	96	102																
12	78	84	90	96	96	102	108	108																
13	84	90	96	102	108	108	114	120																
14	90	96	102	108	114	120	120	126																
15	96	102	108	114	120	126	132	138																

4. Conclusions

Our study area is the U-turn and signalized intersection locations. When considering the equivalent passenger car unit (PCU), we found that the average saturation flow rate at three U-turn locations was 930 veh/hr, significantly lower than the average saturation flow rate at three intersection locations, which was 1,653 veh/hr. This substantial difference of 723 veh/hr underscores the need for further research in this area, as it reveals that the saturation flow rate at U-turn locations is 43.74% lower than at intersections.

The appropriate length of the right-turn and U-turn pocket lane depends on the proportion of the total volume of vehicles that need to turn right or make a U-turn. Considering a 5% increase in the length of the right-turn and U-turn pocket lane, it is found that the suitable length depends on the number of VEPOM. The choice of the proportion of vehicles turn right and make a U-turn may depend on the analyst's discretion, whether they want a longer or shorter waiting lane. For a longer waiting lane, consider the proportion of vehicles turning right and making a U-turn concerning the total volume of vehicles that is smaller. For a shorter waiting lane, consider the proportion of vehicles turning right and making a U-turn concerning the larger total volume of vehicles.

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