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RESEARCH ON TRAFFIC ORGANISATION TO PROHIBIT LEFT TURN AT SIGNALISED INTERSECTIONS IN HANOI

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Abstract

The research was conducted to simulate and evaluate the solution of organising traffic to prohibit left turns at signalised intersections in Hanoi. In this study, PTV Vissim was used to simulate different distances from the U-turn position to the center of the intersection for each traffic approach with different number of lanes in one direction. The methodology includes field data collection, scenario development, model calibration, and comparative analysis of traffic performance indicators such as average travel time. Traffic volume and turning movement data were collected using manual survey and used as input for model validation to reflect real-world traffic conditions. Three case studies were selected to represent intersections with two to five lanes per direction per approach. The results show that the left turn movement should be organised by the left turn prohibition measure based on the traffic volume through the intersection in each direction. Additionally, the most suitable U-turn organisation location was determined based on comparing the average travel time of vehicles.

Keywords: intersection; traffic lights; left turn prohibition; U–turn position; PTV VISSIM; travel time.

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1. Introduction

In an effort to mitigate traffic congestion and enhance safety at signalised intersections, the city of Hanoi has implemented various solutions. While some of these measures have yielded certain successes, many still exhibit limitations or require substantial investments in both time and cost. Several traffic simulation models have been employed to assess the effectiveness of these interventions [1–6].

One of the emerging solutions currently being implemented throughout the city is the prohibition of left-turn movements at signalised intersections. Numerous intersections in Hanoi are being reconfigured to restrict left turns in one or both directions. Instead of making a direct left turn, drivers must now follow one of two alternative travel options, including: (Alternative 1) proceeding straight through the intersection, performing a U-turn at a designated location, and then turning right onto the desired route; or (Alternative 2) turning right onto the opposite approach, making a U-turn, and then proceeding straight through the intersection to reach the intended direction (Fig. 1).

This solution has proven effective in practice, as it reduces conflicts in the centre of intersections and simplifies signal phase arrangements. Additionally, some studies have shown that although the total travel time through the intersection may be higher with left-turn prohibition compared to allowing

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direct left turns, the safety improvements from this U-turn-based approach are substantial. According to Joe Bared and Wei Zhang, the total number of accidents decreased by approximately 20–50% after implementing left-turn restrictions at similar intersections in the state of Michigan, USA [7].

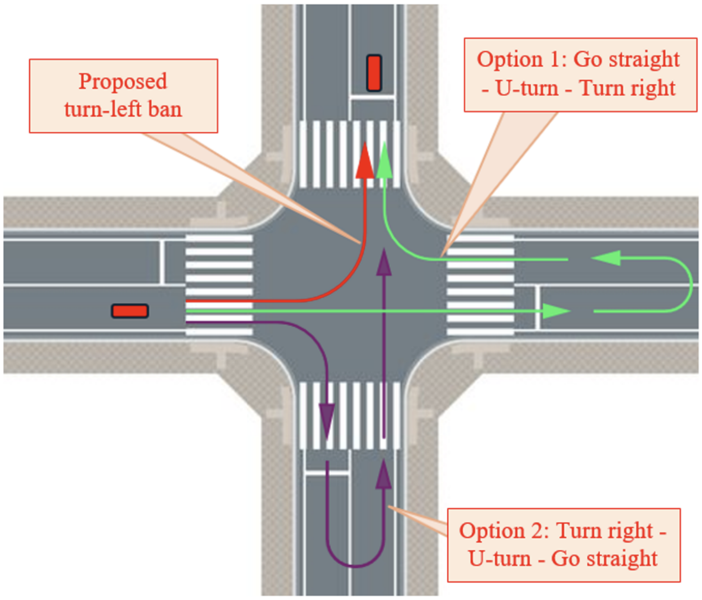

Figure 1. Options for organising U-turn for proposed turn-left ban at intersection

However, this approach increases the traffic volume on the segments where U-turns are permitted, as these segments must now accommodate additional flows diverted from the restricted left-turn movements. Furthermore, vehicles that previously made direct left turns must now travel a longer distance to traverse the intersection [8–11]. This raises important questions: How much farther do vehicles have to travel, and how much longer does the journey take for the left-turn prohibition scheme to be considered optimal? Can the designated U-turn segments accommodate the additional traffic demand?

These questions underline the need to determine the optimal location for U-turn facilities in order to minimise travel time and reduce potential conflicts within the intersection area. The remainder of this paper is organised as follows: Section 2 presents a literature review; Section 3 outlines the research methodology; Section 4 describes a case study application; and finally, Section 5 offers conclusions and recommendations.

2. Literature review

Currently, PTV VISSIM is considered one of the most widely used tools for simulating and analysing traffic flow, public transport, and pedestrian movement. It is capable of modelling heterogeneous traffic streams that include a wide variety of vehicles, including motorcycles. Moreover, the software can simulate nearly all elements of real-world traffic flow, such as vehicle dimensions, speeds, traffic signal phases, and driver behaviours, while providing output parameters that are regarded as highly accurate and realistic [1, 12–15].

Besides, PTV VISSIM has been identified as one of the most flexible and capable tools for simulating heterogeneous traffic. Nevertheless, its default parameters - derived largely from European vehicle norms - do not reflect the real-world performance and behavior of motorcycles in developing countries. As a result, Vu and Preston highlighted a significant gap in the literature regarding the adaptation and calibration of microscopic simulation models for motorcycle-dominated traffic. Their study addressed this gap by proposing a methodology to adjust key parameters (e.g., acceleration profiles, lateral clearance, desired speeds) and validating these through empirical data collected in Hanoi, Vietnam [1].

In a study by Bared et al., the authors evaluated the impact of U-turn locations on traffic performance along urban corridors through field surveys and analyses based on the guidelines in the PKJI 2023 manual [7]. The results indicated that poorly located U-turn points could lead to increased traffic volumes in certain areas, reduced vehicle speeds, and heightened traffic flow disturbances. This study underscored the importance of rational planning for U-turn locations and highlighted the role of simulation tools and traffic modelling in urban network management and design. The findings provided significant empirical evidence to support the scientific basis for evaluating and proposing reasonable traffic management schemes in high-density areas [8].

In addition, U-turn design has been studied as a potential solution for improving traffic efficiency and safety at urban intersections. According to Dixon et al., implementing U-turn lanes helps reduce conflicts between vehicle streams, decrease waiting times, and enhance intersection performance. Applications in major cities such as Houston and Chicago have demonstrated the scalability and potential of this approach in modern traffic management systems [12].

3. Methodology

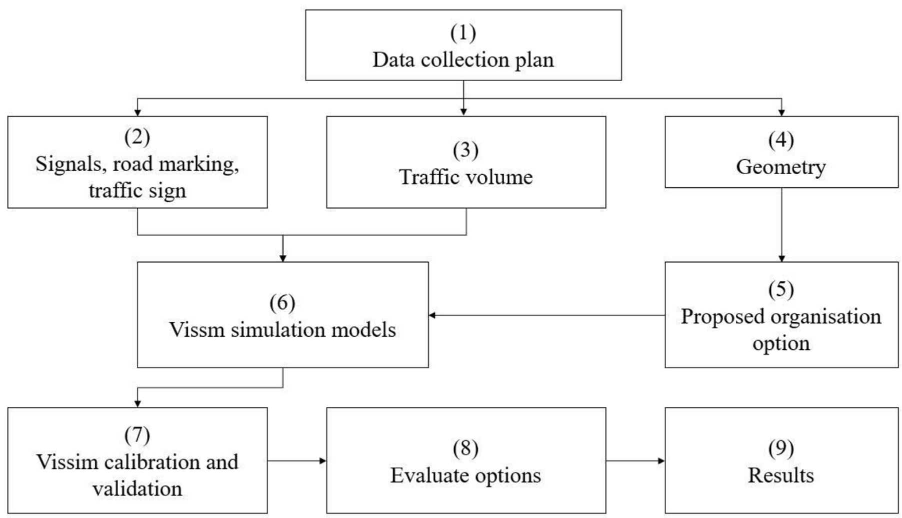

Figure 2. Methodological framework of the study

The research methodology framework is illustrated in Fig. 2, comprising nine detailed steps as outlined below:

Step 1: Conduct a field survey to collect the necessary data for Steps 2, 3, and 4, including traffic signal phases, signage, road markings, traffic volume, vehicle composition, and the geometric configuration of the intersection (e.g. number of lanes on each approach, roadway cross-section).

Step 2–4: Described implicitly in the data collection step; refer to subsequent simulation design.

Step 5: Based on the collected data, develop simulation scenarios to reflect the current traffic conditions and proposed improvement alternatives, enabling comparative assessment.

Step 6: Simulate all scenarios using PTV VISSIM, and record key performance indicators such as vehicle speed, delay, and queue length.

Step 7: Calibrate the simulation model parameters to accurately represent the characteristics of the mixed traffic flow in Hanoi, especially the high proportion of motorcycles and complex driving behaviour.

Step 8: Compare the simulation results across scenarios to evaluate operational efficiency, identify strengths and limitations of each option, and select the optimal solution.

Step 9: Synthesize the results, present relevant indicators, charts, and analyses, which serve as a basis for proposing suitable traffic management solutions.

4. Case studies

Data for this study were collected from three signalised intersections in Hanoi, including: (1) Tran Thai Tong – Duy Tan intersection; (2) Quang Trung – Le Trong Tan – Van Khe intersection; and (3) Vo Chi Cong – Xuan La intersection. These intersections were selected to represent varying numbers of lanes in one direction, specifically with 2, 3, and 4 lanes per direction, respectively. Roads with only one lane in each direction were excluded from the analysis, as their narrow cross-sections do not provide sufficient space for safe U-turn maneuvers and may lead to increased traffic conflicts, congestion, and safety risks.

Based on the field data collected, proposed scenarios for each intersection were developed and simulated. The objective was to determine the travel time parameter for each scenario and conduct comparative analysis across the alternatives. The results are presented in detail below.

4.1. Case study 1 – Tran Thai Tong – Duy Tan Intersection

a. Data collection

The Tran Thai Tong – Duy Tan intersection is a four-legged at-grade signalised intersection (Fig. 3). This site was selected for simulation due to the presence of two approaches, each with two lanes in one direction. The data collection at this intersection yielded the following key datasets: the geometric dimensions of each approach (Table 1), traffic volume by movement (Table 2), and traffic signal phasing configuration.

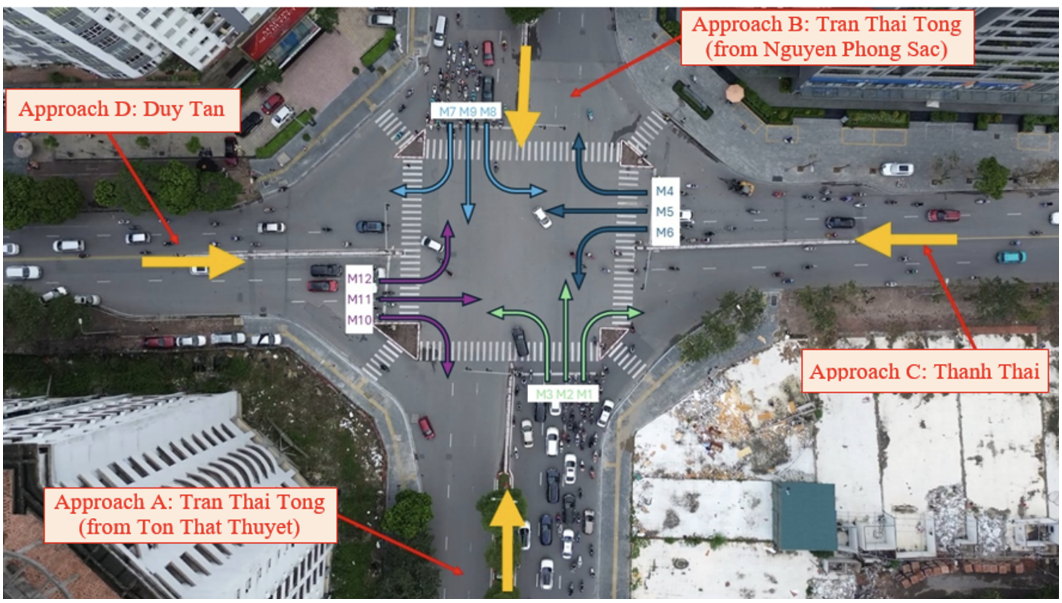

Figure 3. Existing layout of Tran Thai Tong – Duy Tan intersection

Table 1. Geometric characteristics of Tran Thai Tong – Duy Tan intersection approaches

Approach	Approach name	Number of lanes	Approach width
A	Tran Thai Tong (from Ton That Thuyet)	3	3.5 m + 3.5 m + 3.5 m
B	Tran Thai Tong (from Nguyen Phong Sac)	3	3.5 m + 3.5 m + 3.5 m
C	Thai Thanh	2	3.5 m + 3.5 m
D	Duy Tan	2	3.5 m + 3.5 m

Table 2. Traffic volume of each movement at Tran Thai Tong – Duy Tan intersection

Movement	Movement details	Volume (vehicle/h)					
		Motorcycle	Car	Truck	Coach	Bicycle	Total
M1	Approach A – turn right – Approach C	2,364	324	32	0	16	9,116
M2	Approach A – go straight – Approach B	4,588	604	12	4	20	
M3	Approach A – turn left – Approach D	1,016	132	0	4	0	
M4	Approach C – turn right – Approach B	444	60	4	4	0	4,196
M5	Approach C – go straight – Approach D	1,792	156	0	4	0	
M6	Approach C – turn left – Approach A	1,432	288	0	12	0	
M7	Approach B – turn right – Approach D	2,136	272	8	0	0	7,640
M8	Approach B – turn left – Approach C	448	60	4	0	0	
M9	Approach B – go straight – Approach A	4,012	680	4	16	0	
M10	Approach D – turn right – Approach A	712	124	0	4	0	2,488
M11	Approach D – go straight – Approach C	980	184	0	0	0	
M12	Approach D – turn left – Approach B	320	160	4	0	0	

The signal control at the intersection operates on a 142-second cycle length, divided into three signal phases to minimise conflicts across the traffic flows. Apart from right-turn movements, which are not controlled by signals, the remaining directions are grouped into signal phases as follows: Phase 1 with green time of 45 seconds includes movements M3 and M8; Phase 2 with green time of 45 seconds includes movements M5, M6, M11, and M12; and Phase 3 with green time of 40 seconds governs movements M2 and M9.

b. Traffic control scenarios at the Tran Thai Tong – Duy Tan intersection

Based on the collected data, the existing conditions of the Tran Thai Tong – Duy Tan intersection were first simulated. Subsequently, alternative scenarios were developed by prohibiting left turns for two specific movements: M6 (Approach C – left turn – Approach A) and M12 (Approach D – left turn – Approach B). Vehicles intending to make these left turns were required instead to proceed straight through the intersection, perform a U-turn at designated locations, and then make a right turn into the desired approach. Four simulation scenarios were developed and assessed:

- Scenario 1 (PA1-HT) represents the existing traffic conditions as observed during the survey period.

- Scenario 2 (PA2-U100) introduces a U-turn location positioned 100 meters downstream from the stop line on the designated U-turn approach.

- Scenario 3 (PA3-U200) places the U-turn at a distance of 200 meters.

- Scenario 4 (PA4-U300) evaluates a 300-meter distance from the stop line to the U-turn location.

c. Results

The simulation results obtained from PTV Vissim are summarised in Tables 3–5.

Table 3. Traffic volume of each movement in PTV VISSIM simulation of
Tran Thai Tong – Duy Tan intersection

Movement	Movement details	Traffic volume (vehicle/h)			
		PA1-HT	PA2-U100	PA3-U200	PA4-U300
M1	Approach A – turn right – Approach C	496	487	511	512
M2	Approach A – go straight – Approach B	1,876	1,835	1,944	1,936
M3	Approach A – turn left – Approach D	1,652	1,616	1,707	1,705
M4	Approach C – turn right – Approach B	2,020	1,982	1,969	1,967
M5	Approach C – go straight – Approach D	3,922	3,852	3,834	3,818
M6	Approach C – turn left – Approach A	430	414	412	411
M7	Approach B – turn right – Approach D	831	832	832	832
M8	Approach B – turn left – Approach C	1,149	1,147	1,149	1,149
M9	Approach B – go straight – Approach A	480	471	479	482
M10	Approach D – turn right – Approach A	1,707	1,661	1,725	1,735
M11	Approach D – go straight – Approach C	3,233	3,152	3,266	3,276
M12	Approach D – turn left – Approach B	684	669	690	699
Total traffic volume (vehicle/h)		18,480	18,118	18,518	18,522

Table 4. Average travel time of each movement in PTV VISSIM simulation of
Tran Thai Tong – Duy Tan intersection

Movement	Movement details	Average travel time (s)			
		PA1-HT	PA2-U100	PA3-U200	PA4-U300
M1	Approach A – turn right – Approach C	166	175	82	87
M2	Approach A – go straight – Approach B	232	244	135	142
M3	Approach A – turn left – Approach D	243	282	183	207
M4	Approach C – turn right – Approach B	259	277	271	276
M5	Approach C – go straight – Approach D	296	317	313	320
M6	Approach C – turn left – Approach A	391	414	412	422
M7	Approach B – turn right – Approach D	55	61	59	60
M8	Approach B – turn left – Approach C	97	103	96	96
M9	Approach B – go straight – Approach A	133	191	150	178
M10	Approach D – turn right – Approach A	379	382	369	367
M11	Approach D – go straight – Approach C	442	451	437	434
M12	Approach D – turn left – Approach B	684	669	690	699

Table 3 shows that the total number of vehicles entering and exiting the intersection within one hour varied across the different scenarios. Scenario 2 yielded the lowest total traffic volume, whereas Scenario 4 exhibited the highest volume, indicating improved traffic handling capacity with this configuration. Regarding total travel time, Scenario 2 recorded the highest cumulative time for all vehicles passing through the intersection, while Scenario 3 achieved the lowest total travel time. Although vehicles in Scenarios 3 and 4 had to travel longer distances due to the detour, the prohibition of left turns significantly reduced internal conflicts within the intersection. As a result, traffic dispersed more efficiently, leading to improved overall performance compared to the existing condition.

Table 5. Total travel time of each movement in PTV VISSIM simulation of Tran Thai Tong – Duy Tan intersection

Movement	Movement details	Total travel time of all vehicles (s)			
		PA1-HT	PA2-U100	PA3-U200	PA4-U300
M1	Approach A – turn right – Approach C	82,529	85,236	41,944	44,712
M2	Approach A – go straight – Approach B	434,544	447,875	262,037	275,560
M3	Approach A – turn left – Approach D	400,977	455,391	311,582	352,580
M4	Approach C – turn right – Approach B	522,506	549,729	533,675	542,890
M5	Approach C – go straight – Approach D	1,161,478	1,221,758	1,199,420	1,221,807
M6	Approach C – turn left – Approach A	168,046	171,194	169,700	173,494
M7	Approach B – turn right – Approach D	45,314	50,860	49,349	49,547
M8	Approach B – turn left – Approach C	111,535	117,772	110,322	110,082
M9	Approach B – go straight – Approach A	63,844	90,067	71,804	85,715
M10	Approach D – turn right – Approach A	647,768	634,739	636,376	636,086
M11	Approach D – go straight – Approach C	1,428,736	1,422,719	1,427,269	1,422,559
M12	Approach D – turn left – Approach B	442,982	473,212	479,519	472,728
Total travel time		5,510,258	5,720,553	5,292,998	5,387,760

4.2. Case study 2 – Quang Trung – Le Trong Tan – Van Khe Intersection

a. Data collection

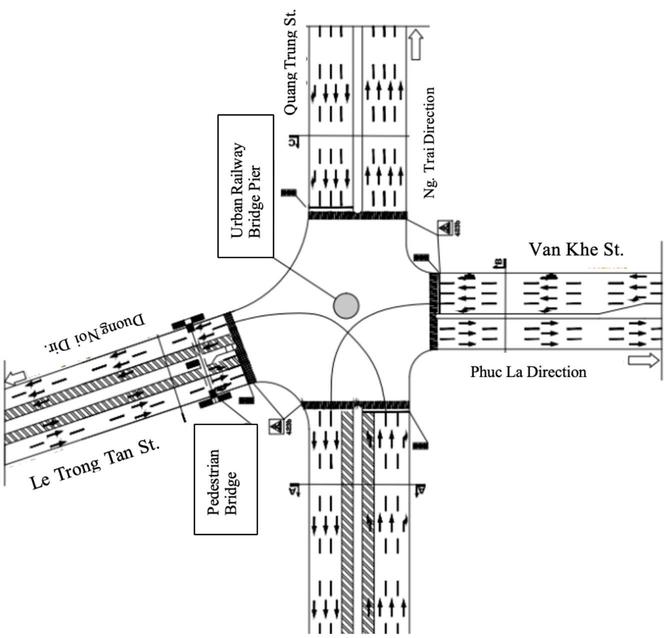

Figure 4. Plan of the Quang Trung – Le Trong Tan - Van Khe intersection

Quang Trung – Le Trong Tan – Van Khe intersection is a four-legged at-grade intersection controlled by traffic signals. This site was selected for simulation since left-turn restrictions have been applied to two approaches: one with a 3-lane configuration and another with a 4-lane configuration. Data collection at the site yielded comparable datasets, including traffic volumes, geometric characteristics, and signal timing information (Tables 6 and 7).

Table 6. Geometric dimensions of the approach directions

Approach	Approach name	Number of lanes	Approach width
A	Quang Trung (from Nguyen Trai)	4	3.5 m × 4 + 3.5 m × 4
B	Quang Trung (from Yen Nghia)	4	3.5 m × 4 + 3.75 m × 4
C	Le Trong Tan	2	3.25 m × 3 + 3.25 m × 4
D	Van Khe	2	3.25 m × 3 + 3.25 m × 4

In addition to simulating traffic volumes during off-peak hour, the study also included simulations for peak-hour conditions. It was assumed that during peak hours, traffic volumes on all approaches and for all vehicle types increased by a factor of 1.5 compared to those numbers in off-peak period.

The signal system operates with a cycle length of 143 seconds (excluding right-turn movements), divided into three distinct phases to minimize conflicts among traffic streams. Phase 1 with green time of 45 seconds controls movements Q4, Q10 and Q12; Phase 2 with green time of 45 seconds governs movements Q2, Q5 and Q11 while Phase 3 with green time of 40 seconds manages movement Q7 and Q8.

Table 7. Traffic flow volumes by movement direction at the intersection during normal hours

Movement	Movement details	Volume (vehicle/h)					
		Motorcycle	Car	Truck	Coach	Bicycle	Total
Q1	Approach A – turn right – Approach C	460	224	8	4	0	3,644
Q2	Approach A – go straight – Approach B	2,204	328	40	76	0	
Q11	Approach A – turn left – Approach D	248	48	0	4	0	
Q3	Approach D – turn right – Approach A	276	80	8	8	0	2,164
Q4	Approach D – go straight – Approach C	796	420	148	0	0	
Q5	Approach D – turn left – Approach B	304	52	56	12	0	
Q6	Approach B – turn right – Approach D	224	112	56	28	0	4,096
Q7	Approach B – go straight – Approach A	2,148	384	60	56	0	
Q8	Approach B – turn left – Approach C	780	164	56	28	0	
Q9	Approach C – turn right – Approach B	780	252	132	0	0	3,380
Q10	Approach C – go straight – Approach D	1,036	168	128	32	0	
Q12	Approach C – turn left – Approach A	640	188	12	4	0	

b. Traffic control scenarios at the Quang Trung – Le Trong Tan – Van Khe intersection

Based on the collected data, the research first simulated the existing traffic conditions at the Quang Trung – Le Trong Tan – Van Khe intersection. Currently, left-turn movements are prohibited for two traffic flows: Q11 (Approach A – left turn – Approach D) and Q12 (Approach C – left turn – Approach A). Vehicles intending to follow these two movements must proceed straight through the intersection, make a U-turn at designated locations, and then turn right into the desired route.

For existing situation, the U-turn position for movement Q11 is located 370 meters from the center of the intersection, while for movement Q12, the U-turn location is 650 meters away. The simulation scenarios were developed by varying the U-turn distance from the center of the intersection along approach C (Van Khe Street), while the U-turn distance for movement Q11 along approach B (Quang Trung Street, from the Yen Nghia direction) remained unchanged. The simulation included the following seven scenarios:

- Scenario 0 (PA0) represents the traffic conditions in 2018, before left-turn prohibitions were implemented for movements Q11 and Q12.

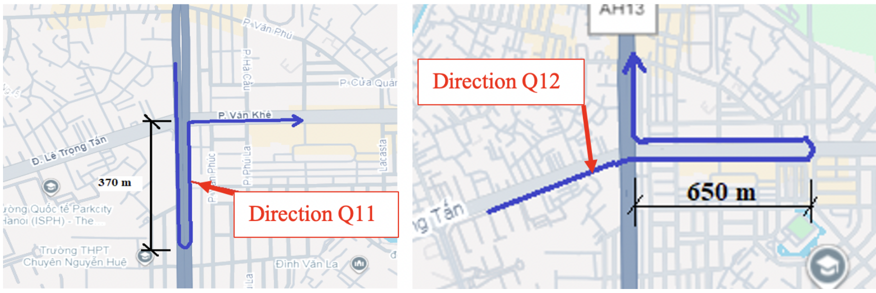

Figure 5. Current status of traffic directions Q11 and Q12 at the Quang Trung - Le Trong Tan - Van Khe intersection

- Scenario 1 (PA1-U110) introduces a U-turn 110 meters downstream from the stop line on the designated approach.
- Scenario 2 (PA2-U220) places the U-turn 220 meters from the stop line.
- Scenario 3 (PA3-U330) tests a U-turn at 330 meters.
- Scenario 4 (PA4-U440) increases the distance to 440 meters.
- Scenario 5 (PA5-U550) places the U-turn at 550 meters.
- Scenario 6 (PA6-U650) reflects current conditions, where the U-turn location is 650 meters from the stop line.

c. Results

• Off-peak period

The simulation results from PTV Vissim are summarised in Tables 8–10.

Table 8. Vehicle flow volume through the intersection after 1 hour of simulation

Movement	Movement details	Traffic volume (vehicle/h)						
		PA0	PA1	PA2	PA3	PA4	PA5	PA6
Q1	Approach A – turn right – Approach C	686	613	686	687	686	686	686
Q2	Approach A – go straight – Approach B	2,618	2,330	2,630	2,631	2,632	2,629	2,631
Q11	Approach A – turn left – Approach D	289	225	246	247	252	248	256
Q3	Approach D – turn right – Approach A	340	333	368	368	368	368	368
Q4	Approach D – go straight – Approach C	1,220	1,220	1,352	1,351	1,351	1,351	1,352
Q5	Approach D – turn left – Approach B	354	373	429	428	424	423	426
Q6	Approach B– turn right – Approach D	415	309	335	337	343	336	340
Q7	Approach B – go straight – Approach A	2,624	1,979	2,136	2,132	2,181	2,129	2,177
Q8	Approach B – turn left – Approach C	1,034	741	827	827	845	824	850
Q9	Approach C – turn right – Approach B	1,371	1,240	1,365	1,365	1,365	1,365	1,365
Q10	Approach C – go straight – Approach D	1,179	1,036	1,165	1,164	1,164	1,165	1,164
Q12	Approach C – turn left – Approach A	883	751	870	871	865	865	866
Total traffic volume (vehicle/h)		13,013	11,150	12,409	12,408	12,476	12,389	12,481

Based on the results presented in Table 8, Scenario 1 exhibited a lower total traffic volume entering and exiting the intersection compared to both the baseline (Scenario 0) and other U-turn scenarios. In contrast, Scenarios 2-6 recorded similar total traffic volumes, indicating that under normal (off-peak) conditions, the different U-turn configurations can not significantly affect the intersection's traffic-handling capacity.

Table 9. Average time for vehicles to pass through the intersection area in each direction

Movement	Movement details	Average travel time (s)						
		PA0	PA1	PA2	PA3	PA4	PA5	PA6
Q1	Approach A – turn right – Approach C	105	106	105	106	105	106	105
Q2	Approach A – go straight – Approach B	163	180	174	173	174	174	172
Q11	Approach A – turn left – Approach D	156	594	610	627	611	627	615
Q3	Approach D – turn right – Approach A	219	127	116	118	117	117	117
Q4	Approach D – go straight – Approach C	338	179	162	162	163	163	164
Q5	Approach D – turn left – Approach B	587	280	255	270	275	268	267
Q6	Approach B– turn right – Approach D	157	477	490	514	502	516	507
Q7	Approach B – go straight – Approach A	166	503	510	529	517	535	524
Q8	Approach B – turn left – Approach C	182	542	562	582	563	590	569
Q9	Approach C – turn right – Approach B	149	120	119	119	119	119	119
Q10	Approach C – go straight – Approach D	232	172	163	163	164	164	164
Q12	Approach C – turn left – Approach A	230	222	200	223	243	262	281

Table 10. Total travel time of all vehicles completing their journeys in each direction

Movement	Movement details	Total travel time of all vehicles (s)						
		PA0	PA1	PA2	PA3	PA4	PA5	PA6
Q1	Approach A – turn right – Approach C	71,809	65,137	72,328	72,666	72,289	72,479	72,250
Q2	Approach A – go straight – Approach B	425,559	418,473	458,256	454,039	456,938	456,333	453,525
Q11	Approach A – turn left – Approach D	45,017	133,635	149,968	154,764	154,035	155,391	157,351
Q3	Approach D – turn right – Approach A	74,544	42,376	42,692	43,384	43,124	43,100	43,097
Q4	Approach D – go straight – Approach C	412,648	218,866	218,935	218,248	219,648	220,233	221,923
Q5	Approach D – turn left – Approach B	207,632	104,599	109,248	115,707	116,437	113,348	113,541
Q6	Approach B– turn right – Approach D	65,288	147,451	164,203	173,055	172,216	173,347	172,249
Q7	Approach B – go straight – Approach A	436,509	995,507	1,089,017	1,128,050	1,127,995	1,138,985	1,139,938
Q8	Approach B – turn left – Approach C	188,022	401,409	464.531	481,134	475,450	485,827	484.047
Q9	Approach C – turn right – Approach B	204,093	148,790	162,457	162,639	162,438	162,306	162,912
Q10	Approach C – go straight – Approach D	273,214	177,735	190,218	190,148	190,880	190,689	191,178
Q12	Approach C – turn left – Approach A	2034,84	166,729	173,707	194,569	210,349	226,478	243,215
Total travel time (s)		2,607,819	3,020,707	3,295,560	3,388,403	3,401,800	3,438,516	3,455,226

Scenario 0 (prior to the implementation of left-turn prohibitions) produced the lowest total travel time for all vehicles passing through the intersection. Following the introduction of left-turn restrictions and the redirection of left-turning vehicles via U-turns, the total travel time consistently increased as the distance between the U-turn location and the intersection center increased from Scenario 1 through Scenario 6.

These results suggest that under normal traffic conditions with relatively low volumes, implementing left-turn prohibitions and rerouting vehicles via U-turns is ineffective. In fact, such configurations led to an increase in total travel time for vehicles passing through the intersection.

- Peak periods

The simulation results obtained from PTV VISSIM are summarised in Tables 11–13.

Table 11. Traffic volume through the intersection after 1 hour of simulation

Movement	Movement details	Traffic volume (vehicle/h)						
		PA0	PA1	PA2	PA3	PA4	PA5	PA6
Q1	Approach A – turn right – Approach C	914	112	450	578	777	885	912
Q2	Approach A – go straight – Approach B	3,501	371	1,688	2,149	2,901	3,293	3,308
Q11	Approach A – turn left – Approach D	391	62	152	158	204	247	245
Q3	Approach D – turn right – Approach A	369	129	292	314	372	408	410
Q4	Approach D – go straight – Approach C	1,329	442	1,028	1,119	1,346	1,479	1,482
Q5	Approach D – turn left – Approach B	411	105	264	315	374	420	419
Q6	Approach B– turn right – Approach D	414	110	182	184	206	248	251
Q7	Approach B – go straight – Approach A	2,585	680	1,266	1,338	1,582	1,698	1,688
Q8	Approach B – turn left – Approach C	1.001	135	423	454	587	651	646
Q9	Approach C – turn right – Approach B	1.222	290	1,012	1,234	1,542	1,669	1,722
Q10	Approach C – go straight – Approach D	1,074	199	738	852	1,084	1,337	1,433
Q12	Approach C – turn left – Approach A	799	82	366	463	637	815	911
Total traffic volume (vehicle/h)		14,010	2,717	7,861	9,158	11,612	13,150	13,427

Table 12. Average time for vehicles to pass through the intersection area in each direction

Movement	Movement details	Average travel time (s)						
		PA0	PA1	PA2	PA3	PA4	PA5	PA6
Q1	Approach A – turn right – Approach C	110	214	269	163	140	153	131
Q2	Approach A – go straight – Approach B	184	406	409	324	292	299	267
Q11	Approach A – turn left – Approach D	174	943	1,215	1,270	1,247	1,246	1,221
Q3	Approach D – turn right – Approach A	637	287	468	422	431	417	388
Q4	Approach D – go straight – Approach C	761	403	580	532	541	512	480
Q5	Approach D – turn left – Approach B	857	631	818	745	777	758	724
Q6	Approach B– turn right – Approach D	673	831	1,124	1,083	1,114	1,099	1,099
Q7	Approach B – go straight – Approach A	690	864	1,117	1,084	1,139	1,130	1,142
Q8	Approach B – turn left – Approach C	739	678	1,165	1,113	1,225	1,223	1,270
Q9	Approach C – turn right – Approach B	740	266	283	221	249	243	211
Q10	Approach C – go straight – Approach D	777	365	405	345	342	258	237
Q12	Approach C – turn left – Approach A	772	689	769	645	682	622	609

Table 11 shows that Scenarios 1, 2, 3, and 4 exhibit lower traffic-handling capacity compared to Scenario 0 (the existing condition prior to any changes). These scenarios caused increased congestion and were therefore considered inefficient traffic control configurations. Scenarios 5 and 6 demonstrated comparable traffic throughput to the baseline condition (Scenario 0). A further comparison was conducted between these three scenarios based on the total travel time of all vehicles entering and exiting the intersection, in order to determine the most optimal solution.

When evaluating the total travel time, Scenario 6 yielded the lowest overall value, outperforming both Scenario 0 and Scenario 5. Therefore, Scenario 6 is considered the most effective traffic control option under peak-hour conditions. The study did not further evaluate Scenarios 1 - 4 due to their inferior traffic performance relative to the baseline scenario.

Table 13. Total travel time of all vehicles completing their journeys in each direction

Movement	Movement details	Total travel time of all vehicles (s)						
		PA0	PA1	PA2	PA3	PA4	PA5	PA6
Q1	Approach A – turn right – Approach C	100,441	23,934	121,119	94,365	108,762	135,230	119,603
Q2	Approach A – go straight – Approach B	645,547	150,464	691,086	697,017	846,078	983,363	882,861
Q11	Approach A – turn left – Approach D	68,178	58,459	184,672	200,711	254,293	307,758	299,246
Q3	Approach D – turn right – Approach A	234,963	37,003	136,722	132,642	160,399	169,991	158,955
Q4	Approach D – go straight – Approach C	1,011,101	178,231	596,438	595,436	727,715	756,898	711,686
Q5	Approach D – turn left – Approach B	352,291	66,279	215,848	234,791	290,650	318,510	303,394
Q6	Approach B– turn right – Approach D	278,690	91,406	204,613	199,309	229,429	272,432	275,891
Q7	Approach B – go straight – Approach A	1,784,539	587,471	1,414,379	1,450,932	1,801,196	1,918,966	1,928,024
Q8	Approach B – turn left – Approach C	739,992	91,558	492,910	505,258	7190,94	795,974	820,166
Q9	Approach C – turn right – Approach B	903,856	77,241	286,387	272,418	383,799	405,029	362,603
Q10	Approach C – go straight – Approach D	834,748	72,699	298,585	294,309	370,428	345,369	339,253
Q12	Approach C – turn left – Approach A	616,560	56,486	281,327	298,693	434,556	507,304	554,599
Total travel time (s)		7,570,904	1,491,231	4,924,086	4,975,881	6,326,399	6,916,824	6,756,282

4.3. Case study 3 – Vo Chi Cong – Xuan La Intersection

a. Data collection

The Vo Chi Cong – Xuan La intersection is a four-legged, at-grade intersection controlled by traffic signals (Fig. 6). This site was selected for simulation because two of its approaches are configured with two lanes in one direction. Field data collection at the intersection produced comparable datasets, including geometric measurements, traffic volumes, and signal timing parameters (Tables 14–15 and Fig. 7).

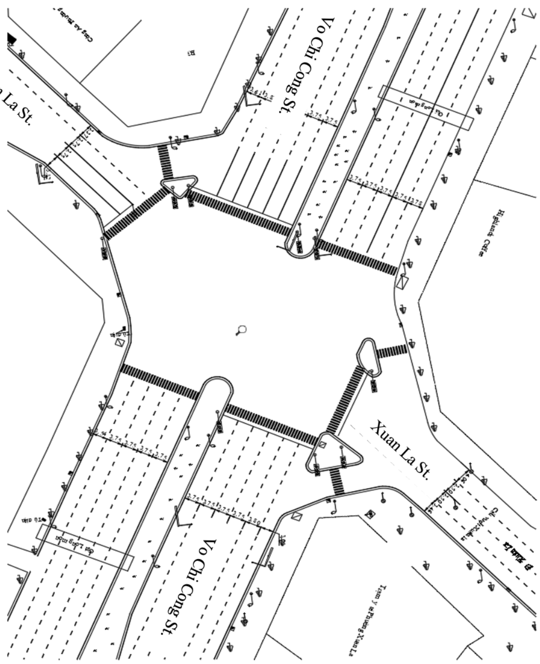

Figure 6. Plan of the Vo Chi Cong – Xuan La intersection

Table 14. Geometric dimensions of the approach directions

Approach	Approach name	Number of lanes	Approach width
A	Vo Chi Cong (from Lang)	5	3.75 m x 5 +3.75 m x 5
B	Xuan La (from Ring Road No.1)	2	3.75 m + 3.12 m
C	Vo Chi Cong (from Nhat Tan Bridge)	5	3.5 m x 5 + 3.5 m x 5
D	Xuan La (from Xuan Dinh)	2	3.5 m + 4.06 m

Table 15. Traffic flow volume on vehicle directions at the intersection during normal hours

Movement	Movement details	Volume (vehicle/h)					
		Motorcycle	Car	Truck	Coach	Bicycle	Total
M1	Approach A – turn left – Approach D	934	120	8	0	0	9,214
M2	Approach A – U-turn	815	165	2	2	0	
M3	Approach A – go straight – Approach C	4,687	1,888	58	20	0	
M4	Approach A – turn right – Approach B	396	113	4	2	0	
M5	Approach B – turn left – Approach A	999	214	2	2	0	4,107
M6	Approach B – go straight – Approach D	2,395	119	3	1	0	
M7	Approach B – turn right – Approach C	287	84	1	0	0	
M8	Approach C– turn left – Approach B	185	76	3	2	0	7,219
M9	Approach C – U-turn	71	32	1	0	0	
M10	Approach C – go straight – Approach A	3,407	2,245	50	39	0	
M11	Approach C – turn right – Approach D	813	281	7	7	0	
M12	Approach D – turn left – Approach C	1,331	322	9	6	0	3,306
M13	Approach D – go straight – Approach B	993	71	1	0	0	
M14	Approach D – turn right – Approach A	523	47	2	1	0	

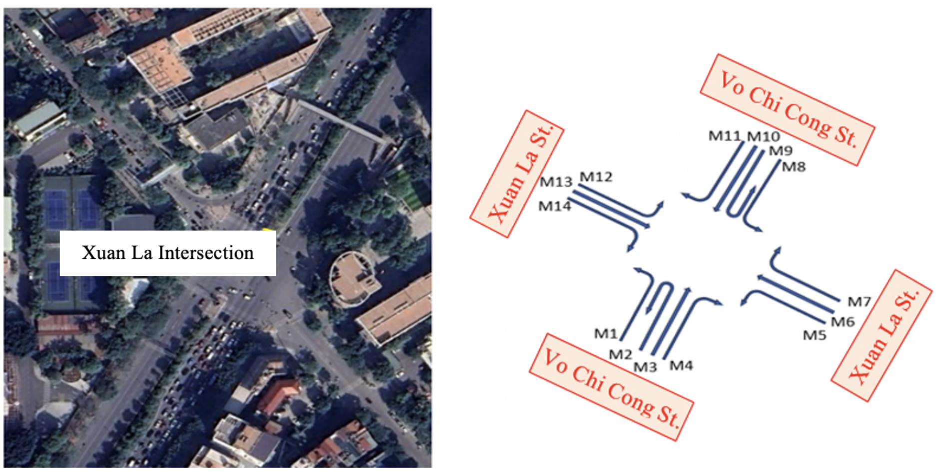

Figure 7. Vehicle movement directions at the Vo Chi Cong – Xuan La intersection

The signal system at this intersection operates with a total cycle length of 162 seconds, excluding right-turn movements. The signal phases are divided into five distinct phases to minimise conflicts and enhance operational efficiency. Specifically, Phase 1 with green time of 34 seconds governs movements M5, M6, M12, and M13; Phase 2 with green time of 85 seconds controls movement M3; Phase 3 with green time of 35 seconds manages movement M1; Phase 4 with green time of 78 seconds is assigned to movement M10; and Phase 5 with green time of 28 seconds controls movement M8.

b. Traffic control scenarios at the Vo Chi Cong – Xuân La intersection (Fig. 8)

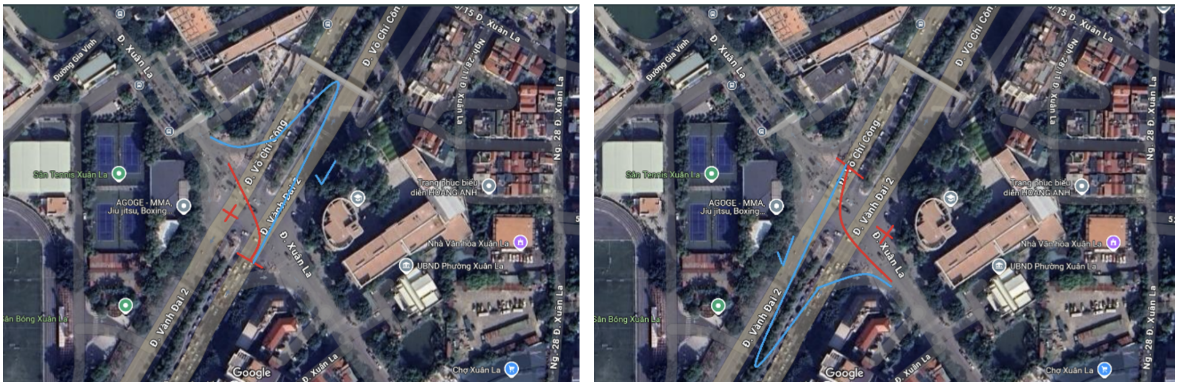

Figure 8. Current condition of directions M1 and M8 at the Vo Chi Cong – Xuan La intersection

In response to the intersection's existing characteristics, five traffic control scenarios were developed and evaluated to assess the effectiveness of prohibiting left turns and introducing U-turns at varying distances from the stop line.

- Scenario 0 (PA0-HT) represents the current condition, in which no left-turn prohibitions are applied.

- Scenario 1 (PA1-U100) introduces a left-turn restriction and places the U-turn location 110 meters downstream from the stop line on the designated approach.

- Scenario 2 (PA2-U200), Scenario 3 (PA3-U300), and Scenario 4 (PA4-U400) progressively extend the U-turn distance to 220 meters, 330 meters, and 440 meters, respectively, from the corresponding stop line on the designated U-turn branch.

c. Results

The simulation results obtained from PTV VISSIM are summarised in Tables 16–18.

Table 16. Vehicle flow volume through the intersection after 1 hour of simulation

No.	Direction	Traffic volume (vehicle/h)				
		PA0-HT	PA1-U100	PA2-U200	PA3-U300	PA4-U400
M4	Approach A – go straight – Approach C	529	471	468	474	478
M3	Approach A – turn left – Approach D	4,117	5,849	6,160	6,106	6,243
M1	Approach B – turn right – Approach C	399	969	1,044	1,056	1,062
M7	Approach B – go straight – Approach D	463	787	820	815	771
M6	Approach B – turn left – Approach A	1,672	2,036	2,023	2,173	2,047
M5	Approach C – turn right – Approach D	773	944	937	1018	950
M11	Approach C – go straight – Approach A	1,093	428	450	455	446
M10	Approach C – turn left – Approach B	2,329	571	652	1,938	1,887
M8	Approach D – turn right – Approach A	411	108	108	110	110
M14	Approach D – go straight – Approach B	16	18	19	601	590
M13	Approach D – turn left – Approach C	977	1,067	1,066	1,063	1,067
M12	Approach A – go straight – Approach C	1,546	1,682	1,676	1,654	1,678
Total traffic volume		14,325	14,930	15,423	17,463	17,329

Table 17. Average time for vehicles to pass through the intersection area in each direction

No.	Direction	Average travel time per approach (s)				
		PA0-HT	PA1-U100	PA2-U200	PA3-U300	PA4-U400
M4	Approach A – turn right – Approach B	690	291	258	270	231
M3	Approach A – go straight – Approach C	679	392	330	345	302
M1	Approach A – turn left – Approach D	1,030	412	359	384	366
M7	Approach B – turn right – Approach C	1,132	839	829	707	767
M6	Approach B – go straight – Approach D	834	558	590	484	566
M5	Approach B – turn left – Approach A	843	564	595	493	569
M11	Approach C – turn right – Approach D	123	125	145	152	154
M10	Approach C – go straight – Approach A	142	185	182	171	170
M8	Approach C – turn left – Approach B	434	379	363	384	364
M14	Approach D – turn right – Approach A	478	312	374	144	138
M13	Approach D – go straight – Approach B	273	138	138	137	138
M12	Approach D – turn left – Approach C	280	157	163	181	161

Table 18. Average time for vehicles to pass through the intersection area in each direction

No.	Direction	Average travel time per approach (s)				
		PA0-HT	PA1-U100	PA2-U200	PA3-U300	PA4-U400
M4	Approach A – turn right – Approach B	365,041	137,079	120,898	128,022	110,366
M3	Approach A – go straight – Approach C	2,795,500	2,294,055	2,033,239	2,103,695	1,884,937
M1	Approach A – turn left – Approach D	410,946	398,904	374,458	404,982	389,038
M7	Approach B – turn right – Approach C	524,184	660,053	679,412	576,126	591,415
M6	Approach B – go straight – Approach D	1,394,703	1,135,805	1,192,711	1,051,888	1,158,973
M5	Approach B – turn left – Approach A	651,625	532,644	557,290	501,454	540,802
M11	Approach C – turn right – Approach D	134,454	533,80	65,236	69,340	68,852
M10	Approach C – go straight – Approach A	330,587	105,399	118,510	330,619	320,140
M8	Approach C – turn left – Approach B	178,370	40,897	39,199	42,230	40,051
M14	Approach D – turn right – Approach A	7,647	5,608	7,099	86,482	81,697
M13	Approach D – go straight – Approach B	266,839	147,687	147,047	145,965	147,048
M12	Approach D – turn left – Approach C	433,533	264,588	272,864	300,021	269,676
	Total	7,493,429	5,776,100	5,607,962	5,740,825	5,602,996

Scenarios 1-4 all recorded higher total vehicle volumes entering and exiting the intersection compared to the baseline (Scenario 0), indicating an improvement in intersection throughput following the implementation of the revised traffic control strategies. Among these, Scenario 3 achieved the highest total traffic volume, suggesting that this configuration offered the greatest enhancement in handling capacity.

The total travel time of all vehicles passing through the intersection was lower in all revised scenarios compared to the baseline condition. This demonstrates that the revised traffic control strategies were effective in reducing overall travel time for vehicles. Scenario 4 yielded the best performance, with the lowest total travel time, making it the most effective configuration among those evaluated.

5. Conclusions and Recommendations

This paper has developed a research framework to evaluate the effectiveness of traffic management strategies that prohibit left-turn movements at signalised intersections by redirecting them through U-turn manoeuvres. The proposed framework enables the identification of left-turn directions to be restricted and the optimal placement of U-turn locations so as to minimise the average travel time of all vehicles passing through the intersection. This systematic approach supports rational traffic management decisions in contexts of limited space and high traffic conflict, as commonly encountered in major cities like Hanoi.

The framework was applied to three representative signalised intersections, with approach roads comprising between two and five lanes. Using the PTV VISSIM simulation model, three corresponding U-turn management scenarios were evaluated. Results indicate that the scenario implementing U-turns on the five-lane road achieved the highest total vehicle throughput and the lowest overall travel time. Replacing direct left turns with U-turns contributed to reducing conflicts and improving intersection clearance, particularly when the road space was sufficient to accommodate appropriately located U-turn points. Although some vehicles experienced longer travel distances, the overall efficiency outperformed the current traffic conditions.

A limitation of the study lies in the absence of real-world implementation and evaluation of the proposed scenarios. Field trials assessing the before-and-after performance of the new traffic organisation are necessary to validate the simulation outcomes. This will form the basis for future research aimed at refining the methodology, advancing from simulation-based proposals to practical implementation.

Given these practical contributions, the study is particularly relevant to urban planners and traffic management authorities in Hanoi. As the city continues to face increasing congestion and limited infrastructure expansion options, the adoption of flexible and cost-effective traffic management strategies - such as the proposed left-turn restriction combined with U-turn implementation - offers a feasible solution. Urban traffic authorities are encouraged to integrate this approach into intersection improvement projects, using both simulation and field evaluation to ensure its suitability for specific locations.

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