FACULTY OF ENGINEERING – SOHAG UNIVERSITY
Sohag Engineering Journal (SEJ) VOL. XX, NO. XX, Month 20XX

Operational Performance Evaluation of the Median U-turn Intersection

Talaat A. Abdel-wahed[1,], Mohamed EL Esawey[2], and Mohamed Ahmed Fayez[3]

[(1)] ***Prof., Civil Engineering Department, Sohag University, Sohag, Egypt.***

Corresponding author. dr.talaat_ali@eng.sohag.edu.eg

[(2)] ***Prof., Civil Engineering Department, Ain Shams University, Cairo, Egypt.***

m.elesawey@eng.asu.edu.eg

[(3)] ***Researcher, Avic Company, Kuwait***

mohammed_ahmed41@yahoo.com

Abstract

In Egypt, recently, unconventional intersections have gained popularity among policymakers where conventional countermeasures that exemplify increasing cycle length, actuated signals, and signal coordination systems did not have the ability to overcome the operational problems of traffic congestion. The most important of these intersections is the intersection of the median U-turn. This research evaluated and investigated the operational performance of the median U-turn (MUT) in urban areas under balanced and unbalanced volume scenarios. SYNCHRO was used to optimize the signal cycle length, and the signal cycle lengths were extracted from SYNCHRO and used as input in PTV VISSIM (student version). This study was based on the average vehicle delay and overall capacity for intersection as measures of effectiveness (MOE) in comparison between the median U-turn and the conventional counterpart. The median U-turn intersection had the lowest average delay under balanced and unbalanced volume conditions in all scenarios. The conventional intersection had the lowest capacity, around 950 vehicles per hour/ approach, while the median U-turn had the highest capacity, around 1650 vehicles per hour/ approach. Compared to this value, the capacity of the MUT is 57% higher than conventional intersection. Finally, the distance between the main and second intersections was investigated of the MUT under balanced volumes. The distance of 300 meters between the main intersection and crossover U-turn was the best in cases of heavy traffic volumes that were close to the capacity of the intersection. In addition, the distance of 200 m was well in cases of moderate traffic volumes, while the distance of 100 m had the highest delay for all levels of volumes.

Key words:

Unconventional intersections, micro-simulations, operational performance, geometric design of intersections, Median U-turn.

Introduction

The increase in population density in Egypt coupled with the increase in car ownership in urban areas, has created a traffic burden on at-grade intersections. Also, it has led to the emergence of many defects in the pavement layers and the use of many techniques to address them [1-4]. Conventional intersections were ineffective and insufficient in dealing with traffic congestion at at-grade intersections as a result of the increased number of signal phases [5, 6]. The traditional solutions, such as adding protected left-turn signal phases, optimization signal timing, exclusive left-turn signal, grade separation, and widening intersection approaches, were also insufficient to alleviate congestion [7]. Therefore, engineers resorted to adopting innovative intersections as an alternative to traditional intersections to alleviate congestion and improve traffic safety. Most of the traffic congestion at conventional intersections was attributed to the increased left-turn volume. This problem has been mitigated by using unconventional intersections that re-route left-turn movements, and thus the operational performance and traffic operation have been improved [8-12]. This study focused on the median U-turn intersection design which was applied widely in urban areas worldwide. The median U-turn or what is called Michigan MUT because it was used widely in Michigan for many years [13]. The MUT has gained popularity as it has the ability to alleviate traffic congestions by prohibiting left-turn vehicles and redirecting them to a U-turn at the median opening downstream of the intersection, as shown in Figure (1). Drivers on the minor road who want to make a left turn onto the major road must first make a right turn at the main intersection, then execute a U-turn at the median opening, and finally merge with the through traffic on the major road. Prohibiting left-turn movements at the main intersection led to reducing signal phases from four to two. This procedure improved the operational performance at the main intersection by reducing conflict points from 32 conflict points to 8 conflict points at the main intersection, so in sequence the average delay for vehicles was reduced and enhanced traffic safety. SYNCHRO and micro- simulation software PTV VISSM were used in this study to investigate and analyze the operational performance of the median U-turn intersection and a conventional counterpart [14]. Some disadvantages of the MUT design include increased travel distances for left-turn movements, an increased number of stops for left-turn movements, driver confusion, and a large right of way (ROW).

Pervious Work

Many researchers have investigated the median U-turn intersection by utilizing hypothetical volumes (balanced and unbalanced volumes) to reflect different congestion levels. However, this does not simulate other prevailing conditions that may have existed at the intersections [13,15-17]. The state of Michigan proposed the median U-turn as an alternative to the conventional intersection to address capacity problems. The MUT design presented an increase in capacity of 20% - 50% compared to conventional TWLTL designs (Maki 1998). With regard to network travel times, the median U-turn designs had lower travel times than conventional five-lanes (TWLTL) designs [18]. Additionally, the median U-turn intersection has been used and implemented in Michigan for more than 40 years [19].

Bared and Kaisar (2002) investigated the use of a median U-turn design as an alternative for a left-turn at a signalized intersection in terms of traffic operational benefits. They compared a conventional intersection (consisting of four lanes intersecting with four lanes) with a signalized median U-turn intersection. CORSIM was utilized as micro-simulation software in this research. The results showed that, for balanced flow, the total reduction in travel time for the median U-turn was significant compared to the conventional intersection [20].

Topper and Hummer (2005) studied the impact of locating U-turns on the major roads and the minor roads for unconventional intersections where left-turns were prohibited at the main intersections. Under the majority of all volume combinations, the results indicated a significant reduction in delay, total travel times, and number of stops achieved by the U-turns located on the minor road compared to the U-turn located on the major road [21].

Another study on unconventional intersections was conducted in Mansoura City, Egypt, by Shahdah et al. (2015). The authors compared the unconventional median U-turn with the conventional signalized intersection in terms of the average delay per vehicle. In this study, the geometric design for both unconventional median U-turn and conventional intersections consists of four legs, and the main street consists of two lanes in both the east and west approaches, while the minor street consists of one lane in both the north and south approaches. The results demonstrated that the unconventional median U-turn design performed better than the conventional signalized intersection under low traffic volumes of up to 3500 vehicles per hour. Also, the unconventional median U-turn completely failed under heavy traffic demands because no vehicle could complete its trip through the intersection and all vehicles had to queue outside the traffic network. The authors also recommended not using the unconventional median U-turn under higher left-turn percentages [22].

The operational and environmental performance of the median U-turn design was further investigated by Hashim et al. (2017) where the authors compared un-signalized conventional three-leg, conventional signalized three-leg with corresponding median U-turn (three-leg with median U-turn) intersections. The authors used hypothetical balanced and unbalanced volume conditions. The findings concluded that, for balanced volume scenarios of up to 1250 vehicles per hour per approach, the median U-turn design showed slightly lower delays than the conventional three-leg intersections. After this volume level, the conventional three-leg intersection experienced fewer delays than the median U-turn design [23].

Some studies have focused on replacing left-turn movements with right-turn movements followed by U-turn movements, like a study conducted by Taha et al. (2017) investigating the three left-turn treatments (three left-turn control types) under different traffic conditions. SYNCHRO software was used to obtain the optimized signal timing, and VISSM micro-simulation software was used as an analytical tool to model three left-turn control types: right turn followed by U-turn, direct left turn, and U-turn followed by right turn by using the optimized signal time that was obtained from SYNCHRO. The impact of a location U-turn from the main intersection on the average delay was also investigated. The findings demonstrated that, when the U-turn locations were 200 meters from the main intersection, unconventional left-turn control types had less delay and travel time than direct left-turn (DLT). Also, when the U-turn locations were 100 meters from the main intersection, the right-turn followed by U-turn (RTUT) outperformed the other left-turn control types [24].

Finally, there were some interesting studies investigating prohibiting left-turn movements on driveways, for example, in the thesis of Derov (2003), eights sites were selected for use in the evaluation of three alternatives for left-turn movements from driveways. Case 1 considered no constraints on making direct left turns from or to driveways. Case 2 prohibited direct left turns in or out of driveways and converted left-turn traffic to a U-turn at the next intersection. Case 3 considered no direct left-turn in or out the driveways and converted left-turn traffic at U-turn at mid-block (after or before the intersection). The results showed that when the non-restricted case was compared to the U-turn alternatives, there was a reduction in delay for some volumes of the main line (corridor) [25].

Methodology

The aim of this study is to investigate the operational performance of the median U-turn design in urban areas and compare it with the conventional counterpart. Synchro was used to create optimal signal cycle length, and VISSM was used to model both the conventional and median U-turn designs under different traffic conditions. Safety and pedestrian movements were not used in the current study. The research gap in this study is the application of this methodology to intersections in urban areas within cities where the width of the island is small, such as intersections in Egypt.

Geometric design

The median U-turn intersection in urban areas had special specifications, the most important of which was that the width of the island was very small compared to the width of the island in rural areas. The MUT intersection had the following geometric design elements:

- All approaches have two lanes: one through-only lane and one shared (through with right) lane. The difference between the conventional and MUT is that the conventional contains two lanes shared (one through with left and another through with right).
- All are four-leg intersections.
- The width of the island was four meters because of the lack of right of way in urban areas.
- To overcome the difficulty of maneuvering vehicles, the opening distance at the U-turn crossover was 10 meters. By visual observation, drivers were able to perform the maneuver as a result of the opening distance at the U-turn crossover being 10 meters; this distance facilitates the maneuvering of one vehicle and not more than one in parallel, according to the behavior of drivers in Egypt.

According to the distance between the main intersection and the U-turn crossover, a distance of 400 to 600 feet was recommended by the AASTHO (American Association Of State Highway And Transportation Officials) Green book, while 660 feet plus or minus 100 feet (170 m to 230 m) was recommended by The Michigan Department of Transportation (MODT). For the median U-turn design, three spacing distances between the main intersection and the U-turn crossover were modeled and tested, including 100 m, 200 m, and 300 m. The purpose of studying these distances is to obtain the optimal distance that meets the lowest delay.

Traffic volumes

This study was based on two types of hypothetical volumes: balanced and unbalanced volume scenarios under default driving behavior parameters. The conventional and median U-turn designs were simulated and tested under the two scenarios. Where a balanced volume scenario refers to a situation where the traffic volumes on each leg of the intersection are the same. In contrast, the unbalanced scenario presents a situation of main-minor intersecting roads. Modelling all volume scenarios with 20% and 30% left-turn volumes despite that keeping the same approach volume allowed for the investigation of the effect left-turn volume percentage on the performance of the intersection. As a consequence, 83 unbalanced volume scenarios were tested in PTV VISSIM. For balanced volume scenarios, the volumes varied from 300 up to 1700 veh/h/approach with 100 veh/h/approach increments except for the volumes 300, 500, and 1200. Using all these scenarios to reflect different traffic volume conditions during peak hour traffic and off-peak hours. Table 1 presents the balanced and unbalanced traffic volume scenarios tested in this research.

Traffic Volumes	**Approach Volume**		**Movements Through/ left/ right**
	Main road	minor road	
Balanced Volumes	300 500 700 800 900 1000 1100 1200 1400 1500 1600 1700	300 500 700 800 900 1000 1100 1200 1400 1500 1600 1700	70 / 20/ 10
Unbalanced Volumes For capacity	1000 1400 1600 1800 2000 (Each volume with all volumes in the minor road)	300 600 900 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500	70 /20 /10 60/ 30 /10
Unbalanced volumes	900	350 550 750 900	70 /20 / 10 60 / 30 /10

Table 1. Balanced and unbalanced volumes scenarios.

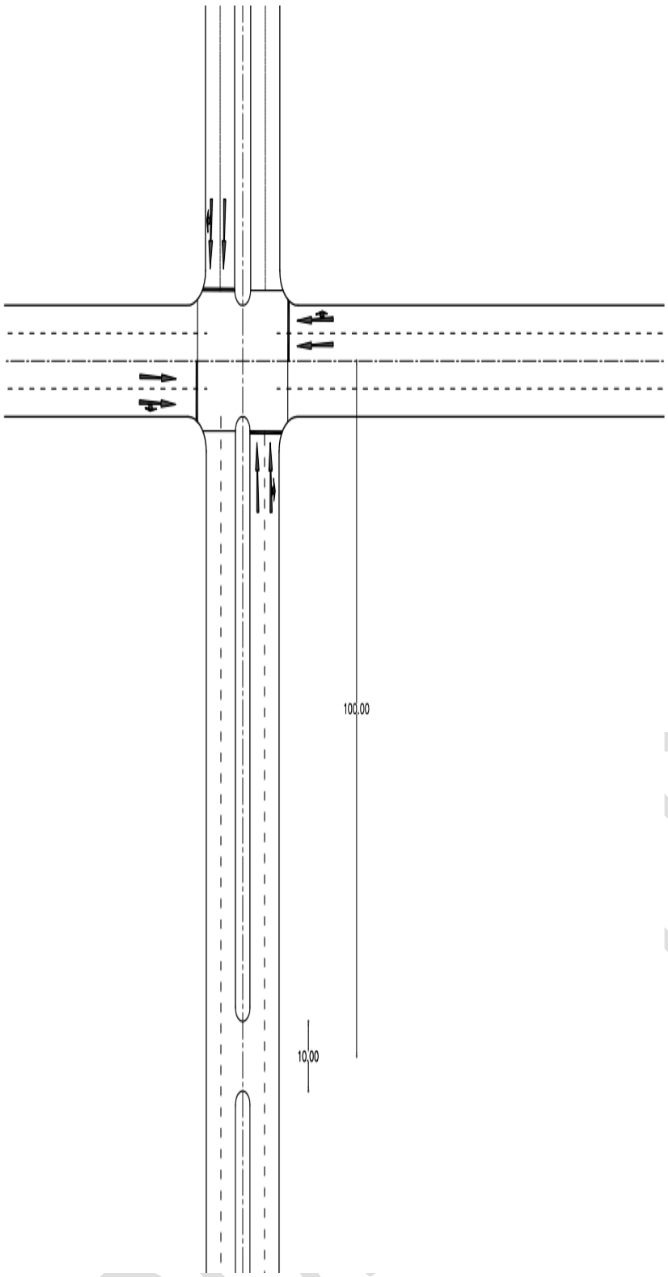


Figure 1. Geometric elements of the median U-turn intersection (MUT).

Traffic micro-simulation models

One of the most popular micro-simulation software tools for modeling and simulating real-world road networks and traffic patterns is PTV VISSIM which was utilized in this study to model all volume scenarios. VISSIM had numerous advantages with regard to the construction of road networks, driving behavior parameters, and different types of vehicles. Heavy vehicles, bus, passenger car, tram, and van were numerous types of vehicles that could simulate the reality of traffic flow on the roads [14-17,26,27]. Only passenger cars and van vehicles was utilized in this study. PTV VISSIM had different car-following models such as Wiedemann 99 and Wiedemann 74 models [28]. The Wiedemann 74 car-following model and default driving parameters was utilized in in this study. The lane width was set to 3.7 m with no shoulders. The average speed for conventional and MUT intersections was 50 km/h (31 mph) for all approaches, whereas the turning speed on right-turn and U-turn zones was set to 25 km/h. The traffic stream was comprised of 98% passenger cars and 2% van vehicles. No Heavy Vehicles (HV) was used in the model as they are prohibited in urban areas in Egypt. SYNCHRO was used to create optimal signal cycle lengths for all balanced and unbalanced scenarios. A pre-timed signal controller was used with 4 s amber and 1 s all-red intervals for all balanced and unbalanced traffic conditions. Each scenario was run four times with a different number of seeds. The first 100 seconds were excluded from the simulation and considered as a warm-up time.

Results and Discussion

The average control delay calculated was used as a measure of effectiveness in the process of evaluating the operational performance of the median U-turn design compared to the conventional counterpart for all volumes. According to the Highway Capacity Manual seven edition (HCM 2022) [29], the intersection capacity is determined as the maximum throughput volume when the average control delay reached 80 s/veh, which corresponds to LOS F.

Balanced volume scenario

Three spacing distances were investigated to obtain the optimal distance and their effect on the operational performance of the MUT design. It was worth noting that none of the three designs was able to accommodate a total approach volume higher than 1700 vehicles per hour. When the input volumes in the VISSIM exceeded this value, an error message stating that the vehicle was not able to finish its trip well and many vehicles were not generated. The effect of spacing distances on the operational performance of the MUT according to average control delay is shown in Figure 2.

As illustrated in Figure 2, the minimum spacing distance between the main intersection and crossover of the MUT design (100 m) had the highest average delays when compared to other spacing distances. From volume 300 up to volume 1200, the MUT design with space distance 200 had slightly lower delay compared to the MUT design with 300 space distance, whereas from volume 1200 up to failure point for the intersections, the MUT 300 was outperformed than other designs. The reason this was superior in large vehicle volumes was that the queue was not at a level where it was able to close the main intersection, or spillback. The conventional four-leg intersection was compared to the median U-turn (space distance 200) and the median U-turn (space distance 300) in terms of the average delay at balanced volume scenarios as shown in Figure 3. The results of the comparison indicated that the conventional intersection exhibited higher delays than other MUT designs and reached its maximum capacity at approximately 950 veh/h for each approach, while the capacity of the MUT (space distance 200) and the MUT (space distance 300 m) was about 1650 and 1700 veh/h/approach, respectively . This rapid failure in capacity for the conventional design was due to increasing the number of signal phases and allowing left-turn movements at the main intersection. This indicated that the capacity of the conventional intersection was about 43% lower than the MUT (space distance 200).

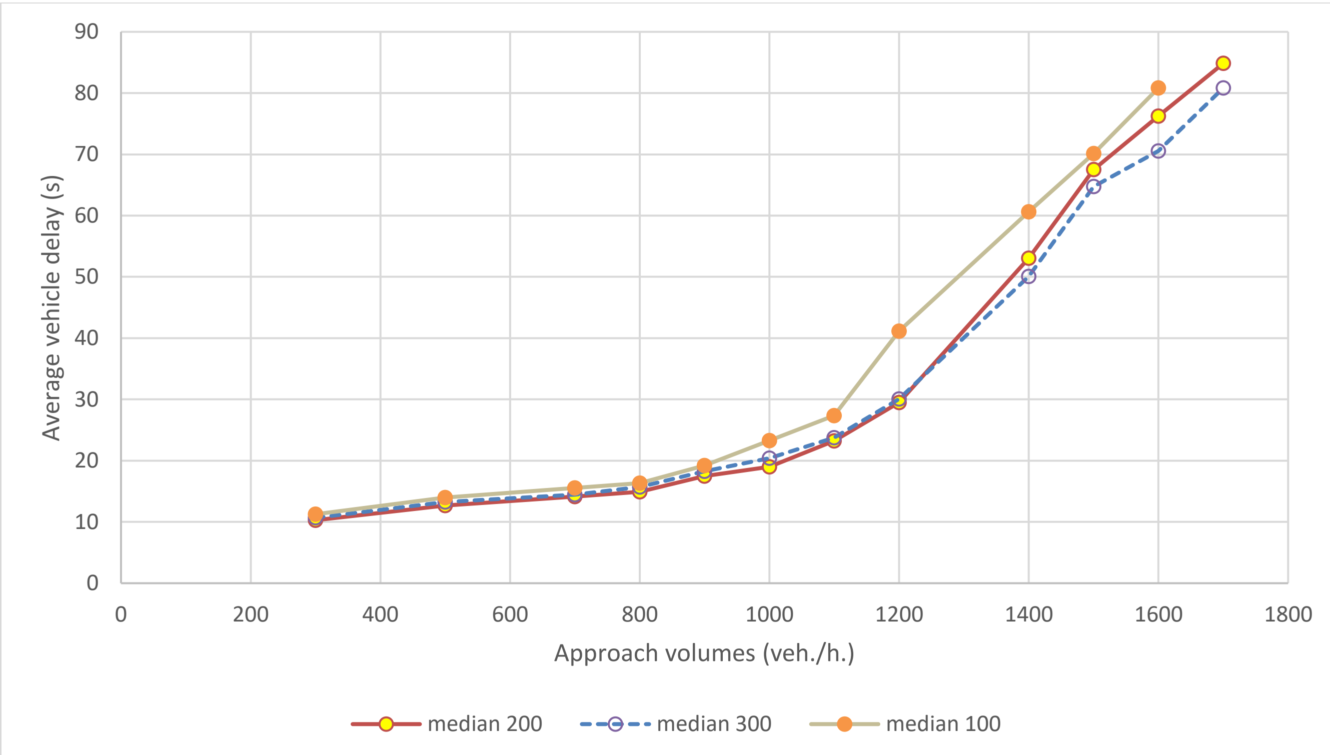


Figure 2. Delay variation with spacing distance change for the median U-turn (MUT)

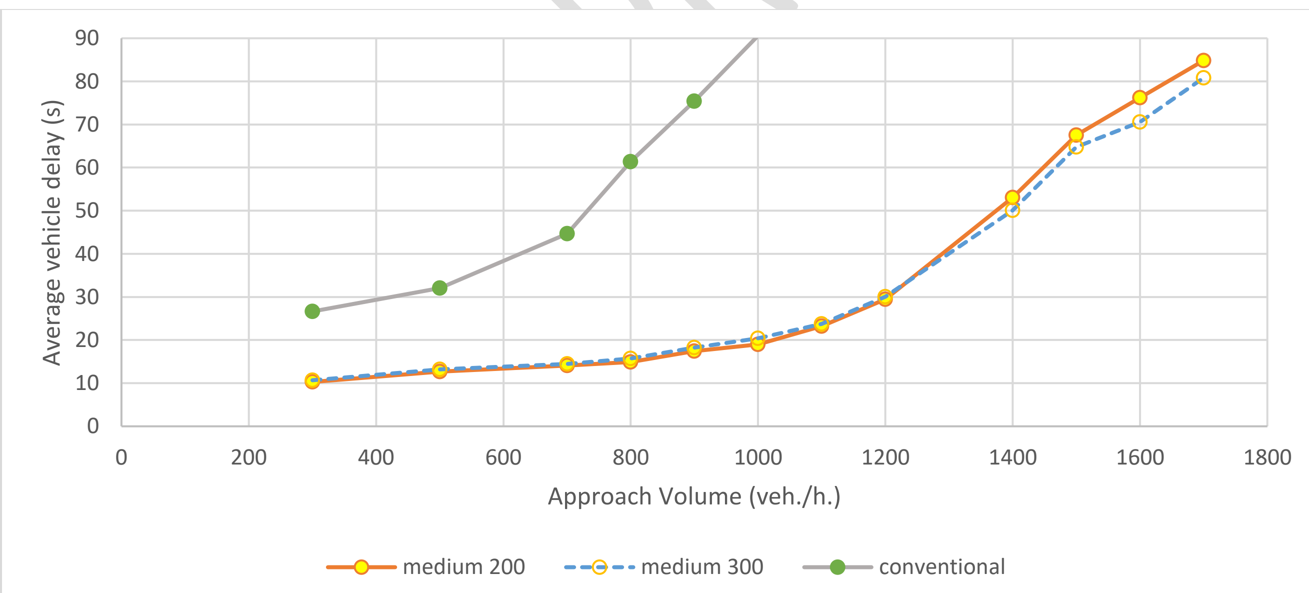


Figure 3. Delay comparison of the conventional, median U-turn (space distance 200), median U-turn (space distance 300).

Effect of increasing left-turn percentage on the performance of the Median U-Turn

20% and 30% of left-turn volumes were used to study their impact on the performance of two median U-turn designs of spacing distances of 200 and 300 m. Increasing the left-turn volumes from 20% to 30% of the total approach volume led to an increase in average delay as shown in Figure 4 and Figure 5.

As illustrated in two previous figures, when the volumes of left-turn were increased from 20% to 30%, this generated additional delays at the intersection. From volume 300 to 1000, the impact of increasing left-turn is low. As the volume exceeded 1000 veh/hr/approach, the difference in average delay becomes significant. It is noteworthy that the capacity decreased from 1650 veh/h up to 1415 veh/h for the median U-turn (spacing distance 200 m), while it dropped from 1700 veh/h up to 1500 veh/h for the median U-turn (space distance 300 m) when increasing the left-turn percentage from 20% to 30%, representing about 14.2% and 11.7% reduction, respectively.

Unbalanced Volumes

The operational performance of the Median U-turn intersection was conducted under different unbalanced volume scenarios at 20% and 30% left-turn splits for both major and minor streets. The unbalanced used volumes were 1000, 1400, 1600, 1800, and 2000 veh/h/approach on the main street where the U-turn crossover was plotted as shown in Figure 6, and the volumes on the minor street were 300 to 1200 in increments of 300 and 1300 to 2500 in increments of 100,.

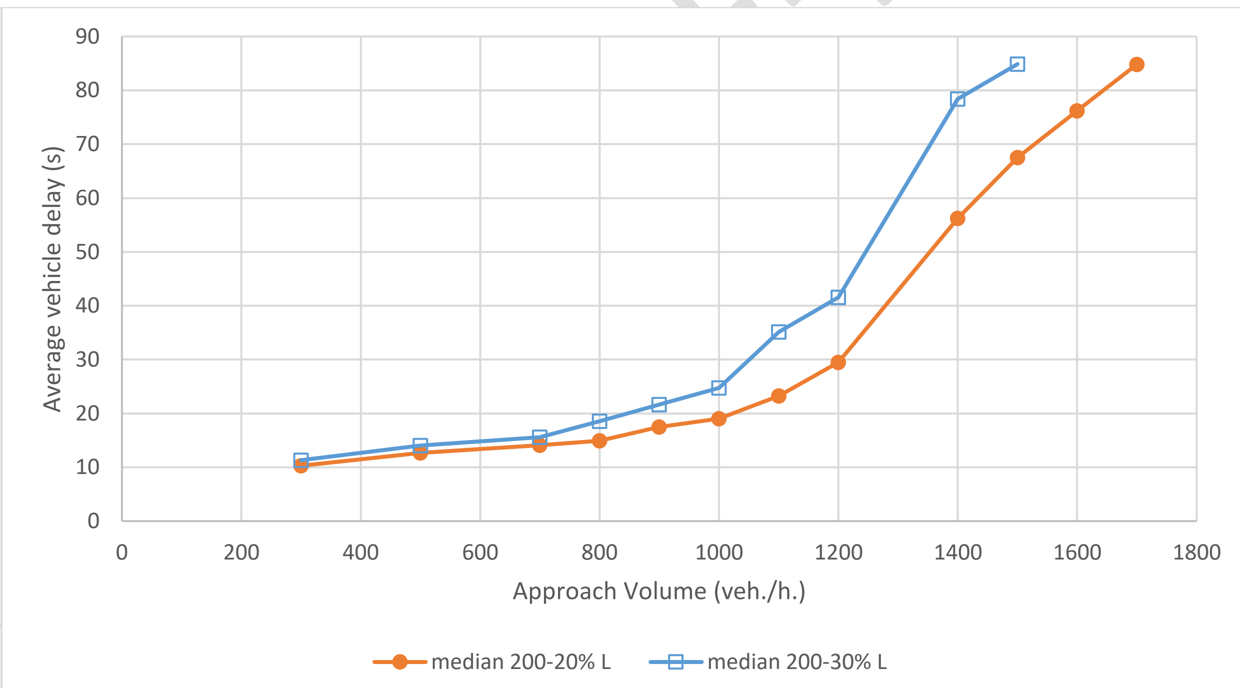


Figure 4. Effect of increasing the Left Turn (LT %) on the performance of the median U-turn (spacing distance 200) under balanced volume scenarios.

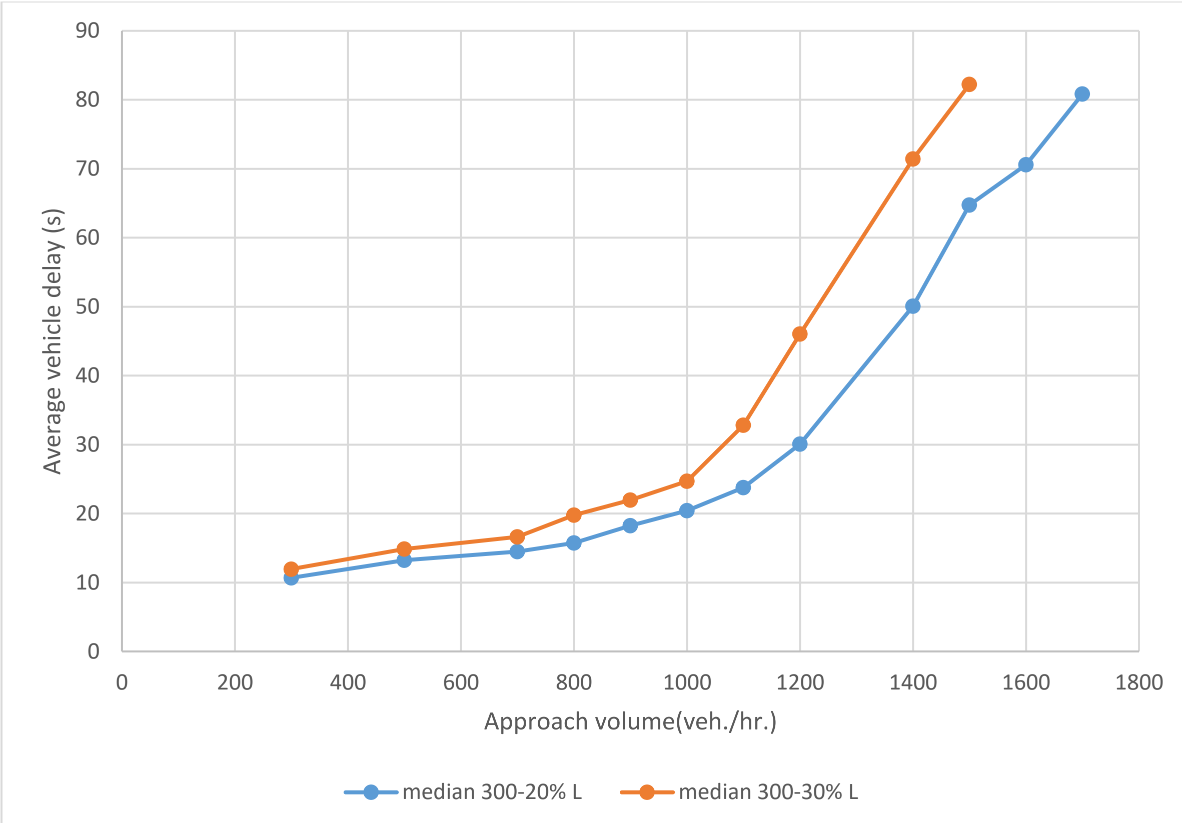
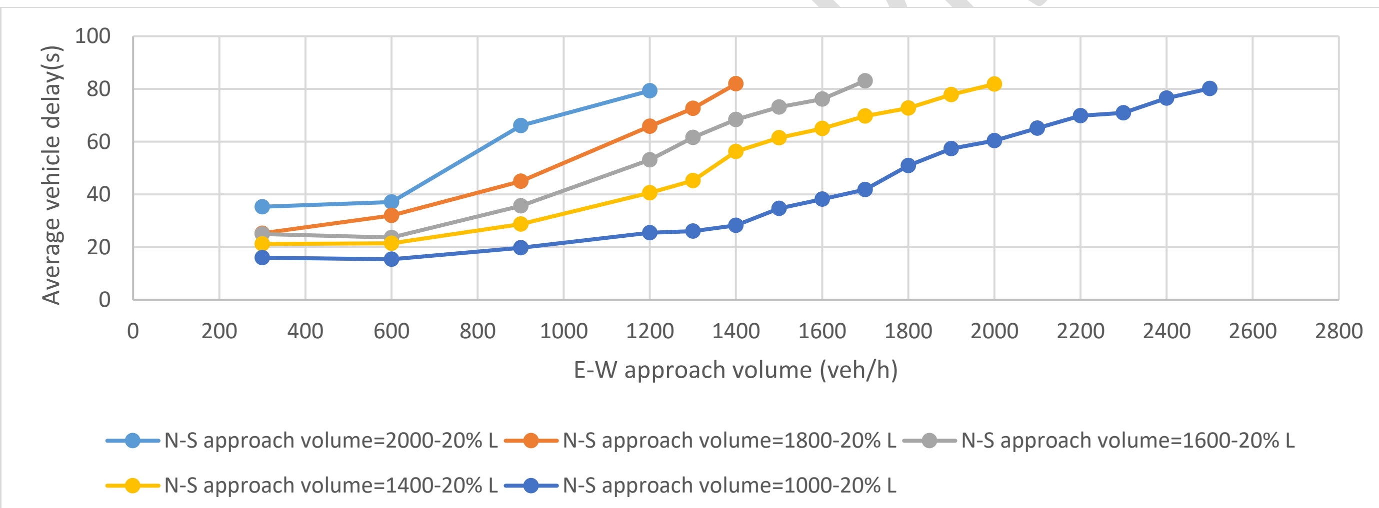


Figure 5. Effect of increasing the Left Turn (LT %) on the performance of the median U-turn (space distance 300) under balanced volume scenarios.

This procedure was used to obtain the failure point of the median U-turn where its capacity reaches its maximum and level of service reaches failure (i.e., LOS F). As illustrated in Figure 5, when increasing the traffic volumes on the main street, the ability of the minor street to accommodate much traffic volume is decreased. When the traffic volume on the major street was 1000 veh/h/approach, the minor street could accommodate traffic volumes up to 2500 veh/h/approach, whereas it could not accommodate larger than 1200 veh/h/approach when the traffic volume was 2000 veh/h/approach on the major street for 20% left-turn. In other words, before the intersection reaches the failure point, increasing the traffic volumes on the minor road in turn reduces the volumes that can be accommodated by the main road. As an example from this study, putting a traffic volume equal to 1000 veh/h/approach on the main road led to the minor road being able to accommodate 2500 veh/h/approach before the intersection reached the failure point, but when we add the extra volumes on the main road, the minor road will accommodate fewer vehicles and vice versa.

Increasing the left-turn from 20% up to 30% had a negative impact on the capacity of the median U-turn. The minor road barely could accommodate 1900 veh/h/approach, whilst the volumes were 1000 veh/h/approach on the main street. While the same volume (1000 veh/h) on the main street when the left-turn percentage was 20% only, the minor road could accommodate approximately 2500 veh/h.



Average vehicle delay(s)
100
80
60
40
20
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
E-W approach volume (veh/h)
N-S approach volume=2000-20% L
N-S approach volume=1800-20% L
N-S approach volume=1600-20% L
N-S approach volume=1400-20% L
N-S approach volume=1000-20% L

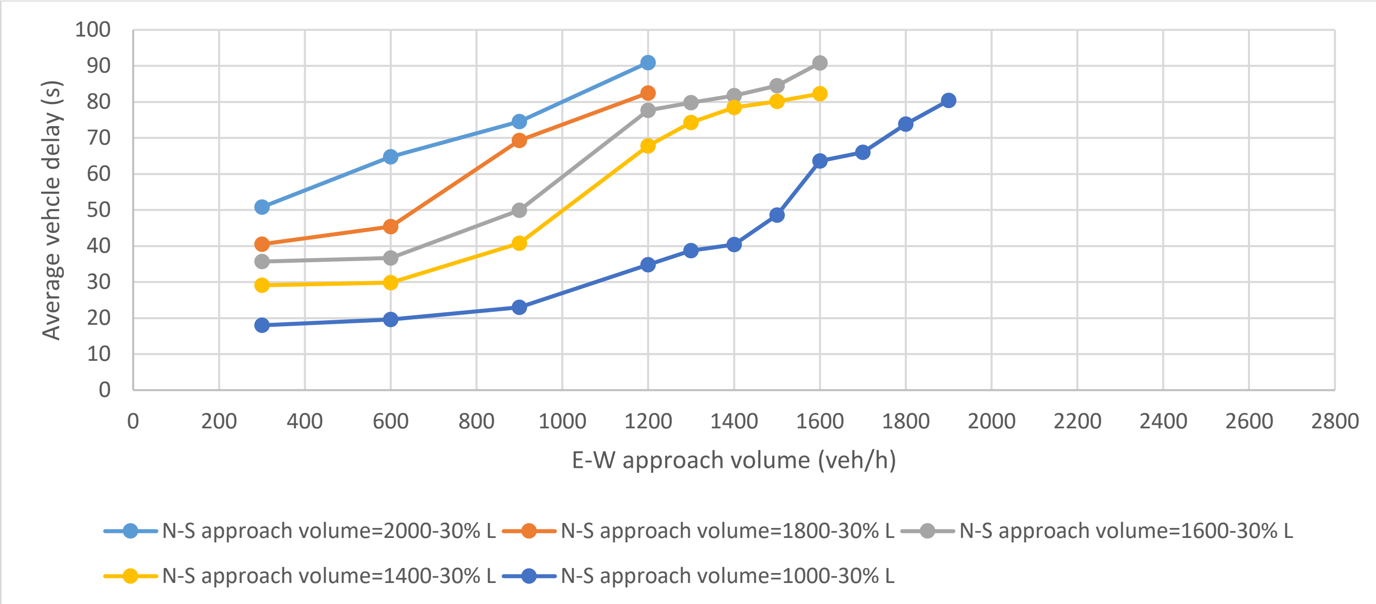


Figure 6. Average vehicle delay for the median U-turn intersection under unbalanced volume scenarios. (a) 20% LT (left-turn) and (b) 30% LT (left-turn).

Finally, as shown in Figure 7, the conventional intersection was compared with the median U-turn (space distance 200 m) and the median U-turn (space distance 100 m) under unbalanced traffic volume conditions. The impact of increasing the percentage of left-turn of the conventional and the median U-turn for the 100 m and 200 m spacing distances was also analyzed. Volume levels were set as moderate volumes, where the volume on the major street was set to 900 veh/h/approach. The results concluded that the MUT designs outperformed compared to the conventional designs. The MUT (space distance 200 m) with 20% left-turn had the lowest delay, whilst the conventional intersection with 30% left-turn experienced the highest delay. The median U-turn (space distance 100) with 20% left-turn had similar delays when compared to the median U-turn (space distance 200 m) with 30% left-turn up to volume 550 veh/h/approach. After this volume, the median U-turn (space distance 100 m) with 20% left-turn experienced slightly lower delays compared to the median U-turn (space distance 200 m) with 30% left-turn. The median U-turn (space distance 100 m) design with 30% left-turn exhibited higher delays when compared to other median U-turn designs and experienced lower delays when compared to the conventional intersection, whether the conventional design was with 20% left-turn or with 30% left-turn.

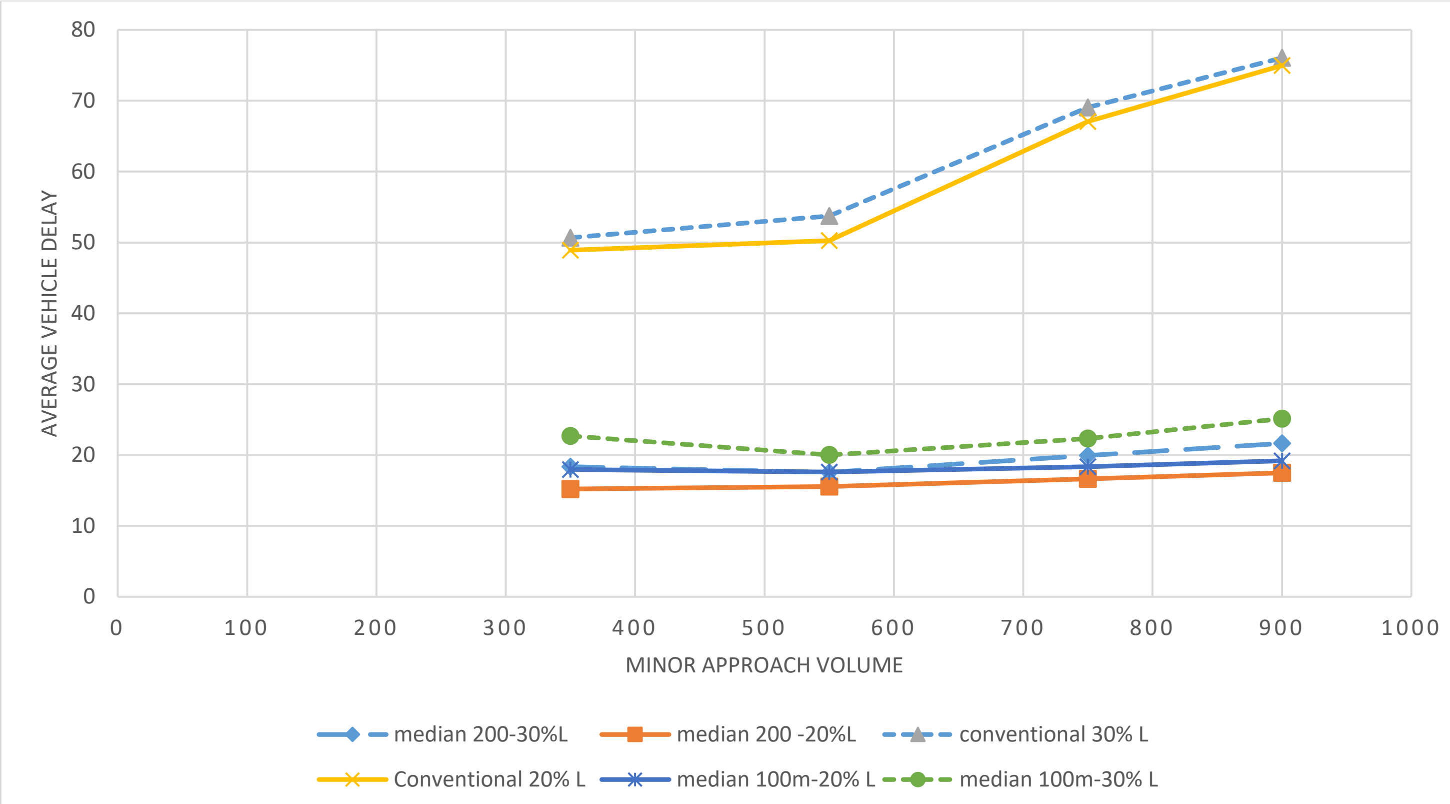


Figure 7. Average delay at the analyzed intersection under unbalanced volume scenarios, major street approach volumes = 900 vehicle / hour, 20% LT (left-turn) and 30% LT (left-turn).

Conclusion and recommendations

This study analyzed the operational performance of the median U-turn intersection under balanced and unbalanced traffic volume scenarios using VISSM. The impact of spacing distance between the main intersection and the U-turn crossover on the operational performance of the MUT design was also evaluated. The MUT intersection with a spacing distance of 100 m had the highest delay and as such it is not recommended for implementation in urban areas. For moderate traffic volumes, it is preferred the MUT intersection with a spacing distance of 200 m, while a MUT with 300 m spacing is recommended for heavy traffic conditions before failure point (LOS F). The comparison between the conventional and MUT designs was made in terms of average vehicle delay. The results demonstrated that there was a reduction in average vehicle delays of the median U-turn designs in all balanced and unbalanced traffic volumes. The capacity of the MUT intersection was 57% higher than the conventional intersection. Despite a similar previous study conducted by El Esawey et al. (2011) concluded that the capacity of the MUT was 8% up to 10% higher than the conventional intersection, this higher increase in capacity is attributed to a number of reasons. Firstly, in the MUT intersection tested in this study, no heavy vehicles were allowed. This enhances the driver's ability to maneuver quickly and easily at the U-turn crossover. Secondly, the signal phases of the conventional intersection were four phases, where one signal phase was dedicated to all movements on the one-leg approach. This led to increasing the cycle length very much. Thirdly, differences in geometric design between this study and the previous study. Finally, the opening at the U-turn crossover was 10 m, where this large distance enhanced the driver's ability to maneuver.

Finally, most of the previous research focused on the operational performance of the median U-turn while was there a little research investigated safety and the effect of pedestrians. Most research results concluded that the median U-turn intersection outperformed in the operational performance compared to the conventional counterpart intersection. Safety analysis and pedestrians left for future research.

References

1. Abdel-Wahed, Talaat, Naglaa K. Rashwan, and Ayman E. Maurice. "The physical properties of bitumen modified with ilmenite and bentonite nanoparticles." HBRC Journal 16.1 (2020): 335-350.
2. Badry, M. M., Dulaimi, A., Shanbara, H. K., Al-Busaltan, S., & Abdel-Wahed, T. (2021, March). Effect of Polymer on the Properties of Bitumen and Pavement Layers, Case Study: Expressway No. 1, Republic of Iraq. In IOP Conference Series: Materials Science and Engineering (Vol. 1090, No. 1, p. 012032). IOP Publishing.
3. Abdel-wahed, T., Younes, H., Othman, A., & El-Assaal, A. (2020). Evaluation of recycled asphalt mixture technically and economically. JES. Journal of Engineering Sciences, 48(3), 360-370.
4. Abdel-Wahed, T., Abdel-Raheem, A., & Moussa, G. (2022). Performance Evaluation of Asphalt Mixtures Modified with Nanomaterials. MEJ-Mansoura Engineering Journal, 47(1), 1-15.
5. Mandor, A., Hashim, I., El-Dessoky, I., & Abdel-Wahed, T. (2022). Calibration and Validation of Microsimulation Models for Estimating Control Delay at Signalized Intersections in Upper Egypt, Sohag city as case study. Sohag Engineering Journal, 2(2), 106-119.
6. Hashim, I. H., Abdel-Wahed, T. A., & Mandor, A. M. (2017). Measuring control delay at signalized intersections: case study from Sohag, Egypt. Int. J. Adv. Res. Sci. Eng, 5.
7. Reid, J. D., & Hummer, J. E. (1999). Analyzing system travel time in arterial corridors with unconventional designs using microscopic simulation. Transportation Research Record, 1678(1), 208-215.
8. Abdelrahman, A., Abdel-Aty, M., Lee, J., & Yue, L. (2020). Evaluation of displaced left-turn intersections. Transportation Engineering, 1, 100006.
9. Al-Omari, M. E. M. A., & Abdel-Aty, M. (2021). Evaluation of a New Intersection Design, “Shifting Movements”. Transportation Research Record, 2675(10), 1352-1363.
10. Guo, R., Liu, J., & Qi, Y. (2021). An innovative signal timing strategy for implementing contraflow left-turn lanes at signalized intersections with split phasing. Sustainability, 13(11), 6307.
11. Song, Y., Chitturi, M. V., Bremer, W. F., Bill, A. R., & Noyce, D. A. (2022). Review of United States research and guidelines on left turn lane offset: Unsignalized intersections and signalized intersections with permitted left turns. Journal of traffic and transportation engineering (English edition), 9(4), 556-570.
12. Chen, K., Zhao, J., Knoop, V. L., & Gao, X. (2020). Robust signal control of exit lanes for left-turn intersections with the consideration of traffic fluctuation. IEEE Access, 8, 42071-42081.
13. Hughes, W., Jagannathan, R., Sengupta, D., & Hummer, J. (2010). Alternative intersections/interchanges: informational report (AIIR) (No. FHWA-HRT-09-060). United States. Federal Highway Administration. Office of Research, Development, and Technology.
14. El Esawey, M., & Sayed, T. (2011). Operational performance analysis of the unconventional median U-turn intersection design. Canadian Journal of Civil Engineering, 38(11), 1249-1261.

15. Naghawi, H., AlSoud, A., & AlHadidi, T. (2018). The possibility for implementing the superstreet unconventional intersection design in Jordan. Periodica Polytechnica Transportation Engineering, 46(3), 122-128.
16. Abo-Bakr, S., Esawey, M. E., & Osama, A. (2022). Operational and safety performance evaluation of parallel flow intersection. Transportation research record, 2676(6), 61-74.
17. El Esawey, M. and Sayed, T. (2007). Comparison of two unconventional intersection schemes: crossover displaced left-turn and upstream signalized crossover intersections. Transportation Research Record, 2023(1), 10-19.
18. Dorothy, P. W., Maleck, T. L., & Nolf, S. E. (1997). Operational aspects of Michigan design for divided highways. Transportation Research Record, 1579(1), 18-26.
19. Hummer, J. E. (1998). Unconventional left-turn alternatives for urban and suburban arterials—Part two. ITE journal, 68(11), 101-106.
20. Bared, J. G., & Kaisar, E. I. (2002). Median U-turn design as an alternative treatment for left turns at signalized intersections.
21. Hashim, I. H., Ragab, M., & Asar, G. M. (2017). Evaluation Of Operational and Environmental Performance of Median U-Turn Design Using Microsimulation. International Journal for Traffic & Transport Engineering, 7(1).
22. Elrawy Shahdah, U., Elshabrawy, M., Elbadawy, S., Gabr, A., & Azam, A. (2015). Comparing the Performance of Unconventional Median U-turn Intersections and Signalized Intersections: A Simulation Study. MEJ-Mansoura Engineering Journal, 40(6), 100-108.
23. Carter, D., Hummer, J. E., Foyle, R. S., & Phillips, S. (2005). Operational and safety effects of U-turns at signalized intersections. Transportation Research Record, 1912(1), 11-18.
24. Taha, M., & Abdelfatah, A. (2017). Impact of using indirect left-turns on signalized intersections' performance. Canadian Journal of Civil Engineering, 44(6), 462-471.
25. DEROV, N. L. (2002). Submitted to Graduate Engineering and Research School of Engineering (Doctoral dissertation, UNIVERSITY OF DAYTON).
26. Autey, J., Sayed, T., & El Esawey, M. (2013). Operational performance comparison of four unconventional intersection designs using micro-simulation. Journal of Advanced Transportation, 47(5), 536-552.
27. El Esawey, M., & Sayed, T. (2013). Analysis of unconventional arterial intersection designs (UAIDs): state-of-the-art methodologies and future research directions. Transportmetrica A: Transport Science, 9(10), 860-895.
28. AG, P. T. V. (2011). Vissim 5.40-01 user manual. Germany: PTV.
29. Transportation Research Board; National Academies of Sciences, Engineering, and Medicine (2022). *Highway Capacity Manual 7th Edition: A Guide for Multimodal Mobility Analysis*. Washington, DC: The National Academies Press. ISBN 978-0-309-27562-0.