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Operational Performance Comparison between Conventional Intersections and Two Unconventional Alternative Intersection Designs (UAIDs) Under Heterogeneous Traffic Conditions in Cairo, Egypt

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Abstract

Although the wave of valuable research works and the numerous efforts done by researchers focused on studying, analyzing and evaluating the different types of UAIDs relying on the homogenous traffic conditions, the heterogeneous traffic conditions still underestimated. Thus, the driving force of this study is to investigate the UAIDs applicability under the heterogeneous traffic complexities. These complexities are characterized by the diversity of some static and dynamic properties of vehicles, and the aggressive driving behavior which results in non-lane based traffic systems. Hence, the purpose of this article is to compare the operational efficiency of existing conventional signalized intersections with two proposed UAIDs schemes namely; the Displaced Left-Turn (DLT) intersection and Superstreet Median (SSM) intersection. As a realistic case study of such traffic conditions, three existing intersections in an arterial corridor in Cairo, Egypt were selected. The microsimulation software VISSIM, as a time-step, stochastic and behavior based model was utilized to accomplish this study objective. The simulation results emphasized the outperformance of the proposed UAIDs over the conventional counterparts. The results indicated to the obvious improvement of the level of service (LOS) of the studied the intersections. It was found that the proposed UAIDs schemes reduced the overall delay and the total travel time while the average speed was increased. On the other hand, it was concluded that the heterogeneous traffic influenced the proposed UAIDs efficiency. The main findings of this research may provide a guidance on presenting UAIDs in the developing cities.

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1. Introduction

Since the turn of the new millennium, urban communities have started facing a growing number of transportation challenges. Accordingly, transportation agencies and engineers around the world have been challenged by such problems, principally, the continuous increase in traffic volumes and its resultant congestions at signalized intersections. As traffic volumes grow and congestion worsens, road users: motorists, pedestrians, and cyclists confront greater risks at intersections. Such innovative and balanced solutions that could emphasize smooth traffic flow and improve safety as well as mobility for all users is highly acquired. Therefore, over the last dictate, the Federal Highway Administration (FHWA, Alternative Intersections/ Interchanges: Informational Report (AIIR) 2010) proposed several alternative measures that known as the Unconventional Arterial Intersection Designs (UAIDs) as a feasible vision for relieving arterials' congestions. These alternative designs have been proposed as innovative at-grade intersection treatments; emphasizing the vehicular LOS with comparable traffic volumes along the corridor. Typically, these proposed schemes share a fundamental concept: facilitating the through traffic movements by eliminating or re-routing one or more movements inside the intersection as an unusual movement structure. Most of these intersections were proposed in the developed world where the less complex homogenous traffic conditions and ideal traffic environments are dominated. Although previous researches emphasized the outperformance of several designs of UAIDs over the conventional countermeasures, the other prevailing conditions that might exist at intersections were ignoring. Therefore, most of the proposed UAIDs have been not examined under the heterogeneous traffic as a significant traffic feature in developing, semi-industrialized and industrializing countries.

This study is a part of an ongoing research project designed to estimate the applicability of UAIDs under the heterogeneous traffic conditions. In the previously conducted work, the operational performance of DLTs was evaluated as isolated intersections under such conditions by the authors (SHOKRY et al. 2017). Also, the DLTs coordination was discussed by utilizing both approaches: the bandwidth maximization progression as well as the delay minimization for improving the overall traffic flow propagation along the studied corridor. Hence, the primary objective of this article is to assess the potential operational capability associated with two proposed UAIDs schemes namely; the Displaced Left-Turn (DLT) intersection and Superstreet Median (SSM) intersection under heterogeneous traffic.

The following two sections describe the operational mechanism of the two proposed UAIDs schemes: The Displaced Left-Turn (DLT) intersection and Superstreet Median (SSM) intersection. Hence, the vehicular movement, as well as the unique geometric design of each design, is discussed. The primary benefits of the two UAIDs studied in this research paper is the reduction of traffic signal phases and conflict points. This is accomplished by diverting or re-locating different movements inside intersections in different ways.

1.1. Displaced Left-Turn (DLT) intersection mechanism

The Displaced Left-Turn (DLT) crossover that is also known as Continuous Flow Intersection (CFI), is one of those innovative intersections designs. This intersection's innovation is the allowance of the operation of both through movements and left-turns at the same time using a two-phase signal. It implements unopposed left-turns at intersections by crossing traffic over to the edge of the other side of the road a few hundred meters in advance. By rerouting the left-turn movements, drivers cross over to the left of the road into an exclusive left-turn lane (Joseph E. Hummer 1998). As drivers enter the primary intersection, the left-turns proceed unopposed. Thus, left-turns are allowed to move simultaneously with through traffic, resulting in significant operational efficiency. The left-turn displacements create four additional secondary intersections in major and minor approaches upstream the primary intersection as Fig. 1 depicts. This design can be described as a system of two-phase intersection for the primary and the four created additional crossovers (Reid and Hummer 2001). As a result, a significant reduction in the total cycle length could be done. By reducing the cycle times, leading to shorter average queues as well as shorter storage bays with an overall significant improvement (Joseph E. Hummer 1998; J. E. Hummer and D.Reid 1998; Jagannathan and Bared 2004). Meanwhile, the individual signals within the DLT are easy to coordinate with each other. By considering this coordination, most of the drivers would only have to stop once and a huge difference in travel time is achieved. Consequently, more traffic flow is processed efficiency, an obvious progression along the corridor is enhanced with shorter travel times on the main roadway (El Esawey and Sayed, 2013). As a result, the DLT design succeeds to keep and maintain traffic moving as its name implies.

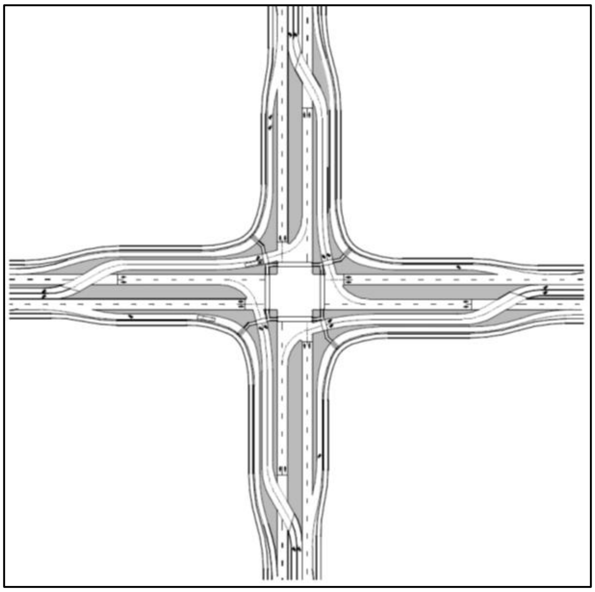

Fig. 1. Displaced Left-Turn Intersection (FHWA, 2014)

1.2. Superstreet Median (SSM) intersection mechanism

Super Street Median (SSM) intersection, that is referred to as Restricted Crossing U-Turn (RCUT) intersection is proposed as a promising solution for more dominant flow on arterials and main corridors. SSM intersections separate two main directions of travel on the main artery by adding an additional break for the through-moving traffic flows as Fig. 2. Since they are all two-phase signals, two one way streets would be provided and an efficient smooth traffic flow is emphasized. Therefore, the signals of each direction allow independent operations on the arterial streets

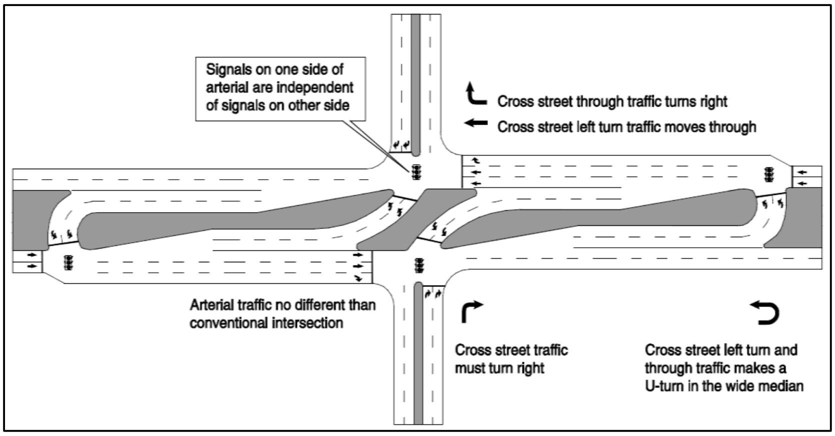

Fig. 2. Supestreet Vehicular Movement (FHWA, 2014)

(FHWA, Restricted Crossing U-turn Informational Guide 2014). The SSM intersection changes traffic from the minor road enters or crosses the main highway by relying on a combination of right turns and U-turns. While the traffic traveling along the main highway can still continue through turn left or turn right, an SSM differs is in how it handles vehicles entering or crossing the main highway from the minor road approaches. In order to operate arterials' movements independently, SSM is channelized through the major street median at specific locations. By channelizing islands at the intersections, the minor road traffic is forced to turn right, joining the main highway through traffic. Shortly, the provided median U-Turn allows the minor road traffic to proceed in the opposite direction as an equivalent of a left-turn. Then to turn right and continue traveling along their original minor route, the equivalent of crossing the major approach at a conventional intersection.

By eliminating two of the highest risk movements from the main intersection and replacing them with U-turns and right turns, safety is substantially improved by reducing the total number of conflict points. On the other hand, one of the trade-offs with RCUT intersections is that vehicles entering from the minor road travel slightly longer distances as compared to a conventional intersection. However, when RCUT are implemented along with a signalized corridor, the average travel times can actually improve, hence the name super street.

2. Previous findings

We are witnessing numerous considerable efforts done by the researchers in the direction of the UAIDs implementation technologies. Although a great deal of literature, as well as the wave of valuable research works, has investigated the qualitative and quantitative benefits of the different UAIDs, little research focused on UAIDs assessment under the homogenous traffic complexities.

In the next section, the later and the most important existing methods of analyzing the operational performance of the two UAIDs proposed in this paper that give a meaningful presentation to this context. Furthermore, the different practices, as well as spare efforts that have been done so far focusing on the heterogeneous traffic conditions, are overviewed.

2.1. UAIDs comparative studies

Lots of considerable and valuable research work has been undertaken to identify the basic principles of the analysis of UAIDs. However, some few research attempts to investigate some UAIDs designs considering the other prevailing conditions under the heterogeneous traffic as a significant and a dominant feature in developing, semi-industrialized and industrializing countries.

The previous research concluded that the conventional designs never produced the lowest average total time, and at least one unconventional scheme would outperform its conventional counterpart in at least one volume scenario (Joseph E. Hummer 1998; J. E. Hummer and D.Reid 1998; M. E. Esawey and Sayed 2013; Joseph E. Hummer and Jagannathan 2008). Although the quadrant roadway and median U-turn designs vied for the lowest average total time, the continuous flow intersection always had the highest move-to-time ratio for all designs (J. E. Hummer and D.Reid 1998). The results also showed that DLT is always superior to other conventional intersections in almost all volume conditions in terms of average intersection delay and the overall intersection capacity. The DLT intersection experienced a significant growth of capacity by 99% higher than that of the conventional one, whereas the Upstream Signalized Crossover (USC) and Double Crossover Intersection (DXI) capacities were about 50% higher than the conventional counterparts, the DLT constantly exhibited the lowest delay among the all compared counterparts (Autey, Sayed, and Esawey 2010). Also, it was emphasized that DLTs exhibited the lowest delays comparing to Median U-Turns (MUTs) USCs and DXIs (Autey, Sayed, and Elesawey 2013). Considerable savings in average control delays and average queue lengths under low, moderate and high traffic volumes comparing three different DLT configurations to their similar conventional designs. A reduction in the average control delay by 48% to 85%, 58% to 71% and 19% to 90% for low, moderate and high traffic volumes respectively caused by DLTs design. Likewise, for under-saturated traffic flows, the average number of stops experienced a reduction of 15% to 30% for and 85% to 95% for saturated traffic conditions. On the other hand, the analysis pointed out a significant increase in intersection capacity for the three studied DLTs over the conventional ones (M. E. Esawey and Sayed 2013).

On the hand, the SSM design consistently showed evidence of decreasing delay time and improving queue length when compared to the conventional design. Significant improvements in traffic performance were found when the SSM design was implemented using real-world traffic data in North Carolina (FHWA, Superstreet Benefits and Capacities 2010). The network experienced a reduction from 27.39 to 82.26, while the average network queue length was almost 97.5 when the SSM was implemented (H. H. Naghawi and Idewu 2014). Meanwhile, the results showed that SSM design is similar to MUT but some additional features that allow for through traffic progression on the major road in both directions by preventing the minor road traffic from crossing the major road (Kim, Edara, and Bared 2007). Also, it was found that the SSM have shorter travel time than the conventional intersection under low minor road volumes compared to total intersection volume less than 0.25 (Joseph E. Hummer and Jagannathan 2008). The critical lane volume procedure was used to estimate the capacity of SSM after readjusting the ideal saturation flow rate for trucks. To calculate the base critical lane capacity of 1587 pcphpl, a 2.1 seconds average saturation headway was used. It was found that SSM can handle major road through traffic volumes and left-turning volumes up to 2600 vph and up to 600 vph respectively, whereas it can handle volumes up to 900 vph and 400 vph for the minor road through and left-turning volumes respectively (Joseph E. Hummer et al. 2007). Also, it was emphasized that the corridors with Superstreet intersections in Korea experienced fewer delays and performed other traditionally operated corridors during peak hour volumes (Moon et al. 2011). The SSM witnessed a reduction of 13 to 87 percent in the average delay and a reduction up to 97 percent in the maximum queue length compared to the existing conventional intersection while studying the feasibility and possibility for implementing the SSM on arterial roads in Amman, Jordon. Although the proposed SSM improved the LOS from F to C, this study concluded that SSM is not appropriate for high traffic volumes (H. Naghawi, AlSoud, and Alhadidi 2018).

Unlike the above-reviewed articles when almost in all of them the vehicle traffic was homogenous, this study addresses some specific aspects of heterogeneous conditions where the complexities are evidential. Considering the complexities of such conditions in Cairo, Egypt, the overall attained results referred to the superior of DLTs over the conventional intersections. However, the mixed traffic conditions influenced DLTs performance improvement rates comparing to the previous studies where hypothetical traffic data was used. The driving behavior, as well as the diverse dynamic properties, could affect the discharge rate in both main intersections as well as left-turn crossovers (SHOKRY et al. 2017).

2.2. Heterogeneous traffic conditions impacts

In the other part of the world, practically, in the developing, semi-industrialized and industrializing cities, the heterogeneous traffic is a dominant operation. The main findings of the early previous studies emphasized the considerable impacts of the heterogeneous traffic conditions on the intersections' LOS (Khan and Maini 1999; Mathew and Radhakrishnan 2010; Kaur and Varmora 2015). The distinguishing aspect of such traffic resulted in a complex movement of traveling vehicles. Such conditions are characterized by two main salient and unique features. First, the mix of vehicle composition having widely varied static (length, width, etc.) and dynamic (desired speed, acceleration and deceleration rates, etc.) properties, with numerous traffic compositions. Second, the aggressive driving behavior as a prevailing condition resulting in a non-lane based traffic phenomenon, especially, when the lane markings are absent (Khan and Maini 1999; Mathew and Radhakrishnan 2010). Due to this phenomenon (the non-lane based traffic) as well as the lack of lane discipline and non-segregation lanes by neither vehicle types nor directional flow, queues at intersections are based on optimum road space utilization. Unlike lane based system, where a driver takes the lane changing decision only if it is possible to perform a complete maneuver in one attempt. On the contrary, under the non-lane based traffic, there is no restriction on positioning a vehicle at any place across the link width. The drivers who would like to change lane does not bother about completing the maneuver in one attempt. As a result, vehicles may occupy any position across the road based on the available space (Khan and Maini 1999; Yulianto 2012). Meanwhile, the smaller vehicles (motorcycles, scooters, etc.) used to maximize the inter-vehicle space by sneaking to reach the head of the queue during the red time (Kaur and Varmora 2015). Also, the heavy vehicles affect the operational performance of the existing intersections. The queueing discharge rate, merging and diverging maneuverability could influence the traffic operational functionality. Accordingly, different vehicular level of service indices such as the saturation flow rates, the start-up lost time and clearance lost time is impacted. Likewise, the previous studies emphasized that the driving behavior of such heterogeneous traffic affects the maneuverability significantly. A unique decision-making process takes place for overtaking and passing when fast-moving vehicle follow slow-moving one under the aggressive driving (Maini and Khan 2000).

3. Site description

For this study context, three consecutive existing conventional signalized intersections located in an arterial corridor in Cairo, the capital city of Egypt were selected to represent a realistic case study. This arterial is considered one of the most significant corridors in Cairo as Fig. 3. It connects the Central Business District (CBD) with new urban residential communities located to the east of the capital retail. To take advantage of its high traffic volume and connectivity, many commercial and industrial facilities are located along the road. Additionally, a largely residential area is also located adjacently next to the studied intersections. The three intersections are namely Al Tayran (AT), Abbass Al-Akkad (AA) and Makram Ebid (ME). The studied intersections are classified as four-leg intersections.

The major and minor approaches are a three-lane divided road with a posted speed of 50 km /hr. However, as a result of the driver aggressiveness as a salient property of the heterogeneous traffic characteristics, drivers used to perform as four lanes per approach flow on the main studied corridor as a non-lane based system. Despite the exclusive bus lane existence, it is not permitted for shuttle buses, private and school buses to use those exclusive lanes. Alternatively, these buses had to use the ordinary lanes with the other vehicles' types as a mixed composition. For major and minor right-turns, a free channelized lane was provided as Right on Red (ROR) operation. The intersections are controlled by a pre-timed traffic signal with a cycle length of 120 seconds, 217 seconds and 86 seconds for AT, AA and ME intersection respectively. Each signal comprises of two signal groups with a conventional phase. The first signal group to control the arterial west-east flow, while the second group is assigned for the minor approach north-flows. The southbound through and left-turns are not permitted to perform at the intersections. These movements must perform in-direct left-turn by using the U-turns provided to the east of each intersection as it is depicted in Fig. 4.

4. Study methodology

4.1. Data collection

In this study context, actual real data were made available by the Department of Civil Engineering, Ain Shams University, Egypt. The intersection details are collected along video observation and included the relevant data needed for the heterogeneous traffic flow. The traffic volumes including the directional flow ratios were collected at three consecutive conventional intersections located in Mostafa El-Nahas Street; an arterial corridor in Cairo, Egypt. The

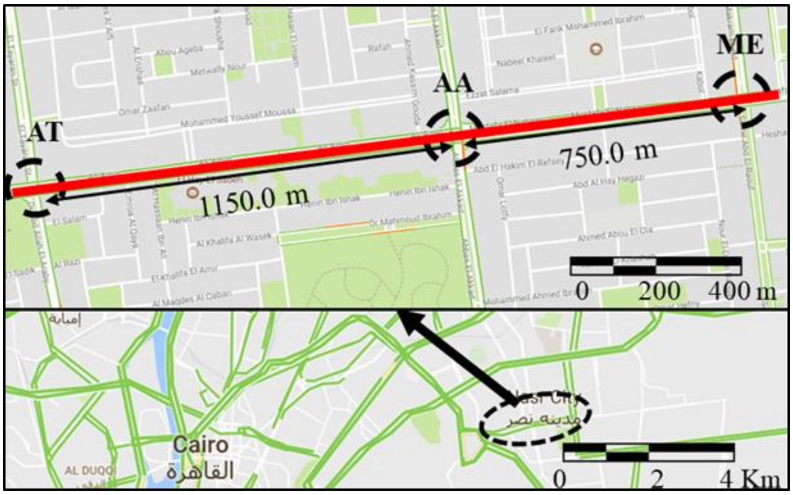

Fig. 3. A Google map of the case study

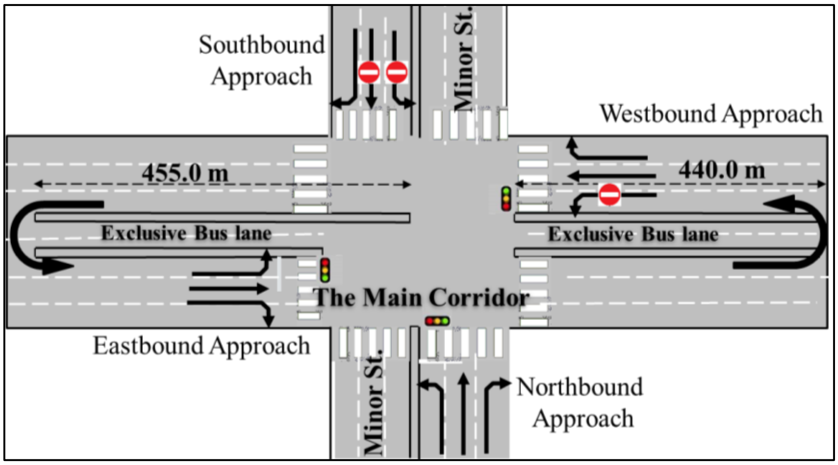

Fig. 4. A typical geometric layout of the case study

conducted survey also included the traffic composition of each turning movement from the different approaches periods including morning, afternoon, peak and off-peak periods. The recorded observation includes the fifteen-minute volumes in the morning between (8:00 to 9:00) and (10:00 to 11:00), while the evening observation between (16:00 to 17:00). It can be seen that the arterial corridor experience high through traffic volumes, while the minor approaches suffer from high left-turning volumes as shown in Fig. 2. The through traffic movement was the highest among the studied intersections between 38% to 79%, while the left-turns ratios were ranged between 6.5% to 65% and the right-turn free flow traffic has oscillated between 2.5% to 23%. The maximum observed traffic volumes were 8364 veh/h, 8795 veh/h and 7448 veh/h for AT, AA and ME intersection respectively. The total traffic volume and the directional flow ratio of each approach for each intersection are illustrated in Fig. 5. The observed traffic composition consisted of 75% of normal vehicles in, 10% heavy vehicles (including buses, minibuses, and small trucks) and 15% of motorcycles. Also, the traffic composition of each turning movements and its complexities was obtained and analyzed.

Based on the observation, it can be seen how the traffic operational functionality was influenced by such heterogamous traffic. Driver aggressiveness was observed through, lane changing behavior as well as the maneuverability of small vehicles and stop line violation. As a result of the lane marking absence, drivers used to minimize the lateral distance and four vehicles were observed in the three lanes divided corridor. Also, the two-

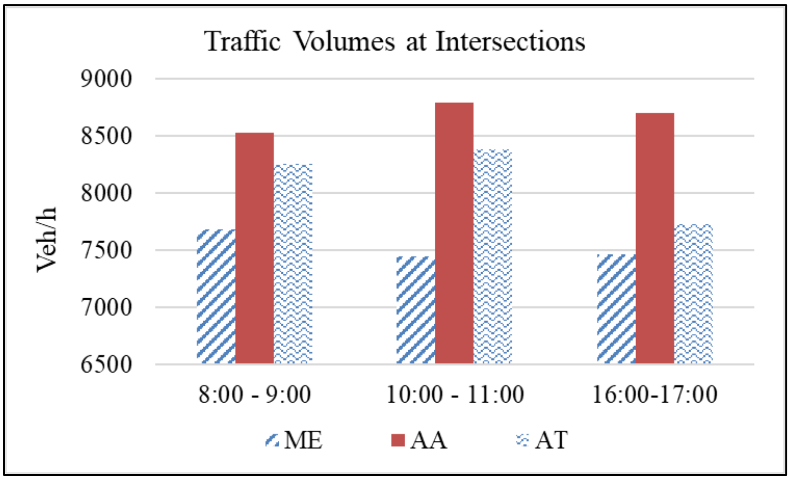

Fig. 5. The traffic volumes of the intersections studied.

wheeled vehicles usually had a continuous stimulus to sneak and occupy the front queues through the interspace between the other bigger vehicles. During the red time, drivers used to exhibit a greedy behavior by occupying reserved for left turning traffic.

4.2. Microsimulation approach

Recently, as a stochastic, time-step and behavior-based model, VISSIM has been broadly used by many practitioners and researchers to evaluate different traffic control scenarios before the field deployments. Meanwhile, due to the novel nature of UAIDs schemes, most of the previous research relayed on VISSIM for their analyses (El Esawey and Sayed, 2013). For the recent study, microscopic models for the existing conventional intersections, as well as the two UAIDs proposed, were developed and tested using VISSIM. The main objective of using VISSIM is to investigate whether such designs could provide some benefits and how significant these benefits might be. The simulated models were built based on Wiedemann model as a psychophysical car-following model. This model provides a combination of psychophysical aspects of physiological restrictions of the driver's perception which is highly acquired to represent the driving behavior under the heterogeneous traffic (VISSIM 5.4 Manual 2012). Likewise, for modeling the field conditions under the heterogeneous conditions as close as the reality, the road network is created by space oriented which allows vehicles to move anywhere in the road without lane restrictions. So that, any number of vehicle types can be created and overtaking can also be allowed on both the sides.

Although VISSIM is so far the best-suited tool, cost and time effective and crucial analytical approach to model, analyze and evaluate different UAIDs schemes, the default set fails to provide credible and reliable results closer to the reality. As a result, inexact, unrealistic and incredible models might be presented (Mathew and Radhakrishnan 2010; Rrecaj and Bombol, n.d.). In order to overcome such incorrect results and discrepancy, the calibration of the microscopic models is necessary. The provided flexibility VISSIM can be optimized in defining the network elements and modeling some of the complex maneuvers commonly adopted by the drivers in such heterogeneous traffic. Special procedures should be taken into consideration to address the unique characteristics of such traffic. Therefore, by utilizing VISSIM, a readjustment process including the geometric configuration, vehicles' static and dynamic properties as well as the driving behavior parameters such as following, lateral and lane change behaviors and maneuverability can be accomplished (VISSIM 5.4 Manual 2012). By bridging a conditional match of the simulated parameter values with observed traffic field data, special attention was paid by the authors in the previous works in order to represent and validate the effectiveness and practicability of the simulated models as close as possible to the reality before providing credible results.

4.3. Model Calibration

The calibration is such a process in which the different default parameters of the simulation model are refined and tuned until the model accurately replicates the field conditions (Siddharth and Ramadurai 2013). Due to the data limitation, the difficulties in field data collection or/and the lack knowledge of the appropriate, readily and available procedures to calibrate and traffic simulation models, most of the previously conducted analysis was done relying on values of default parameters (H. Naghawi, AlSoud, and Alhadidi 2018). As a result, it resulted in inexact, unrealistic and incredible models, particularly, when the mixed or heterogeneous is considered. In principle, it is essential for the models to be well calibrated and validated to minimize a discrepancy before providing credible results. Special procedures are required to address the unique characteristics of such conditions.

Although VISSIM has several simulation parameters that can be adjusted and refined during the calibration, only some parameters may have a significant effect on the models. Most of the previous studies emphasized that the driving behavior parameters that affect the model accuracy significantly. These parameters include desired speed, acceleration and clearance distance (Asamer, van Zuylen, and Heilmann 2018), minimum headway, standstill distance, lane change distance, emergency stopping distance and waiting time before diffusion (Park and Schneeberger 2003). Accordingly, in the present study, the driving behavior parameters also have been considered to accomplish the calibration process. Therefore, the sensitivity analysis is used to find the most significant driving behavior parameter that influences the models' accuracy.

The calibration procedure proposed in this study context is accomplished in four steps. First, accurately model the network elements in VISSIM by representing geometric configuration, vehicles properties, traffic control system and driving behavior with the default setting (pre-calibrated) values to ascertain the need of calibration. Second, the default parameters are changed until the absolute error between the actual and simulated Measure of Effectiveness (MOE) is less than the threshold values. In this study context, the travel time between the consecutive intersections in both directions, west and eastbound is used as MOE. The comparison acceptable variation threshold is 17% or less. Third, to do a sensitivity analysis to define the most significant factors that influence the accuracy. For this purpose, one-way Analysis of Variance (ANOVA) test, as a statistical technique was utilized By drawing inferences about population means, ANOVA is used to come up with conclusions whether the particular studied factors influence the response variable (Siddharth and Ramadurai 2013). Finally, representing the model by the new values given to the parameters until the absolute error is insignificant. In this study, the estimation of the maximum and minimum of parameter values were based on the relevant previous research, as well as the engineering judgment of the authors.

The ANOVA single factor test clearly showed the significant consistency between the simulation models accuracy and the different simulation parameters. As MOE the travel time between the consecutive studied intersections for the different calibration trials as shown in Table 1. The ANOVA results are illustrated in Table 2, (SS) is the sum of squares, (df) is the degree of freedom, (MS) is the mean square deviation, (F) is the test statistics, (P-value) is the probability value under the appropriate F, (F-crit) is the critical value of F (5,30) distribution under 5% significance level. The variance analysis shows the F-value is bigger than F-crit with a small P-value which emphasizes that the null hypothesis is rejected and the readjusted simulation parameters have a significant impact on the models' accuracy.

Table 1. Travel time difference between the consecutive intersections for the different calibration trials

	YA to AT		AT to AA		AA to ME		ME to AA		AA to AT		AT to YA	
Observed	65		223		174		202		593		117	
1st	85.4	31.4%	286.5	28.5%	255.3	46.7%	206.1	2.0%	401.9	-32.2%	78.6	-32.8%
2nd	71.9	10.6%	259.7	16.4%	275.4	58.3%	206.9	2.4%	564.2	-4.9%	79.9	-31.7%
3rd	72.4	11.4%	291.6	30.7%	294.1	69.0%	158.9	-21.4%	657.5	10.9%	94.8	-19.0%
4th	93.7	44.1%	327.1	46.7%	237.2	36.3%	206.3	2.1%	604.2	1.9%	328.5	180.7%
5th	102.2	57.2%	282.1	26.5%	153.0	-12.1%	162.1	-19.8%	226.1	-61.9%	70.3	-39.9%
6th	57.4	-11.7%	239.4	7.4%	155.4	-10.7%	157.7	-21.9%	224.8	-62.1%	42.4	-63.8%
7th	52.9	-18.6%	309.5	38.8%	160.4	-7.8%	157.2	-22.2%	225.7	-61.9%	40.5	-65.4%
8th	53.8	-17.2%	246.9	10.7%	150.1	-13.7%	157.1	-22.2%	226.3	-61.8%	39.1	-66.6%
9th	62.4	-4.0%	247.4	10.9%	153.0	-12.1%	364.0	80.2%	274.7	-53.7%	168.9	44.4%
10th	66.0	1.5%	221.0	-0.9%	195.0	12.1%	206.0	2.0%	594.0	0.2%	98.0	-16.2%

Table 2. ANOVA test results of travel times by different simulation trials

ANOVA: Single Factor						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.160872	9	0.3512	2.351	0.0026	2.073
Within Groups	7.466882	50	0.1493			
Total	10.62775	59				

The analysis of the calibration results showed that the different vehicles' dynamic characteristics, as well as the driving behavior parameters, are the most sensitive parameters. The driving behavior parameters considered by authors include the minimum lateral distances for different vehicle types, the number of observed preceding vehicles, the average standstill distance and look ahead distance.

4.4. Model Validation

The validation process is required to check the extent to which the simulated model is representing the reality. In this study context, the model validation is done based upon the statistical validation method to test the goodness of fit and the confidence intervals to quantify the similarity between observed and simulated values (Toledo and Koutsopoulos 2004; Joseph E. Hummer and Jagannathan 2008; H. H. Naghawi and Idewu 2014). Therefore, for this purpose, a comparison was conducted between the VISSIM generated traffic volumes to the corresponding observed volumes. The most popular goodness of fit measures: GEH empirical test, as well as the Root Mean Square Percent Error (RMSPE) as shown in Table 3. The GEH empirical static test was designed as a modified Chi-square static test, while the RMSPE is used to replicate the error as a percentile rate (Toledo and Koutsopoulos 2004; H. Naghawi, AlSoud, and Alhadidi 2018). Regarding the GEH test, according to Design Manual for Roads and Bridge (DMRB), the model can be used confidently when the variance (the difference between the observed and simulated countermeasures) of 85% of the total population is less than 5 (Oketch and Carrick 2005; Feldman 2012). On the other hand, the RMSPE acceptable threshold should be within a range of 15% or less(Ni et al. 2004; Hourdakis, Michalopoulos, and Kottommannil 2003). Based on Eq. (1) and Eq. (2) the GEH and RMSPE test was calculated. The results indicate that the model replicates reality with high accuracy.

$$GEH = \sqrt{\left(\frac{(m-c)^2}{0.5*(m+c)}\right)} \tag{1}$$

m is output traffic volume from the simulation model (vph)

c is input traffic volume (vph)

$$RMSPE = \sqrt{\frac{1}{N}\sum_{1}^{N}\left(\frac{Y_{Sim} - Y_{Observed}}{Y_{Observed}}\right)^2} \tag{2}$$

N is the number of simulation Runs (vph);

$Y_{Observed}$ is the simulation run throughput volume (vph);

Y_{Sim} is the simulation run throughput volume (vph).

Also, a comparison between the simulated and observed travel time between consecutive intersections was employed for the model validation. The comparison results indicated the accuracy of the model as shown in Table 4. Although the differential ratio between the observed and simulated travel time fluctuated between 0.9% and 1.98, it recorded 12.07% and 16.23% for the travel time from AA to ME and from travel time from AT to YA respectively as a result of the non-lane based system impacts.

5. Signal phasing and timing plans

In this present study, the signal-timing plans for both proposed UAIDs were designed upon Webster's method (1966). According to Webster's, the green time is optimized based on the flow ratio of each phase. Accordingly, the overall delay for the vehicles inside the intersection is minimized (SHOKRY and TANAKA 2015). Following the two signal phase scheme design principle of UAIDs to facilitate through traffic movements by reducing the total cycle

Table 3. Model validation by GEH and RMSPE values

Intersection	Movement	Observed volumes (veh/h)	Simulated volumes (veh/h)	GEH variance value	RMSPE error value (%)
AT	W-E	2270	2346	1.58	1.4
	E-W	3040	2995	0.82	1.5
	S-N	1640	1673	0.81	2.0
	N-S	1434	1394	1.06	2.8
AA	W-E	1905	1978	1.66	3.8
	E-W	3578	3294	4.84	7.9
	S-N	1596	1498	2.49	6.1
	N-S	1716	1699	0.41	0.99
ME	W-E	2245	2142	2.13	4.59
	E-W	2574	2466	2.15	4.19
	S-N	1385	1321	1.74	4.62
	N-S	1244	1266	0.62	1.77

Table 4. The travel time comparison for validating the model

Average Travel Time	Simulated (s)	Observed (s)	% Error
YA - AT	66	65	1.54
AT - YA	98	117	16.23
AT- AA	221	223	0.9
AA - AT	564	593	1.18
AA - ME	195	174	12.07
ME - AA	206	202	1.98

length time, the signal time plans were proposed. With a saturation flow rate of 1900 veh/h/ln and a lost time of 5 seconds per each phase, the total cycle length and split times were estimated.

The DLTs proposed in this context is a full DLT design which includes crossovers in both major and minor approach. Hence, the phasing of DLT intersection consists of six signal sequences as shown in Fig. 6. A special attention is required for the integration and the coordination between the main intersection signals and the left-turn crossovers created signal groups for an efficient operation. Therefore, the signal phases offset coordination should be efficiently considered to ensure the continuous flow with no stopping (SHOKRY et al. 2017). The offset should be equal to the travel time between the primary and the secondary intersections (M. Esawey and Sayed 2007). The cycle time of a two-phase cycle length of each signal group was calculated based on the critical flow ratios of the primary intersection. The split time of each phase of the primary intersections and the left-turn crossovers of major and minor approaches were determined based on the critical flow for each direction consequently. The phasing plan and sequencing of SSM are presented in Fig. 7, which shows that the phasing consists of four different signal control sets with two signal groups per each. Based on SSM principle design, the signal set of each direction allows independent operations on the arterial streets by a different cycle length. The first and the second sets were assigned for the main intersection through and left-turns flow, whereas the third and the fourth groups controlled the upstream U-turns. With a saturation flow rate of 1900 veh/h/ln and a midblock of three lanes per approach, the U-turn signal group failed to accommodate the assigned traffic volumes of 3040 veh/h and 3578 veh/h of AT and AA intersections respectively. As a result, and to keep the same road cross-section with the same right of way, the SSM proposed midblock geometric was changed as four lanes for the eastbound approach and two lanes for the westbound. Similar to the offset of DLT

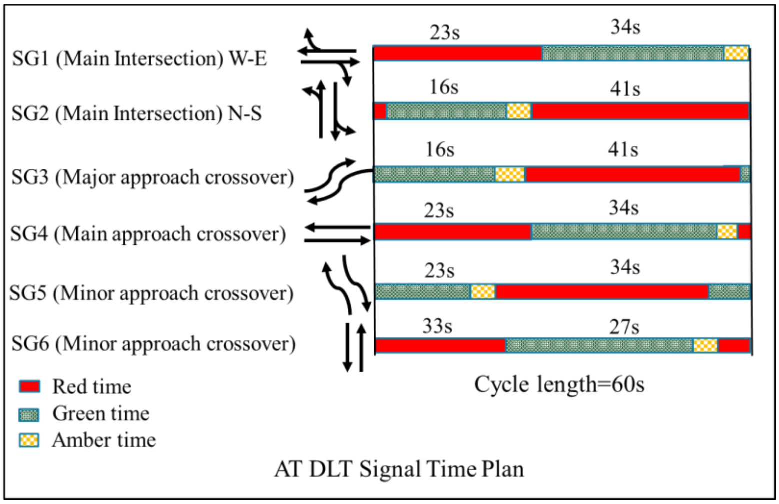

Fig. 6. A representative signal plan of the DLT proposed.

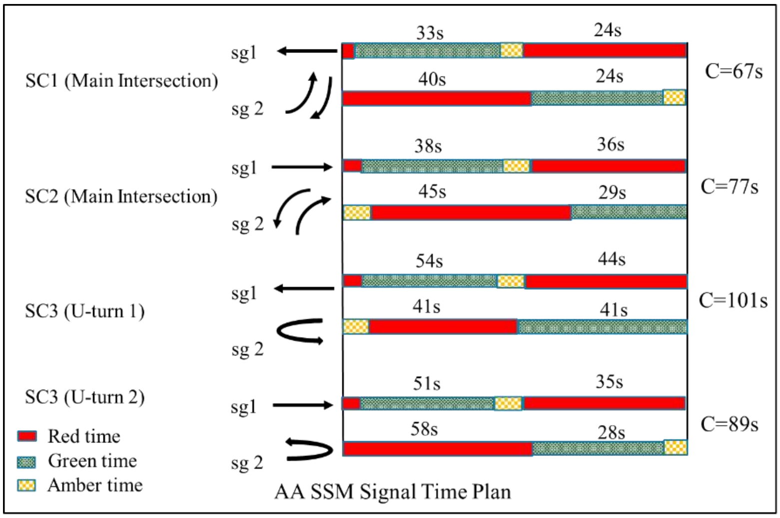

Fig. 7. A representative signal plan of the SSM proposed.

signal groups, the SSM signal groups can be coordinated such the offset is equal to the travel time between the primary and the secondary intersections (M. Esawey and Sayed 2007)

6. Results and discussion

Seeking a credible evaluation, the simulation results were obtained and analyzed. As evaluation indices, the total travel time, the average delay, the queue lengths, the average speeds, and the average number of stops were estimated for the three different studied intersections. All the indices emphasized an undoubted improvement of the UAIDs proposed in this study. The outputs revealed that DLTs consistently reported better results and overcame over the existing conventional intersections as well as the SSM design for the three intersections studied. As it is illustrated in Table 5, the total travel time was dropped by -46.2 %, -79.4% and -24% for AT, AA and ME intersections respectively for DLT designs. Meanwhile, the SSM witnessed a reduction in the total travel time -43.3%, -78.8% and -13.42% for AT, AA and ME intersections respectively. Accordingly, the DLT average and maximum queue lengths for all approaches experienced shorter than the existing intersections and the SSM design. As a representative intersection of the entire intersections studied in this study, ME-intersection aggregated results are presented and discussed. The travel time along the major and the minor approaches was as a measure of effectiveness for the intersection studied. Although both UAIDs overwhelm the conventional intersection by providing shorter travel times for the different approaches, the SSM proposal experienced longer travel time as a result of the indirect left-turning. The travel time of the DLT design for the different approaches; west, east, south and northbound showed a clear improvement as shown in Fig. 8. On the other hand, the results indicated a reduction for the travel time for the major approach in west and eastbound under the SSM design. Also, the southbound travel time was reduced, however, the enhancement was in a few rates. On the contrary, the northbound travel time experienced an adverse impact under the SSM proposal because of the indirect left-turning restriction as shown in Fig. 8. The minor approach northbound through and left-turns flow have to use the U-turns instead of a direct movement in case of the existing conventional and the DLT intersections.

On the other hand, the average speeds experienced an obvious improvement under DLT operation, however, the SSM design did not show a significant improvement. Also, the average stopped delay per vehicle and the average total delay time per vehicle exhibited considerable savings as shown in Table 5. Although it was found that when using the SSM design the overall indices were improved; the enhancement rate was not as significant as the DLT designs because of the indirect left-turning restriction of the minor approach. Based on the previous results, it can be concluded that the SSM is not appropriate for high traffic volumes, practically, under the heterogeneous traffic conditions. However, when the matter of signal coordination is considered, the SSM proposal still can be considered. The SSM provides better coordination system than the DLT design.

The heterogeneous traffic complexities such as the diverse dynamic as well as the aggressive driving behavior influenced the operational performance of the proposed UAIDs. The non-lane based driving system, as well as the queues discharging rates in both main intersections and left-turn crossovers in case of DLT designs and U-turns in case of SSM designs, affected the intersections' LOS. Therefore, in order to fulfill such conditions, the geometric design elements (i.e. the spacing distance between the main intersections and major crossovers for DLTs and the U-turns for SSMs) were adjusted and reallocated based on the traffic demand. In this context, for the proposed DLTs, the ME intersections was designed with two crossover left-turn lanes, whereas the AT and AA intersections with one crossover left-turn lane. Likewise, the spacing distance designed as 200.0 m, 105.0 m and for 85.0 m ME, AT and AA respectively, while the recommended distance is 91.4 m to 152.4 m (FHWA: Displaced Left Turn Intersection Informational Guide, 2014).

Table 5. The simulation indices comparison

Parameter	(AT) intersection			(AA) intersection			(ME) intersection		
	Con.	DLT	SSM	Con.	DLT	SSM	Con.	DLT	SSM
Total travel time (h)	1107	596	628	4075	839.67	856	708	537	613
Avg. delay/veh. (s)	333.13	124.63	368	786.67	168.52	494	199	132.13	160
Avg. speed (km/h)	13.58	24.71	13.77	2.22	21.13	20.5	19.94	23.56	22.14
Avg. No. of stops/veh.	16.17	1.45	10.88	61.82	2.64	3.3	6.05	1.73	2.08
Avg. stopped delay/veh. (s)	141.09	16.87	49.27	1967.03	28.62	44.2	43.07	24.34	25.44

7. Summary

The primary aim of this research is to assess the potential operational capability associated with two proposed UAIDs schemes namely; the Displaced Left-Turn (DLT) intersection and Superstreet Median (SSM) intersection under heterogeneous traffic complexities. These complexities are characterized by the diversity of some static and dynamic properties of vehicles, and the aggressive driving behavior which results in non-lane based traffic systems.

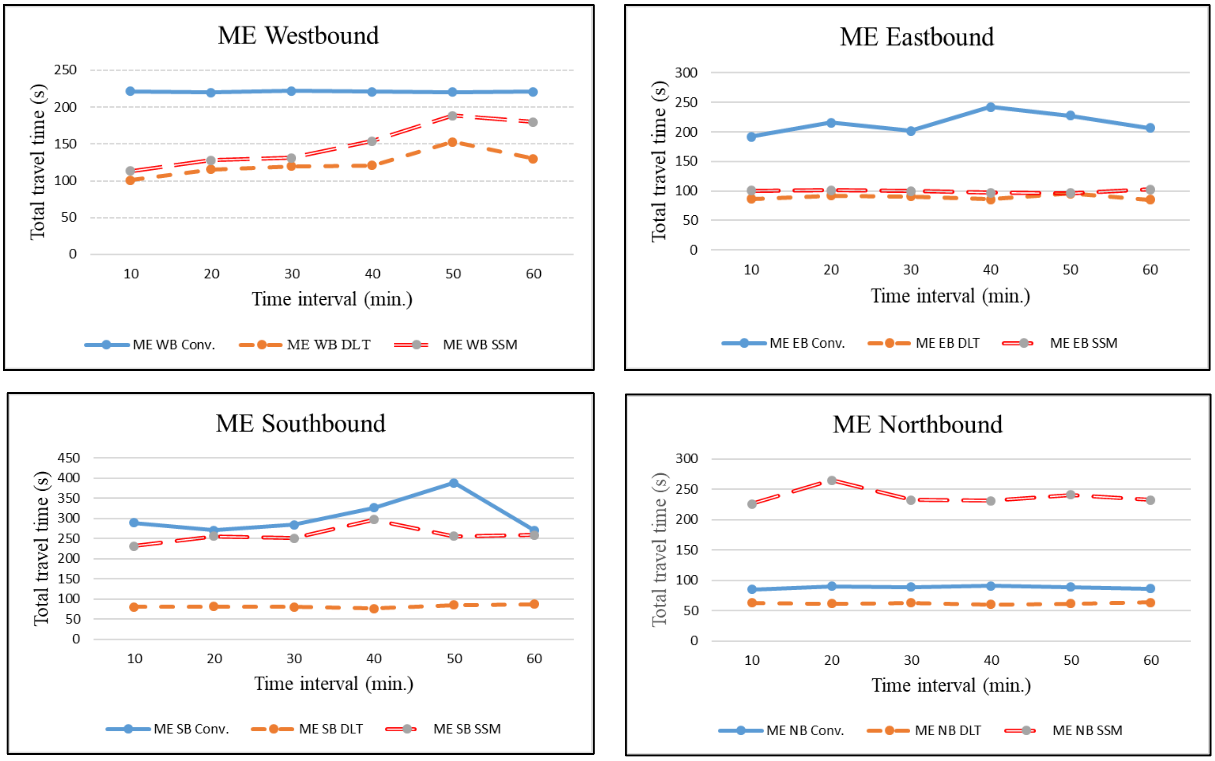

Fig. 8. The travel time of ME-intersection as a representative intersection

As a realistic case study of such traffic conditions, three existing intersections in an arterial corridor in Cairo, Egypt were selected. The three intersections selected for analysis, recently, suffer from long queues, delays and excessive travel time along the corridor. As a microsimulation platform, VISSIM was utilized to accomplish this study objective. To provide credible and reliable results closer to the reality, the models were calibrated and validated carefully. For this purpose, one-way Analysis of Variance (ANOVA) test, to come up with conclusions whether the particular studied factors influence the response variable. The ANOVA single factor test clearly showed the significant consistency between the simulation models accuracy and the different simulation parameters.

Seeking a credible evaluation, the simulation results were obtained and analyzed. As evaluation indices, the total travel time, the average delay, the intersection throughputs, the queue lengths, the average speeds, and the average number of stops were estimated for the three different studied intersections. All the indices emphasized an undoubted improvement of the UAIDs proposed in this study. The simulation results emphasized the outperformance of the proposed UAIDs over the conventional counterparts. The results indicated to an obvious improvement of the LOS of the studied the intersections. It was found that the proposed UAIDs schemes reduced the overall delay and the total travel time while the average speed was increased. As a representative intersection of the entire intersections studied in this study, ME-intersection aggregated results are presented and discussed. The average travel time along the major and the minor approaches was as a measure of effectiveness for the intersection studied. The outputs revealed that DLTs consistently reported better results and overcame over the existing conventional intersections as well as the SSM design for the three intersections studied. However, the SSM design provided non-significant improvement rates. The northbound travel time witnessed an adverse impact under the SSM proposal because of the indirect left-turning restriction of the minor approach. Based on the results, it can be concluded that the SSM is not appropriate for high traffic volumes, practically, under the heterogeneous traffic conditions. However, when the matter of signal coordination is considered, the SSM proposal still can be considered. The SSM provides better coordination system than the DLT design. On the other hand, it was concluded that the heterogeneous traffic influenced the proposed

UAIDs efficiency. The non-lane based driving system, as well as the queues discharging rates in both main intersections and left-turn crossovers in case of DLT designs and U-turns in case of SSM designs, affected the intersections' LOS. The geometric design elements were adjusted and reallocated based on the traffic demand in order to fulfill such conditions.

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