Displaced Left-turn Intersections Under Heterogeneous Traffic Conditions in Cairo, Egypt

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Abstract: Deployment of Displaced Left-turn Intersection (DLTs) has been advocated over the last decade in the developed world where ideal traffic conditions. Despite, the extensive sparse works proposed DLTs, heterogeneous traffic as a dominant operation in the developing countries has never been estimated. Hence, this article investigates the operational performance of DLTs under heterogeneous traffic where the complexities of mixed traffic compositions such as diverse static and dynamic properties of vehicles, aggressive drivers' behavior and the lack of lane discipline are existing. For a realistic data, video observations of signalized intersections located on an arterial corridor in Cairo, Egypt were used. VISSIM was employed to simulate the different configurations. To represent and validate the effectiveness and practicability of the simulator-based test as close as possible to reality, simulation parameters tuning and validating were taken into account. The results indicated that DLTs prevailed over other studied conventional intersections.

Keywords: Displaced Left-turn Intersections, heterogeneous traffic conditions

1. INTRODUCTION

The use of DLT intersection- as one of unconventional arterial intersection designs (UAIDs)- has been proposed for the last decade as an innovative at-grade signalized intersection treatment to alleviate congestions at signalized intersections (El Esawey and Sayed, 2013). The innovation of this design basically aims to reduce the through streams delay as well as the number of conflict points. By eliminating the left-turn conflicts through displacing the left-turn lane to the opposing direction the main concept could be achieved (Hummer, 1998). As a result, both of through and left-turn traffic could move simultaneously at the main intersections using a two-phase signal. Therefore, the design could also refer to the continuous flow intersection (CFI) (Jagannathan and Bared, 2004).

However, most of the previous considerable attempts were proposed in the developed world under ideal traffic operations. Although this new scheme was shown to outperform over conventional signalized counterparts in terms of operational performance, DLTs have been not examined under heterogeneous traffic as a significant traffic feature in developing, semi-industrialized and industrializing countries. The wide variations in the operating performance characteristics of the heterogeneous traffic system compared to homogeneous one resulted in complex operating systems (Maini, 2000). The most common characteristics of the heterogeneous traffics are diverse vehicles static (length, width, etc.) and dynamic properties (desired speed, acceleration and deceleration rates, etc.), different traffic compositions and driving behavior aggressiveness. The absence of lane markings and lack of lane discipline are considered another salient aspects and unique features of such traffic (Khan and Maini, 1999; Manjunatha, Vortisch, and Mathew, 2013). Due to the non-segregation lanes by neither vehicle types nor directional flow, all vehicles travel in the same right of way simultaneously. As a result, side-by-side stacking of vehicles across the road width could be observed. Also, drivers could change lane according to the available opportunity without any restrictions (Mathew and Radhakrishnan, 2010). As a result, traveled vehicles used to occupy any position across the link irrespective the lane lines in which it is available (Khan and Maini, 1999).

Regarding this study context, at intersections particularly, the heterogeneity played a considerable impact on the intersections' performance. The smaller vehicles (motorcycles, scooters, etc.) are sneaking to reach the head of the queue during the red time (Kaur and Varmora, 2015). The traveled two-wheelers used to maximize the inter-vehicle space to occupy the front of the queues stopped (Khan and Maini, 1999). On the other hand, the heavy vehicles' static and dynamic properties obviously affect the traffic operational maneuverability such as queues discharging, merging and diverging phenomena. Apparently, the Saturation Flow Rates (SFRs), the start-up lost time and clearance lost time would be influenced.

The limited capacities of existing traffic network in Greater Cairo Metropolitan Region (GCMR), the 1st largest metropolitan city in all Africa, have not been able to accommodate the growing traffic demands. On its publish report in 2013, the Central Agency for Public Mobilization and Statistics (CAPMS), the official statistical agency of Egypt, emphasized that Egypt has experienced with an average annual traffic demand growth rate of 98% in 2010 (Central Agency for Public Mobilization and Statistics CAMPS, 2013).

As one of a developing city, GCMR traffic conditions characterized as a heterogeneous traffic. As mentioned earlier, therefore, wide-range static, dynamic and maneuverability characteristics flow move unrestrictedly based on road space availability with either absence of lane markings or lack of lane discipline, if provided. Thus, the operational performance indicators such as speed limits, average overall delays, intersections' capacities, headways and the SFRs along the major corridors have been significantly affected. The previous findings revealed that an SFR of 1617 PCU/h/ln was recorded in Egypt, whereas the average nationwide SFR of was reported to be between 1700 and 2080 PCU/h/ln (Turner and Harahap, 1993). Additionally, according to the (WB) published report, the average speeds were reduced by at least half (15 to 40km/h) of the normally expected speeds (60 to 80 km/h) in central Cairo (World Bank, 2010). In particular, as the most critical part of the road network, the intersections have become oversaturated. As a result, regarding the WB conducted studies, it was emphasized that a lack of intersection management in Egypt posed a serious challenge in terms of performance and capacities of the intersections (The World Bank, 2000; SHOKRY and TANAKA, 2015)

Therefore, the objective of this study is to assess the potential operational capability associated with DLTs under heterogeneous traffic, as an unprecedented approach to mitigate congestion at heavily congested traffic flows at ~~at-grade~~ conventional signalized intersections in Cairo, Egypt. The driving force of this study context is investigating the impact of the heterogeneous traffic operations on the operational performance functionality of the DLTs.

2. LITERATURE REVIEW

Owing to explore the operational performance of the UAIDs as an applicable scheme in the developed world, several available and various pioneering studies provided considerable guidelines relevant to this study. On the basis of microsimulation software packages, most of the previous works have been conducted to study the UAIDs deployments.

Autey et al., used VISSIM to evaluate and compare the operational performance of four unconventional intersections: crossover displaced left-turn (XDL), upstream signalized intersection (USC), double crossover intersection (DXI) (i.e., half USC) and median U-turn (MUT) under balanced and unbalanced volume scenarios. Authors aimed to compare the operational performance of the studied intersections in terms of average intersection delay and the overall intersection capacity among themselves as well as a counterpart conventional one. The results showed that XDL is always superior to all other studied intersections in almost all volume conditions. XDL intersections experienced a significant growth of capacity by 99% higher than that of the conventional one, whereas the USC and DXI capacities were about 50% higher than the conventional counterparts, the XDL constantly exhibited the lowest delay among the all compared counterparts (Autey, Sayed, and Esawey 2010).

In another comparative study, considerable savings in average control delays and average queue lengths comparing three different DLT configurations to their similar conventional designs under low, moderate and high traffic volumes. The DLT approaches resulted in 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. Accordingly, the reduction percentages of the average number of stops are 15% to 30% for under saturated traffic flows and 85% to 95% for saturated traffic conditions. On the other hand, the analysis pointed out to a significant increase in intersection capacity for the three studied DLTs over the conventional ones(El Esawey and Sayed 2011).

As an attempt to conduct a fair travel time comparison of conventional and seven unconventional designs- the quadrant roadway intersection, median U-turn, superstreet median, bowtie, Jughandle, split intersection and continuous flow intersection (displaced left turn intersection)- CORSIM was used. Based on the simulation results, authors 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. Although the results showed that 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. DLTs design was also keeping traffic moving as its name implies (Hummer, 1998).

Based on presented preceding review, it could be summarized that much attention was not given to the applicability of the UAIDs under heterogeneous traffic conditions as common characteristics of developing cities around the world.

3. METHODOLOGY

Taking into consideration the pre-deployment of UAIDs as novel implemented schemes, microsimulation platform is so far the best-suited tool, cost and time effective and crucial analytical approach to model, analyze and evaluate these schemes. Thus, traffic system physical components replications such as road network and traffic control systems as well as the driving behavior modeling as in real-world traffic conditions are provided. In addition, different configurations, scenarios and strategies could be evaluated effectively.

The methodology followed in this context is illustrated utilizing PTV-VISSIM, a powerful simulation-based assessment approach as well as a widely psychophysical car-following model, highly recommended to analyze the operational performance of UAIDs. Several configurations could be modeled, and different performance measurements are obtained using VISSIM. It also allows the construction of UAIDs exactly like they would appear in the real life, based on the lane-by-lane development road networks facility (El Esawey and Sayed, 2013).

The used micro simulator (VISSIM), however, has been developed in a developed country where the complex heterogeneous operations are ignored, so that attention was turned to tuning and validating of VISSIM parameters in order to represent and validate the effectiveness and practicability of the simulator-based test as close as possible to the reality. Based on the program flexibility, tuning parameters process included the geometric design, vehicles static and dynamic properties as well as the driving behavior parameters such as: min. lateral distances, lane change behavior and maneuverability (Mathew and Radhakrishnan, 2010; VISSIM 5.4 Manual 2012).

Lastly, a comprehensive before-and-after analysis of simulation outcomes has been carried out among the new proposed scheme, DLTs, and the recent traffic situations in terms of total travel time, intersections average delay, overall capacity, queue length and the number of stops of each vehicle to evaluate the potential implementation of the proposed scheme.

4. STUDIED INTERSECTIONS CHARACTERISTICS

Methodology enhancements could be achieved based on video observations as a realistic data of signalized intersections located in an arterial corridor in Cairo, Egypt. All of the intersections analyzed in this study are consecutive conventional signalized intersections in Mostafa El-Nahas Street; a major urban corridor in Cairo, Egypt as shown in figure1.

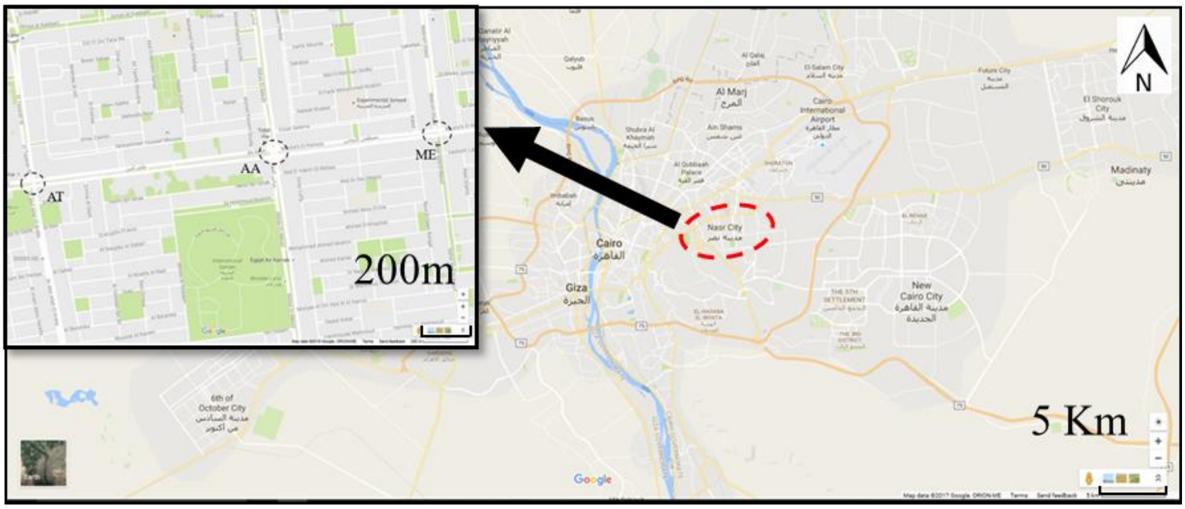


Figure 1. A Google map shows the case of study

This corridor is considered one of the main arterial corridors located in the central business district (CBD) and connects the downtown with the new urban residential communities in the east of the GCMR. Moreover, the adjacent area includes a residential area as well as entertainment activities. Daily heavy traffic volumes, therefore, have been practiced through this corridor. The three intersections studied are namely Makram Ebid (ME), Abbass Al-Akkad (AA) and Al Tayran (AT) intersections. The analyzed intersections had the following geometric criteria:

1) All intersections were classified as four-leg intersections;
2) Each Intersection consisted of three lanes of 3.5m per direction for both the major and minor approaches. However, during the peak hour, because of the non-lane based phenomena as well as aggressive driving behavior as a salient property of the heterogeneous traffic characteristics, vehicles could perform as four lanes per approach flow on the main studied corridor as shown in figure 2.
3) An exclusive bus lane of a 3.5 m width per direction excluding the other three lanes was provided in the main corridor for the public buses. Despite the exclusive bus lane existence, shuttle buses, private and school buses were not allowed to use those exclusive lanes and had to share the other vehicles' types as a mixed traffic condition;
4) A free channelized right-turn lane was also provided on the studied intersections for both major and minor streets.

For the traffic flow characteristics as well as signals' time plans, the intersections could be described as follow:

1) All the studied intersections were operated by two protected fixed cycle signal groups with a conventional phase (red-amber-green) for both major and minor stream as shown in table 1;

Figure 2. Illustrates the four-lane driving performance in the three-lane corridor

2) The major approach signal group controlled only the through traffic flows (west and eastbound), while the minor approach signal phase controlled only the through and left-turning vehicles in northbound in one protected phase;
3) The right-turning flows were free-flow through channelized right-turn lanes;
4) Because of the prohibition of the major stream left-turning flows inside the intersections, the eastbound left-turning traveled vehicles had to make indirect left turns using the U-turns provided in the east of the intersections, while the westbound left flows had to use the U-turns in the west of the main intersections;
5) Similarly, the unsignalized southbound left-turning flows had to use the U-turns in the west, of the main intersections then continue traveling in the major eastbound stream as shown in figure 3.

Table 1. Current signal phasing plans of the analyzed intersections

Intersections	Approach	Green time (s)	Red time (s)	Amber time (s)	Total cycle time (s)
ME	Major St.	43	38	3	86
	Minor St.	33	48	3	
AA	Major St.	143	71	3	217
	Minor St.	64	150	3	
AT	Major St.	67	50	3	120
	Minor St.	43	74	3	

5. DATA ANALYSIS

Requiring the evaluation of the current traffic operational performance and seeking for the accurate representation and simulation of the different scenarios' configurations, both of network geometry and traffic counts were required. Google maps were used to obtain the needed geometric data including intersections designs, lanes alignments and widths of both major and minor intersected approaches as well as U-turn locations for indirect left turns.

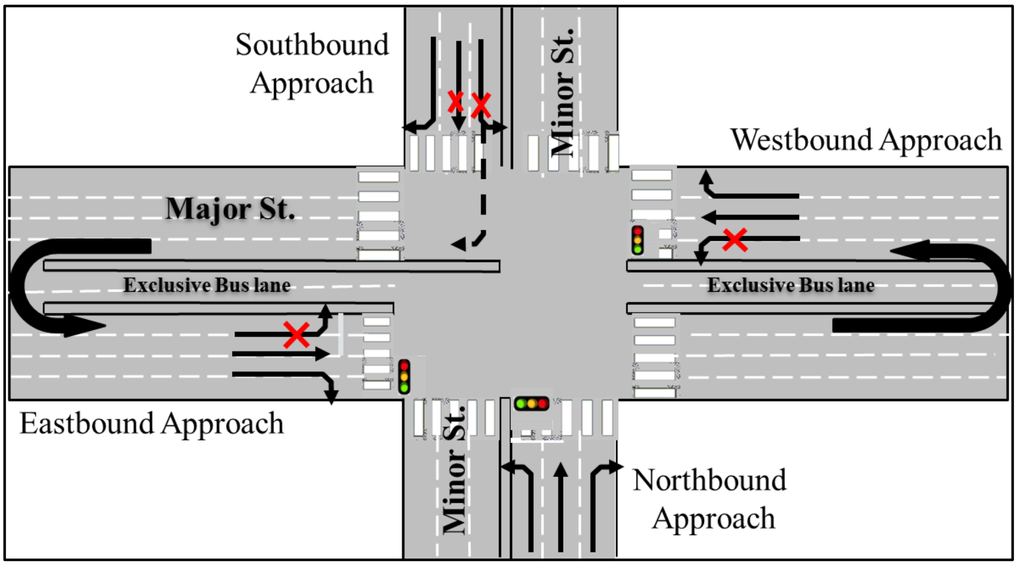


Figure 3. A plan describes traffic flow movements in a typical intersection

On the other hand, based on full motion video observation technique, as an efficient way for data collection to observe an accurate classified count of vehicles' performances, traffic flow elements as well as intersection operations' data were captured on video for the intersections studied. Within this technique, the impact of special conditions could be considered (P. Maini and Khan, 2000; SHOKRY and TANAKA, 2015). Traffic flow characteristics such as time headways; intersections' capacities, traffic compositions, directional distribution ratios and signals' operations for different approaches could be efficiently determined upon the video analysis.

Based on the observed data, the noon peak period had the most congested volumes among the three recorded periods. Abbass Al-Akkad (AA) intersection recorded the highest traffic volumes of 8795 veh/h as shown in figure 4.

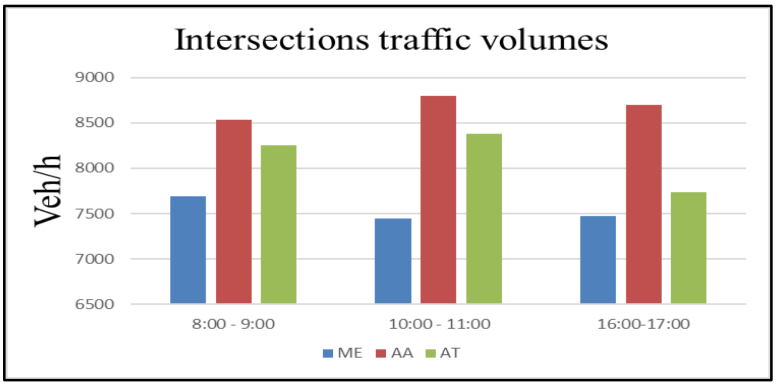
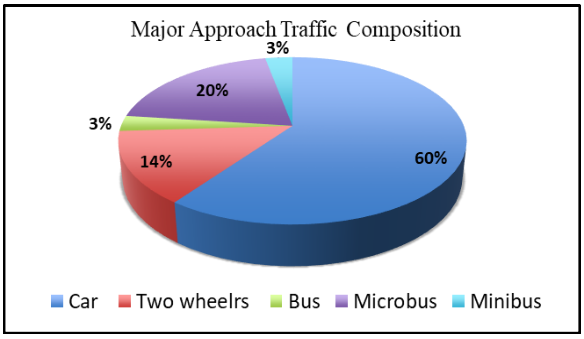


Figure 4. Traffic volumes of the analyzed intersections during different periods

Regarding the traffic flow compositions, major and minor traffic consisted of normal vehicles, heavy vehicles (including buses, mini buses and small trucks) and two-wheels as a mixed traffic composition as shown in figure 5. On the other perspective, the traffic distributions directional ratios are shown in figure 6. The through traffic volumes recorded the highest ratios among the studied intersections with a range of (38% to 79%). Consequently, the left-turn ratios were found (6.5% to 65%) and the right-turn free flow traffic was oscillated between (2.5% to 23%).



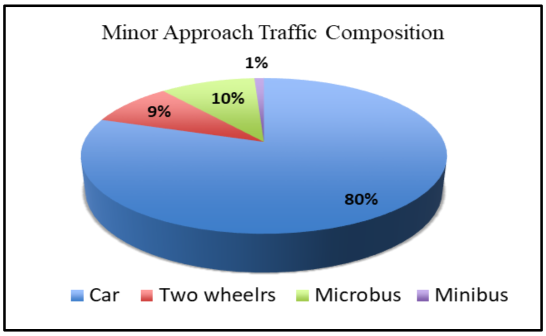


Figure 5. Traffic compositions of studied area

6. SIMULATION MODEL

Considering the applicability of field DLTs deployment and owing to explore their potential evaluation, reliable field obtained data were used to model the typical case study. The simulation process aimed to represent the intersections studied as indisputable as reality. Because of the novel nature of UAIDs, micro-simulation platform is considered so far the best-suited tools for their evaluations (Esawey and Sayed, 2013). Although most of the earlier attempts used different leading commercial micro-simulation packages such as CORSIM, PARAMICS, VISSIM etc., the majority of these software has been developed ignoring the mixed traffic principles such as those in the developing cities around the world. As a result, several simulation parameters are needed to be tuned and calibrated in order to represent the mixed traffic conditions as this study context. In principle, to increase the credibility of the simulated models.

As mentioned earlier, the unique features of mixed traffic could be characterized by diverse vehicle characteristics, geometric design elements and driving behavior properties. Utilizing the given flexible VISSIM capability, model-specific parameters' adjustments were carried out to meet the heterogeneous traffic studied as the following three phases.

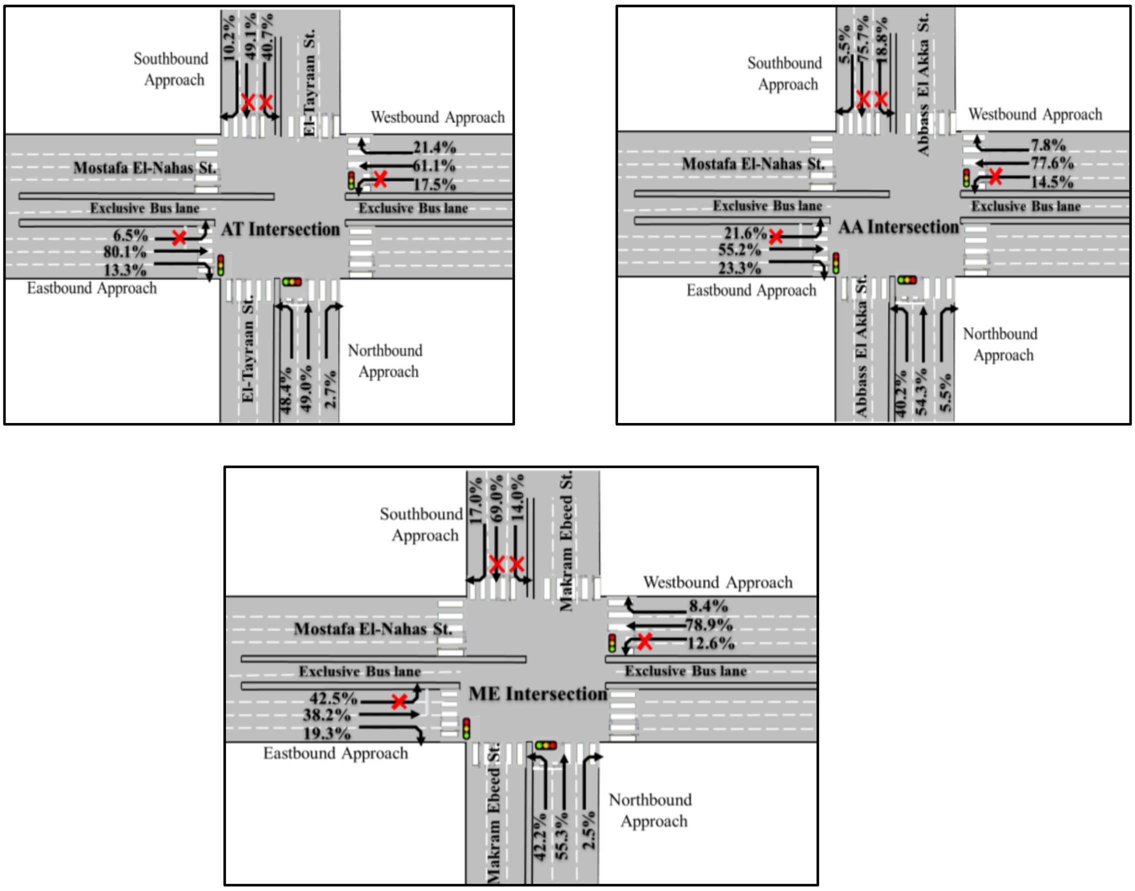


Figure 6. Traffic flow distribution directional ratios of the analyzed intersections

6.1 Vehicle Representation

This phase focused on readjusting VISSIM vehicles standard types for accurate models. Based on the field observation, both of static and dynamic characteristics of the diverse vehicles could be altered. The static properties included vehicles dimensions (length and width) for each vehicle type, where the dynamic ones referred to change acceleration, deceleration and desired speed-distribution. According to the observed data, four vehicles types were observed with different properties as shown in table 2.

6.2 Geometric Layout Representation

Within this step, the main geometric configuration elements could be identified and realigned. Depending on the previous description in section.4 of this article, the three studied intersections were accurately represented as four-leg intersections. However, the field observation emphasized the absence of lane markings as well as non-segregation lanes. Therefore, vehicles could use the three lanes approach on the main studied corridor as four lanes stream as shown in figure 2. Accordingly, the west and eastbound approaches of the main studied corridor could be simulated as four lanes per approach of 3.0 m width instead of three lanes of 3.5m per direction. For the all studied intersections, a free channelized right-turn lane was lane provided. Also, an exclusive bus lane of 3.5 m width was represented for each west and eastbound approach along the main corridor as shown in table 3.

Table 2. Vehicle static and dynamic characteristics

Vehicle type	Length (m)	Width (m)	Desired Speed (Km/h)	Acceleration		Deceleration	
				Max.	Desired	Max.	Desired
Motorcycle	1.8	0.6	40	2.5	1.7	1.7	1.2
Car	4.0	1.6	50	1.5	1.2	1.2	1.0
Microbus	5.0	1.9	50	1.5	1.2	1.2	1.0
Minibus	8.0	2.0	30	0.8	0.7	1.2	0.6
Bus	10.3	2.5	30	1.3	0.8	1.4	0.6

Furthermore, considering the considerable earlier works, guide manuals as well as the pre-deployments of the scheme proposed, the DLTs design could also be simulated. Based on DLTs design concept, which permits simultaneous flow for both through and left-turn movements within the same traffic signal phase, the analyzed intersections could be simulated. Consequently, four additional secondary intersections would be created at the four approaches because of the crossover left-turn lane displacement (FHWA: Displaced Left Turn Intersection Informational Guide, 2014).

Table 3. Geometric configuration of ordinary segments along the analyzed intersections

Intersection	Geometric Design	Major Approach		Minor Approach		Bus lane	Right-turn lane
		West-bound	East-bound	North-bound	South-bound		
ME	4-Leg	4 ln/3.0 m	4 ln/ 3.0 m	3 ln/3.5 m	3 ln/3.5 m	3.5 m	3.5 m
AA	4-Leg	4 ln/3.0 m	4 ln /3.0 m	3 ln/3.5 m	3 ln/3.5 m	3.5 m	3.5 m
AT	4-Leg	4 ln/3.0 m	4 ln /3.0 m	3 ln/3.5 m	3 ln/3.5 m	3.5 m	3.5 m

This study investigates the implementation of DLTs in both major and minor approaches. The typical geometric configuration was assigned for ME-DLT included two exclusive lanes of 3.5m for each direction for through traffic flows. The other two lanes of 3.5m for each for crossover left-turning traffic were employed for the main intersections for each approach as shown in figure 7. However, three lanes of 3.5m were employed for the through westbound flows of the AT DLT because of the high traffic demand. As a result, only one lane of 3.5m was provided for left-turn west and eastbound as shown in figure 8. On the other hand, the high traffic demand of both east and west through flows resulted in assigning three lanes for both AA west and east through flows. Accordingly, the right channeled lane of the westbound as well as the southbound was eliminated and one lane was allocated for left-turn west and eastbound as shown in figure 9. Moreover, the two existing bus exclusive lanes were kept on the main street. A channelized right-turn lane of 3.5m for each direction was provided for all intersections as shown in figure 7,8 and 9 except the eliminated ones in AA DLT. The right of way issue would keep in mind during the design to allocate the new lanes within the same width of the same existing road cross-section.

6.3 Heterogeneous Traffic Representation

Based on the data analyzed, the field observation and the previous works regarding modeling heterogeneous traffic flow, the mixed traffic characteristics could be identified and replicated by utilizing VISSIM capabilities. This procedure aimed to represent the most featured characteristics of heterogeneous driving behavior such as aggressive driving, smaller vehicles (e.g., motorcycles, scooters) maneuverability, lane discipline behaviors. By tuning available driving behavior parameters, mixed traffic unique driving behaviors could be simulated efficiently.

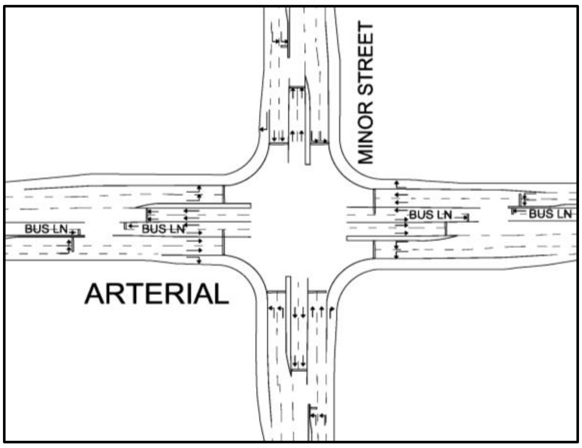


Figure 7. A typical geometric layout of ME DLT

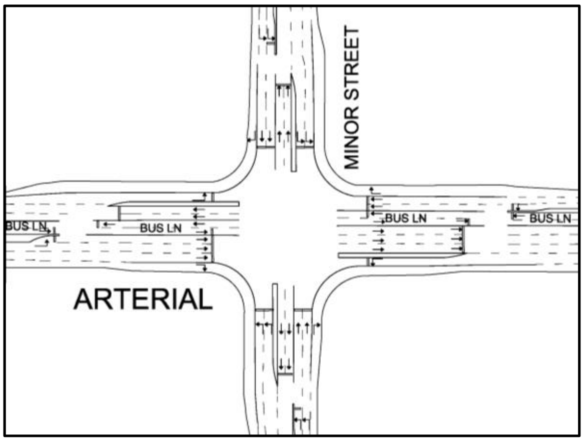


Figure 8. A typical geometric layout of AT DLT

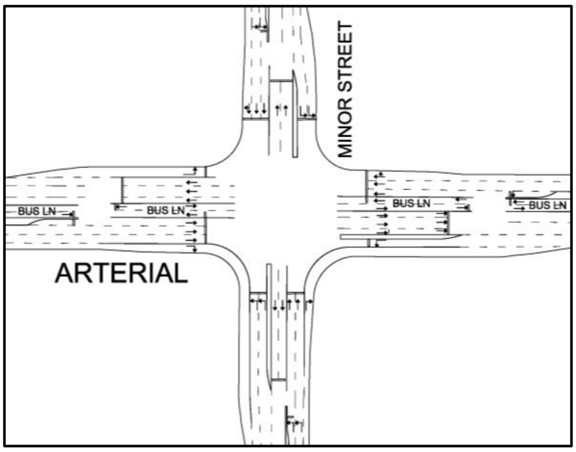


Figure 9. A typical geometric layout of AA DLT

First, based on field observation, two-wheels vehicles had a continuous stimulus to sneak and occupy the front queues through the interspace between the other bigger vehicles. Therefore, through installing two stop lines, the smaller vehicles maneuverability could be represented(Manjunatha, Vortisch, and Mathew, 2013). The first line was only to control two-wheels vehicles with 2.0 m in advance of the second one, which was designated to the other vehicles types.

Second, the obtained realistic data emphasized the side-by-side stacking of vehicles across the road width as a result of lane line absence as well as poor lane discipline. So that, lateral driving behavior also needed to be adjusted. In order to replicate the non-lane based operation of the mixed traffic flow where no restrictions to change lanes exists, both side -left and right sides- overtaking were maintained. The lane change behavior was selected as uncooperative lane change and the free lane selection was also selected. The desired decision at free flow was checked to any position and the same was done to allow diamond shaped queuing. Moreover, the minimum lateral distances were changed for each vehicle type as shown in table 4. On the other hand, the waiting time before diffusion was changed to 180.0 sec. instead of 60.0 sec. as a default value.

Table 4. Min. lateral distances for different vehicle types

Vehicle type	Min. Lateral Distance (m)	
	0 km/h	50 km/h
Motorcycle	0.3	0.7
Car	0.5	0.9
Microbus	0.5	0.9
Minibus	0.6	0.9
Bus	0.6	1.0

Third, on the basis of the car following model Wiedemann 74, the aggressive driving which is considered the most common and unique feature of the heterogeneous traffic, could be represented. By giving appropriate values for different simulation parameters such as emergency stopping distance, the number of observed preceding vehicles, Min. headways and average standstill distance as shown in table 5, this kind of behavior would be simulated.

Table 5. Wiedemann 74 model parameters tuned variables

Parameters	Tuned Variables	
Look ahead distance	Min. 5.0 m	Max. 100.0 m
Look back distance	Min. 30.0 m	Max. 150.0 m
Avg. standstill distance	0.5 m	
No. of observed Vehicles	2 veh	

6.4 Model Validation

As mentioned earlier, the validation process is required in order to ensure the accuracy as well as the practicability of the simulator-based test as close as possible to the real world current situation. However, it should be taken into account that these time plans were not the same during the traffic volumes were recorded. During the observation time, the signals were out of service, and the traffic would be managed manually.

Table 6. Validated parameters comparison

Validated Parameters	Observed	Simulated
Capacity (veh/h)	8264	7866
Total Travel time from AT to YA (s)	65.0	45.0
Total Travel time from YA to AT (s)	53.0	54

Therefore, a validation of a previous study was used in this context. In that validation, a adjacent unsignalized intersection, Yossef Abbass (YA) located to the west of AA intersection, was selected as a validating datum to validate the model as a coordinated corridor (Shokry et al. 2016). The intersection capacity, as well as the travel time from and to it, was validated as shown in table 6.

7. SIGNAL TIMING DESIGN

According to the DLTs design principles, as a two-signal phase scheme in order to facilitate through traffic movements by reducing the total cycle length time; the signal time plan was designed. On the other hand, an integration among the main intersection and the created primary left-turn crossovers should be taken into account. For this purpose, Webster’s (1966) method was utilized to estimate the total cycle and green times of the fixed time signals of the intersections selected. According to Webster’s method, the overall delay for the vehicles inside the intersection could be minimized by optimizing the green time based on the flow ratio of each phase (SHOKRY and TANAKA, 2015; Indonesian Highway Capacity Manual, Part 1 Urban roads, Urban and semi-urban Traffic Facilities, 1993).

Table 7. Primary intersection signal time plan

	Design Parameters	Main Intersections		Major App. Crossovers.		Minor App. Crossovers.	
		Phase (1)	Phase (2)	Phase (3)	Phase (4)	Phase (5)	Phase (6)
ME	Max. flow	1771	957	1094	1771	525	956
	Max. flow/L	885	478	547	885	263	478
	(Q/S)	0.466	0.252	0.288	0.466	0.138	0.252
	ΣFRcrit	0.718		0.754		0.39	
AA	Max. flow	1975	1208	773	1975	690	1208
	Max. flow/L	658.3	604	773	658.3	345	604
	(Q/S)	0.346	0.32	0.407	0.346	0.18	0.32
	ΣFRcrit	0.666		0.753		0.5	
AT	Max. flow	2435	805	397	2435	694	805
	Max. flow/L	811.67	402.5	397	811.67	347	402.5
	(Q/S)	0.427	0.21	0.209	0.427	0.182	0.21
	ΣFRcrit	0.637		0.636		0.394	

First, depending on the primary intersection critical flow ratios, the cycle time (C) of a two-phase cycle length would be calculated as shown in equation 1. Then the green time of each phase (gi) of the primary intersection as well as the other additional upstream left-turn crossovers of major and minor approaches could be determined as shown in equation 2. Six signal groups are required for DLTs design as shown in figure 10. Moreover, adjusting the signal phases offsets should be efficiently considered.

$$C = (1.5 * LTI + 5) / (1 - \Sigma FRcrit) \quad (1)$$

where,

- C : optimal signal cycle time (s);
- LTI : total lost time per cycle (s);
- FR : critical flow ratio for each phase (Q/S);
- FRcrit : Max. value of FR value among the signal group for the same phase in the approaches being discharged during a signal phase;
- Σ(FRcrit) : summation of FRcrit for all phases of the cycle.

The used parameters were estimated upon the data obtained from the field observations as well as analyses conducted as shown in table 7 with 5 sec lost time per phase. However, the saturation flow rates could not be estimated from the field observations because intersections' signals were out of order during the observation time. Therefore, the saturation flow rate was assumed as the standard value of 1900 veh/h/ln.

$$g_i = (C - LTI) * FR_{crit} / (\Sigma FRcrit) \quad (2)$$

where,

g_i = effective green time for phase i (s)

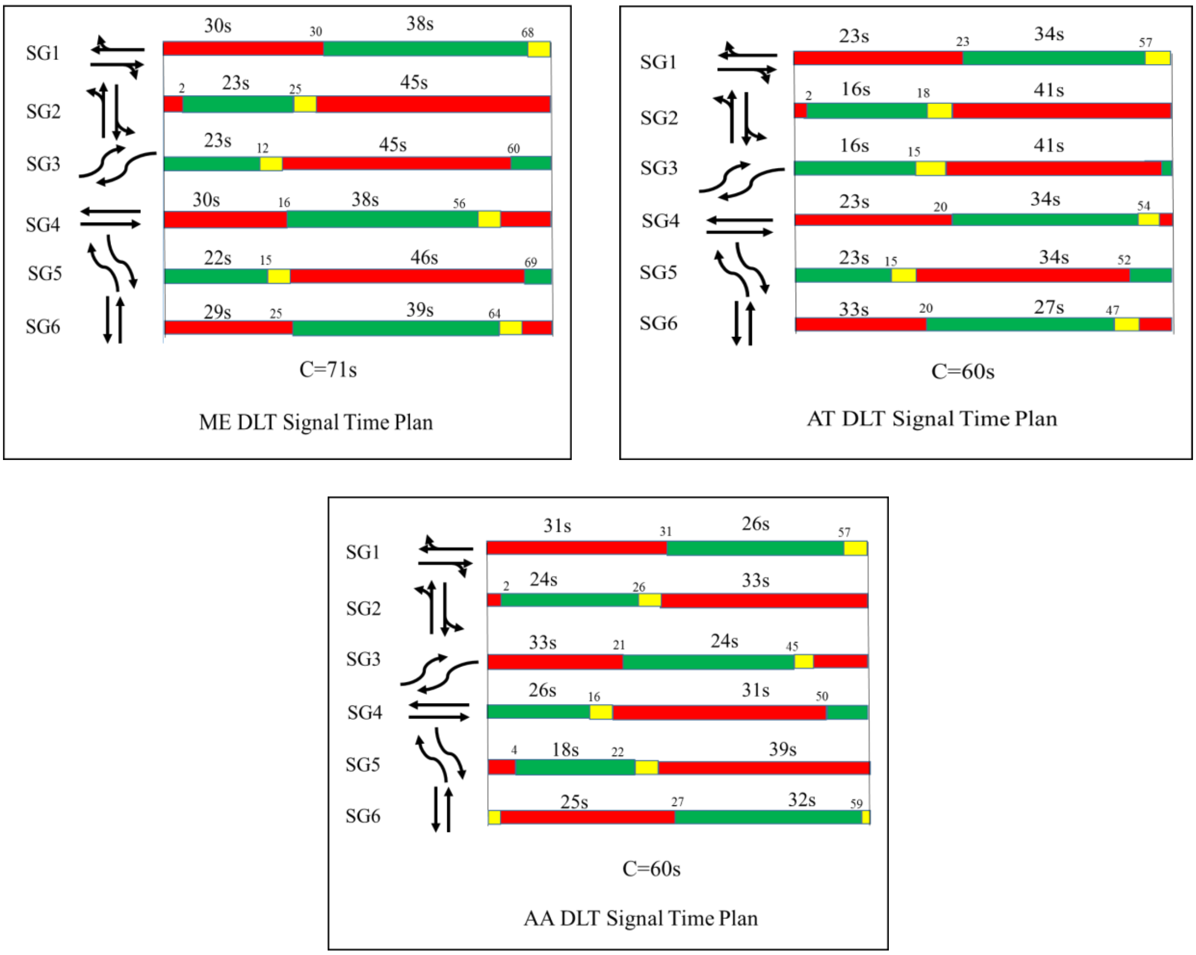


Figure 10. Signal phase diagram of the proposed DLT intersections

8. RESULTS AND DISCUSSION

Based on three simulation hours carried out in this study, the simulation results were obtained and analyzed. Total travel time, overall delay, intersection capacity, queue lengths, average speeds, and the average number of stops were estimated for the three different studied intersections as evaluation indices. The output data pointed to an undoubted improvement for all performance evaluation indicators as a result of DLTs implementation, especially under heavy traffic operation. Due to the continuous flow functionality of DLTs, the results revealed that DLTs overcame over the recent operational situation. An obvious enhancement of intersection capacities, the average total delay time per vehicle, average speeds and average stopped delay per vehicle as shown in table 8.

Similarly, DLTs exhibited considerable savings in both overall delays, as well as total travel time for all the analyzed intersections as shown in figure 11,12 and 13. However, due to emphasizing the major approach traffic demands over the minor ones, the northbound through as well as northbound left-turn flows would not have an obvious enhancement. Moreover, northbound through and left-turn flow had more travel time and delay in case of ME intersection, because of the long red time as well as cycle length as shown in figure 10 and 11.

Table 8. A comparison between before and after applying DLTs

Parameter	ME		AA		AT	
	Before	After	Before	After	Before	After
Capacity (veh/h)	5444	7092	3977	6433	4863	6537
Total travel time (h)	708	537	4075	839.67	1107	596
Avg. delay/veh. (s)	199.0	132.13	786.67	218.63	333.13	124.63
Avg. speed (km/h)	19.94	23.56	2.22	17.36	13.58	24.71
Avg. No. of stops/veh.	6.05	2.08	61.82	6.34	16.17	1.45
Avg. stopped delay/veh. (s)	43.07	24.34	1967.03	73.22	141.09	16.87

Accordingly, the average and maximum queue lengths for all approaches could be shorter than recent ones apparently. It also could be realized that the left-turning queues could be totally vanished as shown in figure 14, 15 and 16.

Although, the clear enhancement of the analyzed intersections because of DLTs, the improvement indices are lower than their similar under ideal condition. As a result of the diverse dynamic and static properties of mixed traffic compositions, the operational performance could be influenced. The queues discharge rates in both main intersections and major approach crossovers as well as clearance time could affect the DLTs results. Therefore, in order to optimize the DLTs performance the different signal group offsets as a key design factor of DLTs should efficiently be studied and set.

On the other hand, the spacing distance between main intersections and major approach crossovers could also be allocated based on the traffic demand and geometric configurations. For instance, for this study, the spacing distance could be placed as 200.0 m, 105.0 m and for 85.0 m ME two crossover left-turn lanes, AT and AA one crossover left-turn lane respectively, while the recommended distance is 91.4 m to 152.4 m (FHWA: Displaced Left Turn Intersection Informational Guide, 2014).

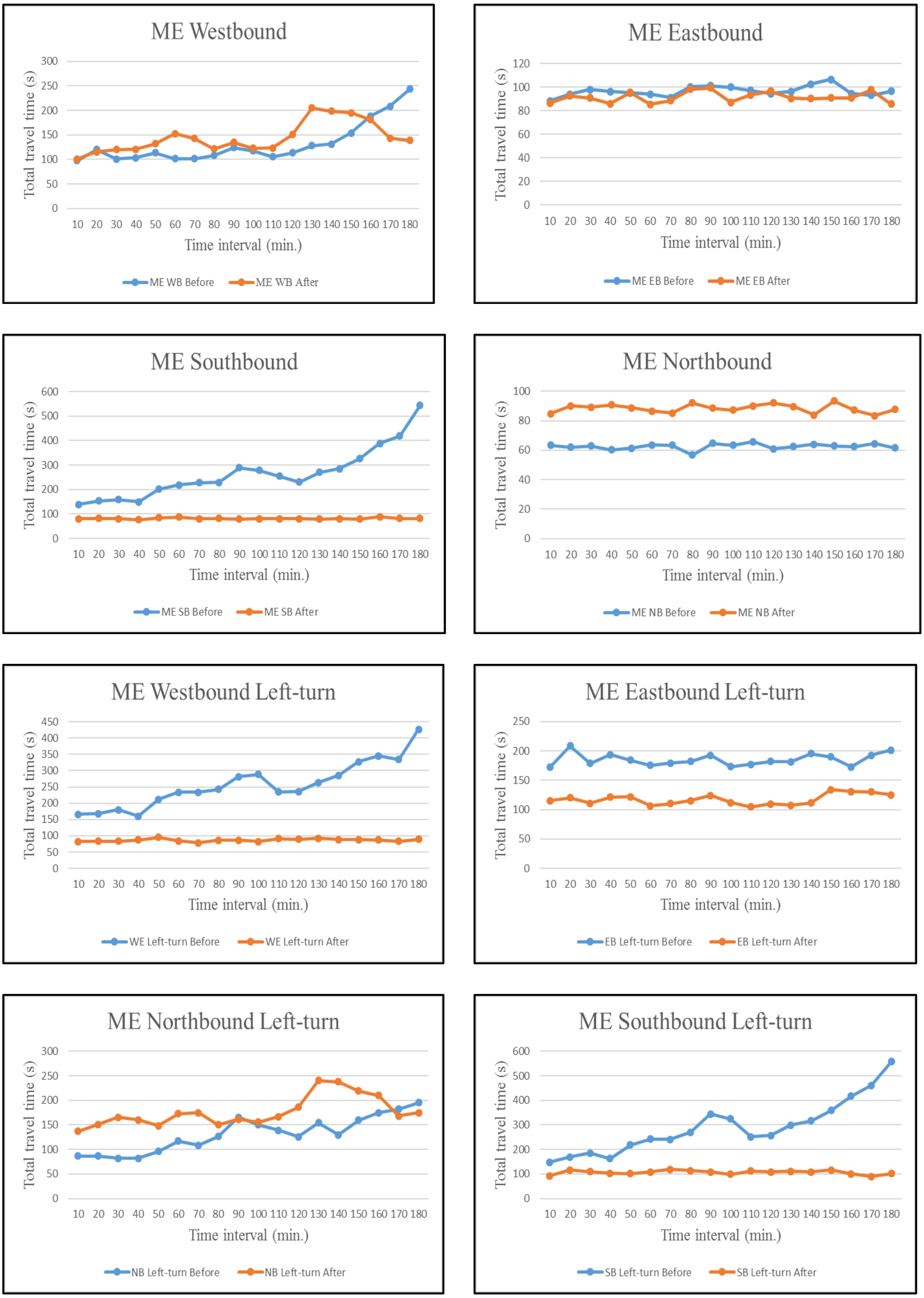


Figure 11. Total travel time of ME intersection vs. DLT alternative

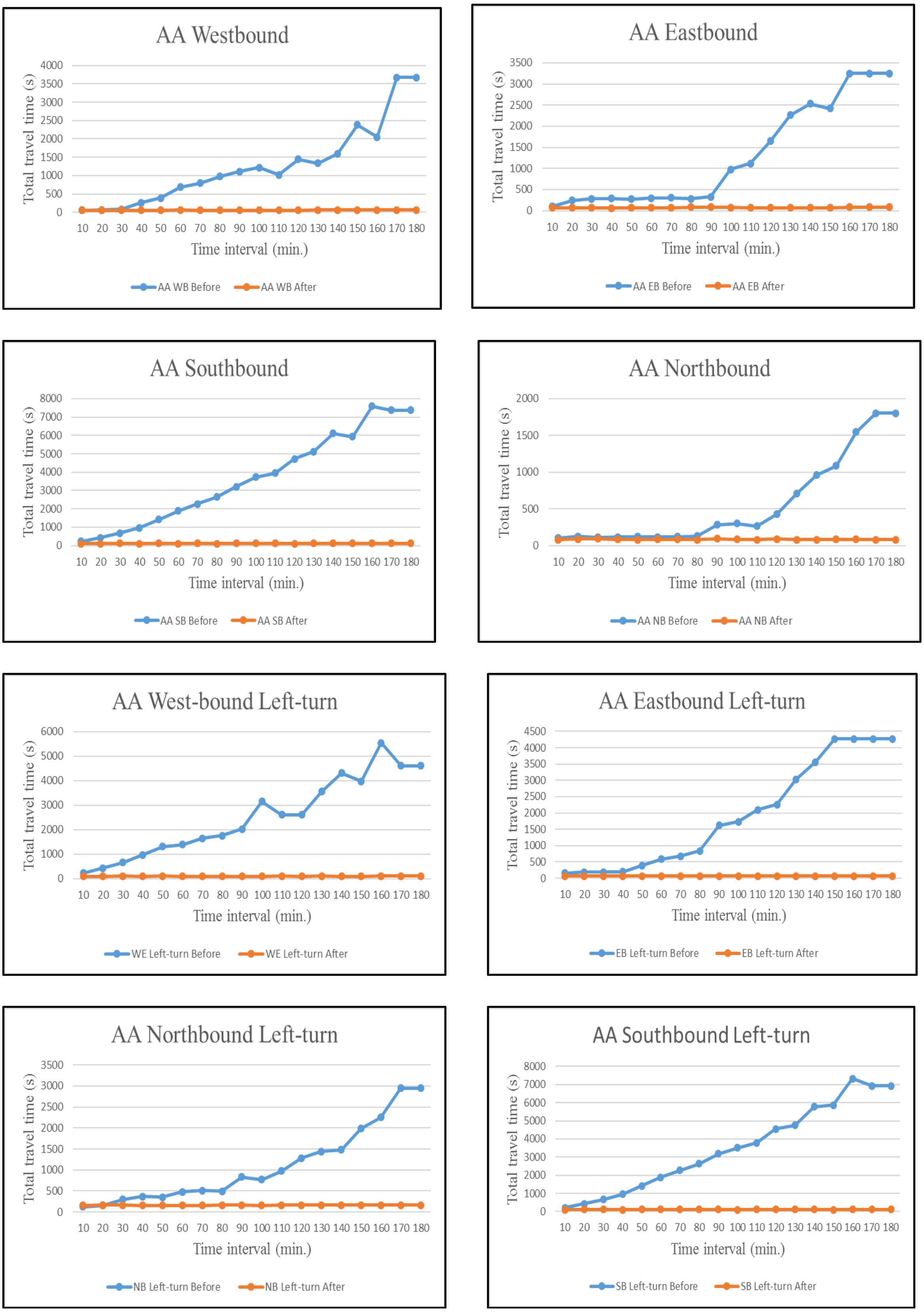


Figure 12. Total travel time of AA intersection vs. DLT alternative

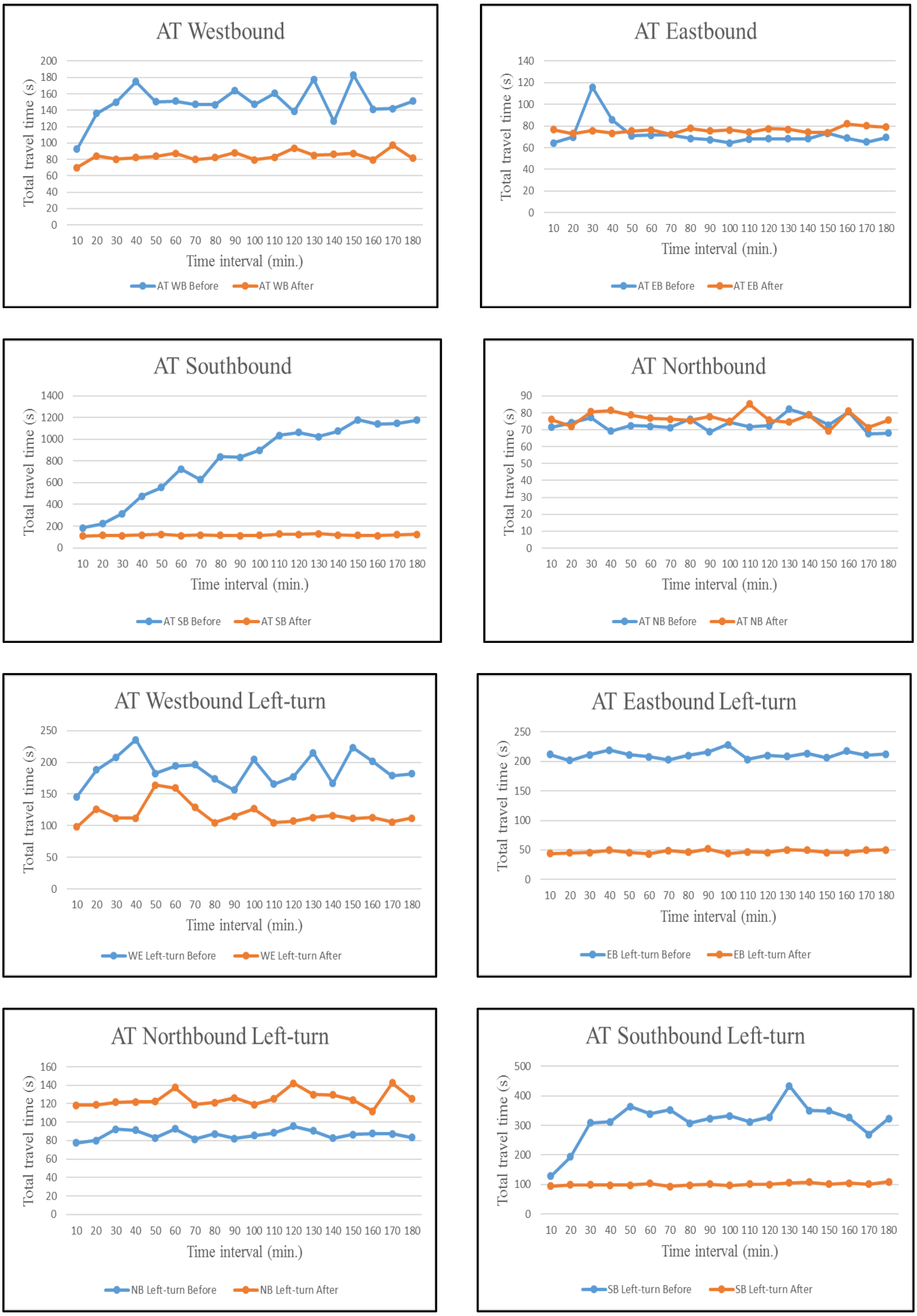


Figure 13. Total travel time of AT intersection vs. DLT alternative

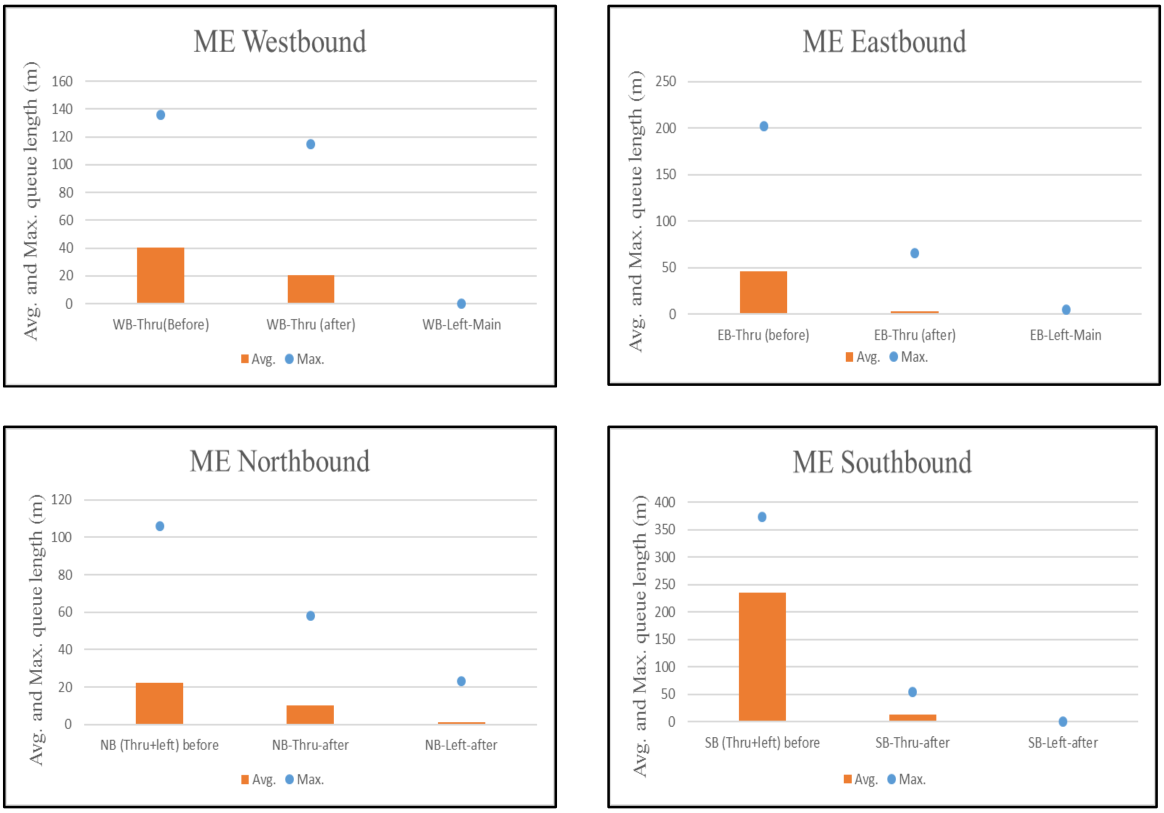


Figure 14. Max. and Avg. queue length of ME intersection vs. DLT alternative

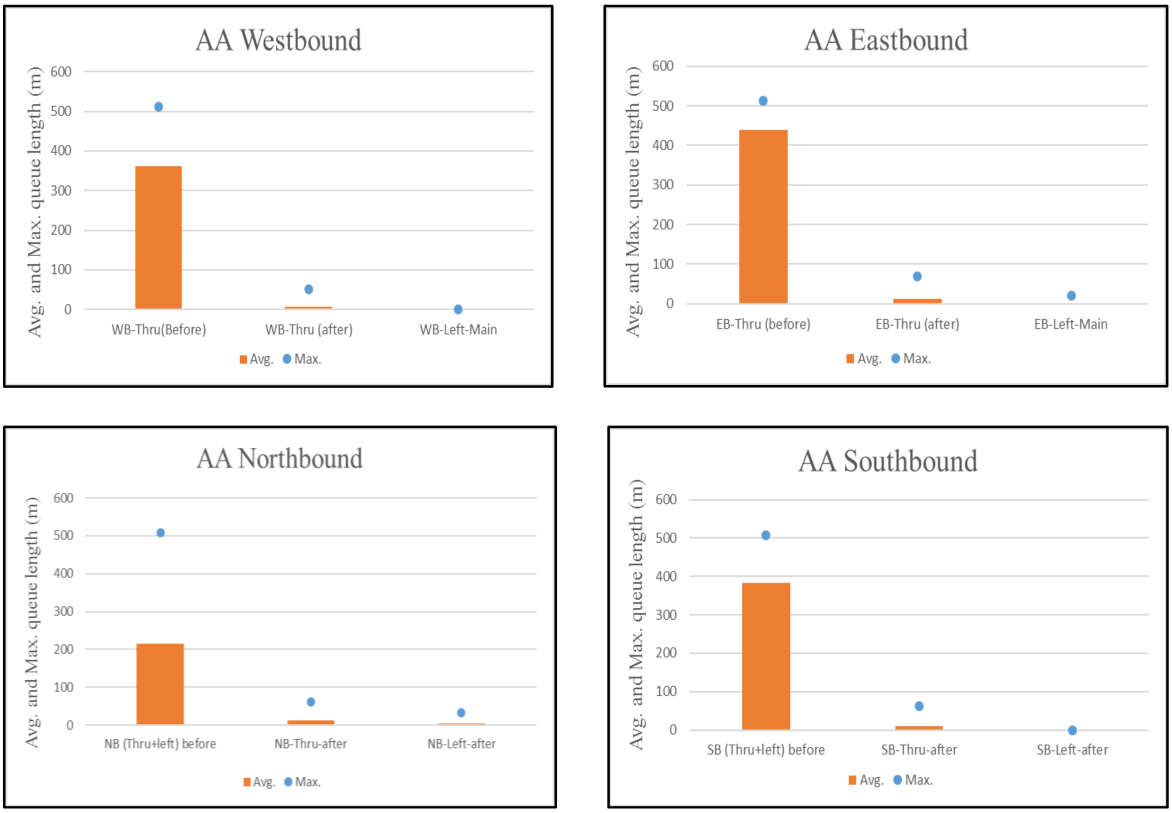


Figure 15. Max. and Avg. queue length of AA intersection vs. DLT alternative

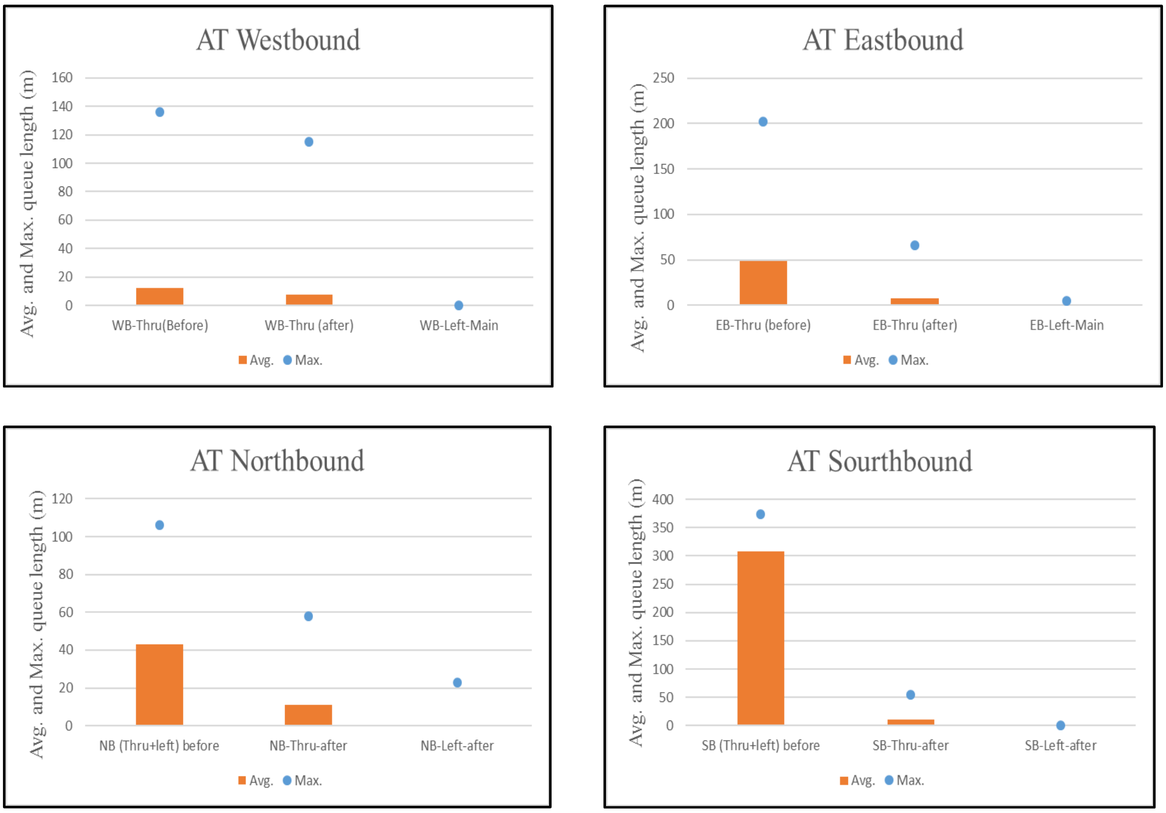


Figure 16. Max. and Avg. queue length of AT intersection vs. DLT alternative

9. CONCLUSION

The overall attained results could be summarized to draw up this study conclusion. This article attempted to estimate the applicability of the DLTs under the heterogeneous traffic characteristics in Cairo, Egypt. Therefore, it compared the operational performance of three existed typical intersections to DLTs alternatives. As a micro-simulation platform, VISSIM was used to simulate different DLTs configurations. However, several parameters were readjusted in order to simulate mixed traffic conditions. As a result of continuous flow functionality, the results emphasized that DLTs overwhelmed the operational performance of the recent intersections. However, the mixed traffic conditions could influence the DLTs performance as well as the improvement rates comparing to the previous studies under ideal traffic operations. The diversity of dynamic properties of mixed traffic compositions could affect the discharge rate in both main intersections as well as left-turn crossovers.

10. FUTURE WORK

A further extension of the recent study should be turned to the integration of the DLTs intersections applicability as a coordinated corridor under dominant mixed traffic operations. The impacts associated with consecutive DLTs implemented among either themselves or other different types of UAIDs should be investigated.

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