Comparative Study between HCM Editions and Simulation Program at Various Percentages of Heavy Vehicles on Signalized intersections

Fathy M. Mandel, Ahmed M. Abdallah, Mohamed I. E. Attia and Mohamed A. Abouzeid

ABSTRACT- Highway capacity manual 6th edition was first published in 2016. HCM 6th edition has major new improvements in freeway facilities, freeway and multilane highway segments, freeway weaving, merges and diverges, urban street facilities, and signalized intersections. The paper investigates the difference of delay time between HCM 6th edition, HCM 5th edition and simulation program at various heavy vehicles percentages (HV%), and develop models to predict HV% to enhance the delay time from level of service (LOS) to another for different cases of intersection types, number of lanes and phasing of the signal. Synchro 10, SIDRA 5.1 and SIDRA 8 are used as they are considered powerful and acceptable softwares in traffic data analysis. The study analyses three and four leg signalized intersection with LOS "F" with delay time 80 sec. The volumes of traffic used in the study give LOS "F" with 25% heavy vehicles. The study considered various lane numbers and signal phasing. It was found that the delay time from Highway capacity manual 2010 is higher than the delay time from Highway capacity manual 2016 but much higher than the delay time from simulation program (Synchro 10). HCM's results of 6th edition become more close to the results of simulation programs. For four leg intersection, the calculated delay using HCM 6th edition, HCM 5th edition and Synchro 10 result in similar LOS. However for the three leg intersection the LOS can vary between the different software. Models were developed to correlate between delay time and HV% in three and four leg intersection.

Keywords: Heavy Vehicles Percentage, Delay Time, Level of Service, Signalized Intersections, Comparison, HCM 6th edition, SIDRA Intersection 5.1, SIDRA Intersection 8.0, Synchro 10.

1 INTRODUCTION

Heavy vehicles (HVs) differ from passenger cars (PCs) in many physical and operational characteristics. Their size and lower operational performance have an adverse effect when present at signalized intersections increasing delay, decreasing level of service (LOS), increasing the travel time, and causing speed variations [1].

As HVs presence at intersections the impact on roadway capacity is exaggerated where they are forced to stop and reaccelerate to the operating speed that slow intersection clearance times will reduce the signalized intersection capacity [2, 3]. Important research has been done to determine the effect of HVs in the traffic stream at the macroscopic level. However, there are still gaps in determining the effects of HVs at the microscopic level [1]. While studying the capacity of signalized intersections, vehicle size and previous vehicle types have an effect on headways [4, 5]. In recent study, the HVs affect signalized intersection capacity very severely and capacity reduced by 22 percent for 30 percent heavy vehicles in the traffic stream [6]. Limited research was conducted to evaluate and quantify the impact of heavy vehicles percentage on delay time and level of service (LOS) on signalized intersections. Traffic signals are used to prevent conflicts between opposing vehicles or walkers at an intersection. Signals are not only established at intersections with congestion but also to provide protection for local streets to enter the arterial road system [2]. To make sure that traffic control brings the lowest delay as possible, timing and phasing of the signal have to be changed and the delay is determined every time [7].

Recent advances in computer technology and traffic flow theory have led to the creation and the

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use of traffic simulation models [8]. The purpose of any software is to model several situations for both existing and future intersections to determine their performance under variety of conditions including geometrical, vehicular and human features applicable for each intersection [9]. Synchro and Sidra were used in the study. Synchro is considered one of the robust softwares in data entry as well as identification of analysis outputs. Synchro is one of the best softwares for determining the control delay time at signalized intersections compared with the control delay time calculated theoretically by using Highway Capacity manual (HCM) [10]. The Signalized and Unsignalized Intersection Design and Research Aid (SIDRA) software was used for calculation of LOS at signalised intersection [11].

When HCM 6th edition analyze signalized intersections, it concerned on three major elements: considering the delay time of unsignalized movements, combining saturation flow adjustment factor for heavy vehicles and grade and new saturation flow adjustment factors for intersection work zone presence. HCM 6th edition provides an improved planning method with reduced input data requirements and simplified calculations.

HCM 6th edition combined the factor of heavy vehicle (F_{HV}) and the factor of grade (F_g) to be (F_{HVg}) in determining saturation flow rate.

HCM 2010 Formula [12] is:

$$S = S_0 \times N \, F_W \, F_{hv} \, F_g \, F_p \, F_{bb} \, F_a \, F_{lu} \, F_{lt} \, F_{rt} \, F_{lpb} \, F_{rpb}$$

HCM 2016 Formula [13] is:

$$S = S_0 \times N \, F_W \, F_{hv} \, F_g \, F_p \, F_{bb} \, F_a \, F_{lu} \, F_{lt} \, F_{rt} \, F_{lpb} \, F_{rpb} \, F_{wz} \, F_m \, F_{sp}$$

Where factor of heavy vehicles and grade in HCM 2010

$$F_{HV} = \frac{100}{(100 + \%HV\,(E_T - 1))} \qquad F_g = 1 - \frac{P_g}{200}$$

But factor of heavy vehicles and grade in HCM 2016 are:

For negative grade

$$F_{HVg} = \frac{100 - 0.79\, P_{HV} - 2.07\, P_g}{100}$$

But for non-negative grade

$$F_{HVg} = \frac{100 - 0.78\, P_{HV} - 0.31\, {P_g}^2}{100}$$

The research objective is to develop models to correlate between HV% and LOS (delay time) at signalized intersection comparing between the three softwares (SIDRA intersection 5.1, SIDRA 8 and Synchro 10) under different lanes number of every leg and plan phasing.

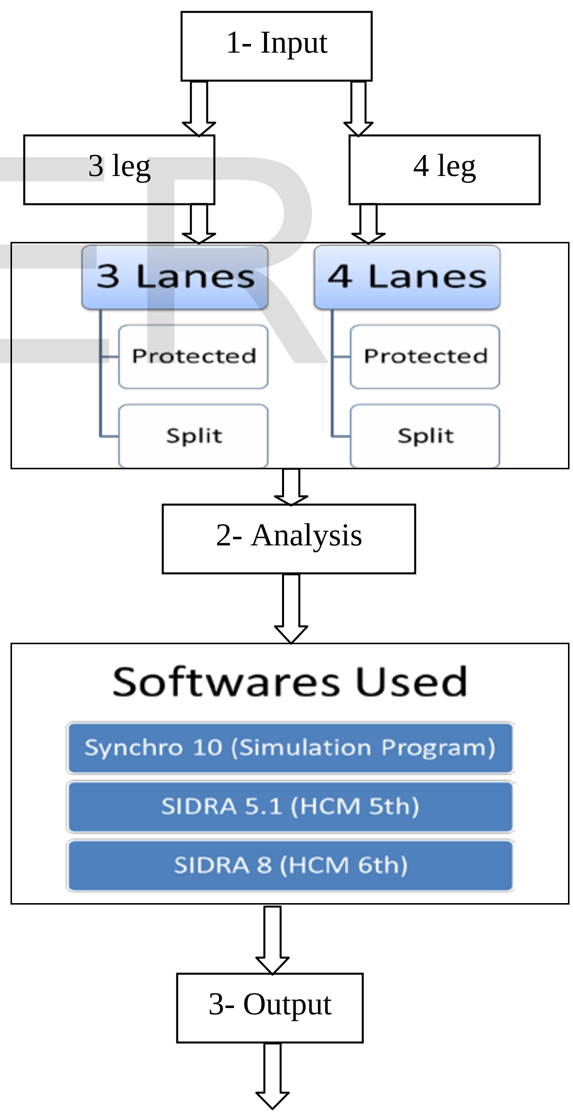
This paper is limited to signalized intersection, pretimed signals and the left turn is exclusive.

All volumes mentioned in the study are volumes of each leg of intersection.

2 METHODOLOGY

- The study analyses three and fou leg signalized intersection with LOS "F" with delay time about 80 sec at HV% equal 25%.
- The volumes of traffic evaluated in the study give LOS "F" with 25% heavy vehicles.
- The study considers various lane number and signal phasing.

Figure (1) shows the methodology considered to achieve the research objectives:



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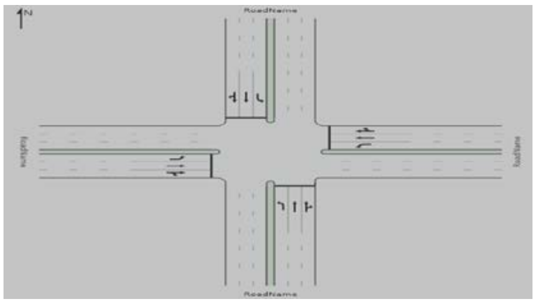
HV% were studied at various level of service of "A", "B", "C", "D" and "E" until HV% reaches 0%.

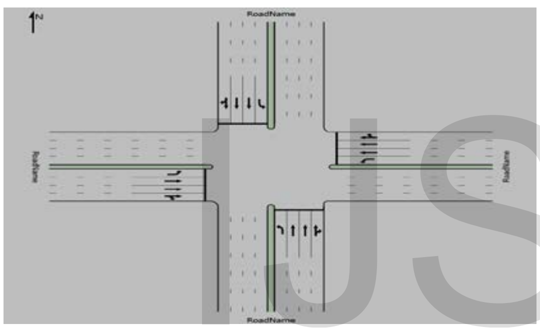
Figure (1): Methodology of the study

2.1 Layout of Intersections

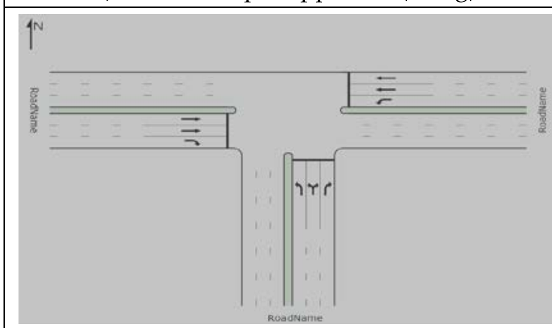
Four layouts of intersection were evaluated in the study as shown in shown in Figure (2)



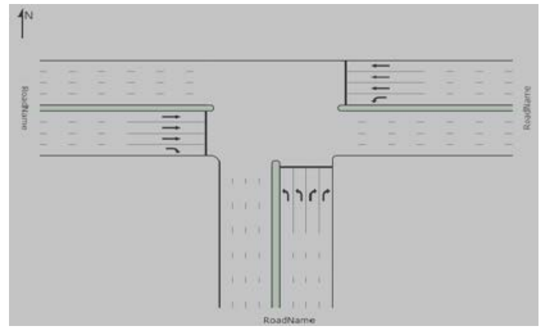
a) Three lanes per approach (4 Leg)



b) Four lanes per approach (4 Leg)



c) Three lanes per approach (3 Leg)



d) Four lanes per approach (3 Leg)

Figure (2): Layout of intersections evaluated in the study

2.2 Software used

In the study, the software package Synchro 10.0 was used along with Sidra intersection 5.1 and SIDRA 8.0.

Synchro 10 is the traffic simulation software used in the study. Synchro was used to calculate delay time, LOS and optimize cycle lengths. This software was developed and distributed by Trafficware Corporation, Albany. Synchro is a complete software package for modelling, optimizing, managing and simulating traffic systems [8]. The Synchro software package performs intersection analysis using the Highway Capacity Manual methods [8, 14].

SIDRA Intersection is a technical software package that can model traffic intersections including light vehicles, heavy vehicles and pedestrians [9].

SIDRA Intersection version 8 includes much improved network model processing efficiency and much improved workflow efficiency through substantial enhancements to the user interface including improved visualization and new output reports and displays It also incorporates various important model improvements [15].

SIDRA 5.1 is based on HCM 2010, while SIDRA 8.0 is based on HCM 2016.

2.3 Phasing of the signal

The study focused on two phasing types for left movement of the intersection. These phases are protected and split. The study assumed that right movement is allowed on red for all approach and at any signal phase.

2.4 Percentage of heavy vehicles

The study focused on reaching LOS "F" at 25% of HVs then from the softwares used in the study lower HV% is used to get better LOS. Data from literature showed that on many Interstate

No. of lanes/ leg	Split	Protected
3	270 L 1070 TH 270 R	400 L 1375 TH 400 R
4	375 L 1600 TH 375 R	450 L 1900 TH 450 R

highways in United States of America, commercial trucks and buses make up more than one-third of the traffic stream [16].

2.5 Lane groups

Four types of lane groups were used in the study; Figure (2) shows the direction of the traffic of each type. The first type has three lanes for every leg of the intersection, the left lane allows through movement and share left movement, the middle lane allows through movement and the third one allows through movement and share right movement.

The second type has four lanes for every leg of the intersection, the left lane allows through movement and share left movement, the two middle lanes allow through movement and the right one allows through movement and share right movement.

The third type has three lanes for every leg of the intersection as shown in Figure (2-c).

The last type has four lanes for every leg of the intersection; Figure (2-d) shows the lane group of this type.

2.6 Traffic Volume

Traffic volumes which were inputted in the

No. of lanes/ leg	Split	Protected
3	50 L 510 TH 50 R	80 L 900 TH 80 R
4	75 L 750 TH 75 R	120 L 1200 TH 120 R

softwares were chosen to get LOS "F" at HV% equal 25%.

The study considered that the delay time of LOS "F" is about 80 sec.

The study assumed different volumes for every layout of intersection used. Table (1) shows the different volumes of traffic for each intersection layout that resulted in LOS "F" at 25% HV.

Table (1) Traffic volumes used in the study for each phase in case of 4 leg intersection

Table (2) Traffic volumes used in the study for each phase in case of 3 leg intersection

2.7 Constant Factors used through the study

The assumptions of this study when using SIDRA Intersection 5.1, SIDRA Intersection 8.0 and Synchro 10 are:

The lane width is 3.6 m for each lane. No curb parking and no local buses were considered. The grades of the intersection are flat "0%". The area Type that was selected in Synchro is other area not central business district (CBD). Peak-hour factor (PHF): 0.92 is the typical value of PHF, as there is no field data for the study. A default ideal saturation flow of 1900 pc/h/ln was used.

Control Type assumed to be pretimed signal.

For All evaluated traffic volumes, right turn on red (RTOR) is allowed at any phasing of intersection and the left lanes are exclusive.

The study assumed that there are no storage lanes. Phase timing was optimized by Synchro for each cases of the study to minimize the effect of phase timing on delay time. The right turn isn't channelized in the study.

2.8 Steps of Analysis

The following steps were followed during presenting the intersections into Synchro 10, SIDRA Intersection 5.1 and SIDRA Intersection 8.0:

- One of the four layouts of movements was chosen.
- One phase of the signal was chosen.
- The traffic volume from table 2 and 3 was chosen for the layout and phase that were chosen before to get delay time for Synchro 10, SIDRA Intersection 5.1 (HCM 5^{th} Edition) and SIDRA Intersection 8.0 (HCM 6^{th} Edition).
- These steps were repeated with lower HV% to have better LOS, and then these steps were repeated with changing the previous steps.

Control delay is the principal service measure for evaluating LOS at signalized intersections. Table (3) shows the relation between LOS and Delay at signalized intersection [12].

Table (3): The relation between LOS and Delay [12]

LOS	Control Delay per Vehicle (sec/veh)
A	< 10
B	> 10-20
C	> 20-35
D	> 35-55
E	> 55-80
F	> 80

The delay time and LOS in the study was calculated as indicated by Synchro 10 (3) and it was calculated also by SIDRA Intersection 5.1 as shown in figure (3) and Figure (4) respectively.

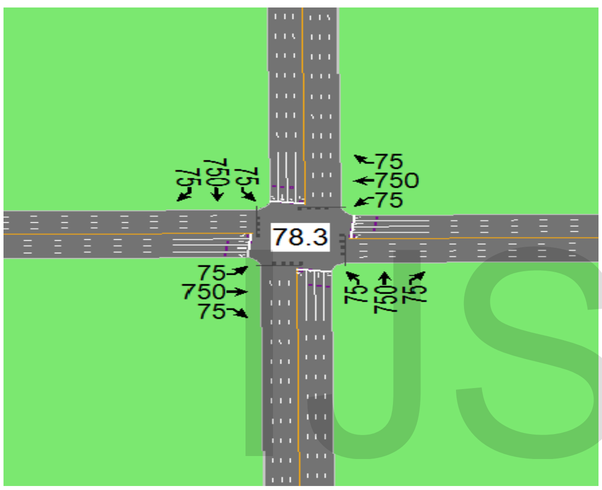


Figure (3): LOS and Delay time using Synchro 10

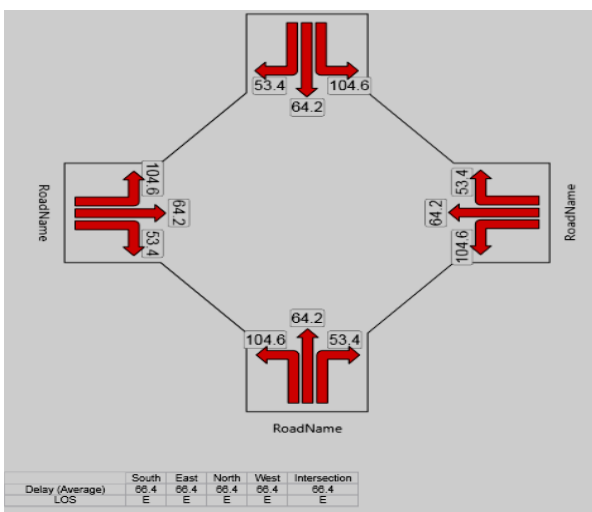


Figure (4): LOS and Delay time using SIDRA 5.1

The delay time and LOS were used to correlate between HV% and LOS at signalized intersection using SIDRA Intersection 5.1 (HCM 5th), SIDRA Intersection 8.0 (HCM 6th) and Synchro 10.

3 RESULTS and Analysis

3.1 Four leg intersection

3.1.1 Split phase

Figure (5) shows the relation between delay time and HV% for three lanes approach in case of split phase using Synchro 10, SIDRA Intersection 5.1 and HCM 6th edition.

Figure (6) shows the relation between delay time and HV% for four lanes approach in case of split phase using Synchro 10, SIDRA Intersection 5.1 and HCM 6th edition.

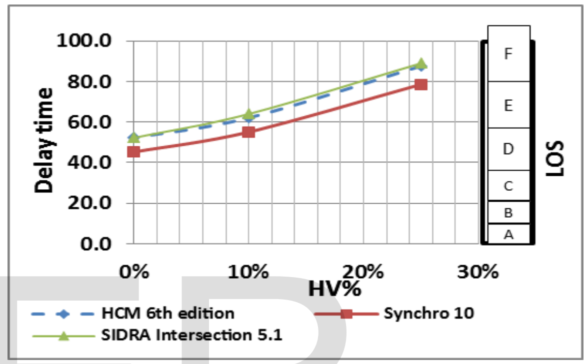


Figure (5): Delay time of three lanes approach

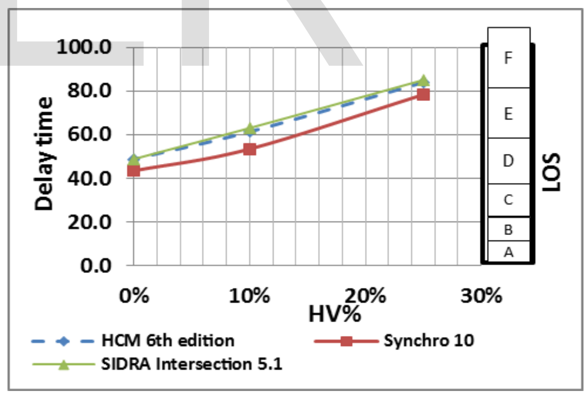


Figure (6): Delay time of four lanes approach

Figure (5) shows that for three lanes approach, HCM 6th edition gives delay time for split phase lower than SIDRA Intersection 5.1 (HCM 2010) by about 2% and gives delay time more than Synchro 10 by about 13%.

The figures show that the lines of delay time of SIDRA Intersection 8.0 (HCM 6th), SIDRA Intersection 5.1 (HCM 2010) and Synchro 10 are almost parallel.

Figure (6) shows that for four lanes approach, SIDRA Intersection 8.0 (HCM 6th edition) gives delay time for split phase almost similar to SIDRA

Intersection 5.1 (HCM 2010) and gives delay time more than Synchro 10 by about 11%.
At HV% equal 0% SIDRA Intersection 8.0 (HCM 6th edition) gives delay time when the signal phasing is split equal SIDRA Intersection 5.1 (HCM 2010).
The delay time that was determined when HV% becomes 0% always in the range of LOS "D".

3.1.2 Protected phase

Figure (7) shows that for three lanes approach, HCM 6th edition gives delay time for protected phase lower than SIDRA Intersection 5.1 (HCM 2010) by about 2% and gives delay time more than Synchro 10 by about 7%.
Figure (8) shows that delay time of HCM 6th edition is almost equal delay time of SIDRA Intersection 5.1 (HCM 2010) in case of four lanes approach and for protected phase, that HCM 6th edition gives delay time for protected phase lower than SIDRA Intersection 5.1 (HCM 2010) by about 2% and gives delay time more than Synchro 10 by about 4%. The delay time of HCM 6th edition is parallel with delay time of SIDRA Intersection 5.1 (HCM 2010) and Synchro 10.
At HV% equal 0% HCM 6th edition gives delay time for split phase equal SIDRA Intersection 5.1.

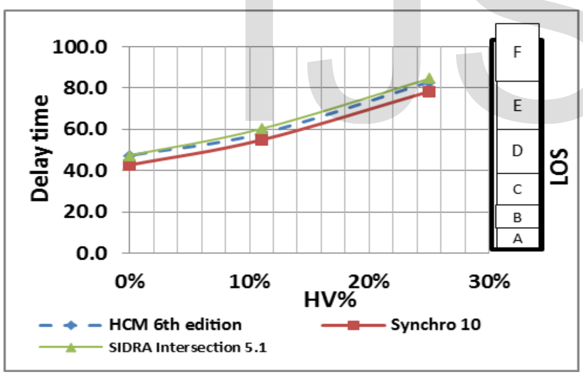


Figure (7): Delay time of three lanes approach

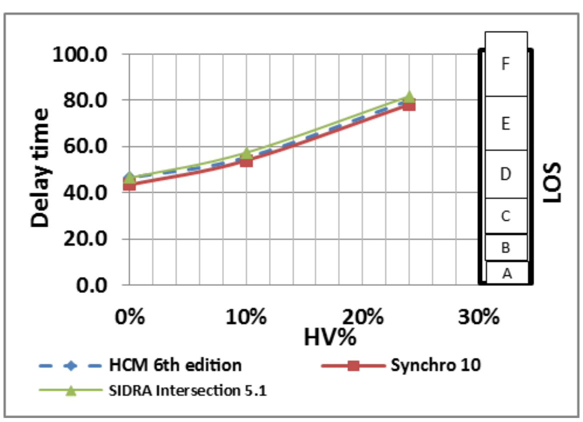


Figure (8): Delay time of four lanes approach

3.1.3 HCM 6th edition results for split

Figure (9) shows delay time by SIDRA 8.0 (HCM 6th editions) for split phasing in case of three lanes per every approach.
The figure shows that the minimum delay is about 50 sec (LOS"D"); this delay can take place when HV equal 0%.
Figure (10) shows delay time by SIDRA 8.0 (HCM 6th editions) for split phasing in case of four lanes per every approach.
The figure shows that the minimum delay is about 48 sec (LOS"D") when HV% is 0%.

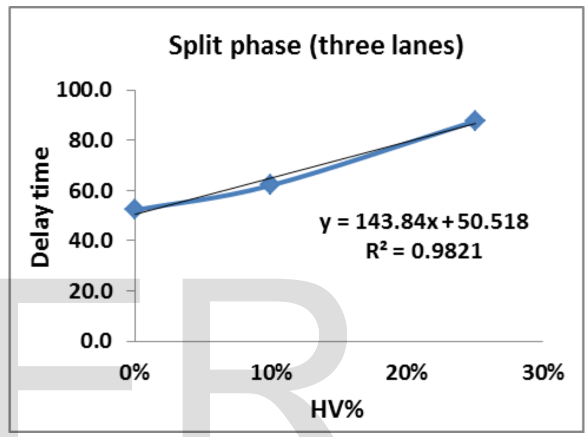


Figure (9)

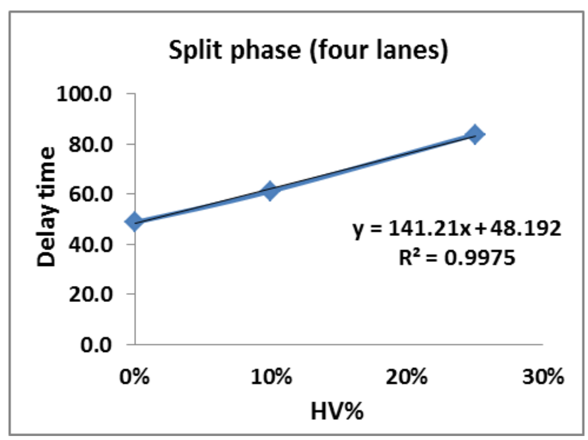


Figure (10)

The figure shows that the minimum delay is about 48 sec (LOS"D") when HV% is 0%.
From the previous two figures equations correlate between delay time and HV% can be concluded for three lanes and four lanes approaches:
Delay time = 143.84 HV% + 50.518 (For three lanes)
Delay time = 141.21 HV%+ 48.192 (For four lanes)

Over all equation for split in case of 4 leg intersection is:

HV % $_{(Targeted)}$ =HV% $_{(Existing)}$ - ((d_1 –d_2) / 142.5)

Where:

HV% $_{(Targeted)}$: is the value of HV% to improve the existing delay.

HV% $_{(Existing)}$: is the value of HV% that takes place in the intersection.

d1: delay time which was determined for existing HV%.

d2: delay time needed to be in the intersection.

3.1.4 HCM 6th edition results for protected

Figure (11) shows delay time by SIDRA 8.0 for protected phasing in case of three lanes per every approach.

Figure (11) shows that the minimum delay is about 46 sec (LOS"D"), when HV equal 0%.

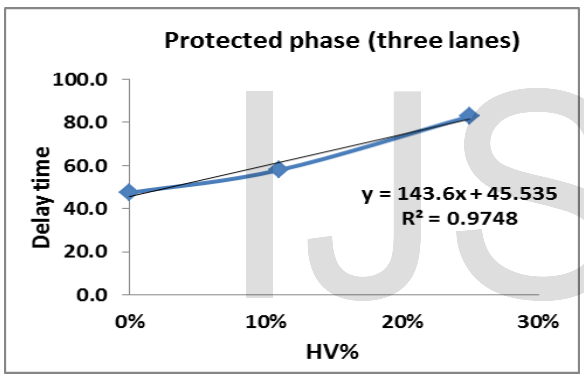


Figure (11)

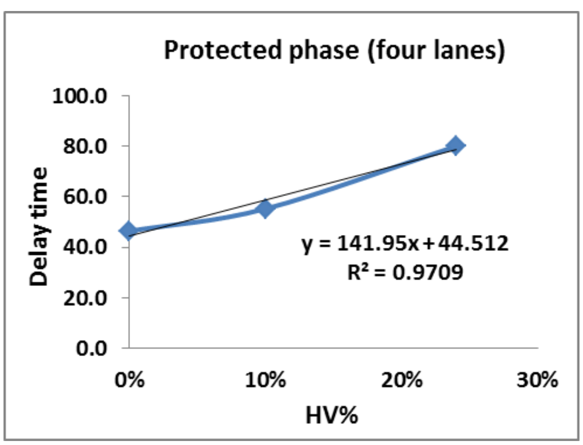


Figure (12)

Figure (12) shows delay time by SIDRA 8.0 for protected phasing in case of four lanes per approach.

The figure shows that the minimum delay is about 44 sec (LOS"D") when HV% is 0%.

From the previous two figures equations correlate between delay time and HV% can be concluded for three lanes and four lanes per approach:

Delay time = 143.60 HV% + 45.535 (For three lanes)

Delay time = 141.95 HV% + 44.512 (For four lanes)

HV %(Target)$_2$=HV%(Present)$_1$-((d_1 –d_2)/142.5)

3.1.5 HCM 5th edition results

The same analysis was conducted for results concluded from SIDRA Intersection 5.1 (HCM 5th edition).

It was found that the minimum delay of split phase for three lanes per approach is about 51 sec and 48 sec for four lanes per approach.

It was found that the minimum delay of protected phase for three lanes per approach is about 46 sec and 45 sec for four lanes per approach.

Equations correlate between delay time and HV% can be concluded for three and four lanes per approach and for split phasing:

Delay time = 148.74 HV% + 51.047 (For three lanes)

Delay time = 144.95 HV% + 48.689 (For four lanes)

Equations correlate between delay time and HV% can be concluded for three and four lanes per approach and for protected phasing:

Delay time = 149.49 HV% + 46.128 (For three lanes)

Delay time = 148.83 HV% + 45.033 (For four lanes)

3.1.6 Synchro 10 results

The same analysis was conducted for results concluded from Synchro 10.

It was found that the minimum delay of split phase for three lanes per approach is about 43 sec and 41 sec for four lanes per approach.

It was found that the minimum delay of protected phase for three lanes per approach is about 41 sec and 41 sec for four lanes per approach.

Equations correlate between delay time and HV% can be concluded for three and four lanes per approach and for split phasing:

Delay time = 135.42 HV% + 43.834 (For three lanes)

Delay time = 141.68 HV% + 41.837 (For four lanes)

Equations correlate between delay time and HV% can be concluded for three and four lanes per approach and for protected phasing:

Delay time = 143.12 HV% + 41.492 (For three lanes)

Delay time = 146.40 HV% + 41.975 (For four lanes)

3.2 Three leg intersection

3.2.1 Split phase

Figure (13) shows the relation between delay time and HV% for three lanes approach in case of split phase using Synchro 10, SIDRA Intersection 5.1 and HCM 6th edition.

Figure (14) shows the relation between delay time and HV% for four lanes approach in case of split phase using Synchro 10, SIDRA Intersection 5.1 and HCM 6th edition.

The figures show that the lines of delay time of SIDRA Intersection 8.0 (HCM 6th), SIDRA Intersection 5.1 (HCM 2010) and Synchro 10 are almost parallel.

HCM 6th edition's delay is lower than HCM 2010 but higher than Synchro 10.

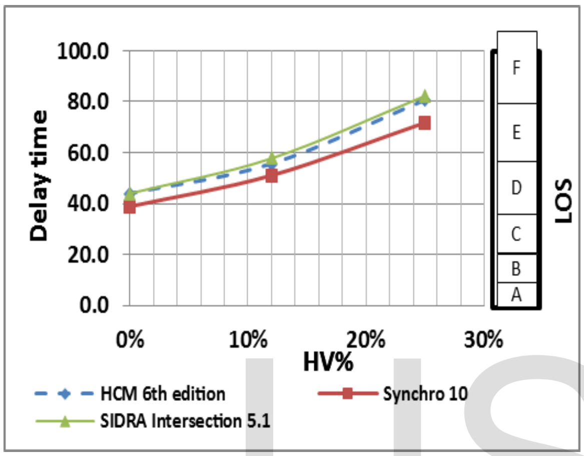


Figure (13): Delay time of three lanes approach

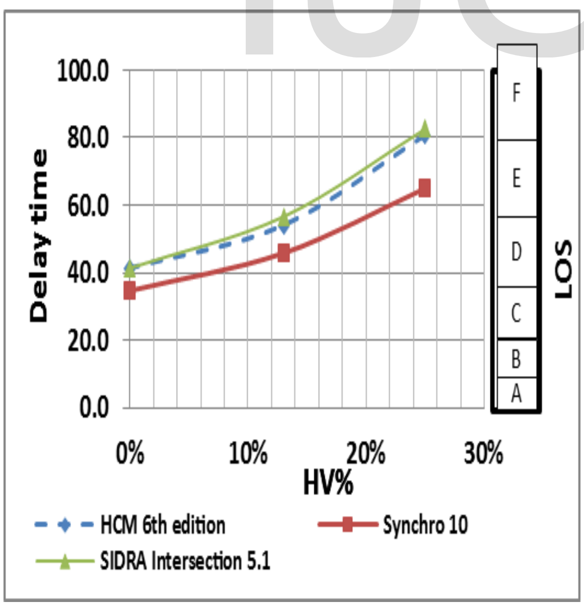


Figure (14): Delay time of four lanes approach

3.2.2 Protected phase

Figure (15) shows the relation between delay time and HV% for three lanes approach in case of split phase using Synchro 10, SIDRA Intersection 5.1 and HCM 6th edition.

Figure (16) shows the relation between delay time and HV% for four lanes approach in case of split phase using Synchro 10, SIDRA Intersection 5.1 and HCM 6th edition.

The figures show that the lines of delay time of SIDRA Intersection 8.0 (HCM 6th), SIDRA Intersection 5.1 (HCM 2010) and Synchro 10 are almost parallel.

HCM 6th edition's delay is lower than HCM 2010 but higher than Synchro 10.

Table (4) shows the equations correlate between delay time and HV%.

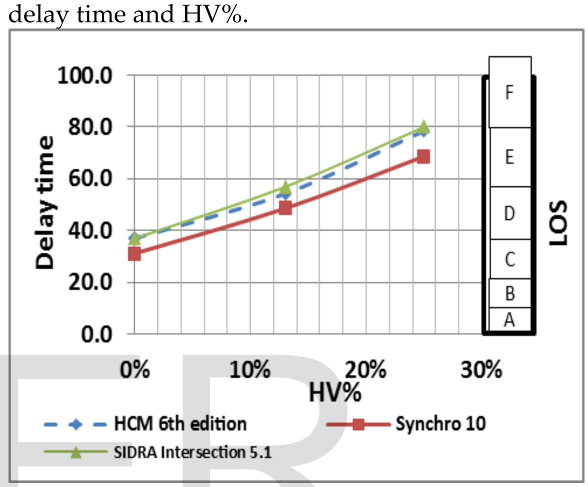


Figure (15): Delay time of three lanes approach

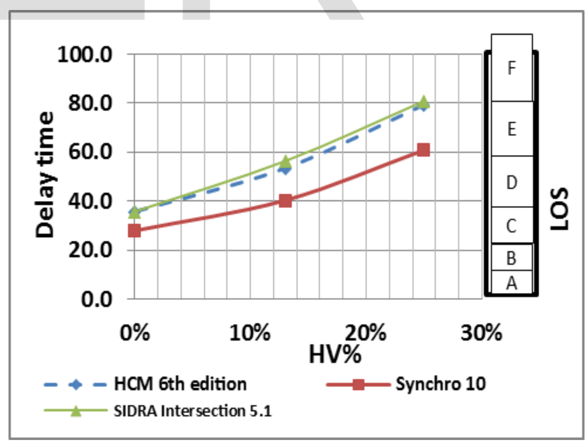


Figure (16): Delay time of four lanes approach

3.2.3 HCM 6th edition results for split

Figure (17) shows delay time by SIDRA 8.0 (HCM 6th editions) for split phasing in case of three lanes per every approach.

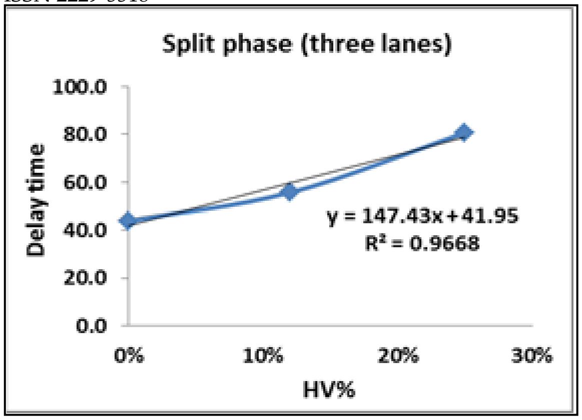


Figure (17)

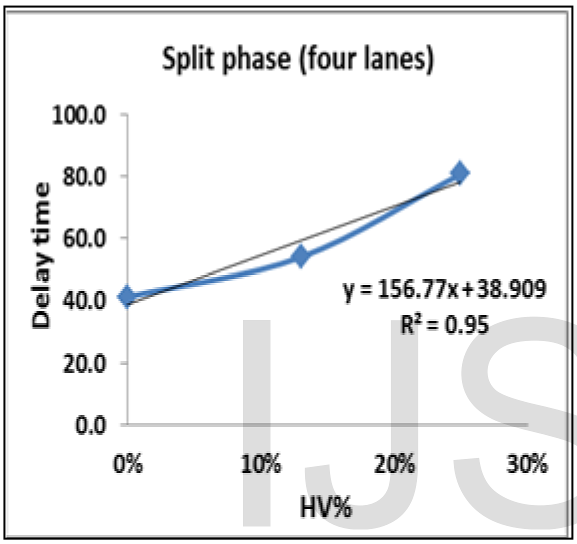


Figure (18)

Figure (18) shows delay time by SIDRA 8.0 (HCM 6th editions) for split phasing in case of four lanes per every approach.

From the previous two figures equations correlate between delay time and HV% can be concluded for three lanes and four lanes approaches:

Delay time = 147.43 HV% + 41.950 (For three lanes)

Delay time = 156.77 HV%+ 38.909 (For four lanes)

Over all equation for split in case of 3 leg intersection is:

HV %(Target)$_2$=HV%(Present)$_1$-((d_1 –d_2)/152)

3.2.4 HCM 6th edition results for protected

Figure (19) shows delay time by SIDRA 8.0 (HCM 6th editions) for protected phasing in case of three lanes per every approach.

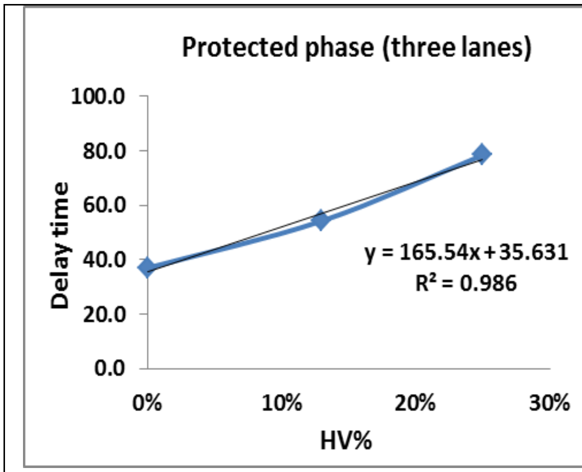


Figure (19)

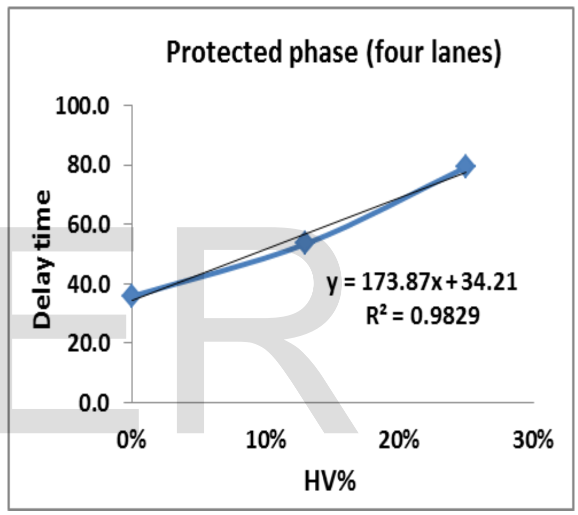


Figure (20)

Figure (20) shows delay time by SIDRA 8.0 (HCM 6th editions) for protected phasing in case of four lanes per every approach.

From the previous two figures equations correlate between delay time and HV% can be concluded for three lanes and four lanes per approach:

Delay time = 165.54 HV% + 35.631 (For three lanes)

Delay time = 173.87 HV% + 34.210 (For four lanes)

HV %(Target)$_2$=HV%(Present)$_1$-((d_1 –d_2)/169.5)

Table (4): The equations correlate between delay time and HV% for each case study

Split	
No. Lanes	**Synchro 10**
Three lane	Delay time =131.98 HV% + 37.655
Four lanes	Delay time =120.70 HV% + 33.211
No. Lanes	**SIDRA Intersection 5.1**
Three lane	Delay time =153.69 HV% + 42.412

Four lanes	Delay time =164.14 HV% + 39.409
No. Lanes	**HCM 6th edition**
Three lane	Delay time =147.43 HV% + 41.950
Four lanes	Delay time =156.77 HV% + 38.909
Protected	
No. Lanes	**Synchro 10**
Three lane	Delay time =149.78 HV% + 30.528
Four lanes	Delay time =131.10 HV% + 26.494
No. Lanes	**SIDRA Intersection 5.1**
Three lane	Delay time =171.74 HV% + 36.213
Four lanes	Delay time =180.10 HV% + 34.888
No. Lanes	**HCM 6th edition**
Three lane	Delay time =165.54 HV% + 35.631
Four lanes	Delay time =173.87 HV% + 34.210

4 CONCLUSION

The following points represent the main conclusions of this research:

1. For signalized intersection has delay time of 80 sec with HV% equal 25%, the optimum of LOS can't be improved other than LOS "D" when HV% reaches zero.
2. At HV% equal 0%, HCM 6th edition gives delay time equal to HCM 5th edition, while Synchro 10 gives lower delay values.
3. For higher HV%, the delay time concluded from HCM 2010 is higher than the delay time from HCM 6th but much higher than the delay from Synchro 10.
4. HCM 6th edition's results are closer to simulation program's results compared to HCM 5th edition.
5. The delay time of HCM 6th edition is higher than the delay time found in Synchro in case of split phase by 11% to 13% and by 4% to 7% in case of protected phase in 4 leg intersection.
6. The delay time of HCM 6th edition is higher than Synchro in case of split phasing by 12% to 21% and by 15% to 30% in case of protected phase in 3 leg intersection.
7. The delay time of HCM 6th edition is lower than HCM 5th edition by about 2% for protected or split for 3 or 4 leg intersection.
8. For four leg intersection, the calculated delay using HCM 6th edition, HCM 5th edition and Synchro 10 result in similar LOS. However for the three leg intersection the LOS can vary between the different software.
9. Mathematical models were developed to show possible enhancement in the delay by lowering HV%.

5 REFERENCES

[1] Dante Perez-Bravo, (Microscopic Modeling of Heavy Vehicle Operations at Signalized Intersection Approaches), University of Idaho, 2012.

[2] Karl Joseph Zeller, University of Southern Queensland, (Evaluation of the operational characteristics of heavy vehicles at signalized intersections in Queensland), University of Southern Queensland, 2011

[3] H. Nassiri, S. Tabatabaie, and S. Sahebi, (Delay-Based Passenger Car Equivalent at Signalized Intersections in Iran), 2016.

[4] Kara M. Kockelman and Raheel A. Shabih, (Effect of Vehicle Type on the Capacity of Signalized Intersection: The Case of Light-Duty Trucks), Journal of Transportation Engineering, 2000.

[5] Scott S. Washburn and Carlos O. Cruz-Casas, (Impact of Trucks on Signalized Intersection Capacity), Computer-Aided Civil and Infrastructure Engineering 25, 2010.

[6] Md. Jobair Bin Alam, Khalid A.Osra, Hamid O. Al-Bar and Shaher Z.Zahran, (Signalized Intersection Capacity Adjustment Factors for Makkah, Saudi Arabia), 2011.

[7] Zinoviy Stotsko, Yevhen Fornalchyk and Ihor Mohyla (Simulation of Signalized Intersection Functioning with Fuzzy Control Algorithm), Transport Problems, vol.8, 2013.

[8] Institute of Transportation Engineers California Border Section Highway Capacity Task Force, "A Report on The Use of Traffic Simulation Models in the San Diego Region", March 2004.

[9] Gladstone regional council, (SIDRA Intersection Guideline), version 1, July 2010.

[10] Abdelrahman Baz, (Evaluation of Common Traffic Operation Software on The Basis of Relevance to Roads and Intersections), Mansoura University, 2016.

[11] Yusria Darma, Mohamed Karim, Jamilah Mohamad and Sulaiman Abdullah (Control Delay Variability at Signalized Intersection Based on HCM Method), Eastern Asia Society for Transportation Studies, Vol. 5, 2005.

[12] Highway capacity manual 2010 (HCM 2010), Transportation Research Board – National Research Council.

[13] Highway capacity manual 2016 (HCM 2016), Transportation Research Board – National Research Council.

[14] Ryan O'Connell, Wen Cheng and Jannet Loera-Gutierrez, (How to Improve the Efficiency of Signalized Intersections with High Left-turn Demand).

[15] SIDRA Intersection 8.0 update history, Sidra Solution, August, 2018

ISSN 2229-5518

[16] Douglas W. Harwood, Ingrid B. Potts, Darren J. Torbic and William D. Glauz (Highway/Heavy Vehicle Interaction), Commercial Truck and Bus Safety Synthesis Program, TRB, 2003.