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The Impact of Heavy Vehicles Percentage on Signalized Intersections Using Simulation

Mohamed A. Abouzeid[1], Mohamed I. E. Attia[2], Ahmed M. Abdallah[3], and Fathy M. Mandel[4]

[1] Mohamed A. Abouzeid, Master Degree Student, Construction Eng. & Utilities Dept., Zagazig University, Egypt and E-mail: mohali24291@yahoo.com

[2] Mohamed I. E. Attia, Assistant Professor of Highways & Airports, Construction Eng. & Utilities Dept., Zagazig University, Egypt and E-mail: moh_sharkawi@hotmail.com

[3] Ahmed M. Abdallah, Associate Prof. Highways & Airports, Construction Eng. & Utilities Dept., Zagazig University, Egypt and E-mail: dr_amohamady@yahoo.com

[4] Fathy M. Mandel, Associate Prof. Highways & Airports, Construction Eng. & Utilities Dept., Zagazig University, Egypt and E-mail: fatyram@yahoo.com

ABSTRACT

Heavy vehicles present safety and operational challenges for traffic engineers especially at signalized intersection approaches. Due to their low power-to-weight ratio, heavy vehicles are unable to accelerate, decelerate or maintain speeds compare to other vehicles, which is a main factor that causes traffic disturbances, generating excessive delay, increase in travel time and reduction in operational efficiency and roadway capacity at intersections. The paper investigates the impact of increasing heavy vehicle percentage (HV%) on the delay time and level of service (LOS) at signalized intersections using simulation technique. The research compares between delay time at different types of lane groups, traffic volumes and different right and left turn percentages for HV% from 0 to 50%. It was found that with increasing heavy vehicle percentage, delay time increases gradually until definite range, and then the rate of increase in the delay increases rapidly. At high traffic volumes, the intersection can handle low percentage of heavy vehicles to keep the LOS below (F). However in low traffic, HV% doesn't have obvious impact on delay time. In low traffic volumes, the percentage of traffic bearing left or right does not have clear impact on delay and LOS. However, in high traffic volumes increasing the percentage of traffic bearing left or right causes clear increase in the delay time. Mathematical models for predicting delay time in intersection were developed.

Keywords: Heavy Vehicles Percentage, Delay Time, Level of Service, Signalized Intersections, Traffic Simulation, Synchro 10.

1. INTRODUCTION

Heavy vehicles differ from passenger cars in many physical and operational characteristics. Their size and lower operational performance have a negative impact when present at signalized intersections generating excessive delay, reduction in travel time, and negative variations in speed [1]. The presence of heavy vehicles in a traffic stream adversely affects capacity of the highway facility [2]. For a constant vehicle density, as percent heavy vehicles increases, the frequency of lane changing and overtaking movements by cars decreases [3].

The impact on roadway capacity is exaggerated at intersections where the heavy vehicles are forced to stop and accelerate back up to operating speed. The acceleration of heavy vehicles will impact on the time it takes for the individual vehicle to clear the intersection. Slow intersection clearance times will significantly reduce the signalized intersection capacity [4, 5]. Significant research has been done to determine the impact of heavy vehicles in the traffic stream at the macroscopic level. However, there are still gaps in capturing the effects of heavy vehicles at the microscopic level [1].

In recent study, the heavy vehicles 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. The research objective is to evaluate the effect of heavy vehicles percentage on signalized intersections delay and level of service (LOS). The research compares between delay and LOS at different types of lane groups, traffic volumes and different right and left turn percentages for HV% from 0 to 50%, based on simulation techniques.

This research focuses on four leg signalized intersection, pretimed signal and the lane groups that were mentioned in methodology.

2. METHODOLOGY

The following methodology was used to achieve the research objectives:

2-1 Traffic simulation technique

Recent advances in computer technology and traffic flow theory have led to the widespread creation and use of traffic simulation models [7]. 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 [9]. Synchro is considered one of the robust softwares in data entry as well as the identification of analysis outputs. Synchro is one of the best softwares for estimating the control delay time at signalized intersections compared with the control delay time calculated theoretically by using HCM [8].

The Synchro software package performs intersection analysis using the Highway Capacity Manual methods [7].

2-2 The study parameters

Figure (1) shows the parameters considered in the study:

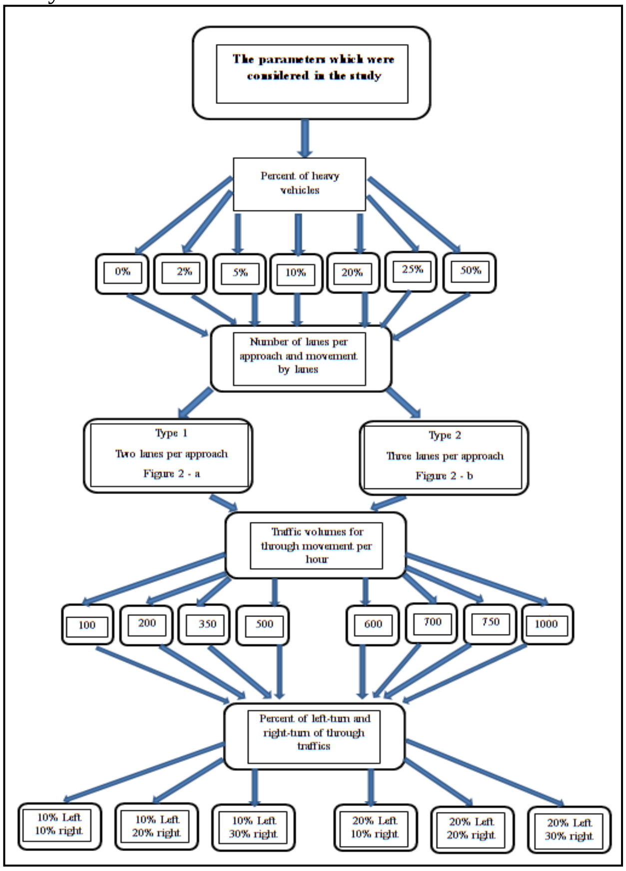


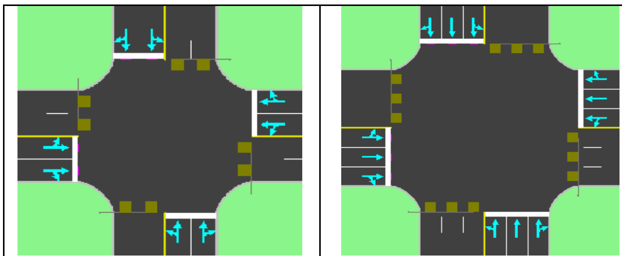
Figure (1): parameters considered in the study

2-2-1 Percentage of heavy vehicles

The study evaluated seven levels of heavy vehicle percentage including 0%, 2%, 5%, 10%, 20%, 25%, and 50%. These levels were selected to cover wide range of expected heavy vehicles percentage in real life. Date from literature showed that on many Interstate highways in United States of America, commercial trucks and buses make up more than one-third of the traffic stream [6].

2-2-2 Layout of Intersections and lane groups

Two types of lane groups were used in the study; Figure (2) shows the direction of the traffic of each type. The first type in the study has two lanes for every leg of the intersection. Two layouts of intersection were evaluated in the study as shown in shown in Figure (2).



a) Two lanes per approach

b) Three lanes per approach

Figure (2):Types of intersection evaluated in the study.

The first type has two lanes for every leg of the intersection, the left lane allows through movement and share left movement and the other allows through movement and share right movement.

The second 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.

2-2-3 Traffic Volume

Eight levels of traffic volumes were evaluated in the study. Traffic volumes of 100, 200, 350, 500, 600, 700, 750, and 1000 vehicles per hour (VPH) were studied as volumes for through movement. These levels were selected to cover wide range of expected traffic volumes that can occur in real life that cause LOS ranging from "A" to "F".

2-2-4 Distribution of traffic

The study evaluated six cases to cover possible percentage of left and right movements. Table (1) shows left and right volumes as percentage of through volumes.
Right turn movement varied from 10% to 30% while left turn movement varied from 10% to 20% of the through movement.

Table (1): Left and right turn movement as a percentage of through movement volumes

Case	Left lane movement percent of through movement	Right lane movement percent of through movement
1	10%	10%
2	10%	20%
3	10%	30%
4	20%	10%
5	20%	20%
6	20%	30%

2-2-5 Constant Factors used through the study

The assumptions of this study are according to the Highway Capacity Manual (HCM2010) [10].

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 available. A default ideal saturation flow of 1900 pc/h/ln was used. Control Type assumed to be pretimed signal. For All evaluated traffic volumes, Left Turn Type assumed to be permitted. For only volume of 700 vph, different types of left turn phase (permitted, split and protected) were evaluated, to study the impact of phasing type on delay. 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. Volumes presented in the discussion presents through volumes of each approach unless otherwise mentioned.
The volumes which were assumed in the study are volumes of each approach not the overall volumes intersection and they are equal in each leg of intersection.

2-3 Steps of Analysis

The following steps were followed during presenting the intersections into Synchro 10:

• One of the two types of movements was chosen (Type 1 or

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Type 2 of approaches).

• One level of traffic volumes was chosen.

• One case defines vehicles turn left percentage and vehicles turn right percentage was chosen.

• One percentage of heavy vehicles was chosen.

• These steps were repeated with other percentage of heavy vehicles, with changing the type of movements, the traffic volumes, percentage of vehicles turning left and percentage of vehicles turning right.

Control delay is the principal service measure for evaluating LOS at signalized intersections [10].

The delay time and LOS in the study was calculated as indicated by Synchro 10 as shown in figure (3). In this research maximum accepted delay was defined as 80 sec, this is the maximum limit of LOS "E" [10].

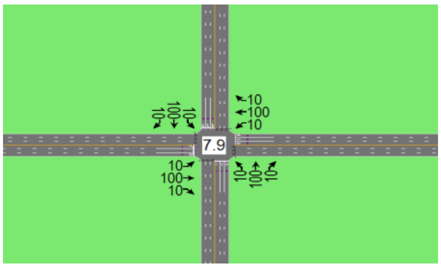

Figure (3): LOS and Delay time using Synchro3.

These combinations resulted in 672 runs of the software for permitted left turn, 84 runs for split left turn and 84 runs for protected left turn.

The delay time and LOS were used to study the effect of heavy vehicle on signalized intersection under different conditions.

3. RESULTS AND ANALYSIS

3-1 Effect of heavy vehicles percentage on two lanes approach

Figures (4) and Table (2) shows the relation between delay time, LOS and HV% for two lanes approach for Case 1 of left and right turn percentages.

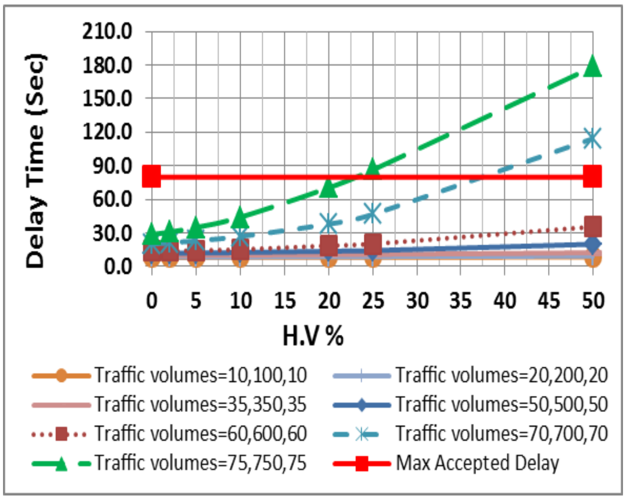

Figure (4): Delay time of two lanes approach, 10% left and 10% right.

When the traffic volumes are low as they were 100, 200 and 350 vph for through movement of the approach, increasing of HV% up to 50% doesn't have a major effect on the delay time, as the delay time increases by less than 3 second, and the LOS is still "A or B" for all HV% evaluated in the study.

For traffic volumes of 500 vph, when HV% increases from 0% to 50%, LOS changes form "B" to "C".

When the traffic volumes are higher than 500 vph, as they reach 600 vph, increasing of HV% has a clear effect on the delay time. For traffic volume equal 700 vph, when the percentage of heavy vehicles increases from 0% to 37%, LOS changes from "C" to "F".

When the traffic volumes become 750 vph, the percentage of heavy vehicles that makes LOS becomes "F" is 23%. When traffic volumes become 1000 vph for through movement of the approach, LOS reaches "F" at 0% HV.

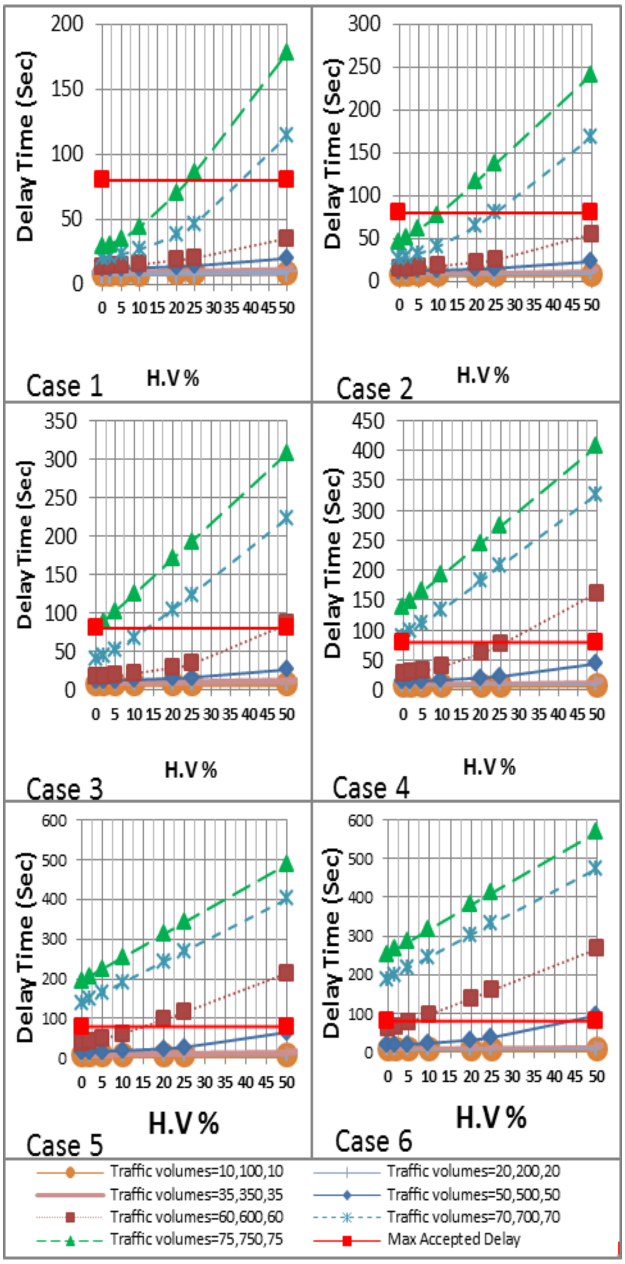

Figure (5): Delay time of two lanes approach

When other percentages of right and left movement of through movement were studied as shown in Table (3) and Figure (5), it was found that the intersection can serve the increase of HV% and LOS doesn't reach "F" for all cases for volumes of 100, 200, and 350 vph for through movement of the approach even if HV% reach 50%.

For traffic volumes 500 vph, LOS doesn't reach "F" for all cases except Case 6 for HV% up to 50%. For the same traffic volumes, LOS reaches "F" for Case 6 when HV% reaches 43%.

For traffic volume of 600 vph, LOS doesn't reach "F" for Case 1 and Case 2 for HV% up to 50%. For the same traffic volume, LOS reaches "F" for Case 3, Case 4, Case 5 and Case 6 when HV% reaches 47%, 26%, 15% and 5% respectively. This result shows the impact of increasing traffic volumes turning right and left.

When traffic volume reach 700 vph, LOS reaches "F" when HV% are 37%, 24% and 13% for Case 1, Case 2 and Case 3 respectively, but it reaches "F" in Case 4, Case 5 and Case 6 even if HV% is 0%.

When traffic volumes reach 750 vph, LOS reaches "F" when HV% are 23% and 11% for Case 1 and Case 2 respectively. Otherwise HV% doesn't affect LOS in Case 4, Case 5 and Case 6 when traffic volumes are 750 vph.

Table (2): Delay time of Type 1 and Case 1

Traffic volumes=10, 100, 10							
H.V%	0	2	5	10	20	25	50
Delay	8.1	8.1	8.2	8.2	8.3	8.3	8.6
LOS	A	A	A	A	A	A	A
Traffic volumes=20,200,20							
H.V%	0	2	5	10	20	25	50
Delay	8.5	8.5	8.6	8.7	8.9	9.0	9.5
LOS	A	A	A	A	A	A	A
Traffic volumes=35, 350, 35							
H.V%	0	2	5	10	20	25	50
Delay	9.9	9.9	10.1	10.3	10.7	10.9	12.4
LOS	A	A	B	B	B	B	B
Traffic volumes=50, 500, 50							
H.V%	0	2	5	10	20	25	50
Delay	11.7	11.9	12.1	12.6	13.7	14.3	20.0
LOS	B	B	B	B	B	B	C
Traffic volumes=60, 600, 60							
H.V%	0	2	5	10	20	25	50
Delay	13.6	13.9	14.4	15.3	18.6	20.3	35.5
LOS	B	B	B	B	B	C	D
Traffic volumes=70, 700, 70							
H.V%	0	2	5	10	20	25	50
Delay	20.3	21.3	23.1	26.9	38.0	46.7	114.4
LOS	C	C	C	C	D	D	F
Traffic volumes=75, 750, 75							
H.V%	0	2	5	10	20	25	50
Delay	28.7	30.9	35.0	44.1	70.4	86.4	178.5
LOS	C	C	D	D	E	F	F
Traffic volumes=100, 1000, 100							
H.V%	0	2	5	10	20	25	50
Delay	249.5	262.6	281.9	314.9	380.5	413.2	576.3
LOS	F	F	F	F	F	F	F

Table (3): Max HV% to achieve LOS "E"

Volume	**Case**	**Max HV% to achieve LOS of "E" for Type 1**	**Max HV% to achieve LOS of "E" for Type 2**
100, 200 and 350	1, 2, 3, 4, 5 and 6	Up to 50%*	Up to 50%*
500	1	Up to 50%*	Up to 50%*
	2	Up to 50%*	
	3	Up to 50%*	
	4	Up to 50%*	
	5	Up to 50%*	
	6	43%	
600	1	Up to 50%*	Up to 50%*
	2	Up to 50%*	
	3	47%	
	4	26%	
	5	15%	
	6	5%	
700	1	37%	Up to 50%*
	2	24%	Up to 50%*
	3	13%	Up to 50%*
	4	LOS "F" at 0%	Up to 50%*
	5	LOS "F" at 0%	Up to 50%*
	6	LOS "F" at 0%	47%
750	1	23%	Up To 50%*
	2	11%	Up to 50%*
	3	LOS "F" at 0%	Up to 50%*
	4	LOS "F" at 0%	Up to 50%*
	5	LOS "F" at 0%	43%
	6	LOS "F" at 0%	35%
1000	1	LOS "F" at 0%	31%
	2		20%
	3		9%
	4		16%
	5		9%
	6		1%
***** 50% is the maximum heavy vehicles percentage evaluated in the study			

3-2 Effect of heavy vehicles percentage on three lanes approach

Figure (6) shows the relation between delay time, and HV% for three lanes approach. This section present Case 4, when percent of left movement equal 20% and 10% for right of through movement under the eight traffic volumes for three lanes approach. Figure (6) shows that when the traffic volumes are low as they were 100 and 200 vph for through movement of the approach, increasing HV% up to 50% doesn't have a major effect on the delay time, or LOS. When HV% increased from 0% to 50%, the LOS did not change, and still "A" during all HV%.

When the traffic volumes are higher as they reach 700 vph, increasing of HV% from 0% to 50% causes LOS changing from "B" to "D". When the traffic volumes become 750 vph, the percentage of heavy vehicles causes a major effect, and LOS changes from "B" to "E" when HV% increases from 0% to 50%. For Traffic volume of 1000 vph, LOS reaches "F" when HV% reaches 16%.

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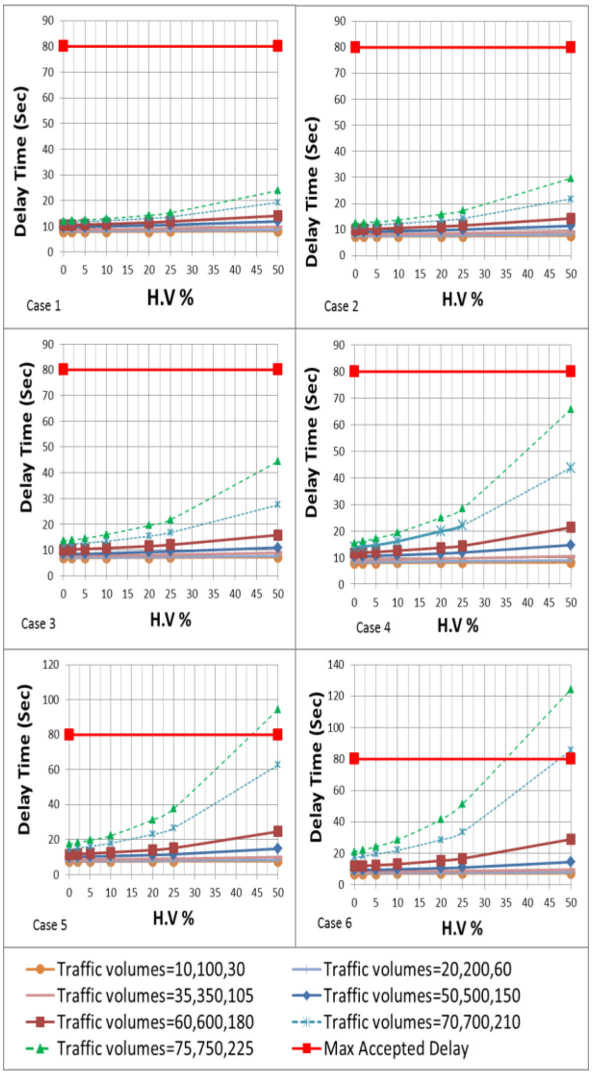

Figure (6): Delay time of three lanes approach

For other percentage of right and left movement of through movement was studied as shown in Figure (6) and Table (3), it was found that LOS doesn't reach "F" for all cases if volumes are 100, 200, 350, 500 and 600 vph for through movement of the approach for HV% up to 50%.

For traffic volumes 750 vph, LOS doesn't reach "F" for Case 1, Case 2, Case 3 and Case 4 for HV% up to 50%, but it reaches "F" for Case 5 and Case 6 when HV% reaches 43% and 35% respectively.

When traffic volumes reach 1000 vph, LOS reaches "F" when HV% becomes 31%, 20%, 9%, 16%, 9% and 1% for Case 1, Case 2, Case 3, Case 4, Case 5 and Case 6 respectively.

Based on the finding in this section, it can be concluded that the traffic volumes less than 500 vph can be considered low volume for two lanes approach and 700 vph for three lanes approach. The bases for this selection is that at these volumes the LOS does not reach "F" for high level of HV% for most of left and right movement percentages.

3-3 Effect off Adding an extra lane in the approach

To quantify the enhancement in delay due to adding of one lane, analysis was conducted for all traffic volumes. Figure (7) presents a sample of these results for traffic volume of 700 vph.

For Case 1, when HV% is 0%, the delay time is 20.3 sec for Type 1 and 11.4 sec for Type 2, however the delay time is 114.4 sec for Type 1 and 19.3 sec for Type 2 when HV% is 50%. Percentage of heavy vehicles can reach up to 37% for the Type 1 to keep level of service "E", but it can be higher than 50% without any obvious effect on LOS for Type 2. This reflects the impact of adding a lane for all leg of the intersection.

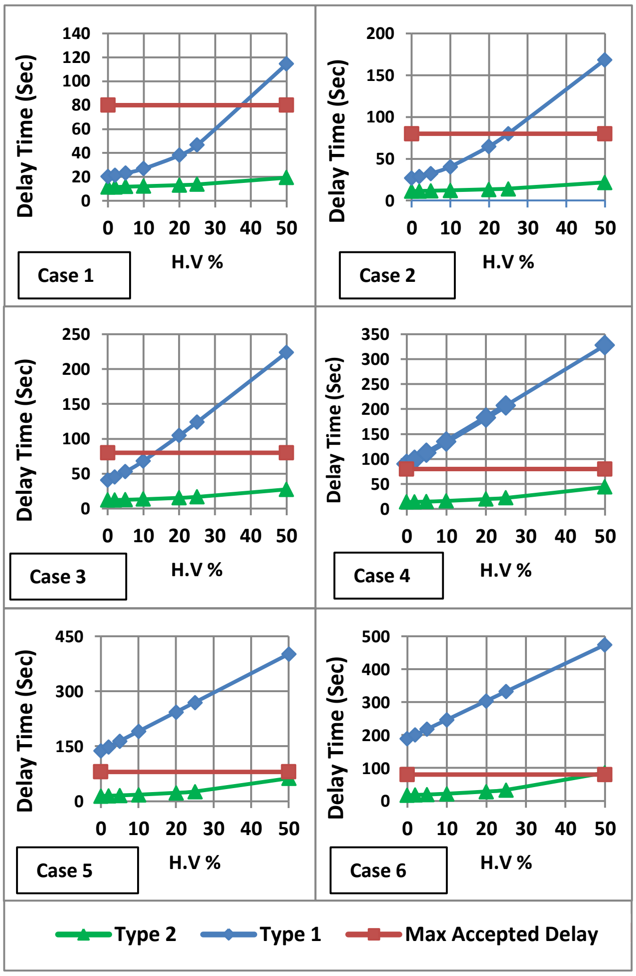

Figure (7): Effect of adding a lane on delay time

For Case 2, the difference of delay time between Type 1 and Type 2 is 16 sec when HV% is 0%, but it increases rapidly to be 147 sec when HV% is 50%. Percentage of heavy vehicles can reach up to 24% for the Type 1 to keep level of service "E", but it can reach higher than 50% for Type 2.

For Case 3, the difference of delay time between Type 1 and Type 2 is 28 sec when HV% is 0%, and it exceeds to be 196 sec when HV% is 50%. Percentage of heavy vehicles can reach up to 13% for the Type 1 to keep level of service "E", but it can reach higher than 50% for Type 2. For Case 4, the difference of delay time between Type 1 and Type 2 is 76 sec when HV% is 0%, and it exceeds to be 284 sec when HV% is 50%. If HV% is 0% for the Type 1, level of service is "F", but it can reach higher than 50% for Type 2.

For Case 5, the difference of delay time between Type 1 and Type 2 is 132.2 sec when HV% is 0%, and it reaches 339 sec when HV% is 50%. For Case 6, the difference of delay time between Type 1 and Type 2 is 172 sec when HV% is 0%, however it exceeds to be 389 sec when HV% is

50%. Whatever HV% is for the Type 1, LOS is "F", but it reaches "F" when HV% reaches 47% for Type 2.

The delay time can be reduced by range from 73% to 85% by adding an extra lane for each approach. Based on this analysis, at any HV% take place in the intersection, it is obvious that adding an extra lane in every approach of the intersection improves LOS and decreases the delay occurred in the intersection.

3-4 Effect of changing the phase of the signal for three lanes intersection

Figure (8) shows the effect of using different options of phasing (split, protected, and permitted) for three lanes intersection. As through volumes equal 700 vph were studied, it was cleared that permitted phase gives lower delay than protected and split phases.

The delay time of protected phase is lower than it for split phase in case of the delay is below 80 sec, but it is higher than split when the delay exceeds more than 80 sec.

When left turn percentage was 20% of the through, the delay time of protected phase is higher than it for split phase at any delay occurred in the intersection.

For high HV%, it is recommended to use split phasing, as it provided the lowest delay compared with protected phasing and it increases the safety of the intersection as it reduces the conflict between traffic movements as every approach has a separate green signal time. Using permitted phase instead of split phase reduces the delay by range from 78% to 80%. Using permitted phase instead of protected phase reduces the delay by range from 73% to 91%.

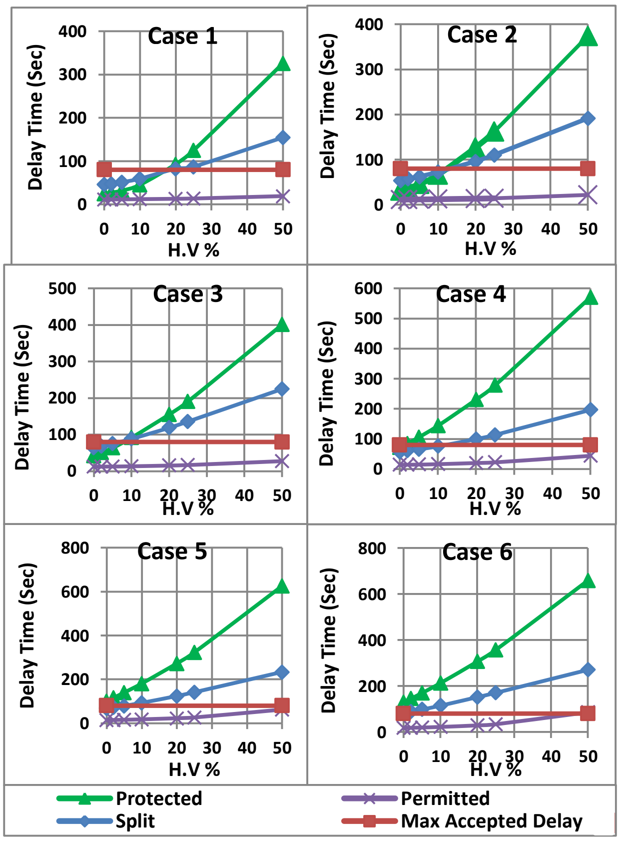

Figure (8): Effect of changing the phase of the signal for three lanes intersection

3-5 Mathematical models for relation between delay time and HV%

Several trials were conducted to develop mathematical relation between delay time and the study parameters including: traffic volume, HV%, % right turn and left turn. Different models were developed however the accuracy for all evaluated models were not acceptable. For this reason, the relation between delay and HV% was modeled for each individual case. The results are presented in Tables 4 and 5. The developed models show that the initial delay at 0% HV was dependent on traffic volume, and varied from 8 to 457 seconds.

The impact of HV% (slope of the model) increased with increasing the traffic volume. The slope of the model was also dependent on the case of analysis (% right and left turn).

Impact of HV% on delay varied from 0.005 * 100 * HV% to 8.5 * 100 * HV%, depending on the case of analysis and traffic volume. In other words, increasing the HV% by 1 % can cause increase in the delay by a range of fraction of a second to 8 seconds. This reflects that using one equivalent value for HV does not reflect their real impact on signalized intersections.

Table (4) Relation between delay and HV% for Type 1 intersection

Case	Volume	Relation between delay and HV%	R^2
1	100	y = 0.0096x + 8.0917	0.98
	500	y = 0.1617x + 11.171	0.95
	700	y = 1.8386x + 12.112	0.93
	1000	y = 6.5394x + 249.5	1.00
2	100	y = 0.01x + 7.5815	0.99
	500	y = 0.2154x + 10.968	0.94
	700	y = 2.833x + 17.93	0.97
	1000	y = 7.2307x + 333.64	1.00
3	100	y = 0.0087x + 7.1743	0.99
	500	y = 0.2842x + 10.653	0.94
	700	y = 3.6864x + 35.079	1.00
	1000	y = 8.1267x + 426	1.00
4	100	y = 0.0106x + 8.1777	0.99
	500	y = 0.5835x + 11.864	0.94
	700	y = 4.7647x + 88.437	1.00
	1000	y = 7.5878x + 350.22	1.00
5	100	y = 0.0103x + 7.6696	0.98
	500	y = 0.9715x + 11.355	0.92
	700	y = 5.2712x + 137.75	1.00
	1000	y = 8.0137x + 403	1.00
6	100	y = 0.0107x + 7.2751	0.99
	500	y = 1.4973x + 11.144	0.92
	700	y = 5.6976x + 189.44	1.00
	1000	y = 8.562x + 457.95	1.00
Y = Delay in sec., X = 100 * HV%			

Table (5) Relation between delay and HV% for Type 2 intersection

Case	Volume	Relation between delay and HV%	R^2
1	100	y = 0.0071x + 7.8557	0.99
	500	y = 0.0453x + 9.5605	0.99
	700	y = 0.1533x + 10.832	0.94
	1000	y = 2.3656x + 11.965	0.95
2	100	y = 0.0064x + 7.3639	0.96
	500	y = 0.0472x + 8.9455	0.99
	700	y = 0.2033x + 10.533	0.94
	1000	y = 3.3009x + 21.801	0.99
3	100	y = 0.0056x + 6.9351	0.96
	500	y = 0.0506x + 8.2634	0.99
	700	y = 0.3018x + 10.915	0.95
	1000	y = 4.1339x + 44.386	1.00
4	100	y = 0.0056x + 7.9567	0.87
	500	y = 0.084x + 10.17	0.97
	700	y = 0.5844x + 11.321	0.93
	1000	y = 3.578x + 26.923	0.99
5	100	y = 0.0053x + 7.4674	0.93
	500	y = 0.0935x + 9.7325	0.96
	700	y = 0.93x + 10.263	0.92
	1000	y = 4.1984x + 45.839	1.00
6	100	y = 0.0057x + 7.0238	0.98
	500	y = 0.0999x + 8.9446	0.95
	700	y = 1.3165x + 10.993	0.91
	1000	y = 4.7359x + 75.426	1.00
Y = Delay in sec., X = 100 * HV%			

4. CONCLUSION

The main conclusions of this research are:

1. The delay time at signalized intersection is sensitive to the presence of heavy vehicles in the high traffic volumes only.
2. With increasing heavy vehicle percentage, delay time increases gradually until definite range, and then the rate of increase in the delay increases rapidly.
3. Based on the finding, it can be concluded that the traffic volumes of 500 vph or less for through traffic can be considered low volume for two lanes approach and 700 vph or less for through traffic for three lanes approach, as these volumes resulted in handling HV% up to 50% for most of the cases without downgrading LOS.
4. In low traffic volumes, the percentage of traffic turn left or right doesn't affect delay time at intersection. However in high traffic volumes, when the percentage of traffic bearing left or right increases the delay time increases clearly.
5. With adding a lane to an intersection has two lanes in each approach, the delay time becomes lower, level of service becomes better and the intersection can handle higher percentage of HV without degrading the LOS. The delay time can be reduced by range from 73% to 85% with adding one lane.
6. Using permitted phase instead of split phase reduces the delay by range from 78% to 80%. Similarly, using permitted phase instead of protected phase reduces the delay by range from 73% to 91%.
7. Using protected phase is better than split phase until the delay reach 80 sec, then for higher delays, using split phasing provided lower delay than protected phasing.
8. Mathematical models were developed for predicting the delay time in two and three lanes approach and in case of permitted phase. The models showed that Impact of HV% on delay varied from 0.005*100* HV% to 8.5*100*HV%, depending on the case of analysis and traffic volume.

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