STYDYING THE INFULENCE OF HEAVY TRANPORTATION VEHICLES IN CONGESTED URBAN TRAFFIC NETWORK USING TRAFFIC SIMULATIONS

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***Abstract*:** Modern cities have highly congested road network with issues and problems that requires to be solved. Problems will rise higher when there is an increased presence of heavy transportation vehicles like trucks and buses. These types of vehicles will increase the congestion in traffic with higher number of stops, delays and blockades. This will require solutions particularly in intersections, whether they are signalized or non-signalized in order to have the best movement scenarios and optimized traffic flow. The study will be done based on the survey of one of most congested streets of Prishtina city, capital of Kosova, where the presence of heavy vehicles, particularly buses, is high up to 20 %÷ 25% during peak hours (≈ 8 AM and ≈ 5 PM), and by modelling the street and doing simulations with traffic software in order to have results that can be implemented in practice.

Keywords: HEAVY VEHICLES, URBAN TRAFFIC, CONGESTION, INTERSECTION, MODELLING, SIMULATIONS

1. Introduction

Study will be done based on the surveys and measurement of several traffic parameters taken in one part of the street – a signalized intersection. This Intersection is shown on the Fig.1, 2, 3. It is one of main Intersections of Prishtina, type of cross-intersection with traffic lights and with double and triple lanes in both directions. This Intersection is crosslink between Agim Ramadani Str. In North-South Direction and Eqrem Qabej Str. In East-West direction. Surveys were done in two times of day (8÷9 AM) and (5÷6 PM), which are considered peak hours of traffic circulation and congestions. Traffic flow reaches up to 1100 vph, which is higher than the capacity limits. The Intersection is regulated with traffic lights on three signal phases. All left turns and right turns are permitted on green phase of through lanes. Another specific of this Intersection is high percentage of heavy vehicles. Heavy vehicles are considered light, medium and heavy trucks and all types of buses. These vehicles are considered to cause delays, stops and queues in urban networks. The aim of this work is to study the negative influence of high presence of heavy vehicles in overall network parameters. Study will be accomplished by using software for traffic calculations, modeling and simulations called *Trafficware 6.65 software* [1].

Fig. 1. Interesection view

2. *Input Parameters*

Input parameters are given for each lane group. From our surveys, presence of heavy vehicles is up to 25% of all vehicles in intersection during the peak hours for some lanes, mainly in North-South direction (SBT,NBT) and West-North turn (EBL) – Fig 3. Input parameters of surveys are shown on Fig.4 and Table.1. All these parameters are fed in software in order to have results and do simulation. Results will be given by doing comparison between theoretical normal presence of heavy vehicles and high presence of heavy vehicles gained by surveys. Results will be discussed based on macroscopic and microscopic approach.

We will approve the acronyms for our study case:

- High presence of heavy vehicles – **hphv.**
- Normal presence of heavy vehicles – **nphv.**

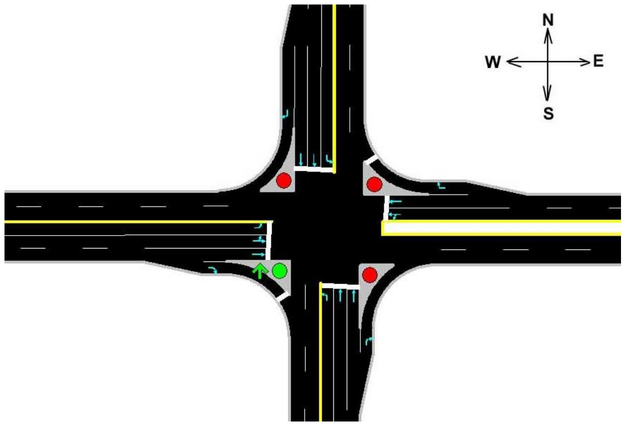


Fig. 2. Model of Intersection

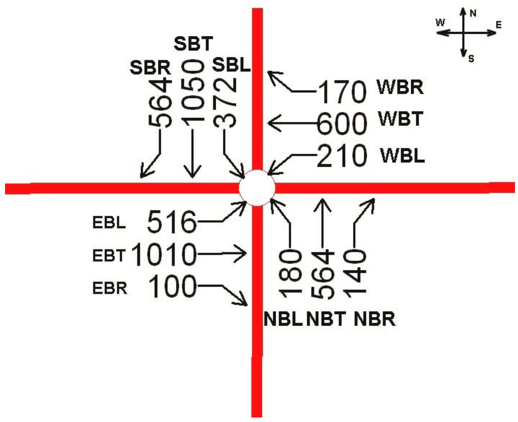


Fig.3. Traffic flow in Intersection for lane groups (vehicles/hour or vph)

Input Parameters that are influential for our case, from Table.1 are *Heavy Vehicles (%) and Bus Blockages (#/hr)*. Normal presence of heavy vehicles (nphv) is considered when they consist of 2%, and bus blockages are 0 for each lane, and high presence of heavy vehicles (hphv) means max 25% of heavy vehicles and max 18 bus blockages for particular lanes. The study will be done mainly by comparing these two situations and discuss the gained results through software calculations and simulations of movements.

LANE WINDOW	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lanes and Sharing (#RL)												
Ideal Satd. Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Lane Width (m)	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Grade (%)	—	15	—	—	-15	—	—	-15	—	—	15	—
Area Type	—	CBD	—	—	CBD	—	—	CBD	—	—	CBD	—
Storage Length (m)	70.0	—	16.0	0.0	—	20.0	50.0	—	16.0	50.0	—	30.0
Storage Lanes (#)	1	—	1	—	—	1	1	—	1	1	—	1
Total Lost Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Leading Detector (m)	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2	15.2
Trailing Detector (m)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Turning Speed (km/h)	30	—	30	30	—	25	24	—	25	24	—	30
Right Turn Channelized	—	—	Signal	—	—	Signal	—	—	Signal	—	—	Signal
Curb Radius (m)	—	—	15.2	—	—	15.2	—	—	15.2	—	—	15.2
Add Lanes (#)	—	—	0	—	—	0	—	—	0	—	—	0
VOLUME WINDOW	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Traffic Volume (vph)	516	1010	100	210	600	170	180	564	140	372	1050	564
Conflicting Peds. (#/hr)	12	—	10	0	—	10	0	—	10	0	—	5
Conflicting Bikes (#/hr)	—	—	0	—	—	0	—	—	0	—	—	0
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Growth Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Heavy Vehicles (%)	22	5	14	4	10	3	12	25	2	4	25	18
Bus Blockages (#/hr)	15	2	10	2	5	2	10	18	1	2	18	15
Adj. Parking Lane?	No	No	No	No	No	No	No	No	No	No	No	No
Parking Maneuvers (#/hr)	—	—	—	—	—	—	—	—	—	—	—	—
Traffic from mid-block (%)	—	0	—	—	0	—	—	0	—	—	0	—
Link OD Volumes	—	—	—	—	—	—	—	—	—	—	—	—

Table.1 Main input parameters for Intersection in case of high presence of heavy vehicles (hphv)

VOLUME WINDOW	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Traffic Volume (vph)	516	1010	100	210	600	170	180	564	140	372	1050	564
Heavy Vehicles (%)	2	2	2	2	2	2	2	2	2	2	2	2
Bus Blockages (#/hr)	0	0	0	0	0	0	0	0	0	0	0	0

Table.2. Main input parameters for Intersection in case of normal presence of heavy vehicles (nphv). Other parameters remain same as in Table.1

3. Macroscopic Results of Calculations

Macroscopic calculations are done for wide traffic networks where the output parameters are influential terms that affect the network performance in general. It is considered that higher presence of heavy vehicles will influence the flow rate. After applying input parameters, we received result of output parameters. Calculations are done with the module of software *Synchro6*.

After the calculations, main output parameters for each lane group are shown for both cases in Table 3 and Table 4.

LANE WINDOW	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Utilization Factor	0.91	0.91	1.00	—	0.95	1.00	1.00	0.95	1.00	1.00	0.95	1.00
Right Turn Factor	1.000	1.000	0.850	—	1.000	0.850	1.000	1.000	0.850	1.000	1.000	0.850
Left Turn Factor (prot)	0.950	0.996	1.000	—	0.987	1.000	0.950	1.000	1.000	0.950	1.000	1.000
Saturated Flow Rate (prot)	1007	2565	1082	—	3007	1438	1430	2574	1458	1370	2215	1023
Left Turn Factor (perm)	0.950	0.996	1.000	—	0.987	1.000	0.133	1.000	1.000	0.280	1.000	1.000
Right Ped Bike Factor	1.000	1.000	0.971	—	1.000	0.971	1.000	1.000	0.971	1.000	1.000	0.979
Left Ped Factor	0.994	0.999	1.000	—	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Saturated Flow Rate (perm)	1000	2563	1050	—	3007	1396	200	2574	1415	404	2215	1002
Right Turn on Red	—	—	No	—	—	No	—	—	No	—	—	No
Saturated Flow Rate (RTOR)	0	0	0	—	0	0	0	0	0	0	0	0
Headway Factor	1.44	1.34	1.40	1.11	1.12	1.12	1.16	1.16	1.11	1.35	1.40	1.44
Adjusted Flow (vph)	561	1098	109	228	652	185	196	613	152	404	1141	613
Lane Group Flow (vph)	462	1197	109	0	880	185	196	613	152	404	1141	613
Actuated Effct. Green (s)	33.0	33.0	33.0	—	19.0	19.0	30.0	30.0	30.0	30.0	30.0	30.0
Actuated g/C Ratio	0.35	0.35	0.35	—	0.20	0.20	0.32	0.32	0.32	0.32	0.32	0.32
Volume to Capacity Ratio	1.31	1.33	0.30	—	1.45	0.66	3.06	0.75	0.34	3.13	1.61	1.92
Control Delay (s)	185.4	184.6	24.9	—	241.2	46.9	984.8	35.3	27.0	995.7	309.2	447.2
Queue Delay (s)	0.0	0.0	0.0	—	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay (s)	185.4	184.6	24.9	—	241.2	46.9	984.8	35.3	27.0	995.7	309.2	447.2
Level of Service	F	F	C	—	F	D	F	D	C	F	F	F
Approach Delay (s)	—	175.0	—	—	207.4	—	—	227.6	—	—	476.9	—
Approach LOS	—	F	—	—	F	—	—	F	—	—	F	—
Queue Length 50th (m)	~119.2	~155.9	14.1	—	~115.2	31.1	~62.4	51.8	20.9	~109.2	~157.5	~172.3
Queue Length 95th (m)	#182.3	#197.1	27.7	—	#152.1	#57.0	#94.9	71.9	37.2	#165.1	#196.8	#235.4
Stops (vph)	329	873	71	—	622	153	141	492	104	290	767	398
Fuel Used (l/hr)	131	340	18	—	288	35	159	89	21	326	364	255

Table.3. Results of output parameters for high presence of heavy vehicles

LANE WINDOW	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Utilization Factor	0.91	0.91	1.00	—	0.95	1.00	1.00	0.95	1.00	1.00	0.95	1.00
Right Turn Factor	1.000	1.000	0.850	—	1.000	0.850	1.000	1.000	0.850	1.000	1.000	0.850
Left Turn Factor (prot)	0.950	0.999	1.000	—	0.987	1.000	0.950	1.000	1.000	0.950	1.000	1.000
Saturated Flow Rate (prot)	1281	2694	1260	—	3229	1464	1636	3272	1464	1408	2815	1260
Left Turn Factor (perm)	0.950	0.999	1.000	—	0.987	1.000	0.133	1.000	1.000	0.280	1.000	1.000
Right Ped Bike Factor	1.000	1.000	0.971	—	1.000	0.971	1.000	1.000	0.971	1.000	1.000	0.979
Left Ped Factor	0.994	1.000	1.000	—	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Saturated Flow Rate (perm)	1273	2694	1223	—	3229	1421	229	3272	1421	415	2815	1234
Right Turn on Red	—	—	No	—	—	No	—	—	No	—	—	No
Saturated Flow Rate (RTOR)	0	0	0	—	0	0	0	0	0	0	0	0
Headway Factor	1.33	1.33	1.33	1.11	1.11	1.11	1.11	1.11	1.11	1.33	1.33	1.33
Adjusted Flow (vph)	561	1098	109	228	652	185	196	613	152	404	1141	613
Lane Group Flow (vph)	462	1197	109	0	880	185	196	613	152	404	1141	613
Actuated Effct. Green (s)	33.0	33.0	33.0	—	19.0	19.0	30.0	30.0	30.0	30.0	30.0	30.0
Actuated g/C Ratio	0.35	0.35	0.35	—	0.20	0.20	0.32	0.32	0.32	0.32	0.32	0.32
Volume to Capacity Ratio	1.19	1.19	0.25	—	1.35	0.64	2.68	0.59	0.33	3.06	1.27	1.56
Control Delay (s)	134.6	125.6	23.8	—	198.6	46.1	814.1	29.6	27.0	963.7	160.5	289.3
Queue Delay (s)	0.0	0.0	0.0	—	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay (s)	134.6	125.6	23.8	—	198.6	46.1	814.1	29.6	27.0	963.7	160.5	289.3
Level of Service	F	F	C	—	F	D	F	C	C	F	F	F
Approach Delay (s)	—	122.0	—	—	172.1	—	—	189.2	—	—	347.4	—
Approach LOS	—	F	—	—	F	—	—	F	—	—	F	—
Queue Length 50th (m)	~129.1	~136.2	13.9	—	~110.7	31.0	~60.6	48.5	20.8	~128.4	~138.4	~158.2
Queue Length 95th (m)	#195.1	#176.7	26.8	—	#147.6	#54.3	#91.4	65.8	37.1	#163.8	#177.6	#221.3
Stops (vph)	396	857	70	—	643	153	133	458	104	287	849	420
Fuel Used (l/hr)	133	274	18	—	262	35	136	85	21	317	246	187

Table.4. Results of output parameters for normal presence of heavy vehicles

After comparison of calculations between Table 3 and Table 4 we notice that some important output parameters change notably between two cases. These parameters are shown in Table 5.

%	EBL	EBT	EBR	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
SFR	-27.3	-5.11	-16.4	-7.38	-1.8	-14.5	-27.11	-0.4	-2.7	-27	-0.23
v/c	10	11.7	-20	7.4	3.1	14.1	27.1	-2.3	2.28	26.7	23
AD		43.4		20.5			20.3			37.2	
QL	-8.3	14.4	1.4	4	0.3	3	6.8	0.5	-17.5	26.8	8.9

Table.5. Difference of results between hphv and nphv in % (hphv-nphv)

From Table.5, acronyms are: **SFR**-Saturated flow rate (perm), **v/c**-Volume to capacity ratio, **AD**-Aproach Delay, **QL** – Queue Length (50^{th}). These are the parameters that are most influenced from the results from table 3 and table 4. Results on Table 5 are given for each group lane. The values of percentage shows the difference between *hphv* and *nphv*.

Saturated flow rates (SFR) [1,3]– are a very important road traffic performance measure of the maximum rate of flow of traffic. The saturated flow rates represent the number of lanes multiplied by the Ideal Saturated Flow Rate (1900 vphpl) and interference factors due to heavy vehicles, buses, parking maneuvers, lane widths, area type, grade, and turning movements. It is maximum number of vehicles per hour per lane when flow is saturated. There is a permitted and a protected saturated flow rate. For left and through lane groups the permitted rate is used when left turns are permitted and the protected rate is used when left turns are protected. Same goes for right turns. For our case of comparison lower saturated flow rates represents lower number of vehicles per hour that pass through intersection. In Table 5 rates are lower for hphv compared to nphv, almost in all group lanes. For some lane directions (EBL, NBT and SBT) the difference is more than 27%, which means that 27% less vehicles pass through intersection per hour when we have high presence of heavy vehicles against the normal presence of heavy vehicles. While the traffic volume (vph) as an input parameter is the same for both cases, this result of SFR is very negative for traffic flow in intersection .

Volume to Capacity Ratio (v/c) [1,2,3] **–** is the ratio using actuated green times and cycle lengths. The v/c ratio indicates the amount of congestion for each lane group. Any v/c Ratio greater than 1 indicates that the approach is operating at above capacity.

Almost all the lanes have v/c ratio above 1 which means that intersection is already working above its capacity. Based on the result from Table.5, v/c for hphv is higher in most cases of lane directions. For NBT, SBT and SBR, which are the lanes with highest traffic volume (vph), v/c ratio for hphv is higher than for nphv for about 27%, meaning that lanes with high presence of heavy vehicles are operating with increased above capacity than those with normal presence of heavy vehicles. This is another negative result of hphv in traffic.

Approach Delay (AD) [1,3] **–** is measured in seconds. This is the delay for the entire approach. It is a volume weighted average of the Total Delays for each Lane Group. The delay is for the movement, not lane group. Based on the results of Table 5, approach delays are higher for hphv then for nphv, meaning that vehicles that approach intersection for the case hphv have to wait longer in line compared to those with nphv. EBT and SBT lanes which have highest traffic volume (vph) are highest in percentage with delays.

Queue Length (50^{th}) (QL) – The Queue Length rows show the 50^{th} Percentile and 95^{th} Percentile Maximum Queue lengths and is measured in meters. The 50^{th} percentile maximum queue is the maximum back of queue on a typical cycle. If the upstream intersection is at or near capacity, the 50^{th} percentile queue represents the maximum queue experienced. From Table.5, Queue Length is longer in % for most of lanes for the case of hphv, notable for EBT and SBT, but is lower for two lanes - EBL and SBT. For these two lanes, queue lengths are longer in case of nphv.

4. Results of simulations

Simulations is a part which will give us more efficient results for influence parameters in total for macroscopic results, but also and will enable to have microscopic results. Simulations will be done using the module of software called *Simtraffic*, for entire network – intersection by recording movements of vehicles and passengers in time intervals of 10 min.

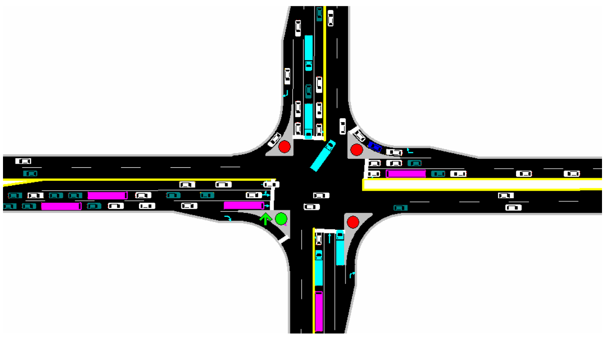


Fig.4. Simulations view

After simulations have been applied for both cases, reports have been generated, which gives better view of results. Results are given for total network performance. After looking the reports for both cases, we generated comparative table.6 with main output results.

	hphv	**nphv**	Difference in % (hphv-nphv)
Total Time of simulation (min)	13	13	
Time Recorded (min)	10	10	
Vehicles Entered	858	943	-9.01%
Vehicles Exited	578	586	-1.37%
Hourly Exit Rate	3468	3516	-1.37%
Total Delay (hr)	40.3	37.8	6.61%
Delay / Veh (s)	202.2	178.2	13.47%
Stop Delay (hr)	28.8	26.9	7.06%
Total Stops	1741	1779	-2.14%
Stop/Veh	2.42	2.33	3.86%
Avg Speed (kph)	23	24	-4.17%
Fuel Used (l)	425	318	33.65%
HC Emissions (g)	229	205	11.71%
CO Emissions (g)	4790	4878	-1.8%
NOx Emissions (g)	533	479	11.27%
Denied Entry Before	2	1	100.00%
Denied Entry After	34	0	38 veh

Table 6. Comparative results after simulations

Results on table.6, are interesting results, and we will comment the meaning of them.

Vehicles entered and exited - are less in count for *hphv* than *nphv*. Ths means that fewer vehicles enter the intersection for the case of hphv (-9.01%) and even less exit the intersection in 10 minutes of recording of traffic during peak hours. Also hourly exit rate is less for *hphv* than for *nphv* (-1.37%). This creates longer time of waiting for *hphv* and is negative for traffic flow.

Delays – All the results for delays which includes Total Delay (hr), Delay / Veh (s) and Stop Delay (hr) are higher for the case of hphv, with max of Delays per vehicle which reaches 13.47% higher than nphv. This proves that delays of *hphv* increase the congestion in traffic more than *nphv* and influence negatively in traffic flow.

Stops – Stops are the number of stops per hour. Total stops are less in number for hphv (-2.14%). This is due to higher number of vehicles that enter and exit the intersection for the case of nphv, which means that higher number of vehicles gives higher number of stops. But, if we compare stops/veh, we see that hpvh has higher stops per vehicle for 3.86%. This gives interesting conclusion: *intersection that has less number of total vehicles that enter and exit but higher number of heavy transportation vehicles in percentage will have higher number of stops/vehicle compared to the intersection that has higher number of total vehicles that enter and exit but less number of heavy transportation vehicles*.

Fuel – This parameter shows the fuel consumption of all vehicles in the network, and is measured in litters. Result shows that fuel used in hphv is 33.65% higher than for nphv. While heavy transportation vehicles consume more fuel, their higher presence in traffic means higher fuel consumption and more pollution of environment, particularly in the area around the intersection.

Emissions – Represents the emission of gases in air in grams. The emissions calculations are based only on fuel consumption. The meaning of three types of emission are: CO = Carbon Monoxide Emissions (g); NOx = Nitrogen Oxides Emissions (g); HC = Hydrocarbon Compounds Emissions (g); F = Fuel Consumption (lit). Based on the results form the table, emissions of HC and NOx are higher for hphv for more than 11%, and slightly lower for CO.

Vehicles Denied Entry – Represents the number of vehicles that are denied entry at the upstream end of each entry link and mid-block for each source. Vehicles are denied entry when there is insufficient capacity, when blocking prevents vehicles from entering the network, or when there are no gaps for vehicles to enter mid-block. From the table 6, we can see that for the case of *Denied Entry Before* for hphv we have 2 vehicles that were denied entry, compared to one for nphv. But, for the case of *Deined Entry after* there is a proportion 34 to 0 for hphv, which means that during hphv a lot of vehicles get blocked in intersection, compared to nphv when we have no vehicle blocked. This is negative result for traffic flow.

Avg Speed – Represents the average speed of all vehicles in intersection, measured in kilometers per hour (kph). The speed is slightly lower for hphv for 4.17 % than for nphv. This difference is better shown in Fig.5 and Fig.6 as a comparison per each lane. Speed shows differences for some lanes for both cases.

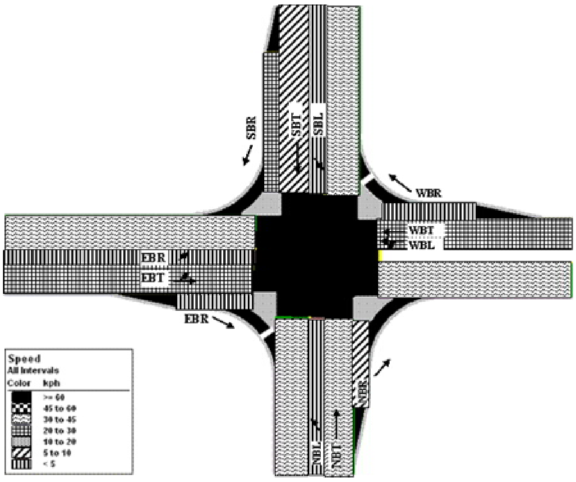


Fig. 5. Average speeds per lanes for the hphv

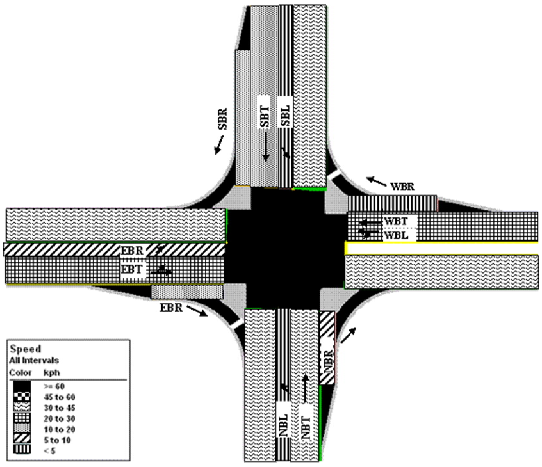


Fig.6. Average speeds per lanes for the nphv

On Fig.5 and Fig.6, is shown speed for each lane with different pattern, each pattern representing a speed interval. Lanes that are different in speed are:

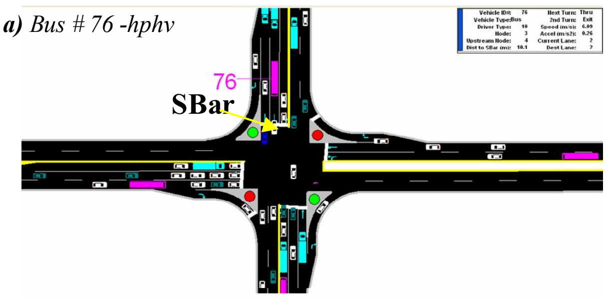
SBT = 5 to 10 kph of hphv is slower in speed compared to SBT = 10 to 20 kph of nphv.

Lanes EBT <5, EBR<5 of hphv are slower in speed than EBT = 5 to 10, EBR=10 to 20 of nphv.

Lane SBR=20 to 30 of hphv is faster then SBR=10 to 20 of nphv. This is a bit surprising result. Other lanes show same pattern of speed intervals.

4.1. Microscopic study

Microscopic study is part of Microscopic Simulation. *Simtraffic* simulates the behavior of each vehicle every 0.5 seconds and gives the results of: distance to the stop bar (Sbar), speed, acceleration, position in the lane, etc. On the Fig.7,a,b is given the simulation comparison between two vehicles – a bus #76 for *hphv* and a car #74 of *nphv*, for the lane SBT, when they approach and exit the Sbar. The parameter that will be compared is the speed of vehicles.



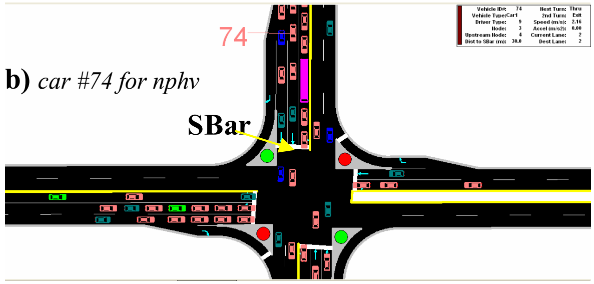


Fig.7. Comparision of two vehicles: a)- bus #76 for hphv and b)-car #74 for nphv

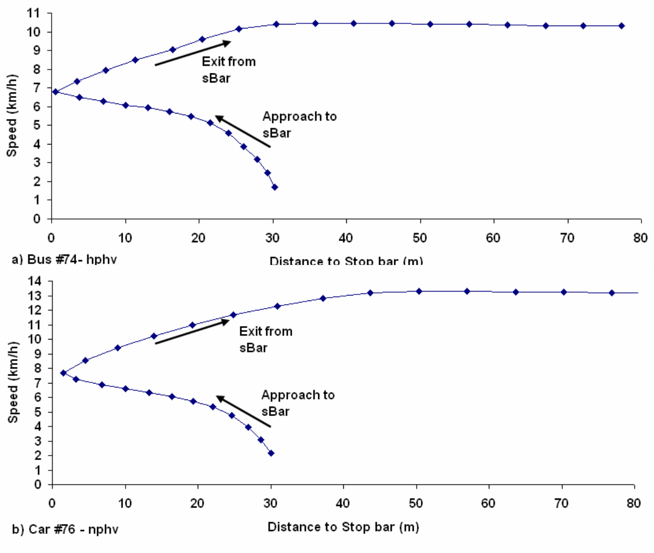


Fig. 8. Graph of speed of vehicles: a)- bus #76 for hphv and b)-car #74 for nphv

Fig.8 represents the graphs of speed of both vehicles, while approaching the sBar and exiting the sBar, during the green phase. The curves of graphs are similar, but the speed is different. a)-For bus of *hphv*, average speed for approach is 4.74 m/s, and for exit is 9.77 m/s. b)- For car of *nphv*, average speed for approach is 5.27 m/s, and for exit is 12.23 m/s. Bus is slower for 10% on approach, and 25.1% slower on exit than the car. This is another prove that heavy vehicles slows the traffic flow.

5. Conclusions

As a final conclusion, higher presence of heavy vehicles creates increased negative effects in congested urban networks, and we showed this by comparing various output parameters. This higher presence does negatively effect in the flow rates, creates increased delays and stops for vehicles, longer queues, higher consumption of fuel, lower speeds on lanes, etc. Results were shown as comparisons between two cases- one with high presence of heavy vehicles and other with theoretical normal presence of heavy vehicles, in percentage difference based on macroscopic and microscopic simulations. The results gained can be used to take further steps on resolving issues like this in congested traffic. For the current Intersection that was studied, we conclude that it already works above capacity, and heavy vehicles are worsening its functionality. We can conclude that using simulation software can be very useful to study problems of traffic networks.

6. Literature

[1] *Trafficware Simtraffic 6 help & user guide.*
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[3] *Highway Capacity Manual 2000*, TRB, National Academy of Sciences, 2000.