Influence of Syncronizing Traffic Lights on Fuel Consumption and Air Pollution: A Simulation by AIMSUN

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Abstract: With population growth and land use developments as well as higher per-capita vehicle ownership in metropolitans, travel demand and traffic volume has been increased on urban streets. Traffic lights are effective to make order in movements in intersections to control vehicle movements. However, further increasing the flow through the intersection, if inappropriate settings for the lights, the amount of delay for most vehicles will be increased and as a result, their effectiveness will be lowered. This will have consequences like high fuel consumption and air pollution. Having syncronized traffic lights in a path, so called Green Wave, one can pass all traffic through it in a shorter time and observe significant decline in air pollution and fuel consumption. A case study undertook on three signalized intersections in Jomhuri Street between Vali-asr and Ferdowsi which have suitable distances and requirements for Green Wave. The results indicate 27% more decline in air pollutant emissions and also 20% more decline in fuel consumption in selected pass ways than before synchronization.
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1. Introduction

With population growth and land use developments as well as higher per-capita vehicle ownership in metropolitans, travel demand and traffic volume has been increased on urban streets. Travel time is among parameters has been transformed to one of the most important problems and challenges in metropolitans and its decline is significant in urban traffic and transportation [1].

Traffic lights are effective in making order for movements on intersections via controlling vehicle movements. However, with more and more passing flows from these intersections, the delay applied for any vehicle is increased and as a result their effectiveness has been decreased in isolated state. Effectiveness decline of traffic lights has some implications such as air pollution and fuel consumption increases which endanger human health in addition to irreversible environmental impacts. Also, with regard to limited sources of fossil fuels and high costs of gasoline production, it should be solved by effective methods beside other problems. Based on 2010 US TTI report, every driver passes annularly average 34hr extra times in the traffic on US pass ways. This loss of time will impose the average cost of 808USD on the country including the loss of fuel [2 and 3].

One method to speed up vehicles and reduce imposed delay on traffic grid intersections is synchronization of traffic lights. Via synchronization of traffic lights on a path, or Green Wave, total traffic will be passed by lower time than the case where the signals come to act separately.

2. Study purposes

The purposes of synchronization are to provide conditions for more vehicles to pass from a path with minimum delay and stop time. Ideally, it is expected each vehicle entering a grid can exit with minimum stops. This, in addition to travel time decline, is accompanied by fuel consumption and air pollution declines. Therefore, it has been tried in this study that following purposes are obtained considering synchronized system of traffic using traffic simulation [4]:

1. The impacts on travel time;
2. The impact on vehicle fuel consumption and
3. The effect on air pollutants.

3. Methodology

As it has been seen in the introduction, this study is defined in four steps:

1. Understanding the current situation.
   This section includes the followings:
   - Determining the area range;
   - Field and statistic data collection and
   - Providing required maps.
2. Modeling and analysis of current situation and getting required outputs from AIMSUN software [5 and 6].
   In this section using data collected from previous step, the analysis of current situation is undertaken. Main activities in this step are simulating pass ways grid and intersections in the study area. Having constructed the grid in the software and entered required data, the results for separate intersections are obtained [7].
3. Simulation.

In this step, studied grid will be simulated by Synchro software by means of which optimum time is obtained for signals in the studied area for their synchronization. Having obtained optimum cycles from Synchro, the control for the resulted grid is converted to synchronized state from separate state in AIMSUN and the model is again loaded. In this step, software outputs will be obtained in a synchronized state [8 and 9].

4. Analysis
Final step is devoted to compare the results from two modeled situation and their analysis. Comparing the results, it can be obtained the influence of synchronization for traffic lights and its effect on fuel consumption and pollutant productions is recognized.

4. Project implementation

4.1 Vehicle traffic volumes in the study area

On the Jomhuri axis, six intersections were selected for surveying vehicle volumes and the vehicles were selected manually (field numbering). Required worksheets were designed and used. Station situations have been shown in Figure 1 [10].

Figure 1: Selected stations for data collection about volume and vehicles on the studied axis

Having finished statistical data collection, the data were transferred to Microsoft Excel and used in ordered files to extract required information. A sheet sample is shown in Figure 2.

Operator: Code: 2

Volume	Vehicle type	From	To	Description
103	Ride	10:30	10:45	
214	Taxi and Van			
0	Heavy vehicles			
201	Motorcycle and Bike	10:45	11:00	
134	Ride			
321	Taxi and Van			
2	Heavy vehicles			
174	Motorcycle and Bike	11:00	11:15	
148	Ride			
239	Taxi and Van			
1				
284	Motorcycle and Bike	11:15	11:30	
109	Ride			
191	Taxi and Van			
0	Heavy vehicles			
265	Motorcycle and Bike	11:30	11:45	
139	Ride			
211	Taxi and Van			

Figure 2: An illustration of datasheet for vehicle volumes in Microsoft Excel

Based on the results, peak hours of a.m. and p.m. in the grid are as follows and PHF's and other required parameters have been shown in Table 1:

- A.M.: 10:30-11:30
- P.M.: 16:00-17:00

4.2 Pedestrian volume in the studied area

Among other factors that can be effective on vehicle volume quality and accordingly transportation system performance is pedestrian volume passing on pass ways and important intersections. Therefore, statistical data for pedestrian volume in the studied area is important [11].

Table 1: A review of the results of data for volume and vehicles on the intersections

Num.	Position	Peak hour (a.m.)		Peak hour (p.m.)	
		Volume (PCU)	PHF	Volume (PCU)	PHF
1	Jomhuri-Felestin	3931	0.90	3181	0.84
2	Jomhuri-Vali Asr	7737	0.96	6495	0.97
3	Jomhuri-Razi	3232	0.90	4399	0.90
4	Jomhuri-Hafez	5266	0.96	4683	0.95
5	Jomhuri-30th Tir	6693	0.96	5310	0.88
6	Jomhuri-Ferdosi	7351	0.96	6424	0.94

By analyzing the data collected, a.m. and p.m. peak traffic hours were determined as follows:

- A.M. peak: 11:00-12:00
- P.M. peak: 17:30-18:30

Other data including value, volume of traffic and pedestrians in a.m. and p.m. peak hours and PHF values were obtained in each station (Table 2).

Table 2: The results for pedestrian volume

Num.	Position	a.m. peak hour		p.m. peak hour	
		Volume (persons)	PHF	Volume (persons)	PHF
1	Jomhuri-Vali Asr intersection	3797	0.90	5067	0.94
2	Jomhuri-Hafez intersection	4643	0.94	4417	0.82
3	Jomhuri-Ferdosi intersection	2490	0.94	2772	0.87

4.3 Data collection and analysis for travel time on the studied pass ways

Performance of urban streets is different from rural roads, highways and freeways. Urban streets are responsible for availability provision for neighborhood applications in addition to movement provisions and pass for vehicles. Their social role also should no longer be ignored [12 and 13].

Speed is one of important and basic parameters in traffic flow which applicable in approximately all programs, plans, analyses and traffics. Speed in traffic engineering has different applications and different definitions with regard to the conditions. These definitions are point speed, travel speed, temporal average speed, movement speed, allowable speed, secure speed, design speed, service speed and loop and ramp speed [14 and 15].

Average travel speed in urban streets is called a vehicle speed or average speed of multiple vehicles between two specific points (source and destination) considering the times for force stops between them. This speed is calculated from Eq. (1) [25]:

$$\boldsymbol{v} = \frac{\boldsymbol{L}}{\sum_{j=1}^{n}(\boldsymbol{t_j}/\boldsymbol{n})} \tag{1}$$

Where:

V: average travel speed (Km/h)

L: the distance between source and destination

t_j: travel time for j^{th} vehicle between source and destination (hr)

n: the number of observations (the number of measured speeds)

Average travel speeds on urban streets is dependent on factors including traffic volume, geometric design of streets, the number of traffic lights, their synchronization, their timing and maximum allowable speed [26].

With the increasing volume of traffic, memorability and movement freedom will be limited for vehicles. This limitation reduces displacement speed. Factors like the number of bands, band width, partition and its type, number and design of access roads, parking facilities, uploading and downloading places outside of street, status of marginal parking lots, presence or absence of specific lanes to turn left and right are among the factors effective on geometry design. In order to determine level of service (LoS) on main streets, average travel speed is measured alongside and then using measures presented in Table 3, traffic quality and LoS of the pass way are determined [16, 17, 18 and 19].

Table 3: Traffic quality measure on main urban streets [28]

Rating	**1**	**2**	**3**	**4**
Free flow speed (Km/h)	80	65	55	45
LoS	**Average travel speed (km/h)**			
A	>72	>59	>50	>41
B	>56-72	>46-59	>39-50	>32-41
C	>40-56	>33-46	>28-39	>23-32
D	>32-40	>26-33	>22-28	>18-23
E	>26-32	>21-26	>17-22	>14-18
F	≤ 26	≤ 21	≤ 17	≤ 14

To investigate LoS of the studied axis, collecting data for travel time was conducted as explained in the following.

4.4 Data collection for travel time

In order to collect data for travel time in the continuous area on Jomhuri axis, it is required to specify method, time and paths for data collection at first. One of applied methods for this is to use test vehicle implemented for this study. In this method a test vehicle is used which crosses on specified paths during peak morning, noon and afternoon times with suitable frequency. Driver of the vehicle selects a speed in each time appropriate for traffic flow and a statistical recorder established in the car records the data related to start time, times wasted along the way, the reason and the place of delay and end time for the travel [20, 21 and 22].

Having collected the data, they are transferred to a Microsoft Excel software database to convert to organized files easy to extract the required information. In Figure 3 a view of datasheet is illustrated.

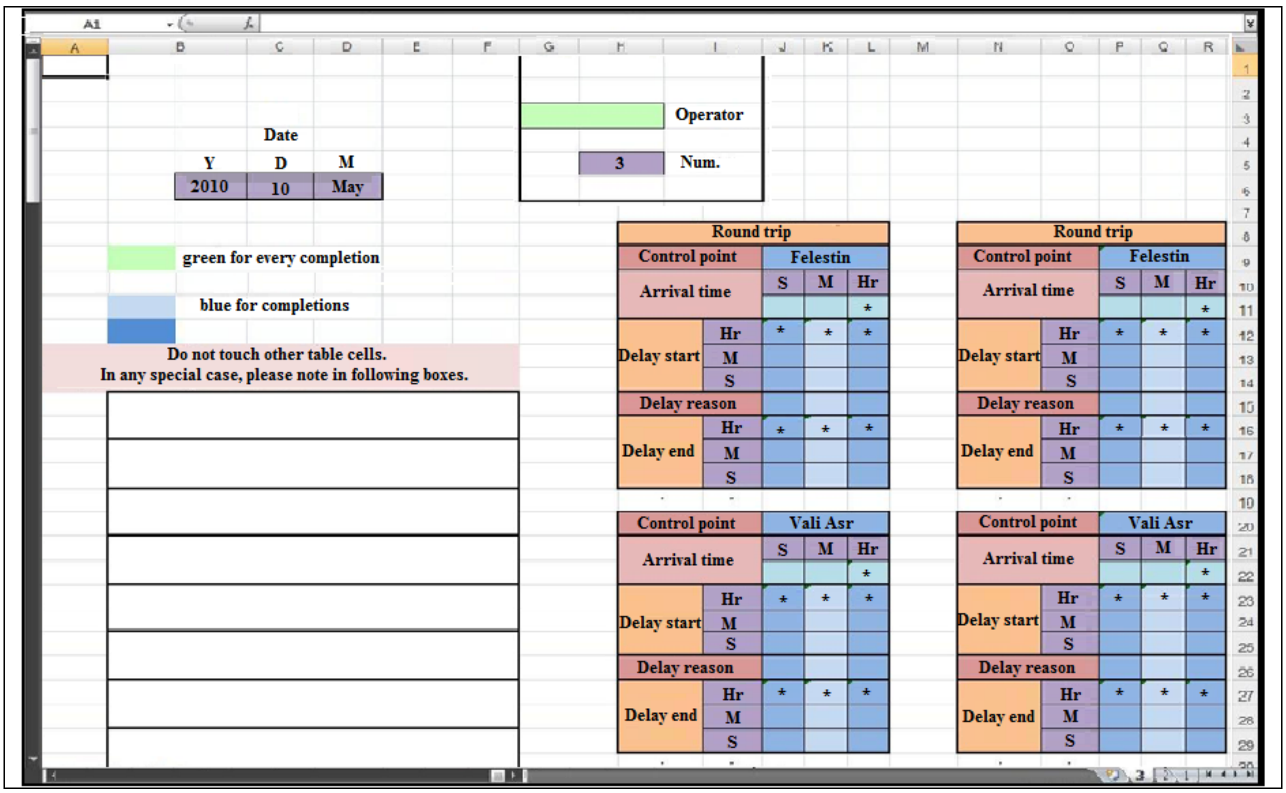


Figure 3: A view of datasheet for travel time in Microsoft Excel software

4.5 Analysis of travel time data in the studied area

Average travel time of vehicles on main ways is considered as one of evaluative measures for traffic performance of urban streets. Beside this measure, average travel time for three transportation modes is calculated in different sections. The results from data collection for travel time including average travel speed and average travel time between control points are indicated in Tables 4 and 5.

Table 4: The results from analyzing data for vehicle travel time in the studied area at a.m. peak

Num.	Control point From	Control point To	Length (m)	Samples	Travel speed (km/h)		Delays (s)		Average speed (km/h)
					Avg.	S.D.	Avg.	S.D.	
1	**Felestin**	**Vali Asr**	198	35	13	11	20	28	21
2	**Vali Asr**	**Sheykh Hadi**	239	35	19	11	7	15	23
3	**Sheykh Hadi**	**Hafez**	460	35	23	15	21	43	32
4	**Hafez**	**30th Tir**	223	35	24	15	4	9	27
5	**30th Tir**	**Ferdosi**	498	35	24	17	21	35	33
6	**Ferdosi**	**Chateau Loshato**	326	35	17	19	25	38	27
7	**Chateau Loshato**	**Hafez**	662	35	25	11	2	6	26
8	**Hafez**	**Razi**	472	35	22	12	8	16	24
9	**Razi**	**Vali Asr**	238	35	11	9	35	37	18
10	**Vali Asr**	**Felestin**	205	35	13	10	18	34	19
11	**Felestin**	**Jomhuri**	178	35	21	8	0	1	24
	Average travel time along Jomhuri axis (go)						18		
	Average travel time along Chateau Loshato axis (back)						20		

Table 5: The results from analyzing data for vehicle travel time in the studied area at p.m. peak

Num.	Control point From	Control point To	Length (m)	Samples	Travel speed (km/h)		Delays (s)		Average speed (km/h)
					Avg.	S.D.	Avg.	S.D.	
1	**Felestin**	**Vali Asr**	198	32	8	12	34	32	14
2	**Vali Asr**	**Sheykh Hadi**	239	32	17	6	7	16	20
3	**Sheykh Hadi**	**Hafez**	460	32	14	14	29	27	19
4	**Hafez**	**30th Tir**	223	32	20	5	4	10	23
5	**30th Tir**	**Ferdosi**	498	32	16	6	37	38	24
6	**Ferdosi**	**Chateau Loshato**	326	32	25	4	0	2	25
7	**Chateau Loshato**	**Hafez**	662	32	23	9	2	4	24
8	**Hafez**	**Razi**	472	32	18	9	15	19	21
9	**Razi**	**Vali Asr**	238	32	7	4	70	46	14
10	**Vali Asr**	**Felestin**	205	32	11	8	9	18	13
11	**Felestin**	**Jomhuri**	178	32	16	5	6	14	18
	Average travel time along Jomhuri axis (go)						13		
	Average travel time along Chateau Loshato axis (back)						17		

4.6 LoS of different sections on the path in the studied area

Free Flow Speed (FFS) on Jomhuri axis and Chateau Loshato are considered 70km/h. Therefore, its rating is 2 among urban pass ways. In order to determine LoS of different sections in the studied area during a.m. and p.m. peak hours, average travel time measure has been used and it has resulted Table 6 [23 and 24].

Table 6: LoS of different sections in the studied area

Num.	Control point From	Control point To	LoS A.M. peak hours	LoS P.M. peak hours
1	**Felestin**	**Vali Asr**	F	F
2	**Vali Asr**	**Sheykh Hadi**	F	F
3	**Sheykh Hadi**	**Hafez**	E	F
4	**Hafez**	**30th Tir**	E	F
5	**30th Tir**	**Ferdosi**	E	F
6	**Ferdosi**	**Chateau Loshato**	F	E
7	**Chateau Loshato**	**Hafez**	E	E
8	**Hafez**	**Razi**	E	F
9	**Razi**	**Vali Asr**	F	F
10	**Vali Asr**	**Felestin**	F	F
11	**Felestin**	**Jomhuri**	F	F

It can be seen that at a.m. and p.m. peak hours, traffic volume along Jomhuri and Chateau Loshato axis is at critical level. Obviously, in such conditions, interference in traffic can result in long delays in movement flow of vehicles.

4.7 Implementing the model in the current situation

As mentioned in previous sections, the purpose of this study is to investigate the influence of synchronizing traffic lights on fuel consumption and air pollution. Thus, studied grid was modeled for current situation and after calibration, AIMSUN software outputs were extracted as shown in Table 7. According to the study subject, three gases (NO_x, HC and CO) have been discussed on air pollution [25, 26 and 27].

Table 7: Summary of outputs from AIMSUN software in available situation

The number of vehicles passing through the grid	8643 veh/hr
The amount of consumed fuel per hour	2769.72lr
CO levels in the air per hour	450.235kg
HC emissions per hour	36.3763kg
NO_x emissions per hour	9.96563kg

Output required diagrams are illustrated in Figures 4-7.

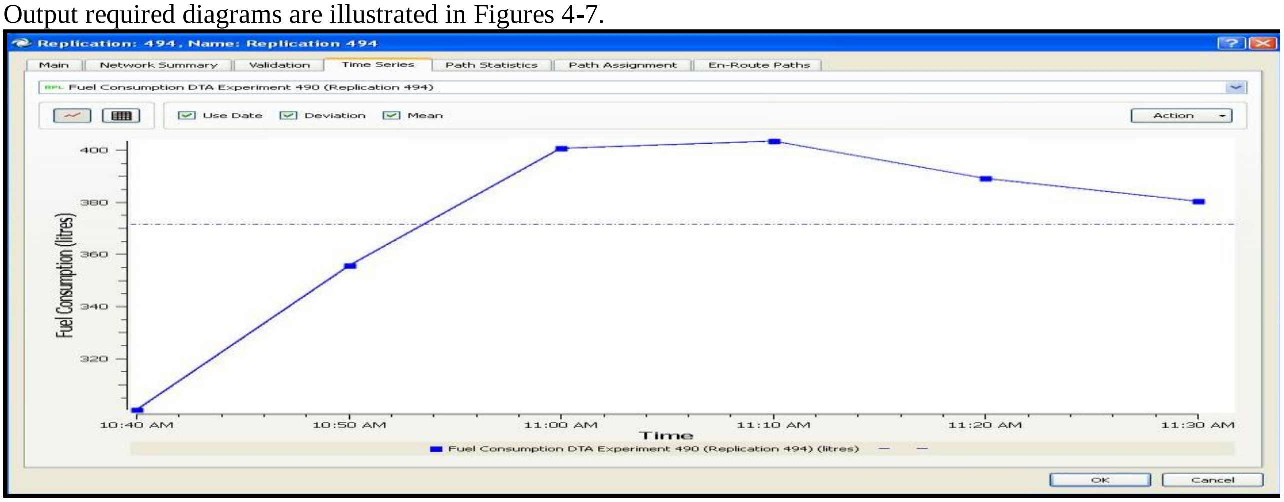


Figure 4: Fuel consumption variations at peak hours diagram in the current situation

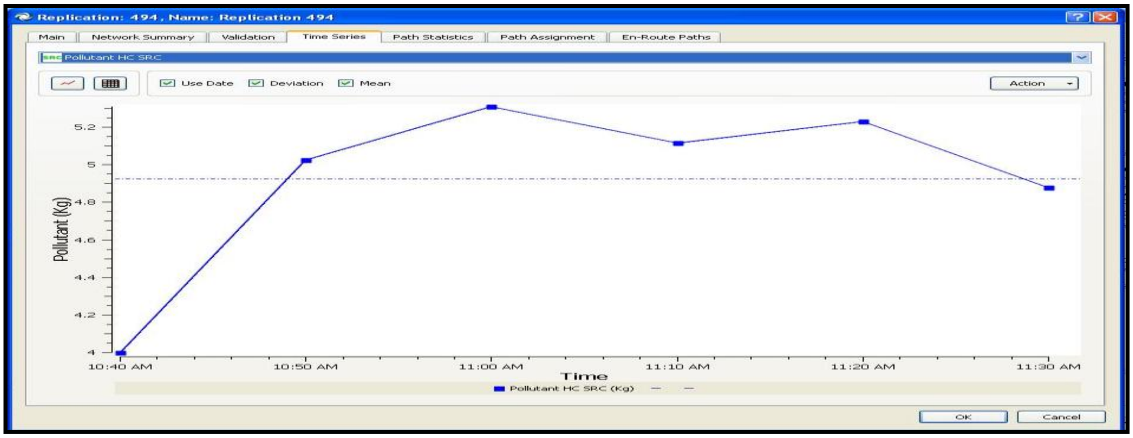


Figure 5: HC emission variations at peak hours diagram in the current situation

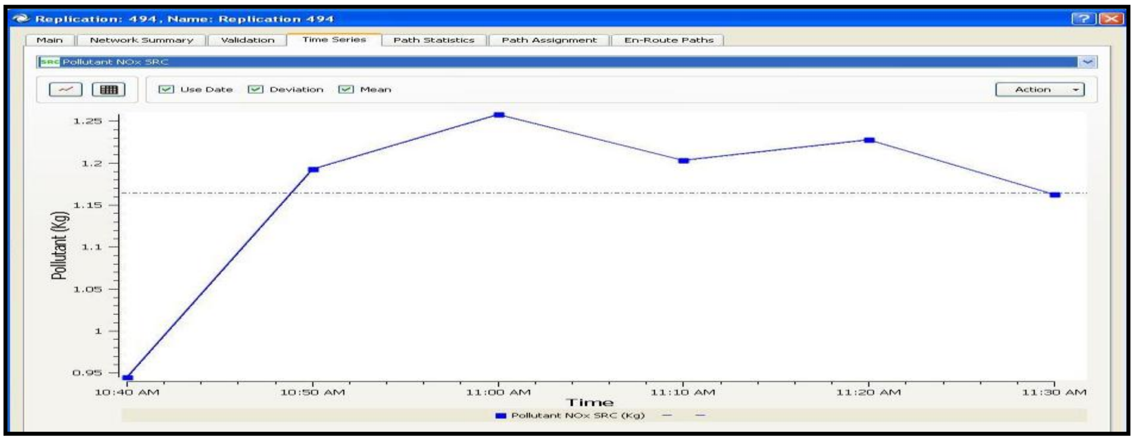


Figure 6: NO_x emission variations at peak hours diagram in the current situation

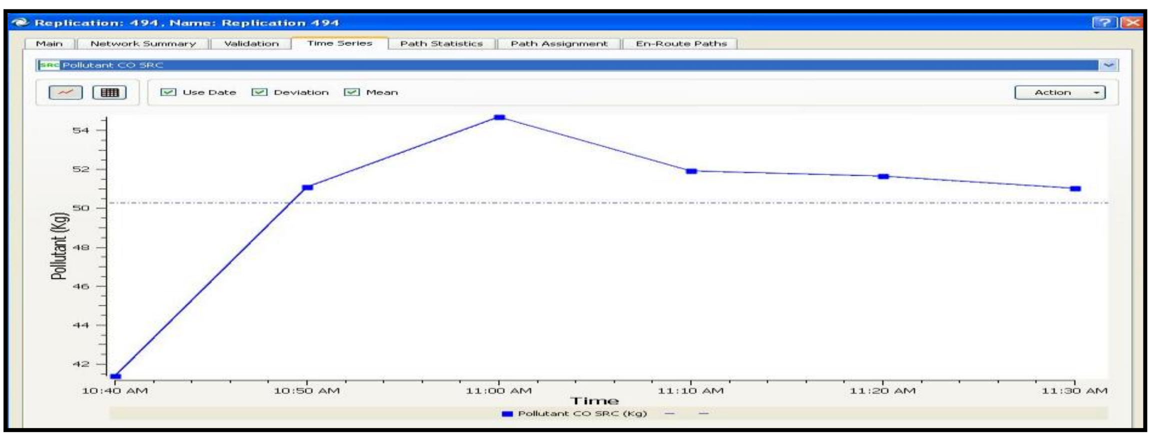


Figure 7: CO emission variations at peak hours diagram in the current situation

4.6 Software outputs after synchronization of traffic lights

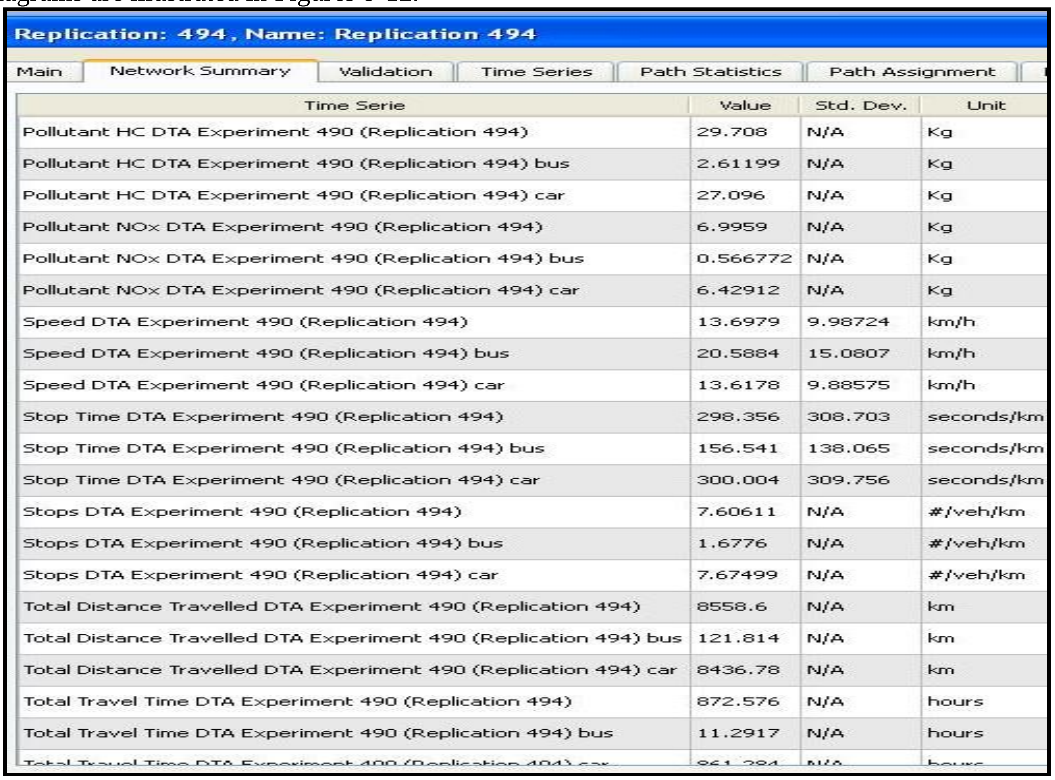
AIMSUN software is designed such that traffic lights established on a path can be adjusted in different and arbitrary states. Synchronizing traffic lights is one of important capabilities of this software. In this study it also has been used to be able to observe and quantify the influences of synchronizing traffic lights on fuel consumption and air pollution.

In the second model for grid structure, number of vehicles, their types and all software settings are unchanged and the same as for current situation. The only change is in the timing of traffic. As indicated, in second model, traffic lights on the studied axis were transferred from fixed to synchronized state and by the way, simulated grid is again run to extract the outputs in this situation. The result rom AIMSUN software outputs are summarized in Table 8 in synchronized state.

Table 8: Summary of outputs from AIMSUN software in synchronized state

The number of vehicles passing through the grid	9229 veh/hr
The amount of consumed fuel per hour	2224.1lr
CO levels in the air per hour	303.242kg
HC emissions per hour	29.708kg
NO_x emissions per hour	6.9959kg

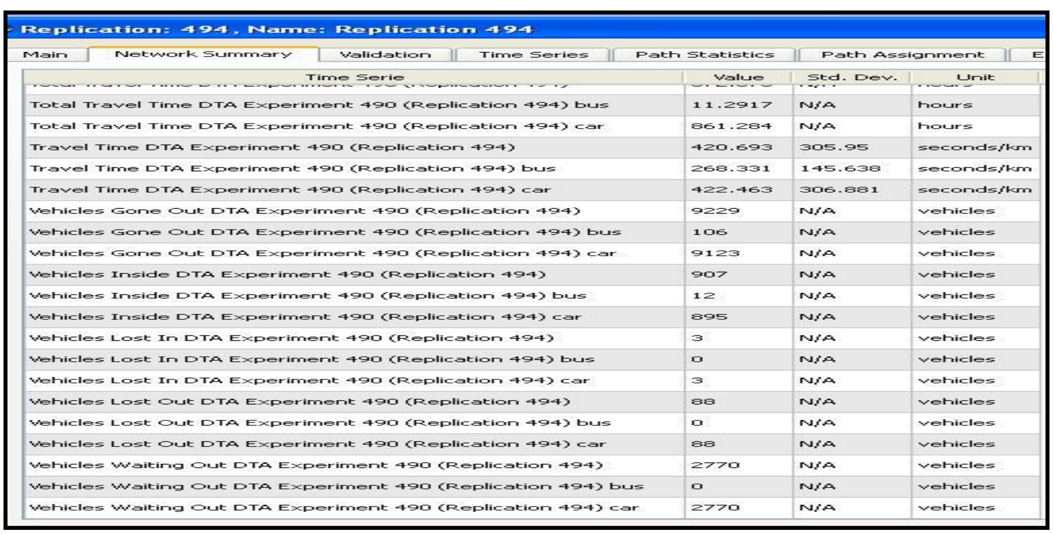
Output diagrams are illustrated in Figures 8-12.


Replication: 494 , Name: Replication 494

Main | Network Summary | Validation | Time Series | Path Statistics | Path Assignment

Time Serie	Value	Std. Dev.	Unit
Pollutant HC DTA Experiment 490 (Replication 494)	29.708	N/A	Kg
Pollutant HC DTA Experiment 490 (Replication 494) bus	2.61199	N/A	Kg
Pollutant HC DTA Experiment 490 (Replication 494) car	27.096	N/A	Kg
Pollutant NOx DTA Experiment 490 (Replication 494)	6.9959	N/A	Kg
Pollutant NOx DTA Experiment 490 (Replication 494) bus	0.566772	N/A	Kg
Pollutant NOx DTA Experiment 490 (Replication 494) car	6.42912	N/A	Kg
Speed DTA Experiment 490 (Replication 494)	13.6979	9.98724	km/h
Speed DTA Experiment 490 (Replication 494) bus	20.5884	15.0807	km/h
Speed DTA Experiment 490 (Replication 494) car	13.6178	9.88575	km/h
Stop Time DTA Experiment 490 (Replication 494)	298.356	308.703	seconds/km
Stop Time DTA Experiment 490 (Replication 494) bus	156.541	138.065	seconds/km
Stop Time DTA Experiment 490 (Replication 494) car	300.004	309.756	seconds/km
Stops DTA Experiment 490 (Replication 494)	7.60611	N/A	#/veh/km
Stops DTA Experiment 490 (Replication 494) bus	1.6776	N/A	#/veh/km
Stops DTA Experiment 490 (Replication 494) car	7.67499	N/A	#/veh/km
Total Distance Travelled DTA Experiment 490 (Replication 494)	8558.6	N/A	km
Total Distance Travelled DTA Experiment 490 (Replication 494) bus	121.814	N/A	km
Total Distance Travelled DTA Experiment 490 (Replication 494) car	8436.78	N/A	km
Total Travel Time DTA Experiment 490 (Replication 494)	872.576	N/A	hours
Total Travel Time DTA Experiment 490 (Replication 494) bus	11.2917	N/A	hours

Figure 8: AIMSUN software outputs after synchronization


Replication: 494 , Name: Replication 494

Main | Network Summary | Validation | Time Series | Path Statistics | Path Assignment

Time Serie	Value	Std. Dev.	Unit
Total Travel Time DTA Experiment 490 (Replication 494) bus	11.2917	N/A	hours
Total Travel Time DTA Experiment 490 (Replication 494) car	861.284	N/A	hours
Travel Time DTA Experiment 490 (Replication 494)	420.693	305.95	seconds/km
Travel Time DTA Experiment 490 (Replication 494) bus	268.331	145.638	seconds/km
Travel Time DTA Experiment 490 (Replication 494) car	422.463	306.881	seconds/km
Vehicles Gone Out DTA Experiment 490 (Replication 494)	9229	N/A	vehicles
Vehicles Gone Out DTA Experiment 490 (Replication 494) bus	106	N/A	vehicles
Vehicles Gone Out DTA Experiment 490 (Replication 494) car	9123	N/A	vehicles
Vehicles Inside DTA Experiment 490 (Replication 494)	907	N/A	vehicles
Vehicles Inside DTA Experiment 490 (Replication 494) bus	12	N/A	vehicles
Vehicles Inside DTA Experiment 490 (Replication 494) car	895	N/A	vehicles
Vehicles Lost In DTA Experiment 490 (Replication 494)	3	N/A	vehicles
Vehicles Lost In DTA Experiment 490 (Replication 494) bus	0	N/A	vehicles
Vehicles Lost In DTA Experiment 490 (Replication 494) car	3	N/A	vehicles
Vehicles Lost Out DTA Experiment 490 (Replication 494)	88	N/A	vehicles
Vehicles Lost Out DTA Experiment 490 (Replication 494) bus	0	N/A	vehicles
Vehicles Lost Out DTA Experiment 490 (Replication 494) car	88	N/A	vehicles
Vehicles Waiting Out DTA Experiment 490 (Replication 494)	2770	N/A	vehicles
Vehicles Waiting Out DTA Experiment 490 (Replication 494) bus	0	N/A	vehicles
Vehicles Waiting Out DTA Experiment 490 (Replication 494) car	2770	N/A	vehicles

Figure 9: AIMSUN software outputs after synchronization

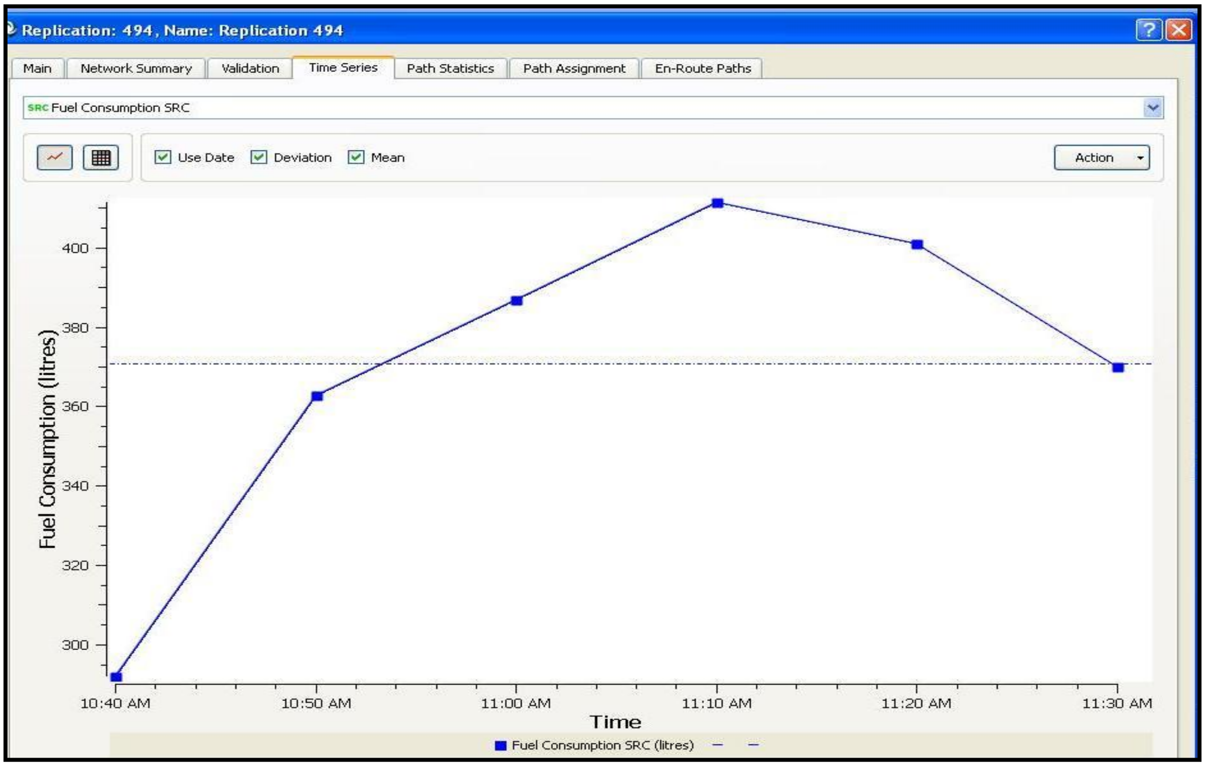


Figure 10: Fuel consumption variations at peak hours diagram after synchronization

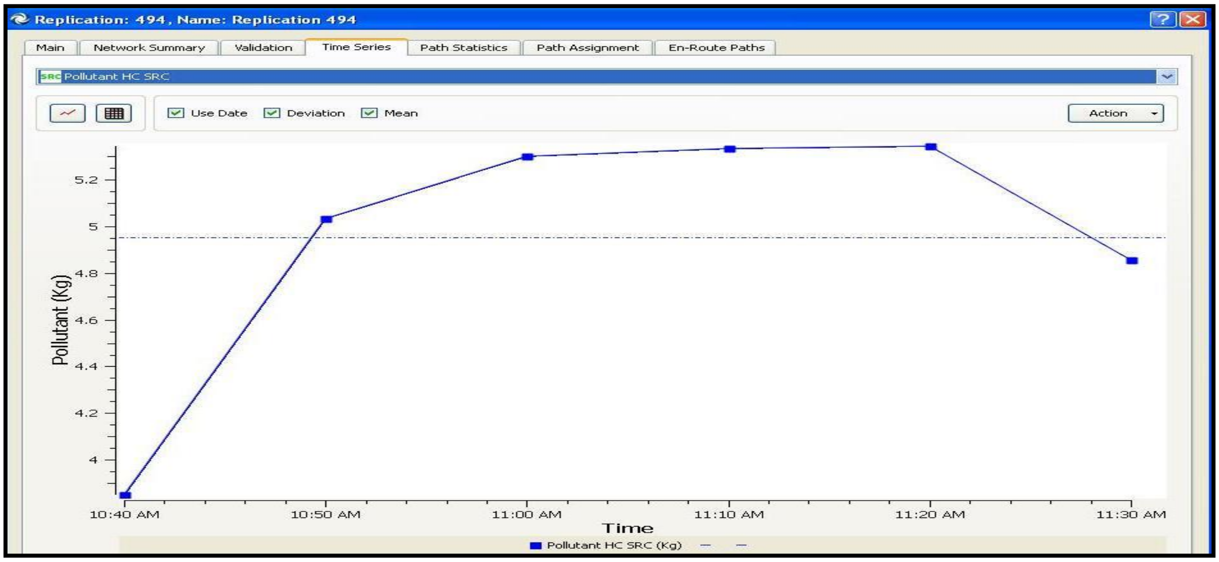


Figure 11: HC emission variations at peak hours diagram after synchronization

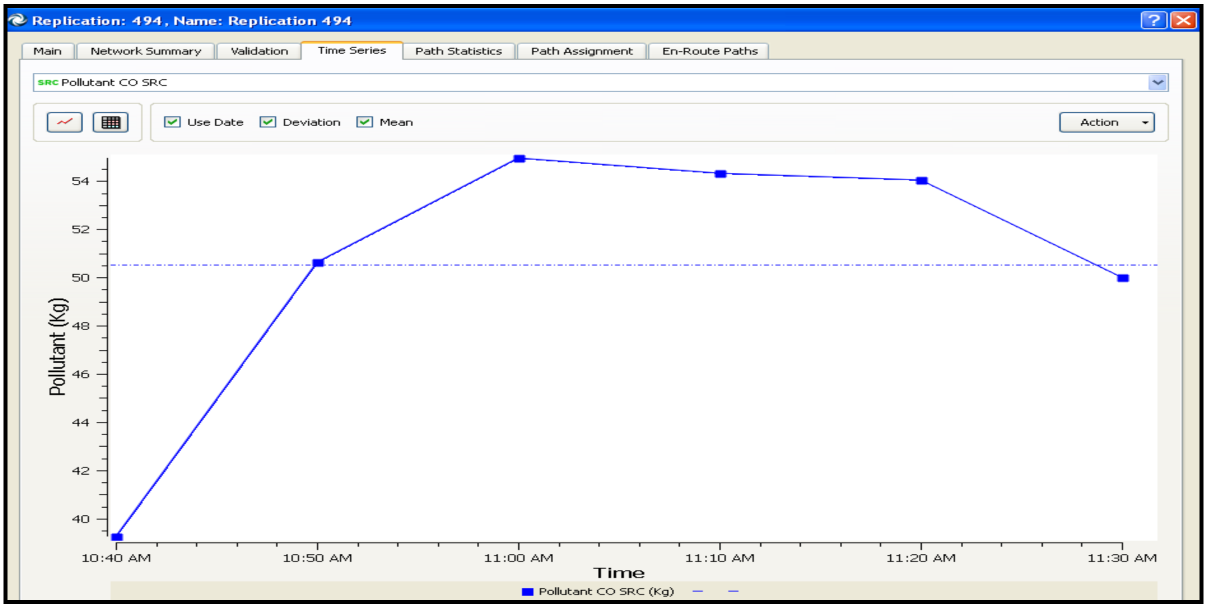


Figure 12: CO emission variations at peak hours diagram after synchronization

5. Analysis, conclusions and recommendations

For years, world countries have encountered with major challenge called energy and each of them was seeking to remove the problem. This problem was not so apparent in countries full of fossil resources but ran out of resources, these communities seek to achieve replacement energies or to use methods for energy savings that require new technologies and correct consumption management.

In this section, the results from the study are evaluated and the result is to determine the influence of synchronization of urban pass ways.

5.1 Fuel consumption comparison

With regard to fuel consumption of vehicles per peak hour, it has been observed that after synchronization, in spite of increase in the number of vehicles, fuel consumption has been decreased. This decline, as shown in Figure 13, is approximately 546lr/hr.

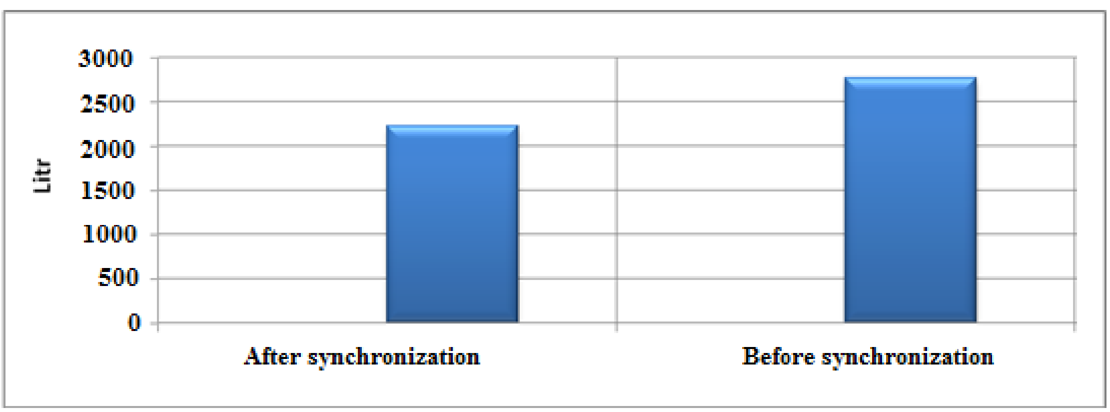


Figure 13: Fuel consumption variability per peak hour

5.2 Comparing environmental pollutants emissions

Having compared the software outputs, it is observed that despite increasing the number of vehicles moving in the grid, emission levels of environmental pollutants has also been decreased. During an hour, CO and HC productions have been 147kg and 7kg, respectively by 3kg more decline than the past, as shown in Figures 14 and 15.

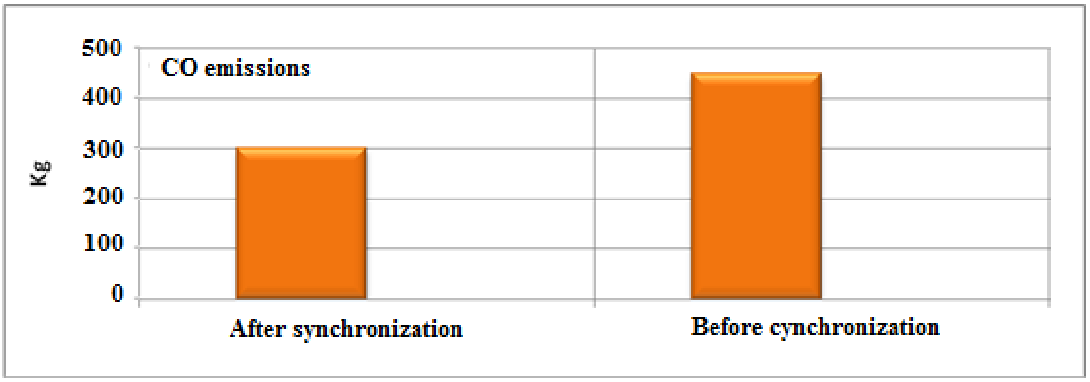


Figure 14: Variability diagram for CO emissions per peak hour

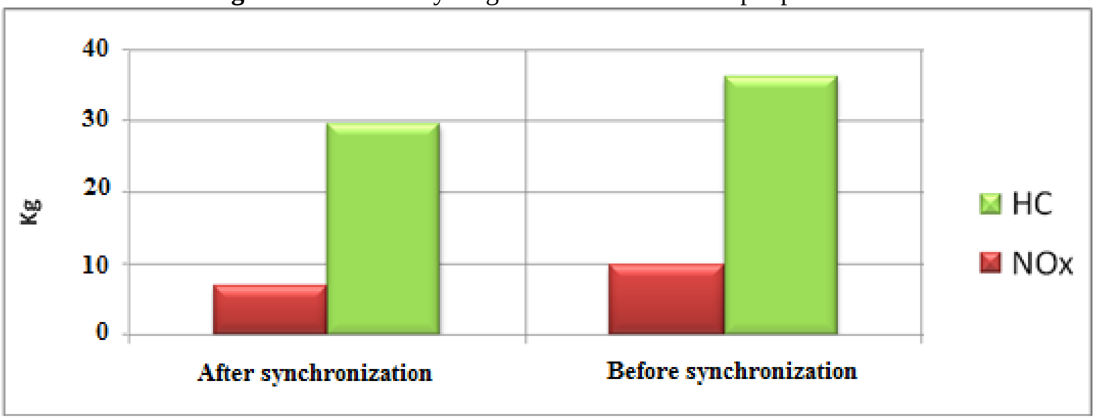


Figure 15: Variability diagram for HC and NO_x emissions per peak hour

5.3 Economic resources

By comparing the results in terms of fuel consumption, reduction in consumption at peak hour is 546ltr. Considering that main pass ways in Tehran have high traffic volumes of vehicles in most daily hours, therefore, savings during 8hr period a day equals to:

546 x 8 = 4368 (fuel consumption savings in a day)

4368 x 365 = 1594320 (savings in a year)

As it can be seen, a significant amount of energy savings will be achieved during a year. Now, if the price for every liter gasoline is 7000Rls, more than ten billion Rails will be annularly saved. In addition to direct economic benefits (Figure 16), indirect economic benefits are including:

- Reduction in gasoline imports;
- Improved weather;
- Increased health of citizens and
- Reduction in respiratory diseases.

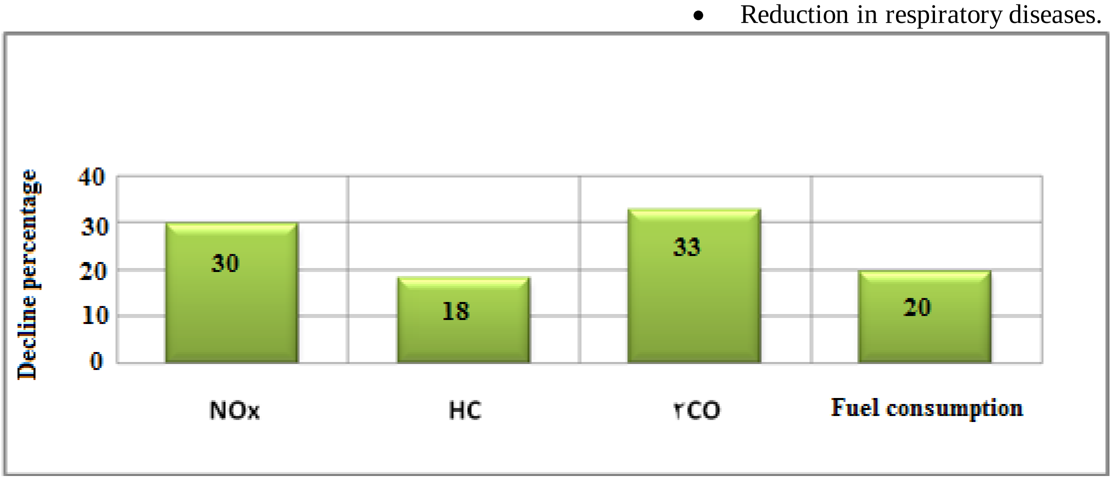


Figure 16: The results of synchronization of traffic lights

Significant point in this design is to decline the pollutants which play major role in improving health of citizens. Therefore using synchronization method, in addition to obvious dimensions, has hidden advantages. It is recommended that specifically in metropolitans of the country, pass ways with similar conditions are investigated and their traffic lights synchronize to take advantage of their benefits.

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