Measuring the Influences and Impacts of Signalized Intersection Delay Reduction on the Fuel Consumption, Operation Cost and Exhaust Emissions

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Abstract

With the rapid urban expansion and economic development, vehicle fuel dissipation and exhaust emissions have been identified as major energy wastage and urban air pollutions in Kalar City and Iraqi Kurdistan Region in general. Traffic congestion is a growing problem in Kalar City and other urban areas. As it increases, the delay at the transportation network will increase. Any increase of the delay in the transportation network will reflect negatively by increasing the delay at the signalized intersections. Therefore, a study on delay and its relation to fuel consumption, operation cost and emissions at signalized intersection are necessary. This paper, studies the influences and impacts of signalized intersection delay reduction on the fuel consumption, operation cost, and exhaust emissions. A simulation is carried out to evaluate the existing conditions of selected intersections by estimating the intersection delay, operation cost, and emissions. The simulation results show that fuel consumption, operation cost, and emissions are high and directly proportional to the intersection delay. To reduce intersection delay, a signal timing optimization is carried out to the selected intersections. The optimization results show that the delay reduction has a significant influence and impacts in reducing; fuel wastage, operation cost, and exhaust emissions.

Keywords: Signalized Intersection; Delay; Fuel Consumption; Operation Cost; Exhaust Emissions.

1. Introduction

The industrial production and transportation exponential growth in the past 150 years became possible by the utilization of coal, fossil fuels, and oil (petroleum) in particular. At the same time, the fossil fuels exponential consumption is followed by threatening side effects such as air pollution and global climate changes, especially within major industrial areas. Since the spent of these natural resources are extremely faster than their natural renewable cycle, a drop in established reserves is inescapable. Taking in consideration that the largest states in the world (e.g. China and India) are just entering the economic expansion period, it is expected that will result rise of oil (crude oil) prices occur in such a manner that is going to endanger economic and political stability, not only individual states but worldwide [1].

Transportation sector is the largest oil fuels consumer and the largest source of carbon dioxide (CO2) emissions in the world. In the year 2011, approximately 59% of oil fuels were used by transportation sector and approximately 22% of carbon dioxide (CO2) emissions resulted from transportation sector [2, 3]. Transportation sector activities account for 28% of the total United States use of energy and 33.4% CO2 carbon dioxide (CO2) emission (CO2 is the major component of greenhouse gas (GHG) emission) production. As consequence, considerable efforts are spent in an attempt to reduce transportation related energy consumption and greenhouse gas emissions in response to global energy and

environmental issues [4, 5].

The carbon dioxide (CO2) emission is playing active role in the warming up of the earth and the increase of greenhouse gas (GHG) emissions. (GHG) emissions are composed of about 72% carbon dioxide, 18% methane, 9% nitrous oxide and 1% other gases. The comprehensive study of (CO2) in the atmosphere layer shows that after the Industrial Revolution in year 1700, the level of (CO2) emission has increased by almost 30% in the world. The reduction of (CO2) will decrease the process of warming up of the earth (global warming) and keep a clean atmosphere for future generations [6].

The transport sector is one of the largest and fastest contributors to energy demand and greenhouse emissions [7]. The transport sector contributes nearly a third CO2 emissions and energy consumption within EU [8]. The ambition of the EU-Strategy for Low-Emission Mobility is to reduce greenhouse gas emission from transport at least 60% than in 1990 by mid-century and be firmly on the bath towards zero [9]. Efforts to achieve greater energy efficiency in transport have resulted in diverse approaches worldwide. The European Union focuses a great deal on policies for energy efficiency which should result in lower emissions [9]. Most efforts to combat this problem are directed towards traffic mode shift, use of energy-efficient vehicles and alternative fuels [10].

Majority of the metropolitan and urban areas around the world suffering from traffic congestion, excrescent fuel consumption and vehicles exhaust emissions, which became obstacle to these areas development and expansion. The energy dissipation and air pollution have caused residential areas environment pollution and huge economic losses. The increase in vehicle ownership and vehicles travels is tied to further accelerate energy consumption, which made the problem of energy becoming more notable. It has been estimated that about 90% of the air pollution in rapid growing cities and urban areas in developing countries can be referred to vehicle exhaust emissions [11].

To a certain extent, transportation infrastructure reflects a country's level of economic development. Substantial growth in road transportation energy consumption is the most direct reason for the increase in road transportation demand, and the main reason for the increasing demand is economic development and social progress. However, the relationship between the economy and transportation is not a simple linear relationship. Therefore, the characteristics of the relationship between social development and transportation demand are the premise for analyzing road energy demand [12].

Because of the global challenge of air pollution and climate change, sustainability and liveability issues are of increasing interest in road transport, and in a more general context, in transportation research. Significant efforts have been devoted to innovations maximizing fuel economy and reduce emissions through optimal fuel consumption estimation [13]. Therefore, in regards to sustainability, there are two sides of energy use in transportation sector. One is in relation to the large contribution made especially by road transportation sources to pollution problems and climate change while the other is related to energy supply for transportation sectors of each country [14].

2. Literature Review

In this section, the energy consumption and gas emissions related to road transport systems and traffic operation latest and newest studies are summarized, in order to focus on the works done in this field, to determine which parts of this field is in need for more works and efforts and what targets should be achieved and accomplished.

The effect of endogenous road capacity on fuel consumption, exhaust emission and the empirical estimate a simultaneous equations system of the road traffic demand, fuel consumption, exhaust emission, in term of an increase in road accessibility and traffic demand, exogenous efficiency policies and technological progress, in term of an increase in fuel efficiency is analyzed using the annual data of 1985 to 2013. The transmission mechanism of effects caused by road capacity and fuel efficiency policies is discussed. The traffic demand fuel efficiency further than the previous studies estimated. It was found that the fuel efficiency and traffic demand in China are larger than most studies of the United States and the effectiveness of fuel efficiency policies to improve fuel efficiency is proved. Regarding the pricing policy, it was found that high price of new cars cannot restrain Chinese demand for cars currently, and rising fuel price did not encourage people to purchase energy-saving vehicles in China [15].

A new mechanical model proposed for vehicle fuel consumption and carbon dioxide (CO2) emissions considering different types of vehicles and their different features, two engine types or models (gasoline and diesel), different types of roads, a range of renewable and non-renewable fuels and wind effect, in order to investigate the effectiveness of new parameters such as driving style, temperature, fuel efficiency and asphalt efficiency. The proposed model is based on top to down mechanical model which has five parts including the energy consumed due to acceleration, loss of gravity, aerodynamic resistance, rolling resistance and cornering losses. Furthermore, the proposed model investigates three types of tolling systems. The validity of this model is also checked and examined by analyzing the parameters in the range of (-10%, +10%) and correlation coefficients between the new parameters and five parts of the mechanical model. The results indicated that: (10%) improvement in driving style in cars reduces (8.81%) of fuel consumption; cold and warm temperature ranges increase fuel consumption by (5.57%) and (1.71%), respectively; the Portland Cement

Concrete type of asphalt has (6.21%) less fuel efficiency than Asphalt Concrete type; and, the fuel consumption of car using gasoline fuel is 6.84 times higher than bio diesel fuel. The results showed that the fuel consumption and carbon dioxide emission rates increase as move from free flow system to electronic tolling system, and then ,to the traditional tolling one. Moreover, the fuel consumption in the electronic tolling system for every fuel is twice less than the amount obtained in the traditional tolling system [16].

With increasing public concern about the environment, sustainability and liveability have become important issues in minimal fuel consumption estimation for transportation systems. Microscopic fuel planning and emission models use vehicle speed and acceleration as inputs and are suitable for estimating the amount of fuel at the link level. However, the lack of microscopic traffic data limits the application of these models. A method is provided for acquiring microscopic information from macroscopic traffic data. The main approach is to reconstruct the state and vehicle group trajectories with an Expectation Maximization algorithm with nice convergence properties and then to apply Dijkstra's algorithm in order to find a transport route with minimum fuel consumption. Validation of the method shows that the estimated fuel consumption reflects the real fuel amount and hence, the route with minimum fuel consumption determined by Dijkstra's algorithm is actually suitable for optimal transport planning [17].

A study of greenhouse gas (GHG) emissions from road transportation in Saudi Arabia revealed that the per capita fuel consumption is increasing at higher rates in recent years compared to some other neighboring countries along with the consistent increase in number of cars and population growth. As a result, the domestic fuel consumption is growing significantly and the growth dynamics of GHG emissions is becoming a challenging for planning, development, and implementation of proper reduction measures. An integrated national effort with strong commitments from all the stakeholders is a strategic necessity for the Saudi Arabia Kingdom to ensure its rapid development and successful implementation of laudable national policy for reducing the emission of GHG, particularly from the road transportation sector. Success of the Kingdom's efforts to manage GHG emissions from the road transportation sector while maintaining its ambitious development step and commitments to a stable global energy supply demands increased and comprehensive focus on vehicle efficiency, environment friendly fuels, and management of growing travel demand considering the specific socio-economic characteristics [18].

Estimating road transport fuel consumption study describes the VKT technique to disaggregate road transport energy consumption by the type of vehicle, applied to Ecuador road transportation system. The results show as the biggest fuel consumers are the heavy duty freight trucks, followed by light duty vehicles. The estimation of greenhouse gas emissions showed that in 2012 the road transport sector released 14.3 million tons of carbon dioxide. When fuel consumption is compared by it costs, it can be confirmed that Ecuadorean Government covered, through subsidies, for 68% of national road transport annual fuel costs, demonstrating the importance of restructuring or reallocating these expenditures in order to achieve an efficient road transport system [19].

Road geometry has a great and significant impact on overall fuel consumption and emissions, where some roads directly connect traffic origins and destinations, while others take indirect routes. Indirect connections result in longer distances driven trips and increased fuel consumption. A similar effect is observed on mountain roads with many changes in elevation and congested roads with stop and go traffic. In this light, a methodology proposed for analysis of road networks based on energy consumed by the vehicles and the energy needed to build more efficient connections. This framework takes into consideration traffic volume, road geometry, shares of vehicle classes, and energy needed for road operation and construction. Its application was illustrated through two case studies, one with macroscopic traffic data and one with microscopic traffic simulation that can also be applied for urban road network optimization [20].

It is fundamental and essential to support the development of effective eco-freight strategies, including eco-driving systems and eco-routing by applying an efficient, simple, and realistic fuel consumption model. The majority of the existing heavy duty truck fuel consumption models recommend that drivers accelerate at full throttle or brake at full braking to minimize their fuel consumption levels, which is obviously not realistic. To overcome this issue, the Virginia Tech Comprehensive Power-based Fuel consumption Model (VT-CPFM) framework is applied to develop a new model that is calibrated and validated using field data collected using a mobile emissions research laboratory (MERL). The results demonstrate and show that the model accurately predict and estimate the levels of fuel consumption harmonious with filed observation and give better results than the motor vehicle emissions simulator (MOVES) model and the comprehensive modal emissions model (CMEM). The results of the model demonstrate that the optimum fuel economy cruise speed ranges between 32 and 52 km/h with steeper roads and heavier trucks resulting in lower optimum cruise speeds, and the model generates accurate CO_2 emission estimates that are consistent and harmonious with field measurements [21].

The historical trends in road transportation energy consumption and gross domestic product (GDP) in developed economies are analyzed to determine the development characteristics of road energy consumption. In order to explore the current status and future trend of road energy transportation in China, path analysis is employed to analyze the impact mechanism of the factors related to road transportation energy consumption. Next, the BMA model is adopted to select the core factors related to road transportation energy consumption in China, and on the model selection basis as well as

uni- variate (ETS and ARIMA) models and multi- variate (multiple regression0 models, the road transportation energy consumption is analyzed and forecast. The results demonstrate that the road transportation energy consumption increases by 0.33% for every percent increase in gross domestic product (GDP) and by 1.26% points for every percent of urbanization increase. It is expected that the road transportation energy consumption in China to reach around 226181.1 ktoe by the end of the year 2015, and about 347,363 ktoe by the year 2020 [12].

Energy consumption and air pollution status in China is serious. It is significant to analyze and estimate the different fuel consumption of various vehicles types under different influence factors. Massive amount of floating vehicle data used to fully describe the relationship between fuel consumption and the impact factors. The congestion pattern and fuel consumption pattern based on large samples of historical floating vehicle data were examined and explored, vehicles' parameters from different group classification and drivers' information were checked, and the average velocity and average fuel consumption in the temporal and spatial dimensions were analyzed respectively. The fuel consumption forecasting model was established and setup by using a Back Propagation Neural Network. Part of the data sample set used to train the forecasting model and the remaining part of the data sample set used as input to the forecasting model [22].

In Indonesia, future transportation energy mix design has become an important issue, because of the oil fuels such as gasoline and diesel sounds to be infeasible options in the coming future due to limited available resources, high subsidy costs, and environmental problems and issues. To overcome this issue, energy mix model for transportation sector in Indonesia is proposed. The model considers and focuses on a variety of feasible and beneficial technologies and includes three competing objectives; energy consumption, fuel subsidy cost, and carbon monoxide (CO_2) emission. Several scenarios were developed and introduced to include business as usual (BAU), vehicle retirement program, the introduction of compress natural gas (CNG) technology, and the implementation of hybrid vehicles energy mix which considers future behavioral factors. The result indicated that the most effective strategy to minimize and reduce energy consumption and fuel subsidy costs is through old vehicles retirement program. The introduction of the compress natural gas (CNG) vehicle on public transportation appears to give little significance in reducing fuel consumption, the annual subsidy costs, and CO_2 emissions [23].

To reduce fuel consumption from the transportation sector, providing guidance and information to drivers to help them make fuel-efficient route choices remains an effective and important strategy in the near term and future. The major component in implementing this strategy is a fuel consumption predicting and estimation model. For this purpose a mesoscopic fuel consumption estimation model that can be implemented into an eco-routing system is developed. The proposed model presents a framework that utilizes large-scale, real-world driving data, clusters road links by free-flow speed and fits one statistical model for each of cluster. The developed model includes predicting variables that were never or rarely considered or used before, such as number of lanes and free flow speed. The model is applied to a real world driving data set based on global positioning system (GPS) travel survey in the Philadelphia-Camden-Trenton metropolitan area. Results of the statistical analyses indicate and show that the independent variables used effect and influence the fuel consumption rates of vehicles. But the direction and magnitude of the effect and influences are dependent on the type of road links, specifically free flow speeds of traffic links. A statistical diagnostic and examination is conducted to ensure the suitability and validity of the models and results. In spite of the real world driving data used to develop statistical relationships are specific to one region, the developed framework can be easily adjusted and used to explore the fuel consumption relationship in other regions [24].

This study addresses the city transportation network growing problems related to the rapid urban expansion and economic development in Kalar City and Iraqi Kurdistan Region in general. As the traffic demand increased, the congestion in the city traffic network increased and caused a significant increase in signalized intersections delay. Vehicle fuel dissipation and exhaust emissions have been identified as major energy wastage and urban air pollutions result from the congestion and delay increase at signalized intersections. Therefore, it is necessary to study and measure the influences and impacts of signalized intersection delay reduction on the fuel consumption, operation cost and exhaust emissions.

The novelty of this study is focusing a spotlight on the relation between the delay reduction at signalized intersections and fuel consumption, operation cost and exhaust emissions, which is clearly not given enough or appropriate attention by the transportation researchers, although the signalized intersections are very critical elements of the city traffic network.

Measuring the influences and impacts of signalized intersection delay reduction on the fuel consumption, operation cost and exhaust emissions can be achieved by applying the following steps:

- Performance evaluation for the selected signalized intersections through a simulation run using SIDRA 5.1 traffic software to calculate the intersection delay, fuel consumption, operation cost, emissions and other important performance indicators for the existing intersections conditions.

- As a scenario of improving operation performance and reducing the signalized intersection delay, a signal timing

optimization run will be applied on the selected signalized intersections using SIDRA 5.1 traffic software.

- Measure and calculate the influences and impacts of intersection delay reduction resulted from the signal timing optimization on the fuel consumption, operation cost, and emissions.

3. The Study Traffic Software Tool

The Signalized and Unsignalized Intersection Design and Research Aid (SIDRA) Software (SIDRA INTERSECTION 5.1) is selected as the study traffic software tool. SIDRA 5.1 software is used for operation analysis (simulation run) and signal timing optimization (optimization run) of the selected isolated signalized intersection.

SIDRA developed in Australia by ARRB Transport Research as a tool for isolated intersection performance and timing analysis. SIDRA is very powerful software for analyzing signalized intersections with up to eight approaches in addition to the optimization of cycle length, splits and phase sequences. SIDRA software includes a rich graphic display of the intersection, geometric design including the number of lanes, channelization and turning lanes [25].

SIDRA software is a tool for evaluation and designing the signalized intersections (pre-timed, fixed time and actuated), signalized interchanges, roundabouts, two-way stop sign control, give-way sign control [26].

Among the traffic software tools, SIDRA can be considered the richest measure of effectiveness based intersection software. It calculates the measure of effectiveness's; time delay (total and average), degree of saturation (v/c ratios), stops, queues, speed, fuel consumption, operation cost and emissions [25].

In March 2011 SIDRA 5.1 was released coinciding with HCM 2010 release. SIDRA 5.1 includes complete HCM 2010 level of service methods, delay models, and parameters defaults were adopted. SIDRA 5.1 include enhancements to program features, traffic models and user interface [26].

4. Highway Capacity Manual 2010 (HCM2010) Signalized Intersection Delay Model

The control delay is computed with Equation 1 [27].

$$d = d_1(PF) + d_2 \tag{1}$$

Where

d = control delay (s/veh),

d_1 = uniform delay (s/veh)

d_2 = incremental delay (s/veh)

PF = progression adjustment factor

$$PF = \left(1 - \left[1.33 g/C\right]/\left(1 - g/C\right)\right) \tag{2}$$

Where

g/C = proportion of green time available.

The progression adjustment factor PF is selected from Table 1. If the subject lane group is uncoordinated, then Arrival Type 3 is appropriate. If the subject lane group is coordinated, then Arrival Type 4 is appropriate.

Table 1. The Progression Adjustment Factor PF Relationship with Subject Lane Group Coordination Type

Arrival Type	Progression Adjustment Factor PF as a Function of Green Ratio					
	0.2	0.3	0.4	0.5	0.6	0.7
Uncoordinated	1.00	1.00	1.00	1.00	1.00	1.00
Coordinated	0.92	0.86	0.78	0.67	0.50	0.22

Approach delay and intersection delay are calculated as a weighted average of the lane group delays. The weight for a lane group is based on the volume of each movement included in the group, as recorded on the input worksheet. The adjusted volumes used to compute capacity should not be used to compute approach delay or intersection delay.

The uniform delay d_1 is computed with Equation 3.

$$d_1 = \frac{0.5\left(1 - g/C\right)}{1 - \left[\min(1, X)\, g/C\right]} \tag{3}$$

Where

d_1 = uniform delay (s/veh),

X = volume-to-capacity ratio

g/C = proportion of green time available.

The notation min (1, X) used in the equation indicates that the smaller of the two values (i.e., 1 and X) is used in the equation.

The incremental delay d2 is computed with Equation 4.

$$d_2 = 900T \left[(X - 1) + \sqrt{(X - 1)^2 + \frac{4X}{cT}} \right] \tag{4}$$

Where

d_2 = incremental delay (s/veh),

c = capacity (veh/h), and

T = analysis period duration (h)

X = volume-to-capacity ratio.

5. The Study Traffic Software Fuel Consumption and Emissions Model

SIDRA 5.1 traffic software uses a four mode elemental model for estimating vehicles fuel consumption, operation cost and pollutant exhaust emissions (see Figure 1). This model provides a highly reliable general method of vehicles fuel consumption and pollutant exhaust emissions estimation. Instantaneous model which is the basis of the SIDRA 5.1 four mode elemental model estimated second-by-second vehicles fuel consumption in urban driving to 2 to 3 percent accuracy level. This method is different from the most of commonly used but less accurate than three mode elemental model (idling and number of stops using excess vehicles fuel consumption, cruise, excess exhaust emissions, or excess cost per stop) used by other traffic software tools [28-30].
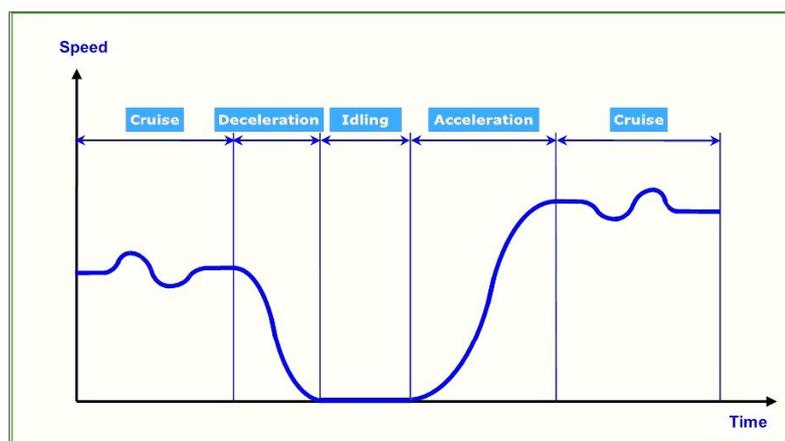

Figure 1. Four mode elemental model used in SIDRA 5.1 for modeling fuel consumption, pollutant exhaust emissions, operation cost and geometric delay [26]

In SIDRA 5.1, the four mode elemental vehicles fuel consumption model contributes to operation cost prediction. SIDRA 5.1 constructs drive cycles consisting of a series of cruise, acceleration, deceleration, and stopped time elements for each lane of traffic. These drive cycles differ according to specific traffic conditions (traffic control including signal timings, geometric design, flow demand driver characteristics and behavior). Drive cycles are separately constructed for stopped and moving vehicles, and light and heavy vehicles. For each drive cycle, vehicles fuel consumption and exhaust emissions are estimated for each of the four modes of driving namely cruise, acceleration, deceleration and stopped time (idling), and the results are added together for the entire driving maneuver. Using the vehicles fuel consumption and exhaust emissions values calculated or estimated for light and heavy vehicles in each lane of each movement, the total and average calculated or estimated values are for each lane. The average or total values for each movement or approach road are calculated by aggregating the values for the lanes that belong to the movement or approach [26]. The geometric design, main stop-start, queue move-up delays and as a consequence, the queuing and idling (stopped) delays are affected by acceleration and deceleration times and distances [31].

The vehicle fuel consumption, operation cost and pollutant exhaust emissions results for all movements are given in

the total fuel consumption, total operation cost and total emissions and fuel consumption, operation cost and emissions (Rate) tables in the detailed output report, and shown in the fuel consumption, operation cost and emissions group under movement displays. In addition to the drive cycle information, the reliability of the estimates of vehicle fuel consumption, operation cost, and exhaust emissions also depend on the quality of vehicle data and information available. The vehicle parameters for fuel consumption, operating cost and exhaust emissions models used in SIDRA 5.1 are based on inclusive research, while the quality of other exhaust emission rates could be improved by using more accurate representative vehicle data. The application of the four mode elemental model in SIDRA 5.1 is summarized below [26]:

1) Traffic operation performance is different in each traffic lane at signalized intersections. Therefore, SIDRA 5.1 calculates the vehicles fuel consumption, operating cost and pollutant exhaust emissions estimates separately for each traffic lane. Each movement or approach average value is estimated or calculated by aggregating the values for the lanes that belong to the movement or approach.

2) In each traffic lane, the model is applied separately to stop (queued) and unstopped (un-queued) vehicles according to the proportion stopped (queued) calculated by SIDRA 5.1. For unstopped (un-queued) vehicles, only the cruise or travel and geometric stop components apply. For stopped (queued) vehicles, SIDRA 5.1 determines the drive cycles distinguishing between major stops, stops in a queue (queue move-ups) and geometric stops (slowing down or fully stop in the absence of any other vehicle). These are very different for different types of intersections (signalized intersections, sign-controlled intersections, roundabouts), for different signal phasing (signal timing) arrangements (one or two green periods in the cycle length), for yield and stop control, and for different congestion levels.

3) The vehicles are subject to an acceleration or deceleration during their travel if the approach and exit section cruise (travel) speeds are different for un-queued (unstopped) through vehicles at traffic signals and priority movements at un-signalized intersections.

4) Drive cycles are defined by the initial and final speeds in each element of the driving maneuver. For this purpose, approach and exit travel (cruise) speeds, intersection negotiation speeds and queue move-up speeds are used. The queue move-up speed is calculated as a function of the capacity of each departure period and the queue space per vehicle in the lane. Some of these speeds are set and specified as input by the user, and others are calculated by the program according to the intersection geometry and traffic levels of congestion and some default parameters are used where applicable.

5) The drive cycle information is used to calculate acceleration and deceleration times and distances for each element of the drive cycle individually. Effective cruise (travel) distance, cruise (travel) time and stopping (idling) time are calculated using this information as well as traffic performance indicators estimates (number of stops and delay). Allowance is made for any negative travel (cruise) distances that may result. The drive cycle information is also used to calculate different types of delays (control delay stopped delay, geometric delay, queuing delay, etc), which are reported to the user along with the proportion stopped (proportion queued), effective stop rate, queue move-up rate, etc. Additional information such as speed and running time, average travel time and speed are calculated as part of this process.

6) The fuel consumption, exhaust emission rates, and operating cost values are calculated for each element of the drive cycle individually using the statistics derived. The results are added together for the entire stopped (queued) vehicle maneuver, and then the results for stopped (queued) and unstopped (un-queued) vehicles are aggregated.

7) Vehicles fuel consumption and exhaust emission rates are calculated from a set of equations which use such vehicle parameters as mass and fuel/emission efficiency rates, as well as road grade and related speeds (travel or cruise, initial, final).

8) In the mentioned above process, vehicles (light and heavy) are treated separately with different parameters (different mass, different acceleration and deceleration rates, different acceleration and deceleration times and distances). Various aspects of the heavy vehicle models developed and used for this purpose.

6. The Study Traffic Software Operation Cost Model

SIDRA 5.1 traffic software operating cost estimates include [26]:

(1) The direct vehicle operating cost (the resource cost of fuel and additional running costs including tire, oil, repair, and maintenance as a factor of the cost of fuel), and

(2) The time cost to driver and passengers.

The cost parameters input dialog allows the user to calibrate the operating cost model for local conditions. Calibration parameters include cost unit (user's own currency), pump price of fuel, fuel resource cost factor, the ratio of running cost to fuel cost, average income, time value factor, average occupancy (persons/veh), light vehicle mass, heavy vehicle

mass, and heavy vehicle maximum power.

The default cost model parameters for Australia (applies to standard left-hand and right-hand versions), New Zealand and the USA are given in Table 2 Values calculated for various parameters described below are also given in Table 2.

Table 2. Default values of cost model parameters for the standard SIDRA 5.1 Australia, New Zealand and US versions (updated January 2011) [26]

Parameters	Symbol	Australia	New Zealand	USA
Cost Unit		$ (AUD)	$ (NZD)	$ (USD)
Parameters for Vehicle Operating Cost	(k_o)			
Pump Price of fuel in " Cost Unit" (or per gallon)	(P_p)	1.3 ($/L)	2.00 ($/L)	$0.8 ($/L) (3.00 $/gal)
Fuel resource cost factor	(f_r)	0.50	0.60	0.70
Running cost/fuel cost ratio	(f_c)	3.0	2.5	3.0
Parameters for Time Cost	(k_t)			
Average income (full time adult average hourly earnings) in "Cost Unit' per hour	(W)	35.00 ($/h)	26.00 ($/h)	23.00 ($/h)
Time value factor as a proportion of average hourly income	(f_b)	0.60	0.60	0.40
Average occupancy in persons per vehicle	(f_o)	1.5	1.5	1.2
Vehicle Parameters				
Light Vehicle Mass (average value in kg or lb)	$(MvLV)$	1400	1400	1400 (3100 lb)
Heavy Vehicle Mass (average value in kg or lb)	$(MvHV)$	11000	11000	11000 (24,000 lb)
Heavy Vehicle Maximum Power (KW)	$(PmaxHV)$	130	130	130
Idling fuel consumption rate for Light Vehicles in millilitres per hour (or gallons per hour)	$(fILV)$	1350	1350	1350 (0.360 gal/h)
Idling fuel consumption rate for Heavy Vehicles in millilitres per hour(or gallons per hour)	$(fIHV)$	2000	2000	2000 (0.530 gal/h)
Calculated Values				
Vehicle operating cost factor in "Cost Unit" per litter (or per gallon) of fuel	$(k_0 = f_c\, f_t\, P_p)$	1.9500 ($/L)	3.000 ($/L)	1.680 ($/L) (6.300 $/gal)
Time cost per person in "Cost Unit" per hour	$(f_p W)$	21.00 ($/h)	15.60 ($/h)	9.20 ($/h)
Time cost per vehicle in "Cost Unit" per hour	$(k_t = f_o\, f_p\, W)$	31.50 ($/h)	23.40 ($/h)	11.04 ($/h)

The vehicle operating cost factor, ko (cost unit per liter or per gallon of fuel, e.g. $/L or $/gal) is calculated from:

$$k_0 = f_c f_r P_p \tag{5}$$

Where

f_c = an aggregate cost factor used to convert the cost of fuel to total running cost including tire, oil, repair, and maintenance;

f_r = fuel resource cost factor (ratio of the resource price of fuel to the pump price); resource price is the wholesale price plus retail margin less taxes;

P_p = pump price of fuel in "cost unit" per liter (per gallon if US customary units are used), e.g. $/L or $/gal.

The time cost per vehicle, kt in "cost unit" per hour, e.g. $/h, is calculated from:

$$k_t = f_o f_p W \tag{6}$$

Where

f_o = average occupancy in persons per vehicle;

f_p = time value factor that converts the average income to a value of time;

W = average income (full-time adult average hourly total earnings) in "cost unit" per hour, e.g. $/h.

Total operating cost for vehicles, Ct in "cost unit" per hour, e.g. $/h, can be calculated from:

$$C_t = \frac{k_o F_t}{1000} + k_t T_t \tag{7}$$

Where

F_t = total fuel consumption (mL/h),

T_t = total vehicle travel time (veh-h/h), and

k_o and k_t are determined from Equations 5 and 6.

Total operating cost for pedestrians includes the time cost only:

$$C_t = k_t T_t = f_p W T_t$$

(8)

Where

T_t = total pedestrian travel time (ped-h/h), and

k_t is determined from Equation (6) using $f_o = 1$ (therefore $k_t = f_p W$).

7. Study Area and Case Study

Kalar City is the center of Kalar District located in the northeast of Iraq, 220 Km northeast of Baghdad the Capital of Iraq and 275 Km south of Erbil Governorate. It is one of Sulaimaniya Governorate Districts and lies on Sirwan (Diyala) river (see Figure 2). Currently, Kalar city is the center of Garmian Area Administration, the population of Kalar City is (197,230 persons) which represent (74%) of Kalar District population according to data and information collected by Directorate of Statistics in Garmian Administration.

Kalar City is a continuous progression toward further infrastructural growth and urban expansion and due to its location which connects Kurdistan, Iraq Central Government part and Iran together. The rapid and large increase of Kalar City population is the major cause of the increasing demand for the efficient and adequate transportation system and network in terms of capacity, operation cost and less harm to the environment, especially during the peak periods.

As a case study, Bukhari, Sherai Naqib and Shahid Hama Rash signalized intersections have been selected as major congested signalized intersections in Kalar City transportation network. They have congested traffic and represents significant traffic facilities in Kalar City traffic network because of their important locations. The locations of the intersections are described in following:

1) Bukhari signalized intersection is located next to the University of Garmian Presidency and connects Kalar-Kefri districts multi-lane two-way highway with the center of Kalar city (see Figures 3 and 4).

2) Sherai Naqib signalized intersection is located in the center of Kalar in the center of number of very important government facilities and departments such as; Sherai Naqib Maternity Governmental Hospital, Saya Private Hospital and Passports Department (see Figures 3 and 5).

3) Shahid Hama Rash signalized intersection is located on a very important commercial route that connects three governorates; Diyala, Sulaimaniya and Salah Al-Din in addition to two official border points with Iran (see Figures 3 and 6).
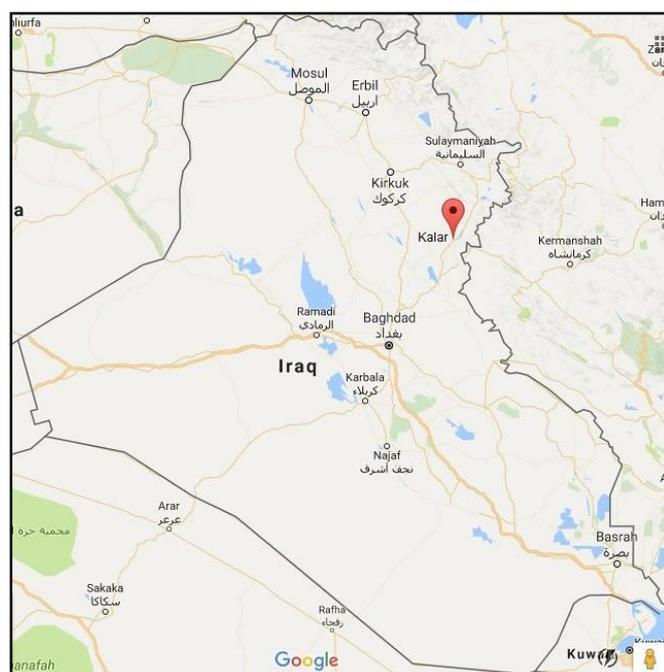

Figure 2. The location of Kalar City on Iraq Map (Google Maps)
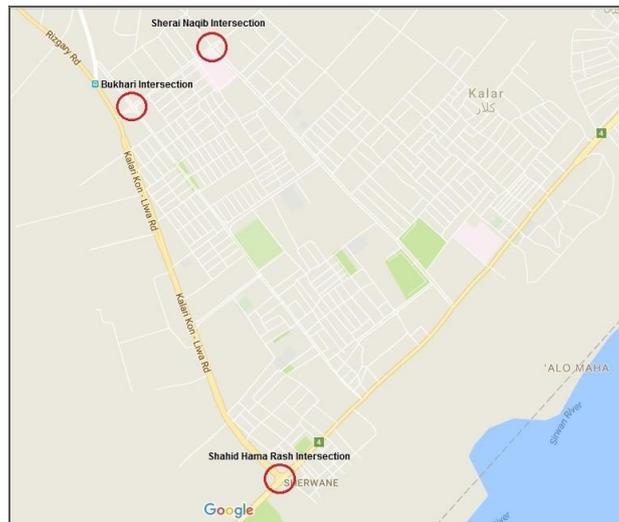
Figure 3. The locations of Bukhari, Sherai Naqib, and Shahid Hama Rash signalized intersections on Kalar City Map (Google Maps)
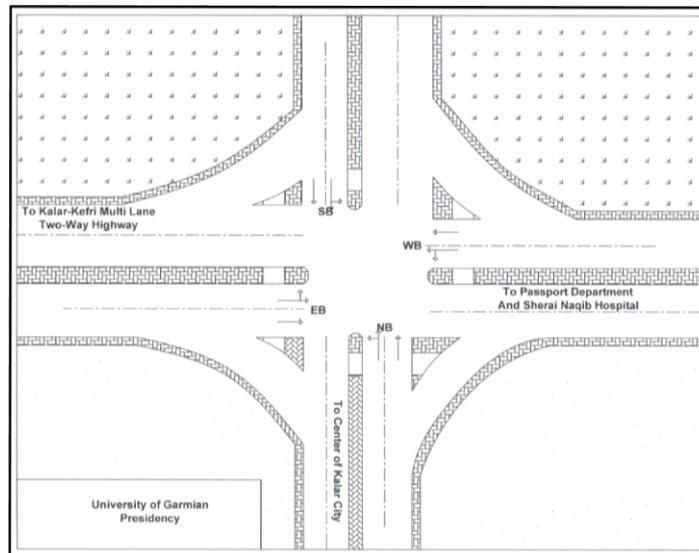

Figure 4. The existing geometric design of Bukhari signalized intersection (field measurement)

Figure 5. The existing geometric design of Sherai Naqib signalized intersection (field measurement)
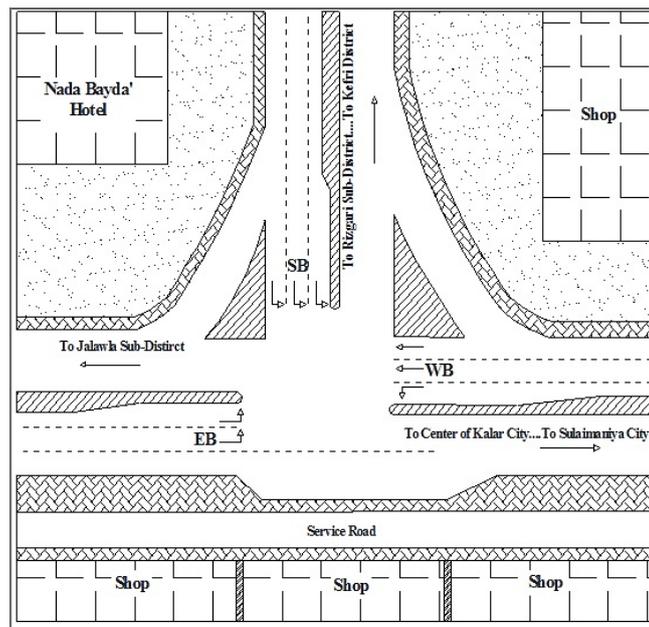
Figure 6. The existing geometric design of Shaid Hama Rash signalized intersection (field measurement)

In order to evaluate the operation performance of the selected isolated signalized intersections using; traffic analysis software tool SIDRA 5.1, field observation including traffic volumes, geometric data, and other required data were collected. The data collection is done manually and using video records on working days during the highest congestion of the transportation system at peak hours.

7.1. Traffic Volume

Traffic volume count carried out at Bukhari, Sherai Naqib, and Shahid Hama Rash intersections during the peak period (the peak period is selected based on the personal observation and information from Directorate of Garmian Traffic Police) as in the following:

1) Bukhari intersection: traffic volume count conducted from (8:25 a.m. to 9:25 a.m.) using video record (see Figure 5) during the working days on 17th of July 2016. The highest traffic volume in each direction is recorded to be used in the analysis of the present study. The traffic volume counting period is divided into 15 minutes intervals; Table 3 shows the total volume for all approaches in addition to other required data in Bukhari signalized intersection collected during the peak period.

2) Sherai Naqib Intersection: traffic volume count conducted from (7:55 a.m. to 8:55 a.m.) using video record (see Figure 6) during the working days on 5th of October 2015. The highest traffic volume in each direction is recorded to be used in the analysis of the present study. The traffic volume counting period is divided into 15 minutes intervals; Table 4 shows the total volume for all approaches in addition to other required data in Sherai Naqib signalized intersection collected during the peak period.

3) Shahid Hama Rash Intersection: traffic volume count conducted from (7:45 a.m. to 8:45 a.m.) using video record (see Figure 7) during the working days on 5th of October 2015. The highest traffic volume in each direction is recorded to be used in the analysis of the present study. The traffic volume counting period is divided into 15 minutes intervals; Table 5 shows the total volume for all approaches in addition to other required data in Shahid Hama Rash signalized intersection collected during the peak period.

Table 3. Traffic Volume, Peak Hour Factor (PHF), Phases Sequence and Signal Timing at Bukhari Signalized Intersection for all Approaches in the Peak Hour Period

Collected Data		NB		SB		EB		WB	
		TH	L	TH	L	TH	L	TH	L
Traffic volume	8:25-8:40 a.m	16	52	37	17	71	4	180	96
	8:40-8:55 a.m	26	48	38	8	120	4	89	60
	8:55-9:10 a.m	19	51	29	10	91	1	116	84
	9:10-9:25 a.m	14	63	17	4	110	6	95	49
	8:25-9:25 a.m	75	214	121	39	392	15	480	289
HV		0	6	1	0	24	0	50	8
HV%		0	3	1	0	6	0	10	3
PHF		0.72	0.85	0.80	0.57	0.82	0.63	0.67	0.75
Signal Timing (sec)		G=20 Y=5 All Red=2		G=25 Y=5 All Red=2		G=25 Y=5 All Red=2		G=30 Y=5 All Red=2	
Phases Sequence									

TH= Through movement, L= Left movement, and
% HV=Percent of Heavy Vehicles

Table 4. Traffic Volume, Peak Hour Factor (PHF), Phases Sequence and Signal Timing at Sherai Naqib Signalized Intersection for all Approaches in the Peak Hour Period

Collected Data		NB		SB		EB		WB	
		TH	L	TH	L	TH	L	TH	L
Traffic volume	7:55-8:10 a.m	20	83	42	12	63	16	110	67
	8:10-8:25 a.m	29	85	60	22	87	28	108	77
	8:25-8:40 a.m	26	73	41	22	51	23	102	65
	8:40-8:55 a.m	46	73	41	11	71	28	68	58
	7:55-8:55 a.m	121	314	184	67	272	95	388	267
HV		0	9	2	1	27	0	31	0
HV%		0	3	1	1	10	0	8	0
PHF		0.66	0.92	0.77	0.76	0.78	0.85	0.88	0.87
Signal Timing (sec)		G=20 Y=7 y=5 ar=2		G=20 Y=7 y=5 ar=2		G=30 Y=7 y=5 ar=2		G=35 Y=7 y=5 ar=2	
Phases Sequence									

Table 5. Traffic Volume, Peak Hour Factor (PHF), Phases Sequence and Signal Timing at Shahid Hama Rash Signalized Intersection for all Approaches in the Peak Hour Period

Collected Data		NB		SB		EB		WB	
		TH	L	TH	L	TH	L	TH	L
Traffic volume	7:45-8:00 a.m	-	-	-	110	-	160	106	31
	8:00-8:15 a.m	-	-	-	139	-	135	94	30
	8:15-8:30 a.m	-	-	-	148	-	138	108	40
	8:30-8:45 a.m	-	-	-	133	-	117	109	40
	7:45-8:45 a.m	-	-	-	530	-	550	417	141
HV		-	-	-	16	-	61	0	3
HV%		-	-	-	3	-	11	0	2
PHF		-	-	-	0.90	-	0.86	0.96	0.88
Signal Timing (sec)		-		G=45 Y=5 y=5 ar=0		G=35 Y=5 y=5 ar=0		G=30 Y=5 y=5 ar=0	
Phases Sequence									

Figure 7. Traffic volume count using video record-Bukhari signalized intersection

Figure 8. Traffic volume count using video record-Sherai Naqib signalized intersection

Figure 9. Traffic volume count using video record-Shahid Hama Rash signalized intersection

8. Results and Discussion

Operation analysis and signal timing optimization of Bukhari, Sherai Naqib, and Shahid Hama Rash isolated signalized intersections using traffic analysis software tool SIDRA 5.1:

8.1. Operation Analysis of Bukhari, Sherai Naqib and Shahid Hama Rash Signalized Intersections

For the Evaluation purposes, a simulation runs applied on the selected isolated signalized intersections using the traffic software tool SIDRA 5.1. The major output results of the simulation runs are summarized in Table 6.

Bukhari signalized intersection operation analysis major outputs show that:

1) The intersection is operating in a congested condition, where the value of the intersection average control delay is high (intersection average control delay= 161.7 sec), it is over saturated (intersection degree of saturation= 144.4% > 100%), intersection level of service (LOS) is F (worse operation condition) and intersection

performance index (Disutility Index) = 260.5.

2) As a result of the intersection is operating in a congested condition, the values of fuel consumption and operation cost are high (total intersection fuel consumption= 340.2 L/hr and total intersection operation cost= 1935 \$/hr).

3) Due to the high fuel consumption resulted from high traffic congestion in Bukhari signalized intersection, the values of emissions are high (total carbon dioxide= 852.8 kg/hr, total hydrocarbons= 1.609 kg/hr, total carbon monoxide= 54.08 kg/hr and total NOx=1.62 kg/hr).

Sherai Naqib signalized intersection operation analysis major outputs show that:

1) The intersection is operating in a congested condition, where the value of the intersection average control delay is high (intersection average control delay= 113.2 sec), it is over saturated (intersection degree of saturation= 138.9% > 100%), intersection level of service (LOS) is F (worse operation condition) and intersection performance index (Disutility Index) = 200.3.

2) As a result of the intersection is operating in a congested condition, the values of fuel consumption and operation cost are high (total intersection fuel consumption= 269.9 L/hr and total intersection operation cost= 1471.47 \$/hr).

3) Due to the high fuel consumption resulted from high traffic congestion in Sherai Naqib signalized intersection, the values of emissions are high (total carbon dioxide= 676.1 kg/hr, total hydrocarbons= 1.277 kg/hr, total carbon monoxide= 44.6 kg/hr and total NOx=1.323 kg/hr).

Shahid Hama Rash signalized intersection operation analysis major outputs show that:

1) The intersection is operating in a good condition in term of traffic congestion, where the value of the intersection average control delay is = 44.7 sec, it is under saturated (intersection degree of saturation= 67.4% < 100%), intersection level of service (LOS) is D (good operation condition) and intersection performance index (Disutility Index) = 112.1.

2) As the intersection is operating in a good condition in term of traffic congestion, the values of fuel consumption and operation cost are normal and not high as in the other two intersections (total intersection fuel consumption= 187.5 L/hr and total intersection operation cost= 806.24 \$/hr).

3) As the total intersection fuel consumption amount is normal and not high, which resulted from the good operation condition, the values of emissions are not high and less than in the other two intersections (total carbon dioxide=469.9 kg/hr, total hydrocarbons= 0.82 kg/hr, total carbon monoxide= 36.14kg/hr and total NOx=1.085 kg/hr).

Table 6. Operation analysis (a simulation run) major output results for Bukhari, Sherai Naqib and Shahid Hama Rash signalized intersections using SIDRA 5.1

Operation Analysis (Simulation Run)			
The Major Outputs Results	**Bukhari Intersection**	**Sherai Naqib Intersection**	**Shahid Hama Rash Intersection**
Intersection Average Control Delay (sec)	161.7	113.2	44.7
Total Fuel Consumption (L/hr)	340.2	269.9	187.5
Total Cost (\$/hr)	1935.15	1471.47	806.24
Total Carbon Dioxide (kg/hr)	852.8	676.1	469.9
Total Hydrocarbons (kg/hr)	1.609	1.277	0.82
Total Carbon Monoxide (kg/hr)	54.08	44.6	36.14
Total NOx (kg/hr)	1.62	1.323	1.085
Intersection Degree of Saturation (%)	144.4	138.9	67.4
Performance Index (Disutility Index)	260.5	200.3	112.1
Intersection Level of Service (LOS)	F	F	D

8.2. Signal Timing Optimization of Bukhari Signalized Intersection

As a scenario of improving operation performance and reducing the delay of signalized intersection, the selected computer traffic analysis software tool SIDRA 5.1 used in applying signal timing optimization run on Bukhari, Sherai Naqib and Shahid Hama Rash isolated signalized intersections. The major output results of optimization runs are summarized in Table 7.

Bukhari signalized intersection signal timing optimization major outputs show that:

1) Good and significant improvement in the intersection operation performance, where the intersection average control delay is reduced from 161.7 sec to 72.2 sec (55.34% reduction), intersection degree of saturation is

reduced from 144.4% to 86.1% and became under saturated < 100% (40.37% reduction), intersection level of service (LOS) is improved from F to E and intersection performance index (Disutility Index) reduced from 260.5 to 186.4 (28.44% reduction) (see Figure 10 and Tables 6, 7 and 8).

2) As a result of reduction in intersection average control delay (55.34% reduction), the total fuel consumption reduced from 340.2 L/hr to 249 L/hr (26.80% reduction) and intersection operation cost reduced from 1935 $/hr to 1167.8 $/hr (39.65% reduction) (see Figure 10 and Tables 6, 7 and 8).

3) The reduction in the total fuel consumption (26.80% reduction) in Bukhari signalized intersection caused a reduction in the values of emissions. The total carbon dioxide reduced from 852.8 kg/hr to 624 kg/hr (26.82% reduction), total hydrocarbons reduced from 1.609 kg/hr to 1.095 kg/hr (31.94% reduction), total carbon monoxide reduced from 54.08 kg/hr to 44.49 kg/hr (17.73% reduction) and total NOx reduced from 1.62 kg/hr to 1.365 kg/hr (15.74% reduction) (see Figure 10 and Tables 6, 7 and 8).

For Bukhari signalized intersection, the results show that improvement in intersection operation performance and intersection delay reduction have a significant influence and impact on reducing the fuel consumption, operation cost and vehicles' exhaust emission gases which includes non-toxic gases such as carbon dioxide (CO2) (CO2 is a greenhouse gas (GHG) participate in increasing of global warming) and toxic gases such as carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxide (NO) (CO, HC and NO gases increase the air and environment pollution and have a negative impact on the public health.

Sherai Naqib signalized intersection signal timing optimization major outputs show that:

1) Good improvement in the intersection operation performance, where the intersection average control delay is reduced from 113.2 sec to 75 sec (33.74% reduction), intersection degree of saturation is reduced from 138.9% to 90.7% and became under saturated < 100% (34.7% reduction), intersection level of service (LOS) is improved from F to E and intersection performance index (Disutility Index) reduced from 200.3 to 179.2 (10.53% reduction) (see Figure 11 and Tables 6, 7 and 9).

2) As a result of reduction in intersection average control delay (33.74% reduction), the total fuel consumption reduced from 269.9 L/hr to 234.2 L/hr (13.22% reduction) and intersection operation cost reduced from 1471.47 $/hr to 1154.14 $/hr (21.56% reduction) (see Figure 11 and Tables 6, 7 and 9).

3) The reduction in the total fuel consumption (13.22% reduction) in Sherai Naqib signalized intersection caused a reduction in the values of emissions. The total carbon dioxide reduced from 676.1 kg/hr to 586.5 kg/hr (13.25% reduction), total hydrocarbons reduced from 1.277 kg/hr to 1.075 kg/hr (15.81% reduction), total carbon monoxide reduced from 44.6 kg/hr to 41.7 kg/hr (6.5% reduction) and total NOx reduced from 1.323 kg/hr to 1.244 kg/hr (5.97% reduction) (see Figure 11 and Tables 6, 7 and 9).

For Sherai Naqib signalized intersection, the results show that improvement in intersection operation performance and intersection delay reduction have a significant influence and impact on reducing the fuel consumption, operation cost and vehicles' exhaust emission gases which includes non-toxic gases such as carbon dioxide (CO2) (CO2 is a greenhouse gas (GHG) participate in increasing of global warming) and toxic gases such as carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxide (NO) (CO, HC and NO gases increase the air and environment pollution and have a negative impact on the public health.

Shahid Hama Rash signalized intersection signal timing optimization major outputs show that:

1) Good improvement in the intersection operation performance in term of average control delay and performance index (Disutility Index) reduction, where the intersection average control delay is reduced from 44.7 sec to 36.8 sec (17.67% reduction) and intersection performance index (Disutility Index) reduced from 112.1 to 93.3 (16.77% reduction). The signal timing optimization had a negative impact on the intersection performance in term of intersection degree of saturation, where it is increased from 67.4% to 79.1% (17.35 % increases). The signal timing optimization caused an increase in one of the intersection approaches which caused the increase in intersection degree of saturation because its calculation depends on the highest value of intersection approaches degree of saturation. The intersection level of service (LOS) is D which remained the same (see Figure 12 and Tables 6, 7 and 10).

2) As a result of reduction in intersection average control delay (17.67% reduction), the total fuel consumption reduced from 187.5 L/hr to 183.6 L/hr (2.08% reduction) and intersection operation cost reduced from 806.24 $/hr to 757.19 $/hr (6.08% reduction) (see Figure 12 and Tables 6, 7 and 10).

3) The small reduction in the total fuel consumption (2.08% reduction) in Shahid Hama Rash signalized intersection caused a small reduction in the values of total carbon dioxide and total hydrocarbons, where the total carbon dioxide reduced from 469.9 kg/hr to 460.1 kg/hr (2.08% reduction) and total hydrocarbons reduced from 0.82 kg/hr to 0.797 kg/hr (2.8% reduction). The total carbon monoxide and total NOx witnessed a small increase

resulted from the increase of the intersection degree of saturation, where the total carbon monoxide increased from 36.14 kg/hr to 36.69 kg/hr (1.52 % increase) and total NOx increased from 1.085 kg/hr to 1.091 kg/hr (0.55 % increase). As the intersection existing operation condition is good in term of traffic congestion, the signal timing optimization had a small impact or effect on the emissions (see Figure 12 and Tables 6, 7 and 10).

For Shahid Hama Rash signalized intersection, the results show that intersection delay reduction has a direct influence and impact on reducing the fuel consumption, operation cost and vehicles' exhaust emission gases which includes non-toxic gases such as carbon dioxide (CO2) (CO2 is a greenhouse gas (GHG) participate in increasing of global warming) and toxic gases such as carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxide (NO) (CO, HC and NO gases increase the air and environment pollution and have a negative impact on the public health.

Table 7. Signal timing optimization run major output results for Bukhari, Sherai Naqib and Shahid Hama Rash signalized intersections using SIDRA 5.1

	Optimization Run		
The Major Outputs Results	**Bukhari Intersection**	**Sherai Naqib Intersection**	**Shahid Hama Rash Intersection**
Intersection Average Control Delay (sec)	72.2	75	36.8
Total Fuel Consumption (L/hr)	249	234.2	183.6
Total Cost ($/hr)	1167.8	1154.14	757.19
Total Carbon Dioxide (kg/hr)	624	586.5	460.1
Total Hydrocarbons (kg/hr)	1.095	1.075	0.797
Total Carbon Monoxide (kg/hr)	44.49	41.7	36.69
Total NOx (kg/hr)	1.365	1.244	1.091
Intersection Degree of Saturation (%)	86.1	90.7	79.1
Performance Index (Disutility Index)	186.4	179.2	93.3
Intersection LOS	E	E	D

Table 8. The percentages of reduction in Bukhari intersection delay, fuel consumption, operation cost, emissions and other important performance indicators

Major Performance Indicators	**Operation Analysis Outputs**	**Optimization Outputs**	**Percentage of Reduction (%)**
Intersection Average Control Delay (sec)	161.7	72.2	55.34
Total Fuel Consumption (L/hr)	340.2	249	26.80
Total Cost ($/hr)	1935.15	1167.8	39.65
Total Carbon Dioxide (kg/hr)	852.8	624	26.82
Total Hydrocarbons (kg/hr)	1.609	1.095	31.94
Total Carbon Monoxide (kg/hr)	54.08	44.49	17.73
Total NOx (kg/hr)	1.62	1.365	15.74
Intersection Degree of Saturation (%)	144.4	86.1	40.37
Performance Index (Disutility Index)	260.5	186.4	28.44
Intersection LOS	F	E	Improved from F to E

Table 9. The percentages of reduction in Sherai Naqib intersection delay, fuel consumption, operation cost, emissions and other important performance indicators

Major Performance Indicators	**Operation Analysis Outputs**	**Optimization Outputs**	**Percentage of Reduction (%)**
Intersection Average Control Delay (sec)	113.2	75	33.74
Total Fuel Consumption (L/hr)	269.9	234.2	13.22
Total Cost ($/hr)	1471.47	1154.14	21.56
Total Carbon Dioxide (kg/hr)	676.1	586.5	13.25
Total Hydrocarbons (kg/hr)	1.277	1.075	15.81
Total Carbon Monoxide (kg/hr)	44.6	41.7	6.5
Total NOx (kg/hr)	1.323	1.244	5.97
Intersection Degree of Saturation (%)	138.9	90.7	34.7
Performance Index (Disutility Index)	200.3	179.2	10.53
Intersection LOS	F	E	Improved from F to E

Table 10. The percentages of reduction in Shahid Hama Rash intersection delay, fuel consumption, operation cost, emissions and other important performance indicators

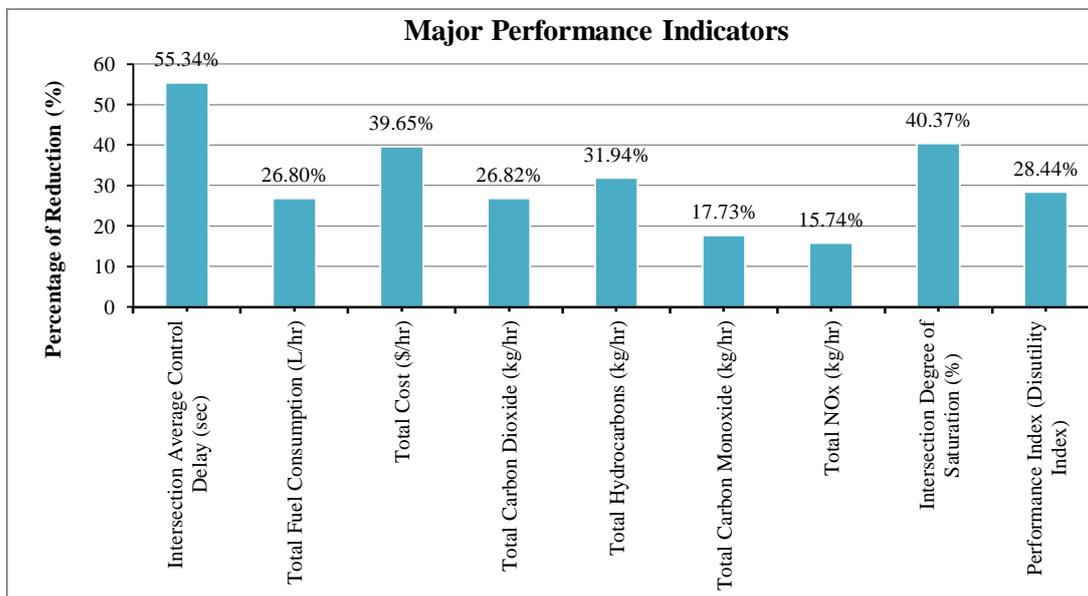| Major Performance Indicators	Operation Analysis Outputs	Optimization Outputs	Percentage of Reduction (%)
Intersection Average Control Delay (sec)	44.7	36.8	17.67
Total Fuel Consumption (L/hr)	187.5	183.6	2.08
Total Cost ($/hr)	806.24	757.19	6.08
Total Carbon Dioxide (kg/hr)	469.9	460.1	2.08
Total Hydrocarbons (kg/hr)	0.82	0.797	2.8
Total Carbon Monoxide (kg/hr)	36.14	36.69	-1.52 (increased)
Total NOx (kg/hr)	1.085	1.091	- 0.55 (increased)
Intersection Degree of Saturation (%)	67.4	79.1	- 17.35 (increased)
Performance Index (Disutility Index)	112.1	93.3	16.77
Intersection LOS	D	D	Remained the same

Figure 10. The percentages of reduction in Bukhari intersection delay, fuel consumption, operation cost, emissions and other important performance indicators
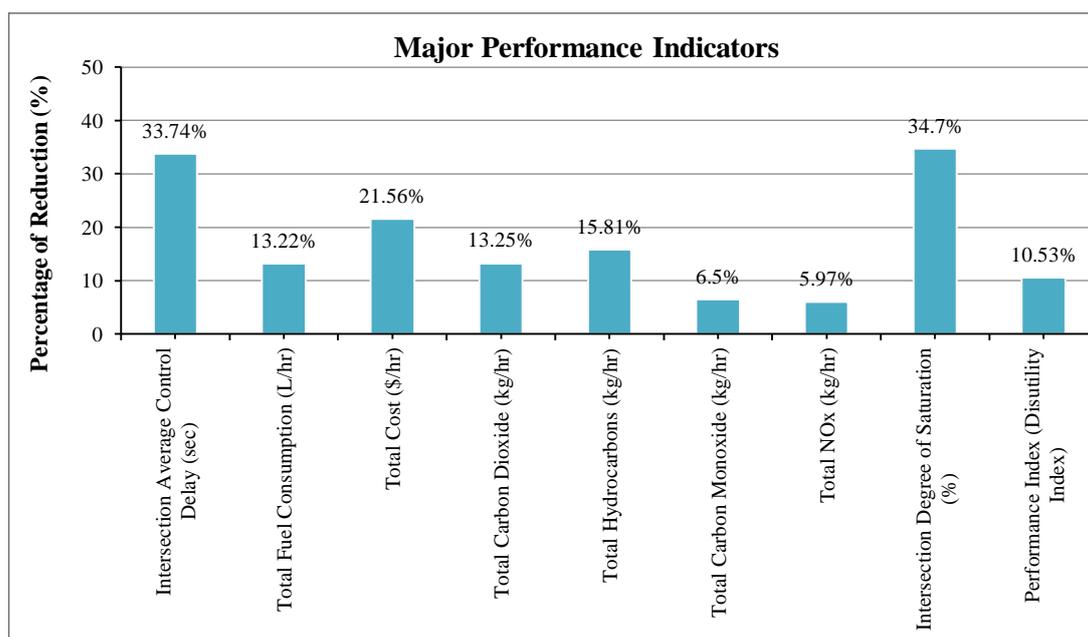

Figure 11. The percentages of reduction in Sherai Naqib intersection delay, fuel consumption, operation cost, emissions and other important performance indicators
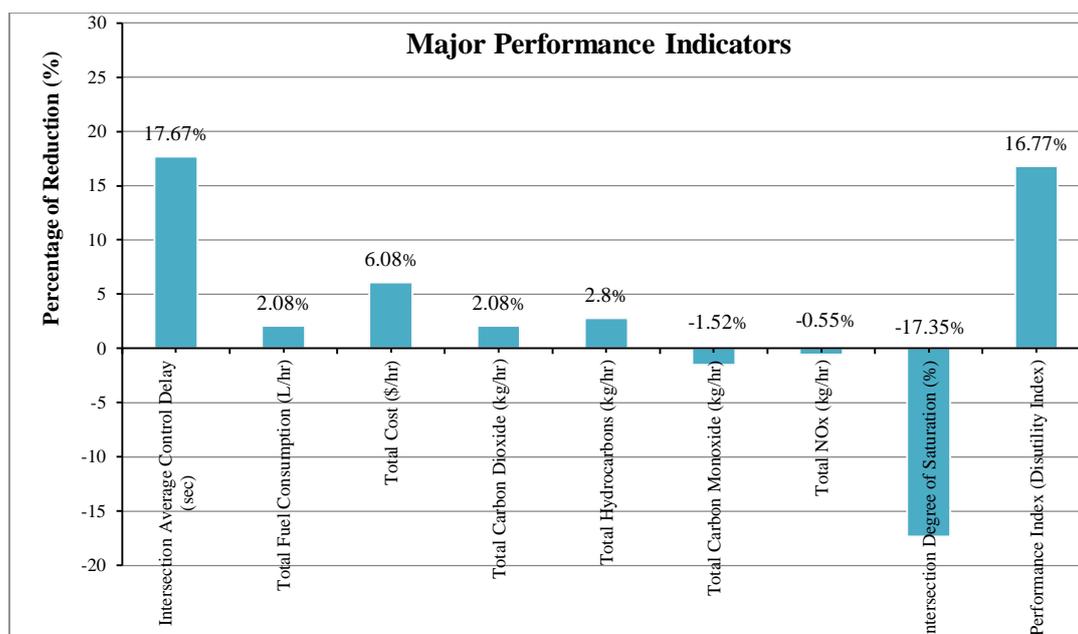
Figure 12. The percentages of reduction in Shahid Hama Rash intersection delay, fuel consumption, operation cost, emissions and other important performance indicators

9. Conclusion

The influences and impacts of delay reduction of selected signalized intersections, which resulted from intersection signal timing optimization were significant on the fuel consumption, operation cost and exhausts emissions. As much the value of the intersection delay reduction is larger, the reduction in fuel consumption, operation cost and exhausts emissions values will be larger.

Reducing the total intersection fuel consumption, total operation cost and emissions will certainly have important benefits and positive impacts as in the following:

- Reduction in vehicles fuel consumption: will reduce the accelerated consumption of the limited resources of the energy especially the fossil fuels.

- Reduction in operation cost: will reduce the economic burdens on the city citizens especially the vehicles owners, which will reflect positively on the country budget, specifically the countries which depend on fossil fuels as a major or only source of energy.

- Reduction of exhaust emissions: will reduce the risks and damages on the public health and the environment.

Based on the results of this study and the importance of fuel consumption, operation cost and exhaust emissions reduction, it is highly recommended to re-define the signalized intersection operation performance to include fuel consumption, operation cost and emissions in the operation performance indicators of signalized intersections and not only focusing on the traffic characteristics.

Most of the traffic engineers and specialist consider the fuel consumption, operation cost and exhaust emissions calculated or estimated values as minor outputs, mostly when they use the traffic software tools in performance evaluation and signal timing optimization of the signalized intersections. It is very important to encourage them to use the simulation and signal timing optimization traffic softwares that calculate and estimate fuel consumption, operation cost and exhaust emissions in addition to the traffic performance indicators in the evaluation and improving the operation performance of signalized intersections.

It is very important to conduct a wide study to calibrate the traffic software tool which used in this study and similar traffic softwares in order to enable the software to calculate and estimate more specific and accurate values of fuel consumption, operation cost and exhaust emissions, which can reflect the reality of the study area conditions to a maximum extent. Through the results of this study it became clear that the calibration should include the following parameters:

- Parameters for vehicle operating cost (pump price of fuel per liter, fuel resource cost factor and running cost/fuel cost ratio).

- Parameters for time cost (average income for a full-time adult average hourly total earning in cost unit per hour, time value factor as a proportion of average hourly income and average occupancy in persons per vehicle).

- Vehicle parameters (light vehicle mass, heavy vehicle mass, heavy vehicle maximum power, idling fuel consumption rate for light vehicles in milliliters per hour and idling fuel consumption rate for heavy vehicles in milliliters per hour).

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