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Estimation of Fuel Consumption in Urban Areas Based on Timing Parameters and Average Vehicular Speed

H. Ceylan, H. Ceylan, S. Haldenbilen, O. Baskan

Department of Civil Engineering, Engineering Faculty, Pamukkale University, Denizli, Turkey

Abstract

This study deals with the estimation of fuel consumption and emission values in an urban transportation networks under fixed time signal operation. The importance of energy savings caused from transport are dealt with. The emission model with traffic control model is proposed which takes the cruise speed, timing parameters and the observed traffic volumes as inputs. The model is applied to a real transportation network which is currently under operation and analyses on system performance are carried out. The current operation state and optimum state in terms of minimum energy consumption and maximum system performance are obtained. Pollutants are calculated using top down approach both for current and optimum states. Results showed that with an efficient improvement on network operation conditions at the optimum state saves the energy by about 8% when it is compared with the current state. The energy savings will also help to improve emission values by about 8%.

Keywords: *Fuel consumption, air pollution, energy savings, urban road networks*

1. Introduction

Energy is a vital input for the economic and social development of a country. Strong population growth and rapid urbanization in developing countries have played an important role for energy consumption. The fastest growth rate of motorization in the world and our countries will bring a problem of traffic congestion in urban and rural roads and will lead to an excess use of energy in urban road networks. Excess use of fuel will also lead to a problem of environmental pollution since the transport sector is one of the main contributors to the global warming.

Traffic engineers and designers have interested in minimizing the energy use in the urban road networks for a long time. Estimating fuel consumption in urban areas depends usually on average vehicular speed, acceleration and deceleration rate of vehicles, stopping rate, intersection delays, type and model years of the vehicles, etc. Thus, this study develops a fuel estimation method by using the traffic model of the TRANSYT (Robertson, 1969) traffic model. TRANSYT is a traffic network study tool to improve signalized urban road network operating conditions. The program has a facility to estimate fuel consumption for a fixed set of signal timings for given timing and link flows. The timing parameters are network cycle time, green time and offsets between junctions.

As half of the travel demand usually takes place in the urban areas, it may be argued that some improvement on road network operating conditions will save energy consumption. Thus there is a need to estimate fuel consumption to take appropriate measures and policies. Estimation of fuel consumption for a given timing parameters, measured link flows and variable cruise speed may also be utilized. Therefore, this study deals with the estimation of fuel utilization for various values of cruise speed and develops a fuel estimation method using traffic model in urban road networks. The model is also used for estimation of air pollutants caused from transport.

2. Traffic Model and Formulation

TRANSYT Traffic Model was developed by TRRL (Robertson, 1969). Its main features are cyclic flow profile, platoon dispersion models and fuel estimation. It simulates traffic in a network of signalized intersections to compute a performance index (PI) for a given signal timing and staging plan as well as fuel consumption. The performance index in TRANSYT is the sum for all signal-controlled traffic streams of a weighted linear combination of estimated delay and number of stops per unit time. Estimation of fuel consumption in TRANSYT, when a particular set of signal timings is in operation, is carried out in the following way (Vincent et al., 1980).

Fuel consumption estimating is:

$$f_c = 17.0 - 0.455 + 0.0049V^2 \text{ (litre/100 veh} - \text{km)} \tag{1}$$

$$f_s = 77010^{-8}V^2 \text{ (litre/1 veh} - \text{stop)} \tag{2}$$

where f_c is the consumed fuel at a constant cruise speed, f_s is the fuel consumed for stops/starts from cruise speed and V is the cruise speed at a signalized road network (km/h).

The expressions (1-2) used to estimate the fuel consumption, and that due to stopping and starting, both depend upon the cruise speed for the link being considered. The fuel used during delay period is calculated as a constant idling rate of 1.4 liters/veh-hr of delay. Fuel consumption differs substantially between one vehicle type and another. Therefore, the mixture of traffic assumed which is typical in urban road networks (Vincent et al., 1980) as: 82% of cars, 10% of light commercial vehicles, 8% medium/heavy commercial and buses.

Model structure of fuel emissions for various values of cruise speed can be seen in Fig.1, where *N* is the pre-specified iteration number.

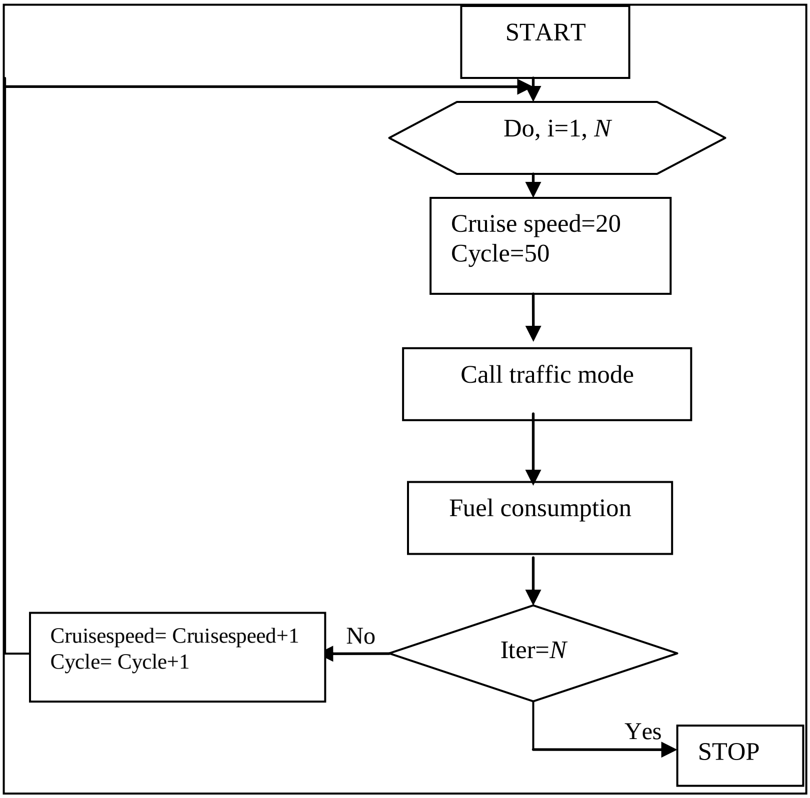

Fig.1. Model of fuel consumption estimation at various levels of cruise speed

3. Estimation of Fuel Consumption

Example road network in studied area, which is a real road network under operation, is firstly divided into two parts. Traffic flow measurements were performed in the morning and evening time periods within two days. Fig.2. shows the studied road network and their corresponding numbers, links and turning movements.

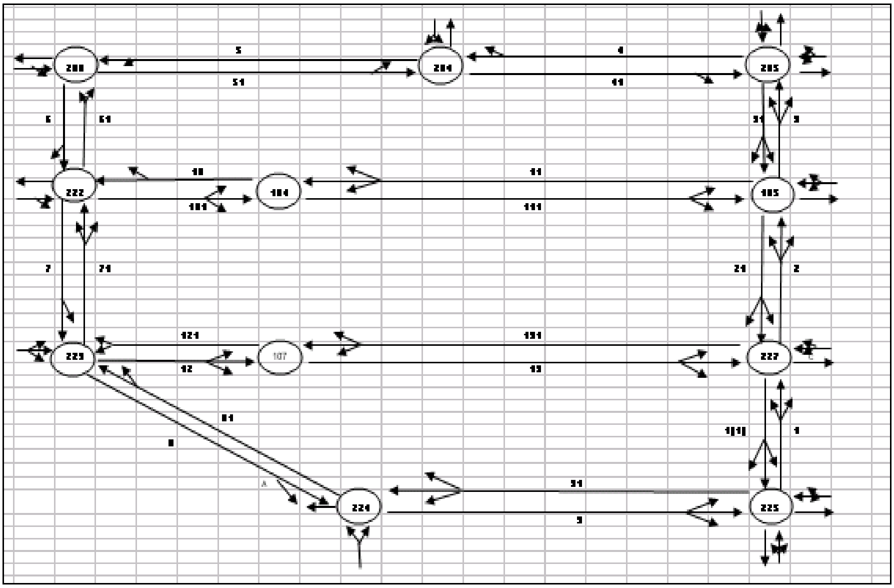

Fig.2. Studied road network

The total network travel times were obtained as 596-918 seconds for the morning and 710-918 seconds for the evening periods with observation on moving test vehicle. Current operating speed was measured as 23.46 km/h. Measured link traffic volumes and link travel time calculations can be obtained in Ceylan (2007). The solution of the fuel estimation model is given in Table 1.

Table 1. Application of the model to an example network

Cycle time (seconds)	**Cruise speed (km/h)**	**Delay (veh-h/h)**	**PI (£/h)**	**Fuel consumption (lt/h)**
50.00	20.00	5044.84	40705.50	8423.60
55.00	25.00	4968.34	40141.70	8244.40
60.00	30.00	4921.64	39834.00	8162.40
65.00	35.00	4885.34	39612.70	8129.30
70.00	40.00	4855.94	39471.70	8170.20
75.00	45.00	4844.04	39465.90	8260.50
80.00	50.00	4821.34	39376.50	8369.00
85.00	55.00	4821.64	39493.10	8570.40
90.00	60.00	4822.94	39634.20	8826.10
95.00	65.00	4831.54	39814.40	9096.90
100.00	70.00	4840.24	40009.30	9415.70
104.00	74.00	4849.24	40163.90	9670.80

The first columns shows the cycle time in seconds, second columns shows the cruise speed in km/h, third column is the estimated delay in veh-h/h, fourth column is the network performance index in £/hr and the last column is the estimated fuel consumption.

4. Analysis of Fuel Consumption and Pollution Calculation

4.1 Fuel Consumption

The fuel consumption and network delays are determined for different cycle times and average operating cruise speed. The average operating speed is given between 20-74 km/h which is typical in urban areas. The relationship between total fuel consumption and total delay can be seen in Fig.3. The values, which are in the *y* axis, are found with indexing of total fuel consumption and total delays.

As shown in Fig. 3, total fuel consumption varied between 1.20 and 1.05 during the solution process for various levels of cruise speeds. Similarly, total delay increased from 1.01 to 1.05 when the cruise speed is between 20-74 km/h. The crossing point of fuel and delay curve may be considered as an optimum point for operating network to save energy consumption. As shown in Fig.3-4, optimum average travel speed and cycle time are found about 48 km/h and 78 seconds, respectively. *PI,* which shows a system performance improvement, varies between 39322 and 40705 (£/h).

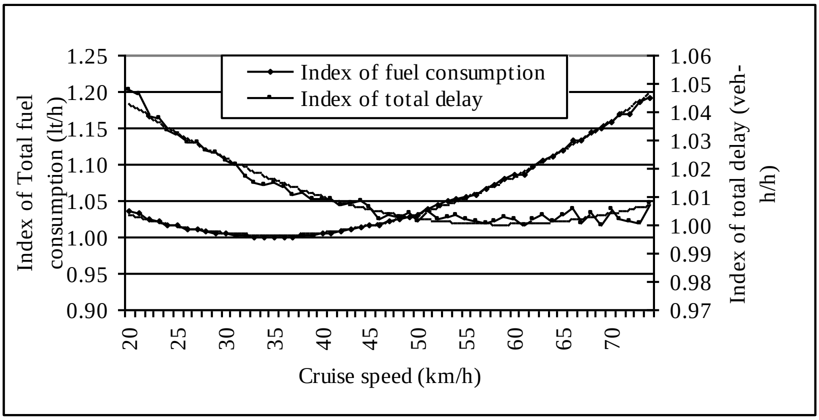

Fig.3. Total fuel consumption and delay according to cruise speed

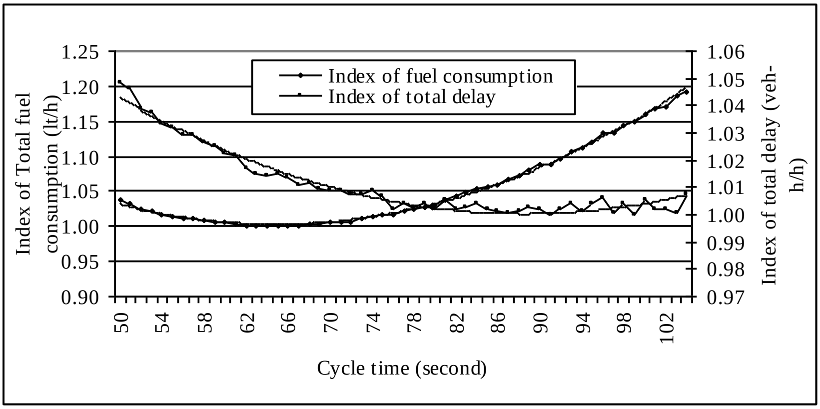

Fig.4. Total fuel consumption and delay according to cycle time

Table 2 shows the fuel consumption and performance parameters of the network under current operation conditions. The cruise speed is about 23.46 km/h. Thus, 23 and 24 km/h are used.

Table 2. Current performance of network

Cycle time (seconds)	Speed (km/h)	Delay (veh-h/h)	PI (pound/h)	Fuel consumption (lt/h)
100	23	5433.24	43845.8	8895.8
100	24	5423.04	43773.7	8867.6

The improvement on the current network with model application and the current operation is about 8% in terms of saving fuel consumed which means about 635 lt/h.

4.2 Air Pollution

Silva et al. (2006) presented numerical models for estimating fuel consumption and emission of HC, CO, NO_x and CO_2 of gasoline vehicles under urban driving conditions. A key conclusion from this study is that the tested models can be used with relatively high confidence to predict fuel consumption and CO_2 emissions. Kun and Lei (2007) developed an integrated microscopic traffic-emission simulation platform by using the microscopic traffic simulation model VISSIM and the modal emission model. The impacts of different traffic control strategies on traffic emissions are investigated. Therefore, the relationship between the instantaneous emission/fuel consumption rate and the instantaneous speed/acceleration is analyzed. After that, the emissions are calculated for a variety of vehicle types in the network.

Top down method is used to determine emissions (see for details, Haldenbilen, 2003). This approach may not be sufficient since it requires some assumptions, but it may be considered as a practicable method to calculate the values of pollutants caused from transport in a studied network. The emissions that come out from fuel consumption per unit tone are given in Table 3 (Ozturk, 1999; Sher, 1998).

Table 3. The amounts of pollutant (kg emission/ ton fuel)

Pollutants	***Fuel***		***Diesel***	
	Optimist	Pessimist	Optimist	Pessimist
CO	276	378	1.2	20.81
CH_X	14.0	14.5	4.16	16.0
NO_X	21.2	24.0	18.01	27.0

Total fuel consumption is assumed as 50% diesel and 50% fuel in order to determine the amount of emissions which cause air pollution (Special Report on Petroleum Products for Turkey, SRPP, 2000). Calculated emissions are given in Table 4. They are given both for current operating conditions and the optimum conditions. Improvement of the emissions is about 8% for all emitters.

Table 4. The amounts of existent and improved emissions

	Existent Condition		*Optimum Condition*		*Decreasing ratio of emission(%)*
	Fuel	**Diesel**	**Fuel**	**Diesel**	
CO	2909	98	2674	90	8
CH_X	127	90	117	82	8
NO_X	201	200	185	184	8

5. Conclusions

This study deals with the estimation of fuel consumption in urban road networks. The effects of improvements of the traffic signal timings and cruise speed on fuel consumption and air quality are investigated. For this purpose, a sample network is selected and related parameters are observed. The literature and the model development are outlined. The application of the developed model for estimating fuel consumption and emissions are correspondingly obtained and analyzed. The following results may be drawn from this study.

Energy saving may be achieved when improving the road network operating conditions such as capacity enhancement of links and preventing the on-street parking. After improvement, cruise speed may be increased from 23.5 km/h (current state) to 48 km/h (optimum state), and cycle time may change from 100 to 78 seconds.

An optimum stage, 8% saving of fuel consumption, 8% decrease on emissions and %10 improvement on system performance may be achieved.

Consequently, with an efficient improvement on road network operating conditions under fix time signal control saves the energy and hence improves environment in terms of reduction on pollutants.

Acknowledgement

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