Science of the Total Environment 633 (2018) 560–570

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The impact of highway base-saturation flow rate adjustment on Kuwait's transport and environmental parameters estimation

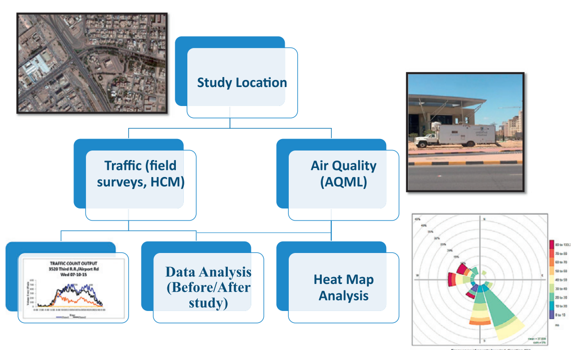
Fahad AlRukaibi [a], Sharaf AlKheder [a,*], Duaij Al-Rukaibi [a], Abdul-aziz Al-Burait [b]

[a] Civil Engineering Department, College of Engineering and Petroleum, Kuwait University, P.O. Box-5969, 13060 Safat, Kuwait
[b] Kuwait Ministry of Electricity and Water (MEW), Kuwait

HIGHLIGHTS

- BSFR was adjusted to reflect local traffic and environmental standards in Kuwait.
- Direct field measurements of BSFR and AQML for emission rates were used.
- Reduction in fuel consumption and vehicle emission after modification was 34%.
- Maximum pollutants' dispersions were in South East, South, and West directions.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 January 2018
Received in revised form 11 March 2018
Accepted 17 March 2018
Available online xxxx

Editor: P. Kassomenos

Keywords:
Flow rate
Sustainable system
Traffic pollution
Pollution reduction

ABSTRACT

Traditional transportation systems' management and operation mainly focused on improving traffic mobility and safety without imposing any environmental concerns. Transportation and environmental issues are interrelated and affected by the same parameters especially at signalized intersections. Additionally, traffic congestion at signalized intersections has a major contribution in the environmental problem as related to vehicle emission, fuel consumption, and delay. Therefore, signalized intersections' design and operation is an important parameter to minimize the impact on the environment. The design and operation of signalized intersections are highly dependent on the base saturation flow rate (BSFR). Highway Capacity Manual (HCM) uses a base-saturation flow rate of 1900-passenger car/h/lane for areas with a population intensity greater than or equal to 250,000 and a value of 1750-passenger car/h/lane for less populated areas. The base-saturation flow rate value in HCM is derived from a field data collected in developed countries. The adopted value in Kuwait is 1800 passenger car/h/lane, which is the value that used in this analysis as a basis for comparison. Due to the difference in behavior between drivers in developed countries and their fellows in Kuwait, an adjustment was made to the base-saturation flow rate to represent Kuwait's traffic and environmental conditions. The reduction in fuel consumption and vehicles' emission after modifying the base-saturation flow rate (BSFR increased by 12.45%) was about 34% on average. Direct field measurements of the saturation flow rate were used while using the air quality mobile lab to calculate emissions' rates.

* Corresponding author.
E-mail addresses: f.alrukaibi@ku.edu.kw (F. AlRukaibi), sharaf.alkehder@ku.edu.kw (S. AlKheder), d.alrukaibi@ku.edu.kw (D. Al-Rukaibi).

https://doi.org/10.1016/j.scitotenv.2018.03.193
0048-9697/

1. Introduction

In recent years, traffic volumes had been increasing rapidly in Kuwait. This required major improvements in road networks to satisfy the new environmental and transportation conditions and enhance traffic safety levels (Alkheder et al., 2013; Alkheder, 2017a, 2017b; Alkheder et al., 2017; Taamneh et al., 2017a, 2017b; Taamneh and Alkheder, 2018). One of the primary components of Kuwait road networks is at-grade intersections. There are two types of at-grade intersections: signalized and un-signalized intersections. Un-signalized intersections are uncontrolled, stop sign controlled, yield sign controlled, and roundabouts used for low to moderate traffic volumes. On the other hand, signalized intersections are used for moderate to heavy traffic volumes, which can cause significant impact on the environment due to vehicles' delay, emissions, and fuel consumption. Therefore, characterizing the relationship between the environmental and transportation system is crucial for developing a sustainable traffic signal control system. In literature, many recent studies associated the transportation system with the persisting environmental problems. This is much better than the traditional system of transportation planning and operation that mainly focuses on improving traffic flow without considering the environmental aspect. Due to the associated high traffic density, signalized intersections are usually major contributors to fuel consumption and air pollution. Developing a sustainable traffic signal system requires a proper design to minimize the environmental impact and to produce an efficient intersection operation. Signalized intersection design is sensitive to many parameters with the base-saturation flow rate being the most important factor. The base-saturation flow rate represents the saturation flow rate under ideal conditions. HCM (2010) suggested a value of 1900 PC/lane/h for cities with a population greater than 250 K and a value of 1750 PC/lane/h for cities with a population less than 250 K. However, the adopted value in Kuwait is 1800 PC/lane/h base on the population density estimation. It can be calculated using the following HCM equation:

$$S_{0,local} = 1900\frac{\sum_{i=1}^{m} S_{prevailing}}{\sum_{i=1}^{m} S_i} \quad (1)$$

$S_{prevailing}$: is the saturation flow rate measured in the field.

S_i : is the computed saturation flow rate using the following HCM formula :

$$S_i = \frac{3600}{\frac{t_{last} - t_{fourth}}{n-4}} \quad (2)$$

However, in Kuwait the BSFR value adopted by ministry of municipal work and road agencies is 1800 PC/lane/h. It was believed that this value better matched the population density constraints in Kuwait as specified by Highway Capacity Manual. So to be consistent with the current practice in Kuwait, the value of 1800 PC/lane/h was used instead of the 1900 HCM value for comparison with the field results.

2. Literature review

Recent studies had emphasized on the importance of localizing the saturation flow rate under local traffic and roadway conditions. Additionally, these studies calculated the saturation flow rate in different countries of the world and showed a significant difference from one country to another. Such variation in the saturation flow rate can be referred to the inconsistency in driving behavior among such countries. According to Jenish (2005), saturation flow rates at Maryland signalized intersections varied between 1900 and 2200 vehicle/lane/h. They recommended a value of 1950 vehicle/h instead of the 1600 vehicle/h used value for planning purposes. Chang-qiao and Xiao-Ming (2012) found that due to the differences in roadway conditions, transportation conditions, drivers' behavior and culture; HCM suggested value of 1900 PC per hour per lane for BSFR was not appropriate for China. Bester and Meyers (2007) noticed that saturation flow rates in South Africa were much higher than the ones in Western countries. They referred that to the aggressive behavior of South African drivers. Shao et al. (2011) reported that the base-saturation flow rate suggested by HCM was inapplicable in China. The base-saturation flow rate was reduced from 1900 to 1800 vehicle/lane/h. It was determined through a direct measurement of the approaches close to the ideal conditions. Mukwaya and Mwesige (2012) found that using the same HCM base-value of 1900 vehicle/lane/h in Uganda had resulted in a capacity overestimation. Same results were found in Qatar (Hamad and Abuhamda, 2015). Hamad estimated the base-saturation flow rate in Doha, Qatar under ideal local conditions. The value of the saturation flow rate in Doha was 2323 pc/h/ln, which was much higher than the value provided by HCM. On the other hand, vehicles at signalized intersections have a major impact on the environment due to vehicles emissions, delay, acceleration and deceleration, and traffic congestion. These considered main contributors to atmospheric pollution, climatic change, and global warming. Therefore, a relationship exists between the increase in vehicles' population & traffic characteristics and existing environmental problems. Many literature associated traffic characteristics with environmental problems. Pandian et al. (2009) concluded that queue length, traffic flow rate, acceleration and deceleration, and red signal timing were extremely affected by the base-saturation flow rate (BSFR). Such traffic related characteristics can control the increase in motor vehicles' emissions at signalized intersections. It was also reported that the intersection type and traffic characteristics were highly affected by the rate of vehicles' emissions. Therefore, to achieve a sustainable development for a transportation system, it is important to characterize the correlation between environmental impacts of the transportation system and mobility, traffic planning, and operation. In Kuwait, a more focus is needed on the environmental impact resulted from the transport systems while improving the traffic system with a smoother flow and lesser congestion. Thus, environmental problems resulted from splitting up the transportation system and environmental concerns and regulations can be reduced. Guo and Zhang (2014), Hallmark and Bachman (2000) and Rakha et al. (2000) connected the environmental parameters with the transportation system as can be seen in the energy consumption domain. They found that based on the total energy consumed in developed countries, transportation accounted for the highest percentage (20–25%). This is due to the heavy traffic density, acceleration and deceleration, and the long vehicle idling time at signalized intersections. These contribute significantly to energy consumption and Greenhouse gas emissions, a primary source of air pollution. According to the relationship between the environmental parameters and the transportation system, the total reduction in delay time and traffic signal coordination at signalized intersections led to a significant reduction in vehicular emissions that could be up to 50%. Likewise, Midenet et al. (2004) and de Coensel et al. (2012) related the environmental conditions improvement to the transportation system development. It was found that stops and delays had the most influence on the environmental cost where they induced the environmental cost by about 25%. CRONOS control strategy achieved high benefits on stops and delay that led to a significant reduction in the environmental damage, about 4% CO_2 reduction. Traffic flow improvement led to a lower vehicle emission. Also, the introduction of a green wave had a significant effect on emissions' reduction by about 10%–40% depending on the signal timing settings and traffic flow. Traffic intensity and green split can cause an effective reduction in emissions. Therefore, desired objectives of the environmental conditions and transport system are related to the ideal design of traffic signal. Pandian et al. (2009) found that the design of a signalized intersection highly affected emission rates. This is true when signalized intersections