Transportation Research Part A 118 (2018) 38–51

Contents lists available at ScienceDirect

Transportation Research Part A

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

Kriging based saturation flow models for traffic conditions in Indian cities

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ARTICLE INFO

Keywords:
Saturation flow
Kriging variants
Heterogeneous traffic
Correlation function

ABSTRACT

Saturation flow is crucial for designing the signal cycle and the corresponding green phase at an intersection. Therefore, it is important to compute saturation flow with a higher order of accuracy. Highway capacity manual (HCM) has provided a saturation flow model for homogeneous traffic condition with strict lane discipline. However, traffic in many parts of the world is highly heterogeneous and hence, it is necessary to develop saturation flow models for such situations. To this end, this paper presents saturation flow models for heterogeneous traffic conditions. To be specific, four saturation flow models based on Kriging variants have been proposed. Unlike available saturation flow models, the proposed models consider the effect of both geometric and traffic characteristics. Field data from fifteen intersections located in five different cities of India – Delhi, Patiala, Chandigarh, Mumbai and Panchkula – are used for developing and validating the models. Results obtained using the proposed models have been compared with other saturation flow models available in the literature. It is observed that the proposed models yield superior results outperforming existing saturation flow models.

1. Introduction

Saturation flow is the equivalent hourly discharge rate at the stop line at which previously queued vehicles can traverse an intersection approach under prevailing roadway and traffic conditions, assuming that the green signal is available all times and no loss times are experienced (Kimber et al., 1985; Michalopoulos et al., 1980). Practically, it is the maximum number of vehicles that can cross the stop line of the intersection approach during the green time. It is mainly used for designing and controlling the signalized intersection. The capacity and level of service of an intersection can be assessed in terms of saturation flow. According to USA Highway Capacity Manual (HCM) (TRB, 2010), saturation flow can be measured by observing the average headways of vehicles arriving at the intersections or passing any prefixed reference point. Based on this concept, HCM has proposed a saturation flow model, assuming homogeneous traffic condition and strict lane discipline. Such a scenario, although common in developed countries, is quite rare for developing countries such as India. Hence, the saturation flow model proposed by USA Highway Capacity Manual (TRB, 2010) will not be applicable for the existing traffic conditions of developing countries. Moreover, measuring headway among different vehicle categories at intersections, where lane discipline is not at all maintained is extremely difficult (Radhakrishnan and Mathew, 2011). Alternatively, USA Highway Capacity Manual (HCM) (TRB, 2010) proposed a saturation flow estimation formula

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https://doi.org/10.1016/j.tra.2018.08.037
Received 27 September 2017; Received in revised form 14 August 2018; Accepted 31 August 2018
0965-8564/

(Eq. (1) by considering base saturation flow to be 1900 and adjust it according to the existing road and traffic conditions.

$$S = S_0 \times N f_w f_{HV} f_g f_P f_{bb} f_a f_{LU} f_{LT} f_{RT} f_{LPb} f_{RPb} \quad (1)$$

where, S = saturation flow (veh/hr), S_0 = base saturation flow of a lane (veh/hr/lane) = 1900 PCU/hr/lane, N = number of lanes, f_w = adjustment factor for width of a lane, f_{HV} = adjustment factor for proportion of heavy vehicles in a traffic stream, f_g = adjustment factor for the gradient of an intersection approach, f_p = adjustment factor for the presence of parking, and lane group, f_{bb} = adjustment factor for blocking effect of buses, f_a = adjustment factor for type of area, f_{LU} = adjustment factor for lane utilization, f_{LT} = adjustment factor for left turning traffic in a lane group, f_{RT} = adjustment factor for right turning traffic in a lane group, f_{LPb} = adjustment factor for left turn movement in presence of pedestrians and f_{RPb} = adjustment factor for right turn movement in presence of pedestrians and bicycles. However, the proposed formula is developed based on the homogeneous and lane disciplined traffic conditions of USA. Therefore, the applicability of this formula in existing heterogeneous traffic conditions is questionable.

In past two decades, a number of studies have been carried out to identify and quantify the effect of various factors on saturation flow at signalized intersection. Arasan and Vedagiri (2006) observed a significant increase in the saturation flow rate with increase in the width of the approach road. Kockelman and Shabih (2000) suggested that special attention should be paid to light duty trucks while computing the saturation flow of a signalized intersection. Hossain (2001) proposed a model relating the effect of approach width, turning proportion, the percentage of non-motorized and heavy vehicles on saturation flow. Minh and Sano (2003) found that saturation flow rate at signalized intersections in Hanoi and Bangkok is strongly influenced by the presence of two wheelers (motorcycles). Vien et al. (2008) also investigated the effect of travel behavior of motorcycles on saturation flow in Malaysia and noticed that vehicles follow the first-in-first-out rule in an intersection and hence, the same should be considered during measurement of saturation flow. Similarly, Anusha et al. (2012) suggested that capacity and proportion of two wheelers have a linear relationship with positive slope whereas other categories of the vehicles have a negative impact on capacity. Webster and Cobbe (1966) and Kimber and Semmens (1982) suggested that not only vehicle composition and road width but turning radius also has some effect on saturation flow. Leong (1964) also encountered the effect of left turning and right turning vehicles on saturation flow.

The saturation flow models in all these studies cited above for heterogeneous traffic condition suffer from three major drawbacks. Firstly, almost all the available models represent saturation flow in PCU/hour of green where PCU indicates passenger car units (Radhakrishnan and Mathew, 2011; Saha et al., 2009; Kimber et al., 1985; Biswas et al., 2016a; Branston and van Zuylen, 1978). This entails computing the PCU factors for different vehicle categories. In almost all the studies mentioned above static PCU has been utilized for computing saturation flow. This naturally results in erroneous prediction as PCU is essentially dynamic in nature (Radhakrishnan and Mathew, 2011; Biswas et al., 2016a). Till date, only one saturation flow model based on dynamic PCU exists in the literature (Radhakrishnan and Mathew, 2011). To compute the dynamic PCU, an optimization based approach is utilized. However, the optimization algorithm is time consuming and computationally inefficient. Moreover, it is observed that the optimization based approach often fails to converge. Secondly, almost all the available saturation flow models are limited in scope. While some studies consider only the effect of geometric parameters (Webster and Cobbe, 1966; Bhattacharya and Bhattacharya, 1982; IRC-SP41, 1994; Haddad and Mahalel, 2014; Xuan et al., 2011), others have examined the effect of traffic composition (Hossain, 2001; Leong, 1964; Hadiuzzaman et al., 2008; Radhakrishnan and Mathew, 2011; Steuart and Shin, 1978) on saturation flow. Thirdly, the models have been developed only based on data from one city. Naturally, modelling uncertainty is associated with the models. Hence, it is necessary to develop a model that considers both the geometric and traffic characteristics which may influence the saturation flow.

In order to address the above-mentioned issues, novel saturation flow models have been presented in this paper. First, unlike available models, the present study represents the saturation flow invehicle/hour of green/lane. As a result, the complicated process of computing PCU factors is eliminated. In this context, it is important to note that representing saturation flow in terms of vehicle/hour of green (for heterogeneous traffic condition) was first introduced in 2001 (Hossain, 2001). The reason behind such a representation is to avoid the computation of PCU – which is the primary source of error in all the available saturation flow models. However, this makes saturation flow dependent on vehicle composition. This relation is extremely complex and cannot be traced by using either empirical or conventional regression methods. It is due to this reason that even after introduction of this concept (representing saturation flow in vehicle/hr) in 2001, it has rarely been exploited. Hence, a highly accurate surrogate model, referred to as Kriging (Biswas et al., 2016a, 2016b: Mukhopadhyay et al., 2016; Kaymaz, 2005), has been used in this study. Second, the models consider important geometric and traffic parameters like traffic composition and percentage of right turn. The effect of width has been circumvented by expressing the saturation flow in per lane width basis and hence, the same has not been considered as an influencing parameter. Third, data from 15 intersections located in 5 cities have been considered. To establish that the proposed models can be easily reused, the models were trained based on data from 7 intersections and validated on 8 other intersections.

Adding to this, the novelty of this work resides in utilization of Kriging for computing saturation flow. Kriging is a method of estimating a variable at an unmeasured location from observed values of its surrounding locations. The advantages of using Kriging are mainly threefold:

- Kriging performs both global and local approximations. Hence, results are more accurate as compared to conventional regression (Biswas et al., 2016a).
- Kriging gives the best unbiased linear estimator (Mukhopadhyay et al., 2016; Kaymaz, 2005)
- The number of data sets required for building Kriging model is less than those required in a conventional method (Denimal et al.,