Evaluating left turn saturation flow rate at signalized intersections by applying Floating Car Data (FCD) Technology

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ABSTRACT

The objective of this research is to apply a recent inventive technology floating car data (FCD) to determine headways between left turning vehicles during protected only signals. Usually time headways are very important parameters in determining saturation flow rate. By observing each turning vehicle's (including freights) travel time from a point to another point , time headways are calculated. This research is innovative because of application of FCD technology which is very helpful in the cities where traffic data may not be monitored. FCD technology can provide a very economic data of obtaining space and time headways. Since FCD can collect real traffic data information based on trajectories, both space headways and time headways can be obtained for left turning vehicles. This study also involves space headway as one of the independent parameters on which traffic saturation flow rate can depend. Moreover determining the time and space headways between the turning vehicles the FCD data can provide a very useful information for detecting large heavy vehicles such as trucks at the intersections. The presence of trucks or freights can definitely impact the left turning time which connects to cycle length perfection at that intersection. The overall aim is to establish a most reliable method of calculating left turning saturation flow rate for all types of vehicles including vehicles using FCD data.

Keywords: FCD, Left turn signal, Saturation Flow Rate, Freights

1.INTRODUCTION

The purposes of promoting efficient mobility and optimum capacity while simultaneously ensuring full safety result in competing interests at signalized intersections. The left turn movement plays a significant factor for safe and sequential operation at a signalized intersection. Usually traffic congestion is identified as the most common reason behind delays at arterials and intersections. The condition becomes more worsening during the peak hour. This research is planned to estimate saturation flow rate based on left turn movement by introducing a new inventive technology of acquiring data called floating car data (FCD).The FCD data is mainly used for traffic signal timing regulation purpose. Depending on the types of left turning protections, the motorists' speed during turning left and their travel time can be monitored where the signal phase and timing information sometimes may not be available directly from a city's Traffic Management Center (TMC).Moreover using infrastructure based approaches for obtaining traffic data, e.g., CCTV and loop detectors can be expensive for both installation and maintenance whereas pure FCD approach can offer relatively lower cost in deployment. The so far application of FCD was in monitoring vehicular speed whereas this research aims at using FCD in obtaining information on left turning vehicles to get informed about speed, time and space headways and in addition the intersection geometric conditions.

There are three fundamental types of left turning control which are i. Permitted only, ii. Compound (Permitted/Protected, Protected/Permitted) and iii. Protected only. This research focuses on Protected Only types of left turn movements. The primary interest is in the observation of left turning vehicles and sorting out the trucks from all types at a certain penetration level using FCD technology. Then estimate the saturation flow rate as a function of speed, headways collected from FCD once a mathematical model is developed. The model validation will be conveyed using a simulation of traffic data for several locations. An anticipation is driver behavior can predicted as well during real-time information relay on congestion through this research.

2. BASIC CONCEPTS IN TRAFFIC ENGINEERING

An authentic knowledge on some terminologies applied in this research (repeatedly) is required before proceeding. Here are the mentions as below:

2.1 Saturation Flow Rate

Saturation flow rate is defined as the equivalent maximum hourly rate at which vehicles can traverse a lane or intersection approach under prevailing traffic and roadway conditions assuming the full availability of green signal time and no lost times.

According to the Highway Capacity Manual (HCM),2010 the saturation flow rate per lane for a subject lane group at a signalized intersection is as below:

$$s=s_o f_w f_{HV} f_g f_p f_{bb} f_a f_{LU} f_{LT} f_{RT} f_{Lpb} f_{Rpb}$$

where,

s=adjusted saturation flow rate (veh/h/ln)

s_o=base saturation flow rate (pc/h/ln)

f_w= adjustment factor for lane width

f_{HV}= adjustment factor for heavy vehicles in traffic stream

f_g =adjustment factor for approach grade

f_p=adjustment factor for existence of a parking lane and parking activity to lane group

f_{bb}=adjustment factor for blocking effect of local buses that stop within intersection area

f_a=adjustment factor for area type

f_{LU}=adjustment factor for lane utilization

f_{LT}=adjustment factor for left-turn vehicle presence in a lane group

f_{RT}=adjustment factor for right-turn vehicle presence in a lane group

f_{Lpb}= pedestrian adjustment factor for left-turn groups

f_{Rpb}= pedestrian adjustment factor for right-turn groups.

2.2 Time Headway

Time headway is defined as the elapsed time between the arrival of pairs of vehicles at a common observation point is defined as the time headway and is expressed in seconds.

In the field the method of estimating the saturation flow rate is as below:

Saturation flow rate, s = 3600/Average Headway ($\bar{h}$)
where, 3600= converted hour into seconds

Average headway ($\bar{h}$)=(Tn-T4)/(N-4)

Tn= total time for N vehicles

T4= time for the rear axle of the fourth vehicle entering the intersection

N=total number of vehicles entering the intersection

3. SIGNIFICANCE OF THE STUDY

The main objectives of this research and the associated are to:

- provide a new concept and challenges by applying FCD to detect the types of vehicles using spacing and time headway trajectories
- apply to the locations where other traffic monitoring systems are not available
- contribute travel time comparison between general (non-equipped) and smart cars (equipped with GPS) during congestion period

The specialization of the study is to detect the presence heavy vehicles (like trucks etc.) in the traffic stream influencing on the saturation flow rate. Due to slower maneuverability~ affecting the saturation flow rate, part of the study is focused on traffic composition in the connected vehicles environment to estimate the saturation flow rate effectively at different penetration levels.

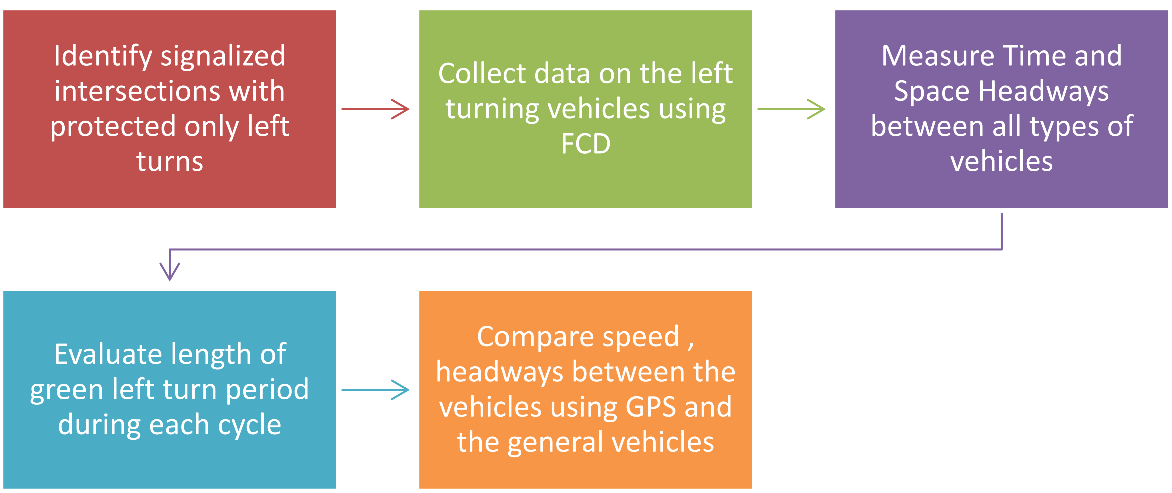
4. OBJECTIVE OF THE STUDY

In a summarized concept, the objectives of the study are depicted here:

- To detect the large, medium and small vehicles and isolate them estimating space and time headways.
- To determine the saturation flow rate by establishing a mathematical model.
- To analyze the overall capacity of the signalized intersection and level of service by integrating left turning travel time into the capacity estimation.

5. PROPOSED WORKFLOW

This research is intended to extend the application of floating car data (FCD) technology to a new dimension where an effective and most reliable method of calculating Saturation Flow Rate can be provided. Based on various sizes of vehicles, the large vehicles can be separated affecting the traffic flow. The workflow chart for the study is shown in a system below:



5. METHODOLOGY

A robust and complete literature review on floating car data and left turn modeling at signalized intersections is done for this study. The methodology for this study basically comprises of three key components:

Platform and Scenario:A simulation platform is required to refine the FCD system requirements. Using the most required input data for FCD system (penetration rate, sample intervals and the number of samples) once the simulation is performed, the real scenario can be applied for any road segment for any locations. A major function expected from FCD is the estimation of current travel speed for a road segment under optimal conditions. The other requirements are to estimate the space and time headway between the left turning vehicles and also the intersection geometric features.

Requirements of FCD: Three parameters are considered: penetration rate, sample interval and number of samples as the minimum requirements of FCD dataset under optimal conditions. These three are interrelated with one another and cannot be applied in isolation. Penetration rate determines the number of vehicles that have to be equipped with GPS probes, significantly influencing the practical feasibility of the FCD deployment in left turning vehicular movements. Penetration rate must be needed to be minimized. The sample interval is maximized next since it determines the amount of data to be transmitted within a very reasonable operational cost. Even if the parameter, the number of samples does not affect costs directly, but it can be used to increase the accuracy for a given combination of penetration rate and sample interval. Intentionally the signalized intersections chosen where heavy vehicles and trucks usually move frequently to make a comparison between the estimated saturation flow between the intersections with and without heavy/large vehicles.

Data Processing: The observation of left turning vehicular movements need to conduct during both AM and PM peak hour congestion period. The level of traffic jam (light, medium and heavy) must be considered to achieve the travel times (average) for left turning vehicles. All traffic data including speed of left turning vehicles, length of left turning radius, length of road segment, number of left turning vehicles can be used as input data for FCD.

6. ANALYSIS & EXPECTED RESULTS

This research will cultivate an integrated mathematical model which will define a well-developed method to define left turn saturation flow rate where the major input variables are vehicular speed, time headway and spacing between the vehicles while turning left.

Mathematically the saturation flow can be expressed as a function of the following variables:

$$S = f(W, v, h, s)$$

Where, S=left turning saturation flow rate

W= Total width of opposing lanes

v= left turning average speed

h= average time headway

s= average spacing between vehicles

The so far application of FCD was in monitoring vehicular speed only to provide efficient signal planning, but this research aims at using FCD in obtaining real time traffic information on left turning vehicles . After obtaining data on travel time, speed and left turning radius for any signalized intersection, the saturation flow rate model can be established using a regression model. The model validation can be carried out using simulation at protected only left turn signalized intersection.

The Preliminary results show the relation between speed, spacing and number of left turning vehicles. These variables are interchangeable in terms of quantifiably when motor vehicles, motor cycles and freight/trucks are classified separately. The freight data can impact the turning vehicles' travel time compared to the general vehicle data. The initial results converge on comparison between obtained traffic data using general vehicles and vehicles equipped with GPS technologies. Here the focus of the ongoing research is to quantify both space headways and time headways with left turning speed in terms of graphs and charts. The goal is thus to establish relations between the independent variables (speed, space headway and time headway) and dependent variable (saturation flow rate) both for motor vehicles and freight trucks.

7. CONCLUSION

The proposed method has the potential to be used in adaptive signal control systems for dynamically estimating the saturation flow rate to respond to unanticipated changes in the traffic caused by road incidents such as temporary lane blockages, accidents, adverse weather conditions, etc. and does not require the disposition of traffic sensors such as loop detectors

FCD offers some advantages over loop detector data such as: it can be inexpensive in terms of non-destruction works (which is costly in cases for installing loop detectors), can offer new algorithms for researchers and engineers and can provide best left turn phasing (efficiency). Again, since this study is biased on travel time estimation of left turning vehicles at protected only left turns with accurate FCD data, drivers' general nature can be obtained by observing car following theory. The research is inventive since it will apply the FCD method to mitigate congestion at signals by collecting and utilizing data and feedback from cars equipped with smartphone (GPS) systems of the left turners. The best left turning green period can be provided by estimating the most accurate travel time. Further the accuracy of travel time estimation method needs to be validated and compared. The overall impact would be to provide cutoff in financial burden for both transportation and environmental agencies and also the reliability of applying FCD data must be thoroughly investigated. One of the current limitation of the research is presently permitted only and protected/permitted types of left turns could not be taken under consideration as of protected only left turns are prioritized here. But future recommendations would be provided for the other types of left turns and pedestrian movements as well as freight movements at the signalized intersections using FCD technology.

REFERENCES

1 Astarita V., Giofrè P., Guido G., and Vitale A. (May,2017). *The Use of Adaptive Traffic Signal Systems Based on Floating Car Data.*

2 Li, X., Zhang, R., & Zhu, H. Research on an intelligent control strategy of signalized intersections for capacity enhancement. *Cictp 2014* (pp. 2042-2049) doi:10.1061/9780784413623.196.

3 Singh, B., & Gupta, A. (2015). Recent trends in intelligent transportation systems: A review. *Journal of Transport Literature, 9*(2), 30-34. doi:10.1590/2238-1031.jtl.v9n2a6

4 Bester,C. J. & Meyers, W.L. (2007).Saturation Flow Rates.*Proceedings of the 26th Southern African Transport Conference (SATC 2007). ISBN Number: 1-920-01702-X*

5 Wolfermann, A., Alhajyaseen, W. & Nakamura, H. (2011). Modeling speed profiles of turning vehicles at signalized intersections *3rd International Conference on Road Safety and Simulation, September 14-16, 2011, Indianapolis, USA.*

6 Vandenberghe W., Vanhauaert E., Verbrugge S. & Moerman I. (2012) Feasibility of Expanding Traffic Monitoring Systems with Floating Car Data Technology. Article in IET Intelligent Transport Systems · December 2012.

7 Brockfeld E., Lorkowski S., Mieth P. & Wagner P. (2007).Benefits and limits of recent floating car data technology – an evaluation study. Conference Paper · June 2007.

8 Liu X., Chien S. & Kim K. (2012). Evaluation of floating car technologies for travel time estimation. Journal of Modern Transportation Volume, Number 1 March 2012, Page 49-56 Journal homepage: jmt.swjtu.edu.cn

9 Bing-Chuan, Z., Bin-Bing, L., Da-Wei, L., & Shu-Hui, Z. (2011). Application of short-term traffic flow forecast in selecting the optimal route. Paper presented at the, *1* 768-771. doi:10.1109/ICICTA.2011.199

10 Lu, J., Filev, D., & Tseng, F. (2015). Real-time determination of driver's driving behavior during car following. *SAE International Journal of Passenger Cars - Electronic and Electrical Systems, 8*(2), 371-378. doi:10.4271/2015-01-0297

11 The Smart/Connected City, & Its Implications for Connected Transportation. *The smart/connected city and its implications for connected transportation*

12 WANG, C., & WANG, L. (2016). Study on the theory of the smart city. *DEStech Transactions on Social Science, Education and Human Science,*(icssd) doi:10.12783/dtssehs/icssd2016/4739

13 Baykal-Gürsoy, M., Duan, Z., & Xu, H. (2009). Stochastic models of traffic flow interrupted by incidents. *IFAC Proceedings Volumes, 42*(15), 442-449. doi:10.3182/20090902-3-US-2007.0107

14 Chang-qiao Shao, & Xiao-ming Liu. (2012a). Estimation of saturation flow rates at signalized intersections. *Discrete Dynamics in Nature and Society, 2012*, 1-9. doi:10.1155/2012/720474

15 Chang-qiao Shao, & Xiao-ming Liu. (2012b). Estimation of saturation flow rates at signalized intersections. *Discrete Dynamics in Nature and Society, 2012*, 1-9. doi:10.1155/2012/720474

16 *Transportation Systems Engineering and Information Technology, 8*(4), 63-69. doi:10.1016/S1570-6672(08)60033-1

17 Shao, C., Rong, J., & Liu, X. (2011). Study on the saturation flow rate and its influence factors at signalized intersections in china. *Procedia - Social and Behavioral Sciences, 16*, 504-514. doi:10.1016/j.sbspro.2011.04.471

18 Zhang, W., Wang, Y., & Yang, X. Influence of the number of through lane groups on saturation flow rates at signalized intersections. *Traffic and transportation studies 2010* (pp. 285-294) doi:10.1061/41123(383)25

19 Increasing the Capacity of Signalized Intersections with, & Separate Left Turn Phases. *Institute of transportation studies university of california, Berkeley;* journal homepage: www.elsevier.com/locate/trc. (a). *Transportation research part C*doi:10.1016/j.trc.2015.09.015journal homepage: www.elsevier.com/locate/trc. (b). *Transportation research part C*doi:10.1016/j.trc.2016.09.012

20 Liang Ren. (2015). Calibration of saturation flow for signalized intersections. *Applied Mechanics and Materials, 713-715*, 2093. doi:10.4028/www.scientific.net/AMM.713-715.2093

21 Mannering, F. L. (2005). *Principles of highway engineering and traffic analysis*. United States: Retrieved from http://catalog.hathitrust.org/Record/004764436

22 Zhao, J., Li, P., & Zhou, X. (2016). Capacity estimation model for signalized intersections under the impact of access point.

23 Bruner, A. (2015). *Initial framework for improving the traffic safety culture in kansas.* Available from ProQuest Dissertations & Theses: Open. Retrieved from http://search.proquest.com.ezproxy.library.csulb.edu/docview/1728737618