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ESTIMATION OF DYNAMIC TRAFFIC DENSITIES FOR OFFICIAL STATISTISCS BASED ON COMBINED USE OF GPS AND LOOP DETECTOR DATA

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ABSTRACT

Traffic density is one of the important variables to identify traffic states, which attracts a lot of attention form both traffic management and Statistics Netherlands. In this paper, we aim to validate the usage of GPS information on estimating traffic density for traffic statistics. Our method of traffic density estimation is based on the definition of traffic density and the combination of loop detector and GPS data. Then the estimated dynamic density is scaled up to the whole road network to be used for official statistics. As such, it provides dynamic information and offers opportunities to reduce administrative burdens in statistics office.

KEYWORDS

Traffic density estimation, traffic population estimation, GPS sample data, loop detector Data, official statistics

INTRODUCTION

Traffic density, defined as the number of vehicles per unit length of a road segment at a certain time period measured in vehicles/km (HCM, 2000), is one of the important characteristics of traffic states. Classical traffic flow theory defines the fundamental relation amongst flow, density and average speed as flow equals density times speed. Flow is the number of vehicles passing a given cross-section of the road per time interval and measured in vehicles/hour. In this present paper we focus on traffic density, as an ideal indicator of traffic conditions (Ni, 2007), which draws attention from both traffic management and official traffic statistics. Traffic management and traffic control use real-time estimation of traffic density as input for the spatial and temporal monitoring of the road network (Qiu et al., 2010). Statistics offices, especially Statistics Netherlands, the national data collection institutes, are interested in real-time measurement of traffic density to support policy makers with more accurate, more relevant and timely statistics about traffic states.

The quality of traffic density estimates is naturally defined by the data sources used. Currently, two collection methods are employed: traffic surveys based on in-out traffic flows or high altitude photographs; and fixed detector data (Hu and Yang, 2008). The use of loop detectors generates the main data source. Traffic surveys are used infrequently as they are relatively costly. At the same time, with the development of information and communication technology, the last decade has seen a massive increase of traffic state signals generated by GPS (Global Positioning System). A marked practical advantage of GPS data collection is that transport and traffic data are captured automatically at highly frequent rates yielding instantaneous, real-time and accurate information, including position, direction, instant speed and time. The question therefore arises whether and how this real-time captured electronic data could serve as alternative, possibly complementary, data to construct traffic statistics. This approach may provide dynamic and real-time information and offer opportunities to reduce the disadvantages of traffic surveys.

However, the adoption of GPS-based statistics is seriously hampered by the fact that relatively few vehicles are equipped with GPS. Qiu, et al. (2010) mention that the penetration rate of GPS vehicles is only 5% of the whole traffic population. GPS-collected data cover only a limited part of all transport and traffic activities for a delineated area and specific time slots. A substantial, continuously varying number of vehicles thus goes unobserved. The combination of GPS data with loop detector data might solve the GPS coverage problem to estimate traffic density and further to improve traffic statistics.

The aim of this paper is to validate the use of GPS information for official traffic statistics. We explore the following research questions: (1) how can we integrate GPS data and loop detector data; and (2) how can the combined data be used to measure dynamic traffic density for official statistics?

STATE OF THE ART

Faced with highly dynamic traffic situations, decision makers find that the current statistics insufficiently support policy making. Current traffic statistics are of a highly aggregate nature and hide much important traffic phenomena. Increasing the relevance of these traffic statistics, in terms of detail, coverage and timely availability, requires the use of adequate raw traffic data, but also of suitable models to process these data. The latter has been the subject of various studies in traffic engineering. There are several researches on traffic density estimation, such as Cell Transmission Model (Daganzo, 1994), Switching-Mode Model (Munoz, 2005) and the model based on the traffic density definition (Qiu. ect, 2010). However, few studies take these traffic density model with the use of electronically captured data for traffic statistics. Most of these studies are about testing the effects of various missing data patterns on existing statistical calculation procedures (Turner and Park, 2008). Our research extends the approach of Qiu.ect (2010) to the more gerneral case for traffic density estimation. And then the model of dynamic traffic population for traffic statistics is built up.

MODEL OF DYNAMIC TRAFFIC POPULATION

The estimation of dynamic traffic density requires information about road networks and vehicle characteristics. Road network information is basically concerned with the number of vehicles in a specific road segment at a particular point in time or during a certain time interval, while vehicle information consists of vehicle characteristics, such as length, weight, engine power and so on. Loop detector and GPS data are the main data sources to capture the traffic information in the network. In this section, we demonstrate the mechanism of data capture through loop detectors and GPS, and discuss why these two data sources are suitable for density measurement. Next, we present the methodology for estimating dynamic traffic population based on these two data sources.

Traffic density estimation

Our method of traffic density estimation is based on the definition of traffic density proposed in Qiu, et al (2010). The number of vehicles is counted directly by the loop detectors. This information is matched with the characteristics of passing GPS vehicles, making use of the GPS location estimates. The travel time of GPS vehicles can be easily obtained, and so the time interval during which the GPS vehicle passes the two loop detectors can be determined. We adopt ‘Method 2’ proposed by Qiu, et al (2010) to measure traffic density on the road segments. We extend their method to handle road segments with on- and off- ramps having no loop detectors installed.

Estimating traffic density is challenging, because it depends on time as well as space. We therefore consider its estimation for road segments of increasing complexity; beginning with typical road segments between two loop detectors on a highway without on- and off-ramps, and then discussing a road segment with on- and off-ramps between two detectors. For both cases, the objective is to estimate the traffic density on the main lane.

For the general situation without loop detectors at on/off-ramps, the number of the vehicles that enter or leave the main lane cannot be observed. However, it is possible to measure the change of traffic counts based on the two loop detectors. Two continuesly equal time windows run by GPS vehciles are defined. During these periodes, the difference between the traffic counts of these two loop detectors is the change of traffic volumes. Then the traffic volume between loop detectors with on- and off-ramps can be measured with only the second loop detector; the influence of the first detector is hidden in the last moment time of GPS running.

Dynamic traffic population estimation

Having modeled the traffic density in a road segment between two loop detectors, the next step is to up-scale the sample results to estimate the desired population. This step is particularly relevant for the potential use of traffic data for official traffic statistics. If each road segment between two loop detectors is regarded as a cell, in the whole highway there are several cells, where the traffic density are changing along the time dimension. Then the output of traffic density estimation in the previous section is taken as the input for the model of dynamic traffic population estimation for the traffic statistics. Regarding to simple random sampling technology, Horvitz-Thompson strategy is applied for the estimation of the population total. Horvitz-Thompson estimator is a general estimator for a population total, which can be used for any probability sampling plan.

CONCLUSIONS

This paper discussed the estimation of dynamic traffic densities with the help of GPS-equipped vehicles for a road network with loop detectors. Based on the definition of traffic density, the model of traffic density estimation is set up.

Using the advantages of both loop detector and GPS data and taking into account that the number of GPS vehicles is limited, the combination of the two types of data is used to estimate dynamic traffic density. The idea of reference road segments is used to scale up the traffic density estimates to the whole road network.

There are several application areas where the combination of GPS and loop detector data is of use. First, once the type of vehicles is determined, the contribution to density by different types of road users can be calculated. From the perspective of official statistics, this is a relevant result in itself, but it will also help to improve the estimations of traffic emission models. Second, other breakdowns of traffic could be made, for example, by short and long journeys and by regions of origin or destination. This would help traffic policy makers to combat congestion more effectively. Third, dynamic traffic state estimates combined with GPS information can be applied to identify road types and determine the road maintenance period. As GPS information offers insight into the exact journeys through network, road usage patterns of the limited number of GPS vehicles may be used to represent the road usage of the same types of vehicles not equipped with GPS. Dynamic traffic state estimation may then provide the information required to predict the road maintenance period.

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