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主論文の要旨

論文題目 UTILIZATION OF PROBE VEHICLE DATA TO ESTIMATE URBAN TRAFFIC CONDITIONS （プローブカーデータを用いた都市道路交通状態の推定に関する研究）

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論文内容の要旨

Traffic congestion is a crucial problem that adversely and significantly affects the environment and transport efficiency in numerous cities. Efforts to solve this problem lead to the development of intelligent transportation systems (ITS). An essential input for ITS is accurate and reliable knowledge about traffic conditions. The objective of this research is to estimate traffic conditions from probe vehicle data for urban networks.

In traffic flow theory, flow, speed (or travel time) and density are three fundamental macroscopic variables representing traffic conditions in the spatial and temporal domains. Therefore, to provide comprehensive knowledge of urban traffic, this research explores estimation of various measurements of traffic conditions from these three aspects. Specifically, firstly methods are proposed to estimate traffic flow (including link flow and origin-destination (O-D) flow) from travel times of probe vehicles. Secondly link travel time distribution is modelled and discussed. Then methodology of traffic monitoring is explored.

In Chapter 1, the background of this research is firstly introduced. And then measurements of traffic conditions and characteristics of probe vehicle data are extracted and discussed. Further, challenges of estimating urban traffic conditions are summarized and analyzed. Then, research objectives are explicitly defined. This is followed by an organization of this thesis.

Chapter 2 gives a detailed review of literatures which most relate with this research. The mechanism of probe vehicle is firstly introduced. And then issues involved in probe vehicle data including data types, polling schemes, penetration and applications are reviewed. Finally, methodologies of estimating flow, travel time and density using probe vehicle data are reviewed, respectively.

Chapter 3 provides a methodology of estimating dynamic link flow from raw probe vehicle data. From the view of practical application, this methodology consists of three steps: travel time allocation, link performance function fitting, and link flow estimation. In the first step, method of proportional allocation is used to decompose probe travel time onto individual links. In the second step, link performance function is obtained from a speed-density function derived from Gazis's nonlinear follow-the-leader model. In the third step, a Bayesian method that incorporates prior distribution of link speed is applied. A traffic network called Kichijoji-Mitaka area is developed and validated in VISSIM according to a rather complete benchmark data set based on this area. The proposed method is tested by using simulation data in this network. Additionally, the effects of polling frequency and penetration of probe vehicle are tested and analyzed. Results show, the Bayesian method can give acceptable estimates of link flows. This methodology avoids of assumption of random sampling and is recommended to be put into practice for urban networks.

Chapter 4 describes a bi-level generalized least square (GLS) model to estimate dynamic O-D flow from estimated link flow in Chapter 3 and historical O-D flow. It is an extension of Tavana's model. Both the distance between the estimated and target OD matrices and the distance between the calculated and observed link flows are considered in the objective function. Hence the extended Bell algorithm is used to solve the upper level of this model. For the lower level, the dynamic traffic assignment (DTA) module in VISSIM is applied. Moreover, the GLS formulation can utilize the variance of estimated link flow from Chapter 3. However setting an identical variance of link flow for links decreases GLS to be ordinary least square (OLS) as Tavana's model. A case study on Kichijoji-Mitaka area validates the superior of the bi-level GLS to OLS. And it illustrates the application of microscopic traffic simulator like VISSIM in solving the lower level of bi-level estimation of O-D flow. As a whole, the proposed methods in Chapter 3 and Chapter 4 are capable of estimating link flow and dynamic O-D flow using probe data in practice, such as in probe vehicle-based dynamic route guidance system, or in situation that link counts are not available.

Chapter 5 presents the formulation of link travel time distribution in the signalized road section by using truncated distribution. Link travel time is decomposed into time-in-motion and time-in-queue. The time-in-motion mainly depends on physical attributes of the link and traffic conditions, and is modelled by a truncated distribution. The time-in-queue is mainly related to signal timings and the signal offset between adjacent intersections, and is derived from hydrodynamic theory and horizontal queuing theory. The derived link travel time distribution is parameterized by fraction of stationary vehicles, red signal time, and motion behavior parameters including truncation points. These parameters are estimated from travel times provided by probe vehicles using a maximum likelihood estimator. It is shown that it's better to model time-in-motion with a truncated distribution instead of a non-truncated one using AICc and BIC criteria. And the results also validate the superiority of applying a truncated distribution to model the distribution of link travel times. It is recommended that truncation of travel time should be considered and which imposes effects on travel time variability and reliability.

Researches in Chapter 3-5 utilize link travel times provided by part of probe vehicles, which has relative high polling frequency. Link travel times become less accurate and reliable for lower polling frequency probe vehicle data because of the difficulties of map-matching and path travel time allocation. Therefore, Chapter 6 explores methodology of mining traffic information from scatted probe vehicle data regardless of polling frequency.

Chapter 6 describes the formulation of a joint probability distribution of vehicle location and speed on arterial road using hydrodynamic theory and horizontal queuing theory. By assuming that sample vehicle locations are proportional to the traffic densities, the probability distribution function (PDF) of vehicle location is derived. Conditioned on certain location, speed is distributed according to a mixture distribution of distributions with different densities. Then the joint PDF of vehicle location and speed is derived using multiplication rule. Particularly, the joint PDF is derived for both under-saturated and saturated regimes. This model is parameterized by link parameters (cycle light time, red light time, etc.), parameters of driver behavior, and traffic states (densities and remaining queue length). To validate these distributions, a Kolmogorov-Smirnov test is performed using probe data collected during a field test in Toyota City. The numerical results validate the use of proposed models for both under-saturated and congested regimes. Additionally, the proposed models capture most features of vehicle location and speed distributions. Additionally, the derived models are simplified by neglecting some small details to improve the computation efficiency when applying it into network-level estimation. The proposed model is a brand new model which models location and speed distributions simultaneously. The derived joint PDF makes it possible to learn macroscopic traffic parameters and link parameters from location and speed data of probe vehicles.

Chapter 7 concludes this research by summarizing the proposed models and their performance, and pointing out the limitations of this research and indicating the future researches.