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A method of emission and traveller behavior analysis under multimodal traffic condition

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ABSTRACT

The growth of urban traffic in recent decades has led to environmental problems in terms of increased emissions. In some cities located along waterfronts, multimodal transportation that includes ferry trips plays an important role in public transportation. Compared with roadway traffic, ferry service can often provide shorter routes between given origins and destinations as well as reduce emissions. However, in some areas with high ferry demand, travel delay occurs frequently because of traffic congestion caused by drivers waiting to board the ferry, which can significantly increase travel time and decrease its reliability. In addition, changes in other factors, such as fuel prices, also may influence drivers' decision making processes in terms of route choice. In this paper, a study focusing on travel time and travel time reliability of ferry service during peak travel periods is performed. Furthermore, as a key result an emission loss model under multimodal conditions is developed that also takes travel cost into account. The analysis of route choice is conducted based on a mixed logit model which is able to handle individual preference. Based upon validation with data from the Seattle area, the proposed model is verified as an efficient way to analyse emission factors in a multimodal transportation environment.

1. Introduction

Economic growth has resulted in serious environmental issues in the world, especially in terms of air pollution and emissions, causing substantial losses to economic development and residents' health (Brajer et al., 2006; Yang and He, 2016). With rapid urbanization, traffic volumes have grown rapidly and associated congestion become increasingly serious. Air pollution caused by traffic emissions has thus been becoming a critical issue in urban areas. According to a previous study (Yang and He, 2016), transport emissions have increased by annual growth rates averaging 10% over the past three decades in some areas with rapid economic development; such increases can cause serious environmental and health problems (Brajer et al., 2006).

Issues surrounding emissions from transportation have attracted the attention of some scholars in recent years. Several studies were conducted to that focused on providing guidance in policy-making for traffic management through intelligent traffic systems (Gkritza and Karlaftis, 2013), traveller behavior research, and flexible methods for of travel pricing (Sharma

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and Mishra, 2013). In particular, Transportation system optimization in multimodal conditions is an effective way to reduce emissions due to the obvious differences in emission patterns for different traffic modes. Therefore, how to optimize the share of different traffic modes, in an effort to reduce emissions, through policy has being become a research hotspot. As such, many scholars have presented methods to decrease emissions in multimodal traffic systems (Nagurney et al., 1998). For example, Zhao et al. (2016) developed a bi-level model for greenhouse gas emissions based on a continuous distribution of travelers' value of time; Mishra and Welch (2012) studied vehicle emission pricing strategies for large transportation networks. At present, however, these studies focusing on multimodal traffic have not devoted much attention to ferry services.

In some cities located along bodies of water, ferry service can play an important role in effectively reducing roadway traffic volumes on (Zhang et al., 2016a, b) and in turn, emissions. One such location is the Puget Sound area in Seattle, where there are a total of 22 ferry terminals. It has been reported that the ferry terminal service greatly shortens the journey around the Puget Sound bay, and therefore significantly reduces emissions caused by commuter drivers in this area.

However, during peak travel periods, the volume of vehicles making use of the ferry service significantly increases, often exceeding the capacity of the ferry ships, and finally resulting in long queues of vehicles waiting to board the ferries as well as traffic delay. In this situation, commuter drivers' route choice decisions may be affected by the estimated delay, and they may choose to take another route that they perceive as candidate with less delay. Thus, traffic congestion during peak periods may ultimately cause changes in emission patterns compared to what was initially expected.

Therefore, it is necessary and meaningful to study route choice of commuters under a multimodal traffic condition (Wilner et al., 2016) that features both roadway and ferry traffic. This study will not only lead to better comprehension and formulation of the emissions patterns impacted by ferry travel delay and other factors, but will also aid ferry service administration in optimizing service levels and scheduling during peak travel periods. Several key factors are classified in the route choice decision making procedure under multimodal conditions including travel time, travel time reliability, and travel cost. Since commuters, who are classified as main contributors of emissions, typically have to follow fixed timetables, travel time reliability is identified as a critical factor influencing their route choices. Therefore, in this paper, ferry travel time and corresponding reliability are studied, and travel costs influenced by gas prices are also examined.

Route choice and mode choice have been thoroughly researched for many years (Yang et al., 2016; Zou et al., 2016; Agrawal et al., 2016). The logit model is often viewed as an efficient method for route choice behavior analysis and prediction. One variant, namely the C-Logit model (Cascetta et al., 1996), has been proposed as a method in which a commonality factor measures the degree of similarity of each route with the other routes in a given choice set. Several other advanced logit models have been developed to overcome the limitations of C-Logit, each of which has been applied in a variety of relevant scenarios, such as the Path Size Logit model (Prato, 2009), and the Multinomial Logit model (Ding and Zhang, 2016). Specially, an advantage of the Mixed Logit or Mixed Multinomial Logit (MXL) (Munizaga and Alvarez-Daziano, 2001; Hensher and Greene, 2002) is that it adopts random coefficients that can handle different coefficient values that indicate the preferences of individuals. Based on a mixed logit route choice method, such as that used in the aforementioned studies, a new model to estimate emissions in a multimodal transportation environment is proposed. Specifically, the model formulates the relationship between emission loss and factors under multimodal traffic conditions such as ferry travel time, reliability, and travel cost.

The contributions in this study contain, (1) travel time and travel time reliability formulation in ferry service; (2) route choice model of traveller behavior in multimodal condition based on the empirical distribution of travel time and travel time reliability studied; (3) formulation of emission loss in joint condition of freeway and ferry service, and relative analysis in peak time. Through modelling emission and main factors to influence traveller behavior decision making in this study, a method of emission loss analysis under multimodal condition is achieved, and more analysis are capable to be conducted as the aid of urban planning and administration.

The rest of this paper is organized as follows. Section 2 describes the details of the studied problem, and gives the reader a better understanding of the wider context and purpose of the proposed method. Section 3 presents the mathematical procedure for emission loss calculation, including sub-sections on travel time reliability in ferry service, cost analysis, discrete choice models, and emission loss calculation. In Section 4, the proposed method is applied to estimate emission loss in the Puget Sound area to validate the model, and related analyses are presented. In section 5, some discussions are performed. Finally, concluding remarks are provided in Section 6.

2. Problems description

Greenhouse gases (GHG) are emitted by natural and man-made processes, and include a wide range of gases such as methane and nitrous oxide. The primary sources of GHGs include generating electric power (except for hydro-electric, wind, and solar power generators); transporting goods, services, and people; industry (manufacturing of goods); agriculture; and commercial/residential energy use. Carbon dioxide (CO_2) accounts for the majority of emissions by weight, and is frequently used as the primary metric for reporting GHG emissions. In this study, transportation emissions are measured by carbon dioxide equivalents (CO_2e), which is obtained by converting multiple other GHG emissions based on their relative global warming potential compared to carbon dioxide.

Although a variety of transportation modes, like car, bus, airplane, ferry, etc., will produce emissions, the quantities of such emissions produced are very different depending on the mode (Munshi, 2016). In general, driving private car by individuals leads to more emissions on a personal average basis than travel via public transportation, such as bus or ferry.