Transportation Research Part D 53 (2017) 178–192

Contents lists available at ScienceDirect

Transportation Research Part D

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

Evaluating lane reservation problems by carbon emission approach

Xue Bai [a,b], Zhili Zhou [a], Kwai-Sang Chin [b,*], Bin Huang [c]

[a] School of Management, Xi'an Jiaotong University, 28 Youyi West Road, Xi'an, Shaanxi 710049, PR China
[b] Department of System Engineering and Engineering Management, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong
[c] Shenzhen Yiliu Technology Co., Ltd., PR China

ARTICLE INFO

Article history:
Available online 25 April 2017

Keywords:
Lane reservation problem
Carbon emission
Integer programming
Traffic state estimation
Trajectory data

ABSTRACT

The lane reservation strategy is an efficient way for traffic control and management. Design of reserved lanes on existing network is called lane reservation problem. This paper examines the lane reservation problem from a new perspective of carbon emission in real urban transportation network, which incorporates the environmental impact and the traffic state of a city into design of reserved lanes. A carbon emission index is constructed to measure the impact of the reservation strategy. An integer linear programming model is used to improve the efficiency of special transports with the objective of minimizing the carbon emission index. Real urban traffic state is considered when the lane reservation strategy is implemented. The gird approximation method is developed to estimate the traffic state of a city using 30-day trajectory data of 14,000 vehicles in Shenzhen, China. Extensive computational analyses have been presented by several experiments based on real traffic data. The results indicate that lane reservation strategy can bring not only efficient transportation on reserved lanes, but also air pollution. The growth trend of the increased emissions becomes smooth after a sharp rise during the onset of the introduction of the reserved lane. With same improvement, fewer reserved lanes are required, but more emissions are produced under congested traffic than smooth traffic.

1. Introduction

The development of the economy has engendered a high degree of urbanization. Although urbanization paved the way to numerous achievements, it has also introduced challenges, among which, congested traffic is one of the most serious urban ills. The increasingly intensive traffic situation gives rise to transportation delay, which consequently results in a considerable number of problems. To overcome these problems, we can design and build new transportation infrastructure or introduce new traffic policies to manage and control traffic flow. The latter one is advantageous in its sustainability since it exploits the existing infrastructure (Guerrieri and Mauro, 2016). According to existing situations, a lane reservation strategy is employed to improve the efficiency of the specific urban transportation for some management purposes. In this strategy, some existing general purpose (GP) lanes are selected and converted into reserved lanes or managed lanes for specified types of vehicles, such as buses and commercial vehicles. Bus lanes, which are utilized in many cities in China, are examples of the converted lanes.

* Corresponding author.
E-mail address: mekschin@cityu.edu.hk (K.-S. Chin).

http://dx.doi.org/10.1016/j.trd.2017.04.002
1361-9209/

Air pollution has become a growing global problem, which is directly harmful to the health of residents. Transportation significantly affects environmental quality, especially air quality. Carbon dioxide emission is one of examples of air pollutions. Globally, transportation accounts for approximately 21% of carbon dioxide emissions (Jabali et al., 2012). Therefore, environmental impact is increasingly taken into consideration when a new transportation policy is adopted (Lin et al., 2014). Improving air quality is one of the purposes of the lane reservation strategy (Boriboonsomsin and Barth, 2008). The reserved lanes improve the efficiency of special vehicles, such as public and heavy freight vehicles. Meanwhile, increased emissions incurred by more congested normal traffic may ensue. Thus, the environmental impact should be considered in lane reservation problem. Further, the real traffic information is also a very important factor in making decisions about lane reservation. On the one hand, a set of reserved lanes should be in accordance with the current traffic state. If the goal is to improve travel efficiency of public or special transportation, a link with low travel speed would more likely require a reserved lane. On the other hand, converting GP lanes to reserved lanes will affect the future traffic state. Reserved lanes may worsen normal traffic because normal vehicles are restricted from using them, thereby producing more emissions. To reduce the harmful effect on traffic and environment, a more free-flowing link should be considered while selecting a reserved lane.

According to the above background, the following important questions appear: How to design reserved lanes considering the impact on environment? How to incorporate the real traffic information into the decision-making? Selection of reserved lanes among existing network with some objectives has been studied as lane reservation problem. To address these new questions, we examine the lane reservation problem from a new perspective of carbon emission in real urban transportation network, which considers the environmental impact of the lane reservation strategy and the traffic state of a city. This paper is an expansion of previous Lane Reservation Problem from urban environmental perspective. The decisions involve: which lanes in the road network to be reserved along with how to arrange special transportation flows between origins and destinations.

First, a new measure of the impact of reserved lanes is developed and mathematical models are proposed to optimally select lanes to be reserved to achieve certain traffic improvement. Fuel consuming of vehicles produces carbon monoxide, volatile organic compounds, oxides of nitrogen, carbon dioxide and a variety of other emissions including lead compounds, Sulphur compounds and fine particles. All of these compounds are associated to some degree with air pollution problems ranging from local direct health effects to global concerns such as the greenhouse effect (Hickman et al., 1999). Among all the emissions, carbon dioxide is the major ingredient. Therefore, a carbon emission index is used to measure the impact of the lane reservation strategy. The objective of the problem shifts to the minimization of carbon emission index caused by reserved lanes on the urban road network. Subsequently, we use 30-day trajectory data of 14,000 vehicles in Shenzhen of China to extract real urban traffic information. A method to estimate traffic state from the data is proposed, according to which we define a congestion indicator to measure urban traffic. Finally, computational results are presented through several experiments conducted based on real traffic state information and randomly generated road networks. Different scenarios are discussed and some conclusions are abstained which is helpful when a city tries to implement the lane reservation policy.

The remainder of the paper is structured as follows: A literature review focusing on lane reservation problem is presented in Section 2. Section 3 illustrates how the carbon emission index function for lane reservation strategy is built and how the problem is formulated as an integer linear programming model. Section 4 describes the data used in this paper and proposes the grid approximation method employed to estimate urban traffic state with the use of trajectory data. Computational experiments and results are presented in Section 5. The final section summarizes our findings and gives directions for future research.

2. Literature review

Due to traffic congestion, a lane reservation strategy is employed to improve the efficiency of the specific urban transportation for some management purposes. The result of reserved lanes in the network is of two sides. On the one hand, they improve the travel efficiency of the specified transportation. Vehicles with allowance to use reserved lanes can improve their travel time. Shalaby (1999) found the average performance of the buses improved after implementation of bus lanes. On the other hand, they negatively impact normal vehicles which cannot use reserved lanes. Cohen (2011) reported that the average travel time on GP lanes increased by approximately 26% after one lane was converted into a reserved lane based on a three months of implementation in Paris in 2009. How to select reserved lanes to achieve certain transportation requirement with minimum negative impact on normal traffic is called lane reservation problem.

Transportation concerns, such as network design and transportation planning and scheduling, have drawn the attention of researchers in the past few years. However, studies that focused on the lane reservation problem are minimal. Ravi et al. (2007) proposed prioritizing lanes to provide congestion-free travel in a city transportation network and described the rationality of this design. Wu et al. (2009), motivated by the requirement to transport participants to geographically distributed stadiums during the 2010 Asian Games held in Guangzhou, studied lane reservation strategy as mathematical problems and subsequently obtained quantitative results by considering a lane reservation problem with time-constrained transportation. Fang et al. (2011, 2012) significantly expanded the lane reservation problem by proposing the residual capacity of a lane as a measure, and consequently developed an optimal algorithm based on the cut-and-solve method for the