Investigation of the traffic congestion during public holiday and the impact of the toll-exemption policy

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ABSTRACT

Traffic congestion has long been a noticeable issue worldwide. Besides congestion caused by the daily commuters, congestion during public holidays is also very typical. The traffic volume often has a sharp increase during public holidays, which puts a heavy burden on the road capacity and results in severe congestion. This is especially true for the beginning and ending of the holidays. The situation is even worse under some government policies designed initially to benefit people, e.g. the highway toll-exemption during public holidays in China. The focus of this paper is to model the evolution of traffic congestion caused by the demand from residential place to the famous resorts during public holidays. The research questions include: (1) how do tourists tradeoff between schedule delay, queuing time and the overcrowding of the resort? and (2) the impact of the toll-exemption policy during public holidays on tourists' departure time choices and the social welfare. By adopting the bottleneck model, we obtain the cumulative departure curves of tourists during public holidays. Closed-form results of tourists' departure time variation with the toll-exemption policy are obtained, as well as the resulting social efficiency loss, which is significant for the management of the traffic mobility during public holidays.

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1. Introduction

Owing to the dramatic growth in car ownership in the twentieth century, traffic congestion has become one of the most serious challenges faced by urbanized areas. During the past decades, researchers have paid great attention to the large range of undesirable consequences of congestion (e.g., productivity lost, increased vehicle operating costs and pollution). Various theoretical issues arising from traffic congestion, such as the urban transportation network design problem, the morning commute problem, and the parking problem, etc. have been extensively studied and a large body of achievements have been obtained (e.g., Farahani et al., 2013; Arnott et al., 1998; Inci, 2015). However, some new issues have emerged in recent years, which play an important role in generating congestion but less attention has been paid to them. One of these issues is the severe traffic congestion on major corridors from the urban area to famous resorts in the suburbs during public holidays. Especially in developing countries, with the rapid increase of income, tourism develops very fast and the dramatically increasing demand for tourism has made the congestion during public holidays a prominent problem worldwide.

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Instead of enjoying their vacation, tourists have to spend a mass of time on the roads, resulting in a loss of social efficiency and a decline in the quality of the vacation on an overall level. The situation is even more serious in China, since the vacation time are shared by just a few big national public holidays with relatively long time windows. The limited number of holidays generates huge demand for tourism during the same time period, and it is almost impossible for tourists to avoid traveling peaks. In fact, millions of tourists crowd in the roads every day during public holidays (Xinhua Online, http://news.xinhuanet.com/world/2014–10/03/c_127061456.htm, downloaded on October 5, 2015). Sometimes, the highways are so congested that people even spend more time on the road than at the resort.

In addition to the increasing tourism demand, the public holiday toll-exemption policy could also be responsible for the severe traffic jam on holidays in China. In 2012, the Chinese government proclaimed that the highways are free of charge for minibuses and motor vehicles with up to 7 seats on important public holidays. As a benefit to the public, such regulation is of great political significance and has received huge support from the society, even it may worsen the already grave traffic situation. It can be observed that some drivers wait at the tollbooth hours before the beginning of the public holidays in order to get free passage, causing a waste of the road capacity (http://www.fawan.com/Article/fwkx/2015/10/01/005208308872.html, downloaded on October 5, 2015). Such "tactical waiting" phenomenon has also been observed and discussed by Xiao et al. (2012) and Lindsey et al. (2012) in the regular commuting problems. Therefore, the public holiday toll-exemption policy, which was initially carried out to benefit people, turns out to incur social efficiency loss.

Given the fact that the concentrated departures of all tourists at the beginning/ending of the holidays are the fundamental reason of the severe congestion during public holiday, it is essential to analyze the cumulative departure curve. The aims of this paper are twofold. Firstly, we formulate a model to depict the time-dependent traffic congestion on the corridor from the urban residential area to the suburb resort during public holidays. The basic idea of the peak-hour congestion modeling is to capture the peak versus off-peak period tradeoffs in tourists' travel-related decisions. For example, Vickrey (1969) introduced the bottleneck model and defined an equilibrium based on commuters' departure time choices, which describes the trade-off between bottleneck congestion and schedule delay. Over the past several decades, the standard bottleneck model was broadly extended in numerous ways, such as by considering the heterogeneous travelers (e.g., Lindsey, 2004; Liu et al., 2015), bottleneck congestion pricing (e.g., Laih, 1994, 2004; Xiao et al., 2011; Lindsey et al., 2012) and recently, utility maximization of activity model (e.g., Zhang et al., 2005; Li et al., 2014). For a comprehensive literature review, readers can refer to Arnott et al. (1998), Lindsney and Verhoef (2001) and Ramadurai et al. (2010). The difference between the proposed model in this paper and the bottleneck models in the literature lies that we incorporate the overcrowding cost in the resort into tourists' departure time choices. Besides the congestion/queue delay and schedule delay, tourists also suffer from the overcrowding at the resort. The actual number of tourists in the resorts usually exceeds the carrying capacity of the resorts themselves during public holidays, which brings discomfort to the tourists and causes a decline in vacation quality. Thus, tourists must choose their arrival time and try to avoid the peak congestion in the resort. In this paper, we formulate a model to incorporate this tradeoff into tourists' departure time choices.

The second purpose of this paper is to evaluate the public holiday toll-exemption policy. We model tourists' departure time choices under this policy and compare the resulting equilibrium departure rates with and without this policy. Although the toll-exemption policy provides tangible benefits to the public, it is questioned a lot because of the social efficiency loss it caused. In fact, the government is also considering whether this policy should be replaced by other welfare measures. Therefore, this paper provides theoretical support about the effects of the policy, demonstrating the social efficiency losses and possible need for better measures that can both keep the public's benefit and increase the total social welfare. Given a flat toll, drivers' behavior changes from the no-toll to the tolled cases (or the reverse) are somehow complicated. Laih (1994, 2004) analyzed this problem by assuming that there are two queues at the bottleneck, one waiting for the toll to be lifted while the other passing through the bottleneck by paying tolls (the Laih model). On the other hand, Xiao et al. (2012) and Lindsey et al. (2012) assumed that all drivers tactically wait or speed down at the bottleneck until the toll is lifted or lowered while Ren et al. (2016) assumed that some drivers brake on the lanes, which results in dropped capacity. In this paper, we adopt the Laih model and assume that there exists the other queue waiting at a secondary lanes or shoulders. Incorporating the overcrowding cost and adopting the two queues assumption in Laih Model, a detailed investigation is carried out to demonstrate the variations of social efficiency caused by the toll-exemption policy.

This paper is organized as follows: Section 2 develops a model to depict tourists' departure time choices during public holidays and the resulting equilibrium. Section 3 investigates the impact of the public holiday toll-exemption policy on tourists' equilibrium departure time as well as on individuals' travel cost and system efficiency. Section 4 investigates the variable vacation length case. Section 5 extends the proposed model into elastic demand case and Section 6 concludes the study.

2. Modeling the traffic congestion during public holiday

Consider a public holiday period $[t_a, t_b]$, where t_a and t_b denote the starting and ending time of the public holiday, respectively. A fixed number, N, of tourists intend to take vacation during this period. The residential and resort areas are connected by a single highway which has a bottleneck with capacity s. Traffic is not congested except at the bottleneck; if the arrival rate at the bottleneck exceeds s, a queue develops. Here we assume that all tourists except the first and last departures experience congestion. Denote t as the departure time from home, then the travel time from home to the