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Bicycle lane priority: Promoting bicycle as a green mode even in congested urban area

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ABSTRACT

The main obstacles to boosting the bicycle as a mode of transport are safety concerns due to interactions with motorized traffic. One option is to separate cyclists from motorists through exclusive bicycle priority lanes. This practice is easily implemented in uncongested traffic. Enforcing bicycle lanes on congested roads may degenerate the network, making the idea very hard to sell both to the public and the traffic authorities. Inspired by Braess Paradox, we take an unorthodox approach to seeking latent misutilized capacity in the congested networks to be dedicated to exclusive bicycle lanes. The aim of this study is to tailor an efficient and practical method to large size urban networks. Hence, this paper appeals to policy makers in their quest to scientifically convince stakeholder that bicycle is not a secondary mode, rather, it can be greatly accommodated along with other modes even in the heart of the congested cities. In conjunction with the bicycle lane priority, other policy measures such as shared bicycle scheme, electric-bike, integration of public transport and bicycle are also discussed in this article. As for the mathematical methodology, we articulated it as a discrete bilevel mathematical programing. In order to handle the real networks, we developed a phased methodology based on Branch-and-Bound (as a solution algorithm), structured in a less intensive RAM manner. The methodology was tested on real size network of city of Winnipeg, Canada, for which the total of 30 road segments – equivalent to 2.77 km bicycle lanes – in the CBD were found.

1. Introduction

A futurist author, H.G. Wells (1866–1946) stated: "Cycle tracks will abound in utopia" (Stephenson, 2015). The bicycle as a green and sustainable mode of transport is gaining ground (Mesbah et al., 2012; Milne and Melin, 2014; Smith, 2011). In one estimate half of the morning trips in the US is less than 5 miles (Stephenson, 2015), should it be made by 24 min cycling, no job is left for transport engineers. Governments across the world have started to invest in more bicycle facilities (Duthie and Unnikrishnan, 2014; Mesbah et al., 2012; Smith, 2011). A strong correlation has been reported between the usage rate of bicycles and health indices (Milne and Melin, 2014). Fortunately the use of bicycle is on the rise (Brady et al., 2010), so much so some coined the term of "bicycling renaissance" (Pucher et al., 2011). The main obstacles to boosting the bicycle as a

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regular mode of transport are safety concerns due to interactions with motorized traffic (Buehler and Dill, 2015; Habib et al., 2014; Menghini et al., 2010).

Based on GPS dataset, a recent study in the United States suggests cyclists give high value to off-street bike paths and enhanced neighbourhood bikeways with traffic calming features (Broach et al., 2012). A similar observation has also reported for cases in Canada (Su et al., 2010). In other words, "segregation" is the cyclists' most heralded slogan. In the Netherland which is the mecca of the cyclists, the public see the separated bicycle lanes an indispensable part of their transport system (Stephenson, 2015). Retrofitting existing facilities at no (or least) cost to better accommodate cyclists and pedestrians has emerged as an effective tool in the hands of policy makers (Buehler and Dill, 2015) One option is to segregate bicycles and motorized vehicles by providing exclusive lanes for the cyclists (Lin and Liao, 2014; Mesbah et al., 2012; Smith, 2011). The importance of bicycle lane has been correlated to the "bikeability" of the cities (Habib et al., 2014). Empirical analyses strongly suggest that bicycle lanes improve safety of both cyclists and motorists on multi-lane roadways (Brady et al., 2010). Even in narrow streets where space is scarce a simple lane marking in the shared lanes (known as "Sharrows") can greatly contribute to betterment of driving behaviours and hence the safety (Brady et al., 2010; Meng, 2012).

Bicycle lanes come at the expense of restricting the motorists to less space (Alliance for Biking & Walking, 2014), which may lead to a much worse traffic circulation and hence more severe congestion. This genuine fear has precluded the introduction of bicycle lane in many cities. Despite great efforts to analyse network design problem – notably road and transit network design – (Bagloee and Ceder, 2011; Bagloee et al., 2013b, 2015; Farahani et al., 2013; Mesbah et al., 2011a, 2011b; Sarvi et al., 2016) the literature has yet to address the Bicycle Priority Lanes Design (BPLD) problem.

The introduction of bicycle lanes needs to be viewed in the context of the motorized modes at the urban network level. A recent review on the literature sheds light in the shortcomings of the methodologies based on which the importance of network level approaches has been highlighted (Buehler and Dill, 2015).

As such one can divide the task into two categories: uncongested and congested urban networks:

- In uncongested urban networks, bicycle lanes cause no congestion. Under this category, bicycle lanes are relatively unproblematic, and one can follow standard procedures in urban design and planning.
- In congested urban networks, bicycle lanes are more contentious, and debate arises when a portion of the road space of the already congested network is reserved for cyclists.

Mesbah et al. (2012) consider the BPLD problem as a bilevel programing problem and a genetic algorithm was developed as a solution method. In their attempt although the both transport classes of bicycle and motorized vehicle are considered, the interaction between these modes is not considered (the problem is modelled as if they are operating on two separate networks). Furthermore the application of their method to a large size network has yet to be addressed. Duthie and Unnikrishnan (2014) investigate the design of an integrated bicycle network while the impact of congestion is overlooked. Lin and Liao (2014) tackle the BPLD problem with an all-out binary programing framework. Enforcing all the variables as a binary variable makes the solution computationally prohibitive as the size of the problem increases. Regardless the congestion is largely overlooked.

The intent of this study is to address the BPLD problem in the context of a congested city, and we show that even in this context there might be some latent spare capacities that can be released and allocated to the cyclists without worsening the overall congestion. This seemingly unorthodox notion is rooted in the Braess Paradox (Braess et al., 2005) that is; adding road to the network may worsen the traffic circulation. In other words, there might be some roads in an existing network whose closure could improve traffic circulation (Bagloee et al., 2013a).

This study contributes to the literature by addressing the BPLD problem in the congested cities considering three important features: (i) network-wide impact, (ii) congestion, and (iii) scalability to real-size networks. We model the BPLD problem as a bilevel programing problem. In the upper level the total system cost is minimized, while the lower level accounts for the behaviour of the users (motorists and cyclists). Specifically, the lower level models a Multiclass User Equilibrium (MUE) traffic flow. The bilevel programing problems are proven to be NP-hard, a term referring to utmost difficulty in solving the respective problems (Bard, 1998; Jeroslow, 1985).

The necessity of studying mixed modes traffic flow (bicycle with motorized mode) is rooted in the fact that, it is not always possible or feasible to provide a fully-fledged and connected network of exclusive bicycle lanes. In other words, having mixed mode roads in some part of the (bicycle) network is inevitable. In a similar fashion, shared lanes between motorized modes such as heavy trucks and cars are omnipresent in traffic modelling. Hence we articulate the problem as a multiclass traffic flow model using the concept of bias term (Spiess, 1984) that is, both motorized modes and bicycles will experience a common delay term plus an exclusive term (the bias term). Nevertheless, arriving at a proper estimation for the parameters of the roads' delay functions including the bias terms for car and bicycle requires a field survey and model calibration. Using the bias term is computationally efficient and has been consolidated by much empirical evidence (INRO, 2009). Other alternative methods give raise to either microsimulation or asymmetric delay functions via approaches such as Variational Inequality and Complementarity Methods which are computationally expensive.

Given a set of candidate roads where bicycle lanes can be allocated, and a budget to cover the implementation costs (marking, curb raising, etc.), the decision variables are binary variables (1 or 0) associated with the candidate roads. The value 1 indicates a bicycle lane is allocated, and 0 that it isn't. Inspired by the work of Leblanc (1975) we develop a purpose