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Bicycle-vehicle interactions at mid-sections of mixed traffic streets: Examining passing distance and bicycle comfort perception

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ABSTRACT

This paper studies the relevant factors in mixed urban traffic that may impact the lateral spacing between bicycles and vehicles (passing distance, PD), and their resulting effect on a bicyclists' comfort based on a study of six sites in Ottawa, Canada. The observations are: [i] the average position of bicycles from the curb is 0.57 m, and lesser (*i.e.* 0.35 m) in the presence of parking; [ii] 90% of passes exceed 1.23 m; [iii] PD is positively correlated with motor vehicle speed, lane width, and bicycle position from adjacent curb edge line, whiles inversely correlated to ambient traffic density and bicycle speed; [iv] motor vehicle speed has the highest prediction of PD variability; [v] PD and ambient traffic density (ATD) are found to be the most important factors to a bicyclists' comfort perception (BCP). Two linear regression models for PD and BCP were developed and significant variables are identified as: motor vehicle speed, bicycle speed, ATD, number of lanes, and lane width. The presence or absence of a grade slope is found to be significant to the PD model and not to BCP. The models both exhibit limited predictive ability, however residual plots and significance of included variables are indicative of correct assumptions for the models. It is recommended that speed calming, sharrows, road signs instructing road sharing, and educating road users against "dooring" crashes be considered in improving road sharing, especially for narrow lanes (*i.e.* less than 3.6 m) and lanes wider than 4.5 m. It is also prudent for designers to avoid installing parking zones on narrow shared roads.

1. Introduction

After centuries of the bicycle's invention, it is still an efficient mode of transportation that can compete with many modern modes. Bicycling makes an efficient use of limited roadway capacity, and improves health. It is also a more pleasurable, low-cost, low-polluting mode of transport when compared to several more modern modes such as the motor vehicle (Handy et al., 2010; Li and Faghri, 2014; Pucher and Buehler, 2008; Shackel and Parkin, 2014). However, modal share of bicycling is still low relative to other transport modes even for short trips within cycling distance, especially in North America (Pucher et al., 1999). Studies by Chataway et al. (2014), and Hull and O'Holleran (2014) show that among all the deterrents to bicycling, number one is comfort or safety risk, while many of the other factors are to some extent safety implied or comfort related.

The perception of safety is shown by many survey studies to be highly and positively dependent on the existence of bicycle facilities (Harkey et al., 1997; Parkin and Meyers, 2010). This perception of less safety in the absence of bicycle facilities can be postulated as due to bicycle interaction with vehicular traffic (Hull and O'Holleran, 2014; Pucher and Dijkstra, 2003; Abdul Rahimi et al., 2013). It is however, difficult to avoid mixed traffic situations due to frequent discontinuity of on-street bicycle facilities and limited right of way situations, especially in urban areas. Therefore, it is pertinent to seek understanding of bicycle and motor vehicle interaction in road sharing since those situations tend to be the weakest link for most bicycle commuters.

Most studies regarding bicycling are either focused on roads with marked lanes for bicycling or concerned with conflict and safety issues at intersections. As such this study is aimed at building understanding of the interactions at mid-sections on roads without bicycle lanes (segregated or painted), where motor vehicles and bicycles are required to co-operatively share the road. The main objectives are to: [i] study the various elements that are important to bicyclists in their interaction with motor vehicles on shared roads and [ii] develop statistical models for lateral vehicle passing distance and bicyclist comfort perception. The motivation of this study is to provide a foundation for building microscopic traffic simulation models which involve bicycles being modelled with adequate representation of their attributes, behavior and interaction with vehicles.

This study was carried out in Ottawa, Canada. Ottawa has a cycling

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master plan aimed at providing a citywide connected network of cycling facilities that will be actively used by all types and ages of bicyclists to meet their transportation needs (Ottawa Cycling Master Plan, 2013). The City of Ottawa has an extensive network of bike paths and is actively building new facilities and modifying existing infrastructure to accommodate bicyclists. It is also worth mentioning that Ottawa has a road safety legislation that requires drivers to keep a one meter space when passing bicycles (City of Ottawa, 2015). A total of six sites were monitored as part of this study with focus on events in which bicyclists and vehicles share the outer right lane side by side.

2. Literature review

In 1987, Davis' model (Landis, 1994) was the first step into studying bicycle and motorized vehicle interactions. The model was initially meant to make crash predictions using traffic volume, number of through lanes, pavement condition, and location factors. The study provided a worthwhile insight into the hazards in mixed traffic interaction from the bicyclist's perspective, while also stimulating similar studies. Similar to the Davis' model were the initial Broward County Bicycle Facilities Network Plan Roadway Condition Index (RCI) and the Florida Bicycle Coordinator's consensus developed segment condition index (SCI) models in 1991 and 1993 respectively. The three models were all limited by a subjective methodology in the assignment of values for their pavement condition and location factors (Landis, 1994; Epperson, 1994). Landis in 1994 created a hazard rating model called the Interaction Hazard Score (IHS) by modifying the Epperson-Davis version of the Road Condition Index (RCI) model. A lower value of the IHS shows better quality or less hazard and the value may further be categorized into a level of service (*i.e.*, A-F) (Landis, 1994).

Sorton and Walsh, (1994) sought to create a bicycle compatibility model for evaluating the stress experiences of bicyclists on shared roads in the city of Madison, Wisconsin. Their results indicated that traffic volume, curb lane width and traffic speed affects the stress experienced while biking. Harkey et al. (1997) investigated the effectiveness of three different shared facilities such as roads with paved shoulders, roads with bicycle lanes, and wide curb lane roads in Florida. The conclusion was that, passing distance is not significantly affected by the type of facility, while bicyclists are more likely to ride closer to the curb on wide curb lanes. Shackel and Parkin (2014) established that, the road width positively affects motor vehicle passing distance while width restricting conditions such as nearside parking and an opposing vehicle reduces the passing distance given by motor vehicles.

Love et al. (2012) assessed the level of compliance of Baltimore motorist to a three-foot (1m) spacing law enacted by the state of Maryland. In addition, they attempted fitting a linear model to passing distance. The linear model had an R^2 of 0.26, for which the significant variables were: lane width (explaining 9% of the variance in passing distance with $p < 0.0001$), the presence of bicycle lanes (explaining 8% with $p < 0.0001$), bicyclist identity (explaining 7% with $p < 0.0001$), and street identity (explaining 10% with $p < 0.0001$). Motor vehicle type was not significant (Love et al., 2012). Stewart and McHale (2014) developed two GLM models for the passing distance afforded to bicycles on urban roads in Edinburgh, UK. The predictor variables included: absolute road width, opposing motor vehicles, vehicle speed, relative speed, nearside parking, opposite side parking, bicycle speed, effective lane width, bicycle lane width, presence of traffic Island, color of lane, presence of a bus and opposing flow. They fitted a GLM model to 1908 measured passing distances and the resulting fit had R^2 of 0.275. Their original data totaled 2387 events, however, passing distances greater than 2.50 m were excluded because of difficulty in measuring these passing distances. Subsequently, a second GLM was fitted to all the 2387 events for which the additional data were all assumed to have passing distances of 2.51 m. The R^2 improved to 0.424, still a limited improvement.

Winters et al. (2011) conducted a survey study of 1402 current and potential bicyclists in Metro Vancouver (Canada) to establish the major motivators and deterrents to cycling. The factors most likely to influence bicycling were obtained based on a weighted mean score for all respondents, where +1 = much more likely to cycle, +0.5 = more likely to cycle, 0 = neutral, −0.5 = less likely to cycle, and −1 = much less likely to cycle. The top influencing factors were found to include: high traffic volume (−0.83), high traffic speed *i.e.,* beyond 50 Km/h (−0.76), route with glass or debris (−0.76), unsafe driving while near bicyclist (−0.73), potholes and uneven pavement (−0.55), long steep sections on route (−0.5) etc. Clearly, most of the top influencing factors on the willingness to bicycle are indirectly comfort and safety related, especially when considering bicycle motor vehicle interactions. Kirner and Penha (2011) utilized a similar survey study within two medium sized Brazilian cities, 447 respondents completed a survey which established the most relevant factors to bicycling promotion to be lane width and motor vehicle speed. Li et al. (2012) studied 29 separated bicycle facilities and 14 on-street facilities in the metropolitan area of Nanjing, China. The bicycle lane width, width of the curb lane, presence of slope, presence of a bus stop, amount of occupied car parking spaces, bicycle flow rate, motor vehicle flow rate, and bicycle traffic volume were found to be the significant variables for comfortable on street bicycling.

Table 1
Site Features and Data collection.

Street Name	#No. of Days	#No. of Hours	#No. of Edges	Section Length (m)	Lane Width (m)		
					R	L	Total
Bank	4	30	1	60	3.6	3	6.6
Gladstone	2	10	2	50	4.2	4.5	8.7
Pleasant Park	2	10	2	50	5.1	5.1	10.2
Preston	2	10	2	50	4.6	4.6	9.2
Wellington	2	15	2	50	3.3	3.3	6.6
St. Patrick	2	15	2	90	4.1	4.1	8.2

3. Study methodology

3.1. Site description and data collection

Six sites in the City of Ottawa were selected for the study. All sites were shared routes without bicycle lanes (segregated or painted) or shoulders, and had 40 Km/h speed limits. Since bicycle and motor vehicle interaction is the main focus, it is required that the selected roads have a significant volume of both bicycles and motor vehicles. A combination of Strava[1] heat maps, Google maps and site visits were used to identify the required sites. First, the Strava heat map was used to identify roads with high bicycling frequency. Google map was then used to check if these roads meet the physical criteria (*i.e.,* no segregated or painted bicycle lanes). The sites were then visited and traffic observed for thirty minutes at peak hours (*i.e.,* either 7–9 am or 4–6 pm) of the day to confirm the presence of both bicycles and motor vehicles. The Streets selected for the study include: Bank (had sharrows), Wellington, Gladstone, Pleasant Park, Preston and St Patrick.

Video data totaling 90 h was collected on the six selected streets by firmly attaching high-definition Go-Pro cameras to street light poles at three meters above ground. Table 1 shows the site features and distribution of data collection. For the sections studied, three streets had parking while the other three did not. Except for Bank Street, all the streets have a single lane in both directions, which are labeled left and

[1] Strava is a social network of athletes and the Strava heat maps are created using uploaded frequencies and live routes of members, allowing a map user to identify routes that are mostly used by runners, bicyclists and triathletes (see (Strava Global Heatmap, 2016)).