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Bicycle route preference and pollution inhalation dose: Comparing exposure and distance trade-offs

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ABSTRACT

Do bicyclist preferences for low-traffic facilities lead to route choices that minimize air pollution inhalation doses? For both preferences and doses a routing trade-off can exist between exposure to motor vehicle traffic and trip duration. We use past studies of bicycle route preferences and pollution exposure levels to estimate exposure/distance trade-offs among roadway facility types. Exposure/distance trade-offs for preferences and doses are found to be similar when comparing off-street paths, bike boulevards, and low-to-moderate traffic streets with or without bike lanes; when choosing a route among these facilities we expect bicyclists to approximately minimize inhalation doses. Compared to dose-minimizing behavior, bicyclists tend to use high-traffic streets too often if there is a bike lane and not enough if there is not. The recommendation for practice is to provide low-traffic routes wherever possible in bicycle networks, not to limit bicycle facilities on high-traffic streets. Networks with extensive low-traffic bicycle facilities are robust to misalignments between preferences and doses because they reduce both the likelihood and severity of excess (non-minimum) doses.

1. Introduction

Long-term exposure to traffic-related air pollution is associated with increased mortality (Hoek et al., 2013); short-term exposure during travel also has acute health effects (Peters et al., 2013). Although the long-term health impacts of exposure during travel specifically have not been established, it is often assumed in health impact assessments that the effects of changes in pollution inhalation during regular (commuting) travel, as a percent of daily inhalation, are similar to the effects of a proportional change in long-term exposure level (de Hartog et al., 2010; Schepers et al., 2015). Hence, routing behavior that minimizes pollution inhalation dose during travel can also be expected to minimize the pollution-related health risk of that travel.

Bicyclists choose routes based on a range of factors, including a preference for lower-traffic and off-street facilities, possibly motivated by considerations such as perceived safety, comfort, noise, and vehicle exhaust (Broach et al., 2012; Kang and Fricker, 2013; Sener et al., 2009; Tilahun et al., 2007; Winters and Teschke, 2010). But bicyclists will only accept a limited amount of additional travel duration or distance in order to use lower-traffic facilities. Use of low-traffic and off-street facilities reduces air pollution exposure for urban bicyclists (Bigazzi and Figliozzi, 2014); but if low-exposure bicycle routes require longer exposure duration, total inhaled pollutant dose for the trip can increase despite lower pollutant concentrations. For both preferences and pollution doses a routing trade-off can exist between exposure to motor vehicle traffic and trip duration.

A study of bicycle trips in Montreal found lower-pollution-exposure alternatives to shortest-distance routes for 57% of surveyed origin/destination pairs (Hatzopoulou et al., 2013a). Minimum-exposure routes had on average 5% lower modeled concentrations of nitrogen dioxide (NO_2) and 1% longer distance than shortest routes, with a net reduction in cumulative exposure (as concentration × distance) of 4%. A similar study of bicycle trips in Copenhagen estimated larger differences: 20–40% lower carbon monoxide (CO) and nitrogen oxides

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(NO_x) concentrations and 15% longer duration on low-exposure vs. shortest routes, with a net reduction in cumulative exposure (as concentration × time) of 10–30% (Hertel et al., 2008). Neither study included actual traveled routes nor route preferences, so willingness to detour to low-exposure routes was not addressed.

Route recall surveys and portable GPS devices have allowed researchers to identify and analyze the actual routes taken by urban transportation bicyclists. Observed routes commonly deviate from the shortest path, with mean distance deviations of 7% to 12% (Aultman-Hall et al., 1997; Broach et al., 2012; Winters and Teschke, 2010). Both revealed preference (RP) and stated preference (SP) data have been used to develop models of route choice that estimate the attributes that affect the attractiveness of travel routes. In addition to distance, RP-based models have found significant effects of upslope, bike facilities (e.g. bike paths, bike lanes, and signed bike routes), and delay factors (e.g. turns, traffic controls, busy crossings) (Broach et al., 2012; Hood et al., 2011; Menghini et al., 2010). Broach et al. (2012) reported strong and significant effects of traffic volumes greater than 10,000 vehicles per day for streets without bike lanes. Hood et al. (2011) did not find a significant effect of traffic volume, but this may be because they did not distinguish between busy streets with and without bike lanes.

SP work has found additional factors predicting route choice such as: adjacent vehicle parking, pavement condition, and traffic speed. Among SP studies, Sener et al. (2009) reported significant negative effects of increasing traffic, while Stinson and Bhat (2003) established negative correlations between higher-order streets (minor and major arterials) and stated route choices. In addition to route choice models, SP-based "level of service" (LOS) studies have often found traffic volume and the presence of bicycle facilities to be key determinants of perceived cycling quality (Jensen, 2007; Landis et al., 1997; Petritsch et al., 2007).

To our knowledge, low-pollution-exposure bicycle routing has not been compared with route preferences. It is unknown whether bicyclists tend to make route choices that minimize inhalation doses (and by extension minimize pollution-related health effects), or if they under-avoid or over-avoid high-traffic roadways compared to minimum-dose routes. The goal of this paper is to improve understanding of the air pollution risk implications of bicycle route preferences – information that is potentially important to the health-conscious design of bicycle networks and bicycle route guidance. The primary research questions are: (1) is the strength of bicyclist preferences for low-traffic facilities consistent with inhalation dose-minimizing behavior, and (2) what types of facilities most likely lead to route choices with excess (non-minimum) inhalation doses? These research questions are addressed by comparing route trade-offs between traffic exposure and travel distance for both preferences and inhalation doses (a more generalizable approach than a case study of a specific network). Future work will incorporate bicycle power and respiration models to estimate the effects of other route attributes (such as stops and grades), and examine route choices and doses in real-world transportation networks.

2. Methods

Routing preference trade-offs between two route attributes can be represented by the marginal rate of substitution (MRS): the change in one attribute that exactly offsets a change in another attribute. The MRS between a route attribute and distance can be expressed as an equivalent distance for preference (ED_p): the relative change in travel distance that has an equivalent effect on route preference as a change in another route attribute – see Broach et al. (2012). For example, a bicyclist might be ambivalent about the choice between a 10% longer route and a route with 5000 vehicles per day (veh/day) higher average daily traffic (ADT), all other factors being the same. This ED_p of 10% implies that the bicyclist would accept a route of up to 10% longer distance to avoid an increase of 5000 ADT.

Inhalation dose (I) in pollutant mass for a trip or trip segment is the product of the ventilation (breathing) rate of the traveler (V_E) in volume per unit time, the pollutant concentration in breathing-zone air (C) in mass per volume, and the trip duration, which is distance (d) divided by travel speed (v): $I = V_E C \frac{d}{v}$. We define the equivalent distance for inhalation dose, ED_d, as the % change in travel distance d that has an equivalent effect on trip inhalation dose I as some change in exposure level C. ED_d is also the maximum additional distance that can be traveled on a lower-exposure route while still achieving a lower total inhalation dose than a higher-exposure alternative. Calculation of ED_d is described in the next section.

Consider a shortest-path route compared with a lower-traffic but longer alternative route (detour), as illustrated in the left side of Fig. 1. If the difference in distances between the routes (Δd) is less than ED_d, then the detour is the lower-dose route (and vice-versa). If Δd is less than ED_p then the detour is also the preferred (and presumably traveled) route (and vice-versa).

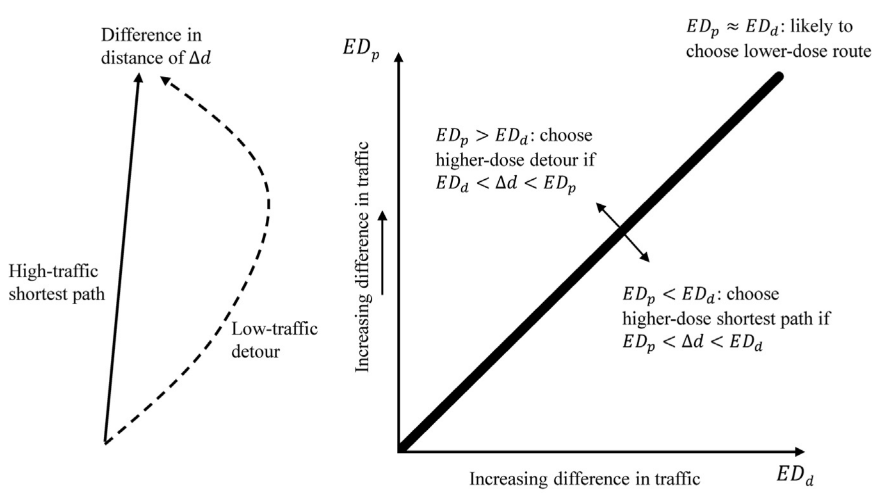

Fig. 1. Illustration of equivalent distance comparisons.