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A web-based route planning tool to reduce cyclists' exposures to traffic pollution: A case study in Montreal, Canada

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ABSTRACT

We developed a web-based route planning tool for cyclists in Montreal, Canada, using spatial monitoring data for ambient nitrogen dioxide (NO_2). With this tool, we estimated exposures to NO_2 along shortest routes and lower exposure alternatives using origin-destination survey data. On average, exposures were estimated to be lower by 0.76 ppb (95% CI: 0.72, 0.80) relative to the shortest route, with decreases of up to 6.1 ppb for a single trip. Cumulative exposure levels (ppb km) decreased by approximately 4%. In general, the benefits of decreased exposure could be achieved with little increase (less than 1 km) in the overall route length.

1. Introduction

Many cities around the world have made considerable investments in cycling infrastructure, including bicycle sharing programs and campaigns aimed at promoting bicycling as an affordable, environmentally-friendly mode of transportation (Rojas-Rueda et al., 2011). In some cases, however, cyclists may be exposed to higher concentrations of traffic-related air pollution than other road users owing to their close proximity to traffic, high respiration rates, and longer journeys (Panis et al., 2010). In addition, some data suggest that exposure to traffic-related pollution during cycling may contribute to altered autonomic regulation of the heart (Weichenthal et al., 2011), increased oxidative DNA damage (Vinzents et al., 2005), and acute myocardial infarction (Peters et al., 2004). Therefore, user-friendly tools that can be used to limit cyclists' exposures to air pollution may have important public health benefits. As a case study, we developed a web-based route planning tool for Montreal, Canada, and evaluated whether this tool could be used to lower air pollution exposures. This tool is based on spatial monitoring data for ambient nitrogen dioxide (a marker of traffic pollution; NO_2) (Crouse et al., 2009) and provides users with the shortest route between an origin and a destination as well as a "lower exposure" alternative. We briefly outline the development of this tool and examine theoretically its ability to reduce air pollution exposures.

2. Materials and methods

2.1. Developing routing capabilities that incorporate air pollution measures

Road network data for Montreal were obtained through OpenStreetMap (2011). The building blocks of these data are road segments separated by intersections that can be connected to build routes (bicycle paths are not included and will be incorporated in the model at a later date). Two different attributes were assigned to every road segment: length and average concentration of NO_2. NO_2 has been used as a marker of traffic pollution for different reasons. Outdoor sources of NO_2 include motor vehicles and fossil fuel power plants. In Montreal, more than 70% of NO_x emissions are from traffic (Busque et al., 2009). Studies have found NO_2 to be highly correlated with traffic-based attributes such as traffic volumes and distance from the road (Hochadel et al., 2006; Hoek et al., 2008; HEI, 2010). In a study of ten Canadian cities, mean NO_2 was found to be most strongly correlated with NO and particulate matter ($PM_{2.5}$ and PM_{10}). In Montreal, levels of benzene, toluene, ethylbenzene, xylenes, acetylene, and 1,3-butadiene were also found to be correlated with NO_2 (Brook et al., 2007). Active measurements of NO_2 and $PM_{2.5}$, ultrafine particles, ozone, and black carbon, had high correlations ($r=0.7$–0.96) near a major expressway (Beckerman et al., 2008).

2.2. Assigning ambient nitrogen dioxide Concentrations to road Segments

We computed average ambient concentrations of NO_2 to road segments from a land use regression model for the island of Montreal (Crouse et al., 2009).

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This model was based on a series of dense sampling campaigns (133 locations) conducted in 2005–2006 and explains approximately 80% of the spatial variability of NO_2 in Montreal. We overlaid a raster map of concentrations of NO_2 with the road network layer breaking down every road segment into a number of fragments all contained within a single pixel (5 by 5 m resolution) of the raster map and thus computed the average concentration per segment. We validated the NO_2 data against vehicle-induced nitrous oxide (NO) and NO_2 emissions (two reasonable indicators of near-road NO_2 levels) generated on every road link in the region using calibrated traffic assignment and emissions models for Montreal. We observed strong correlation ($r=0.632$) between NO_2 concentrations (generated by the land-use regression model) and NO_x emissions (modelled using traffic and emissions simulators) along roadways.

2.3. Computing lengths and exposures of trips

Shortest routes between origins and destinations and lower exposure alternatives were determined using a shortest path algorithm available through the Network Analyst function in ArcGIS (Version 10.1, developed by ESRI). In order to identify the lower exposure route, we multiplied the average NO_2 concentration of a given road segment by its length (whereas length alone was used in calculating the shortest path between two points). Cumulative exposure to traffic-related air pollution was calculated as the sum across road segments of the product of the segment-specific average concentration of NO_2 and length. This is mathematically equivalent to integrating the concentration of pollutants over the length of all possible routes connecting an origin and destination and selecting the route that minimizes this attribute.

2.4. The planning tool for selecting bicycle routes

The route-finding mechanism to compute the shortest and lowest exposure routes was exported to an ArcGIS Server (version 10.1, developed by ESRI) which offers a web-service allowing us to develop a cycle planning tool and post it online. The front-end of the application uses Google Maps and allows a user to click on an origin and destination on the base map of Montreal. This input is sent to the ArcGIS server (back-end) which computes the shortest route and lower NO_2 alternative; the ArcGIS server returns the coordinates of the two routes which are then drawn on the map (Fig. 1). In addition to providing users with the shortest route and an alternative low exposure route, it also provides a table comparing the two routes in terms of total length, estimated average NO_2, as well as cumulative exposure to NO_2 (Informing Cyclists on the Air Quality of Routes on the Montreal Island, 2012).

2.5. Distributions of exposures to traffic-related air pollution using cyclists' survey data

To determine the distribution of potential trips, we estimated concentrations of NO_2 along the shortest and the lower exposure alternative routes for cycling trips extracted from origin-destination (OD) survey data collected by the *Agence Metropolitaine de Transport* (Secrétariat à l'enquête Origine-Destination, 2010). This survey is conducted every five years and is the primary source in Montreal of information on travel habits. The most recent survey was conducted in 2008 and the results were released in 2010. Participants in the survey were identified through a random sample of the Montreal population using telephone listings; the sample is validated against census data using a wide range of variables (age, gender, status, home location, work location, etc.). In 2008, 66,100 households (representing 4% of the population) were interviewed including 156,700 individuals comprising 319,900 trips. Telephone interviews took place in autumn, a time period when most urban travel habits are stable since the survey aims to capture a "typical day". The survey included individual and household-level socio-demographic information as well as a diary of each trip (i.e., trip origin, destination, purpose, mode of transportation).

Approximately 4400 cycling trips were identified in the 2008 survey. Since air quality data were limited to the island of Montreal, we eliminated cycling trips with origins or destinations off the island. In addition, we removed trips for which origins and destinations were not defined clearly. For each trip, mean (ppb) and cumulative (ppb km) NO_2 concentrations were estimated along the shortest route and the lower exposure alternative using the route planning tool. Descriptive statistics and mean paired differences (95% confidence intervals, CI) in estimated exposures of NO_2 and route lengths were calculated.

3. Results

In total, 2307 cycling trips from the origin-destination survey were included in the analysis. Cyclists were predominantly male (63%) and had a mean age of 38 years (range: 4–82 years). In general, cycling trips tended to be less than 10 km in length (95%) but several trips of 20–30 km were reported (5%). The spatial distributions of cycling trips are presented in Fig. 2 and suggested a high density of trips in the downtown area, which is also characterized by the highest levels of NO_2.

Comparisons of shortest and lower exposure routes indicated that a lower exposure alternative was available for 57% of the trips; in approximately 43% of these trips for which an alternative was available (983 of 2307 trips) the shortest route was also the lowest exposure route. When analyses were limited to trips with an available low exposure route (Table 1), exposures decreased on average by 0.76 ppb (95% CI: 0.72, 0.80) per one-way trip with decreases of up to 6.1 ppb predicted for a single trip. On average, cumulative exposure levels (ppb km) decreased by approximately 4% (mean difference = 2.78 ppb km, 95% CI: 2.46, 3.12). Not surprisingly,

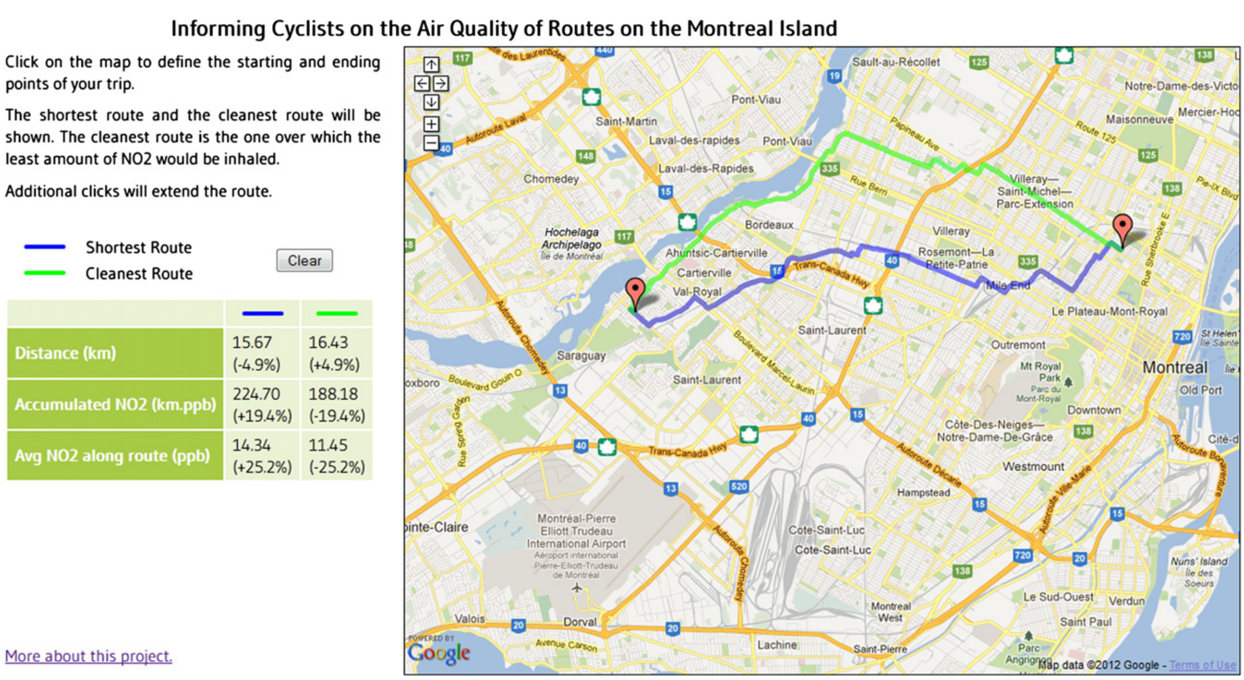

Fig. 1. Screen image of route planning tool for Montreal, Canada.