A STATISTICAL EXAMINATION OF THE EFFECTS OF THE BUILT ENVIRONMENT ON CYCLIST EXPOSURE TO AIR POLLUTION WITH A REGIONAL DATA COLLECTION EXERCISE

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Introduction

This paper will detail a data collection exercise aimed at explaining the variation in ultra-fine particles (UFP) in the urban setting. UFP is particulate matter with a diameter of less than 0.1 µm. Short-term exposure to UFP has been associated with acute health effects including reduced heart rate variability[1], oxidative-stress induced DNA damage[2], and respiratory and cardiovascular inflammation[3]. A number of studies have attempted to understand the determinants of cyclists' exposure to pollution, especially UFP where mobile monitoring equipment has only recently become available[4]. Specifically, they have attempted to create spatiotemporal regression models that account for meteorology, traffic density, and various land use characteristics. Moreover, studies show strong evidence that UFP is correlated with traffic density, and especially truck traffic, and are inversely related to temperature and wind speed[4,5,6]. Additionally, many road geometry and land use variables have shown strong correlations such as distance to a major cross-street[7], distance to the nearest road[8], fast food restaurants[6], and many such factors. With respect to cycling facilities there is far less evidence either way, although some studies have shown mild reductions in UFP levels on separated cycle tracks compared to in-street facilities[5,9].

Methodology

The data collection campaign took place on during the summer of 2012. Pre-defined 25 km cycling routes were charted in and around the Island of Montreal and were measured in the morning and afternoon for approximately 1.5 hrs each period. There was a particular focus on designated cycling facilities and an effort to include a broad range of micro-environments. The extent of the network is pictured in FIGURE 1 (a). Each trip was cycled together by a pair of research assistants riding bicycles equipped with air pollution monitoring instruments. In total, approximately 475 km of unique roadway are represented, including about 350 km of designated cycling facilities.

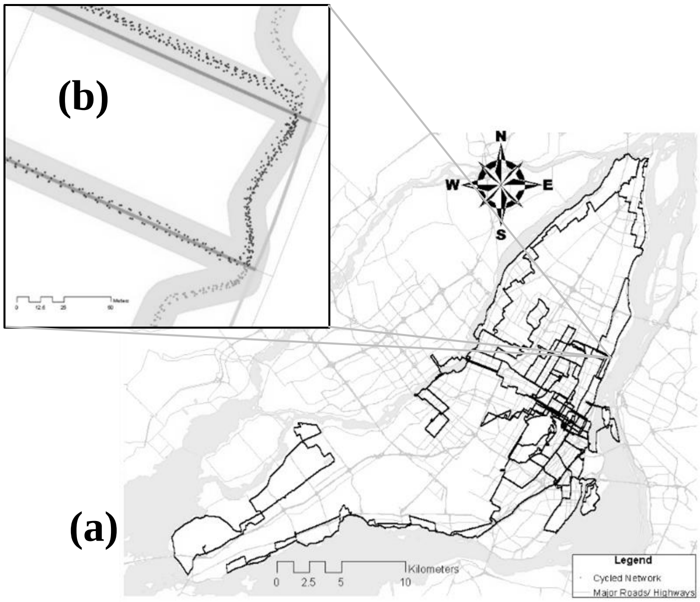

FIGURE 1: (a) Extent of the data collection campaign (b) Depiction of GPS points associated with a roadway links

All four project bicycles carried a condensation particle counter (TSI, CPC Model 3007) to measure UFP (#/cm^3) along with a GPS unit (Garmin, Edge 800). Both instruments recorded data at a sampling rate of 1 Hz. The internal clocks of the instruments were synchronized to one another in order to relate the second-by-second air quality measurements to their respective geographic coordinates. The CPC was stored in a pannier above the rear wheel connected to a hose tied to the frame of the bicycle and terminating at the handlebars. In total, approximately 213 hours of real time measurements were recorded.

GPS coordinates were used to geocode each record with GIS software (ESRI, ArcGIS). The software was then used to spatially associate each measurement with a number of street and land use characteristics. Through a combination of visual inspection and automation, each of the 751,251 one-second air quality measurements was associated with the vehicular street that was either cycled on or alongside of. In the event that the cyclists' location could not be reasonably associated with any particular street, such as through parks, the nearest was selected. FIGURE 1 (b) illustrates this process. Points were then associated with the cycling facilities within 25 m.

Data were first averaged by each trip on each link and subsequently, the trips on each link were averaged to generate a single value for the link. Ultimately, 4,058 links were included in the database, recording a median of 4 trips each. All analysis was performed with respect to the natural log of UFP so that its log-normal distribution could fit the assumptions required of linear analysis.

Results

For the purpose of investigating the full extent of traffic effects in this study, live traffic counts on every cycled link would have been infeasible. For this reason, the authors made use of prior research into a mesoscopic traffic simulation model developed for the Greater Montreal Area[10]. UFP was in fact correlated with the simulated daily traffic (r=0.1656, *p<0.0001). This confirms intuition and suggests that the meso-simulation is accurate enough to detect associations with measured. When considering speed rather than volume, the speed limit of a road was positively associated with UFP, suggesting that larger roads produce more pollution, however the simulated speed showed a negative correlation to UFP (r=-0.216*). This stands to reason considering that emission factors are typically higher at lower speeds. The correlation becomes slightly stronger when directly measuring congestion. This was done by taking the ratio of the difference between the speed limit and the simulated speed over the speed limit (r=0.228*).

While the distance between the cyclist and the nearest roadway had a very small effect (r=-0.037*), the distance from the nearest major road (r=-0.1134*) and even more so, highway (r=-0.212*), influence the UFP concentrations more substantially. This suggests not only that these large roads generate much of the measured pollution, but that their effects can be observed at substantial distances from their source.

One potential factor that has been shown to be important is the presence of restaurants *(9)* and was observed using the distance from the measurement to the nearest restaurant (r=-0.258*). Although this could be seen as simply a surrogate for downtown location, the regression analysis will show that it explains effects beyond this. Next we look at areas zoned for “parks and recreation” (r=-0.029, p=0.064) and areas zoned for “industrial and resource” (r=0.084*). Uultimately, these associations were weak, yet the signs were consistent with our expectations. Building footprints were analyzed as a percentage of the area they occupied within a 50 m buffer around the link (r=-0.321*). This serves as a crude surrogate for the urban canyon effect yet indicates that the effect of air circulation between building lines may be detectable even at a highly aggregate level.

Finally, we investigate the effect of the design of cycling facilities: in particular, the difference between in-street facilities, cycle tracks, and park trails. Although detecting notable statistical trends proved difficult, a closer exploration of the data reveals why this may be so. Class 1, or ‘In Street,’ describes measurements recorded where there were either no cycling facilities, shared streets, or painted lanes. Class 2, or ‘Cycle Tracks,’ describe fully separated lanes in which the cyclist has restricted midblock interaction with traffic. Finally, Multi-Use Trails are predominantly found in parks, and are often shared between cyclists, joggers, pedestrians, and others.

Comparing Class 1 and 2, we find that despite the latter occurring on roads with over twice as much traffic (128 to 281 veh/hr), it appears that its UFP levels are nearly identical than its counterpart. Yet we also see that its distance from the centerline of the street is also over twice as large (3.4 to 8.4 m). Consider now Class 3, which has nearly half the pollution of the other two despite having roughly twice the traffic on the nearest streets (396 veh/hr). Yet its median distance from the street is substantially greater than the other two (115.5 m). It is for this reason that the only notable regression statistic drawn from the cycling facility data was a dummy variable representing these cycling trails. Although not a particularly high coefficient it points in the expected direction for UFP (r=-0.060*).

Temperature and wind speed have consistently been found to be strong determinants of UFP. The data confirmed previous literature on the subject with minimum trip temperature (r=-0.318*) and (r=-0.233*) wind speed showing inverse relations to UFP.

A linear regression created for UFP, shown in TABLE 1, is ordered in terms of decreasing strength of the normalized beta coefficients. Despite the presence of a number of land use indicators, the 'downtown Montreal' dummy variable still outperforms all other effects, and suggests that there are still many characteristics of the downtown environment that are not fully captured in this study. Following that, the meteorological variables for wind speed and temperature show strong inverse effects, as expected. The fact that the distance to the nearest restaurant performs well strongly suggests that restaurants are in fact significant contributors of UFP in their own right, independent of their association with other urban characteristics.

TABLE 1: Linear Regression for UFP (n = 4058, R^2 = 0.3963)

Variable	Units	β	Coef.	Std. Err.	P>|t|
Downtown	(dummy)	0.357	0.488	0.021	0.000
Wind Speed	km/hr	-0.247	-0.044	0.002	0.000
Min Trip Temp	°C	-0.192	-0.081	0.006	0.000
Dist to Restaurant	km	-0.115	0.240	0.000	0.000
Traffic Volume	10^3 veh	0.077	0.004	0.000	0.000
Trail	(dummy)	-0.074	-0.326	0.056	0.000
Dist to Highway	km	-0.066	0.060	0.000	0.000
Cyclist Speed	km/hr	-0.060	-0.009	0.002	0.000
Bldg Area w/i 50 m	%	0.051	0.047	0.014	0.001
Congestion	(ratio)	0.046	0.070	0.020	0.001
Industrial	(dummy)	0.023	0.049	0.026	0.060
Constant		.	11.999	0.123	0.000

The remaining attributes were not as strong, though their presence allows us to better understand their interactions. The distance from the nearest highway still has an impact, but it is much milder than the correlation coefficient alone. This is perhaps because the downtown areas, where points were usually closer to these highways, are already being accounted for, leaving a smaller effect from the highways themselves. The same can be said of the building area, which still remains a positive contributor in the model, suggesting that even considering that the building density is higher downtown, the buildings themselves may also play a role in the increased UFP exposure, perhaps through the urban canyon effect.

Measures of traffic, congestion, multi-use trails, and industrial all remain significant in the expected direction and point to the more subtle associations with the micro-environment. Overall though, the dominant message from this regression is how much stronger regional effects appear to be compared to micro-level effects.

Conclusion

With larger datasets one is able to acquire more robust measurements, however they may also introduce an exceptional amount of variability in the data. Any passing truck or change in local wind direction may cause variation inexplicable by such an aggregate model. In addition, the nature of collecting data over such a broad and varied spatial extent precludes capturing detailed local effects such as more direct measurements of the urban canyon effect, the wind direction relative to the cyclists, and the composition of traffic, especially the proportion of truck traffic. Yet with this in mind, the findings we observed bear through this variability strengthening our understanding of these underlying trends. The aim of this study was not so much to develop a predictive model but to unveil the aforementioned associations. Still, despite substituting extremely labor-intensive field visits to manually collect traffic, road geometry, and land use data collection with regional, GIS based methods, the study was still able to detect evidence of both large and small scale effects that support the findings of similar experiments.

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