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Impacts of Cyclability Features on Optimal Cycling Route

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Abstract. More and more cities around the world are trying to promote active transport as a good alternative to private car. Decreasing the share of motorised trips in cities, namely those by private cars, contributes to reduce air pollution, GHG emissions, congestion in addition to increasing road safety and public health through increased level of physical activities. This paper proposes a sensitivity analysis of optimal cycling routes by varying the generalized cost of the road segments to account for the travel conditions proposed to cyclists. As reported in the literature, many factors can change the perception cyclists have of the route quality and, therefore, they may select a longer but most fitted route for their travel. By changing the generalized cost of each road segment to account for these factors, it is possible to measure how variable is the optimal cycling route. The sensitivity analysis is conducted in the city of Montreal, Canada and relies on coefficients (of the cost function) that were found in the literature. The proposed analysis can also help assess whether there is a lack of bicycle infrastructures in an area. Results of this paper give an estimation of the average detour a cyclist may accept to maximize his uses of bicycle infrastructures and to limit exposure to risky situations. The value of this detour is 17% of the shortest distance.

Keywords: Cyclability, Cycling routes, Cost function, Sensitivity analysis, Detour

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INTRODUCTION

Many cities around the world are promoting active transport as a way to decrease road traffic, air pollution, GHG emissions as well as improve road safety and public health. One of the most efficient strategies is by improving infrastructures for both walking and cycling. Travel conditions have important impacts on the decision to select an active mode as well as on the selection of a particular route to travel between two points. This is even more critical for active modes as they are more vulnerable, and consequences can be more critical if they face an incident. Building good infrastructures for walking and cycling everywhere is not necessarily a straightforward solution, but it is possible to promote some existing infrastructure or only to build a new infrastructure at key places. To do so, we need to account for walkability and cyclability in route calculation for active modes. This paper will further focus on cycling routes.

We first need to identify the factors having an impact on the cyclability of routes. Many researchers have addressed this question in the past and their outputs will be used as input in our sensitivity analysis.

Hence, this paper has various objectives. It aims to enlighten the importance of good infrastructures and travel conditions for cycling trips, to assess how sensible are cycling routes when cyclability features are accounted in a bicycle route calculator , and to determine if there is a lack of bicycle infrastructure in a network using various indicators such as detour level resulting from the accounting of cyclability features..

This paper is organized as follows. First some bibliographic searches have been made on the factors impacting cycling and walking. This allows us to determine which factors we should include in our sensitivity analysis. Secondly, some factors have been found on previous documents which approach our topic. These factors have been added to the OpenStreetMap database according to 4 different scenarios. Thereafter, the data from the MonRésoVélo app give us some OD pairs which have been used on QGIS for the different scenarios. This led us to our sensitivity analysis on the factors that have an impact on cyclability.

BACKGROUND

Factors Impacting Cycling and Walking

The previous literature identifies many factors that have an impact on walking and cycling. Some of them are obvious like the availability and quality of infrastructures (1), trip distance (2), slope of the road segment (2), number of potential destinations (shop, school) (3) neighborhood safety (4), speed limit and density of car traffic (2) and quietness of the neighborhood. Other factors are less obvious such as the intersection density (1), the culture and the ethnical origin of the traveler (4), a sense of belonging to a neighborhood or a community (4) and the aesthetics of the neighborhood (4). There are probably many more factors that affect walkability and cyclability, indeed there are as many factors as people studying them (5).

Coefficients of Cost Functions

All these factors do not have the same importance. To account for them in route calculation, we must rely on coefficients embedding perception (some segment may seem longer to cross due to the travel conditions). This study benefits from previous research to identify plausible coefficients for cyclability features. The relevant research stems from studies on route planners for active modes. The previous literature has proposed values for many of these factors. The study by (6) has determined the consequence of the presence of upslope, turns, car traffic, and bike lane on route choice. (7) has shown the difference between different kinds of bicycle infrastructure and how the cyclist perceived them. Some other authors (8) have proposed a route choice model that takes the perceived risk and the distance into account and demonstrates the best value for both factors to make the most appropriate decision. Another study (9) has elaborated, for two different cities, a route choice model that considers the route visibility and the level of risk and compared the results between the two cities. Authors (10) have proposed two route choice models and compare the results they output. Maximum value for a detour in active travel to use a more appropriate route was also examined in (11) and (12). Table 1 proposes a summary of the values obtained by these researches.

Table 1 : Summary of bicycle route choice coefficients

Ref.	Comments	Parameters and coefficients					
(7)	**Marginal Rates of Substitution** (ratio between marginal utilities of different attributes)	Turns (km/turns)	Length wrong way	Length of bike paths	Length on bike lanes	Length on bike routes	Total rise (k/10m)
		0.17	4.02	0.57	0.49	0.92	0.59
(8)	**Generalized Cost (Scenario 1)**	α1	α2	β1	β2	γ	
		2.193	0.961	-0.054	-0.145	0.405	
(9)	**Generalized Cost**	Road with level 1 (α2)	Level of risk: Least (β2)	Level of risk: Lower (β2)	Level of risk: Moderate (β2)	Route visibility: Level 1 (γ2)	Route visibility: Level 2 (γ2)
	Kharagpur (city 1) : Regular / Irregular cyclists	-3.31 / -12.56	-9.82 / -28.95	-6.73 / -18.57	-3.42 / -13.11	-7.62 / -25.67	-2.87 / - 19.39
	Asansol (city 2): Regular / Irregular cyclists	-12.86 / -16.8	-38.43 / -55.3	-28.08/ -28.03	-16.62 / -23.6	-18.51/ -14.7	-14.11/ -11.54
(10)	**Utility function with both interactions**	β_Length (coefficient associated with route length)	β_Risemax (coefficient associated with max gradient m/100)	β_Tlights (coefficient associated with the number of traffic lights)	β_Bike path (coefficient associated with % of bike path along the route)	β_rise length (coefficient associated with the rise traveled)	
	Model 1	-3	-26.29	0.09	0.4	-	
	Model 2	-2.99	-25.85	0.09	0.4	-0.34	
(6)	**Distance Value**	Prop. Upslope 2-4%	Prop. Upslope 4-6%	Prop. Upslope 6% +	Prop. AADT 10-20k w/o bike lane	Prop. AADT 20-30k w/o bike lane	Prop. AADT 30k + w/o bike lane
	Non commute	1.72.	3.904	12.6	1.22	2.373	7.194
	Commute	1.37	2.203	4.239	1.368	2.40	8.715

METHODOLOGY

Coefficient values

Various coefficients have been proposed in the literature. To account for cyclability features in the analysis if the sensitivity of optimal cycling route, we must determine values to implement on the network. Actually, each segment of the Montreal OpenStreetMap (OSM) network will be allocated different cost factors to test how it will change the proposed least cost cycling route. The factors are evaluated in this paper are the type of cycling infrastructure, the road slope, and the level of risk. When factors are combined, they may result in large differences in the optimal route returned by the route calculator. Hence, no single value was found in the literature so lower and upper bounds are set as plausible coefficient range for these factors. Table 2 presents the upper bound and the lower bound of the coefficient that were selected. The level of risk is like what is proposed in (9). Least risk corresponds to a low level of traffic on the road and low-density of on-street parking. Low level of risk is associated with a low level of traffic on the road and high-density of on-street parking while moderate risk is associated with a high level of traffic on the road and low-density of on-street parking. The reference road considered in the study is the highest risk level which is associated with a high level traffic on-road and high-density of on-street parking (9). The value for the kind of cycleway are extracted from documents (7) and (13), while values for slopes are from (6). Table 2 can be interpreted as follows: 1 km on a bike route can be perceived as being equivalent to 1.22 km to 1.368 km if travelling on a route with an AADT (Annual average daily traffic) of 10-20k vehicles.

Table 2 : Summary of the chosen coefficient

REFERENCE: Perfect Street			
Factors	**Comparison with reference**	**Coefficients**	**Source**
Cycle Tracks	=	1	(7) & (13)
Bike Lane	+=	1	(7) & (13)
AADT – 10-20k (bike route)	+	1.22 - 1.368	(6)
Slope 2-4%	++	1.37 - 1.72	(6)
Slope 4-6%	+++	2.203 - 3.904	(6)
AADT 20-30k (bike route)	+++	2.373 - 2.40	(6)
Slope > 6%	+++++	4.239 - 12.6	(6)
AADT 30k + (bike route)	+++++	7.194 - 8.715	(6)

The road network data from the OSM database has been uploaded in a PostgreSQL relational database which allows to edit the costs (in generalized kilometers) of each road segment using the factors listed in Table 2. By doing so, the cost of each segment is updated to account for the risk level, the type of infrastructure, and the slope. Unfortunately, there is no information about the annual average daily traffic (AADT) available for all the road segments in the area. Hence, the street type is used as a proxy for traffic volume and allows to account for possible risk level, as is shown in Table 3. This is certainly a simplification since similar road types can have different traffic values. Still, it allows to account for typical features of such route. The assumptions have hence been fixed to have a more conservative model:

- It is similar to ride against and with the traffic when it is possible (cycleway lane and cycleway opposite lane);
- A risk is considered in both a cycleway lane and a cycleway share busway since even if cyclists benefit from a dedicated lane, they are still exposed to car traffic as well as to cars parked on the side.
- It is identical to ride a bike in a shared busway lane than in a cycleway lane.

It must be noted that the "highway" feature refers to any type of route in OSM and must not be confused with motorways which are per se excluded from the cycling network used in this analysis.

Table 3: Attribution of AADT to the different kind of infrastructure

Type	Coefficients
Highway primary	7.194 – 8.715
Highway secondary	7.194 – 8.715
Highway tertiary	2.373 – 2.40
Highway residential	2.373 – 2.40
Highway road	2.373 – 2.40
Highway unclassified	2.373 – 2.40
Highway service	2.373 – 2.40
Highway living street	1.22 – 1.368
Highway pedestrian	1
Highway track	1
Highway path	1
Highway cycleway	1
Cycleway lane, cycleway opposite & cycleway opposite lane	1.22 – 1.368
Cycleway track & cycleway opposite track	1
Cycleway share busway, Cycleway opposite share busway & cycleway shared lane	1.22 – 1.368

These assumptions were made because of the lack of coefficients available in the literature, to the knowledge of the authors.

Route Calculation

The next step of this study consists in editing the OSM network using the previous coefficients. It must be noted that the bicycle network available in OSM may not be fully completed for the area under analysis but the sensitivity analysis will still illustrate the value of conducting sensitivity analysis and provide relevant insights into critical segments of the Montreal cycling network. The OSM database is edited according to 4 scenarios. The first one does not have any coefficient; it is used to generate the shortest path, without accounting for any cyclability features (S1). The second (S2) considers every coefficient: the type of road, bicycle infrastructure, and the slope. The next one (S3) only considers the slope and the last one only accounts for the type of road and bicycle infrastructures (S4). With these scenarios, it is possible to make a sensitivity analysis of the routes and so to enlighten the impacts of accounting for these factors in the identification of cycling optimal routes.

After updating the OSM database according to the 4 scenarios, a python code is used with an OD pair. The python code allows to visualize the routes with the resulting, corrected cost (in generalized kilometers) for each segment using a GIS tool such as QGIS. The OD pairs come from the MonRésoVélo data, freely available on the Montreal Open Data portal. MonRésoVélo is an application that Montreal residents can download to record their bicycle trips and feed analysis conducted by Montreal planners. The data have been collected from June 2013 to August 2015. After data processing, 4881 OD pairs are used for analysis. Figure 1 shows in black the different routes taken as simulated on QGIS for scenario 1.

Figure 1: Routes in scenario 1

RESULTS

Maps as presented before are more illustrative than informative so indicators must be estimated to facilitate the comparison between scenarios' results.

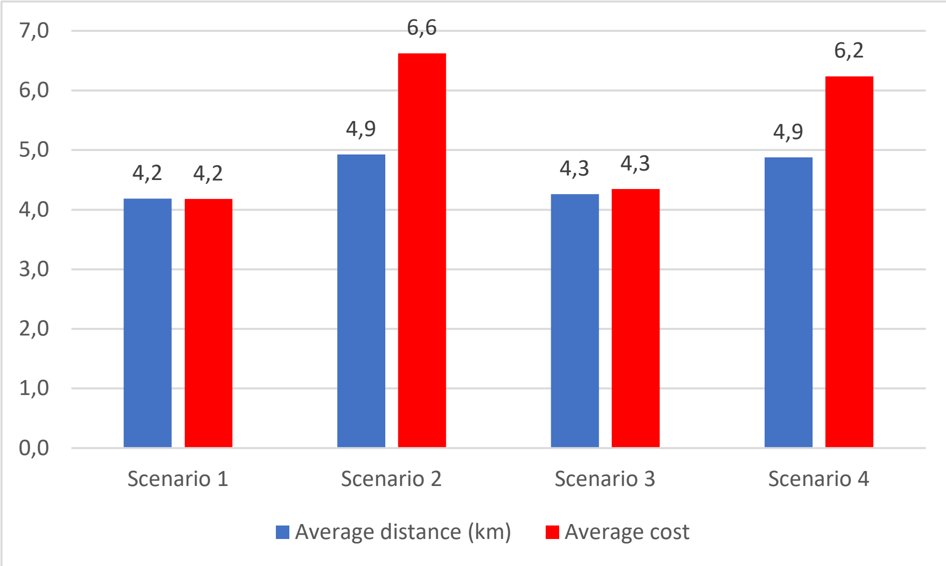

Figure 2 : Comparison of average distance and average cost

Figure 2 presents the average distance (real distance so estimated without the cost coefficients) and the average cost resulting from the assignment of cycling trips using the four different scenarios. Logically, the average distance and cost for scenario 1 are similar since there are no cost coefficient used. Hence, as expected, costs and distances are higher for the 3 other scenarios since including cost coefficients changes the optimal route returned by the trip calculator. The lowest difference in average distance and cost is observed for scenario 3. This can be explained by the fact that Montreal is mostly a flat city with slopes being concentrated in particular locations. The difference between average distance and average cost in scenario 2 and scenario 4 shows the lack of bicycle infrastructure in Montreal (as reported in the OSM dataset). Effectively, if the average cost and distance were similar, it would mean that riders would benefit from infrastructures and good conditions near their optimal shortest route. But based on these results, they must travel on some shared roads with cars for a significant part of their travel which increases the average cost and the resulting distance they must travel.

Table 4 shows the percentage of the average traveled distance which is travelled on a bicycle infrastructure. This table also reveals the lack of dedicated bicycle infrastructures because only 23.64% of a route is estimated to be on cycling infrastructures for scenario 1. Logically, this value is much higher for scenarios 2 and 4 because of the penalties assigned to certain road segments especially due to the absence of infrastructures. The fact that this value is high shows that even if there is some deficiency in some infrastructures at key places, there are also good infrastructures not far from the cyclists. Effectively there is not a major difference in term of distance between scenario 1 and scenario 2 as it is shown in Figure 2. This means that for a small detour (an average 800m), the percentage of travelled distance on bicycle goes from around 25% to near 80%.

Table 4 : Percentage of the traveled distance on bicycle infrastructure

	% of the traveled distance on bicycle infrastructure
Scenario 1	21.35%
Scenario 2	78.27%
Scenario 3	22.99%
Scenario 4	78.6%

Table 5 shows the difference in average distance between scenario 1 and the other scenarios as well as the percentage increase. It can be understood like this: when accounting for some cyclability factors in S2, the optimal route is, on average, 740 meters longer than the shortest one (1.17 times the average length). Interpretation is similar for the two other scenarios. These values are of course depending on the set of OD pairs examined and will further need to be validated using more cycling desire lines.

Table 5: Additional traveled distance

	Difference of average distance (m)	Average additional distance (%)
Scenario 1	-	-
Scenario 2	740 m	17 %
Scenario 3	78 m	2 %
Scenario 4	691 m	16 %

The results of the scenarios are then compared with values estimated for the routes selected by cyclists for work purpose trips (sample of 2393 trips from the MonRésoVélo data). Figure 3 compares distances for work purpose trips. As shown in the figure, the difference between the observed data and scenario 2 & 4 is small. This means that the commuting cyclists consider cyclability features when selecting their routes and seem to maximize their uses of bicycle infrastructures as well as to limit their interactions with cars. This can be explained by the fact that commuters typically know quite well travel conditions for regular trips such as going to work and tend to choose the most appropriate route. The fact that the difference between the observed scenario and scenario 1 & 3 is small confirms the idea that the commuters prefer to have a safe and quiet road for they commute travel and also confirms that it is essential to account for cyclability features in the identification of optimal cycling routes.

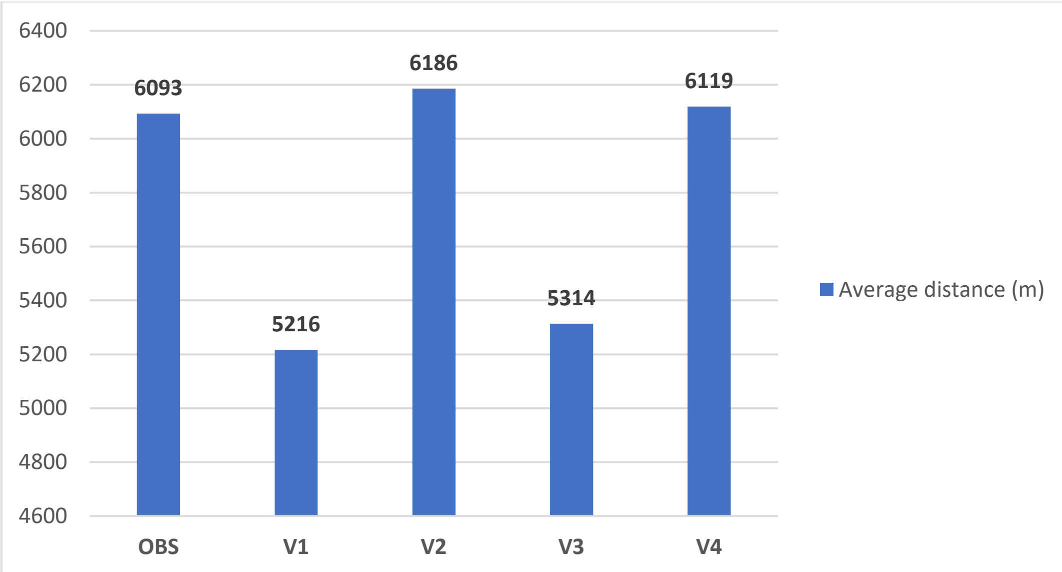

Figure 3: Average traveled distance for work pattern

DISCUSSION

The purpose of this paper was to contribute to the body of knowledge on the impacts of cyclability features on cycling routes. Using a set of OD pairs from real cyclists, it has proposed an analysis of the sensitivity of optimal routes while accounting for some factors affecting the quality of a cycling route. Factors accounted for are the slope, the type of cycling infrastructures and the level of risk as revealed by the type of road segment. Using a trip calculator and scenarios of cost values on the Montreal road segments, it was possible to observe how distance and generalized cost of the optimal cycling route change while accounting for some cyclability features.

Using coefficients proposed in the literature, this paper allowed showing the importance to consider different factors such as the slope, the risk, and the type of bicycle infrastructures in bicycle route calculators as it can change the route that cyclists may consider as pleasant. Conducting a sensitivity analysis of the proposed routes while accounting for different factors also help assess the scale of detours required for cyclists to use the optimal route and pinpoint the level of interventions required to improve the network. Mapping segments which are removed from optimal routes can actually pinpoint problematic segments that prevent cyclists from using the shortest path.

There are some drawbacks in the proposed methodology. First, the fact that the coefficient used were outputted from studies across the world may question their transferability to the Montreal context. As discussed in (9), values can differ a lot between cities so values for Montreal may be different to what is observed elsewhere. Hence, there is also high preference heterogeneity among cyclists, and this is not considered currently. Moreover, the data used are probably from cyclists who ride often (since they downloaded a cycling app) so their routes (OD pairs) may not cover the full range of desire lines of people wanted to travel by bike.

Many steps are planned to improve the sensitivity analysis. First, ranges of values for the various factors must be tested so variance of each scenarios should be estimated to better understand the impact of the selected factors on optimal route. There is an important data enrichment step to be undertaken to make sure that the cycling infrastructures are more widely geocoded into the OSM platform and make the results ready to support decision making. Other sets of OD pairs should also be used to systematically assess the quality of the cycling infrastructures and make sure they can cover a wider range of travel needs. Finally, a process to adapt the coefficients to the Montreal context will be undertaken, probably using a survey along with data collection, to better understand the preference of Montreal cyclists and account for preference heterogeneity in the trip calculator parameters.

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AUTHOR CONTRIBUTIONS

The authors contribution to the paper as follows: Study conception and design: Axel Grante, Catherine Morency, Jean-Simon Bourdeau; data collection: Axel Grante, Jean-Simon Bourdeau; analysis and interpretation of results: Axel Grante, Catherine Morency; draft manuscript preparation: Axel Grante, Catherine Morency, Jean-Simon Bourdeau.

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