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Analysis of bicycle commuter routes using GPSs and GIS

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Abstract

This paper reports on the information obtained by analyzing actual urban bicycle-commuter routes in a Brazilian medium-sized city using Global Positioning Systems (GPSs) for collecting the data and a Geographic Information System (GIS) for analyzing the data.

In order to accomplish this objective, the actual routes used by cyclists were compared with the shortest-path routes, by means of the extra distance travelled. To therefore determine which characteristics that influences the choice between the two paths.

The information collected showed that the speed of motorized traffic and volume (*proxi* variable, from classification of the roads) at the last, quality of the pavement influence directly in choosing the way to go. Other observed characteristics in this work, not shown to have great importance on the route selection, the absolute difference in most of the variable means were very small.

The first part reports the motivations and goals of this paper, followed by a brief literature review on work carried out in the same scope, in the chapter 2. The third chapter describes the methods of data collection for this research and the compared with the shortest paths. Following chapter, describe the resulting from this information's, finally chapter 5 presents conclusions and limitations of this paper.

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1. Introduction

In recent years, transportation specialists and urban planners have been promoting bicycling as an effective and sustainable mode of transportation.This renewed interest in cycling has created a quick increase in the demand for safe and efficient cycle infrastructure. However, transportation planners must predict where cycling infrastructure is needed, and what type of facility will best serve the cycling community.

Conventional knowledge about route choice is not sufficient to deal with this problem because the characteristics of the bicycle are very different from the characteristics of a motor vehicle. Cyclists' route choice does not depend solely on minimizing travel distance. Cyclists may choose paths that are longer for a variety of reasons including: minimizing elevation changes, avoiding on-road segments on which auto volumes or speeds make cycling uncomfortable or reducing the number of controlled intersections at which cyclists must stop.

In this study, Global Positioning Systems (GPS) are used to assess the travel characteristics of bicycle commuters and gain more detailed insights into their behavior and the analysis of routes used by cyclists is developed in a Geographic Information System –GIS.

The focus of this research is the utilitarian (commuter) trip, considering that the factors that influence the choice of routes for utilitarian trips are different from those that influence cycling for recreation or sport. For the latter, the effort and the difficulties of the route may even be attractive.

The conclusions of this research will help transportation planners in determining the placement and design of new bicycling infrastructure. Observing the travel behavior of cyclists will give them a greater understanding of the preferences of cyclists for infrastructure types and dedicated bicycle improvements.

2. Using GPSs to collect information about routes used by cyclists

Several researches reported in the literature have collected information about the routes used by cyclists (Aultman-Hall, 1997; El-Geneidy, 2007; Stinson and Bhat, 2003;Papinski, 2009; Menghini et al, 2010).These studies usually compare the route chosen by the rider with the shortest path and try to identify the reasons for the cyclist to make such choice.

In the first studies in which this strategy was used, the cyclists were requested to draw on a map the routes they used more frequently (Aultman-Hall, 1997; Hyodo et al, 2000; Howard and Burns, 2001). These studies revealed that most people can only provide inaccurate data about their routesand the duration of their trips.

However, with the availability of automated equipment to record the paths taken (Global Positioning Systems - GPSs), collecting data about cyclists routes is becoming increasingly easier and accurate (Stopher et al, 2008). GPSs, when used with a Geographic Information System - GIS, offer the possibility to acquire precise data on the routes taken and the speeds of cyclists.

In the research reported by Harvey et al (2008), GPSs and a GIS were used in conjunction to collect and analyze data about cyclists´ routes. These routes were subsequently compared with the shortest paths between the origin and destination of the cyclist. The analysis results suggest that as cyclists become more comfortable riding in heavy traffic conditions, they are less likely to travel additional distance beyond the shortest network path. It was also found that many bicycle users have no real perception about the distance they travel because the data collected with GPS and the self-reported distances were significantly discrepant.

Hood et al. (2011) collected data about the cyclists´trips using applications installed in mobile phones which recorded data on the length and speed of travel and also permitted users register the travel motive. One of the findings of the study was that cyclists prefer routes with cycling infrastructure (especially those who do not use the bike very often) and that female cyclists preferred paths with gentle slopes.

A report by Hudson et al (2012) summarizes the many processes employed in a study to evaluate the application of smartphones for gathering bike route choice data, describing in detail all the steps of the survey from marketing to data analysis.

A survey conducted in Ontario, Canada by Casello et al. (2011, 2012) employed low cost GPSs units to collect origins, destinations, paths and times for cycle trips. From the data, the researchers produced relationships between land use density (at the origin and destination) and the number of cycling trips generated and attracted.

Menghini et al (2010) used an existing GPS record of routes used by cyclists (which had been collected for another research) and used a multinomial logit model to model the choice of the route. Dill and Gliebe (2008) used GPSs to collect cyclists´ tracks for a period of 7 days and the data was downloaded and converted to routes using a GIS. This study found that cyclists tolerate only short detours from the minimum distance path. However, the set of additional variables analyzed (number of traffic lights, terrain gradient, and utilization of bicycle facilities) wassmall.

To better understand bicyclists' preferences for facility types, GPS units were used by Broach et al (2012) to observe the behavior of commuter cyclists in Portland, Oregon, USA. The authors used these data to estimate a bicycle route choice model.

All these researches show that GPS technology is an effective way of collecting real-time data from bicycle commuters. The use of GPS data has the potential to eliminate user bias errors and errors induced through self-reported data.

3. Method

Data for this research was collected in São Carlos – SP, a Brazilian medium-sized city with around 220 thousand inhabitants, using the GPS Garmin Edge 200. The sample included 50 cyclists, but one of the survey participants folded during data collection, so used information from 49 regular cyclists who reported riding more than 1 day per week, year-round. They were asked to clip the device to their bicycles on all the trips they took for work or school. The GPSs were programmed to collect data as frequently as possible. All riders kept the equipment and recorded data for a period of at least one week.

Each participant also completed a survey with questions about demographics and the importance of various factors for choosing a route. The survey was divided into two parts. In the first were related 18 factors (selected from the literature review) that may influence the choice of routes. For each respondent should assess the importance on a 5-point scale ranging from "very important" (coded as 5) and "Not important" (coded 1). In the second part of the questionnaire consisted of five multiple-choice questions directed to the rider profile (age, gender, frequency of cycling, travel by bike motif and usually plan their routes).

At the end of the period the equipments were collected and the data were downloaded to a computer. GPS traces were matched to network links using TransCAD 5.0 (GIS software used for data analysis). The information obtained underwent an initial analysis for data consistency and veracity of the routes and finally resulted in maps for each bicycle trip recorded with their origin and destination points. These routes were then assigned to segments of a roadway network map of the city.GPS data including: elevation, speed, length and travel time in the segments were joined to the other link attributes necessary for this study: road hierarchy, condition of pavement and cyclist infrastructure.

Using TransCad routines, the shortest paths along the roadway network were calculated for each observed origin-destination pair.The extra distance the cyclists travelled was determined by equation 1.

$$ED = (AD - SPD)/SPD \quad (1)$$

Where: ED = extra distance travelled
AD = actual distance travelled
SPD = shortest path distance

4. Results

4.1. Characteristics of the trips

Table 1displays the descriptive statistics for the bicycle trips.During the study, participants recorded an average of 2.5 commuter bicycle trips per day.

Table 1. Descriptive statistics for thebicycle trips

		Mean	Std Deviation	Minimum	Maximum	p*
	All participants	2561	1744	94	10.036	
Trip length (m)	Men	2812	1800	107	10.036	0.000
	Women	1678	1164	94	4709	
	All participants	11.3	7.1	1.5	56.6	
Trip duration (min)	Men	12.1	7.2	1.5	46.3	0.000
	Women	8.4	6.3	1.2	56.6	
	All participants	17.6	4.7	3.3	31.7	
Trip speed (km/h)	Men	18.5	4.5	3.3	31.7	0.000
	Women	14.3	4.5	5.5	28.6	

* Statistically significant at the 95% level

The data showed that men travel longer distances than women (2.8 km compared to 1.7 km on average).Most trips (80.0%) were less than 4 km long and 90% were shorter than 5 km (Figure 1).

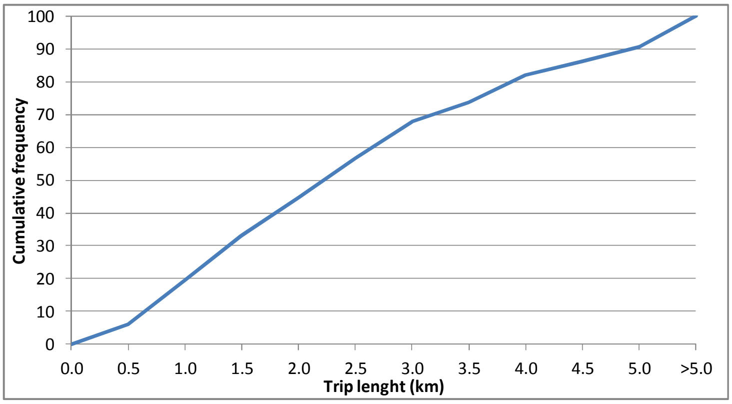

Fig. 1. Cumulative frequency of trip lengths

A great part of the recorded trips (87.2%) took up to 20 minutes (Figure 2). The average duration of bicycle trips was 11 minutes (standard deviation 7.1).

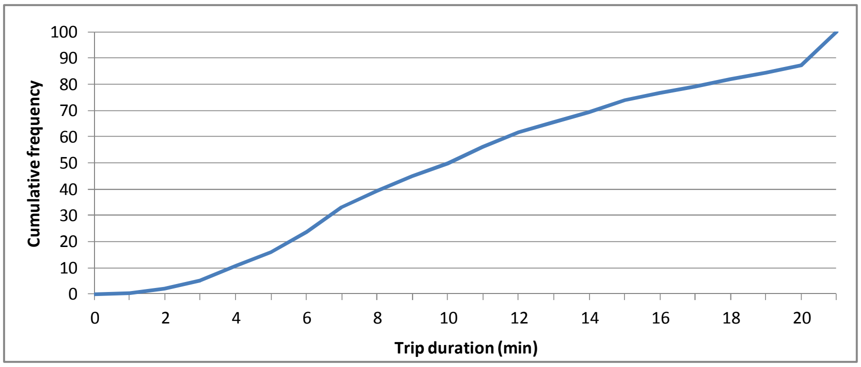

Fig. 2.Cumulative frequency of trip duration

The average speed for the bicycle trips was 17.6 km/h (standard deviation 4.7). Women's trips were slower, averaging 14.3 km/h compared to 18.5 km/h for men. The speed in 70% of the trips did not exceed 20 km/h. Average speeds above 25 km/h were observed in only 4.4% of the trips. Speeds lower than 8 km/h were observed in only 7.8% of the trips (Figure 3).These values are acceptable for travel by bicycle and compatible to values found in the literature.

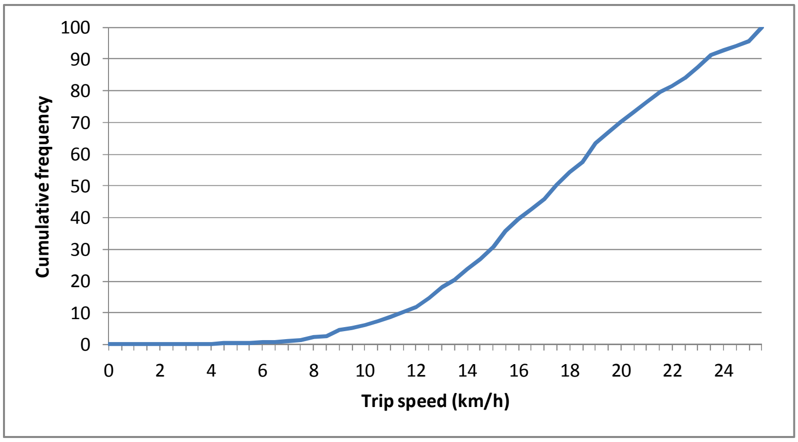

Fig.3. Cumulative frequency of trip speeds

The distribution of trip starting times is shown in Figure 4. There is not an evident peak period for the bicycle trips and. as would be expected. 75% of the trips started between 06h00 and 19h00.since they are all commuter trips. Due to night classes almost 16% of the trips were recorded at night (after 19h00).

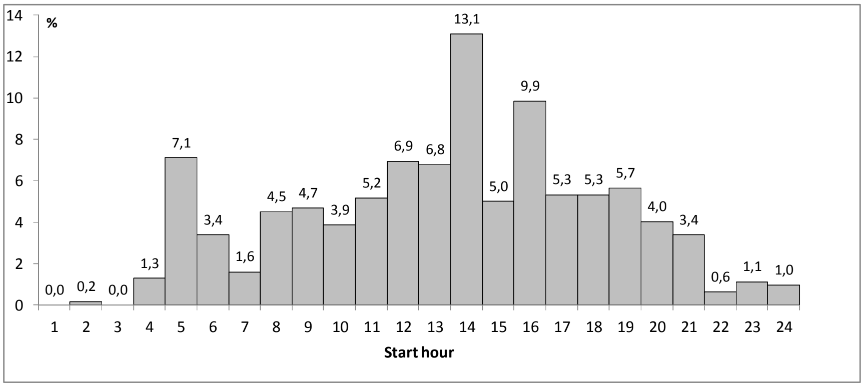

Fig. 4. Bicycle trips start hours

The percent of the total travel that was undertaken on each type of road is displayed in Table 2. More than half of the length of commute bicycle trips in undertaken on local roads. This is due to the fact that travel on local roads is often necessary to enter and exit the local neighborhood where the cyclist´s origin or destination is located. Only 24% of travel was on arterial roads that that would be expected to have high volumes of motor vehicle traffic.

Table 2 – Percent of total travel on each type of road

Type of road	% travel
Local	53.5
Collector	22.3
Arterial	24.2

For 19% of the tripsthe shortest paths were longer than the observed bicycle trip (in average. 166 meters longer). This means that in these trips.the cyclist rode part (or all) of the route on the wrong way on a one way street. This behavior is, of course, against the law and so these trips were excluded from the following analysis. For the other trips the extra distance traveled was on average 14.6% longer than the shortest path (Figure 5).

The distribution of extra distances traveled indicates that nearly 83% of the cyclists chose paths with distances that are within 20% of the shortest path. Only for 4.5% of the tripsthe chosen path exceeded the shortest path by more than 50% (Figure 5).

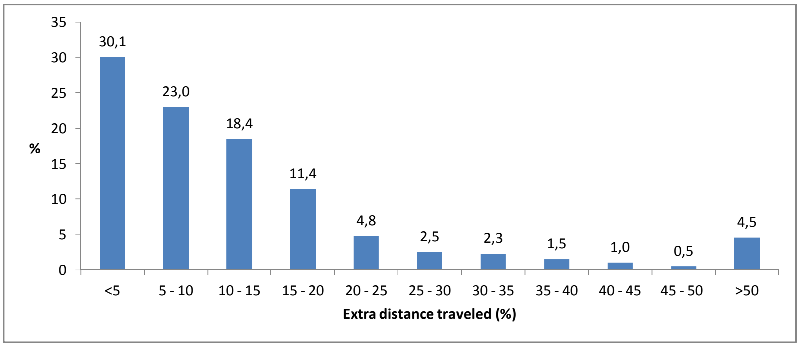

Fig. 5. Extra distance traveled

A t-test was used to compare the means of the shortest and preferred route distances. The difference in means was determined to be statistically significant at the 95% level (p = 0.016).

Comparing the extra distance travelled by men and women reveals that men rode 10.7% more and women 12.4% more, but these values are not statistically different (t stat = -0.644. p = 0.523).

The shortest and actual routes of two cyclists are shown in Figure 6 as an example. In both cases, the cyclist was willing to travel greater distance to use a preferred route.

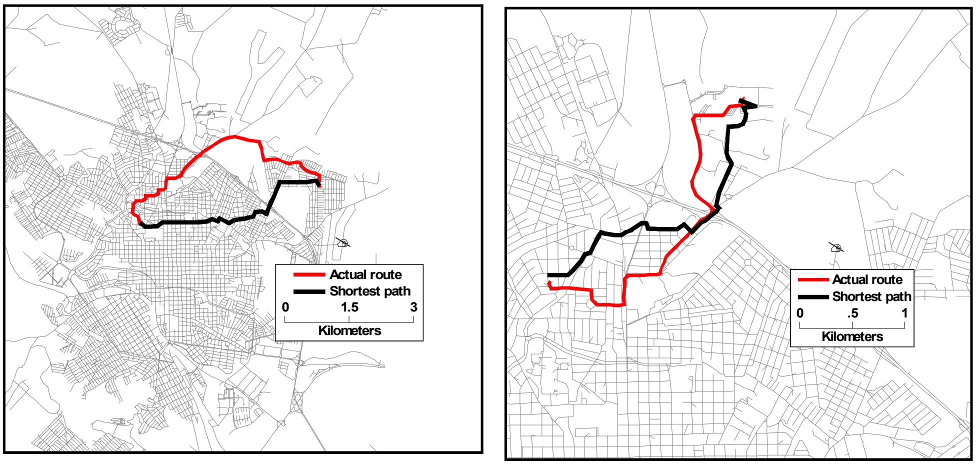

Fig 6. Actual and shortest routes for two cyclists

4.2. Results of the survey

Besides recording the GPS data,participants also completed a survey with questions about demographics and the importance of various factors for choosing a route (previously explain in the section *3 - Method*). Although detailed results of this survey are not discussed in the paper. Table 3 show the importance attributed to each factor (“Very important” = 5 to “Very unimportant” = 1).

Table 3. Scores for the importance of factors (average and standard deviation)

Factor	Average	Stand Dev	Factor	Average	Stand Dev
1. Number of trucks	4.59	0.82	10. Type of pavement	3.76	1.09
2. Number of buses	4.59	0.73	11. Number of intersections	3.62	1.27
3. Traffic volume	4.55	0.91	12. Trees	3.52	1.09
4. Traffic speed	4.52	0.83	13. One-way street	3.52	1.09
5. Street lighting	4.34	0.77	14. Roundabouts	3.52	1.48
6.Security	4.28	1.03	15. Number of stop signs	3.48	1.06
7. Quality of pavement	4.24	0.87	16. Number of traffic lights	3.45	1.18
8. Trip length	3.93	0.96	17. Parking permitted	3.41	0.94
9. Street Width	3.93	1.07	18. Slope	3.34	1.23

To better explain the research, we chose the factors that have values greater than 4 (the most important factors). Three groups of factors may be identified within the most important characteristics. One of them includes: number of truck, number of buses, traffic volume and traffic speed. The second group consists of: street lighting and security and the last group contains only one factor: quality of pavement.

Data for the factors in the first group could not be collected for this research and so, following the work of Snizek et al (2013), the functional classification of the roads (local. collector. arterial) was used as proxy forcomposition, volume and speed of traffic that influence the route choice by cyclists. To classify roads as their hierarchy, use the features described byRibeiro (2005), show in Table 4.

Table 4. Hierarchy condition evaluation criteria

<table>
<tr><th>Characteristics</th><th>Arterials street</th><th>Principal collector street</th><th>Collector street</th><th>Local street</th></tr>
<tr><td>Continuity Network</td><td>Continues network</td><td>Its not necessary a continues network</td><td>Create a set of continuous networks associated with each local space</td><td>Shouldn’t be continuous</td></tr>
<tr><td>Type of connection</td><td>Straight to other structuring routes</td><td>Local distributors, the structural network</td><td>Among themselves, and the principals local street</td><td>Among themselves, local distributors</td></tr>
<tr><td>Local traffic</td><td>Very short</td><td>Some</td><td>Predominant activity</td><td>None (only public transport)</td></tr>
<tr><td>Activities of heavy goods vehicles</td><td>Appropriate (especially for the long trips)</td><td colspan="2">Minimal</td><td>Prohibit(except the delivery of goods and servicing)</td></tr>
<tr><td>Velocity</td><td>Above 80km/h</td><td>Next to 50km/h</td><td>Lower than 30 – 40km/h</td><td>Between 20 – 30 km/h</td></tr>
<tr><td>Parking</td><td>Prohibit</td><td>Authorized (but avoid areas next to intersection)</td><td colspan="2">Authorized</td></tr>
</table>

The factors in the second group are related to personal safety. There are no regions in the city of São Carlos that could be considered unsafe for cycling, except for some areas in the periphery of the city where the participants of this survey did not go(to survey and mapping these areas would be impracticable, so that will be the focus of future work to be performed). Thus, this factor was excluded from analysis, which is a limitation of the study.

The last factor considered as important, pavement quality, was evaluated according to the FHWA Highway Performance Monitoring System (HPMS) Pavement Condition Factors (US DOT. 1987) show in Table 5.

Table 5. Pavement condition evaluation criteria

Condition	Score	Description
Very good	5	Only new or nearly new pavements are likely to be smooth enough and free of cracks and patches to qualify for this category
Good	4	Pavement.although not as smooth as those described above. gives a firstclass ride and exhibits signs of surface deterioration
Fair	3	Riding qualities are noticeably inferior to those above.may be barelytolerable for high-speed traffic. Defects may include rutting.map cracking (thesurface has thin cracklines covering sections of it. as if it were a roadmap). and extensive patching
Poor	2	Pavements have deteriorated to such an extent that they affect the speed offree- flow traffic. Flexible pavement has distress over 50% or more of the surface.Rigid pavement distress includes join "spalling" (where sections of joinedpavement are chipping and breaking apart at the join).patching. etc.
Very poor	1	Pavements that are in an extremely deteriorated condition. Distressoccurs over 75% or more of the surface.

4.3. Characteristics of actual and shortest-path routes

Table 6 provides the means of variables for the chosen (actual) route and the shortest path route. Comparison of these values provides the initial insight into the attributes that may affect bicycle-commuter route choice. Notice that no road used by the cyclists or the shortest path had a very good pavement (score 5). This is not surprising because only a few stretches of roads in the city attain a high quality pavement.

Table 6. Variable means for actual and shortest path routes

	Actual route	Shortest path	t stat (p)
% of route on local roads	53.5%	58.2%	-1.235 (0.220)
% of route on collector roads	22.3	21.7%	0.217 (0.829)
% of route on arterial roads	24.2%	20.1%	0.999 (0.321)
% of route on pavement quality 2	4.1%	3.1%	0.812 (0.419)
% of route on pavement quality 3	63.5%	71.8%	-2.286 (0.025)
% of route on pavement quality 4	26.6%	21.1%	1.711 (0.091)
% of route on pavement quality 5	5.8%	4.0%	1.117 (0.267)

The absolute difference in most of the variable means is very small, especially because attributes have been aggregated over the whole route. Only on variable mean is statistically different for the two routes.based on a paired t-test at the 0.05 confidence level: percentage of route on road with pavement quality 3. Comparing the facilities used for the observed trips to the shortest paths does not reveal any preferences in facility type. The apparent preference for arterial and collector roads is not statistically significant compared with the shortest route.

Even though the variables in Table 5do not show significant differences between the shortest and actual route, it is necessary to consider that not all variables could be properly considered in this research. There are other variables that might be expected to affect cyclist route choice but could not be considered because they were not in the data base, like lane width number of intersections and parking.

Further more,the shortest path is only one of a very large number of alternative routes available.Within a traditional grid street system, there are often numerous paths that are essentially the same distance, each of which is likely to have different characteristics. Much of the street network in São Carlos follows a standard grid that allows cyclists to travel numerous routes that are essentially the same length. Probably, when cyclists are traveling within the grid network, they choose a desirable route with their preferred attributes without adding any additional distance to their route.

5. Conclusions

The objective of the research described in this paper was to evaluate the importance of attributes influencing bicyclists' route choice preferences. One of the motivations for this research was to study the route choice ofcurrent commuter cyclists to determine what types of policies and infrastructure programs might encourage the use of the bicycle for utilitarian trips.

In order to accomplish this objective, the actual routes used by cyclists were compared with the shortest-path routes, by means of the extra distance travelled. Data about the actual routes were collected by GPS receivers and the shortest paths were calculated with a Geographic Information System (GIS).

The average trip length was 2.5 km. average trip duration was 11.3 minutes and average speed was 17.6 km/h. Observed paths were on average 14.6% longer than the shortest path. These values are acceptable for travel by bicycle and compatible with the values found in the literature, for example the values found byDILL (2009).

Although comparisons between the shortest and actual routes may provide some information about the travel behavior of bicycle commuters, there are some assumptions in the procedure that limit the ability to make conclusions from the results. First, it is assumed that cyclists completely know the attributes of each route. Cyclists are not always aware of the shortest network path available to them, and in many cases it is difficult to determine the shortest network path between a given origin and a destination. Second, information on routes not chosen is needed to indicate whether the cyclists are choosing a route because they like its characteristics or whether they have no other reasonable choice.

Also, the bicyclists participating in this study do not represent all bicyclists. The sample consisted of cyclists from only one Brazilian medium-sized city which with a low bicycle modal share. Moreover, participation in the survey was voluntary and therefore the obtained sample is not random. Different results could possibly be obtained with larger samples and in other contexts.

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