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Bicycle Mobility Management

User's needs and preferences for network planning and management in the city of Lisbon.

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October 2012

Abstract

In cities where the bicycle is growing as a mean of transport for commuting trips or recreational purposes, cycling network planning still lacks data on its real use. Usually it is the theory and good practices of other cities that informs the development of solutions for the cycling network plan, but sometimes it does not respond to bicycle users in their own city – the routes they really choose and the requests they claim. So there is the need for an effective interaction between the municipality and bicycle users, in order to understand their needs and to plan and manage a cycling network for the future based on data provided directly by users.

This dissertation proposes a geographical information system (GIS) based tool for cyclists which helps to choose the best routes in a city, based on data about their own cycling experience: profiles, chosen routes, route frequency, location of accident spots, suggestions and opinions, among other information. Based on this, a Municipality may step in a specific street, by changing the surface type or adding some infrastructure for cyclists, providing an area with facilities that support the bicycle mobility (parking facilities, street lighting, information signs), doing a better network management or improving/expanding the cycling network.

The aim is to apply this system in Lisbon, a city that is taking the first steps on promoting this mean of transport. A survey to cyclists was conducted to obtain data on the motivations for choosing routes and other important data. Based on the answers it was possible to define profiles for the bicycle users in Lisbon. The results were applied in the evaluation of the costs of travelling through the cycling network and integrated in a GIS. A discussion on the most relevant considerations about the adopted model, and on the results of the prototype, is presented. In the document are also included overall considerations and suggestions for future work.

Keywords: Urban Mobility, Bicycle, GIS, Cycling Network, Lisbon.

1 Introduction

Cycling is a promising way for urban mobility, which has been strongly encouraged by the European Agenda for transport and sustainable mobility and by national and local policies, in several countries. In cities where there has been an increase in bicycle use as a mean of transport, the municipal planning for bike lanes and infrastructures relies mainly in replication of the best practices from other cities. However, this practice is not always able to generate effective solutions, efficient and locally adapted, mainly due to lack of data and information about the *de facto* movements of local cyclists.

The area of accessibility for cyclists extends beyond the network of existing or planned cycle paths. It is important to know who actually cycles this network and why, how they choose the routes and which strategies they have developed for bicycle circulation. This information is a key element in the management of a transport network, in changing to a new paradigm of urban mobility, based on growth of bicycle trips in modal split. For the municipal urban managers it is important to monitor the evolution of urban mobility, with a frequency that enables the monitoring of the growth rate of cycling in their city. On the other hand, the costs of collecting and processing data of cyclists movements are substantial, so its integration into an online website that provides a free service of bike route planning and allows feedback from cyclists may be an indirect, but a relatively efficient way of collecting data about the street network itself and about the rider, constituting both an useful tool for planning and management support, in particular to improve the network cycling infrastructures.

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2 Bicycle mobility, cycling network planning and route planner models

In Portugal, the bicycle modal share in 2000 was 0.26% (Rietveld, 2004). Data from Census in 2001 was not conclusive about this mean of transport for commute trips, and Census 2011 results are not yet available. Even in the absence of official data collected by systematic observations and monitor information about the number of bicycle users in Portugal, in the last decade there has been an investment in bicycle infrastructures in several urban centres. This is due to the perception that local actors have of the increase of soft modes of transport, despite the fact that planning of these infrastructures was not based on objective data about their users (and potential users) that would support decision-making, at municipal level, for the investments on expansion and improvement of the bicycle infrastructures and facilities.

It becomes important to have metrics that can inform planning and mobility management about the degree of the users' adhesion to politic options and measures adopted, and the level of performance that is obtained. In recent years, a number of studies have been developed to discuss the transition of mobility systems, allowing the assessment on how cities are committed to the promotion of the bicycle as a mean of transport - for instance, the PRESTO (2010) and Copenhagenize Urban Cycling Index (2011) programs.

The collection of data on bicycle usage has gone through many solutions of direct observation. In several cases semiannual or annual systematic counts of cyclists are conducted in various points of the city. These counts not only allow to estimate the number of bicycle users in a city but also the most frequent places where cyclists pass by, and to monitor the modal split based on data collected at regular intervals. Typically, these counts are complemented by annual surveys of mobility.

Geographical information systems (GIS), as bike route planners, may be explored as a solution for data collection by indirect observation. These route planners may also be useful for the urban mobility management, mainly in cases where this data is not so easy to get with methods of direct observation.

Urban cyclists are not all the same and do not travel with the same purpose or the same frequency. It is possible to identify different groups of cyclists, according to the experience level, risk perception and behaviour, while driving on the road. Several studies have been addressed on how cyclists choose their routes: the set of criteria they have, how they evaluate them, and what relevance they attach to these criteria. Hochmair (2004) considers that the decision behaviour of most users can be explained through a compensatory decision rule. Stinson & Bhat (2003) investigated, by a stated preference survey, which criteria bike users have when choosing routes. They concluded that time (distance) is the most important factor, and the presence of bike lanes, the slope and type of pavement are also common criteria in the choice of routes. The same authors (2005) examined differences in bicycle route preferences across individuals with different levels of experience in bicycle commuting, experienced and inexperienced. In the first case, travel time was considered the most important criteria, while cycling infrastructures, a safety-related attribute, were also relevant. For inexperienced users the most important was the separation from car traffic, also a safety-related attribute. Hochmair (2004), through a survey conducted to 42 cyclists, concluded that the most important route selection criteria would be the presence of bike lanes, sights, avoidance of heavy traffic and distance. The same author (2005) asked 12 participants to classify all criteria from the previous study into classes and assign a name to each class. The most suggested classes were: fast, safe, simple, attractive and comfort. With this study he established more widespread criteria that users take into account when choosing routes. Harvey & Krizek (2007), through a study in Minneapolis, found that cyclists travelled on average 67% longer in order to include a cycle path facility on their route.

Su *et al* (2010) proposed an online bike route planner (*Cycle Vancouver*) that, while considering multiple criteria, does not allow users to consider them simultaneously, and whose proposed routes are always optimized for a single criterion. On the other hand, Ehrgott *et al* (2012) propose a route choice model based on two functions (bi-objective): travel time (quantitative measure) and suitability of a route for cycling (qualitative measure), considering criteria as road gradient, motor traffic volume, traffic speed, pavement condition or presence of cycle facilities.

The literature review on the criteria that cyclists state having when choosing routes, concluded that the shortest route is not necessarily the most attractive route to a cyclist, once there are numerous other factors that when combined can determine other alternatives. Some of these are subjective criteria, such as safety, which cannot be measured directly. Other criteria are objective, such as distance or slope, and can be observed. On the other hand cyclists' decision on choosing a route may vary, which in part may be related to the fact that some decisions are taken during the trip and not always pre-planned.

Bike route planners have emerged as an extension of the car route planners, but not always with the best results. The most interesting algorithms, more specific to bicycle trips, cover only a few cities where bicycle use is more intense or frequent. Several existing bike route planners and their features and functionality were analysed and evaluated. Out of the bike route planners evaluated, only two cover the Lisbon area and none considers the slopes when calculating the best route which is essential for a model that fits a city with irregular terrain. None of the bike route planners revealed the algorithm or its functions for calculating the lowest-cost path, releasing only tracks on the method of data acquisition, such as Su *et al* (2010) on some variables included in the platform *Cycle Vancouver*.

The information produced by a bike route planner may be used as a useful and non-expensive resource for the estimation of bicycle demand on the streets network and for the identification of network segments where improvement of bicycle facilities would be beneficial for a high number of cyclists and potential cyclists (Fu & Hochmair, 2009; Hochmair, 2009). Hochmair (2012) suggests that it is necessary to distinguish between actual routes and test routes, proposing that a possible way is to bring a mandatory user response in the web interface on whether the user would make a trip between the specified origin and destination, or whether this was only a test request. He also suggests that it would be interesting, for the mobility management, to know the trip purpose in order to predict how often a particular trip will be taken. Georeferencing cycling accidents shows the most dangerous areas (black spots) for cycling. This information is not only useful for cyclists that can avoid these areas, but mainly to provide means which prevent or reduce road casualties in specific city locations.

With this information mobility, managers may have a stronger and updated basis for the planning and management of the cycling network, and thus meet more effectively the real needs of the cyclists. The definition of priority intervention areas as well as the required measures and actions, in each case, is one of the municipal powers that can benefit from a platform of communication between management and users - for example, the design of infrastructure in segments with higher bicycle traffic or with major circulation problems, where it is most urgent to improve the accessibility. On this point, and considering particularly the mobility systems in transition, it seems essential to go beyond the availability of information from the mobility managers. It also seems to be important to strive for high levels of participation/communication within the cyclist community so that change can occur with guaranteed mutual interaction, favouring better degrees of adaptation of the mobility system.

3 Methodology and Case Study

3.1 The city of Lisbon

Lisbon, capital of Portugal, is the urban center of the Lisbon Metropolitan Area. The city, where about 550.000 people live, has a high volume of traffic, both from the periphery to the center and within the city. In recent years the number of cyclists has been increasing in Lisbon. It is not possible to confirm this evolution with official data – because there is none – nevertheless this growth of bicycle use can be clearly assigned for those who live or work in the city. Part of this growth was due to municipal investments in cycle infrastructures (2008-2009), namely the bike lane network or parking areas for bikes. However the accessibility by bicycle to the entire city is not yet guaranteed. It is thus appropriate to study the demands of mobility in cycling and investigate the factors that may influence the choice of routes as an important input for planning and management of the cycling network.

The city is characterized by an irregular terrain, with a historic district whit its "seven hills" (with a maximum altitude of 110m), a plateau region in North Central, Monsanto Mountain (West) with maximum altitude of 228m, and the 18km long waterfront along the River Tagus. Lisbon is a very special case in comparison to the cycling cities, which has been used as an argument for the non-adoption of cycling. Its topography, the various types of pavement, the presence of tram rails, and the behaviour of car drivers - associated with the sense of unsafe circulation - may influence the choice and optimization of routes to bicycle users.

3.2 Methodological approach

The approach relies on data collected by an online survey launched on bicycle users aiming to obtain information directly from them about their socio-economic profile, urban cycling behaviour, stated preferences on factors that may influence route choice and needs for better cycling conditions. It was available online for one month (January-February 2012). The sample was composed of 892 valid answers, which corresponds to 83% of the responses collected. This sample size is considered representative and quite satisfactory, contributing to more consistent and closer to reality results and conclusions. Its subsequent statistical treatment through a multivariate statistical analysis using different techniques made possible to define profiles of cyclists with different preferences in route choices.

Based on road network and elevation data provided by Lisbon Municipality, this information was then integrated into a GIS in order to create a model for bike route planner using *ArcGIS* software.

4 Characterization of bicycle users' profile in Lisbon

The lack of information on issues such as 'who are actually the users of bicycle in Lisbon', their 'level of experience', 'how and for what purposes do they move', 'how do they choose the routes', represent some of the main gaps that should be filled. For that purpose it was necessary to conduct a survey for bicycle users, to understand and draw some conclusions regarding: Bicycle User Profiles; route choice criteria, type of bicycle they use, urban behaviour, accidents and thefts, community, needs and suggestions for promoting regular use of a bicycle, among other statistics. The survey also included questions concerning the utility and functionality of a platform to support users in choosing bike routes in Lisbon, at the same time having the capacity to produce useful information for managing the cycle network and management of urban mobility

Concerning the usefulness of an online platform to identify the best route according to their preferences, 95% considered that would be useful. Regarding an online platform to serve as a means of contact between users of bike and cycle network managers, this percentage increases to 97%, indicating the availability for involvement of the cyclist in this type of interaction with the municipality, mediated by an information tool.

Survey results on the route choice criteria showed that, whenever possible, the routes that Lisbon cyclists choose are: the fastest, safest, streets with low traffic speed. They avoid routes with steep slope, though this criterion is not stated as the most important - the knowledge of the city and technology available in bicycles can contribute to its appearance in 3rd place. This result challenges and demystifies "the city of seven hills" as an obstacle to the movement of cycling in Lisbon. Cyclists prefer routes with a nice landscape and less air pollution. The type and condition of the pavement are also relevant criteria.

In order to trace profiles of bicycle users (and taking into account the type of variables), an automatic method of cluster formation was used - *Two Step Cluster* (Chiu *et al,* 2001; SPSS, 2001). The optimal number of clusters was automatically determined; three clusters have been suggested, and formed by six selected variables: *age*, *gender*, *cycling for commuting purpose*, *cycling for sport / fitness maintenance*, *experience of urban bike* and *helmet use*.

The identification of the clusters allowed for a labelling of these groups with "Beginner", "Sport / weekend " and "Commuter", which seems adjusted to their characteristics. Table 1 describes each of these groups depending on their profile, preferences in route choice, urban behaviour, needs and proposals for bicycle mobility, based on the survey answers.

Table 1 – Summary of the characterization of different bicycle user profiles in Lisbon

Beginner	Sport / weekend	Commuter
• Young (μ= 32,7 ; δ=10,33) • Any gender • Beginner • Uses the bike for less than 2 years • Weekend trips for touring and sport • Cheap bicycles • Mountain and city bikes • Safety is the most important criterion • Prefers bike lanes and streets with pleasant sights • Rides on sidewalk and on the road • Respects traffic lights • Group with fewer proposals of policies and measures for better accessibility	• Middle age (μ= 36,06 ; δ=9,47) • Male • Owns a car and a great part lives outside Lisbon • Weekend trips for touring and sport • Mountain and road bikes • Expensive bikes • Safety is the most important criterion • Fastness, pleasant sights and air pollution are important criteria • Wears a helmet • Rides with confidence	• Young (μ= 31,71 ; δ=7,59) • Lives in Lisbon • Daily bike commuter • Experienced • Road, mountain, hybrid, folding and city bikes • Fastness and slope are the most important criteria • Gives a lot of importance to type and pavement conditions • Rides on the road • Does not wear a helmet • Does not claim for bike lanes • Rides on opposite direction and on BUS lane, when they exist • A third already suffered a bicycle accident in urban traffic • A quarter had already a bike stolen • Group with more proposals of policies and measures for better accessibility • Group most connected to cyclists community

In what concerns the set of route choice preferences, the groups are also distinguished by the relevance they attach to different criteria (Figure 1 and Table 2).

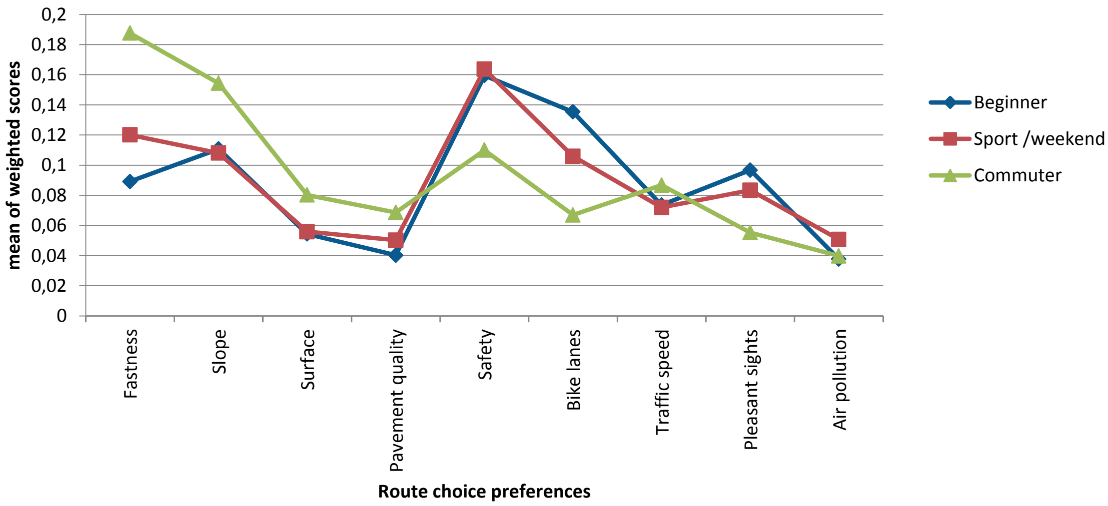


Figure 1 – Relevance of each route choice criteria for each profile

Table 2 – Average of weighted scores of each criterion, for each profile

	Fastness	Slope	Surface	Pavement quality	Safety	Bike lanes	Traffic speed	Pleasant sights	Air pollution
Beginner	0,0891	0,1107	0,0543	0,0403	0,1594	0,1353	0,0736	0,0966	0,0377
Sport /weekend	0,1201	0,1080	0,0559	0,0502	0,1636	0,1059	0,0719	0,0833	0,0507
Commuter	0,1876	0,1543	0,0802	0,0687	0,1100	0,0669	0,0867	0,0553	0,0398

From Figure 1 it is noticeable that the "Beginner" profile attaches a lot of importance to safety - the most important criteria - and prefers to circulate on bike lanes. The pleasant sights are an important criterion for “Beginner” and the surface and condition of the pavement are not relevant criteria while choosing a route. The rider with a "Sport / weekend" profile, like the "Beginner", attaches great importance to safety, preferring to circulate on bike lanes and flat or slightly sloped streets. Fast routes are an important criterion, as well as the pleasant sights. This rider assigns slightly more importance to air pollution when comparing to other groups. For the "Commuter" profile, fastness is the most important criteria, followed by slope, which distinguishes it from other groups. The surface and condition of the pavement are important criteria in route choice. It is the group that favours less safety, presence of bike lanes and pleasant sights. It is also concluded that “Beginner” and “Sport /weekend” have a very similar set of route choice preferences, only being distinguished by “fastness” and preference level for bike lanes.

This data is essential for producing a model that determines the best route from A to B according to the user’s profile.

5 SIRCuL – Information system for cycling network management

Based on the results the necessary information to build a support tool for mobility management was listed. Its functionalities were specified in order to ensure that the information generated by users might be useful in cycle network planning and management by municipality, from a perspective of progressive interaction. SIRCuL is the acronym for this support tool - information system for cycling network management, in Lisbon. SIRCuL integrates some components and functions into an online platform which promotes direct participation and communication between cyclists and municipality, given its usefulness for planning and urban mobility management, particularly in a context of growth of this transport mean.

One of the most important components of SIRCuL consists in a bike route planner, which advises cyclists in choosing the best route in the city. In order to continuously improve the bike route planner, SIRCuL collects bike users’ data, profile, routes they actually do, frequency of a street segment usage, accidents indication, suggestions and opinions.

Based on the continuously generated information about users, statistics and summary reports, municipality may be able to plan a better cycling network and mobility management by making informed decisions about the intervention on a street segment. Figure 2 presents a summary of the SIRCuL functions for each entity.

To provide useful recommendations on the cycle routes in Lisbon, it is necessary that the model consistently suits the criteria of each user, assuming that not all cyclists have the same set of preferences in route choice.

In addition to the bike route planner, users are offered the possibility to access useful information, add information to the system, make suggestions or give opinions about the network and the bicycle facilities. The urban mobility managers might therefore better meet the needs of the target-public of their measures and actions.

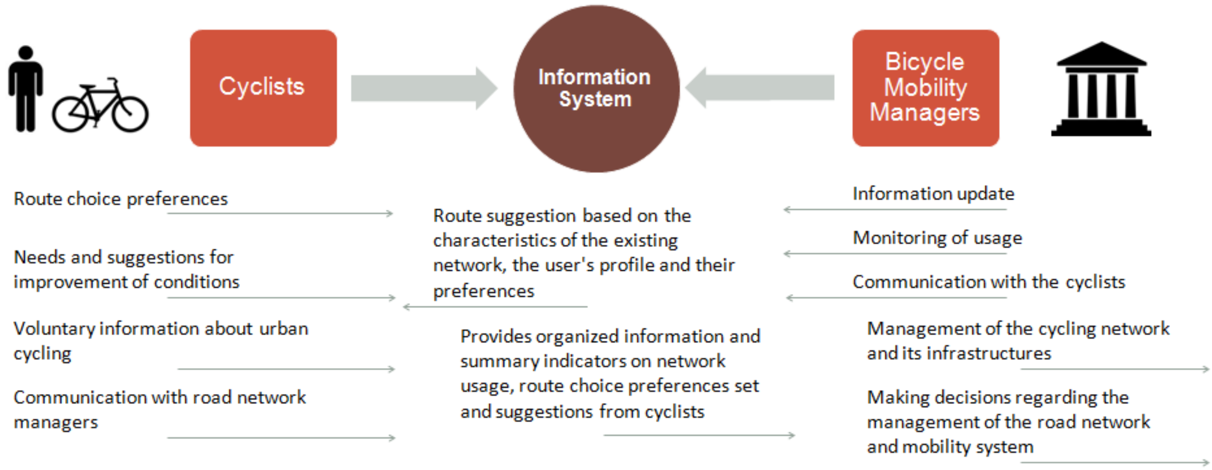


Figure 2 – Summary of functions and relationships between cyclists, bicycle mobility managers and information system

This platform can be integrated into an official website dedicated to urban accessibility and mobility, which includes all existing mobility systems and a bike sharing program system. The municipal administration is responsible for updating information on existing and developing networks and to inform the system about their changes (eg, interruption or suppression of streets due to road works). The effective operation of the system depends on three key conditions: 1) The use and feedback from the users should be made on a high and on frequent basis; 2) Users should feel their contributions met and their participation considered in decision-making; 3) The administration should keep the system functioning assuring reliability and data updating.

5.1 Bike Route Planner model in GIS

The development of route models for cyclists adds a greater complexity to automobile route planners, resulting from higher number of degrees of freedom associated with the motion of the bicycle (smaller vehicle, lighter and more versatile in terms of maneuvers). Moreover non-motorized vehicle pulled by the cyclist follows a series of particularities in its driving, namely: a large number of variables relevant to the cost function; existence of more subjective variables. The complexity involved in modelling choices of routes for cyclists is therefore a challenge.

The GIS allows for modelling of a road network in a topological graph which can be applied to a variety of functions and algorithms, namely the least-cost path (Dijkstra, 1959). Associating each arc of the network to a travel cost, the path cost is defined as the sum of the arc costs that it contains.

This section describes the process of developing a GIS application for modelling street network and public space characteristics and generating bike routes in Lisbon, tailored to the preferences of different cyclist profiles. Then it presents and assesses the tests to the GIS model and the suggested routes.

Modelling the network and street characteristics

After eliminating some streets not relevant to the analysis, the road network is a graph representing the street network on Lisbon centre, with 3330 arcs and a total length of 276.77 km. The criteria chosen for the cost-function model are the 6 most relevant: fastness, slope, pavement (surface and conditions), safety, bike lanes and pleasant sights.

Algorithm and cost function

The modelling of route choices rooted in the criteria and weights is based on a linear combination of weighted criteria. The shortest path algorithm does not suggest alternative routes, but only the optimal path, i.e., one for which the sum of costs of each included arc is the minimum. For each arc, its travel cost (abstract) is given by:

$$C^j = \sum_i w_i^j \cdot \alpha_i \cdot c(l, v_{av})$$

where:

i, relevant criteria for route choice {fastness, slope, safety, pavement, bike lanes, pleasant sights}

j, cyclist profile {Beginner, Sport /weekend, Commuter}

w_i^j, weight of criteria for each profile

α_i, cost factor

$c(l, v_{av})$, reference cost, depending on the length $l\ [m]$ and average speed $v_{med}\ [^m/_s]$, in time units $t[s]$.

and:

$\alpha_i \cdot c$, cost function for i criteria

- *Fastness* depends only of the length and travel speed.
- *Slope* depends on grade and length of the street. The cost function is asymmetric, different for uphill and downhill streets, and reproduces the relationship effort/slope.
- *Pavement* has many categories depending on surface (asphalt or cobble stone), quality (perturbations) and presence of tram rails.
- *Safety* depends only of the level of service (hierarchy) of each street.
- *Bike lanes* depend on their presence or absence.
- *Pleasant sights* depend on streets with nice sights, near parks and gardens, or with alignment trees.

For each cost function a neutral value (1) was defined corresponding to travel through an arc in "normal" conditions which, when combined to the travel cost function, represents the reference cost. The "normal" conditions are: slope= 0%, asphalt pavement without perturbations, residential streets (safety), absence of bike lanes, common urban sights. Other values for each criterion would benefit or penalize the travel cost.

For example, bike lanes have a cost factor that reduces its travel cost in 40%. Safety has a cost factor that penalizes the travel cost in 200% when traveling through a street with a high level of service.

Table 3 - Weighting of traveling cost, depending on the characteristics of the street network

Criteria	**variable**	**Cost function domain**
Fastness	Continuous	1
Slope	Continuous	0,1 - 10
Pavement	Discrete	1 ; 1,5 ; 2 ; 3
Safety	Discrete	0,75 ; 0,8 ; 1 ; 1,5 ; 2
Bike lanes	Binary	0,6 ; 1
Pleasant sights	Binary	0,75 ; 1

This iterative process of maximizing the likelihood of the routes generated by the model was based on the opinion of a group of experienced cyclists, who were asked to provide feedback over the itinerary suggested between A and B.

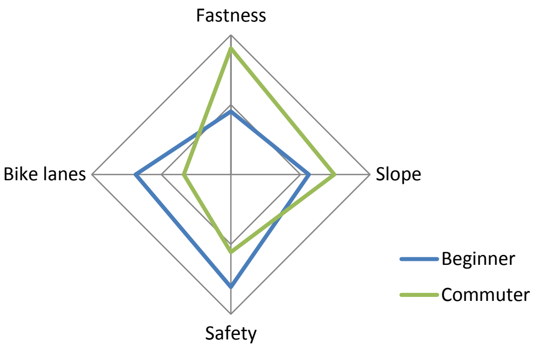
The weights which reflect the importance criterion for each profile represent a compensatory component in the decision model. Their sum should be equal to 1.

$$\sum_i w_i^j = 1$$

However, the restriction underlying the compensatory model causes them to have very slight relative differences between the weights (*w)* and, consequently, the costs associated with each criterion are very close. It seems that the differences between the profiles (Table 2) are not significant at this scale, which may result in undifferentiated routes based on these weights. Given the similarity between the parameters of the variables between profiles Beginner and Sport, the following examples do not include the suggested routes for the user profile Sport. The profiles of different users are weighted by the parameter of the cost function according to the values expressed in Table 4.

The cost factors associated with *pleasant sights* and *pavement* were also reduced to zero, which simplified the model compared to the data collected in the survey. In the case of *pavement* this was because it is difficult to quantify its cost and it does not show significant differences between the profiles. For *pleasant sights* it is difficult to quantify the cost and it has small weight in the cost function (it would be a tiebreaker only between very similar alternatives).

For what was described above, the following tests include only the criteria with significant differences in the results of routes obtained by the model, i.e. fastness, slope, safety and bike lanes.



	Beginner	Commuter
Fastness	0,1802	0,3616
Slope	0,2238	0,2975
Safety	0,3223	0,2223
Bike lanes	0,2736	0,1353

Figure 3 and **Table 4**– Parameters (weights) of each criterion for the cost function, depending on the profile, after reducing the number of variables

5.2 Tests

Test 1 analyses the routes suggested for the two profiles, in the presence of a bicycle lane where the distance, safety and slopes are similar. The origin and destination are Alameda D. Afonso Henriques and R. Marquês Sá da Bandeira.

Figure 4 – Suggested routes between Alameda D. Afonso Henriques and R. Marquês Sá da Bandeira, for the Beginner and Commuter profiles, respectively. The bike lanes are represented in dashed red.

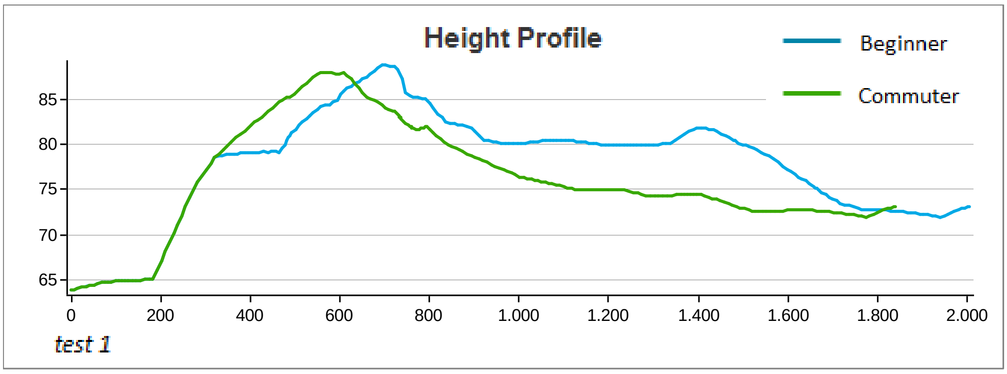


Figure 5 - Height profile for test 1

In this route the suggested route for the Beginner is 200m longer, though about half of the route is performed in a bike lane. The profile Commuter chose not so safe roads, but a faster route. The bike lane criterion might induce the choice of the suggested route for the beginner, even if it is a longer route comparing to the Commuter. The slopes are relatively identical. Test 2 compares the suggested routes on distance, safety and slope. The origin and destination are located at Av. Infante D. Henrique (Santa Apolónia) and Pç. Paiva Couceiro.

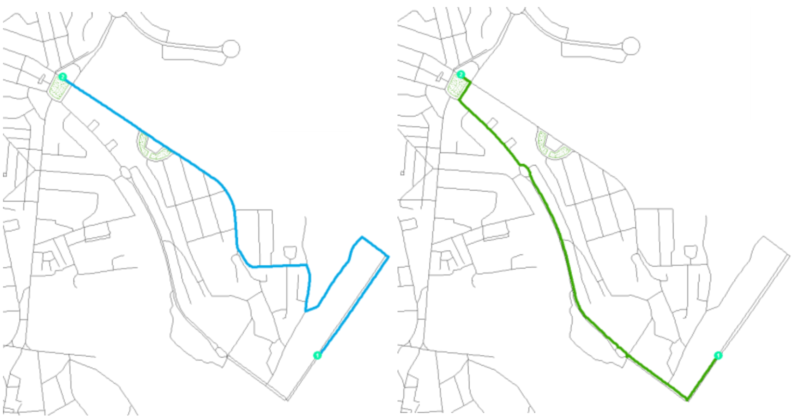


Figure 6 - Suggested routes between Av. Infante D. Henrique and Pç. Paiva Couceiro, for the Beginner and Commuter profiles, respectively.

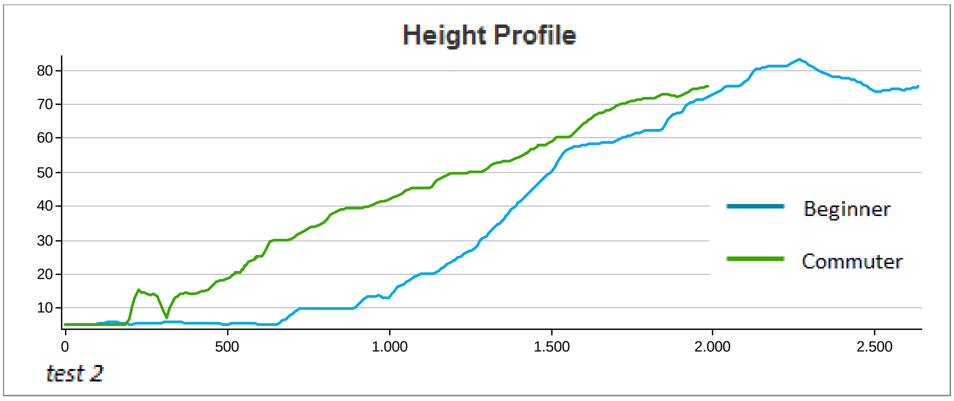


Figure 7 - Height profile for test 2

This test shows a clear difference between the suggested routes for the profiles Beginner and Commuter: the profile Beginner chose a safest route instead of steeper slopes in some sections. The profile Commuter opts for a faster route with a difference in the total distance of over 650m and with more progressive slopes but on the other hand, the route consists in streets with higher level of service.

Other tests were conducted to test some criteria individually. All results proved to be very suitable presenting significant differences between suggested routes for different profiles.

6 Conclusions and suggestions for further research

The characterization of Lisbon bicycle users, assessed from a sample of about 1000 answers (a quite relevant response level given the current use of bicycle in the city), allowed to collect new data and updated information on cycling in Lisbon city. Survey results reveal that bicycle users acknowledge the relevance of a bike route planner and a communication platform between users and mobility management entity (as well as the infrastructure) as a tool for public participation. The collected data analysis showed that there are at least three distinct cyclist profiles, with significant differences among different dimensions such as socio-demographic, driving behaviour, route choice, set of preferences, needs and anxiety.

The aim of developing a GIS model that would suggest different routes for different bike users, with different preference systems, seems to have been accomplished. The results are considered as a close representation of reality, although a further calibration of the model and of cost functions is needed.

The simplicity of the route (number of turns) was not considered as a relevant factor in the choice of routes by the inquired cyclists. In fact the algorithm does not consider the continuity of the routes, attributing higher importance to direct paths instead of suggesting a route with many turns which may separate the results from reality. This is similar to motor vehicle algorithms which take the street network hierarchy into account, by choosing higher order routes. When one gets close to their destination, it then transposing them to a lower level path (in case of local access) at the end part of the trajectory.

The *safety* cost function depends only on the hierarchy of the street network, which may be a very reductive indicator for a very complex and subjective criterion. The *pleasant sights* cost function could also have been better defined (qualitative characteristics, attractiveness, beauty, etc.) with much more than a binary value, but we have to recognize that in that case the interaction would become more complex. The independence of subjective variables was not guaranteed. For instance, safety is not independent of bike lanes, neither bike lanes are independent of the pavement.

Test results revealed to be a good approximation to reality, perhaps due to the simplicity of the model. Some sensitivity analysis of the criteria weights would also make sense, in order to calibrate the model and get it even closer to the reality and to the profiles of cyclists (on average). The survey analysis was very interesting as a starting point but should be complemented and calibrated continuously through SIRCuL, collecting data and analysing the set of routes held for stated preferences.

There are users which may not fit the profiles suggested by a bike route planner. In this case the route planner might ask the users directly to adjust themselves the weights attributed to each criterion. With this step the system would collect and update the set of route preferences of each user type, and it might even create a new cyclist profile if thought appropriate given the amount of cyclists.

Once the problems were identified in the model, a more careful calibration could lead to even more realistic results. It is also worth mentioning, as future developments, the ability to automate the calibration process that SIRCuL could include, while route aggregator for registered users (with a previous structured profile description). The calibration would be progressively performed based on feedback from users regarding the routes suggested by the system.

SIRCuL intends to be a platform for mutual interaction, support and sharing information among users of the cycling network and the municipality or entity committed to mobility management. For the improvement of SIRCuL, it could be interesting to investigate which data is relevant to the management of municipal mobility. The efficiency and likelihood of SIG model for route suggestions are crucial for the success of SIRCuL, since the bike route planner is the main attraction for the bike users (and potential bike users). This kind of system may automatically collect, and produce *in continuum* information about:

- the characteristics of bicycle users;
- their route choice preferences;
- the streets with higher demand or more frequented use by cyclists;
- the most frequented areas of origin and destination;
- accidents and thefts of bicycles, allowing to monitor levels of road safety and security;
- the needs and suggestions for improvement of conditions;
- other statistics.

The method of data collection proposed appears to be an efficient solution that could allow a city council to fill the information gap, even in a context of financial constraint. Although such a system requires a certain level of investment for both its development and the maintenance of the application, it appears to be a relatively economical solution given the benefits that can be achieved. Municipal mobility management could have data to monitor the cycling mobility and thus manage the network, plan and decide investments in improvements of the cycling network and its expansion, in a context of increased demand and where the cycling network still has insufficient coverage.

It is important for a city council to evaluate the efficiency and effectiveness of their policies and measures with regard to the promotion of cycling as a transport mean. This platform – SIRCuL- is useful for monitoring and dissemination of local solutions, enabling benchmarking in a European and global context in terms of the best practices (PRESTO, Copenhagenize Index). The use of this system in a city which is changing its mobility paradigm is particularly important for good planning and management of the cycling network, to monitor the changing needs of cyclists, and to better promote this mean of transport in a city.

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