Cali Bikeability Index Map: A tool for evaluating public investment and future needs

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ABSTRACT

Cycling is an affordable, environmentally friendly transport mode that is a proven alternative to motorised travel. Cali, a state capital in Colombia, has a significant cycling share trips using this transport mode\(^1\). However, minimal information exists about current conditions for cycling across the city, limiting effective planning and maintenance of infrastructure.

This research developed a bikeability index for Cali. It was based on four variables: slope, environmental quality (EQI index), quality of infrastructure (road safety and maintenance) and personal safety. Using advanced raster analysis under a geographic information system, a grid map (50 by 50 metres) was produced for each variable and then combined in a weighted manner, with a value of 1 to 5 for each area of the city. A value of 1 represents poor conditions for cycling, while 5 is to areas where all aspects are at their best.

The Cali bikeability index map was then used to evaluate connectivity between major zones that generate and attract cycling trips. As a result, in many cases cycling trips involve areas with very low bikeability, suggesting that cycling users prefer this mode as usage exists even under limited cycling conditions. The evaluated bikeability index and its major transport routes results show that the potential impacts of proposed cycling investments are in areas with low bikeability. However, not all these areas are part of corridors with high bicycle demand.

KEY WORDS

Bikeability, GIS, DSS

\(^1\) Over 11% of all the trips of different transport modes (Belalcazar, 2011)
1 INTRODUCTION

Urban physical infrastructure and the use of bicycles as transportation are related. Mass transport systems articulated with active transport (walking and cycling) could help to reduce the number of private car travel and promote the practice of physical activity. Cali opened the first phase of a Bus Rapid Transit System (BRT), named MIO, in 2009, and a construction of articulated bike lanes were projected (Gobernación de Santiago de Cali, 2009).

Many studies try to model and measure the relationship between the built environment and aspects of travel behavior. After all, people mainly travel in order to access activities such as living, working, shopping and recreating, which are in most cases spatially separated (Acker, 2012). Consequently, there seems to be a correlation in the way that travel patterns might be altered by changing the location of these activities and the design characteristics of these locations. The greater part of these studies uses aggregated or macro-environmental data to characterise the built environment.

A decrease in travel distance likely results in cycling having a much higher share of mode of transport. Non-cyclists often mention having to travel long distances as an excuse for not travelling or commuting by bicycle (Kos, 2012). As a consequence of the relationship between the built environment and bicycling, policy makers and academics try to determine what makes a city bikeable. Such indexes mainly focus on how attractive it is to bicycle from a specific neighbourhood to facilities. However, such indices do not measure how safe or how easy it is to bicycle and do not evaluate the bicycle infrastructure itself.

This paper, therefore, aims to illustrate the construction of such a systematic infrastructure, environmental quality (EQI index), topography and security-based bikeability index, explaining the detailed methodology used for calculating each geographical weighted factor for the four variables taken into account, namely, topography, infrastructure, environmental quality and security. Mapping bikeability provides a powerful visual aid to identify zones where changes are needed to support sustainable travel. The overall bikeability score and its four component factors can guide local action to stimulate changes in cycling rates. It uses widely available data types, thus facilitating easy application in other cities. Furthermore, the flexible parameters and weighting scheme enable users enhance each one by using evidence about local preferences and conditions.

Decision Support System (DSS) will incorporate community input, proposed investment plans, topologies, among other features. This in order to generate a more detailed analysis incorporating the evaluation of the proposed interventions, including road crossings,
maintenance of an existing off-road path or a new on-road segregated bikeway. The proposed analysis should be run through spatial analysis, verifying new interventions according to the plans established by the city.

2 STUDY AREA

Santiago de Cali is located southwest of the Republic of Colombia, from 3 ° 20’ and 3 ° 30’ north latitude and 76 ° 27’ and 76 ° 33’ west longitude, in the department of Valle del Cauca. In physiographic terms, the city is located in the Rio del Cauca Valley, bounded by the Cordillera Occidental to the west, the Rio del Cauca to the east, the industrial zone of Yumbo north and the rural area of Cali to the south (DAP, 2008). It is in this last direction in which the city suffers its greatest expansion. The altitude varies from 940 metres, near the Cauca River, to 1,050 metres in neighbourhoods located in the mountains. The dry climate is tropical, with an average annual rainfall of 1,477 mm and average annual temperature of 24.1 °C. In 2003, the city covered an area of approximately 120 km², with a population of 2.35 million (DAP, 2008).

![Figure 1. Cali location (Rodriguez, 2011)](image)

Regarding the cycling community in Cali, 1’705,440 daily trips are made in the city, 11% of which are made using the bicycle as the preferred transportation mode (Belalcázar, 2011). This high percentage of bicycle trips is in contrast to the lack of existing bicycle road infrastructure (31.2 km). Considering that Cali has a tropical savanna climate, the temperature is also a contradictory factor compared with this percentage, taking into
account that in Colombia and Cali the average temperature is 15°C and 23.6°C respectively.

3 METHODOLOGY

The methodology used throughout the development of the model involves weighted regression (WR). This weight was defined using Prevalence OR coefficient by a multilevel logistic regression model (Salud Pública, Universidad del Valle, 2013), which is used in the analysis of cross sectional data, to evaluate different models for the multivariable estimation. To evaluate the bikeability index, a four term equation was deducted, which takes into account the four variables mentioned previously multiplied by four different factors that were calculated using the OR coefficient, taking into account the importance of each term for the citizenship in Cali. The equation for calculating the bikeability index is as follows.

\[ BI = \alpha x_1 + \beta x_2 + \gamma x_3 + \delta x_4 \] (1)

Where,

- \( BI \) = Bikeability index
- \( x_1 \) = Infrastructure factor
- \( x_2 \) = Topographical factor
- \( x_3 \) = Security factor
- \( x_4 \) = Environmental quality factor
- \( \alpha \) = Weighted infrastructure coefficient
- \( \beta \) = Weighted topographical coefficient
- \( \gamma \) = Weighted security coefficient
- \( \delta \) = Weighted environmental quality coefficient

A probabilistic, conglomerate and multistage sampling was conducted. Considering that each stage sample had a known probability of selection, the probabilistic sampling was conducted as the principal parameter following a systematic selection procedure; conglomerate, because of the primary sampling unit, were the micro-territories of residence; and multistage involved different stages of sample selection. Micro-territories of residence more suitable to the study were urban sections defined by DANE (Departamento Administrativo Nacional de Estadística). These had the following attributes: similar urban forms in urban sections, low variance heterogeneity and socio-economic strata and absence of large urban or natural barriers within the same and suitable size.
The study “Evaluacion del impacto de la red de ciclo-rutas en la actividad física utilitaria en la población adulta de Cali” done by the department of public health of the Universidad del Valle, evaluated the impacts of cycling use as a transport mode in the citizens health. For evaluating coefficients $\alpha, \beta, \gamma$ and $\delta$, a sample of 914 people were surveyed in different places, neighbourhoods and income level of Cali, accounting for the sample territories defined previously in the previous study mentioned. After collecting the whole data and coefficient obtained in the previous study, they proceeded to the analysis using the software Stata as a tool for establishing the multilevel logistic regression model, using as input variables the percentage of people who consider infrastructure, environmental quality, topography and security as an important or unimportant parameter for choosing the bicycle as a mode of transport.

The average age of the study population was 29.9 years; 19.3% of the surveyed population reported having a car, 36.6% a motorcycle and 67.9% a bicycle. The multilevel logistic regression model about the influence of the existence of bicycle lanes on the use of bicycles as a transportation mode in Cali found a positive association with male gender, perception of neighbourhood safety for cycling and perception of the ease of riding a bicycle due to variable traffic conditions. The coefficients were calculated using prevalence odds ratio criteria, measuring the effect in the analysis of cross-sectional data and evaluating models for the multivariate estimation of the PR (Salud Pública, Universidad del Valle, 2013). The resulting coefficients using in the bikeability equation are presented as follows.

- $\alpha = 0.193$
- $\beta = 0.125$
- $\gamma = 0.44$
- $\delta = 0.242$

### 3.1 Infrastructure analysis

In September 2013, two observers cycled 31.20 km with the aim of evaluating the existing bicycle road infrastructure in Cali. Four typologies of bike lanes were established: 1) Bike lanes with appropriate characteristics of lane width, demarcation, signage and lighting; 2) bike lanes with mixed characteristics – recent sections with similar conditions to the previous type, and old sections with fair or poor signage, lighting and pavement with dangerous crossings; 3) bike lanes with good signage, lighting, pavement conditions and protective barriers, but narrow, one-lane and nonfunctional, used as a pavement or motorcycle parking; 4) bike lanes located on the road but with a cord line that separates vehicles, with good signage, lighting and free of obstacles. These segments, found from information posted on the government webpage of the city, were each evaluated. The
scoresheet used evaluated the index based on infrastructure across the whole city (Acker, 2012). The methodology is explained as follows:

<table>
<thead>
<tr>
<th>Hierarchy</th>
<th>Infrastructure-based item</th>
<th>Priority (relative to state)</th>
</tr>
</thead>
<tbody>
<tr>
<td>biking facilities</td>
<td>Screening</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Width</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>General state</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Marking</td>
<td>0.2</td>
</tr>
<tr>
<td>Safety aspects</td>
<td>Risky crossings</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Raised bicycle paths</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Interaction with vehicles</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Hindrances</td>
<td>0.2</td>
</tr>
<tr>
<td>Extra bicycle amenities</td>
<td>Occupancy rates</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Mode integration</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>Green space</td>
<td>0.1</td>
</tr>
<tr>
<td>Parking hindrance</td>
<td>Parking</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 1. Infrastructure index scoresheet

For street segments without a bicycle path, the safety aspects (risky crossings, raised bicycle path, interaction with vehicles and hindrances) were assigned a value of zero.

3.2 Topography analysis

With regard to the topography analysis, the Aster global digital elevation map DTM (NASA, National Aeronautics and Space Administration, 2004) was used as a tool for evaluating this specific topic. Based on an ASTER satellite, a digital elevation model is determined at a horizontal resolution of 1 arc second, examining basic geomorphic parameters: the elevation, slope and curvature.

3.3 Security Analysis

The security factor was based on a previous work performed by the Cali police department (Romero); different quadrants across the city were evaluated to determine the odds of being a victim of a crime, in order to prioritise which zones in the city needed important intervention in terms of security. This probability was calculated based on crime indexes.
across the whole city and the percentage that each zone represented of the total crimes in Cali was determined. The factor identified by the police was normalised to the index used in this project.

### 3.4 Environmental quality Analysis

With the aim of obtaining a Cali environmental quality index (EQI) – the results of a previous work which required such an index to implement public policies to solve urban environmental problems in the city – a model to obtain this index from satellite images is proposed (Rodriguez, 2011). From a Landsat ETM+ (NASA, Landsat Science, 2013) image of Cali-Colombia, three environmental indicators were obtained: temperature of surface (TS), normalised difference vegetation index (NDVI) and leaf water content index (LWCI) that measures the moisture of the environment, from which the EQI (environmental quality index) was estimated, at a neighborhood level, using multivariate analysis.

\[
TS = \frac{T_L}{1} + \left(\lambda \ast \frac{T_L}{\rho}\right) \ast \ln(\varepsilon)
\]  

- **TS**: Surface temperature
- **$T_L$**: Light temperature
- **$\lambda$**: Average wave length
- **$\varepsilon$**: Surface emissity

After evaluating the surface temperature, the emissivity was calculated using equation (3). This shows the emissivity from the soil and vegetation, which is the ability of a surface to emit energy by radiation.

\[
E = f_v \varepsilon_v + (1 - f_v)\varepsilon_s
\]

- **$\varepsilon_v$** = Vegetation emissivity, using a factor of 0.985
- **$\varepsilon_s$** = Solu emissivity, using a factor of 0.978
- **$f_v$** = Vegetation fraction
The vegetation fraction was calculated using the normalised difference vegetation index NDVI shown in equation (4), which is a simple graphical indicator used to measure the growth of plants, determine vegetal covers and control the production of biomass.

\[
NDVI = \frac{(NIR - R)}{(NIR + R)}
\]  

- \(NIR\) = Near infrared
- \(R\) = Red

The NIR and R are taken from the Landsat ETM+ image.

Finally, with the aim of evaluating the leaf water content index LWCI proposed by Hunt et al. (1987), an infrared reflectivity based correlationship was used to calculate LWCI.

\[
LWCI = -\log[1 - (NIR - SWIR)] / -\log[1 - (NIR_{FT} - SWIR_{FT})]
\]  

- \(NIR\) = Near infrared
- \(SWIR\) = Short wavelength infrared
- \(NIR_{FT}\) = Near infrared for maximum turgor pressure leaves
- \(SWIR_{FT}\) = Short wavelength infrared for maximum turgor pressure leaves

Using a factor of 0.444 for \(NIR_{FT}\) and 0.255 for \(SWIR_{FT}\), the leaf water content index was calculated to evaluate the moisture across the whole city.

Finally, after evaluating three environmental indicators – temperature of surface (TS), normalised difference vegetation index (NDVI) and leaf water content index (LWCI) that measures the moisture of the environment – the EQI (environmental quality index) was estimated, at a neighbourhood level, using multivariate analysis.

4 RESULTS

When deciding which mode of transportation should be taken, the built environment is shown to have an influence. Although existing data for the built environment are available, there are no combined data that provide concrete information for a single type of transportation mode. Taking the bicycle as a specific case, existing data and knowledge
were used to define a bikeability index map as a reference to determine which parts of the city are more suitable for cycling.

Hence, by carrying out empirical research, advanced raster analysis under a geographic information system, and applying the whole methodology explained previously, a heat map was produced for each variable and then combined in a weighted manner. Weighting for variables in Cali was calculated using surveys, focus groups and expert knowledge of local users (Poblacional, 2013). Pertinent geospatial data layers were scored and combined using a flexible weighting scheme to create a composite map highlighting both high and low bikeability areas. A map for the whole of Cali with the index was produced with a value of 1 to 5 for each area of the city based on a grid of 50 metres by 50 metres. A value of 1 represents poor conditions for cycling, while 5 is given to areas where all aspects analysed are at their best.

The bikeability index consisted of four factors shown to influence cycling consistently: slope (12.5%), environmental quality (tree canopy and shaded areas) (24.2%), quality of infrastructure (both in terms of road safety and maintenance) (19.3%) and personal safety (44%).

4.1 Infrastructure results

In terms of infrastructure, in the following streets were found bike paths.

- 70th street 11 avenue: three sections.
- 91st street 28D avenue: one section.
- 28D avenue 72F Street: one section.
- 29th Transversal 44 Street: one section.
- 3N avenue 44 street: one section.
- 2N Avenue Cr 1 and 25 street: one section.
- 13th street between 100 avenue and 70 avenue: two sections.
- Simon Bolívar avenue and 70 street: four sections.
- 5th street between 100 avenue and 52 avenue: five sections.
Figure 2. Cali bike path infrastructure
Figure 3, illustrating the slope map across the whole city, shows that the highest percentage of the city area has mild slopes. This is a positive factor for bicycling in the city.
4.3 Environmental quality

Figure 4 illustrates the environmental quality in the city. As can be seen, the environmental quality around the centre of the city presents loss values due to the lack of vegetation and the significant presence of industry. A contrast is shown in the places outside of the city where the vegetation percentage is higher, as well as being decentralised.
4.4 Security results

Figure 5. Cali security map

Figure 5 illustrates the resulting security levels in the city. Places near the centre of the city have low security levels and the safer places are located in the south and the extreme west of the city.
4.5 Weighted average Cali bikeability index

Figure 6 illustrates the Cali bikeability index map, which is the result of the four maps presented previously multiplied each by the corresponding coefficients calculated from the survey.
5 ANALYSIS AND CONCLUSIONS

The analysis of the resulting bikeability index map for Cali, in which four factors were taken into account (infrastructure, environmental quality, topography and security), suggests that due to the lack of bike path infrastructure, this makes it an unimportant factor in the decision-making of cyclists. Besides infrastructure, the topography of the city is an important factor due to the mild slopes that are present in the city. On the other hand, analysing the environmental quality as well as the security of the city, which shows in general better results in places near the outside of the city, and taking into account that these factors present the highest coefficients in the equation of the bikeability index, it makes the city more bikeable towards the southern and western parts.

A remarkable situation that has to be taken into account is that the highest percentage of trips made is in the direction of the city centre. Hence, it can be concluded that of the citizens of Cali who cycle, they do not have a bikeable city but still choose this mode of transport, which shows a representative percentage in the city due to the advantages that this mode implies.

The bikeability index appears to be a suitable tool to support decision-making, particularly to evaluate the impact of infrastructure planning. The index is more suitable for strategic analysis than the individual evaluation of specific interventions.

Opportunities for future research are in embedding the index in a Decision Support System (DSS). Under such a system, input from the community, proposed investment plans and other topological characteristics can be combined to evaluate proposed interventions, such as a new road crossing, maintenance of an existing off-road path or a new on-road segregated bikeway. The development of this DSS would also require a spatial analysis that incorporates latent demand so investment in cycling takes into account potential new users.

6 REFERENCES


