An Index for Evaluation for Urban Bicycle Lanes

G Pesshana¹, C Romanel², J Novo³

¹ Pontificia Universidad Católica do Rio de Janeiro
² Pontificia Universidad Católica do Rio de Janeiro
³ Pontificia Universidad Católica do Rio de Janeiro

E-mail: gpessanha@hotmail.com, romanel@puc-rio.br, jeannfn@gmail.com

Abstract. Traditionally, the focus of urban transportation design is on motorized vehicles with less attention to green travel alternatives such as cycling. Public policy makers are now trying to increase cycling as a sustainable travel mode due to increasing concerns with respect to environmental pollution, traffic jams and health problems from today's sedentary way of life. In the city of Rio de Janeiro, Brazil, the first bicycle lanes were built in 1991 along the urban seafront for leisure and touristic purposes almost exclusively, but today the city counts on a cycling network of more than 150 kilometres under different conditions of conservation and use by the population. The manner in which this network is designed, built and managed can have a significant effect on the utility and safety of cycling. The primary objective of the current study is to develop a methodology and to propose an evaluation index that could be used as a practical instrument by municipal authorities, transportation planners, traffic engineers and others to determine the quality of bicycle lanes under 14 criteria based on social, technical and environmental aspects. The availability of a such comprehensive index is believed to be a key factor guiding cycle-friendly politics to build more sustainable cities.

1. Introduction
The practice of cycling has been following our civilization for over a century. In recent decades, the so-called developed or developing countries have come to consider the cycling mode in their public policies, especially in urban mobility plans.

In Europe, as an urban phenomenon, the explosion of bicycle use from 1972 to the present day stands out. From 1972 to 1995, there was a 50% increase in the number of trips in former West Germany. Due to problems with congestion on urban roads and the environment in large cities of that country, car use has been reduced and the incentive to practice daily cycling has become a reality for the population.

In recent decades, the application of urban mobility policies by bicycles has gained prominence in the Brazilian scenario, especially in Rio de Janeiro. The history of Rio's bicycle lanes began in 1991, when the first bicycle lanes were built from a program for the redevelopment of the city's waterfront.

In 2008, the Rio de Janeiro city cycling plan had the goal of expanding its 150 km network in 2009 to 450 km by the end of 2016, during which time the city hosted the World Cup mega events and the 2016 Olympics Games. However, a cycling infrastructure is not only sustained by its length, but a set of socio-spatial criteria is required for its effectiveness.
The Ministry of Cities, in its Bicycle Mobility Plan in Cities, states that linking with different transport systems is a key factor for bicycles to be adopted by the population while traveling and that urban infrastructure in cities must adapt to this mode.

The observation of the use of bicycles in large cities, with varied and constantly changing technologies and organizations, was the starting point of the research that used a bibliographic review in search of concepts and methods of evaluation of the service level and the quality of the bicycle lanes and cycle tracks.

There are several bicycle lane settings, depending on their applications. Similarly, the concepts of service level and the qualitative evaluation applied to these infrastructures also vary. For this research, these concepts follow those of large metropolises around the world with characteristics of planned cities and contribute to a new concept, built here, called Viable Bicycle Path.

Once the new concept is defined, it is now feasible to develop a model capable of aggregating relevant information for the assessment of bicycle paths. Therefore, after surveying studies on national and international bicycle-related indexes, Brazilian technical standards and norms and urban elements necessary for the formation of a viable bicycle path, this research presents a methodological design with several elements (dependent and independent variables) that represent the landscape around bicycle paths in neighbourhoods of the city capital.

1.1. Objective

In search of a conceptual model that supports indicators for the evaluation of the quality of a useful, ecological and safe bicycle path, according to the social, environmental and technical dimensions, the general objective of this research is to develop a methodology and to propose an evaluation index that could be used as a practical instrument by municipal authorities, transportation planners, traffic engineers and others to determine the quality of bicycle lanes under 14 criteria based on social, technical and environmental aspects.

This objective is intended to be achieved by means of a conceptual model that serves as the basis for the evaluation of a cycle path that meets the minimum needs of its users and also enables the elaboration of a synthetic indicator called the Viable Bikeway Index (VBI), which may subsidize diagnoses, choice of priorities and decision-making to the public manager for the correct construction and maintenance of adequate bicycle lanes.

2. General plan of research

Regarding the purpose, this research is applied in nature, since it is related to the observed reality and offers tools for timely improvement interventions to public managers. In relation to the procedures used, it is exploratory, as it seeks new approaches to understand and modify urban problems, and revert to a qualitative approach aiming to define the characteristics of a viable bike path in a metropolitan urban area, considering as viable a way that includes the social, technical and environmental dimensions represented by 14 variables.

Therefore, it was considered as viable bike path that meets some minimum normative and technical criteria listed in this research. The concept of viable bike path seeks to meet the respective criteria in the social, technical and environmental dimensions and be appropriate to the reality of the municipal management body dedicated to the conservation of cycle paths with a view to efficient management of operational and conservation demand imposed by users.

According to figure 1, the methodological model accommodates the concepts studied to achieve the intended objective. Recent methods for assessing the quality of service levels of cycle lanes and lanes in several countries were reviewed, and some of these were chosen that most closely match the characteristics of the city of Rio de Janeiro.

After defining the methods that best fit the characteristics of bicycle lanes in urban areas in metropolises, it was necessary to investigate how to combine these methods with evaluation criteria. The gathering of these main methods was of great value for the development and refining of the proposal of a specific method of qualitative evaluation of the Rio de Janeiro cycle paths. Indicators
were created based on normative variables and technical variables that compose indexes with the perspective of dimensions.

With the observation in the field of 3 busy bicycle lanes in the South and West Zones of the city of Rio de Janeiro, it was possible to register values for variables related to the main elements that, in this research, compose an indicator that qualifies the urban bicycle lanes by 14 indicators distributed in 6 themes and 3 dimensions.

The results of the field application are shown here where each observed segment receives an evaluation score of the Viable Bike Path Index or VBI and using an arithmetic mean between the sections on the same bicycle path reaching the VBI of the evaluated bicycle path.

**Figure 1. Plan of research. Source: Own Authorship**

3. The Viable Bike Path Index and its dimensions (VBI)
After in-depth research into the three evaluation methods, technical standards, master's dissertations, and scientific papers, the need to shape the scope of these methods and obtain some variables in indicators has been identified.
Indicators can be defined as models, imperfect representations of reality. Influenced by the subjectivity of their creator, they are a quick way of portraying the real world from a certain perspective and at a given moment. They were categorized into dimensions. The Viable Bikeway Index (VBI) is an approach for direct measurement of infrastructure bicycle path quality and other aspects from selected indicators in three dimensions and 6 themes defined. The justification of this model is based on the context that with the unbridled growth of the big metropolises, the bicycle lanes will have a great role as integrator modal and it is necessary to have a more realistic evaluation method and adapted to the real conditions of the streets, lanes and bicycle lanes.

The basic structure of the VBI has 3 layers as follows: VBI – level zero, which corresponds to the Analytic Structure Level in the index, which synthesizes the highest hierarchy level and should be on the normalized scale between 0 and 1; Dimensions - level 1, which corresponds to the Analytical Structure Level in the Dimensions, which summarizes the level of subordination between the VBI and the Dimensions; Themes - level 2, which corresponds to the Analytical Structure Level in the Themes, which summarizes the level between the Dimensions and the Indicators; Indicators - level 3, which corresponds to the Analytical Structure Level in the Indicators, which summarizes the lowest level of layers in the VBI Graphic Structure.

The three dimensions have results ranging from 0 (worst) to 1 (best); a sum between the three derives the index, which therefore also ranges from 0 to 1. The arithmetic mean rule between the levels of the index analytic structure is applied successively from the last level to the first level.

3.1. Technical dimension
The diversity of bicycle paths and bicycle lanes in the city of Rio de Janeiro is considerable. There are unidirectional, bi-directional bicycle lanes, bicycle lanes dividing the road with cars among other models that have been adapting according to the local condition of the cycling mode.

Among the service level and infrastructure quality evaluation methods raised in this research, some criteria that it is considered basic to evaluate the quality of a bicycle path were chosen, such as: bike lane width, illumination and conservation.

3.2. Social dimension
It is the obligation of the city of Rio de Janeiro to offer and maintain safe and viable bicycle paths to provide a healthy mode for the Rio de Janeiro population and to promote their well-being. In this dimension, the focus was also on the bicycle path, verifying the policies of local applied education and constructive parameters around the bike path to better adapt the population with reduced mobility.

Among these parameters were for example observed the type of pavement and whether there is a sound signal for pedestrian crossing.

3.3. Environmental dimension
The Copacabana neighbourhood, like other neighbourhoods in the south and west of Rio de Janeiro, has a large concentration of people and vehicles. The neighbourhood is characterized by the large number of shops and the hotel business is also prevalent in the region.

The bike lanes studied are close to main roads where cars and dozens of bus lines are the main source of pollution.

Thus, measuring air polluting components is fundamental for the environment that the cyclist circulates and other users of the transport systems that feed the region.

3.4. Likert scale
The most widely used and debated model among researchers was developed by Rensis Likert to measure attitudes in the context of behavioural cities (Costa, 2014).

In the table 1, a model of the Likert scale is exemplified:
The table above shows a scale for measuring service evaluation at 5 distinct points. In his published study, Dalmoro (2008) sought to evaluate the influence of the number of items on the Likert scale and the effect of scale arrangement on the results of a measurement and came to some conclusions to highlight:

- In terms of the ability to express the opinion accurately, the three-item scale has the worst results. Should be deprecated in relation to the five- and seven-point scales;
- The five- and seven-point scales are very similar in terms of average results. The choice may depend on subjective factors such as subject complexity and number of questions.

Thus, it is possible to find in the literature articles that point to different ranges of scale. In this context of the research, there is no single theoretical framework that states that the number of points on the scale is correct with 3, 5, 7 or 10 points on the scale. What we can affirm is that two points of the scale with positive evaluations, two points with negative evaluation and 1 neutral point, facilitates the user of the scale in evaluating the various criteria in this context of the urban bike path.

### 3.4.1. Scale Normalization

As the final objective of the research is to have XY plotted graphs, normalization is necessary for scale adaptation.

The formula to apply to the VBI table for normalization is:

\[
(Z_i^k)_N = \frac{Z_{ki} - Z_{kmin}}{Z_{kmax} - Z_{kmin}}
\]

(1)

The above formula refers to an attribute \( k \), where alternative \( i \) has the value \( Z \) which may range from \( k \) to \( i \), where:

- \( (Z_i^k)_N \) = transformed value of the \( i \)-th observation of variable \( K \)
- \( Z_{ki} \) = observed value
- \( Z_{kmin} \) = lowest observed value
- \( Z_{kmax} \) = maximum value of variable \( K \)
- \( Z_{kmin} \) = minimum value of variable \( K \)

Based on the viable cycleway model proposed in this research and based on the criteria selected in this research, the problem was equated in a formula with 6 terms.

The criteria and quality indicators of bicycle lanes and cycle lanes selected in each dimension have a score for the calculation of the index, according to the following equation:

\[
VBI = \frac{\sum Proj - 4}{16} + \frac{\sum Obra - 1}{8} + \frac{\sum Elem. - 2}{8} + \frac{\sum MA - 1}{4} + \frac{\sum Amp. - 2}{13} + \frac{\sum Acess. - 1}{7}
\]

(2)

number of themes applied

### 3.5. VBI analytical framework and its criteria

Below is the table of the VBI with its criteria and respective evaluation scales:
### Table 2. Analytical framework of the VBI and its criteria

| Dimensions | Theme | Indicator | Criteria | Points of scale | Option for evaluation |
|------------|-------|-----------|----------|-----------------|-----------------------|
| Technical  | Project | Width of the bicycle lane | Less than 1,10 m | 0 | Unique Choice |
| | | | Between 1,11 e 1,30 m | 2 | |
| | | | Between 1,31 m e 1,40 | 3 | |
| | | | Between 1,41 e 1,50 | 4 | |
| | | | More than de 1,50 m | 5 | |
| | Lighting | Tree canopy preventing incidence of illumination | -2 | Multiple Choice |
| | | Less than 3 lux | -1 | |
| | | From 3 to 5 lux | 2 | |
| | | More than 5 lux | 3 | |
| | Project | Portion of lanes with sidewalk | Less than 80% of the road | 0 | Unique Choice |
| | | | Between 81 and 99% | 1 | |
| | | | 100% of the road | 2 | |
| | Construction | Conservation | Slope on the track | -4 | Multiple Choice |
| | | | Traffic light with burned lamp | -3 | |
| | | | Horizontal Signage in Faulty Ink | -2 | |
| | | | Cracked floor | -1 | |
| | | | Bike path in perfect condition | 1 | Unique Choice |
| | | Bicycle deaths | Between 0 and 0,5 | 1 | |
| | | | Between 0,6 and 1 | 0 | |
| | | | More than de 1 | -1 | |
| | Environmental Mitigating Elements | Bicycle path extension with trafficalming | Not applied when needed | 0 | Unique Choice |
| | | | Partially applied as needed | 1 | |
| | | | Applied when needed | 2 | |
| | | Resident population with access to green or recreational areas | No access at all | 0 | |
| | | | With access to green areas / recreation above 500 m | 1 | Unique Choice |
| | | | Access to green areas / recreation below 500 m | 2 | |
| | Environment | CO2 emission | 9 ppm for 8-hour average concentration | -1 | Unique Choice |
| | | | Above 9 ppm for 8-hour average concentration | 1 | |
| | Social | Bike Path Extension | Bike path extension is over 80% of the main thoroughfare of the neighbourhood | 2 | Unique Choice |
| | | | Bike path length is over 50% and below 80% of the main thoroughfare of the neighbourhood | 0 | |
4. Results
The following shows the numerical results obtained by applying the BVI table. It is important to reinforce that the 3 observed cycle paths were divided into sections so that the research had a larger amount of values to collect and use.

4.1. Leme – Copacabana bicycle path
Thus, the whole bike lane VBI was obtained:

\[
VBI = \frac{(VBI_{section1} + VBI_{section2} + VBI_{section3})}{3} = \frac{(0.67 + 0.66 + 0.66)}{3} = 0.66
\]  

(3)

The VBI rating scale score for the Leme-Copacabana bike path was very high, with at least 0.50 for all sections. Therefore, the bike path can be considered viable.

4.2. Flamengo bicycle path
The VBI of the entire bike path was then obtained:

\[
VBI = \frac{(VBI_{section1} + VBI_{section2} + VBI_{section3})}{3} = \frac{(0.67 + 0.65 + 0.67)}{3} = 0.66
\]

(4)
The VBI rating scale for the Aterro do Flamengo bike path was also very high, with at least 0.60 for all stretches. Therefore, the bike path may be viable for use according to BVI criteria.

4.3. Barra da Tijuca bicycle path

Then, the whole bike path VBI was obtained:

$$\text{VBI} = \left( \frac{VBI_{\text{section 1}} + VBI_{\text{section 2}} + VBI_{\text{section 3}} + VBI_{\text{section 4}} + VBI_{\text{section 5}}}{5} \right) = 0.63$$

As shown numerically, all bike paths were considered viable but with improvements to be implemented and with a state of conservation that needs more attention in everyday life.

4.4. Indexes behaviour per section and bicycle path

Regarding to the graphic 1, the 2 worst indicators evaluated were bike rack and lighting. Already the indicators that evaluate the geometric parameters had a good evaluation due to their width and extension by all the observed neighborhoods. An improvement to be urgently implemented is the adaptation of the access ramps to the bike path or sidewalk for people with reduced mobility, such as the installation of sound signals for crossing. As for the indicator on CO2 pollution, the levels are still within the acceptable range and the fact that observing sections are in large open areas with high ventilation, facilitating the dispersal of pollution. To conclude with the conservation indicator, which ranged from grade 1 to grade 2, considered low and medium grades, it is worth mentioning a continuous and more effective improvement is necessary. Cracks in the floor, poorly talked about kerbs and signs needing painting were the most observed features.

**Graphic 1. Indicators behaviour x bicycle path and its section**
5. Conclusion
Urban mobility and the use of the bike path is a topic that is under discussion among users, wheeled equipment suppliers and the public manager. The Viable Bikeway Index (VBI) was introduced in this paper with the objective of serving as a tool for municipal managers to diagnose and monitor the quality of bicycle path infrastructure in an urban environment. During the literature review, research was found on bicycle users and their needs. However, no research was found to cover the social, environmental and technical aspects that involve the cycling infrastructure for a comparative analysis.

The index was established based on various indicators related to the technical, social and environmental dimensions and gathered into 6 themes.

VBI is simple and quick to apply to a bike path. It is intended to be a useful tool for the managing bodies that manage the bike lanes of the city of Rio de Janeiro and its surroundings, and to draw a diagnosis with the main conversation parameters of a public cycle path in an urban environment.

References
[1] Associação Brasileira de Normas Técnicas. NBR 9050: Acessibilidade a edificações, mobiliário, espaços e equipamentos urbanos. Rio de Janeiro, 2004.
[2] CERVO, A.L. e BERVIAN. P. A. Metodologia Científica. 3ª ed..São Paulo, Ed. Mc Gran-Hill,1983.
[3] Mensuração e Escalas de Verificação: uma Análise Comparativa das Escalas de Likert e Phrase Completion. 2014. SDS JÚNIOR, FJ COSTA - PMKT–Revista Brasileira de Pesquisa de Marketing.