

MULTI-CRITERIA EVALUATION OF THE BICYCLE PATHWAYS IN CARAGUATATUBA, BRAZIL

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Abstract

Caraguatatuba, the most populous municipality on São Paulo's northeastern coast, experiences high travel demand. Despite gaps in public transport coverage, the city's flat topography encourages intensive bicycle use. This study evaluates the efficiency and technical limitations of Caraguatatuba's cycling infrastructure by developing a quantifiable performance index. A survey with 70 users was conducted to determine the key criteria that affected their cycling experience. A cognitive mapping approach supported the criteria selection, later refined through expert consultation using the Delphi method. Criteria were weighted using the Analytical Hierarchy Process (AHP), and efficiency scores were assigned to 100-meter segments along major cycling routes using Geographic Information Systems (GIS). Results indicate that 47% of the network falls within a medium-efficiency range (index scores between 3.1 and 4.0). Higher-performing segments were primarily located along the seaside avenue, while lower scores were observed in southern areas with greater social vulnerability and less tourist activity. Deficiencies in maintenance and drainage were the most significant contributors to reduced infrastructure quality in these areas. The study offers a replicable framework for evaluating cycling infrastructure, which can assist urban managers in prioritizing investment and improvement strategies. It contributes to the broader goal of increasing cycling mode share and enhancing the overall efficiency and equity of urban transport systems.

Keywords: Cycling way; urban management; multicriteria analysis; decision making; urban infrastructure maintenance.

1. INTRODUCTION

In urban areas, vehicle congestion is an everyday situation fact of life. In addition, this excess of automotive vehicles is associated with environmental, health and safety increasing the concerns of the population for individuals and governments alike (Abadi and Hurwitz, 2018). Most of the world's population live in cities where urban transport alternatives — including public and active transport — are not fully developed. Moreover, to improve the economy and social development of these places, investments in transport infrastructure is essential (Rockwood and Garmire, 2015).

Enabling bicycle journeys is a key tool to increase of sustainable mobility in cities is related to the use of bicycles. Another way to maximize transport system efficiency the transport system is to create an integration between the mass transit system and non-motorized means of transport. Because of this integration, it is possible to improve the quality of urban life and offer more social equality to the local communities (Monteiro and Campos, 2011).

Currently, 55% of the world's population lives in urban areas and this proportion is expected to increase to 70% by 2050 (United Nations, 2020). One of the sustainable Development Goals (SDGs) is to promote more sustainability in cities, including the mobility process in urban mobility. The Urban sustainable transportation policy is related to the citizens' rights and aims to respond to the needs of society at the economic, social and environmental levels. However, without interfering in a citizen's right which is mobility (Castañón, 2011).

In Brazil, a few studies regarding the mobility by the use of bicycles revealed that the main initiatives have been in the City of Rio de Janeiro and Curitiba, State of Parana (Medeiros and Duarte, 2014; Procopiuck et al. 2021; Tucker and Manaugh, 2017). The lack of public policies causes a situation of semi-marginality for the users (Geopot, 2011). The National Urban Mobility Policy (Brazil, 2012) aims to integrate the different modes of transport and improve accessibility across the country. According to this law, it is foreseen that the municipalities must elaborate the develop local Urban Mobility Plans and include the bicycle infrastructure in plans, integrated with the other transportation modes (Brazil, 2012).

Bicycles are one of the most used individual vehicles transport modes in small urban centers. This is because in these places, the public transport is not accessible and one of the transportation alternatives for the population is the use of bicycles (Geopot, 2011).

Teschke et al. (2012) compared the types of routes and infrastructure resources for bicycles with the risks of injuries in Canada. The authors concluded that the route infrastructure, when properly designed, avoids the risk of accidents to users. Thus, the study demonstrates the importance of a good bicycle network.

Multicriteria methods combined with geographical information systems (GIS) have been widely used by urban planners for the decision-making processes (Guerreiro et al., 2017; Hrnir et al., 2017; Maciel and Freitas, 2016; Zuo and Wei, 2019) due to the possibility of processing a significant amount and variety of data. This assists in the development of bicycle networks and informs the decision making process as to where investment is needed.

The purpose of this study is to develop a methodology that is able to evaluate the efficiency of a bicycle network by the use of a combination of indicators that when associated result in an overall index. The case study is in the City of Caraguatatuba, State of São Paulo, Brazil. A multicriterial analysis is used for the development of this study based on the Delphi-AHP approach proposed by Boulomytis et al. (2019) and Boulomytis et al. (2024).

2. MATERIALS AND METHODS

2.1. Study area

The City of Caraguatatuba is located on the northeastern coast of the State of São Paulo, and has a population of 119,625 residents. In Figure 1 it is possible to observe that the altitude of the city of Caraguatatuba is low and very close to the sea level. The city's flat topography is conducive to daily use of the bicycle as a means of transportation.

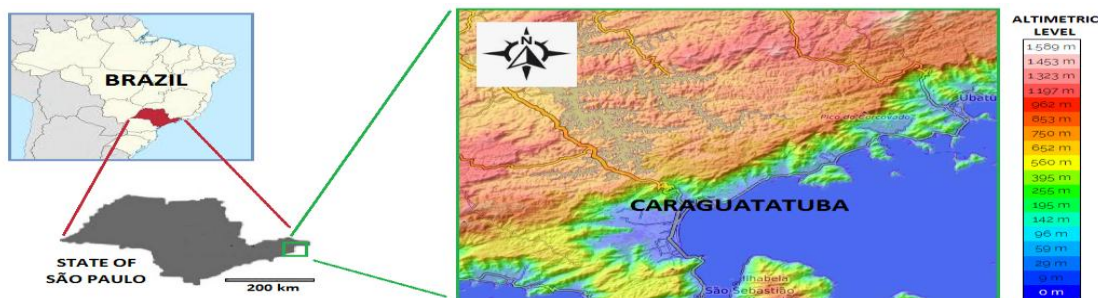


FIGURE 1- MUNICIPALITY OF CARAGUATATUBA. SOURCE: AUTHORS.

Caraguatatuba is a tourist city and therefore, there is a large amount of floating population. The climate is tropical with significant rainfall throughout the year. The average annual temperature is 25 °C, and the average annual precipitation is 1,652 mm, predominately influenced by orographic rainfalls (Boulomytis et al., 2016; Boulomytis et al., 2017).

2.2. Methodology

2.2.1. Initial survey with users

The first part of this study was an online survey, using Google Form, with the users of the Caraguatatuba bicycle network. The form was answered anonymously and the target audience of the research was the IFSP students, between 16 and 52 years old, from professional to undergraduate

courses. This target audience was chosen because they use the bike paths and lanes every day to move around the city, from different locations and time periods - including the suburban areas early in the morning and late at night. The reason for choosing this is public is that it reflects a more reliable user experience than only by targetting people who occasionally use their bicycles for leisure. The survey was carried out for a month in 2018 and had 70 participants who defined the key factors that influenced their cycling experience. The purpose of the questionnaire was to determine the technical parameters that affect the quality of the bicycle network.

2.2.2. Definition of the analyzed criteria

After conducting the survey, all the data were analyzed. Based on the results, the factors assessed on the local bicycle network were determined. In the literature, several authors use different methods and criteria to analyze the specific bicycle network. Each of the criteria was chosen based on the characteristics of the places studied, according to Keeney (1992), where consistent criteria must be essential, independent, controllable, operational, decomposable, non-redundant, complete, measurable, concise and understandable. A cognitive map was developed to subsidize this part of the study.

2.2.3. Conference with experts

In this stage, a conference was carried out with experts so that the parameters could be properly ranked. The interview took place in 2019. The first step was to select the appropriate experts to be part of the conference including professional and amateur cyclists, traffic agents, engineers and technicians.

At the conference, we mentioned what the purpose was and how the criteria would be ranked. The experts assigned scores from 0 to 10 for the criteria individually, according to the degree of importance. The selected and weighed criteria were: drainage, integration, light, maintenance, planning, safety, signaling, and paving. The Delphi expert-survey method was used for the data treatment (Figure 2).

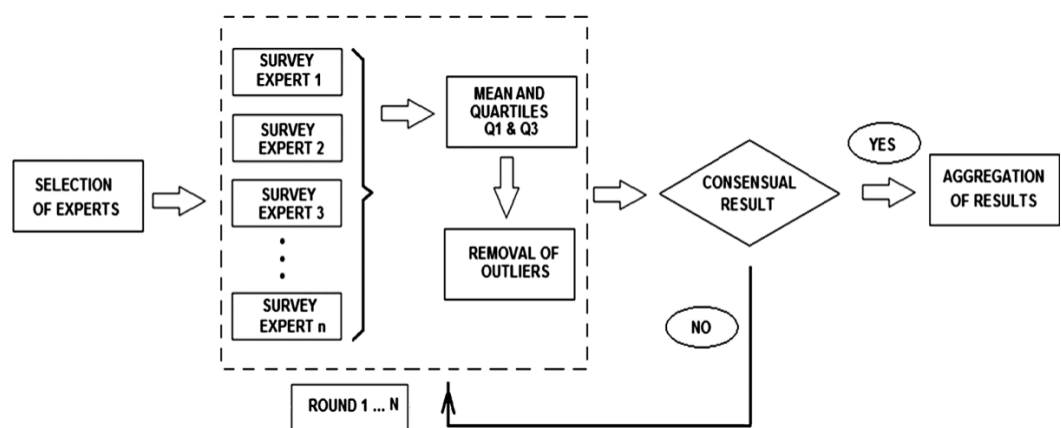


FIGURE 2 - CONFERENCE WITH THE BICYCLE NETWORK EXPERTS. SOURCE: BOULOMYTIS ET AL. (2019).

2.2.4. Bicycle network assessment

Based on the criteria attribution, an on-site verification along the bicycle network was carried out to determinate the exact situation accurately survey the bike paths and numerically qualify their features. For the data analysis, the paths were divided into three parts (CBD area, along the highway and along the sea) and the respective subsections. The allocation of grades was based on literature review. The grade was given on a scale of 1 to 5, where 1 was considered “insignificant” and 5 was “very good”.

2.2.5. Method AHP

The Analytic Hierarchy Process (AHP) was used at the study to rank the criteria in a prioritisation mechanism of pairwise comparisons. The root square judgment scale was adopted according to Boulomytis et al. (2019). One of the advantages of the AHP is the use of a consistency analysis for evaluate the results (Boulomytis et al. 2019).

The AHP assessment is performed with the comparison of the pairs of matrix A (n x n), given by:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} = \begin{bmatrix} z_1/z_1 & \cdots & z_1/z_n \\ \vdots & \ddots & \vdots \\ z_n/z_1 & \cdots & z_n/z_n \end{bmatrix}$$

The matrix highest eigenvalue (λ_{max}) is calculated by:

$$\lambda_{max} = \sum_{i=1}^n (Av)_i / (nv_i)$$

And the definition of the consistency index (CI), as expressed by:

$$CI = (\lambda_{max} - n) / (n - 1)$$

To improve the evaluation of consistency errors, the measure of the consistency index (CR) is used, RI being the random index. The best solution would be to

CI = 0. Thus, consistent values correspond to CR < 1.

$$CR = CI/RI$$

2.2.6. Efficiency Index

The data was spatialized by the use of the ArcGis software version 10.3. Thematic maps were generated for each of the eight criteria used, based on the classification of the bicycle network subsections. The Efficiency Index was derived for each segment of the bicycle network using the weighted average. This measure aimed to optimize the comparison among the sections of each individual criteria.

3. RESULTS AND DISCUSSION

3.1. Attribution of Criteria

The online questionnaire had 70 participants. They were students from the Federal Institute of Education, Science and Technology of São Paulo, Campus Caraguatatuba, from Civil Construction Technology and Bachelor of Civil Engineering programs.

Respondents indicated that with better infrastructure conditions, they would use the bicycle more as a means of transport. About 67.1% suggested improvements in paving, drainage, maintenance, signaling and safety.

From The collected data, it was possible to verify indicates that the bicycle network in Caraguatatuba is widely used, but it needs improvements in all parameters covered by the study. A cognitive map was drawn for the understanding of the connection among the proposed criteria and the problem statement (Figure 3) and the conditions of Kenney (1992), were properly analyzed. The final attributed criteria were: drainage, integration, light, maintenance, pavement, planning, safety and signaling.

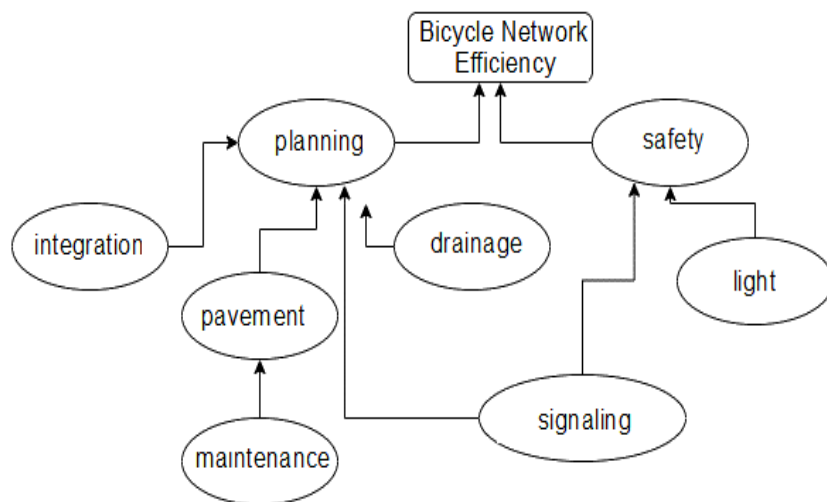


FIGURE 3 - COGNITIVE MAP WITH THE CRITERIA PROPOSED IN THE SURVEY. SOURCE: AUTHORS.

3.2. Attribution of scores

The total number of experts who attended the decision-making conference was 12 (twelve), comprising professional and amateur cyclists, traffic agents, engineers and technicians. They assigned scores according to the degree of importance considered for each of the parameters. The scores were treated using the Delphi method (Table 1).

TABLE 1 – DELPHI METHODOLOGY TO TREAT THE SCORES FROM THE DECISION-MAKING CONFERENCE.

1st round	1	2	3	4	5	6	7	8	9	10	11	12	Average	Q1	Q3
Pavement	7	9	7	8	10	9	8	9	10	9	10	8	8,67	8,00	9,25
Light	6	8	10	8	7	7	7	8	10	10	8	5	7,83	7,00	8,50
Safety	8	10	8	10	10	9	9	10	10	8	9	6	8,92	8,00	10,00
Signalling	6	8	9	8	8	8	8	10	9	8	10	7	8,25	8,00	9,00
Drainage	6	10	8	8	6	7	7	7	10	9	10	9	8,08	7,00	9,25
Maintenance	8	8	10	8	8	9	9	8	10	9	10	3	8,33	8,00	9,25
Planning	10	10	8	8	5	10	9	7	9	10	10	10	8,83	8,00	10,00
Integration	9	7	5	10	4	8	10	8	9	7	10	4	7,58	6,50	9,25

2nd round	1	2	3	4	5	6	7	8	9	10	11	12	Average	Q1	Q3
Pavement		9		8		9	8	9		9		8	8,57	8,00	9,00
Light		8		8	7	7	7	8			8		7,57	7,00	8,00
Safety	8	10	8	10	10	9	9	10	10	8	9		9,18	8,50	10,00
Signalling		8	9	8	8	8	8		9	8			8,25	8,00	8,25
Drainage			8	8		7	7	7		9		9	7,86	7,00	8,50
Maintenance	8	8		8	8	9	9	8		9			8,38	8,00	9,00
Planning	10	10	8	8		10	9		9	10	10	10	9,40	9,00	10,00
Integration	9	7				8		8	9	7	10		8,29	7,50	9,00

3rd round	1	2	3	4	5	6	7	8	9	10	11	12	Average	Q1	Q3
Pavement		9		8		9	8	9		9		8	8,57	8,00	9,00
Light		8		8	7	7	7	8			8		7,57	7,00	8,00
Safety		10		10	10	9	9	10	10		9		9,63	9,00	10,00
Signalling		8		8	8	8	8			8			8,00	8,00	8,00
Drainage			8	8		7	7	7				9	7,67	7,00	8,00
Maintenance	8	8		8	8	9	9	8		9			8,38	8,00	9,00
Planning	10	10				10	9		9	10	10	10	9,75	9,75	10,00
Integration	9					8		8	9				8,50	8,00	9,00

4th round	1	2	3	4	5	6	7	8	9	10	11	12	Average	Q1	Q3
Pavement		9		8		9	8	9		9		8	8,57	8,00	9,00
Light		8		8	7	7	7	8			8		7,57	7,00	8,00
Safety		10		10	10	9	9	10	10		9		9,63	9,00	10,00
Signalling		8		8	8	8	8			8			8,00	8,00	8,00
Drainage			8	8		7	7	7				9	7,67	7,00	8,00
Maintenance	8	8		8	8	9	9	8		9			8,38	8,00	9,00
Planning	10	10				10				10	10	10	10,00	10,00	10,00
Integration	9					8		8	9				8,50	8,00	9,00

SOURCE: OWN PROCESSING.

There were 4 rounds and the final score of the parameters, from the most important to least important, was: planning; safety; pavement; integration; maintenance; signaling; drainage; light (Table 2).

TABLE 2 - FINAL CRITERIA SCORE AND HIERARCHY.

Order of Importance	Score	Criteria
1	10.00	Planning
2	9.63	Safety
3	8.57	Pavement
4	8.50	Integration
5	8.38	Maintenance
6	8.00	Signalling
7	7.67	Drainage
8	7.57	Light

SOURCE: OWN PROCESSING.

3.3. Criteria qualitative features

Factors such as the location of bicycle paths and lanes, demand and safety are requirements that must be considered when planning a road. A bicycle path or lane planning enhances the areas in which the implementation of infrastructures for the circulation of cyclists must occur. The term 'bicycle infrastructure' includes on-road lanes, off-road paths, parking hoops, and underground walkways, among others (Monteiro, 2011). When designing bicycle infrastructure in a city, key factors to be taken into account include the suitable location of bicycle paths and lanes, potential demand, integration with

other transport modes, and safety considerations. So proper planning was considered what mostly influenced the performance of the bicycle pathways by the experts.

Paving can be described as one of the essential factors to ensure good conditions for the circulation of users. Factors such as cracks, patches and holes in the pavement to calculate the Road Condition Index based on the condition of the bicycle path pavement. This method evaluates each road segment with homogeneous geometry and traffic conditions (Epperson, 1994).

The basic requirements for paving a bicycle network are regular surface for the bearing, waterproof and non-slip. Preferably, the bike path and pedestrian walk should have visual differences, to avoid accidents. It is possible that the bicycle is used to integrate the different modes already present in cities, such as buses, trains and subways. In this way, it will be possible to improve the urban quality of life of all segments of society (Monteiro, 2011).

In the drainage criterion, drainage must be natural. Therefore, the lateral slope of the runway is 2%, always to the side of the existing tracks. An important aspect is the position of the drops in the manhole, which should not be positioned along the road, but on the sides, so that accidents would not occur with cyclists (Monteiro, 2011).

Caraguatatuba is a low-lying area that presents a high incidence of rainy days throughout the year, primarily driven by orographic conditions. Even though drainage is complex in the area, the experts considered that planning would mostly interfere in the local condition of the pathway throughout the entire year, and not only when it is in the rainy season.

TABLE 3- CONSIDERATIONS FOUND IN LITERATURE ABOUT THE BICYCLE NETWORK DEMANDS.

Literature	Consideration
Monteiro and Campos (2011)	Location Ease and comfort for the cyclist Accessibility and mobility Safety Security
Highway Capacity Manual (TRB, 2000)	Flow Speed Density of vehicle entrances
Dixon (1996)	Cyclist facilities Conflicts between cyclists and drivers Unobstructed visibility distance Improvements to intersections for cyclists Speed difference between vehicles and bicycles Motor vehicle volume Maintenance Programs for the improvement of bicycle transport
Botman (1995)	Traffic volume Overtaking frequency
Epperson (1994)	Road characteristics (paving, number of lanes, speed, width) Traffic volume Location
Landis (1994)	Traffic volume Track characteristics (speed and width)

SOURCE: OWN ELABORATION.

The safety of cyclists is one of the factors that must be taken into account when analyzing Brazilian bicycle paths. And key methods by which this can be evaluated include the distance between cyclists and the flow of motor vehicles, and as well as the ability of entry for vehicles to enter or cross over the cycle path, are variables that should be used as determinants in this index (Monteiro; Campos, 2011).

The maintenance of the roads is determined by the physical conditions of the road, noting abandonments or construction deficiencies. A scoring system was based established on variables according to the frequency of problems, namely: frequent; not too often; smoothly to classify this factor (Dixon, 1996).

Cycle paths must have vertical and horizontal signs. Vertical signage is represented by signs, which inform users about the particularities of the road. The horizontal signage is represented by paintings on the floor, through banners and drawings. The lighting of the lanes must guarantee the comfort and safety of cyclists. It ensures that motor vehicles are aware of the cyclist's presence and provides more safety to cyclists, preventing robberies (Monteiro, 2011). Table 3 presents different methods and analysis found in the literature regarding the analysis of bicycle network.

3.4. *On-site assessment for the qualification of the criteria*

For the analysis of drainage, paving, lighting, safety and signaling, the frequency of occurrence of anomalies during the subsections was taken into account. This analysis was done because these parameters are measurable. The analysis was carried out on the total of 31.76 km of the considered bicycle network. Table 4 presents the specifications used for these criteria in the validation of the excerpts.



FIGURE 4 - THE BICYCLE NETWORK FEATURES ON-SITE.

SOURCE: OWN ELABORATION. BACKGROUND PHOTO FROM GOOGLE (2022).

The analysis of qualitative parameters, planning, maintenance and integration was performed in a different way. They were classified as very bad, bad, average, good and very good, from 1 to 5, respectively. The features assessed on-site are presented Figure 4, except from the light, which depended on the presence or absence of poles and distance between them.

TABLE 4 - QUANTITATIVE FEATURES OF THE CRITERIA ASSESSED ON-SITE.

Mark	Indicator	Feature
1	P a v e m e n t	Totally imperfect, holes larger than 60 cm in length, every 200 meters
2		Numerous imperfections, holes between 45 and 60 cm in length, every 350 meters
3		Few imperfections, holes between 30 and 45 cm in length, every 500 meters
4		Spot imperfections, holes below 15 cm long, every 650 meters
5		Track without imperfections, no holes
1	L i g h t i n g	Absence of poles
2		Numerous imperfections, 10 poles running every 300 meters
3		Few imperfections, 10 poles running every 250 meters
4		Spot imperfections, 10 poles running every 200 meters
5		No imperfections, 10 poles running every 150 meters or less
1	S a f e t y	Unsafe track, with car entrance, lowered guide, without indentation with the track
2		Track with low security, high contact with the street, less than 1 meter of retreat from the track
3		Track with medium security, medium contact with the track, between 1 and 2 meters of retreat from the track
4		Track with high security, little contact with the track, between 2 and 4 meters of retreat from the track
5		Totally safe track, without contact with the track, more than 4 meters from the track
1	S i g n a l i n g	Runway without horizontal and vertical signage, no crosswalk, no painting
2		Track with low horizontal and vertical signs, pedestrian crossing and painting every 500 meters or more
3		Lane with regular horizontal and vertical signage, pedestrian crossing and painting between 350 and 500 meters
4		Lane with medium horizontal and vertical signage, pedestrian lane and painting between 200 and 350 meters
5		Track with good horizontal and vertical signage, crosswalk and painting every 200 meters or less
1	D r a i n a g e	Abundant flooding points, absence of stormwater pits.
2		High flooding points, at least 1 stormwater pit every 600 meters
3		Average flooding points, at least 1 stormwater pit every 450 meters
4		Low flooding points, at least 1 stormwater pit every 300 meters
5		No flooding points, at least 1 stormwater pit every 150 meters or less

SOURCE: OWN ELABORATION.

3.5. Criteria Individual Scores

The extended AHP approach was carried out, which generated the pairwise comparison matrix with the root square judgement scale (Zuffo, 2011; Boulomytis et al. 2019). The other AHP steps were conducted to obtain the normalized weight. The consistency Index was 0.03 and the consistency ratio was 0.02. Thus, both presented consistent results as they were less than 0.1 (shown in Table 5).

3.6. Development of individual criteria maps

Based on the quantitative features of the criteria, the bicycle network was analysed and classified. Figure 5 presents the result of this analysis and which situations were considered according to the featured conditions.

TABLE 5 - RESULTS OF THE PAIRWISE COMPARISON CARRIED OUT IN THE STUDY.

AHP extended approach of Zuffo (2011)	Planning	Safety	Pavement	Integration	maintenance	Signalling	Drainage	Light
	10,00	9,63	8,57	8,50	8,38	8,00	7,67	7,57
Planning	0,00	0,37	1,43	1,50	1,62	2,00	2,33	2,43
Safety		0,00	1,06	1,13	1,25	1,63	1,96	2,06
Pavement			0,00	0,07	0,19	0,57	0,90	1,00
Integration				0,00	0,12	0,50	0,83	0,93
Maintenance					0,00	0,38	0,71	0,81
Signalling						0,00	0,71	0,81
Drainage							0,00	0,81
Light								0,00

Pairwise Comparision Matrix	Planning	Safety	Pavement	Integration	maintenance	Signalling	Drainage	Light
Square root judgement scale	10,00	9,63	8,57	8,50	8,38	8,00	7,67	7,57
Planning	1,000	1,732	2,450	2,450	2,646	2,828	3,000	3,000
Safety	0,577	1,000	2,236	2,236	2,450	2,646	2,828	2,828
Pavement	0,408	0,447	1,000	1,414	1,414	1,732	2,000	2,236
Integration	0,408	0,447	0,707	1,000	1,414	1,732	2,000	2,236
Maintenance	0,378	0,408	0,707	0,707	1,000	1,732	2,000	2,000
Signalling	0,354	0,378	0,577	0,577	0,577	1,000	2,000	2,000
Drainage	0,333	0,354	0,500	0,500	0,500	0,500	1,000	2,000
Light	0,333	0,354	0,447	0,447	0,500	0,500	0,500	1,000

Normalized S'	3,79	5,12	8,62	9,33	10,50	12,67	15,33	17,30
Planning	0,264	0,338	0,284	0,262	0,252	0,223	0,196	0,173
Safety	0,152	0,195	0,259	0,240	0,233	0,209	0,185	0,163
Pavement	0,108	0,087	0,116	0,152	0,135	0,137	0,130	0,129
Integration	0,108	0,087	0,082	0,107	0,135	0,137	0,130	0,129
Maintenance	0,100	0,080	0,082	0,076	0,095	0,137	0,130	0,116
Signalling	0,093	0,074	0,067	0,062	0,055	0,079	0,130	0,116
Drainage	0,088	0,069	0,058	0,054	0,048	0,039	0,065	0,116
Light	0,088	0,069	0,052	0,048	0,048	0,039	0,033	0,058

Eigen Vector	x	w	Weight
Planning	0,249	2,06	10,00
Safety	0,205	1,698	8,24
Pavement	0,124	1,025	4,98
Integration	0,114	0,941	4,57
Maintenance	0,102	0,837	4,06
Signalling	0,084	0,689	3,34
Drainage	0,067	0,543	2,64
Light	0,054	0,443	2,15

SOURCE: OWN PROCESSING.

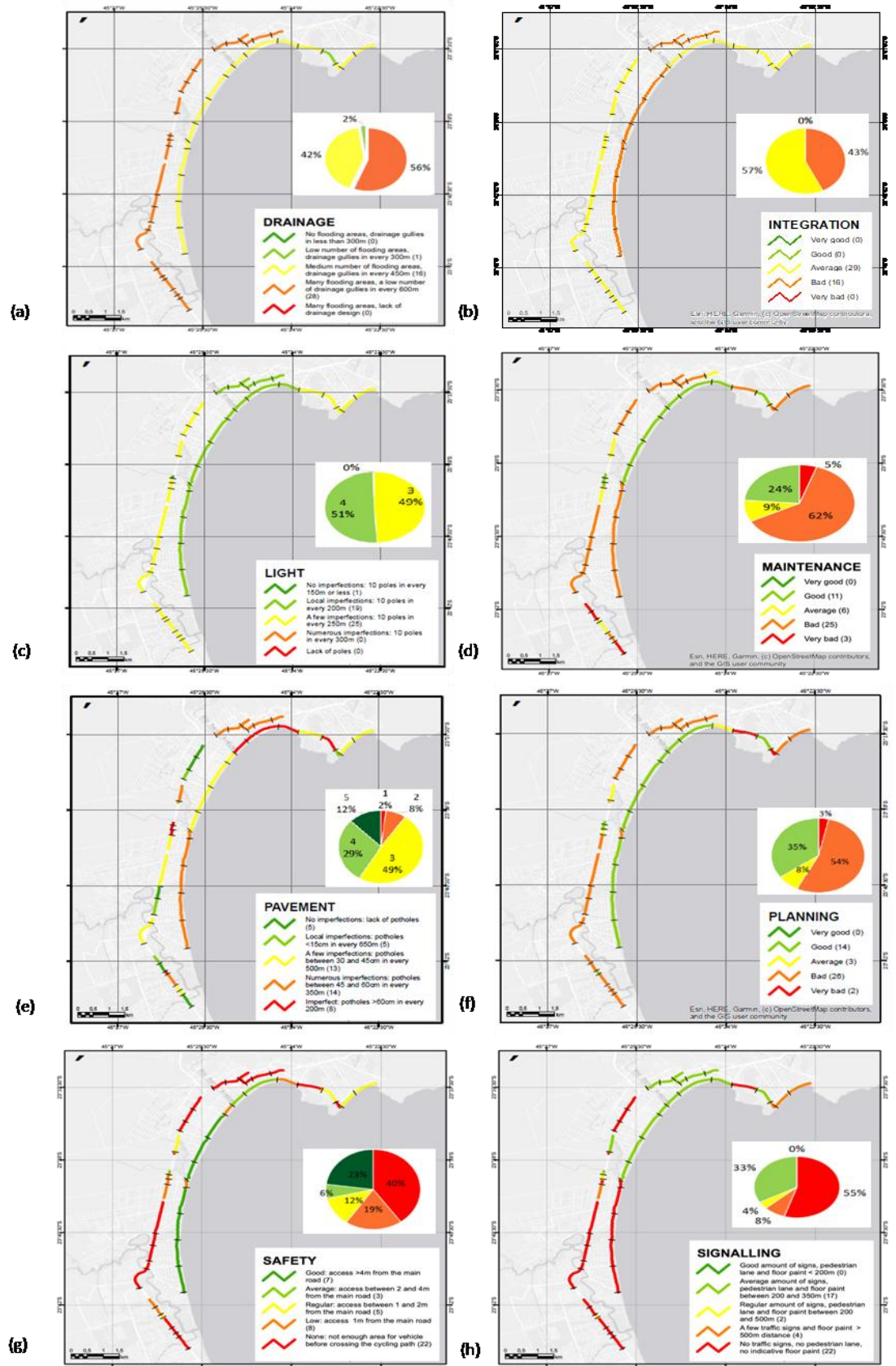


FIGURE 5 - INDIVIDUAL INDICATOR OF EFFICIENCY:(A) INTEGRATION, (B) LIGHT. SOURCE: AUTHORS.

Each section of the cycle path received scores for all the criteria evaluated. With these data, individual maps were created by criteria to facilitate data analysis using quantitative features of the criteria assessed on-site. For the drainage criterion, 56% of the cycle path scored 2 and these stretches are located on the city highway (Figure 5a). For all the criteria, the figures indicated the number of sections in parentheses. For instance, there were 29 sections considered average and 16 sections considered bad. The ratio (in %) was based on the length of each classified pattern and the total length.

Regarding the integration, 57% of the bike path received an average grade (Figure 5b), which means that wherever the bike paths are, there is a satisfactory connection among them but still needs improvement. The light obtained 51% of grades 4 and 49% of grades 3, which represents a reasonable quality of this criterion in the city's cycle paths (Figure 5c). Maintenance results were not good. 62% of the stretches scored 2, which means poor maintenance (Figure 5d).

In the pavement criterion, five categories were found, however 49% of the sections were evaluated with grade 3 (Figure 5e). In the planning criterion, 54% of the bike path was rated as bad and 35% was rated as good (Figure 5f). For the safety criterion, 40% obtained grade 1, which represents indicates that a significant amount of the bicycle network is unsafe for its users (Figure 5g). In the signaling criterion, 55% of the stretches obtained an evaluation score of 1 (Figure 5h), a result that indicates that most of the cycle path does not have adequate signage.

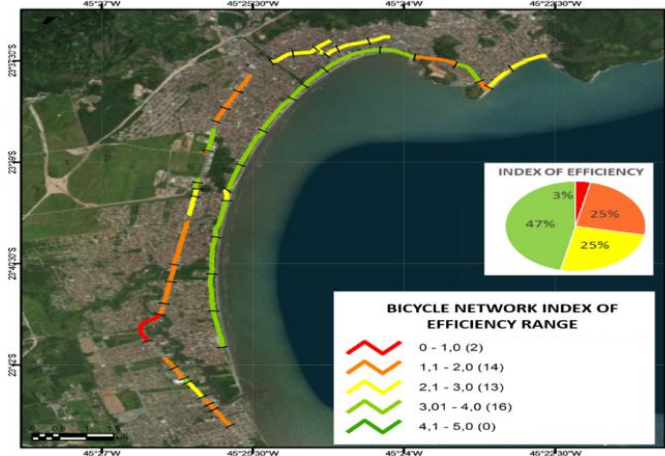


FIGURE 6 - BICYCLE NETWORK INDEX OF EFFICIENCY. SOURCE: AUTHORS.

3.7. Efficiency Index of the bicycle network

In Figure 6, the thematic map that was prepared with weighing each criterion, according to the score found by the use of the AHP method along the main bicycle network of Caraguatatuba municipality. The study findings show that no subsection from the bicycle network have the efficiency index between the range of 4.1 and 5, and just 3 % of the network were classified between 0 and 1. The indexes between 3.1 and 4 corresponded to the highest percentage of the bicycle network (in km), which represents average efficiency pattern (47 %).

In the southern bicycle network alongside the highway, where there are fewer tourists and more social vulnerability, the individual criteria scores and the indicators of efficiency were lower than at the other locations, particularly concerning the drainage and maintenance (Table 6).

TABLE 6 - INDEX OF EFFICIENCY ACCORDING TO THE BICYCLE NETWORK SECTIONS.

Section	Highest Index	Lowest Index	Average Index
Downtown	2.56	2.15	2.34
Along the highway	3.93	1.65	2.18
Along the coastline	3.04	1.82	3.20

SOURCE: OWN PROCESSING

4. CONCLUSIONS

The findings of this study developed a methodology to determine Caraguatatuba's bicycle network index of efficiency using the combination of the Delphi expert-survey method, the AHP and GIS spatial analysis. This methodology assessed the quality of It was possible to characterize the bicycle network, based on according to qualitative and quantitative features assessed on-site.

During the study, some areas ended up undergoing some type of change by the public authorities. Some of these changes were improvements to the current system, but other times they were only local maintenance services. As shown in Table 6, the bike paths along the coastline have the best average index, but this location is not the most used by the population. The most used cycle lanes are located on the downtown and along the highway, and were the sections classified with the lowest scores.

We concluded that the bicycle network serves the majority of the population, but there are several types of specific and general problems. In the busiest times of the city, such as school and end-of-year holidays, which are the seasonal periods and long holidays, maintenance and upkeep is often prioritised in the centre, in places parts of tmanagers previously seek to maintain the bicycle network for the central and most used places of the city by tourists. However Meanwhile, in the suburbs, the network is often overlooked and suffers from deterioration. The methodology used in this study can be applied in any location and offers the public sectors the possibility of identifying the most critical locations to be prioritized for upcoming improvements.

5. ACKNOWLEDGEMENTS

We gratefully acknowledge the research funding provided by the Federal Institute of Education, Science and Technology of São Paulo, which supported the development of this study. We also acknowledge the contribution of Jack McGuane, who was the Transport Planner at the City of Port Phillip, VIC, Australia, during the development of this paper, for his technical feedback and proofreading the manuscript.

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